White Papers for: *"Toward Zero Deaths: A National Strategy on Highway Safety*

—White Paper No. 6—

SAFER INFRASTRUCTURE

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NOTICE

PREFACE

While many highway safety stakeholder organizations have their own strategic highway safety plans, there is not a singular strategy that unites all of these common efforts. The dialogue began towards creating a national strategic highway safety plan at a workshop in Savannah, Georgia, on September 2-3, 2009. The majority of participants expressed that there should be a highway safety vision to which the nation aspire; even if at that point in the process it was not clear how or when it could be realized. The Savannah group concluded that the elimination of highway deaths is the appropriate goal, as even one death is unacceptable. With this input from over 70 workshop participants and further discussions with the Steering Committee following the workshop, the name of this effort became "Toward Zero Deaths: A National Strategy on Highway Safety." The National Strategy on Highway Safety is to be data-driven and incorporate education, enforcement, engineering, and emergency medical services. It can be used as a guide and framework by safety stakeholder organizations to enhance current national, state, and local safety planning and implementation efforts.

One of the initial efforts in the process for developing a National Strategy on Highway Safety is the preparation of white papers that highlight the key issue areas that may be addressed as part of the process. Vanasse Hangen Brustlin has prepared nine white papers on the following topics:

1. Future View of Transportation: Implications for Safety
2. Safety Culture
3. Safer Drivers
4. Safer Vehicles
5. Safer Vulnerable Users
6. Safer Infrastructure
7. Emergency Medical Services
8. Data Systems and Analysis Tools
9. Lessons Learned from Other Countries

Experts in these areas were retained to prepare these papers. The authors were challenged to be thought provoking and offer strategies and initiatives that, if implemented, would move the country towards zero deaths.

The highway infrastructure is rarely cited as the sole contributing factor in crashes, yet it enables travel. The interaction between the driver and infrastructure collectively contribute to a significant proportion of fatal traffic crashes, thus a safer infrastructure is undoubtedly an important component of the Toward Zero Deaths goal. In this paper, infrastructure experts from The Thomas D. Larson Pennsylvania Transportation Institute—Dr. Paul Jovanis and Dr. Eric Donnell—propose a set of long-term strategies to provide a safer infrastructure.

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VISION STATEMENT

Safer infrastructure has been a focus of the national road safety research program for the last 10 years or more. Substantial progress has been made in the development and implementation of new tools for road safety management. These efforts provide the foundation for the suggested long-term strategies for providing a safer infrastructure.

Our vision for safer infrastructure recognizes that there are many useful countermeasures that have been developed. However, the fatality trends over the last decade suggest that none of the countermeasures is sufficient to bring about the breakthrough reductions in fatalities and serious injuries envisioned in the Towards Zero Deaths program, with the exception of automated speed enforcement. We base this exception on the proven track record of automated enforcement and discuss the infrastructure implication of this strategy. Our other strategies are broad initiatives that support many strategies and seek to strengthen the foundation provided by the safety advantages of the last 10 -15 years.

BACKGROUND

For the purposes of this white paper, the infrastructure is defined as the roadway (travel lanes and shoulders), roadside (clear zone on either side of the roadway, including the median and all associated hardware), and all traffic control devices present along the roadway (i.e., pavement markings, signs, traffic signals, etc.). To illustrate the importance of a safer infrastructure in the Toward Zero Deaths goal, consider Figure 1, which shows the distribution of contributory factors in traffic crashes. These factors are broadly codified into the driver, roadway, and vehicle. The roadway was identified as the sole contributory factor in approximately 3% of all crashes on the highway and street network by Rumar (1985), in a study using data from Britain and the United States (U.S.). When combined with the driver and the vehicle, the roadway is cited as a contributory factor in 34% of traffic crashes. While infrastructure strategies alone will not likely produce significant reductions in traffic crashes or fatalities, when considering the connection between the driver and infrastructure, it appears from Figure 1 that significant reductions in traffic crashes fatalities may be realized. Although this white paper is focused on safer infrastructure strategies, it is important to recognize that these strategies will have an important and direct effect on driver behavior.

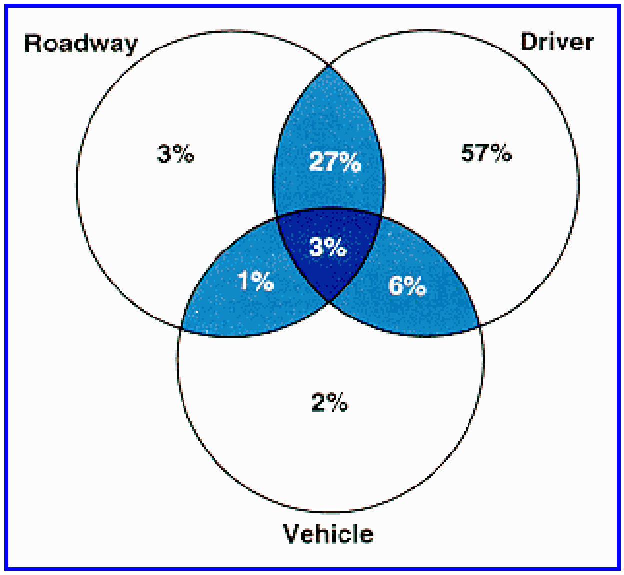

Figure 1. Crash Contributory Factors (Rumar, 1985; reproduced by Lum and Reagan, 1995).

