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FINAL REPORT

Implementing Safe Systems in the United States:
Guiding Principles and Lessons from International Practice

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This report examines the state-of-the-practice in Safe Systems. It is divided into two sections. The first examines the concept of Safe Systems, focusing on our emerging understanding of crash causation, as well as how this understanding may be applied to integrate safety considerations into transportation practice in the United States. The second presents a review of the practices of the four countries with the most established Safe Systems programs—Sweden, the Netherlands, Australia, and New Zealand—and details how each has structured their approach to road safety around Safe Systems principles.</td></tr>
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Implementing Safety Systems in the United States

Introduction

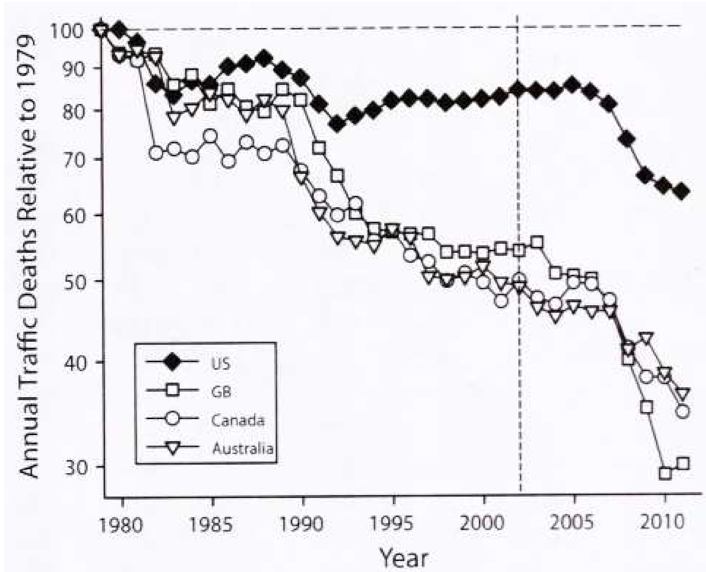
According to the World Health Organization, traffic crashes claim the lives of more than 1.25 million people annually and are the leading cause of death in young people between the ages of 15 and 29 (World Health Organization, 2018). The economic and societal costs from these incidents are tremendous. In the United States in 2016, The National Safety Council estimated that the costs of road trauma (deaths, injuries, and property damage) were $432.5 billion (National Safety Council, 2016). Improvements in road safety have been achieved over the last few decades from advancements in vehicle safety, law enforcement, and safety education; however, the number of traffic-related fatalities and injuries is still significant. In recent years, these numbers have increased in countries of all economic backgrounds, including the U.S. (Organisation for Economic Co-operation and Development, 2016).

This global epidemic has prompted local and national governments and road safety practitioners to seek out new strategies to address the increasing risks on our roadways. In 2010, the United Nations General Assembly proclaimed 2011 to 2020 the "Decade for Action for Road Safety." Co-sponsored by 100 countries and endorsed by leading institutions, including the World Bank and the World Health Organization, this declaration aims to "stabilize and then reduce the forecast level of road traffic fatalities around the world by increasing activities conducted at the national, regional and global levels" (United Nations General Assembly, 2010). The overall goal is to prevent five million road traffic deaths and 50 million injuries worldwide by focusing on road safety management, road infrastructure, vehicle safety, road user behavior, road safety education, and crash response (World Health Organization, 2011).

During the 1970s, the United States had the safest roads in the world; however, we now lag far behind when it comes to improving road safety outcomes. Leonard Evans, the president of Science Serving Society, compared traffic fatality trends in the U.S. to those of 25 other countries - that we once surpassed in safety - and found that all countries outperformed the U.S. in reducing fatalities since reaching their all-time highest death toll (Evans, 2014). As an example, fatalities in Sweden and the U.S. both peaked in 1972, but by 2011 Sweden had reduced traffic fatalities by 81%, while road fatalities in the U.S. only declined 41%. Compared to the average traffic fatality reduction across three other similar countries, the difference in progress is equally dramatic. Between 1979 and 2002, the average reduction across Great Britain, Canada, and Australia was 49%. In the U.S., our reduction was 16%, resulting in 200,000 more traffic deaths. If the U.S. had kept pace with even the average rate of decline of all 25 comparison countries (1972-2011), over 16,330 deaths may have been prevented (Evans, 2014) (See Figure 1).

Recent data show that circumstances are worsening. The road toll in the U.S. increased more than 8% between 2014 and 2015 (2,741 additional deaths) and another 5.5% in 2016. Compared to five years ago, the increase is nearly 10% (National Highway Traffic Safety Administration, 2016). In 2015, crashes were the leading cause of death for those between the ages of 17 and 23 (National Highway Transportation Safety Administration, 2017). According to official data released by the U.S. Department of Transportation, deaths related to drunk driving, speed, and failing to use a restraint all increased in 2016, as did pedestrian and bicyclist deaths. Official data for 2017 have not yet been released, but early estimates from the first nine months of 2017 suggest fatalities will be similar to 2016 (National Highway Traffic Safety Administration, 2018).

Figure 1: Traffic Fatalities in the US vs. Peer Countries (Source: Evans, 2014)



Rethinking Crash Causation

Why has the United States fallen so far behind our international peers? Much of the problem is likely attributable to the fact that our approach to addressing traffic safety is underdeveloped. Conventional safety practice in the United States employs clinical causation analysis to understand the reasons why a crash occurred. Specifically, crashes are investigated using either police accident reports or on-site investigations, which detail factors such as the direction in which the involved parties were traveling prior to the crash, or whether one or more of the involved parties was under the influence of drugs or alcohol (Shinar, 2007). This analytical approach directs researchers' attention towards the pre-crash behaviors of the persons involved in a crash, resulting in the identification of behavioral causes of crashes, termed "*critical factors*." These fall into one three general categories:

- **Recognition error,** which may include driver inattention or distraction, as well as inadequate surveillance for oncoming hazards before entering an intersection of making a lane change.
- **Decision error,** such as driving too fast for conditions or misjudging gaps in oncoming traffic.
- **Performance error,** such as poor directional control over the vehicle prior to a crash, a factor most often attributable to drowsy driving.

This approach was first employed by Treat et. al., in 1979, and has continued to be the primary means for understanding crash causation through the present (NHTSA, 2015). Because most crashes can be categorized as belonging to one of these three general categories, these studies have led to the current assertion that driver error is responsible for 90% (or more) of all crashes that occur.

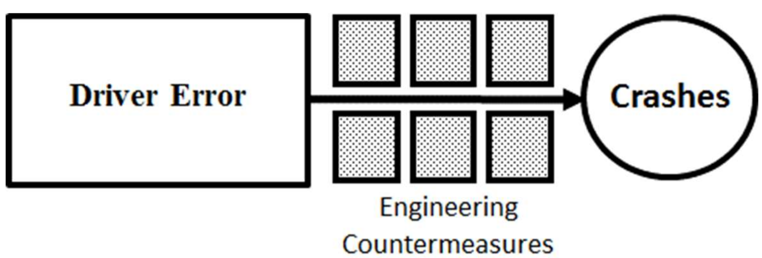
While such explanations seem plausible, it has led the profession to overlook a more critical question: why do drivers make errors that result in traffic crashes? The prevailing theory, contained in AASHTO's (2010) *Highway Safety Manual* [HSM], the traffic engineering profession's reference guide on traffic safety, is that crashes are "rare and random events" [p. 3-5] associated with failures in human performance. People will randomly commit errors, make mistakes, and engage in behaviors that put them at risk. Such errors are viewed as being unpredictable. As stated by the HSM: "the potential for a crash is avoided by a driver's advance action… circumstances that lead to a crash in one event will not necessarily lead to a crash in a similar event. This reflects the *randomness* that is inherent in crashes" (p. 3-5) [*ital. added*]. The 1979 study by Treat et. al., described above, is cited as the basis for this assertion.

This approach regards driver error as a largely random phenomenon attributable to innate human fallibility. It also presumes that system designers have little role to play in the crash prevention; crashes are random, individual phenomenon that are only preventable through modifications of the behaviors of road users. *If only* the involved parties had behaved differently immediately prior to the crash event, it would have been prevented. While such logic has a superficial appeal, it represents a common bias in casual reasoning referred to as the *simulation heuristic* (Kahneman and Tversky, 1998). When examining an accident or crash event, people are predisposed towards engaging in counterfactual thinking, examining the events that occurred immediately prior to the crash to identify a single "critical factor," or antecedent condition, which, had it been altered, would have prevented the crash. This places psychological weight on actions with temporal proximity to the crash event, which leads to a focus on the pre-crash behaviors of the involved parties, and a systematic disregard of broader environmental factors that may have influenced the crash event (Roese, 1997).

While these conditional "if-only" propositions may be logically true, they lead to the oversimplification of what may be a far more complex chain of causes. Psychological studies have consistently found that when individuals are primed with behavioral information, such as that contained in police accident reports, they cease to expand their analysis to consider broader factors that may have produced the error (Kahneman and Tversky, 1982; Morris, Moore, and Sim, 1999). This is particularly true if the antecedent action is perceived as violating the norms of expected behavior, such as when a driver exceeds the posted speed limit or drives while under the influence of drugs or alcohol (Kahneman and Miller, 1986; McCloy and Byrne, 2000).

Once these antecedent conditions are identified, causal investigation stops, and the focus is directed on reversing the precipitating behaviors. As such, crash prevention programs are largely embedded in the domains of education and enforcement, which target these pre-crash behaviors. Since these errors are presumed to be random and unpredictable events, the solution is to employ engineering countermeasures, such as wider lanes or "forgiving" roadsides, to reduce the consequences of unsafe behaviors (See Figure 2).

Figure 2: Addressing Road Safety in the US



Passive Safety

Collectively, this has led conventional transportation design practice to focus principally on reducing the consequences of random driver error, an approach referred to as "passive safety." Passive Safety first emerged in the 1960s, and continues to be the dominant mechanism for addressing safety through design. Passive safety begins with the assertion that crashes are the largely unpreventable result of random driver error, and that the best approach for addressing safety is to engineer countermeasures into streets and roadsides that minimize their consequences (Dumbaugh, 2005).

For passive safety, the relevant concept is termed the "design driver." The *design driver* is not a real person, but a series of "reasonable worst-case" events that may lead to a crash, such as an impaired driver, with diminished reaction times, traveling at excessive speeds (Parsonson, 2002). The theoretical presumption is that by designing a street to be safe for such "extreme" behaviors, the design will also be safe for more typical behaviors as well. The approach is similar to the concept of design failure applied in conventional engineering practice. For example, if the expected load for a bridge is 40 tons, using a design load of 60 tons in the bridge's design will prevent the bridge from failing. Similarly, if the desired operating speed for a roadway is 35 MPH, designing the roadway for 60 MPH is expected to provide an extra margin of safety. Correspondingly, conventional design engineering practice seek to apply higher design values for elements such as design speed and sight distance. This theoretical assumption underpins the design recommendations contained in street design manuals such as *A Policy on Policy on Geometric Design* (AASHTO, 2011a) and the *Roadside Design Guide* (AASHTO, 2011b).

Passive safety thus begins from the proposition that the road user is to blame for crash events, and that crash prevention is principally addressed through education and law enforcement programs. The responsibility of the system designer is simply to attempt to minimize the consequences of these "unpreventable" events by ensuring that the roadway is designed to accommodate worst-case scenario driving behaviors.

Road Safety and Organized Complexity

The theoretical problem with passive safety is that the traffic environment is not a physical system with static properties; it is a social and dynamic system, where the constituent elements adapt and respond to one another. To continue with the bridge analogy: it is uncertainly true that increasing a bridge's design load from 40 tons to 60 tons makes a bridge better able to safely carry 40-ton loads. Yet changing the design speed of a roadway from 35 to 60 MPH does not simply make the road safer for motorists traveling at 35 MPH. It changes the dynamics of the entire system, with the system's safety determined by drivers' adaptations to the newly-modified environment. Stated another way, they are systems of *organized complexity* (Weaver, 1948)

Organized complexity pertains to the idea that the constituent elements of a system interact with one another in a dynamic, non-random manner. Modifications to one element of a system will result in a corresponding changes to the other elements of the system, such as drivers adopting higher operating speeds in response to the redesign of a street. The safety implications are contingent upon the context in which these modifications occur. For example, the use of higher-speed design solutions may enhance safety on limited access routes with high prevailing operating speeds and little pedestrian or access-related activity. But the same design solution likely to be problematic on urban arterials where higher operating speeds crate conflicts with pedestrians or vehicles attempting to access adjacent driveways. As has been observed in the empiric literature, crash patterns are not random, as assumed by the *HSM* and the "Green Book," but instead the product of patterns of organized complexity, which are dependent upon behavioral adaptions to the characteristics of the road and roadside environment (Dumbaugh, 2005; Dumbaugh and Rae, 2009).

To illustrate the problem using the example of roadside safety, the passive safety assumption, embedded in AASHTO's (2011) *Roadside Design Guide*, is that the frequency and severity of crashes involving roadside features such as trees and utility poles can be minimized by removing them further from the travelway, creating roadside "clear zones." As stated by the Transportation Research Board (2003), "the wider the clear zone, the safer it will be" (Transportation Research Board (p. V-43). Where this can't be achieved, remedies are to move the object farther from the road, or to modify the environment to reduce the severity of the hazard, such as through the installation of guardrails.

Yet examinations of roadside crashes in urban environments found that vehicle departures from the roadway are not random. Instead, the overwhelming majority of these crashes occurred as the result of a specific, non-random behavior, where drivers were attempted to turn onto driveways and intersections at the prevailing speed of the adjacent arterial (see Figure 3). Fully 83% of fixed-object crash locations occurred near driveways or intersections, with the provision of wider clear zones often resulting in fixed objects being located at the most likely point of roadside encroachment (Dumbaugh, 2006). A subsequent examination similarly reported that urban fixed-object crashes were twice as likely to occur near intersections as at non-intersection locations, and, as a result, there was little safety benefit associated with providing clear offsets greater than 5 feet (Maze et al., 2008). It is the design of the environment, and the behaviors that drivers adopt in response, that influence these crashes.

Figure 3: Urban Roadside Encroachments Are Not Random

In order to meaningfully address traffic safety, one must first understand the system's operating dynamics. This is comprised of both the *physical environment*, which entails the design characteristics of the roadway and its surrounding environment, as well as a *social environment*, which is governed by the behaviors and decision processes applied by users of the system. It is the recognition that traffic crashes occur within a system of organized complexity that distinguishes Safe Systems from conventional safety practice.

Structure and Organization of this Report

This report examines the state-of-the-practice in Safe Systems. It is divided into two sections, the first examines the current literature on Safe Systems, with a particular focus on its application in the United States. The second examines the application of Safe Systems concepts in other countries.

Part I of this report is organized around four guiding principles. They are:

1. The human body has a known and limited ability to tolerate crash forces.
2. People make mistakes that lead to crashes.
3. System designers share responsibility with road users for crash prevention.
4. All elements of the system should be strengthened to multiply their effects.

Part I sought to examine the available literature on the subject. Nonetheless, it became clear early in our review that Safe Systems, as an approach to road safety, remains somewhat underdeveloped. To advance our understanding of the subject, we expanded our review to more broadly examine crash causation and prevention in transportation's nature as an organized, complex system. This led to an examination into the areas of organizational systems safety and behavioral economics, which help explain the behaviors of individuals in complex systems.

Organizational systems safety is concerned with how people interact with complex systems. Injury-producing errors occur when people, engaging in ordinary human behavior, interact with systems in the manner in which the system designers did not intend, leading to death and injury (Reason, 1997). Organization systems safety seeks to understand how system design may encourage, or prevent, errors that lead to death or injury. The second domain is behavioral economics. Behavioral economics is concerned with errors in decision-making, particularly when people are making adaptive decisions in complex environments where the outcomes of specific decisions are not known, and are relying on intuitive judgment (Kahnemann, 2011). These processes, known as heuristics, are useful for identifying the nature of the errors and mistakes that may result in preventable death and injury.

Because some of the terms used in this literature may be unfamiliar to some readers, we have identified the first instance of these terms italics, and have included their definitions in the Glossary.

Part II of this report provides a scan of the practices of the four countries that have the most well-established Safe Systems programs: Sweden, the Netherlands, Australia, and New Zealand. Each of these countries have structured their approaches to road safety around the Safe Systems core principles and implemented innovative measures to address their specific priorities. We framed our examination by answering five questions for each of the representative nations:

1. What was the motivation for implementing a Safe Systems program?
2. What exactly was implemented to improve road safety?
3. What challenges did the nation face in its implementation?
4. How effective was the implementation?
5. What recommendations, if any, does this nation have for others seeking road safety improvements?

Part I: The Elements of Safe Systems

The concept of Safe Systems emerged out of Vision Zero policies. Vision Zero begins from the moral assertion that traffic-related death and major injuries are unacceptable, and that the only ethical safety target is zero fatalities and injuries. From this perspective, mobility should be provided only if it can be provided without injury or loss of life (Tingvalle and Haworth, 1999). The adoption of Vision Zero has encouraged a fundamental reconsideration of safety practice. The resulting approach, termed Safe Systems, is based on four guiding principles (OECD, 2016):

1. The human body has a known and limited ability to tolerate crash forces.
2. People make mistakes that lead to crashes.
3. System designers share responsibility with road users for crash prevention.
4. All elements of the system should be strengthened to multiply their effects.

Part I of this report conducts a synthetic review of the literature relating to each of these four principles. While Safe Systems is a relatively new concept in the arena of transportation, the underlying theory on which these principles are based has been well-established in the domains of organizational systems safety, behavioral economics, and traffic psychology. Central works in these areas are thus examined in this review, and considered in light of their application to traffic safety.

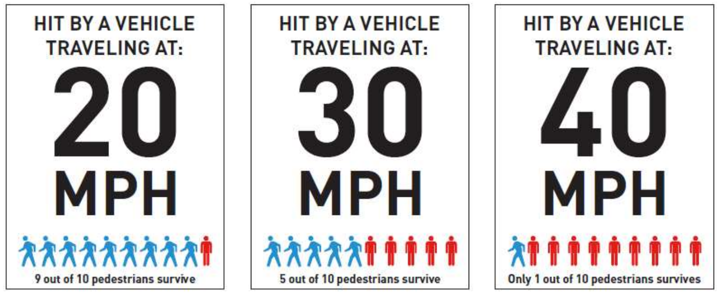
Principle 1: The human body has a known and limited ability to tolerate crash forces.

Crash severity is fundamentally a product of crash-related trauma, with the likelihood of a fatality increasing greatly above impact speeds of 20 MPH (Rosen and Sander, 2009; Zegeer et. al., 2002, See Figure 4). Safe systems begin by acknowledging these physical limits of the human body. If the elimination of traffic-related death and injury is to be accomplished, this requires that human bodies are not forced to absorb forces exceeding this critical threshold. To do so, Safe Systems has abandoned the passive safety concept of the design driver in favor of a new basis for transportation system design: the *most vulnerable user* (OECD, 2008; 2016). Rather than designing the transportation system to address extreme behaviors, this approach begins by identifying the user most likely to be injured or killed in a specific operating environment, and then designing the system to ensure that vehicle operating speeds are reduced to survivable levels. As stated by the OECD (2016):

> *Speed is at the heart of a forgiving road transport system. It transcends all aspects of safety: without speed there can be no movement, but with speed comes kinetic energy and with kinetic energy and human error come crashes, injuries, and even deaths.* (p. 107).

The focus on the most vulnerable user has led to an emphasis on reducing speeds to survivable levels for pedestrians and cyclists, leading to campaigns such as the European Association for Deceleration's "30km/h-making streets liveable!" program, which has resulted in the adoption of 20 MPH speed limits in more than 100 locations throughout western Europe (European Association for Deceleration, 2018). The adoption of Vision Zero programs in the United States has led cities to reassess design speeds on urban streets, though they remain higher than their international counterparts. NACTO (2013), for example, recommends target speeds of 30 MPH or less. The City of Boston (2013) recommends the use of 25 MPH as a target speed in urban areas. Chicago (2013) recommends that major thoroughfares be designed to operate at 25 to 30 mph, connectors to be designed for 20 to 30 mph, and other streets to be designed for 10 to 20 mph. New York City simplified the issue by establishing a citywide speed limit of 25 mph (Mueller, 2014).