The existing and planned highway and street infrastructure has evolved based on a collection design policies, criteria, and standards. Examples include the American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets* (2004, herein referred to as the Green Book), the AASHTO *Roadside Design Guide* (2006), and the Federal Highway Administration's (FHWA) *Manual on Uniform Traffic Control Devices* (MUTCD, 2009). The Green Book evolved out of the need to produce a set of uniform set of geometric design guidelines (principally roadway elements) for the highway and street system in the U.S. While these guidelines have provided both mobility and access to goods and services throughout the nation, safety is implied by designing to "standards." Similarly, the MUTCD provides a clear set of color, shape, size, and message standards for application on publically-owned roadways throughout the U.S. However, safety is not explicitly considered in the document with regards to application of traffic signs and pavement markings (safety is explicitly considered in traffic signal warrants).

While safety performance of the growing highway and street network was difficult to forecast when the Green Book and MUTCD were contemplated and developed, the significant number of traffic fatalities occurring on the network has lead to several important developments. The *Roadside Design Guide* was developed in an attempt to reduce the severity of crashes resulting from roadway departures. The FHWA *Interactive Highway Safety Design Model* and *SafetyAnalyst*, and the first edition of the AASHTO *Highway Safety Manual* (2010) provide tools to assess the safety performance of existing and planned roadways. All are important steps in providing a safer infrastructure. Further, the AASHTO *Strategic Highway Safety Plan Implementation Guides* (NCHRP Report 500 series) provide a collection of proven, tried, and experiment behavioral or infrastructure-based countermeasures that can be used to reduce traffic fatalities. These tools and guidance documents should continue to be utilized by transportation agencies throughout the U.S. to provide a safer infrastructure. The purpose of this white paper is not to provide a synthesis of the myriad infrastructure-related safety strategies contained in these collective media; rather, this paper proposes several strategic, long-range strategies that could be used to realize significant fatality reductions in relation to the infrastructure.

EXTENT OF INFRASTRUCTURE SAFETY PROBLEM

This section of the white paper provides recent trend data related to fatal crashes involving speeding, roadway departure, and intersection crashes. A brief interpretation of the data is provided.

Recent Trends in Speeding-Related Fatalities

Speeding related crashes are defined by NHTSA as crashes where a driver was charged with a speeding-related offense, or where the officer noted a speeding-related contributing factor (racing, driving too fast for conditions, or exceeding the posted speed limit). As shown in Figure 2, speeding-related fatalities remained at a relatively constant level from 2004 to 2007, and then decreased in 2008. As with other fatal crash types, this decrease in 2008 can be attributed to the nationwide drop in all crashes that was experienced in 2008. Examining speeding-related fatalities as a percentage of all fatalities shows that relatively little changed in the nationwide picture. Although speeding-related fatalities dropped from 13,040 in 2007 to 11,670 in 2008, the percentage of all fatalities remained almost the same, near 31%. This indicates that there was little progress made in speed-related safety when compared to other areas, such as young drivers or unrestrained drivers.

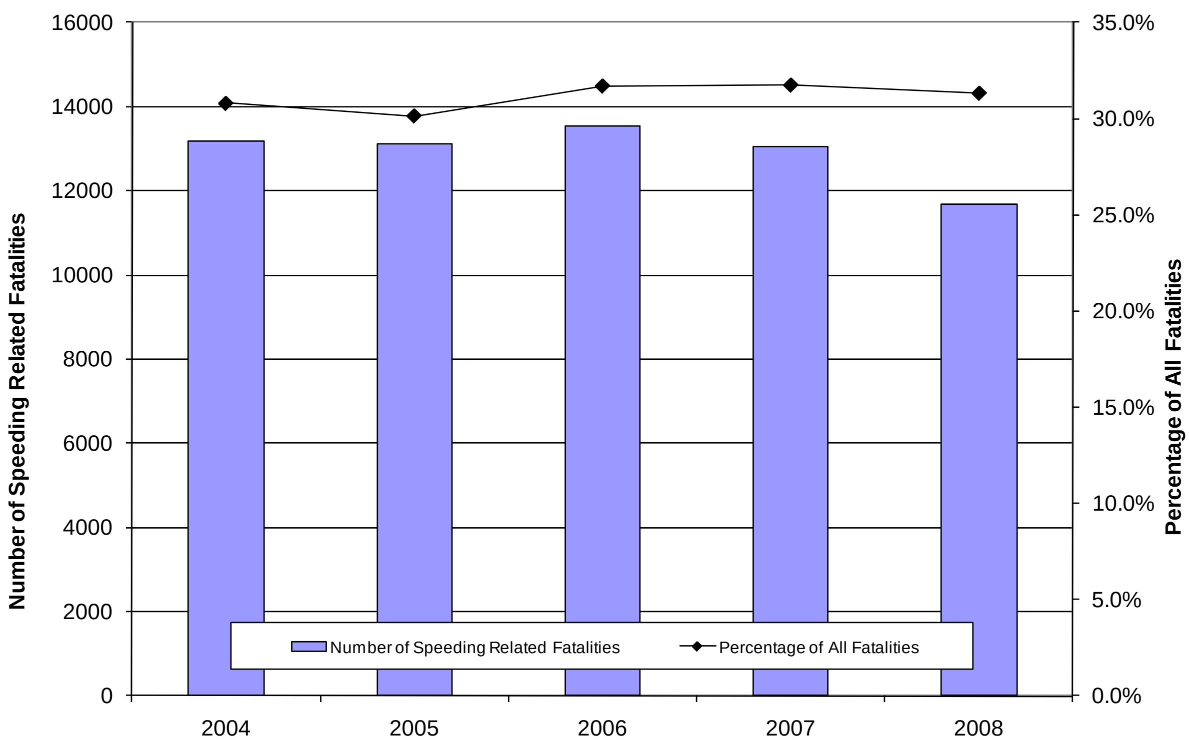

Figure 2. Trends in Speeding-Related Fatalities

Recent Trends in Roadway Departure-Related Fatalities

Roadway departure crashes represent a large percentage of the highway fatality picture. In recent years, approximately half of highway fatalities have been due to single-vehicle run-off-road crashes. As shown in Figure 3, roadway departure fatalities remained at a fairly constant level from 2004 to 2007, but experienced a sharp drop in 2008. Given that roadway departure fatalities as a percentage of all fatalities remained constant, the drop in fatalities in 2008 seems to be tied to the overall nationwide drop in fatalities experienced that year. As described later in this white paper, two cross-cutting strategies are proposed to reduce roadway departure fatalities. One is the establishment of a Safety Center of Excellence to provide technical assistance related to safety on existing and planned roadways.