Figure 4: Speed and Pedestrian Survival Rates



It should be noted that a focus on the safety of the most vulnerable user is not a prohibition against vehicle use, nor a prohibition against vehicles traveling at high speeds. Instead, this approach seeks to ensure that automobiles are used in a manner that is consistent with safe behavior in different operating environments. In areas where pedestrians and cyclists are likely to be encountered by motorists, such on urban streets, lower speeds are clearly necessary to prevent death and injury. Higher operating speeds can be safely accommodated on limited-access freeways, from which pedestrians are excluded both through design and legal prohibitions. On these facilities, safety is addressed through in-vehicle safety features, such seat belts, air bags, and the use of child safety seats, as well as through the application of forgiving design elements, such as wider lanes and fixed-object offsets.

Pedestrians and cyclists, by contrast, lack the protection provided by being encased in a personal automobile and its attendant safety systems, leading Safe Systems proponents to direct their attention to this area of professional need. In the United States, 70% of all pedestrian and cyclist fatalities occur in urban environments, which comprises 40% of all urban traffic fatalities (NHTSA, 2018). With cities taking the lead for implementing Vision Zero in the United States, pedestrian and cyclist fatalities have become a central area of concern.

The Safe Systems literature has not emphasized limited-access freeways or similar high-speed facilities, which is likely attributable to the fact that the transportation profession has already done a commendable job of addressing their safety. Interstates, for example, are far safer than all other classes of roadway, not only in terms of fatalities per million miles of travel, but also in terms of total fatalities as well (See Table 1, below) (FHWA, 2015). Nonetheless, Safe Systems differs from conventional engineering practice in the United States by recognizing that the safety of these facilities is not simply because of their use of higher, “more forgiving” design values for lanes, shoulders, and fixed object offsets, but also because they limit access through dedicated on- and off-ramps, and exclude use by vulnerable users such as pedestrians.

Principle 2. People make mistakes that lead to road crashes

The assertion that people make mistakes that lead to road crashes is one that seems obvious on its face, but which has profound implications for practice. As stated by the Organisation for Economic Cooperation and Development:

> The basic principle of Safe Systems starts with the insight that human error should no longer be seen as the primary cause of crashes. Instead, road crashes are seen as a consequence of latent failures created by decisions and actions within the broader organizational, social or political system which establishes the context in which road users act (2016, p. 27).

Table 1: Urban and Rural Traffic Fatalities, by Functional Class (2012)

2012 Traffic Fatalities	Rural	Urban	Total
Interstate	1,814	2,160	3,974
Other Principal Arterial	4,082	1,137	5,219
Minor Arterial	3,465	4,500	7,965
Major Collector	4,203	3,023	7,226
Minor Collector	955	1,267	2,222
Local	3,456	3,170	6,626
Unknown Class	195	39	234
Total	18,170	15,296	33,466

(Adapted from FHWA, 2015)

Safe Systems departs from conventional safety practice in that it recognizes that *active failure*, or random errors due to human fallibility, is rarely the sole factor in the production of errors or mistakes. *Latent conditions* may exist within complex systems that can encourage the production of unsafe behaviors. Unlike active failure, the crashes produced by latent conditions are not random; they are the result of environmental conditions that, when activated by predictable patterns of human behavior, lead to a correspondingly predictable crash event. Stated another way, latent error is designed into the system. As described by Reason (1997), latent errors can be regarded as the resident pathogens designed into complex systems, which lie dormant until activated by local circumstances.

Aeroperu Flight 603: How the Concept of Latent Conditions is Applied in Aviation Safety

The important role of that latent conditions can play in our understanding of crash causation can be readily illustrated using an example from the field of aviation safety, which has long adopted an organizational systems approach to safety. In the case of Aeroperu Flight 603, which originated from Miami International Airport and crashed into Pacific Ocean outside of Lima, Peru, the "critical factors" were that the pilots were traveling too fast on their descent and erred in their judgment of the plane's altitude. The result was the death of the pilots and 70 passengers.

Under the classification framework established by Treat et. al., 1979, and currently employed in the domain of traffic safety, such errors would be categorized as performance errors, and attributed to the pre-crash actions of the pilots. Yet in the field of aviation safety, knowledge of the pilots' actions immediately prior to a crash is rarely sufficient for establishing cause. Instead, information is sought regarding the conditions that led the pilots to make these errors.

A review conducted by the National Transportation Board found that the plane's displays were giving erroneous estimates of airspeed and altitude, causing the pilots to underestimate their speed and overestimate their altitude (NTSB, 1996). Because of overcast weather conditions, the pilots were not aware of their actual altitude until the plane's left wing touched the water, causing the plane to dive into Pacific.

The NTSB further sought to understand the reason for the instrumentation failure. Information on altitude and speed is derived from air pressure readings taken from static ports located on both sides of the plane's fuselage. Because the plane's manufacturer did not provide covers to protect the ports during routine cleaning and maintenance, nor guidance for how to appropriately do so, the ground crew at Miami International Airport developed their own procedure, which entailed covering the static ports with masking tape for routine cleaning. The ground crew failed to remove this tape prior to the plane's departure from MIA. This triggered the instrumentation failure, which in turn resulted in the pilots' performance error and created the latent conditions caused these errors to occur. While the pilots certainly erred in their estimation of speed and altitude, attributing the cause of the crash solely to active failure, as would have been done in conventional traffic safety practice, ignores the underlying conditions that led the pilots to err.

For road safety professionals, the lesson to be learned here is that we must not only focus on the immediate pre-crash decisions that led to a crash event, but the broader situational contexts that result in these decisions. Such an approach requires an understanding of not only how road users makes behavioral decisions, but how the environmental context of these behaviors shapes the decisions they ultimately make. This requires an understanding of human cognition and behavioral response.

Slips, Lapses, and Mistakes

Conventional safety practice views error as a random product of human fallibility, which may be exacerbated by individual choices such as driving under the influence of drugs or alcohol or driving or walking while distracted. Nonetheless, Safe Systems recognizes that errors are far more complex than poor choices, and that most crashes can be understood as a misalignment between human behavior and the design of the transportation system, creating conditions where errors are more likely to occur (Rand Corporation, 2018). Addressing error requires safety professionals to understand the different types of errors that can result in an injury or death.

In the domain of organization systems safety, human errors are categorized as belonging to one of two primary types. The first are *slips* and *lapses*, which are errors that occur when people fail to take appropriate actions to avoid a crash, such as driver inattention (a slip), or the failure to observe and respond to a present hazard, such as failing to yield at an intersection (a lapse). These errors, referred to as *active failures*, occur as a part of innate human fallibility, and are impossible to eliminate entirely (Reason, 1997). The safety consequences of slips and lapses can be mitigated through design solutions, such as reducing operating speeds to levels that prevent such actions from resulting in a death or injury.

The second type of error is classified as a *mistake*, which occurs because a road user lacks an understanding of safe behavior in a specific context, or because environmental conditions result in behaviors that lead to an increased likelihood of death or injury. In practice, this may entail the use of high design speeds in environments where higher speeds may increase one's likelihood of being injured or killed, or the failure to provide protected, adequately-timed crossings in environments where pedestrian crossings are likely to occur. Mistakes are thus the product of latent conditions embedded into the design of the built environment.

Environmental Conditions Associated with Mistakes

Recent research into the relationship between the built environment and traffic safety has increasingly found that latent conditions are playing an important, and to date unaddressed, role in crash incidence. Dumbaugh and Li (2011) examined the incidence of urban crashes for San Antonio-Bexar County, seeking specifically to understand which environmental conditions made crashes more likely to occur after controlling for active failure. The presence of surface arterials, which are designed for high speeds, strip commercial uses, big box stores, and 4-leg intersections all increased multiple-vehicle crashes, fixed-object crashes, vehicle-pedestrian crashes, and vehicle-cyclist crashes, in a significant and non-random manner. Freeways, which are limited-access facilities appropriate for conventional passive safety applications, were notable in that they were associated with significantly fewer crashes involving motorists. Importantly, the presence of pedestrian-scaled retail uses, which is a proxy for the low-speed design environments encouraged by Vision Zero advocates, were associated with statistically fewer crashes (See Table 2). These findings led the authors to conclude that many urban crashes were not random, as conventionally assumed, but *systematic*; that is, a non-random event induced by the characteristics of the built environment. In the language of Safe Systems, these crashes are the result of latent conditions. Further, the influence of these conditions far outweigh the crashes attributable to random error, captured here by the use of VMT as a surrogate.

Table 2: Environmental Conditions that Induce Crash-Producing Mistakes

	Motorist	Multiple-vehicle	Fixed object	Parked car	Vehicle-pedestrian	Vehicle-cyclist
Block group acreage	–0.000 ***	–0.000 ***	–0.000	0.000	–0.000 ψ	–0.000 *
VMT (millions)	0.006 ***	0.005 ***	0.005 ***	0.001 **	0.001 *	0.000
3-leg intersections	0.000	0.000	–0.001	0.000	–0.004 *	0.002
4-or-more-leg intersections	0.006 *	0.006 *	0.009 ***	0.004	0.009 **	0.013 ***
Net population density	0.000	0.001	–0.000	0.001 ψ	0.003 **	0.000
Freeway miles	–0.042 *	–0.053 **	–0.001	–0.037 *	–0.017	–0.014
Arterial miles	0.098 ***	0.114 ***	0.030	0.066 **	0.093 **	0.066 ψ
Strip commercial uses	0.022 ***	0.024 ***	0.014 ***	0.021 ***	0.030 ***	0.017 ***
Big box stores	0.077 ***	0.084 ***	–0.011	0.114 ***	0.087 ***	0.033
Pedestrian-scaled retail uses	–0.031 ***	–0.035 ***	–0.010 ψ	–0.012 ψ	–0.016 ψ	–0.012

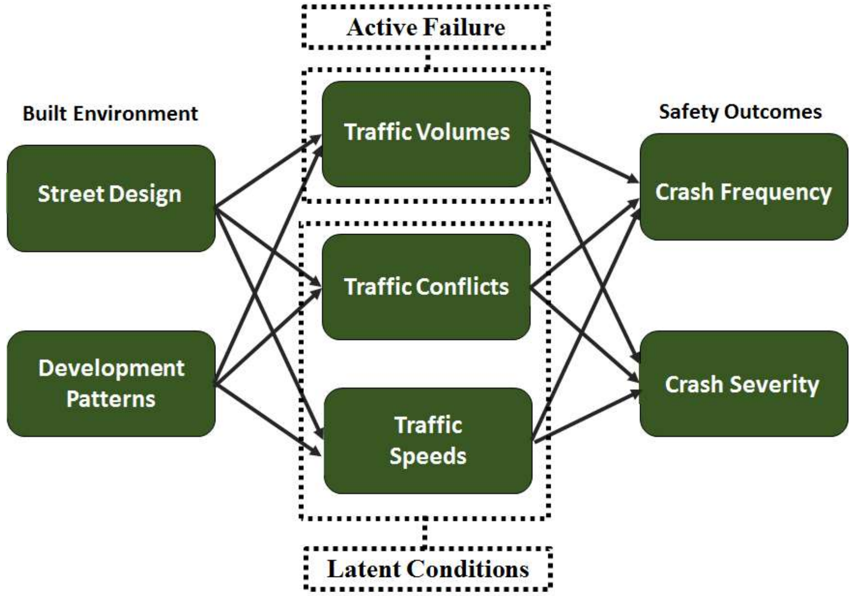
ψ $p < .10$ * $p < .05$ ** $p < .01$ *** $p < 0.01$

(Source: Dumbaugh and Li, 2011).

Further evidence of the role of latent conditions is evidenced in a study by Ewing, Hamidi, and Grace (2016), who report that sprawling counties are associated with significantly higher fatality rates than more compact, urban ones. Dumbaugh and Rae (2009) examined block groups and found that total, injurious, and fatal crash incidence is higher in block groups with more strip commercial uses, big box stores, and four-leg intersections. Similarly, Yu and Xu (2018) find that block groups with higher percentages of commercial or office space experience more total and injurious crashes. Each of these papers examines the environmental factors that lead to the increased incidence of death and injury, factors which, in the context of Safe Systems, are latent conditions.

In a comprehensive review of the literature on traffic safety and the built environment, Ewing and Dumbaugh (2009) posited that the built environment influenced crash frequency and severity through the mediating effects of three elements: traffic volumes, traffic conflicts, and vehicle speeds. Considered in light of the approach embodied by Safe Systems, these three elements can be divided into active failure (which are slips and lapses) and latent conditions (which lead to mistakes). As shown in Figure 5, higher traffic volumes serve as a proxy for active failure; presuming error is a randomly-occurring product of human fallibility, more people and more travel should lead to a proportionate increase in crash-producing errors. Traffic conflicts and travel speeds, however, create latent conditions that may make crash-producing mistakes more likely to occur than would be expected from random error alone. Traffic conflicts occur when the environment creates locations where multiple streams of traffic intersect, whether this traffic involves motorists or pedestrians. Vehicle speeds influence crash frequency by increasing stopping sight distance, which is the distance a vehicle travels before coming to a stop. At higher speeds, vehicles are less able to stop quickly in response to a conflicting movement entering the vehicle travelway. Similarly, higher speeds increase the force that will be absorbed during a crash event, which in turn increases its severity.

Figure 5: Environmental Factors that Mediate Crash Frequency and Severity



(Source: Ewing and Dumbaugh, 2009)

Scripts, Schemata, and the Cognitive Processes Influencing Road User Behavior

Latent conditions are transformed into a crash event when drivers make incorrect decisions based on their understanding of the traffic environment. To understand the impact of latent conditions on crash incidence, it is necessary to first understand the cognitive processes that people use in making decisions on safe behavior. Driving is a mundane activity that is typically accomplished by an intuitive, non-conscious process. Operational decisions, such as speed selection and lane placement, are automated and require little cognitive effort. As detailed by traffic psychologists, individuals process environmental information by relating it into specific cognitive categories, which allow them to quickly and efficiently process large amounts of sensory information, and apply it to the situation at hand (Rosch, 1978; Van Elslande and Faucher-Alberton, 1997). With respect to a roadway, what this means is that drivers infer an overall sense of a roadway based on their existing knowledge of, and experience with, similar "types" of roadways, with a roadway's "type" being inferred by the presence of key environmental indicators, such as lane widths or the massing of roadside development. This categorization then produces expectations regarding the nature of the traffic environment, which trigger *behavioral scripts*, or patterns of behavior, which are derived from education and prior experience.

It further results in expectations regarding the hazards that are likely to be present in the environment, which are referred to by traffic psychologists as *schemata*. Schemata are relevant because humans are incapable of processing all of the information present in the built environment (Kahnemann, 2011). This task is cognitively simplified by an intuitive process of scanning the environment for expected hazards at expected locations, and filtering out most other (presumably irrelevant) information (Theeuwes, 2002; 2012). In the language of behavioral economics, environments have the ability to "prime" certain expectations about crash hazards, as well as to leading to the systematic disregard of others.

An example of the influence of schemata on crash incidence is the "looked-but-failed-to-see" crash, a crash type that typically involves pedestrians, bicyclists, and motorcyclists. In these cases, drivers are not primed to expect these users, resulting in the driver's failure to "see" these users prior to a collision, even when they were located in the driver's cone of vision. As demonstrated by Chabris and Simons (2011) in their selective attention test (“the invisible gorilla”[1]), individuals will fail to see even highly unusual events if they are not primed to do so. A UK study by Brown (2002) found that looked-but-failed-to-see crashes, which are attributable to the schemata applied in road scene interpretation, comprised 10% of all fatal crashes that occurred.

Taken collectively, the cognitive process used to establish traffic behavior is relatively straightforward: individuals cognitively gleam an overall sense of a roadway by relating it to similar types of roadways they have encountered previously, which produces expectations on the potential hazards they can expect to encounter (schemata), as well as the patterns of operating behavior (scripts) that they expect will minimize their exposure to these hazards. This process thus allows individuals to rapidly scan their environments and adjust their operating behavior.

There is thus a communicative process that occurs between the road environment and the roadway user that directs the user’s safety expectations for a particular roadway and the subsequent behavior he or she perceives as being safe and appropriate. Since a roadway is a human-designed product that provides information to a user, this suggests that the design of a roadway results in a communicative event between a roadway designer and a roadway user. In other words, the roadway is a text that, when successfully designed, provides the roadway user with clear information on safe and appropriate behavior. Stated another way, “drivers read the road.”

Mistakes and Violations

A prerequisite of a safe road environment is that it clearly communicates information on safe operating behavior. As we have observed, latent conditions in the environment may lead drivers to unwittingly adopt unsafe behaviors that lead to traffic-related death and injury. These are not the routine slips and lapses that naturally occur and may be categorized as active failures. They are instead *mistakes*, or patterns of behavior than an individual adopts in response to a misreading of their environment. These can be categorized as belonging to one of three types: *Knowledge-based mistakes*, *rule-based mistakes*, and *incentivized violations*.

Knowledge-based Mistakes

Knowledge-based mistakes are mistakes that occur when a driver or other road user encounters an unfamiliar situation where the correct behavior cannot be immediately intuited from prior experience. In this situation, the individual is forced to make a conscious decision about how to proceed in the absence of adequate information about the consequences of potential behaviors. As observed by Daniel Kahneman (2011), conscious decisions in complex situations are cognitively-intensive and require time for deliberation. Errors can be expected to occur when the time needed to make a correct operating decision exceeds the available time in a complex operating environment.

Knowledge-based mistakes can be observed at complex intersections, notably at interchanges between freeways and arterials, where drivers are unsure about how to appropriately access the freeway, resulting in drivers driving onto a freeway off-ramp. These crashes, known as “wrong-way driving,” are the result of an individual’s lack of knowledge about how to safely maneuver along complex interchanges, and alone produce roughly 360 deaths in the US each year (Pour-Rouholamin et. al., 2015). To date, there has been little examination of the role of knowledge-based mistakes on crash incidence, though it is likely they are responsible for a significant share of crashes that occur at complex, multi-phase intersections.

Rule-based Mistakes

The second and more common type of mistake is the rule-based mistake. Driving is often psychologically-automated through the application of behavioral rules established from prior experience (Kahnemann, 2011). Where these rules are consistent with the actual behaviors needed to operate safely, crashes are largely

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[1] An excellent demonstration of schemata and expectation can be found here: https://www.youtube.com/watch?v=vJG698U2Mvo. Accessed September 20, 2018.

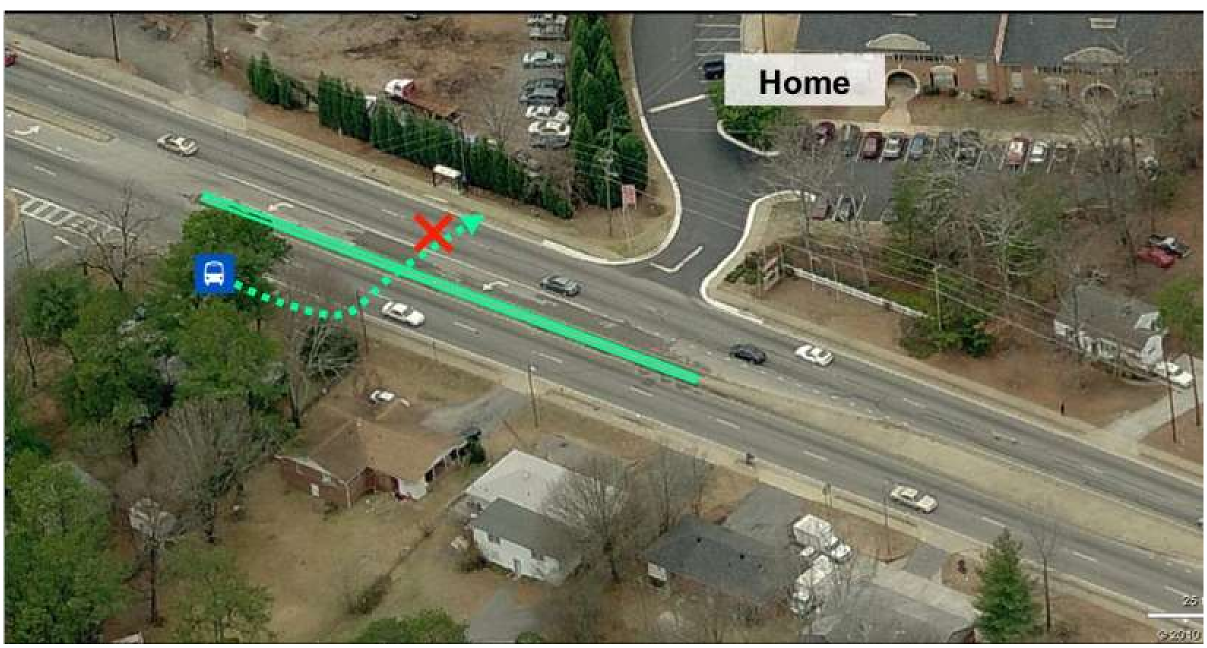
avoided. Safety problems emerge, however, when the environment activates behavioral scripts that expose the driver to risk.