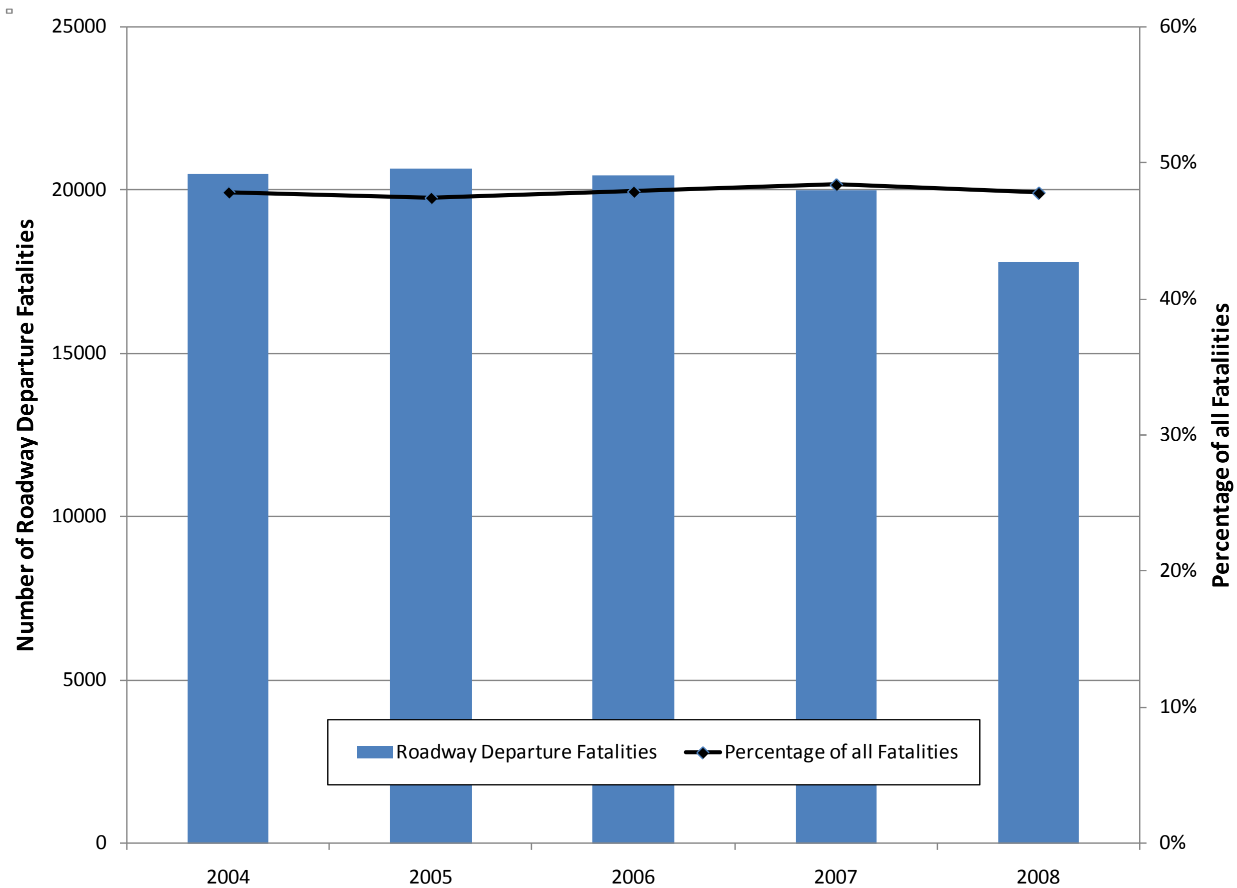

Figure 3. Trends in Roadway Departure Crashes

Recent Trends in Intersection-Related Fatalities

Intersection-related fatalities continue to be a large part of the highway safety picture in the U.S. As shown in Figure 4, intersection-related fatalities have declined since 2004, from 7,850 to 6,715 in 2008. The decline was fairly consistent since 2004, indicating that the decrease in these crashes was not solely due to the nationwide drop in all fatalities that was experienced in 2008.

However, the percentage of all fatalities that are intersection-related has remained fairly constantly around 18%, indicating that intersections continue to be a large safety concern. The breakdown of intersection-related fatalities by traffic control in Figure 4 shows that about 2/3 of these fatalities occur at unsignalized intersections.

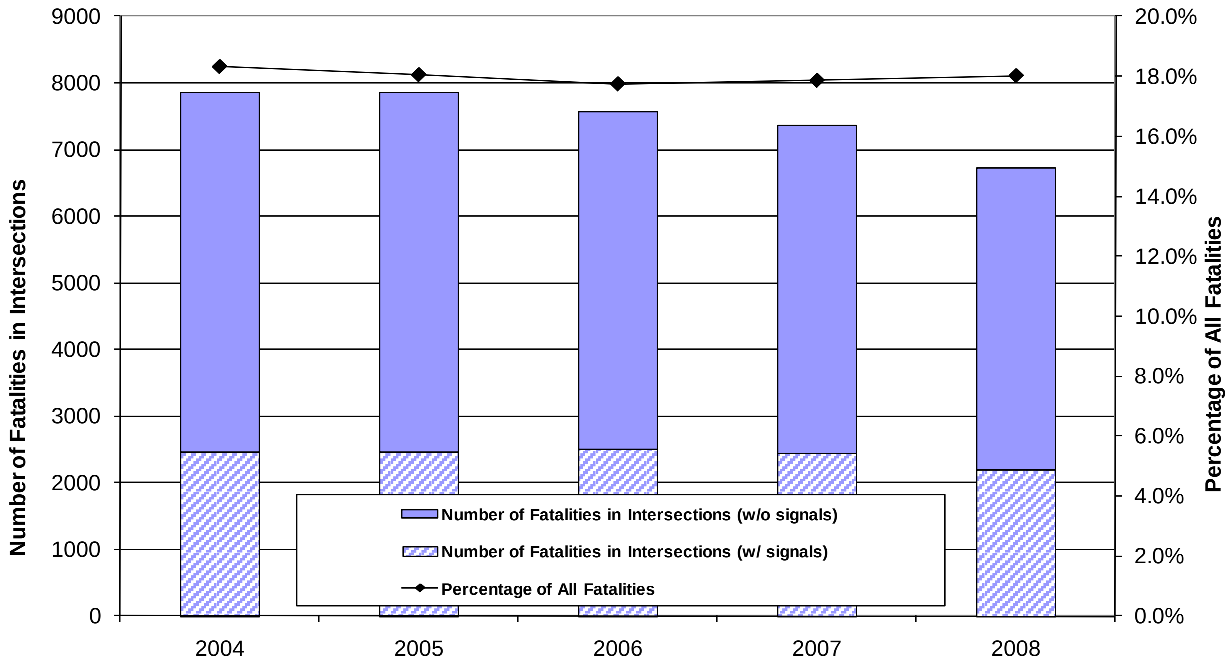

Figure 4. Trends in Intersection Fatalities

OVERVIEW OF THE STRATEGIES

The strategies proposed in this white paper are intended to address the infrastructure component of speeding, roadway departure, and intersection crashes. Below is a summary of the strategies proposed and the rationale for proposing them. The strategies are:

1. Automated enforcement of speed and traffic signal violations. This discussion focuses on the infrastructure elements of the system and the implementation of an automated enforcement system in the current policy environment. The Safer Drivers white paper addresses the driver behavior aspects of automated enforcement.

2. Safety Center of Excellence to provide technical advice and assistance in support of Strategic Highway Safety Plans (SHSP). This initiative cuts across the entire safety management process and seeks to provide a supporting structure for the selection of the right countermeasures in the right locations addressing the right patterns of crashes.

3. Enhanced application of performance-based design to better support road safety goals. This too is a cross-cutting infrastructure strategy proposed to integrate safety universally in all transportation agency policy documents, criteria, and standards.

For each strategy, we have structured the discussion as opportunities (things we need to do to implement the strategy) and challenges (obstacles that need to be addressed including a discussion of how to overcome them).

PROGRESS TOWARDS A SAFER INFRASTRUCTURE

As briefly alluded to earlier, there are many positive initiatives in safer infrastructure currently underway. We summarize the most prominent, discuss their implications for the TZD goals and describe connections to the four proposed strategies.

Decade of Progress on Tools

There has been substantial progress on the development of enhanced tools for road safety analysis. It is difficult to identify a decade in which more tools have been developed, refined and moved into practice.

Opportunities

These tools include the NCHRP 500 series of reports on problems and countermeasures; providing summaries of the state of knowledge about the countermeasures including the expected magnitude of their effectiveness. The Highway Safety Manual contains a wealth of knowledge about specific methods for managing road safety as well as a very useful summary of additional knowledge about road safety *per se*.

In addition, the Interactive Highway Safety Design Model and Safety Analyst, are available for additional detailed, practical analysis of road safety issues. While both tools are products of lengthy research programs, they are clearly targeted to the practitioner. They have practitioner panels from state highway associations that have provided comments on tool development as they have evolved. These tools are thus poised to support the implementation of new ways to make decisions about road safety if properly applied.

Challenges

The transportation safety community needs to assure successful implementation of the new tools. Education programs are underway and in development. Are they enough? Especially important is the need to properly indentify correctly Sites With Promise (SWiPs); many old methods still in use are known to be faulty, resulting in wasting scarce safety resources.

Each of these issues will be addressed with the implementation of the Safety Center of Excellence strategy proposed below. The strategy of Safety Centers of Excellence provides support for this opportunity by providing training about methods and support for implementation of the new methods.

Strategic Highway Safety Plans and Safety Conscious Planning

Strategic Highway Safety Plans (SHSP) offer the promise of improved processes in safety management. The SHSP seeks to develop more integrated, multidisciplinary approaches to safety management. At the same time, there have been programs supporting the concept of safety conscious planning – an effort to integrate safety concerns within the regional transportation planning process so that more discretionary highway funds can be used for safety.

Opportunities

Both of these initiatives have important broad longer term benefits for safety investments as they set the stage for enhanced attention to safety. SHSP provides opportunity to attack serious safety problems from multidisciplinary perspectives. The initiation of safety conscious planning has elevated safety explicitly into the discussion of projects at the regional level that are typically driven by congestion mitigation.

Challenges

While SHSP provides a framework for improved investment, there is no certainty that appropriate methods will be used; the right problems identified; the right countermeasures selected; and important post-implementation evaluations of effectiveness conducted. These are crucial additional steps if the TZD goals are to be approached. In addition, safety conscious planning is limited by the availability of planning tools to quantitatively assess project-level safety benefits. The Highway Safety Manual will help, but it is more oriented to design and operations than planning. The proposed Center of Excellence program will support the utilization of quantitative methods; existing methods for SHSP implementation and future methods for safety-conscious planning.

Countermeasure Implementation

There are many countermeasures that have been demonstrated to reduce severe crashes (e.g. cable median barriers, rumble strips, etc.). These have tended to be spot improvements, though there is some evidence of broader benefits from systemic safety investments.

Opportunities

The view of the authors is that these countermeasures should continue to be pursued; they are a foundation upon which additional declines in fatal and serious injury crashes are to be built. These experiences have been documented and need to be pursued for broader implementation as part of the SHSP program.

Challenges

It is doubtful that encouraging widespread adoption of these countermeasures, while effective within the current safety program structure, will be enough to achieve Toward Zero Deaths goals. The combination of strategies related to Performance-based Design and the Safety

Centers of Excellence will are intended to address this issue. However, both strategies will require significant financial investment and, likely, a cultural shift in the infrastructure profession.

Performance-based geometric design is evolving

Performance-based process exist in many transportation-related industries (e.g., construction specifications, pavement warranties, seismic design, etc.), yet safety performance with regards to roadway design is typically only considered after the (re)design is complete and (re)constructed. There is a need to develop and implement a performance-based design process for the highway and street network in the U.S. with explicit consideration of safety to reduce roadway and roadside-related fatalities.

Opportunities

The use of performance-based design may provide quantitative performance measures to better guide investments when transportation projects are being considered within transportation agencies. The Highway Safety Manual is the first tool available focused on crash and injury outcomes. As new tools become available, they can be supported by the proposed Center of Excellence, providing enhanced technical implementation support.

Challenges

The HSM is just rolling out as a user tool; while expectations are high, acceptance and payoff in safety management is still uncertain.

Advanced technology is cross-cutting

The use of advanced computing, communications and sensing technologies cuts across many possible strategies for safety improvement. The advances in these technologies are driven largely by other market forces, but safety certainly has benefitted.

SHRP 2

Opportunities

The SHRP 2 safety program is using advanced measurement technologies on-board vehicles to preserve information about the circumstances surrounding crash and near crash events. The expectation is that the output of the analysis of the data will be a much better understanding of crash etiology, in particular an improved understanding of the linkage between driver, environmental and roadway/roadside features which are measured at a high level of precision. As such, a clearer picture of speed-related, roadway departure and intersection-related crashes may be gleaned from this program. Strategies related to these topics are described in the Data Collection and Analysis white paper, but several opportunities related to safer infrastructure are worth noting here.