Rule-based mistakes are evidenced in the high number of crashes that occur on arterial thoroughfares lined with strip commercial uses. Arterial streets are designed and intended for high-speed automobile travel, a condition that, independent of other factors, need not lead to mistakes. Nevertheless, the introduction of commercial uses along the thoroughfare results in the introduction lower-speed, access-related traffic into the vehicle stream, which in turn, introduces traffic conflicts as vehicles attempt to enter or exit driveways through right- or left-turns. The design of the environment in this example creates the expectation that the behavioral rules for higher-speed environments are safe, when in fact, they leave the driver unprepared to react suddenly to the appearance of a motorist or pedestrian in the traffic stream (Dumbaugh and Rae, 2009; Ewing and Dumbaugh, 2009).

Incentivized Violations

The third category is an **incentivized violation**. An incentivized violation occurs when a road user is aware of the behaviors that are expected in an environment, but where the prevailing conditions encourage the road user to deviate from them. This phenomenon is readily observed in jaywalking. While there is the legal requirement that pedestrians cross the street at crosswalks or intersections, their location may not be readily accessible at the location where the pedestrian seeks to cross, thereby encouraging the pedestrian to jaywalk. A tragic example of this phenomenon is the death of 4-year old A.J. Nelson, who, along with his mother Raquel and two siblings, was attempting to cross an arterial in suburban Atlanta from their bus stop to their apartment. The nearest signalized intersection was one-third of a mile away. Instead of walking to this intersection, the family attempted to directly cross the street, resulting in A.J. being struck and killed by an oncoming driver (Snyder, 2011). In this case, Raquel Nelson was likely aware the crossing violated traffic laws, but the perceived benefits of undertaking the unprotected crossing, combined with an expectation that it could be safely accomplished, resulted in the death of her son (see Figure 6).

Figure 6: An Incentivized Violation Leading to a Pedestrian Death



(Image Source: Snyder, 2011)

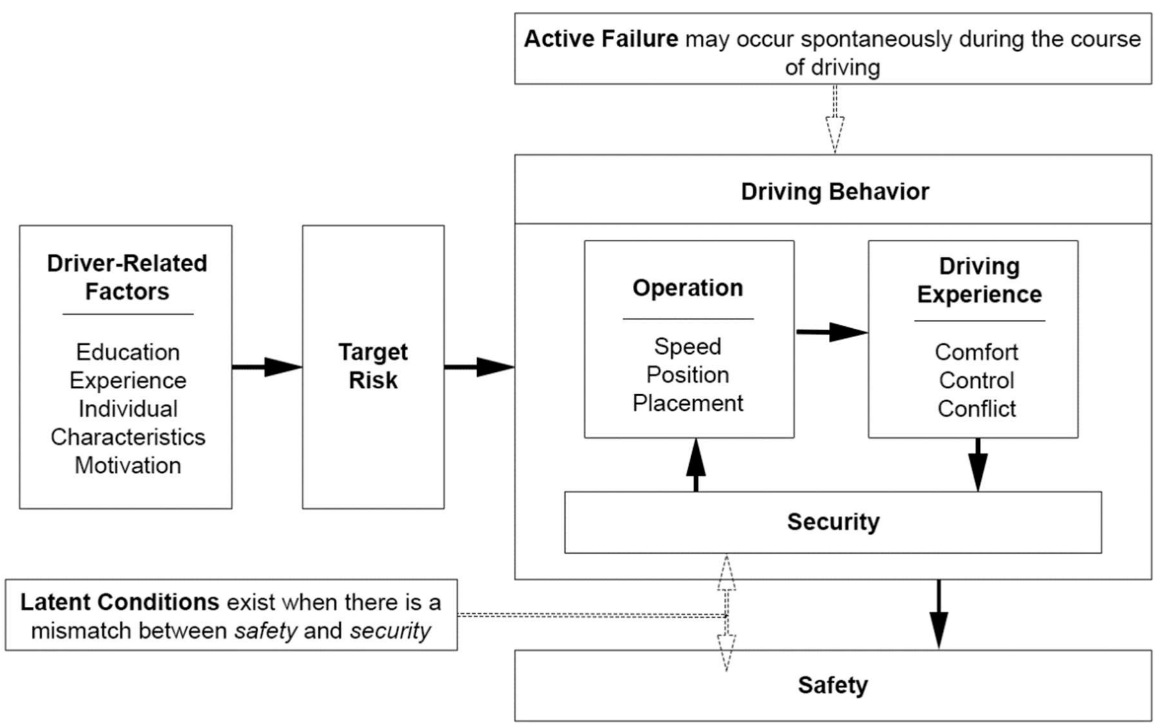
Another common form of an incentivized violation is drivers' widespread disregard of posted speed limits on urban streets. This occurs principally in areas where a roadway's design speed is deemed as being undesirable, leading local officials to attempt to remedy a perceived speeding problem by adopting lower posted speed limits. Yet in the absence of active police enforcement, drivers simply elect to ignore the posted speed limit Fitzpatrick et. al., 2001; 2001; Tarris, Mason, and Antonucci, 2000).

A Prescriptive Model of Cognition, Behavior, and Human Error

Taken collectively, a cognitive model can be developed to understand the communicative relationship between road users and their environment which, in turn, explains the production of active failures and latent conditions. As discussed in Wilde (1994), all activities involve some non-zero level of risk that an individual is willing to accept as a consequence of engaging in an activity. Once an individual elects to undertake an activity, such as driving, their target risk level directs their subsequent behavior, with the objective of the being not simply to minimize risk, but to maximize the benefits derived from an activity without exceeding their target risk threshold.

As shown in Figure 7, these individual factors inform individual's risk acceptance during the driving task. Subsequent operating behaviors are continuously adjusted based on a feedback loop involving current operating conditions, one's current experience, and the resulting sense of *security*, which is the perception the current behaviors are safe in the given context. Each of these factors is discussed in the sections below.

Figure 7: Cognition, Behavior, and Error Production



(Source: Dumbaugh 2013)

Driver-Related Factors

Four major driver-related factors function as inputs into a driver's level of target risk. First, education on driving hazards can shape drivers' target risk levels by increasing their awareness of their potential exposure to a crash or injury. Driver education programs often take the form of specific courses intended to provide instruction on safe driving behavior, such as those often offered in high schools or state-funded traffic schools. In these cases, the educational objective is to increase a driver's knowledge and awareness of the potential hazards of driving, as well as to provide instruction on the types of driving behavior that will help minimize his or her exposure to harm. A second common educational approach is embodied by national advertising campaigns, such as those on the risk associated with driving under the influence of drugs or alcohol. In this case, the educational objective is targeted towards increasing a driver's perception of the risk associated with this activity in the hopes of encouraging them to forego the activity.

Previous driving experience likewise shapes target risk. Individuals develop subjective assessments of the risks associated with driving, which in turn directs their behavior. Generally speaking, one expects that risk tolerance declines as people age, which is evidenced in the fact that the number of people involved in crashes declines with age. Nevertheless, there may be exceptions to this rule, such as when individuals repeatedly drive while under the influence of alcohol without consequence. Based on such experience, one may begin to believe that the risk associated with this behavior is overstated, and modify his or her behavior accordingly (Van Elslande and Faucher-Alberton, 1997).

Target risk levels may also vary as a result of individual characteristics. Individual characteristics can include demographic factors, such as the higher-risk behavior exhibited by young males, but may also be influenced by psychological characteristics and personality types as well. For example, "Type A" personalities may be more aggressive about accomplishing their travel objectives than other personality types. Likewise, many individuals may be psychologically-predisposed towards higher risk behavior due to decreased concern about harm or injury, or an overestimation of their driving abilities.

Finally, motivation is also an important factor that shapes an individual's level of acceptable risk. When an individual has an important travel objective to accomplish, such as being on-time for work, he or she may be willing to accept higher levels of short-term risk than under normal, less time-constrained occasions. Alternatively, the presence of a child or loved one in the vehicle may reduce a driver's level of risk acceptance out of concern for the safety of the passenger.

Driving Behavior

Collectively, these driver-related factors shape a driver's level of target risk, which in turn directs his or her driving behavior. Under the framework presented above, driving behavior is treated as a dynamic process that involves vehicle operation, driving experience, and a subjective sense of security. With an individual's target risk functioning as a static threshold against which driving behavior is based, an individual determines their acceptable operating speed, lane placement, and position in relation to other vehicles or roadway features. The adequacy of vehicle operation is determined through the individual's driving experience, which is a combination of a driver's comfort with current vehicle operations, the degree of control he or she has over the vehicle, as well as the identification of possible conflicts with other vehicles or roadway hazards. This driving experience thus provides the driver with a subjective sense of security, or a perceived likelihood of being involved in a hazard or injury. Where the driver feels secure, he or she is likely to continue with the current behaviors. Security thus serves as a psychological feedback mechanism that is used to adjust vehicle operation (Dumbaugh, 2013).

Errors, Mistakes, and Violations

Where this driving behavior is consistent with the demands of the current environment, the resulting behavioral routines are unlikely to result in mistakes, or violations. Nonetheless, errors may occur through one of three categories: active failure, which are slips and lapses that are a product of human fallibility, and through mistakes or violations, which are behaviors that are adopted in response to the built environment, but which encourage behaviors that expose individuals to traffic-related death an injury. These occur when the feedback that the driver is receiving from the environment lead to decisions on speed and vehicle placement that seem safe (i.e., create a sense of security), but which are in fact not appropriate to adequately respond to present hazards. This may include the adoption of behavioral scripts that make a driver unable to respond to a present hazard, such as traveling at speeds that prevent the driver from stopping prior to encountering another road user entering the travelway. It may further be a result of inadequate schemata, or the failure to identify the presence of specific hazards or road users in the environment. Stated another way, the design of the environment creates a “false sense of security” that results in behaviors that place road users at increased risk. This false sense of security is the cognitive mechanism that transforms a latent condition into a crash event. It is a direct product of the disconnect between the information communicated by the system to the road user, and the associated scripts and schemata applied by road users in response.

Principle 3. System designers share responsibility with road users for crash prevention.

Crashes are more complex than random human error. Many errors are designed-into the system, creating latent conditions that result in traffic related deaths and injuries. And even those that are the product of human fallibility, the slips and lapses that inevitably occur, can be mitigated through design solutions that seek to mitigate their consequences. As such, Safe Systems asserts that it is no longer sufficient to attribute the cause of traffic-related deaths and injuries to human error. Designers share a responsibility for the safety of the transportation system, both by ensuring that the system is designed for the safety of the most vulnerable user, and through the identification and elimination of latent conditions.

It is important to recognize that the transportation system does not relate only, or even primarily, to public rights-of-way, but encompasses the entire built environment. It is individual land uses that generate the trips that the transportation system must serve. The location and configuration of these uses in turn determine the types of movements that will occur between them, and establish the scripts and schemata used by road users. Those responsible for the design of the transportation include not only traffic engineers and transportation planners, but also state and local governments, elected officials, land developers, and other groups responsible for the design of the built environment. The creation of a safe system necessitates that the transportation system and its surrounding uses are designed in a manner that both eliminates latent conditions and minimizes the consequences of slips and lapses. Achieving this end requires normative guidance on how to appropriately balance speed and traffic conflicts in different developmental contexts, and how to modify design speeds over time as a roadway’s operating context changes as a result of changes in its surrounding environment. Three design strategies have emerged for addressing safety through system design: road classification, self-explaining roads, and speed evaluation and management. Each is descried below.

Road Classification

Given the sensitivity of the human body to crash forces, Safe Systems is particularly concerned with ensuring that vehicle speeds are appropriate for their specific operating context. In environments where vulnerable users such as pedestrians and cyclists are likely to be present, speeds are to be kept to survivable levels. Traditionally, speeds have been governed by the use of the functional classification system, which categorizes roadways based on their mobility function for automobiles. Under this framework, streets are designated as local roads, collectors, or arterials, with local roads intended for lower-speed, access-related uses, and arterials designed and intended to high-speed, limited-access operations. Once a road is designated as belonging to a specific class, design speeds are selected from ranges prescribed by AASHTO (2011). These designations, based entirely on a street’s mobility function, do not account for the safety implications of applying these design speeds in different design environments (see Figure 8).

Figure 8: The Functional Classification System

Classification	Example	Description	Design Speed
Arterial		Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.	**30-60 mph**
Collector		Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.	**30 mph or higher**
Local		Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through-movement.	**20-30 mph**

The New Zealand Transportation agency, which has aggressively pursued Vision Zero, has sought to replace the functional classification system with their "One-Network Road Classification," framework, which integrates environmental features into the establishment of design speeds. In this case, streets are categorized by both their mobility functions as well as the environmental characteristics that influence safety, including roadway curvature and whether or not the street is in an urban environment (See Figure 9).

On urban surface streets, acceptable speeds are generally between 30-50 km/h (20-30 MPH), with the lower end of the range applied to environments with high volumes of pedestrians or cyclists. Higher speeds may be applied on Class 2 routes when they can be achieved without exacerbating crash risk, which includes environments with few intersections and firm separations between motorists and other road users. Shared spaces, which are spaces where pedestrians and motorists can freely interact, are permissible at speeds of 10 km/h (6 MPH).

This framework does not prevent the design of higher-speed, mobility-oriented thoroughfares. Instead, it establishes specific criteria to determine the conditions where such designs are safe and appropriate, based on International Roadway Assessment Programme criteria, which estimate's a roadways likely safety performance based on thethe geometric characteristics of the roadway, median presence, geometric alignment, topography, roadside conditions, and intersection frequency and design (see Table 3). Speeds in excess of 45 MPH are prohibited on all urban roads, as well as those that fail to meet 3-star safety criteria.

Figure 9: New Zealand's One-Network Road Classification System

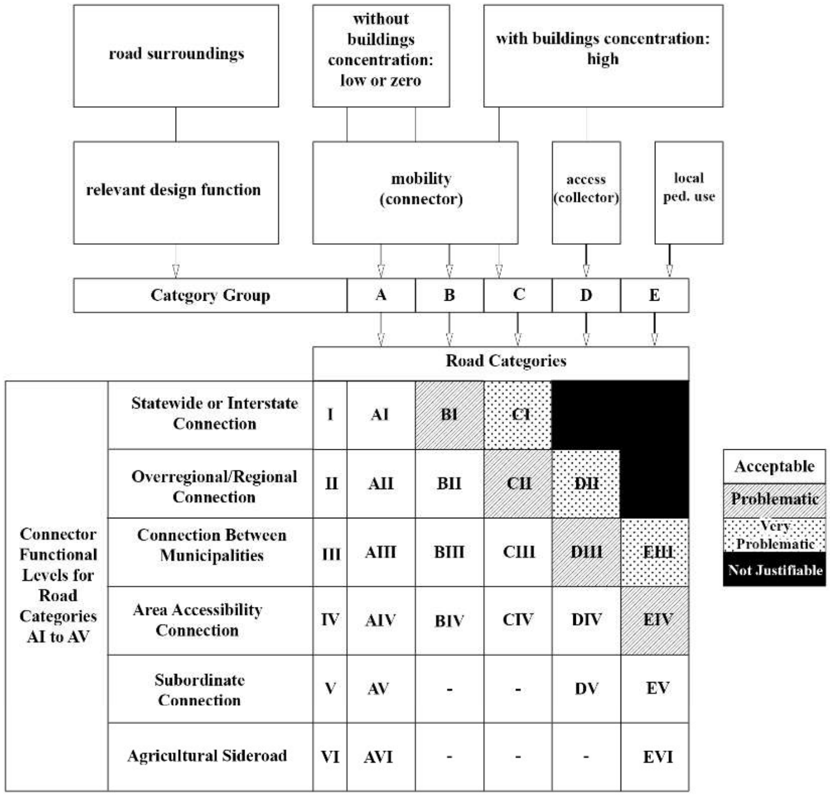
<table>
<tr><th>Classification</th><th>Straight open road /urban motorways</th><th>Curved open road</th><th>Winding open road</th><th>Urban (not motorway)</th></tr>
<tr><td>Class 1
High volume national</td><td>100–110km/h[4]
Depends on design and safety risk (e.g. divided 4–5 star, grade separated intersections, safety barriers) and factoring in enforcement thresholds</td><td></td><td rowspan="4">60–80km/h</td><td></td></tr>
<tr><td>Class 2
National, Regional, Arterial</td><td colspan="2" rowspan="2">80–100km/h
Depends on safety risk and whether volumes justify investment to bring the road up to 3 star equivalent, also enforcement thresholds</td><td>50km/h
60–80km/h where safety risk allows, e.g. fewer intersections, mode separation for active users</td></tr>
<tr><td>Class 3 Primary and secondary collector</td><td rowspan="2">30–50km/h
30km/h if high volumes of cyclists/pedestrians
Recognise access and place
10km/h for Shared Spaces</td></tr>
<tr><td>Class 4
Access and low-volume access
All winding/tortuous</td><td colspan="2">60–80km/h
Depending on roadside development, pedestrian and cyclist volumes, whether sealed or not</td></tr>
</table>

Table 3: KiwiRAP Road Safety Classification System

Rating Scale	Description of Features	
	Divided	Undivided
5-Star	Straight with good line marking, wide lanes and sealed shoulders, safe roadsides and occasional grade separated intersections. Roads with a local, minor or major at-grade intersection cannot achieve a 5-Star Rating.	No undivided road can achieve a 5-Star Rating.
4-Star	Deficiencies in some road features such as lane width, shoulder width or roadside hazards.	Straight with good overtaking provision, good line marking and safe roadsides. Such a road will not achieve a 4-Star Rating if it has high traffic volumes.
3-Star	Major deficiencies in some road features. These may include poor median protection against head-on crashes, many minor deficiencies and /or poorly designed intersections at regular intervals.	Deficiencies in some road features such as alignment, roadsides, and /or poorly designed intersections at regular intervals.
2-Star	Many major deficiencies such as poor alignment, poor roadside conditions and median protection, and poorly designed intersections at regular intervals.	Major deficiencies in some road features such as poor roadside conditions and /or many minor deficiencies such as insufficient overtaking provision, narrow lanes, and /or poorly designed intersections at regular intervals.
1-Star	Poor alignment, in mountainous terrain, narrow lanes, narrow shoulders, severe roadside conditions and many major intersections.	Poor alignment, in mountainous terrain, narrow lanes, sealed shoulders, poor line markings and severe roadsides conditions.

Germany has developed an even more precise, matrix-based approach to the classification of streets (see Figure 10). Streets are categorized based on the types of mobility they are intended to accommodate, as well as on the presence of adjacent buildings, recognizing that not all developed environments can be appropriately classified as urban. The system classifies mobility-oriented roads based on the type of mobility function they are intended to serve, including specific designations for interstate routes, cross-regional connections, and interregional connections between municipalities. Nonetheless, the system recognizes that these higher-speed functions are inappropriate in areas with adjacent development, or areas with significant pedestrian use, where speeds are constrained to 20-30 km/h (12-18 MPH). An advantage of this matrix-based framework is that it clearly identifies environments where specific operating speeds and mobility functions are problematic or not justifiable. Indeed, most conventional suburban arterial treatments in the United States would be defined as problematic under this framework.

Figure 10: German Street Classification System



	Road Category	Travel Speed Range (km/h)
	AI	70 - 100
	AII	60 - 90
	AIII	50 - 80
	AIV	40 - 60
	AV	NO
	AVI	NO
Primary Arterial	BII	50 - 60
Secondary Arterial	BIII	40 - 60
Main Collector	BIV	30 - 50
Primary / Secondary Arterial	CIII	30 - 50
Main Collector	CIV	30 - 40
Collector	DIV	20 - 30
Local	DV	NO
Local	EV	NO
Pedestrian Use	EVI	NO

Self-explaining Roads

A related concept is that of self-explaining roads. In the United States, it is common for a street's design speed to be greatly in excess of its desirable, or posted speed. This is often done in the interests of safety, under the assumption that higher design speeds are more "forgiving" to driver error. Nonetheless, this approach ignores a street's communicative function, with design speeds and posted speed limits communicating very different information. The long-term result is that drivers learn to disregard posted speed limits and other signage entirely, as they discover that road signs have do not meaningfully correspond to their actual driving experience (Chowdhury et. al., 1998; Fitzpatrick et. al., 2001; 2003; Tarris Mason and Antonucci, 2000).

In the United States, the Institute for Transportation Engineers and the Congress for the Urbanism sought to address this problem through the development of *target speeds* for urban streets (ITE 2010). A roadway's target speed is its desirable operating speed. Once a target speed is established, the street's design speed and posted speed should be brought into alignment, with the design speed not exceeding 5 MPH above the street's posted speed. The target speed concept has subsequently been applied by a host of cities, including Boston, Chicago, New York, and Los Angeles, among others (Dumbaugh and King, 2018). The concept of target speed is further embedded into the National Association of Transportation Officials' (2013), *Urban Street Design Guide*, which has emerged as the authoritative reference on the design of urban surface streets.

Self-explaining roads thus seek to bring design speed, posted speed, and operating speed into alignment. Doing so requires an understanding of how drivers process environmental information. Theeuwes (2012) notes that "the repeated experience of similar events and situations generates mental structures and rules that represent them" (p.12). This definition corresponds to the establishment of schemata and behavioral scripts, detailed above. As such, design needs to move towards better understanding the cognitive processes through which information is categorized, and then ensuring that this information is clearly conveyed through design.

Self-explaining roads are designed using three general principles (Theeuwes, 2012):

1. First, streets should be *easily recognizable*, which is that streets with similar functions, similar mixes of users, and similar speed characteristics should look similar.
2. Second, streets should be *easily distinguishable*, or that different classes of streets with different operating characteristic should look different.
3. Finally, the street's design should be *easily interpreted*, which is to say that that design of the street and its surrounding environment should strive to trigger safe operating behaviors.

Taken collectively, this suggests there should be a common language used in design, with designers focusing not simply on geometry, but also on the information communicated to the road user through the design of streets and the surrounding environment.

Martens et. al (1998) sought to identify the specific elements that individuals use in categorizing streets into different cognitive classes, with the authors hypothesizing that drivers would be able to correctly infer safe speeds if roads are designed in a manner that is consistent with their subjective categorization of different road classes. Study participants were asked to sort road images into different categories, which were then grouped using cluster analysis. The authors then used a driving simulator to test how different design applications influenced behavior. Errors in estimating the correct speed were greatly reduced when all of the street's elements, including lane widths, centerline markings, road coloration, and reflector posts, consistently reinforced the street's intended speed. Nonetheless, the study found that subjects typically used only one or at most two street characteristics to infer safe operating speeds, with lane widths and the presence of bicycle lanes being most notably associated with the selection of lower operating speeds. The authors conclude that the identification of specific road classes should be based on only a few elements, consistently applied within road classes and significantly different between them, such as the number of lanes, lane widths, and lane delineation, rather than on more complex design specifications. The authors further assert that:

> providing a lot of redundant information is not useful since road users only use a few dimensions to classify road environments. In general, it appears to be better to include a limited number of consistent design characteristics in one road category than to have a large number of design elements that can give rise to occasional deviations from the pattern (p. 14).

Self-explaining Roads and the Recognition Heuristic

This study's finding that drivers use only a limited amount of the environmental information available to them in making decisions has been consistently observed in the field of behavioral economics, and is known as the *recognition heuristic*. Heuristics are cognitive "rules-of-thumb" applied by humans to make quick decisions in complex situations where complete information is unavailable (Tversky and Kahnemann, 1974). When confronted with a complex environment about which much is unknown, individuals will make inferences about the nature of the environment based on the first object or feature that they recognize or, if the interpretation remains unclear, the second. Once these objects are identified, all other sources of information are ignored (Goldstein and Gigerenzer, 2002). This process is largely intuitive, entailing a quick scan for environmental cues to identify those which seem most valid in the current decision context, the cessation of searching when a specific cue is identified, and then an operating decision based on the discriminating cue (Hutchinson and Gigerenzer, 2005).

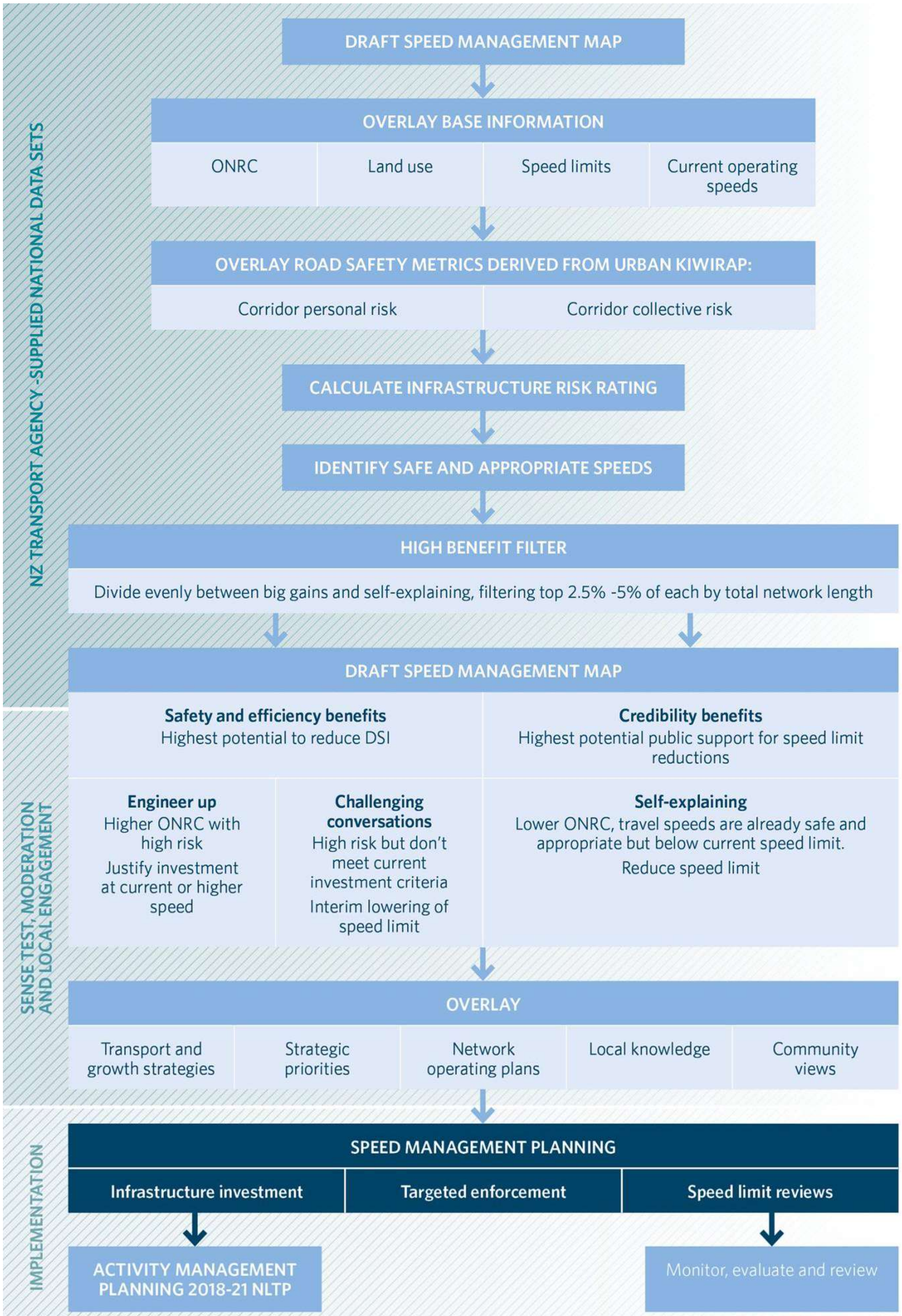
The recognition heuristic explains the cognitive processes observed by Theeuwes (2012) and Martens (1998). In general, it would appear that observations of the number and widths of travel lanes and the presence of bicycle facilities is being used to make broader inferences about appropriate speeds in the current operating environment. It further highlights the need for the development of design guidance with clear and specific design parameters that distinguish different roadway classes to ensure that street design is consistently conveying appropriate behavioral information. While this decision process is consistent with what is known about driving behavior, there is a need for research that examined the specific environmental cues that trigger specific scripts and schemata.

Speed Evaluation and Management

While these classifications are a useful starting point in determining safe speeds in different developmental contexts, they presume that streets and their surrounding environment are static; which is to say, that they remain unchanged over time. The reality is that cities undergo a dynamic process of change and modification as demographics shift and buildings adapt themselves in response to new social and economic demands (Brand, 1995). This can result in substantial changes to the uses and users of the system over time, which may render former, successful solutions unsafe. As such, there needs to be a continuous process of modifying and adapting the transportation system to new and evolving demands.

The New Zealand Transport Agency (2016) has developed a speed management program to assess the appropriate design and speed limits for existing streets, and to determine where engineering or design interventions are warranted. The One-Network Road Classification and the KiwiRAP safety assessment are applied to the nation's street network to identify locations where operating or posted speeds deviate from recommended practice. Those areas that deviate most from safety improvements or speed modifications are selected for modification. To minimize the disruption of speed modification on communities, only 5% of the network is examined for modification each year, half focused on supporting safe mobility, and half focused on reducing speeds. This creates an ongoing process of reviewing the appropriateness of current speeds and speed limits, allowing the network to adapt itself to changing needs. The resulting road segments are then divided into three categories: engineer up, challenging conversations, and self-explaining roads (See Figure 11).

Figure 11: New Zealand Transport Agency's Speed Management Framework



Engineer Up

The speed-management plan identifies high-volume, economically-important roads that may not perform well on the KiwiRAP safety criteria, resulting in higher-speed travel that is unsafe. On these roads, engineering improvements are developed to bring the street to a safety standard that will permit safe travel at the road's intended operating speed.

Challenging Conversations

The second category is termed "challenging conversation." These are roads where the operating or posted speeds are in excess of the desirable operating speeds, but where environmental conditions, such as topography or local development, do not warrant increases in a roadway's design speed. In these cases, transportation agencies work with the public to develop a shared understanding of the street's specific safety problems, and develop consensus for solutions that will reduce speeds to safe levels.

Self-explaining Roads

There are also roads where the posted speed is in excess of the safe operating speed, but where road users already travel at desirable speeds. These are conditions often found in very urban environments, where local development, high traffic volumes, and geometric conditions limit vehicle speeds. For these roadways, the posted speed limit can be justifiably reduced to the safe speed. The advantage of this approach, according to the New Zealand Department of Transportation, is that it increases the credibility of the nation's speed-limit practices by ensuring that posted speed limits are consistently linked to actual operating speeds.

Principle 4: All elements of the system should be strengthened to multiply their effects.

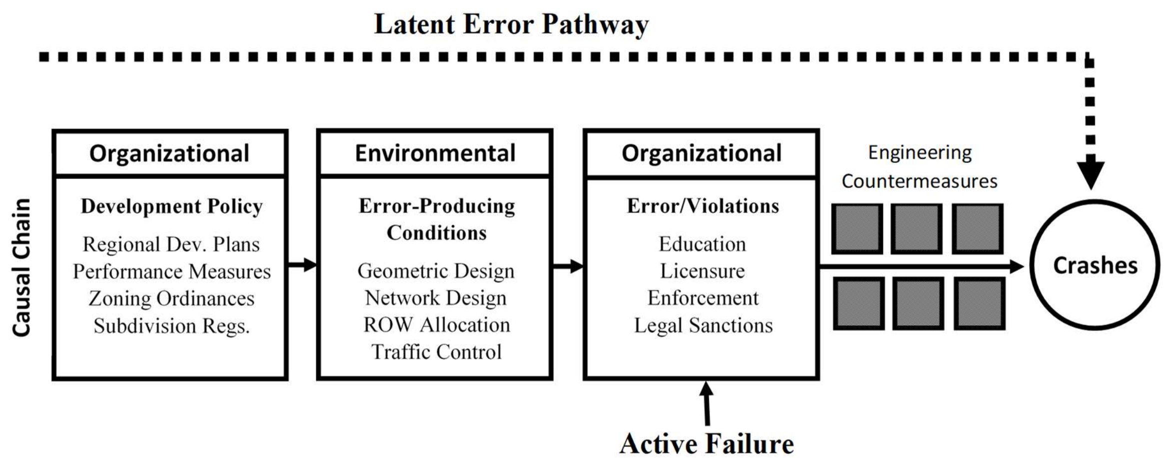
The previous sections discussed the relevant components of a safe system, including a focus on human vulnerabilities, the cognitive processes that result in errors and mistakes, and the shared responsibility between systems designers and road users. Nonetheless, these constituent elements need to be understood as part of a complete system, where the constituent elements build upon each other, introducing redundancy that strengthens the system as a whole. Further, it must be understood that the factors that result in crashes, injuries and deaths are often attributable not simply to the immediate pre-crash behaviors of road users, but also to the broader environmental conditions that inform these behaviors, conditions established by both high-level policy decisions, land development practices, and cultural factors.

Defenses in Depth: Eliminating Latent Conditions

Much of the focus of safety practice in the United States has been focused on educational and enforcement programs that seek to eliminate the behavioral errors of road users. Yet, as Reason (1998) has observed, human "errors are the product of a chain of causes that in which the precipitating psychological factors—momentary inattention, misjudgment, forgetfulness, preoccupation—are often the last and least manageable links in the chain" (p. 129). As has been discussed in this report, a host of upstream factors regarding land development policies, transportation priorities, and geometric design practices establish the conditions in which crashes occur, and may introduce latent conditions that can make crashes more—or less—likely to occur.

Figure 12 presents an integrated model that illustrates how these upstream decisions can establish the latent conditions for a crash event. It also depicts the latent failure pathway that may route through organizational, environmental, individual, and engineering defenses to produce a crash event. Under a Safe Systems model, each of these links in the causal chain provide an opportunity to strengthen the safety of the overall system, and are addressed in the subsections below.

Figure 12: Defenses in Depth



Organizational Factors

Organizational factors are the higher-level policy and planning decisions that establish the developmental context in which the transportation system operates. Decisions regarding the location and configuration of new developments, as well as policies and practices relating to roadway classification and transportation priorities can have a profound effect on the creation of safe, or unsafe, environments.

Regional Development Plans

Title 23, section 134 of the U.S. Code of Federal Regulations (CFR) requires all census-designated metropolitan areas to develop long-range plans (LRP) the region's transportation needs. In practice, this entails the forecasting and spatial allocation of future jobs and housing, and the identification of the system's resulting travel patterns. While federal regulations require safety to be considered as part of long-range plans, the safety implications associated with allocating growth to different locations are rarely considered. Instead, the typical process simply examines changes in congestion and delay (see *Performance Measures*, below).

Addressing safety in a proactive way requires an understanding of the safety implications of these development decisions. The location of development determines travel patterns and distributes trips along the regional transportation network, which may entail travel on facilities that are ill-equipped to safely accommodate the resulting changes in travel patterns. Similarly, new development may change the operating profile of the transportation network itself through the introduction of traffic conflicts onto streets ill-equipped to handle them. The types of environments created through regional development policies can thus create situations where traffic-related deaths and injuries are more likely to occur. A study examining counties in metropolitan areas in the United States, for example, finds that traffic fatalities are more likely to occur in environments with lower densities, little developmental centering, a low balance between jobs and housing, and large block sizes (Ewing, Hamidi, and Grace, 2016).

To encourage the consideration of safety into the regional development decisions, researchers have sought to develop safety forecasting tools that can be applied to the long-range transportation planning models to proactively identify the safety effects of different developmental configurations. Crash prediction models can be applied to the traffic analysis zones used in conventional long-range planning applications to provide forecasts of future crash incidence based on readily-available information such as VMT, population density, network configuration, and speed limits (Abdel-Aty et. al., 2011; Cai et. al., 2017; de Guevara, Washington, and Oh, 2004). The use of these models can thus allow decision-makers to understand the safety implications of different regional development scenarios.

Performance Measures

A related issue is the selection of performance measures used to evaluate transportation alternatives identified through the long-range transportation planning process. A survey of DOTs and MPOs found that most transportation projects are driven by concerns about vehicle congestion and delay, which encourage the advancement of projects that increase vehicle capacity, vehicle speeds, or both (Shaw, 2003). This is typically established through the use of performance measures such as peak-hour delay or level-of-service. Traffic safety is only considered, if it is considered at all, during the project development process, after planners have issued a project needs statement that establishes capacity expansion as the project's primary purpose (see *Environmental Factors*, below).

The problem with these measures is that they result in the advancement of projects that seek to increase operating speeds and vehicle capacity with little regard to their safety implications. The appropriateness of higher speeds needs to be a consideration in the advancement of projects, which can be achieved through the classification of roadways based on their environmental context, using frameworks such as those developed by New Zealand and Germany (see Figures 9 and 10). Where desired speeds cannot be safely achieved, other methods for addressing mobility needs should be evaluated. This may entail solutions such as transit, pedestrian and bicycle facilities, or other strategies appropriate to lower-speed mobility in urban environments. It may also entail the evaluation of network-level solutions, which seek to reduce demand on specific corridors by providing diffusing traffic onto parallel routes (Bern and Marshall, 2013; NACTO, 2013; Kulash, 1990). This has the advantage of allowing for more direct trip routing, which can not only reduce VMT, but support walking and bicycling as well. It further increases the operating efficiency of the overall system. As noted by the Federal Highway Administration

> *Wide streets with multiple travel lanes and turn lanes at intersections are less efficient in terms of motor vehicle capacity than a denser network of streets with fewer travel lanes. Research has shown that "the marginal capacity increase of additional lanes decreases as the size of the intersection increases (p. 30).*

Network-level analyses can be conducted using most conventional traffic simulation software. In practice, this entails examining not only a specific corridor, but also the surrounding street network. Modifications to the connectivity of the surrounding street network can allow traffic to be redistributed to less congested routes, resulting in improved operational performance along the larger network, as well as creating opportunities to support walking, cycling, and transit.

The profession appears to be moving away from LOS and peak hour delay as urban mobility measures, and towards *person capacity* and *person delay*. The use of person capacity and person delay allow planners to value the experiences of all street users equally, regardless of travel mode (Dumbaugh, Tumlin, and Marshall, 2014; NACTO, 2016). The Federal Highway Administration is in the process of adopting a rule that would permit person delay to be used in lieu of vehicle delay and level of service (Transportation for America, 2017), and the Institute of Transportation Engineers (2012) is in the process of revising its *Trip Generation* manual (2012) to evaluate development projects not based on vehicle trips, but person trips (Institute of Transportation Engineers Urban and Person Trip Generation Panel, n.d.).

To assist in the evaluation of person capacity and delay on urban streets, Table 1, below, shows the lane capacities of various transit modes, per lane. It includes both the highest observed capacities in North America, as well as the highest theoretical capacities, based on calculations derived from the Transit Capacity and Quality of Service Manual (Kittelson et. al, 2017). To provide a common basis for comparison, it further compares maximum theoretical capacities for freeways—which are facilities that remove all operational constraints on automobile throughput—against the maximum capacity of rail, bus, and light rail. It should be noted that arterial thoroughfares operate at much lower automobile capacities than freeways, and that the benefits of optimizing transit performance on these streets will result in much higher lane equivalencies than is reported Table 4.