Challenges

While there have been 4 recently completed projects analyzing existing naturalistic driving data, the real benefit of SHRP 2 Safety will be realized when the large naturalistic driving field study data are collected and analyzed. Support for enhanced data analysis to reduce fatalities by investing in the right locations and identifying appropriate countermeasures is contained in strategies C and D.

IntelliDrive

This program seeks to test and evaluate the ability to use real-time vehicle-to-vehicle communications to improve travel efficiency and safety.

Opportunities

One aspect of the system issues real-time warnings to motorists based on information provided by vehicles ahead. The lead vehicle that confronts an event of unsafe condition transmits this information to trailing vehicles so the drivers of those vehicles are better prepared to respond. The program includes an analysis of incident or curve warnings as well as intersection collision avoidance. It is hoped that the system will provide substantial additional safety benefits to the traveling public. The ability to receive warning in advance of dangerous conditions or locations has potential advantages for reducing crash risk during rural travel. This is potentially advantageous for the run-off-road events of interest to TZD.

Challenges

IntelliDrive may provide advanced driver warning of temporarily dangerous conditions ahead, but it difficult to foresee the likely deployment of such services. It may be difficult to manage the evolution of a potentially complex system involving government and automobile manufacturers in an era of increased competition for declining resources. As a result of system deployment uncertainties, IntelliDrive did not get included in our list of recommended strategies.

Effective Speed Management

It is well-established that reducing vehicle speed will reduce crash severity (kinetic energy). While speeding-related crashes suggest that drivers are most often cited as the contributory factors, the infrastructure has an important supporting role to play.

Opportunities

There is a need to critically evaluate the design speed concept in geometric design of highways and streets. Donnell et al. (2010) describes, through case studies, the relationship between the design speed, operating speed, and posted speed limit. These relationships are not often in harmony from the designer's perspective. A more complete understanding of how drivers select speeds, based on cues provided by the infrastructure, could be used to develop and implement "self-enforcing" roadways. In other words, how do we get what we want with respect to driver speed selection on the highway and street network? As proposed in this white paper, automated speed enforcement appears to provide the most significant opportunity to reduce fatalities associated with speeding.

Challenges

Any effective speed management strategy will require significant changes to either the geometric design policies/standards in the U.S., or a significant investment in an area-wide automated enforcement strategy. Either could be controversial if not supported by the design community or the public at-large.

STRATEGY A: AUTOMATED SPEED ENFORCEMENT

Background

There are persistent problem with speeding and widespread violation of speed laws. One of the neglected strategies for the U.S. is to get serious about automated speed enforcement and violations. The technology for this strategy has existed for over 20 years, yet the U.S. has lagged behind the world in implementing and testing its effectiveness.

The Safer Drivers paper will discuss driver-related acceptance of automated speed enforcement. We focus on the infrastructure-related elements of a program including the hardware and software needed for automated enforcement and the nature of the different ways that the automated enforcement can occur.

Another aspect of automated enforcement "infrastructure" has to do with the location of systems (i.e. fixed locations or mobile) and whether the systems function with the explicit site knowledge of the motorist (i.e. overt enforcement) or whether the location of the enforcement units is unknown and even hidden from the motorist (i.e. covert) (Delaney et.al., 2005). A review of international experience quickly reveals that the enforcement may be focused on spot treatments or area-wide (Thomas et.al. 2008; Delaney et.al. 2005). These are fundamental design decisions that need to be made early in system development as they directly affect likely system effectiveness, cost and the public service announcements and other media messages used to garner public support for system deployment.

While we provide an overview of the entire literature in the field, our specific focus is on area-wide adoption. Such systems offer the potential for broader benefits in crash and injury reduction. A related policy decision is the level of fines to be assessed and whether points (also referred to as "demerits" in some papers) will be assessed. Disposition of revenues has been a particular controversy in the U.S., so clearly this is an important long-term policy question for this strategy in support of TZD.

Opportunities

International Experience

There is substantial opportunity to reduce speeding through widespread automated enforcement using proven technology (e.g. Thomas et.al. 2008; Delaney et.al. 2005; Bourne and Cooke, undated). The referenced reviews indicate substantial success with automated enforcement in terms of reductions in speed and crash frequency and severity. Thomas and his co-authors indicate that reductions in fatalities and serious injuries can be reasonably expected to reach 25%, although they warn about the effect of regression-to-the-mean and spillover effects (to adjacent areas) which might be inflating the estimates of effectiveness.

In New South Wales Australia, the state within which Sydney is located, the trends in fatality rates are plotted in Figure 5. Three major drops occurred in the last 35 years:

1. From 1968 to 1972 the fatality rate drop was attributed to mandatory seat belt laws.
2. Another major drop occurred around 1983 with the institution of random breath testing for alcohol.