Table 4: Person Capacity per Lane, By Transit Mode

Mode	Persons Per Hour One-Direction	Highest Observed (North America)	Highway Lane Equiv. (Observed)	Max Theoretical Capacity (PPH)	Highway Lane Equiv. (Theoretical)
Commuter Rail	2,000-20,000	20,000	8.3		
Heavy Rail	13,000-41,000	50,000	25	72,000	30
Light Rail (Exclusive ROW)	7,000-18,000	10,000	5	22,000	9.2
Light Rail (On Street)	3,000-14,000	5,000	2.1		
BRT/Dedicated Bus Lanes	2,000-10,000	11,100	4.6	36,000	15
Bus (Mixed Traffic)	1,000-3,000	3,000	1.3		

Highway lane equivalency is MAX theoretical capacity (2000 vehicles per hour and 1.2 persons per vehicle). Transit theoretical capacity based on maximum loadings and train lengths, and optimized headways and stations configurations

(Source: Dumbaugh and King, 2018)

Zoning Ordinances and Subdivision Regulations

While locations for future growth are identified as part of the long-range transportation process, the specific location and configuration of that growth is not determined by transportation agencies, but by local governments. Zoning ordinances dictate permissible land uses, their density, as well as parking requirements. These, in turn, establish the types of trips that will require access to the transportation system. Subdivision regulations further determine the placement and configuration of buildings on a site, and may address issues such as landscaping and sight triangles at intersections. Considered collectively, they establish the transportation network's environmental conditions. If latent crash conditions are to be prevented, specific attention needs to be given to how these regulations access the transportation system, and whether the associated network is designed to safely accommodate the resulting traffic patterns, which can be remedied through attention to design (See *Environmental Factors*, below).

Environmental Factors

Environmental factors relate to the policies and practices that govern the design of specific transportation projects, and which occur during the project planning and development process. As shown in Figure 13, transportation projects are typically triggered by a project needs statement, which may emerge from long range planning activities or from requests to address an area of identified need. This results in the issuance of a project needs statement, which establishes the purpose and scope of a proposed project. The specific alternatives that are developed are focused on addressing this identified need.

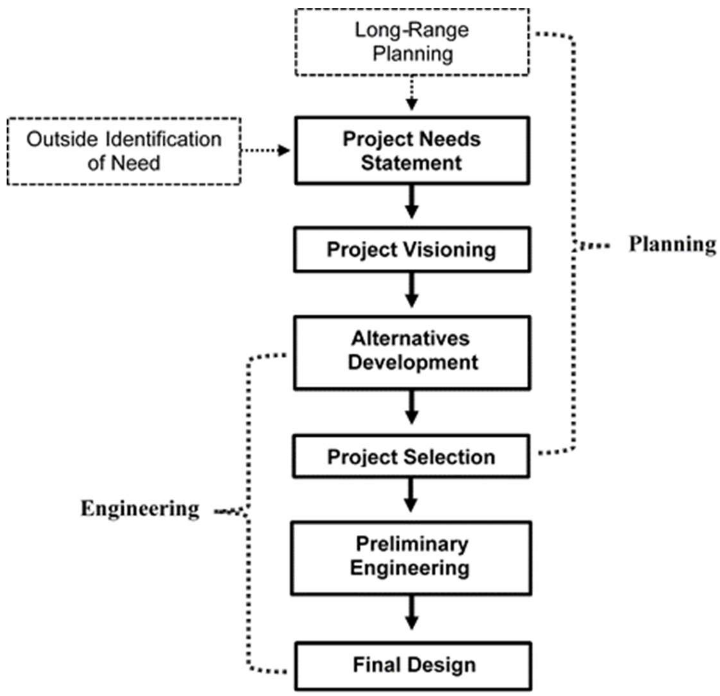
By and large, safety is not considered as part of the project development process, nor are capacity expansion projects regarded as being detrimental to safety. In general, the professional assumption is that safety is adequately addressed through adherence to the passive safety recommendations contained in design engineering manuals such as the AASHTO's (2011) *A Policy on the Geometric Design of Highways and Streets*. The safety impacts of a project need not to be further considered if a project adheres to the recommendations contained in these manuals (Hauer, 1999).

A major point of departure for Safe Systems is the assertion that mobility should not come at the expense of safety, and that safe design must be sensitive to the contextual and environmental conditions in which a transportation facility is placed. Procedurally, this requires that safety be identified as a core element of a project's vision, and that safety considerations be integrated the design parameters used to develop specific project alternatives. The design guidance established by New Zealand (Figure 10) and Germany (Figure 11) show how this may be achieved.

Individual Factors

Finally, Safe Systems recognizes that designers and road users have a shared responsibility for safety. This requires road users to behave in a manner that does not place them in undue harm, which further presupposes that they are aware of safe and appropriate behavior. Mechanisms for addressing road user behavior have been long-established, and are currently the focus of organizations such as the National Institute for Highway Safety and State Governor's Offices of Highway Safety. Their activities include education and licensure programs to ensure that road users are knowledgeable in safe behavior and have the physical capacity to safely operate a vehicle, law enforcement campaigns that seek to restrict undesirable behaviors, such as failure to wear a seatbelt or drink-driving, and legal sanctions to impose consequences on reckless or hazardous behaviors.

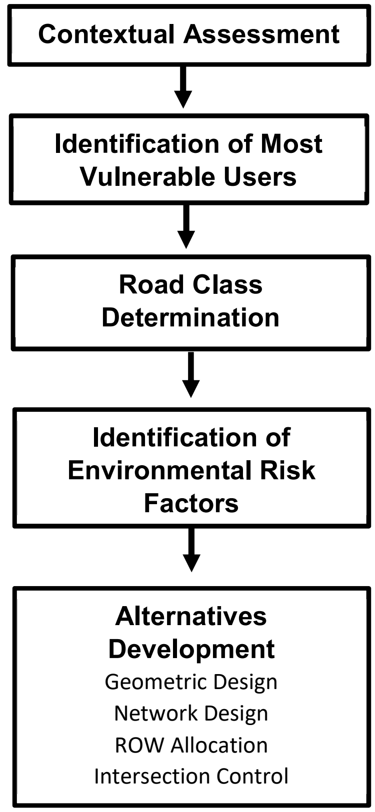
Figure 13: The Project Development Process



A Safe Systems Approach to Project Planning and Design

For safety to be meaningfully integrated into project design, safety considerations need to be integrated into the project's vision and scope, which will in turn inform the development of project alternatives and final design through the project development process. As shown in Figure 14, the first step in doing so is to conduct a *contextual assessment* of the project to understand the environment in which the project is located, both now and in the project's ultimate horizon year. This includes the identification of the characteristics of the development surrounding the roadway and the likely levels of access the facility will provide to these uses. Understanding the project's developmental context will in aid in the identification of the facility's *most vulnerable user*, or the user who is most likely to be injured or killed in a crash event. For Safe Systems, the most vulnerable user is the focus of design.

Figure 14: A Safe Systems Approach to Project Planning and Design



Information on the roadway's development context and its most vulnerable user in turn informs the project's *road class determination*, which is used to define the ultimate purpose and function of the facility, and which is further used for the determination of the project's design speed. Each developmental context is further associated with a particular set of *environmental risk factors*, or elements that increase the incidence of traffic crashes. While further research into this area is warranted, many of the likely risk factors can be identified by examining the relationship between speed and traffic conflicts along the corridor. If the road is appropriately classified, most of the major problems relating to speed should be addressed. A more complex issue is the identification of traffic conflicts that may occur on the site, which are associated with vehicles or pedestrians entering the travelway or attempting to access developments located adjacent to the corridor. They may further be influenced by the location and control of intersections and driveways, which may create, or inhibit, opportunities for safe access and street crossings. Similarly, the number of travel lanes on a facility increases crossing distance and may increase traffic conflicts. These items need to be specifically assessed for both the current and future horizon year.

The understanding of the roadway's environmental conditions, the selection of road class, and an assessment of environmental risk factors should in turn inform the development of specific *project alternatives*, which seek to mitigate the effects of traffic conflicts through the geometric design of the project, the allocation of right-of-way to specific users, the design and configuration of the street network, and the location and provision of intersection control.

It should further be observed that the responsibility for safe design does not rest solely on the traffic engineers responsible for a facility's design; as discussed above, organizational decisions regarding the location and configuration of development establish the baseline conditions that must be mitigated through design. For projects with a longer-term horizon year, or for those projects being developed to address future projected growth, partnership with local governments and regional planning agencies are essential for preventing future land development that degrades the facility's future safety performance.

Part II: Safe Systems in Other Countries

Part II of this report provides a review of the practices of four countries that have well-established Safe Systems programs: Sweden, the Netherlands, Australia, and New Zealand. Each of these countries have structured their approaches to road safety around the Safe Systems core principles and implemented innovative measures to address their specific priorities. We framed our examination by answering five questions for each of the representative nations:

1. What was the motivation for implementing a Safe Systems program?
2. What exactly was implemented to improve road safety?
3. What challenges did the nation face in its implementation?
4. How effective was the implementation?
5. What recommendations, if any, does this nation have for others seeking road safety improvements?

Sweden

Motivation and Trends

Sweden is generally credited, along with the Netherlands, with initiating the Safe Systems approach to roadway safety through its careful and rigorous approach to reorganizing the top-down structures responsible for transportation safety management (World Road Association, 2015; Sisson, 2018). Sweden has a reputation for excellence in road traffic safety and has been praised for its leadership and success in managing road safety issues for decades. Overall, road deaths in Sweden have declined sharply since the 1970s, despite a growing population and a steady increase in traffic volume. In 2016, Sweden had the fewest number of road fatalities on record (254) and still maintains the lowest road traffic fatality rate worldwide with approximately 2.9 deaths per 100,000 people (SAFER Vehicle and Traffic Safety Centre at Chalmers, 2018).

This was not always the case. Annual road deaths in Sweden peaked at close to 1,300 in the late 1970s then steadily declined in the years that followed until the late-1980s, when numbers plateaued, hovering at about 500 deaths per year (Belin, 2012). The road transport system carried a considerably higher risk level than other modes of transport (Belin, 2017). This reality was completely unacceptable to road safety practitioners. Around this same time (1994) the lives of over 500 Swedish citizens were lost in one of the worst maritime disasters in modern times when a ferry carrying over 800 passengers sank in the Baltic Sea. This tragedy, along with diminishing gains in the road toll, strengthened interest in improving public transport safety and set the stage for Sweden's comprehensive road safety strategy, *Vision Zero* (Whitelegg & Haq, 2006).

Developed by the Director of the Swedish National Road Administration, Claes Tingvall, and the Minister of Transport, Ines Usmann, *Vision Zero* aimed to address this road safety problem using a comprehensive Safe Systems approach. With strong support across all party lines, the concept was written into law by Swedish Parliament in 1997 and proposed that "no-one shall be killed or seriously injured as a consequence of the transportation system" (Beling, Tillgren, & Vedung, 2011; Whitelegg & Haq, 2006).

Based on Safe Systems principles, *Vision Zero* emphasized that the responsibility for road safety should be shared by both designers and road users (Whitelegg & Haq, 2006). The designers of the system are always ultimately responsible for the design, operations and use of the road transport system, and are thereby responsible for the level of safety within the entire system.

1. Road users are responsible for following the rules for using the road transport system set by the system designers.
2. If road users fail to obey these rules due to a lack of knowledge, acceptance or ability, or if injuries occur, the system designers are required to take the necessary steps to counteract potential death or serious injury.

Policies and Implementation

Following the *Vision Zero* legislation, the Swedish Government launched a short-term action plan that proposed 11 priority areas. These priorities included focusing on the most dangerous roads, improving traffic safety in built-up areas, and placing more emphasis on the responsibilities of road users and transport system designers (Table 5).

Table 5: Priority Areas for Vision Zero

1. A focus on the most dangerous roads (e.g. priority for installing centre-guardrails for eliminating head-on collisions, removing obstacles next to roads, etc.)
2. Safer traffic in built-up areas (e.g. a safety analysis of street networks in 102 municipalities led to reconstruction of streets; the efforts are continuing.)
3. Emphasis on the responsibilities of road users (e.g. creating more respect for traffic rules in particular with regard to speed limits, seat belt use, and intoxicated driving.)
4. Safe bicycle traffic (e.g. campaign for using bicycle helmets, a voluntary bicycle safety standard.)
5. Quality assurance in transport work (e.g. public agencies with large transportation needs will receive traffic safety (and environmental impact) instructions on how to assure the quality of their own transportation services and those procured from outside firms.)
6. Winter tyre requirement (e.g. a new law mandating specific tyres under winter road conditions.)
7. Making better use of Swedish technology (e.g. promoting the introduction of technology - available or to be developed - that relatively soon can be applied, such as seat belt reminders, in-car speed adaptation systems (ISA), alcohol ignition interlocks for preventing drinking and driving, and electronic driver licences.)
8. Responsibilities of road transport system designers (e.g. establishment of an independent organisation for road traffic inspection is proposed by a commission of inquiry on the responsibilities of the public sector and the business community for safe road traffic.)
9. Public responses to traffic violations (e.g. a commission of inquiry is reviewing existing traffic violation rules in the light of the Vision Zero principles and of ensuring due process of law.)
10. The role of voluntary organisations (e.g. the government is evaluating the road safety work of the 'Nationalföreningen för trafiksäkerhetens främjande' (National Society for Road Safety (NTF)) and its use of state funds.)
11. Alternative forms of financing new roads (e.g. possibilities are studied for other forms of supplementing public financing of major road projects.)

(Whitelegg & Haq, 2006)

A number of key transportation experts also outlined specific ways to mitigate Sweden's road safety problem. Tingvall and Monash University Accident Research Centre's Narelle Haworth proposed several strategies that they believed could easily be adopted independent of any political sphere (Haworth & Tingvall, 1999):

- gradually aligning vehicle speed to the inherent safety of the system by rating roadways according to their infrastructure;
- improving vehicles to address driver behavior issues by incorporating seat belt interlocks, alcohol interlocks, and intelligent speed limiters; and
- motivating the community to use the system in a safer way.

They also emphasized that societal benefits, such as mobility within the transportation system, should never be prioritized at the expense of life and health, and when a death or serious injury occurs, steps must be taken to prevent a similar event (Haworth & Tingvall, 1999).

Roger Johansson of the Swedish Road Administration also summarized how incompatible traffic elements should be separated, including diverse road users, based on human tolerances to physical violence, as shown in Figure 15 (Johansson, 2009). He emphasized that when separation of road users was warranted, this separation should always be by physical means, such as a barrier. This approach to design places a greater emphasis on more rigid stratification of functional use for roadways; roadways with high mobility demands should not create situations through open access that expose road users to excess risk.

Figure 1: Human tolerance to speed exposure

1. *Vulnerable road users should not be exposed to motorised vehicles at speeds exceeding 30 km/h.*
2. *If 1. cannot be satisfied then separate or reduce the vehicle speed to 30 km/h.*
3. *Car occupants should not be exposed to other motorised vehicles at speeds exceeding 50 km/h in 90 crossings.*
4. *If 3. cannot be satisfied then separate, or reduce the angle, or reduce the speed to 50 km/h.*
5. *Car occupants should not be exposed to oncoming traffic (other vehicles of approximately same weight) at speeds exceeding 70 km/h or 50 km/h if oncoming vehicles are of considerably different weight (Fig. 3).*
6. *If 5. cannot be satisfied then separate, homogenize weights or reduce speeds to 70 (50) km/h.*
7. *Car occupants should not be exposed to the road side at speeds exceeding 70 km/h, or 50 km/h if the road side contains trees or other narrow objects (Fig. 4).*
8. *If 7. cannot be satisfied separate or reduce speed to 70 (50) km/ h.*

(Johansson, 2009)

Drawing upon these guiding principles of road user separation and speed reduction, Sweden implemented multiple roadway measures to improve safety for all users. In application, *Vision Zero* primarily focused on speed limit reductions, road design improvements, and extensive data analysis and monitoring (Trafikverket Swedish Transport Administration, 2012).

Transportation agencies implemented Large-scale speed limit reduction to 30 km/h (19 mph) in many urban areas which previously had default speeds of 50 km/h (31 mph) (Goodyear, 2014; Fotheringham, Symmons, & Corben, 2008). Beginning in 2008, they also implemented speed limit reductions of 10-20 km/h (6-12 mph) on several rural road types with pre-existing speed limits of between 90-110 km/h (56-68 mph), shown in Table 6 (Trafikverket Swedish Transport Administration, 2012). These reductions purportedly reduced deaths from 41% to 14%, although no significant change in serious injuries was observed (Vadeby and Forsman, 2017). A large-scale road safety camera program was also implemented in 2006 to encourage drivers to comply with posted speed limits. Adherence to speed limits improved from 50% in the 1990s to more than 80% across Sweden and 95% at camera sites as of 2014 (ITS International, 2014).

Table 6: Speed Limit Changes in Sweden

Type of road	Description
1. Motorways, 110 → 120 km/h	Motorways where the speed limit increased from 110 to 120 km/h
2. 2 + 1 roads, 90 → 100 km/h	A continuous three-lane road with alternating passing lanes and the two directions of travel separated by a median barrier
3. 2 + 1 roads, 110 → 100 km/h	A continuous three-lane road with alternating passing lanes and the two directions of travel separated by a median barrier
4. Rural roads, 110 → 100 km/h	Two-lane rural roads
5. Rural roads, 70 → 80 km/h	Two-lane rural roads
6. Rural roads, 90 → 80 km/h	Two-lane rural roads
7. Rural roads, 90 → 70 km/h	Two-lane rural roads

(Trafikverket Swedish Transport Administration, 2012)

Transportation agencies also made Structural improvements to roads and roadsides. Efforts included constructing center median wire rope barriers and roadside barriers to roadways as well as removing dangerous objects from roadsides (Trafikverket Swedish Transport Administration, 2012). Another effort was the conversion of three-lane undivided roads to a “2+1” road configuration. In a “2+1” design, a continuous flexible center barrier separates opposing lanes of traffic, but the presence of a second lane alternates from one direction of travel to the other as the location of the barrier shifts toward or away from the single lane. It is estimated that fatalities on these roadways have been reduced by up to 90% (Larsson, Candappa, & Corben, 2003).

Multiple actions pertaining to vehicle safety were also implemented. The use of winter tires became mandatory in 1999. Beginning in 2005, laws required 70% of new cars to have seat-belt reminders (Johansson, 2009). Following this policy, the seat-belt wearing rate increased from 92% to 99%. Cycle helmets became mandatory for those aged 15 years and younger (Road Traffic Technology, 2008).

To assess these gains in safety and to ensure that countermeasures were properly evaluated, Swedish authorities also established a rigorous data collection and safety measurement program. Since 1997, Sweden has conducted individual investigations of every fatal car crash to separate which factors contributed to the crash and which contributed to the fatality. Based on these factors and what aspect of road safety failed, crashes fall into one of three groups: “excessive force,” “excessive risk,” and “beyond system recommendations” (Whitelegg and Haq, 2006).

Road safety professionals in Sweden also monitor numerous other metrics related to roadway safety, including drunk driving, speeding, seatbelt use, cyclist helmet use, emergency services rescue times, and motor vehicle crashworthiness (Trafikverket Swedish Transport Administration, 2012). Analysts combine hospital data with police reports and regularly review and share injury reports at national conferences each year. In addition, agencies routinely identify locations on roadways that share similar attributes to problematic locations on roadways to apply safety measures before road safety issues develop.