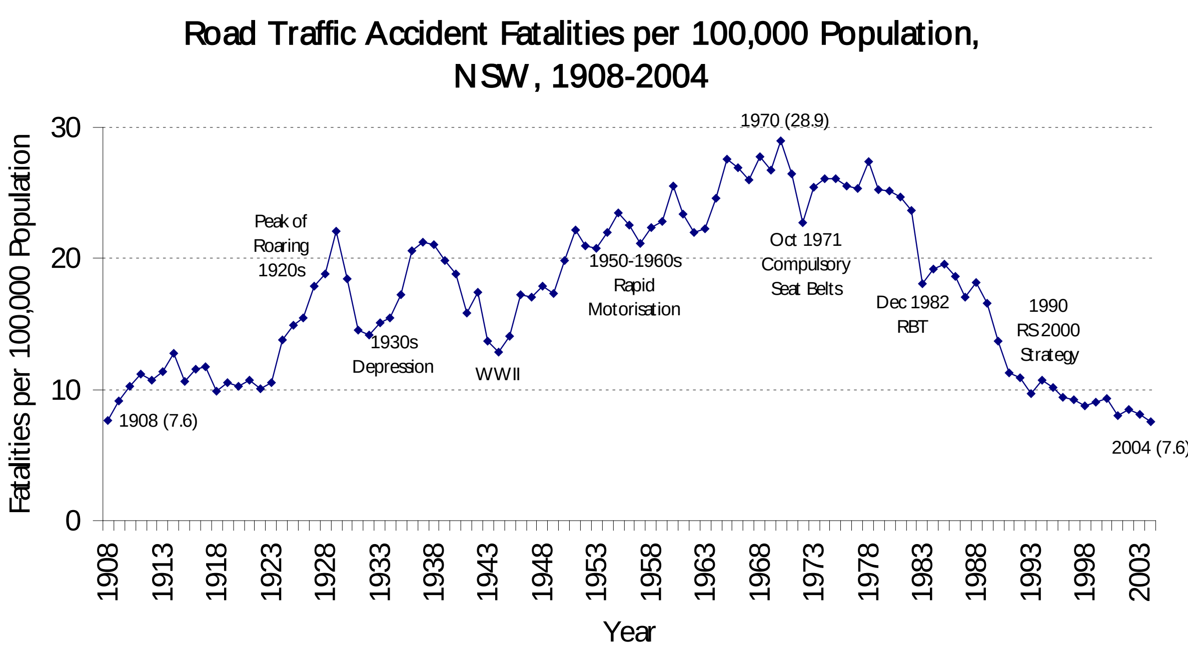

Figure 5. Trends in Fatality Rates for New South Wales

3. The last major drop occurred between 1988 and 93, attributable to the introduction of automated speed enforcement (Graham, 2005).

Interestingly, the three major drops were due to behavioral countermeasures. The Australian fatality rate has leveled off since the mid-1990 and the government is seeking additional savings from infrastructure countermeasures. They are concerned that they will not be able to find reductions through infrastructure that compare to those achieved in the last 35 years with behavioral countermeasures. This re-emphasizes the point made in the introduction: infrastructure improvements tied closely to changes in driver behavior have greater promise in achieving TZD goals than traditional infrastructure improvements in isolation.

Scottsdale, Arizona

The most detailed study of automated speed enforcement in the U.S. is likely that conducted in Scottsdale Arizona (Shin, et.al. 2009). Using and comparing several statistical methods, the team found that the total number of target crashes was reduced by 54%, total injury crashes by 48% and PDO crashes by 56% (although there was some variation in specific reductions depending on the statistical method employed). They estimated economic benefits of the system as $16 million/year. While single-vehicle and side-swipe crashes were reduced by 63% and 48% respectively, there was some evidence of a much smaller change (or possibly an increase) in rear end crashes.

This was a fixed-location study in which the drivers knew, in general, the location of the enforcement devices. As a result, there may have been some shifting of traffic: the most aggressive drivers may have chosen other routes with safer drivers choosing the speed enforced route. There was some testing of changes in crash patterns at other locations, but the authors admit that this remains a bit of an open question.

Benefits of $16 million per year were estimated for this system (through reductions in fatalities and serious injuries).

Challenges

The lessons learned concerning the requirements for success in the U.S. pose the following challenges for implementation

- Reliability and accuracy of equipment is crucial in maintaining system credibility. Victoria, Australia's automated program faced a serious challenge when one of their vendors was found to be operating defective equipment (Delaney et.al. 2005). Substantial opposition arose and several cameras were removed. After re-establishing credibility, the cameras were ultimately re-installed.
- Level of precision is an important technological aspect of speed enforcement, particularly as it relates to the magnitude of deviation from the speed limit that warrants a citation. Victoria does not reveal the precision used for its citations, fearing an effect on driver behavior. It is known (Delaney et.al. 2005) that the government reduced the speeding tolerance from 6.2mph to an estimated 1.9mph. The number of citation doubled in the following 12 months before dropping due to driver behavioral response. This issue needs to be carefully discussed; many areas of the U.S. currently seem to operate with a 10mph rule. NHTSA already has detailed procedures for across the road radar (NHTSA, 2007) and other technologies such as cameras and longitudinal radar. Developing specs for an automated system to achieve a given level of accuracy and precision would seem a logical next step.