Efficacy of the Solutions

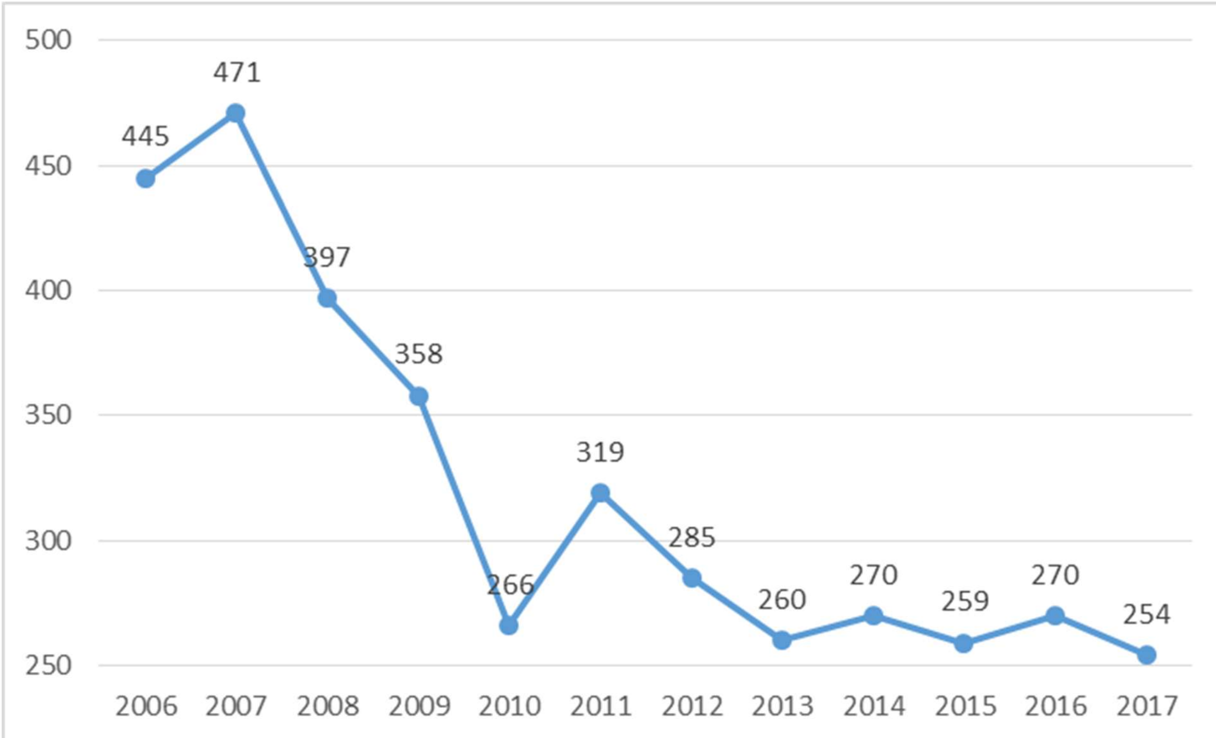
Given the number of factors that can influence a system, it can be difficult to attribute road safety trends to any one specific cause. However, several positive trends have been observed in Sweden since *Vision Zero* was implemented. Fatalities declined by 50% between 2000 and 2014, and pedestrian fatalities, specifically, declined by 50% between 2009 and 2014 (Strömgren, 2017). Fatalities of children seven years of age and younger also plummeted, from 58 in 1970 to one in 2012 (S.N., 2014).

Other road safety improvements, as mentioned, include:

- Reduction of 90% of fatal crashes on three-lane undivided roads (Larsson, Candappa, & Corben, 2003)
- Seat-belt compliance at 99% (Road Traffic Technology, 2008)
- 95% compliance with red-light cameras at enforcement sites (ITS International, 2014)

Sweden had 254 road fatalities in 2017, a slight decline from 2016 and its lowest number ever recorded. Despite this achievement, significant drops in fatalities have stagnated over the last several years (Figure 16). The majority of these deaths were motorists and motorcyclists (67%) while approximately one-fourth of deaths were of pedestrians and cyclists (17). These stagnations are not themselves indications of failure but highlight many of the difficulties and challenges still faced by countries that have adopted Safe Systems approaches. These challenges, and the potential opportunities for improvement they invite, are discussed in the next subsection (SAFER Vehicle and Traffic Safety Centre at Chalmers, 2018).

Figure 2: Road Traffic Fatalities in Sweden 2006-2017



Challenges and Opportunities

Despite widespread support of Sweden's *Vision Zero*, there was some early opposition from industry experts. Matts-Åke Belin, a *Vision Zero* architect and road safety strategist with the Swedish Transport Administration, has said that the one of the main challenges of implementing the strategy was shifting system stakeholders' mindsets from "cost-benefit" to "Safe Systems," i.e., placing a greater emphasis on health and autonomy (Goodyear, 2014). In addition, since traditional approaches focused on changing human behavior, road engineers were reluctant to accept shared responsibility for roadway safety. However, in an interview with the ITE Transportation Podcast, Belin emphasized how critical a role traffic engineers play in enhancing safety by comparing the consequences of a crash at a 4-lane intersection with a traffic light to a crash at an intersection controlled by a roundabout (Belin, 2017).

For example, Belin illustrated that at an intersection controlled with a traffic light, the total number of conflicts will be reduced, but any crashes that occur will likely be severe due to the high speed and high-energy transfer of those impacts. At a roundabout, traveling speeds are reduced by design and crashes will inherently be much less severe. These aspects could literally mean the difference between life and death. Since road engineers make these determinations of roadway design, they ultimately bear the responsibility for the safety of the road user. For this reason, Belin believes it is essential for road engineers to understand the *Vision Zero* philosophy and to shift their mindsets dramatically to implement new road safety solutions (Belin, 2017).

Although it may be initially difficult to encourage transportation engineers to adopt Safe Systems principles, especially at the cost of mobility, reframing the argument beyond a simple cost-benefit analysis and instilling a moral imperative for promoting safety and health may encourage buy-in from these key stakeholders. An approach Sweden took early on to shift the paradigm was to reorganize their road safety management structure from the ground up, so as to not promote the idea that road safety is a process isolated from society, rather one that integrates stakeholders from a wide variety of disciplines, including engineering (International Transport Forum, 2016).

Matts-Åke Belin believes that an approach like *Vision Zero* is transferable to road systems around the world, but he emphasizes that strong political support is essential (Belin, 2017). He also emphasized that it is important to understand that the mechanical, scientific basis of *Vision Zero* remains constant and is relevant in any system. Critics often cite a lack of accountability for risk in Safe Systems approaches (Zwetsloot, Leka, and Kines, 2017), but the data management and evaluation process implemented by Sweden highlights a dedicated approach to measuring safety improvements and scientifically responding to risks in the system. Human tolerances to violence and crash energies remain the same. The approaches to resolving these problems, however, will be different because traffic dynamics and aggregations of road users will vary from one locality to the next.

Belin also suggested that road safety practitioners focus on unprotected road users when designing transportation systems, as they will set the standard for safety. Since North American society is more dependent upon motor vehicles, adapting the U.S. system to vulnerable road users like pedestrians and cyclists will pose a greater challenge than for those regions with more diverse transportation systems (Belin, Tillgren, and Vedung, 2011).

Most importantly, Belin believes that the motivation must come from the ethical imperative that fatalities and serious injuries in the transport system are unacceptable.

New Zealand

Motivation and Trends

Like Sweden, New Zealand traffic safety has improved dramatically over the last several decades. Despite an increase in traffic volume, road deaths have declined by 50% since 1970 (New Zealand Ministry of Transport, 2018). Between 1990 and 2000, road deaths and serious injuries attributed to drug and alcohol use also declined significantly.

However, this progress was beginning to stabilize, and in 2007 New Zealand still had one of the highest rates of road fatalities per capita in the developed world (about 10 per 100,000 residents) (New Zealand Ministry of Transport, 2009). New Zealand acknowledged that it would not meet 2010 targets to reduce deaths and serious injuries under the status quo of road safety management. Other factors that had great potential to influence the safety of road users were also emerging, including a growing and aging population, an increase in motorcycle use and overall traffic volume, and novel illegal drugs. To address these road safety challenges, new strategies were needed.

In 2009, the New Zealand National Road Safety Committee (NRSC) proposed *The Safer Journeys Strategy*, which was based on Safe Systems and envisioned “A safe road system that is increasingly free of road deaths and serious injuries.” NRSC members included the Ministry of Transport, the New Zealand Transport Agency, the New Zealand Police, the Accident Compensation Corporation, and Local Government New Zealand, but many other supporting members also played important roles (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

As part of this strategy, The New Zealand Minister of Transport, Hon Steven Joyce, released a discussion document to the general public. The document outlined New Zealand’s achievements in road safety, the proposed *Safer Journeys* vision and approach, and proposed over 60 possible road safety initiatives under consideration. Many more initiatives were proposed than the government expected to fund; however, this was intentional and provided a platform for public discussion (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

These initiatives were placed into 13 priority areas broken into three groups: areas of high concern, areas of medium concern, and areas for continued focus and emerging issues (Figure 17). It was explained that high concern areas were those most likely to result in the greatest road safety improvement. The five areas of highest concern included reducing alcohol/drug impaired driving, increasing the safety of young drivers, safer roads and roadsides, safer speeds, and increasing the safety of motorcycling. Some specific initiatives proposed to address high priorities included reducing the legal adult blood alcohol limit from 0.08 to 0.05 g/100mL, raising the driving age to 16 or 17, adopting lower speed limits in urban areas, and improving motorcycle riding training (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Figure 3: New Zealand 'Safer Journeys Strategy Discussion Document' Priority Areas

(New Zealand Ministry of Transport, 2009)

The document explained the relevance and scientific merit of each priority area, presented relevant trends and statistics, and discussed various aspects of the proposed initiatives, including benefits and limitations. During a two-month public consultation period, citizens were asked to submit their choices for the top 10 or 20 initiatives and share general thoughts about how to improve outcomes in each priority area (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Overall, New Zealanders responded favorably to the Discussion Document and provided over 1,500 submissions to the Ministry of Transport. The public strongly supported most priority areas but expressed interest in improving a few specific areas, shown in Table 7 (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Table 7: Public support of "The Safer Journeys Strategy Discussion Document" Priority Areas

Initiatives with strong public support	Public desired more focus on
• Lowering legal BAC limits • Raising driving age • Changing 'give-way' rules • Improving walking/cycling infrastructure	• Enforcement and compliance in all areas • Drivers and road users • Stronger penalties for repeat drug/alcohol offenses

(New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009)

Citizens felt that the most emphasis should be placed on initiatives aimed at road users (one of the four elements of a Safe System). Since submissions were disproportionately focused on this one element, with less focus on safe speeds, roads, and vehicles, the Ministry of Transport questioned whether the public fully understood the overall premise of the Safe Systems approach. Not all issues that received strong support from the public were actually backed by evidence, i.e., mandatory third party insurance was a popular proposed policy, but given that the rate of insurance was already high, this policy would not have significantly improved road safety (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Using input received from the public, as well as research and experience from other countries that implemented Safe Systems approaches, New Zealand developed the *Safer Journeys Strategy 2010-2020.* The strategy was led by the NRSC, but other partners included the New Zealand Police, the New Zealand Transport Agency, the Accident Compensation Corporation (ACC), and Local Government New Zealand (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Over the long-term, the goal of the strategy was to, "Improve the safety of our roads and roadsides to significantly reduce the likelihood of crashes occurring and to minimize the consequences of those crashes that do occur," but it was designed to be implemented through a series of smaller Action Plans (2011-2012, 2013-2015, and 2016-2020) and tailored to address individual community needs (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Policies and Implementation

The first Action Plan 2011-2012 focused on advancing the Safe Systems approach, addressing the areas of high and medium concern with initiatives that could most greatly reduce the road toll. Some specific goals included (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009):

- targeting high-risk rural roads and high-risk urban intersections;
- improving speed management through public campaigns, safer speeds, and expanding the use of safety cameras;
- generating consumer demand for safe vehicles and improving child restraint use;
- increasing the safety of motorcycling through training, road treatments, and enforcement;
- reducing alcohol/drug impaired driving through regulations, education, and enforcement;
- increasing the safety of young drivers through regulations, education, and enforcement;
- reducing the impact of high-risk drivers through rehabilitation, regulations, and enforcement;
- improving pedestrian and cyclist safety through education and safer infrastructure; and

- reducing the impact of distraction and fatigue through education and road infrastructure.

The second Action Plan 2013-2015 consolidated efforts from 2011-2012 but laid out specific goals for each element of the Safe System. Some of these goals included identifying the 100 highest-risk intersections and implementing improvements for a subset of 20, developing a consistent and effective national speed management program, accelerating the removal of less safe vehicles from the roads, and strengthening drug-driving enforcement. The plan also focused on demonstrating the effectiveness of the Safe Systems approach by launching two new initiatives, the Safe System Signature Programme and the Safe System Partnership Programme (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2016).

The Safe System Signature Programme sought to identify specific projects that had the potential to collectively reduce the road toll for all road users by using innovative approaches. Specific projects included: the Future Streets Project to improve pedestrian and cyclist safety on urban streets; Behind the Wheel, which supported young learning drivers in the community of Mangere; and the Visiting Drivers Project, aimed at improving road safety for visiting tourists (New Zealand Ministry of Transport, 2018). The Safe System Partnership Programme created new initiatives with partners to demonstrate the effectiveness of collaboration in reducing road trauma (New Zealand Ministry of Transport, 2016).

The third and final Action Plan 2016-2020 focuses on the use of current and emerging technologies and on areas of road safety that relate to disproportionate road toll. The plan aims to (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009):

- Enable smart and safe choices on the road by using technology to provide real-time safety information to road users.
- Make motorcycling safer by increasing rider awareness and training, encouraging use of motorcycle technologies, and improving protective clothing.
- Ensure safer roads and roadsides on urban arterial routes and increase low-cost safety improvements on high-risk rural routes.
- Encourage safe vehicles through the uptake of vehicle safety technologies into the vehicle fleet.

Efficacy of the Solutions

In the few years immediately following the introduction of the strategy, three-fourths of actions proposed in the first action plan were completed, and various road safety outcomes were drastically improved. Between 2009 and 2012, road deaths declined 20%, and 284 fatalities in 2011 marked the lowest road toll since 1952. Deaths of young drivers (ages 15-24) decreased 38%. Alcohol-related crashes with fatal and serious injuries also declined significantly (New Zealand Ministry of Transport, 2013).

The New Zealand Ministry of Transport also implemented several other actions to promote safe and healthy use of the roadway in each of the priority areas. Some of these actions included (New Zealand Ministry of Transport, 2013):

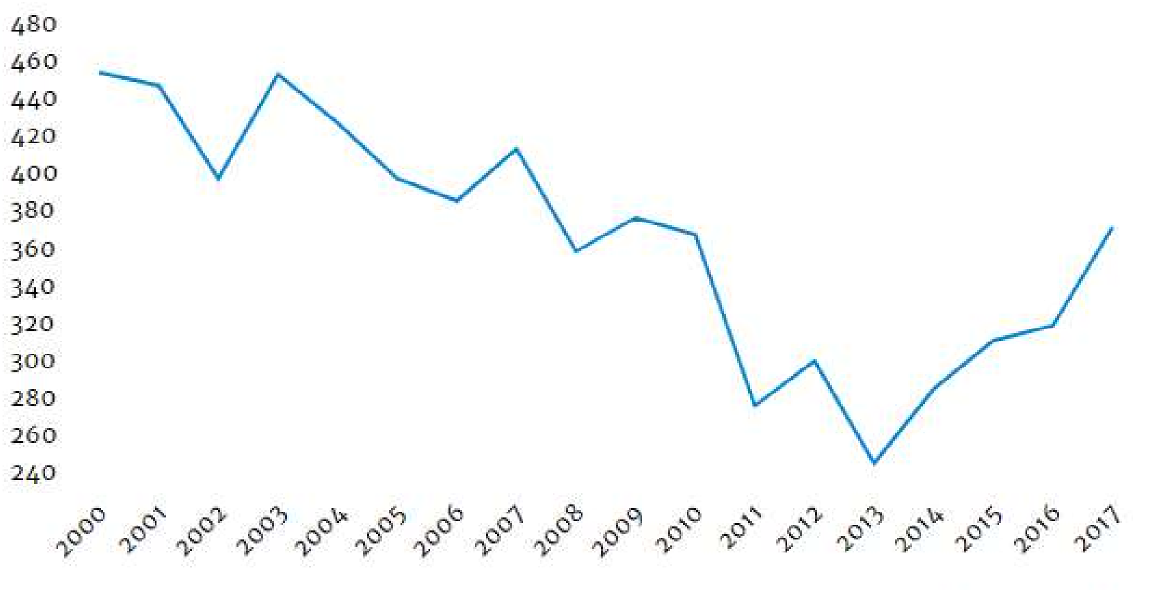
- Raising the minimum driver age from 15 to 16;
- Implementing stricter child restraint regulations and BAC limits; and
- Enhancing speed management with red light and speed cameras.

A more comprehensive list of actions implemented in *Safer Journeys* is presented in Table 7. More recently, 5-star vehicle ratings for new light cars entering New Zealand roads increased from 51% (2009) to 95% (2016). There are also ongoing efforts to install rumble strips and safety barriers, widen shoulders, improve signage, and implement more appropriate speed limits (New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009).

Challenges and Opportunities

Despite achieving great improvements in road safety since implementing *Safer Journeys*, some areas still need improvement. Motorcycle deaths and serious injuries have risen since 2013 (New Zealand Ministry of Transport, 2016), and road fatalities overall have risen over the last several years (Figure 18). Fatalities from failing to use seatbelts doubled between 2014 and 2016, which also correlates with drunk driving among male drivers. During this same time, the number of high-risk drivers (e.g., repeat offenders and disqualified and unlicensed drivers) involved in fatal or serious injury crashes increased dramatically, from 183 in 2014 to 346 in 2016. Crash deaths per 100,000 among 15- to 24-year-olds has increased slightly since 2012. Alcohol or drug-related fatalities or serious injuries per 100,000 also increased slightly during 2014-2016, as did motorcycling entitlement claims. Overall, since 2013, the fatality rate has steadily increased, and 2017 may have reached the highest total since 2010 (New Zealand Ministry of Transport, 2018). Although New Zealand still faces a number of challenges, particularly those that require enforcement of traffic laws, researchers like Bambach and Mitchell believe a holistic approach that integrates design, enforcement, and education, may provide substantial reductions to road tolls, particularly for vulnerable road users, in countries with Safe Systems programs (Bambach Mitchell, 2015).

Figure 4: New Zealand Road Traffic Fatalities



New Zealand Ministry of Transport, 2016)

Table 8: Actions implemented in “Safer Journeys 2010-2020”

Priority Area	Action Implemented
Young Drivers	• Raised minimum driving age from 15 to 16 • Implemented zero BAC for drivers <20 years old • Strengthened Restricted Driver License Test • Introduced Community Driver Mentor Programme • Launched online interactive website “Drive” for learner drivers • Produced road safety resources that supported school curriculum
Drink Driving	• Implemented zero BAC for drivers <20 years old • Lowered BAC to .05 for drivers >20 years old • Focused on reducing drink driving through the “Legend Campaign” • Implemented Alcohol Interlock Programme
Motorcycling	• Introduced power-to-weight restriction for novice riders • Introduced Competency-based Motorcycling License Testing • Increased numbers of motorcyclists trained in Ride Forever Program • Updated *Safer Journeys* for motorcycling on New Zealand roads
Drug Driving	• Raised awareness of the risks posed by drug driving (TV ads)
Restraint Use	• Increased age of compulsory child restrain use to 7 years of age
Safe Speeds	• Published a Speed Management Guide • Developed resources for Road Controlling Authorities to facilitate better road risk conversations with communities/stakeholders • Developed new geospatial tool to identify where to target roads to best reduce deaths and serious injuries for all crashes
Safe Vehicles	• Developed Vehicle Standards Map to identify new vehicle technologies • Promoted and expanded vehicle safety information with RightCar • Mandated Electronic Stability Control for new light vehicles • Adjusted motor vehicle levies to reflect vehicle safety • Increased 5-star vehicle ratings for new light cars entering NZ roads

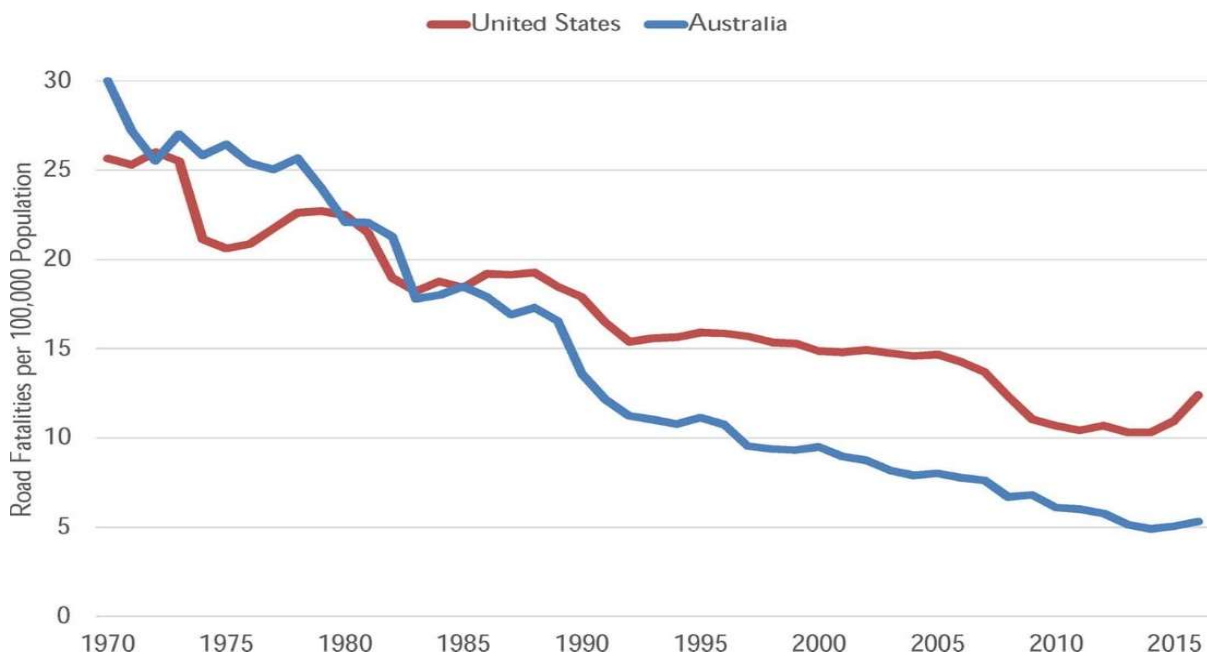
(New Zealand Ministry of Transport, 2018; New Zealand Ministry of Transport, 2009)

Australia

Motivation and Trends

As in the U.S. and Sweden, Australia has halved the death toll from road traffic crashes since the 1970s when road fatalities were at their peak (Figure 19). Much of this decline can be attributed to a road safety countermeasure program that was progressively implemented over the years (Langford and Oxley, 2006). Some measures put in place included graduated driver licensing, roundabouts, mandatory seat belt laws (1973) and bicycle helmet use (1990), random breathalyzer testing (1976 in Victoria), and speed camera programs (Mooren and Grzebieta, 2011).

Figure 5: Comparison of road fatalities per 10,000 people between the United States and Australia



Additionally, the Motor Vehicles Standards Act of 1989 introduced strict safety standards for all vehicles entering the Australian market. In 1990, the Australian Government implemented a Black Spot Program to target specific road segments and locations with a proven crash history or significant crash potential (Australian Government Department of Infrastructure, Regional Development and Cities, 2017). The National Road Safety Strategy of 1992-2001 marked Australia's first collaborative effort to improve road safety. Significant reductions in the road toll were achieved but the rate of improvement gradually slowed and remained relatively constant.

Tingvall and Haworth together advocated for a *Vision Zero* Safe Systems approach in Australia, starting with the state of Victoria (Haworth & Tingvall, 1999). Their recommendations focused on infrastructure improvements and speed management, citing that the most important aspect of *Vision Zero* centered around the human body's biomechanical tolerance to an external force. Specifically, they proposed that speed limits be reduced to levels more appropriate for the road infrastructure and significant separation should exist between road users on roads where speed exceeded 60-70 km/h (37-43 mph). Further, where conflicts between vehicles and pedestrians occurred, speed limits should be no more than 30 km/h (19 mph). Otherwise, vehicles and pedestrians should be physically separated (Haworth & Tingvall, 1999). These recommendations are highlighted in Table 9.

Table 9: Long-term Travel Speeds based on Best-practice Vehicle Design

Type of infrastructure and traffic	Possible travel speed (km/h)
Locations with possible conflicts between pedestrians and cars	30
Intersections with possible side impacts between cars	50
Roads with possible frontal impacts between cars	70
Roads with no possibility of a side impact or frontal impact (only impact with the infrastructure)	100+

(Haworth & Tingvall, 1999)

Policies and Implementation

Recognizing the need for stronger measures, the Australian Transport Council formally adopted Safe Systems principles in the subsequent National Road Safety Strategy 2001-2010 (Australian Transport Council, 2001). This effort aimed to reduce the rate of road fatalities by 40% by 2010 (equivalent to a 30% reduction in the number of fatalities). The Strategy proposed a number of Strategic Objectives to be implemented through a series of two-year Action Plans. Proposed initiatives included improving road user behavior, occupant protection, emergency response, and reducing human error through the use of technology. Strategic Objectives for the National Road Safety Strategy are summarized in Table 10.

The National Road Safety Strategy 2011-2020, still in progress, expanded this vision by setting a goal for reducing serious roadway injuries as well as fatalities. The Strategy aimed to reduce both the number of deaths *and* serious injuries by at least 30% by 2020 using evidence-based safety countermeasures (Australian Transport Council, 2011).

At the time that this strategy was launched (the 2011-2020 Strategy), several trends were apparent. Speeding accounted for the greatest proportion of deaths and serious injuries on the country’s roadways, followed by drunk driving and fatigue (in fatalities only). The majority of fatalities and serious injuries occurred in regional areas (65% and 59%, respectively), and fatalities per capita (per 100,000 residents) increase dramatically the more remote and further a region was from a major city. Traffic-related deaths were three times higher for indigenous people than non-indigenous people. Three crash types also dominated Australian roadways: intersection, single vehicle run-off-the-road, and head-on crashes (Australian Transport Council, 2011).

To address these challenges, interventions were proposed around four “cornerstone areas” that aligned with the Safe Systems approach: *safe roads, safe speeds, safe vehicles, and safe people.* Specific actions that were to be implemented in the first three years of the strategy are outlined below (Australian Transport Council, 2011).

The Australian Transport Council proposed numerous vehicle safety countermeasures, including improving new vehicle safety standards, reducing the average vehicle fleet age, and using intelligent technology systems, such as advanced seatbelt reminders, lane departure warning systems, and brake assist systems (Australian Transport Council, 2011).

The overall objective within this area is to encourage people to maintain consistent and compliant behavior within the road system. Specific measures include improving the graduated driver and motorcycle rider licensing programs and introducing programs that focus on the road safety of the indigenous community and disadvantaged groups. Additional measures focus on irresponsible road users and include lowering BAC limits, expanding the use of alcohol interlocks, and increasing penalties for repeat drink and drug-driving offenders (Australian Transport Council, 2011).

Interventions are also designed with the expectation that they be customized to local and regional differences across Australia. A diverse National Road Safety Strategy Panel provided guidance on all aspects of the Strategy implementation, and strategies are assessed through systematic reporting on the progress of Targets, Strategic Objectives, and Action Plans at annual meetings (Australian Transport Council, 2011).

Table 10: Strategic Objectives Outlined in Australia's National Road Safety Strategy 2001-2010

Objective	**Proposed Strategies and Focus Areas**
Improve Road User Behavior	• Educate young road users responsible road safety behavior • Driver Training & Licensing – Improve competence and attitudes • Enhance police enforcement using targeted campaigns
Improve the safety of roads	• Improve crash cost estimates • Conduct widespread road safety audits of improvement projects • Conduct safety investigations on existing road network (prioritize sites with a crash history) • Create safer environments for pedestrians, cyclist, and motorcyclists through road design and traffic engineering
Improve vehicle compatibility and occupant protection	• Improve vehicle safety standards and vehicle design • Provide consumers with information on relative safety of vehicles
Use new technology to reduce human error	• Incorporate Intelligent Transport Systems into vehicles and roads
Improve equity among road users	• Implement programs that target vulnerable road users
Improve trauma, medical and retrieval services	• Systematically link crash types with injury and treatment outcomes • Improve all components of trauma management systems reduce deaths and serious injuries for all crashes
Improve road safety programs and policy through research of safety outcomes	• Collect and analyze evidence from road safety outcomes • Improve learning and communication processes across local and international governments
Encourage alternatives to motor vehicle use	• Land-use planning and transport planning • Expansion of telecommuting • Promoting benefits of public transport, walking and cycling

Efficacy of the Solutions

During the first National Road Safety Strategy, a number of measures were implemented, many of which demonstrably reduced the road toll. The introduction of a 50 km/h (31 mph) urban default speed limit was linked to a greater than 20% reduction in serious injury and fatality crashes. Safety outcomes were also improved by implementing 40 km/h (25 mph) and lower speed limits in school zones and high-risk pedestrian areas. When the state of Victoria adopted School Speed Zones, pedestrian and bicycle crashes decreased by 24% (Australian Transport Council, 2011).

Australia introduced alcohol-interlock programs for repeat drink-driving offenders and roadside drug testing programs were implemented in most states, producing high detection rates. While no specific safety assessment has been conducted on these programs, they have the potential to contribute to road safety efforts by increasing overall awareness of drug-driving (Australian Transport Council, 2011).

A number of actions pertaining to vehicle safety were implemented. Three-point seatbelts mandated for all new passenger car models, new standards for front and side impact protection for new vehicles were put in place, and consumer ratings programs including the Australasian New Car Assessment Program (ANCAP) were developed to promote vehicle safety (Australian Transport Council, 2011).

While the National Road Safety Strategies have been implemented on a national scale, individual states also developed their own Safe Systems strategies, including Victoria, New South Wales, and Western Australia (Mooren, Grzebieta, & Job, 2013). In 2000, Victoria implemented a speed camera program that included strengthening speed enforcement and extensive public campaigns about speeding. After four years, fatal crashes declined by 27% and injury crashes declined by 10%, clearly demonstrating that comprehensive speed management programs can improve road user safety.

The 2001-2010 strategy resulted in a 34% reduction in the rate of road fatalities nationally but fell short of the 40% target. In general, however, programs targeting high-risk behaviors such as driver impairment, seatbelt wearing, and speeding made substantial improvements. Outcomes varied across states and territories, with the greatest 10-year reduction in road fatalities (per 100,000) occurring in Tasmania (47.5%) while the Northern Territory experienced the least overall reduction (16.1%) (Australian Transport Council, 2011).

Challenges and Opportunities

According to annual road trauma summary reports, total road deaths in Australia have declined by 20% overall and an average of 3% each year over the last decade. However, in 2015 and 2016, the death toll increased by approximately 6%. Researchers have projected that at the current rate, Australia will not reach its 2020 goal of reducing annual numbers of deaths and serious injuries by 30% (Hasham, 2018).

In response, the government has launched a comprehensive review of the National Road Safety Strategy. Leading road safety expert and chair of the Royal Australasian College of Surgeons' Trauma Committee, Dr. John Crozier, and the director of the Centre for Automotive Safety Research at the University of Adelaide, Jeremy Woolley, have been appointed to conduct the review (Hasham, 2018).

Dr. Crozier strongly criticized Australia's Black Spot Program in early 2018. He suggested that proactively improving entire road corridors, rather than high crash-prone areas, would be much more effective at addressing road safety issues. He also recommended coordinating road safety legislation across all states and strengthening Australia's speed camera program (Hasham, 2018).

It is difficult to predict road trauma levels due to the range of factors that influence road safety outcomes. Since Australia has enacted policies similar to Safe Systems measures for decades, it is difficult to parse out which specific gains can be attributed to Australia's broad Safe Systems approach (Marshall, 2018). However, by monitoring strategy implementation, evaluating safety outcomes, and periodically reviewing and revising safety-oriented actions, municipalities can adjust their road safety strategies as needed.

The Netherlands

Motivation and Trends

While Sweden may be better-known for being the first nation to adopt the Safe Systems approach, the Netherlands was the first country to construct quantitative road safety targets (Kraay, 2002). In the 1980s, the Dutch Government introduced several road safety plans that set long-term road safety policy goals. The *Meerjarenplannen Verkeersveiligheid* (MPV-I) set a goal of a 25% reduction in the number of injury crashes from 1985 to 2000. To meet this goal, the Dutch Government aimed to reclassify roadways and set focus areas targeting alcohol, speed, hazardous locations, children, elderly, and safety devices (Schermers and van Vliet, 2001). An updated road safety plan, the MPV-II, was adopted in 1989 and highlighted the importance of incorporating road authorities and stakeholders into the policy process.

The second Structure Plan for Traffic and Transport (SVV-II) of 1990 set a goal for a 50% reduction in fatalities and a 40% reduction in injury crashes by 2010 (Schermers and van Vliet, 2001). Doubt arose as to whether these goals could be met because, while the focus areas were well documented, they did not address the root of the manifested safety problems. There were reductions in the number of injury crashes, but there were also large discrepancies between different road classes that were unaddressed, specifically with arterials. The high crash rates occurring on arterials ultimately led to the *Sustainable Safety Program*.

Policies and Implementation

The *Sustainable Safety Program* was a proactive approach that aimed to prevent serious crashes and to eliminate the risk of severe roadway injury (Institute for Road Safety Research, n.d.). The program was built around the idea that the majority of road accidents can be attributed to the limitations and the unpredictable nature of humans. Recognizing that behavior modification was unsustainable over the long term, *Sustainable Safety* was based on the interactions between all elements of the transportation system (driver, vehicle, road design, regulations, usage, intended function) and included five guiding principles: the functionality of roads, the homogeneity of traffic, a predictable road design, a forgiving environment, and road user awareness (Table 11) (Schermers and van Vliet, 2001).

Table 11: The Five Sustainable Safety Principles

Sustainable Safety principle	Description
Functionality of roads	Monofunctionality of roads as either through roads, distributor roads, or access roads in a hierarchically structured road network
Homogeneity of mass and/or speed and direction	Equality of speed, direction, and mass at moderate and high speeds
Predictability of road course and road user behaviour by a recognizable road design	Road environment and road user behaviour that support road user expectations through consistency and continuity of road design
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behaviour
State awareness by the road user	Ability to assess one's capability to handle the driving task

The program was implemented in two phases to meet crash reduction goals. Phase 1 (1998-2002) was outlined in the 1997 document “Start-up programme – Sustainable Safety” (Schermers and van Vliet, 2001) and targeted sections of the road network that were considered dangerous or potentially dangerous. A number of short-term action plans were established and formal agreements between the Central Government and other major stakeholders (Association of Dutch Local Authorities, Union of Water Management Authorities, Interprovincial Consultation Body) were reached.

Proposed measures included establishing a general urban speed limit of 30 km/h (19 mph), expanding 60 km/h (37 mph) zones in rural areas, and classifying the road network into three functional categories: through function (involving rapid vehicle movements), distributor function (to disperse traffic), and access function (providing access to homes, shops, and offices). Priorities were also aimed at law enforcement and information campaigns to educate road users about the new initiatives (Schermers and van Vliet, 2001).

Phase 2 (2002-2010) focused on ensuring that the new road categorization plans were implemented and securing new funding to support the proposed actions. Specific proposed measures included expanding the urban and rural speed limits to other areas, as well as setting target speeds in areas where pedestrians and bicyclists interact with traffic and where motor vehicles have greater potential to interact (Table 12) (Schermers and van Vliet, 2001). The program was updated in 2005, putting more emphasis on education, regulations, enforcement, and technological developments. It also recommended establishing a system of quality assurance and highlighted the importance of integrating road safety with other policy areas (Institute for Road Safety Research, n.d.).

Table 12: Sustainable Safety Phase 2 Target Speeds

Location	**Target (Maximum) Speed**	**Application Areas**
1. Where pedestrians cross the road 2. Where bikes are in mixed traffic	20 mph	1. Local streets 2. Crossings
Where vehicles meet at a 90-degree angle	30 mph	Intersections, signalized and unsignalized
Where vehicles pass in opposite directions	40-45 mph	Undivided highways

Efficacy of the Solutions

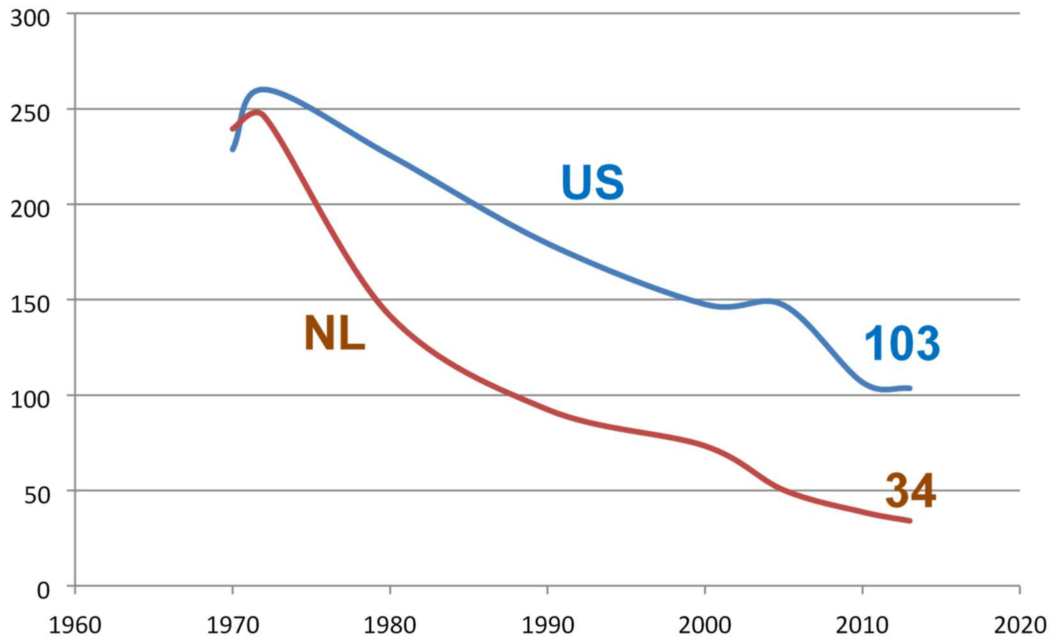
Initial road efforts under *Sustainable Safety* were projected to produce a wide range of benefits (Schermers and van Vliet, 2001), including:

- Crash reductions up to 10% by assigning priority with better traffic control at intersections
- Crash reductions up to 20% from speed management efforts
- Uniformity of roundabouts
- Improved safety for other traffic modes
- Increased compliance with seat-belt and helmet regulations

Although some of these benefits are difficult to evaluate quantitatively, researchers did note a general sense of compliance and security among the traveling population due to the programmatic improvements (Institute for Road Safety Research, n.d.). In practice, the *Sustainable Safety* efforts did produce quantifiable gains in safety. Fred Wegman of the SWOV Institute for Road Safety Research reported a direct effect of infrastructure change amounting to a 6% reduction in all fatalities and serious road injuries during the 1997-2002 period. By 2007, road traffic fatalities had been reduced by 30% but there was not any significant reduction in serious road injuries (Institute for Road Safety Research, n.d.). According to civil engineering professor Peter Furth, 70% of urban roads are now in 20 mph zones (Furth, 2015).

The most important aspect of the *Sustainable Safety* approach, however, was self-categorization of roadways. With roadways that promote healthy flow by either prioritizing mobility or access, but not both, the Netherlands was able to create shared spaces for road users where high speeds do not prevail. Where high speeds are needed, such as outside cities, conflicts are reduced by strictly adhering to access limitations (Institute for Road Safety Research, n.d.).

Figure 6: Comparison between Traffic Deaths per Capita in the United States and the Netherlands



Challenges and Opportunities

As with other strategies, the Netherlands's *Sustainable Safety* encountered a few challenges. There were difficulties implementing some of the proposed measures. Initial subsidies under Phase 1 were not sufficient to expand 30-km/h (19 mph) zones to all desired areas due to the cost of signing and control. Some local authorities did not comply with recommended infrastructure changes to accommodate moped users on 80 km/h (50 mph) roadways, perhaps indicating resistance to the new measure. There was some concern that implementing countermeasures at a large-scale would be too time consuming to be effective and would be better coordinated at the regional level. Some road authorities resisted initial safety diagnoses, such as road safety audits, citing the auditing process as a difficult and unnecessary planning step (Schermers and van Vliet, 2001).

Since the implementation of *Sustainable Safety*, it seems issues relating to bicycle-only crashes have come to the forefront in light of infrastructure changes (Institute for Road Safety Research, n.d.). Other outcomes of *Sustainable Safety* included an increase in elderly cyclist injuries, a lack of appropriate countermeasures for e-bikes, decentralization of planning, budget cuts, and competition among policy domains (van der Knaap, 2015). Researcher van der Knaap also cited a need for more evidence through more countermeasure evaluation, especially pertaining to education, and a need for smart enforcement (van der Knaap, 2015).

The National Institute for Road Safety Research believes an extensive look at the relationships between infrastructure and bicycle crashes could be beneficial and could lead to further infrastructure changes. They also recommend investigating other Safe Systems practices and guidelines to enhance their own policies, better incorporation of intelligent transportation system (ITS) devices, and more cooperation and shared responsibilities between involved parties. Including education and enforcement as initial steps rather than through a slow integration may have been beneficial as well (Institute for Road Safety Research n.d.).

Similar International Programs

The four nations we outlined above each adopted some form of a Safe Systems program in response to national road toll trends. However, these nations are not alone in their pursuit of more holistic or systemic road safety programs. Government agencies in England, Ireland, and Northern Ireland have in recent years adopted programs that share some similarities to Safe Systems or worked actively toward the adoption of a Safe Systems program. While we do not believe these programs illustrate optimal deployment of Safe Systems principles, they do support the suggestions and findings produced by the four countries previously examined.

England

Great Britain has a strong record of road safety; in 2017, the Department for Transport reported only 1800 traffic fatalities for the previous year (Department of Transport, 2017). Between 2005 and 2014, road deaths in England dropped 45%. England also had its lowest recorded number of road deaths in 2013. The Secretary of State for Transport attributes these gains in road safety to a number of factors, including safer infrastructure, stronger enforcement, new vehicle technologies, and improved trauma care (Secretary of State for Transport, 2015).

The Department for Transport in England has not formally adopted a comprehensive Safe Systems approach as a national policy but recognizes this strategy as a best practice in road safety. The Department for Transport listed Safe Systems as a top priority and established Highways England to implement a Safe Systems approach across the strategic road network over a 5-year period, beginning in 2015. With an investment of £11 billion, Highways England aims to reduce deaths and serious injuries on the strategic road network by 40% by 2020 and will strive to approach zero deaths and serious injuries by 2040 (Secretary of State for Transport, 2015).

As part of their road safety strategy, the Department for Transport outlined a number of priorities. These objectives directly targeting road users included road safety education and training opportunities for children and vulnerable road users, improving licensing and testing, increasing road user awareness through targeted campaigns, encouraging the use of safer vehicles and equipment, improving motor vehicle insurance, and providing more effective enforcement. They also specified additional areas of focus, including investing in safer infrastructure, enhancing emergency services, and partnering with local authorities and the road safety community (Secretary of State for Transport, 2015).

Further, Highways England outlined numerous national actions as part of their strategy to improve road safety. These actions included improving air quality through monitoring and research activities, engaging in noise mitigation programs across the road network, improving pedestrian and cyclist facilities, and enhancing economic growth (Highways England, 2014). These actions are noteworthy because they express a national interest in promoting healthy transport in England that extends beyond simply reducing crashes.

Overall, the government believes that local authorities are best equipped to manage road safety measures according to local needs, as local roads comprise 98% of England's road network. However, road authorities initiated some initiatives on a national scale. Community Speedwatch developed a program to reduce vehicle speed and increase public awareness of speed. Trained volunteers are equipped with speed detection devices and cooperate with local police to monitor vehicle speeds in their communities. Live data from monitoring activities are accessible to police through an online platform, Community Speedwatch Online, and the organization tracks a number of metrics, including cases of repeat and excessive speeding offences, allowing authorities to target their enforcement activities (Community Speedwatch Online, 2018).

Another novel initiative is Bikeability cycle training for school children. This program educates children on road cycling skills and road awareness; The Secretary of State for Transport reports that the program improves child perception of road hazards (Secretary of State for Transport, 2015). Again, programs like Community Speedwatch Online and Bikeability indicate the Department for Transport's interest in promoting more than crash reduction. The Department is using or intends to use education, enforcement, and policy to comprehensively improve transportation safety and healthy transport, and this vision is comparable to that of Safe Systems.

Several local municipalities have already adopted a Safe Systems strategy. The Bristol City Council incorporated this approach in a 10-year road safety plan for 2015-2024. In Bristol, pedestrians and cyclists incur over half of all road deaths and serious injuries. Further, the two age groups that are projected to experience the largest increases in population are also the most vulnerable to pedestrian injuries (ages 0-15 and 65-74). The City Council designated improving walkability and pedestrian safety top priorities. Targets proposed for 2020 included a 30-50% reduction in deaths and serious injuries and 20% of the mode of transport to work occurring by bike, as well as 30% by foot by 2021. Specific actions implemented by the Bristol City Council included 20 mph speed limits across all residential streets (and some local streets), cyclist safety improvements at intersections with records of cyclist deaths or serious injury, and a number of projects to train and educate the general public and high-risk road users (children, pre-drivers, young male drivers) on road safety (Bristol City Council, 2015).

Ireland

Similar to England, Ireland has a strong road safety record. Following the first Road Safety Strategy in 1997 (Louth County Council, 2017), total road fatalities in Ireland dropped 65.7% during the period of 1997-2012. The Louth County Council attributes this reduction in part to more compliant road user behavior, such as wearing seatbelts, adhering to speed limits, and fewer alcohol-related offenses. Additional legislative actions through The Road Traffic Act have also contributed to improved road safety. Some measures that were introduced by road authorities in Ireland include checkpoints for mandatory alcohol and intoxication testing, stronger penalties for vehicle offenses, road network upgrades, and safety cameras.

Following the safest year on record in 2015, Ireland ranked seventh (out of 28 EU countries) for fewest road deaths per million inhabitants (Louth County Council, 2017). Despite this achievement, Ireland's Road Safety Authority recognized the need to incorporate a Safe Systems approach in the National Road Safety Strategy 2013-2020, stating, "There is a cause for every collision, fatality and injury. Collisions are avoidable. They are not accidents" (Road Safety Authority, 2017).

The National Roads Authority's specific targets are to reduce road fatalities to no more than 25 deaths per million population, a target set by the European Union, and to reduce serious injuries to 330 by 2020. One particular emphasis in the strategy is improving roadside safety, one of the major tenets of a Safe Systems approach. The National Roads Authority developed the Forgiving Roadsides program to improve the outcomes of run-off-the-road crashes by removing and relocating obstacles, modifying roadside elements, and shielding obstacles (National Roads Authority, n.d.).

Several cities and counties in Ireland have also developed road safety strategies that align with the National Road Safety Strategy and the Safe Systems approach, including the Louth County Council, the Dublin City Council (Gormley and Cuddy, 2013), and the Dún Laoghaire-Rathdown County Council (Transportation and Water Services Department, 2015). These agencies adopted a shared focus on education, engineering, enforcement and evaluation to reduce road collisions. The Louth County Council identified mobile phone distraction, fatigue, speeding, drink and drug driving, and failure to wear a seat belt as specific challenges that must be addressed (Louth County Council, 2017). Addressing these issues comprehensively indicates a move toward a more holistic approach to traffic safety in line with many of the tenets of Safe Systems.

Northern Ireland

Northern Ireland has adopted the Safe Systems approach in the country's Road Safety Strategy to 2020. While Northern Ireland experienced a rapid decline in fatal road collisions during the ten-year period between 2003 and 2013, road fatalities increased significantly in 2014 for unknown reasons (McKibbin, 2016). To implement the strategy to reduce fatalities, The Northern Ireland Assembly and system stakeholders developed a Road Safety Partnership that includes members of the Department of Environment, Transport Northern Ireland, the Police Service of Northern Ireland, the Northern Ireland Courts and Tribunal Service, and the Department of Justice. Specific objectives of the Partnership include delivering educational campaigns, using safety cameras to reduce speeding and collisions through targeted enforcement, and focuses on protection for children under 15 years of age and young adults (16-24 years old), also Northern Ireland's most vulnerable road user group (McKibbin, 2016). The Northern Ireland Assembly's comprehensive approach of education, enforcement, and engineering aligns well with Safe Systems principles, and its desire to protect vulnerable road users highlights the importance of promoting a healthy transportation system for all road users.

Lessons from International Practice

Given the complexity of the road transport system, it can be difficult to fully understand specific causes of road casualties or measures that will be effective across a system. Crash analysis methods, data collection, and data reporting are often inconsistent. Crashes may be caused by multiple factors, and interactions between these factors are poorly understood. Population demographics, economic conditions, driver behavior, and road and vehicle characteristics all contribute to road safety outcomes. For these reasons, comparing strategies from one location to the next is challenging. Still, in reviewing the Safe Systems approaches in Sweden, the Netherlands, New Zealand, and Australia, as well as England, Ireland, and Northern Ireland, some overall trends emerge, and general conclusions about the applicability of Safe Systems in the U.S. can be made. These trends include:

1. **Speed Management** – The relationship between speed and safety has been consistently evidenced throughout this report, and we believe that speed management should be one of the first steps taken in the United States to improve road safety (Candappa et al., 2015; Woolley et al., 2018). Since the repeal of the National maximum speed limit in the United States, there has been at least a 3.2% increase in road fatalities attributable to raised speed limits across functional road classifications (Friedman, Hedeker, and Richter, 2009). However, since the repeal, states now have sovereignty to raise and lower speed limits as they deem appropriate. There is some concern that the traditional approach to setting speed limits may no longer be the most effective approach. Most speed limits are based on the "85th percentile speed," the maximum speed at which 85% of drivers travel on a given road segment but are often set lower (Forbes et al., 2012). In recent years, the National Transportation Safety Board has recommended that road safety practitioners revise the current speed standards to incorporate crash history and the safety of vulnerable road users (National Transporation Training Board, 2017). Tools, such as USLIMITS2 may facilitate adjusting speed limits (Federal Highway Administration, 2018). This tool generates an appropriate maximum speed limit for a particular section of road based on its roadway characteristics, crash history, and prevailing speed trends.

2. **Functional Classification** – In addition to controlling speed, transportation agencies should adopt and promote policies of improved separation and access control, especially on roadways where road user mobility is prioritized. All of the nations surveyed in this document promote road user safety by limiting the potential conflicts among different road user groups on high-speed roadways. They tend to do this by separating different road user groups (e.g., pedestrians and bicyclists from drivers of motor vehicles) and limiting road users' access to certain higher speed roadway types.

3. **Intersection Design** – All of the surveyed nations advocated for the use of roundabouts as alternatives to signal-controlled intersections to mitigate the effects of speed and sharp-angle collisions. There are

other intersection types – such as cut-throughs, elevated stoplines, raised intersections, or intersection with green light speeds – that researchers recommend to better integrate Safe Systems principles with our existing infrastructure (Candappa et al., 2015; Woolley et al., 2018; Corenelissen et al., 2015). Decision makers should also be prescriptive in approaching alternative intersection promotion since the public is often reticent to accept non-traditional designs; careful crash data collection and proactive communication with the public may assuage some of these concerns.

4. **Enforcement** – Since driver behavior is still an issue even when safe designs are implemented, transportation agencies should consider increasing enforcement of both speeding and red-light-running, particularly at high risk intersections, segments, and corridors.

5. **Moral Imperative to Improve Safety** – When developing and implementing the country's Safe Systems approach, Swedish leaders recognized that the country's transportation system should not operate separately from the diverse stakeholder groups who design, plan, enforce, and use the system. Thus, in finding common ground among all transportation stakeholder groups, the Safe Systems approach satisfies the basic safety needs of road users prior to addressing other system contributions (e.g., access, aesthetics, and mobility). These approaches are philosophically and ethically distinct from cost-benefit frameworks, which reduce traffic considerations to trade-offs among project costs, high-speed mobility, and road user safety.

Although these five principles are not novel, they do distill the combined wisdom of years of Safe Systems practice throughout the world. However, it should also be noted that Safe Systems itself entails far more than simply improving engineering and enforcement. Those responsible for the transportation system should consider more visible public outreach programs.

However, as this report clearly indicates, there are a number of challenges and new issues that arise from Safe Systems implementation. This literature search consistently highlighted three specific concerns that any entity seeking to implement Safe Systems should consider.

1. **Vulnerable Road Users** – The exact reasons why pedestrian and bicyclist injuries and fatalities continue to rise in the surveyed nations are not clear, but plausible contributors to the rise are two-fold. First, in locations like New Zealand, the rising number of at-risk vulnerable road users may simply reflect changes in population demographics and in travel behavior, whereby the population is aging and a growing number of people walk, bike, or drive to get around (New Zealand Ministry of Transport, 2009). Second, it may also be a symptom of infrastructural changes that encourage use of increasingly larger motor vehicles (e.g., Sport Utility Vehicles), thereby increasing the exposure of vulnerable road users to risk (Institute for Road Safety Research, n.d.). Whatever the contributing factors, the gains in safety for motor vehicle users but less substantial improvements for other road users highlights the need for more targeted focus on vulnerable road user safety in Safe Systems planning. With pedestrian fatalities on the rise in the United States, this consideration is critical (Retting, 2018).

2. **Structural Organization** – The exact structure for implementation of Safe Systems varies from location and should be a response to local conditions. In the Netherlands, a top-down management structure that ultimately enabled local municipalities to take ownership of their own goals through decentralization worked best (Schermers and van Vliet, 2001). In Sweden, a bottom-up reorganization was necessary to get buy-in from different stakeholders (International Transport Forum, 2016). Due to the differences between these nations and the United States, the exact nature of Safe Systems implementation domestically is difficult to predict. Whatever the exact organizational structure may be, researchers like Salmon and Lenné (2015) and Scott-Parker et al. (2015) emphasize that vertical integration between stakeholders at all levels of government is key to the success of a Safe Systems program.

3. **Integrated Approach to Education and Enforcement** – Evaluations of the Netherlands' *Sustainable Safety* program highlighted that Safe Systems efforts could have benefitted from a better initial integration of education and enforcement from the program's inception rather than a gradual deployment of these strategies (Institute for Road Safety Research, n.d.). Education and enforcement themselves may be effective depending on the way they are employed, but a true Safe Systems approach should seek to combine these efforts with engineering and emergency response to truly produce a holistic plan to improve road users' health and safety. One model that that may be considered in the United States is an initial public feedback program such as that conducted in New Zealand (New Zealand Ministry of Transport, 2009).

Conclusion: Advancing Safe Systems in the United States

This report details the state-of-the-practice in the development of Safe Systems. Part I presents a synthetic review of the Safe Systems literature, paying specific attention to how advancements in organizational systems safety and behavioral economics may inform safety practice. Part II provides a scan of the application of Safe Systems principles in international contexts. Considered as a whole, there is a clear need for transportation professionals in the United States to broaden their understanding of crash causation. Conventional safety practice in the United States treats crash prevention principally as a function for education and enforcement programs, rather than a product of design. The sole function of design engineering is to mitigate the severity of otherwise unpreventable crashes.

Safe Systems rejects the idea that traffic-related crashes, injuries, and deaths are the random and inevitable products of innate human fallibility, as well as the idea that system designers have no responsibility for the deaths and injuries that occur. Few road users intend to be injured or killed as a result of their travel. Safe Systems encourages us to broaden our understanding of crash causation and prevention.

Traffic crashes, and the deaths and injuries that result, are associated with slips, lapses, and mistakes. Slips and lapses, which deal with driver inattention and inadequate performance are the primary focus of traffic safety programs currently adopted in the US. The transportation profession operates under the assumption that crashes are the product of unpredictable human errors, and that the primary mechanisms for crash prevention are education and enforcement programs. Yet the literature in organizational systems safety informs us that the majority of deaths and injuries associated with complex systems are the result of latent conditions embedded in the system's design. They establish baseline conditions that, when combined with predictable—and thus preventable—patterns of human behavior, lead to traffic related death and injury.

This understanding transforms the nature of the safety problem away from one of education and enforcement, and towards one that is focused on the dynamics of how humans interact with their environment. Our profession has spent a great deal of effort attempting the make cars and environments "crashworthy," and comparatively little effort in understanding the behaviors that cause crashes to occur. Driving is a mundane activity, where most decisions are automated through an intuitive process of scanning and adapting to expected conditions. Advancements in behavioral economics and traffic psychology reveal that the cognitive processes adopted in response to the transportation environment—scripts and schemata—establish the behaviors that make road users more or less likely to be involved in a crash event. There is a communicative process that occurs between the transportation environment and its users that influences crash incidence. It is our task to understand this language.

In this report, we have detailed the profession's current understanding of the cognitive processes that influence crash causation, as well as how our international counterparts have sought to address these problems. We have further illustrated how this new understanding of crash causation may be addressed into the transportation system planning and design processes. Decisions occurring at the policy and planning levels, such as the spatial allocation of future growth and municipal land use regulations, can have a profound influence on the establishment of the latent conditions that result in crash events (see Figure 12). Such decisions typically occur without regard for their safety implications, and present important new avenues for reducing crash frequency and severity. Similarly, project-level decision regarding the design and configuration of proposed transportation projects are typically derived from project needs statements, are typically do not include a formal assessment of the unique operational conditions established by the project's surrounding environment. Figure 14 presents a procedural framework for doing so.

This report thus concludes with the hope that our emerging knowledge on Safe Systems will provide a new framework for reducing traffic-related deaths and injuries.

Glossary

Active Failure: Random errors, attributable to human fallibility, that lead to crashes. See *Slips* and *Lapses*

Behavioral Economics: A field of psychology that is concerned with how people make intuitive decisions when confronted with complex and uncertain situations. See *Heuristics*.

Design Driver: A hypothetical "worst case scenario" condition where a driver is behaving in an extreme and unsafe manner. The design driver is often used as the basis for geometric design. See *Passive Safety*.

Heuristics: Cognitive shortcuts that people use to make quick decisions when faced with complex choices and limited information.

Incentivized Violation: A violation of the norms of traffic behavior that occurs when the benefit of violating traffic laws exceeds the perceived cost.

Knowledge-based Mistake: An error that occurs when a motorist or other road user is confronted with an unfamiliar situation where extant heuristics do not apply.

Lapse: A random error that is the product of a road user's failure to respond to an immediate hazard.

Latent Conditions (*"Latent Failure"*): Conditions in the transportation environment that induce crash-producing behaviors.

Mistake: An error that occurs as a result of a road user's selection of an unsafe behavior in a specific environmental context.

Most Vulnerable User: The road user who is most vulnerable to injury and death in a specific environment.

Organizational Systems Safety: A field of study that is concerned with the errors that may occur when humans interact with complex systems.

Organized Complexity: Systems with constituent elements that interact with one another in an integrated manner. Modifications to any one element of the system thus changes the dynamics of the system as a whole.

Passive Safety: The conventional approach to traffic safety in the US. Passive Safety presumes that crashes are random events, and that the best means for addressing safety is to design streets to minimize injury during a worst-case-scenarios crash event. See *Design Driver*.

Priming: A mechanism for triggering intuitive awareness to a specific phenomenon.

Random Error: Errors that occur as a result of innate human limitations.

Recognition Heuristic: The process by which individuals extract information from their environment to guide their behavior.

Rule-based Mistake: An error that occurs when a road user applies a behavioral script that places them at risk of a crash event. See *Scripts*.

Schemata: A mental diagram of the anticipated location of environmental features. Schemata prime expectations regarding the presence of location of potential traffic hazards.

Scripts: Intuitive behavioral routines established in response to one’s comprehension of the environment.

Security: A feedback mechanism used by road users to adjust their behavior based on their subjective sense of exposure to environmental hazards.

Self-explaining Road: A roadway designed to communicate safe operating behavior.

Slips: Errors that occur as a result of short-term inattention.

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