- Studies have shown that many in the public perceive that speeding can be tolerated and do not perceive it as a crime (Delaney et.al. 2005). The perception that speeding is a serious problem and is connected to safety (crashes) needs to be a cornerstone of any major national effort as part of TZD.
- There remains a concern about the use of fines as a pseudo-tax. One way to diffuse this issue would be too issue points for automated violations and use the fines to cover costs for the government and private sector (if involved). This may be a serious legal challenge but again, European experience is that the challenge can be met. Moving forward with this initiative as part of TZD, the FHWA should assess what would need to be done legally to overcome the limitation on issuing of points for automated violations. In Europe, the law makes the driver responsible to identify the driver at the day and time of the citation.
- The covert/overt decision is a key factor in success. In Britain, there has been violent opposition to cameras by MAD (Motorists against Detection) who have sought out and destroyed several hundred cameras (Delaney et. al. 2005). This is a decision that needs to be carefully considered.
- Some see speeding as a right. This need to be fundamentally changed as part of our safety culture.
- The issue of automated enforcement has been heavily politicized (http://www.highwayrobbery.net/redlightcamslinksref.htm). The former speaker of the House of Representatives has a web site titled www.highwayrobbery.net which rails about automated enforcement. These notions of a conspiracy need to be challenged and dismissed before national adoption of this potentially significant strategy.
- Anticipate media scrutiny and prepare for it ahead of time (Delaney et.al. 2005). As it pertains to TZD, prepare the public with an organized media campaign based on focus group issues and terminology. Focus groups and other techniques should be used to gauge the public's acceptance for each aspect of the proposed system. Important system design issues should be discussed in a series of national scale focus groups. Include issues such as: level of fines; where the collected fines will be spent; number of points assigned for violation; use of covert cameras, etc. Announce that all equipment will be check for quality control and quality assurance by independent engineering testing organizations; someone paid outside the process of fine generation. This will support the notion that the program is scientific and of high quality. Emphasize that speed cameras are fair; you can't negotiate with the camera.

STRATEGY B: SAFETY CENTERS OF EXCELLENCE TO PROVIDE TECHNICAL SUPPORT AND OUTREACH FOR STRATEGIC HIGHWAY SAFETY PLANS

Background

Anecdotal experience suggests that states may be continuing to use outdated methods to identify sites and undertake the other steps in road safety management. Even as many new methods are being tested and developed, there is a need to stimulate new method *adoption* so that more effective use may be made of scarce safety resources. As described in the introduction to this white paper, there are many new methods on the cusp of implementation and there are likely to be even more in the years ahead. While Strategic Highway Safety Plans (SHSP) provide a process for coordination, they, by themselves, do not assure that the right methods are used to guide safety investment.

Another perspective on this strategy is obtained by considering the SHRP 2 program. After expending many millions of dollars in 4 research areas, SHRP2 is now embarking on a pre-implementation activity which explicitly includes training. They are seeking to support the proper implementation of the tools and methods developed throughout the program. This activity recognizes he importance of preparing for and supporting implementation of research products.

It is proposed that FHWA and NHTSA consider the development of regional Safety Centers of Excellence to support rigorous scientific implementation of Strategic Highway Safety Plans (SHSP) and other institutional elements in safety developed over the last 5-10 years.

Opportunities

Scientific rigor is being applied inconsistently to safety management, particularly in the critical steps of: selection of sites with promise; identification of contributing factors linked to countermeasures; evaluation and selection of countermeasures tied to crash contributing factors; and, finally, evaluation of the countermeasure after the fact. Failure to use the best methods is likely to result in sub-optimal allocation of highway safety investments. The Center will support the existing FHWA Safety and Design Resource Center initiative to support states, counties and municipalities in using rigorous methods for safety management.

The idea of the Centers is that government is spread too thin to properly support scientific implementation of the right processes for road safety management. The “Centers of Excellence” would do more than provide courses. The vision is of an integrated set of contractors across the U.S. (regionally), supported by latest technology, helping to guide implementation of SHSP’s. Plans would be reviewed for substance by the Center and returned if poor scientific principles are used. The Centers would be responsible for working with the states to improve their plans using the right methods. The Centers will also be available for technical assistance (e.g. during evaluation of countermeasure effectiveness after implementation). This is viewed as continuous and on-going support for safety method implementation. The vision is one of regional subcontractors positioned to provide “local” support on the ground, but also to use electronic media to brief states on how to improve their plans as needed. The need for a safety educational center has been raised previously (e.g. Transportation Research Board, 2007), although this proposal describes a mandate broader than education alone.

Precedent for the Center

There is a precedent for engineering centers of excellence in the existing pavement technology centers (superpave web site, 2010; interview with Dr. Mansour Solaimanian, Director NECEPT Center). A series of 5 regional centers evolved from the conclusion of the original SHRP program. These centers had a focus on implementation and technical assistance for the new proposed superpave products.

In addition to technical assistance the Superpave centers provide technical assistance by responding to specific questions from implementers. The centers offer training classes for field and plant technicians and others involved in the paving technology business (e.g. quality assurance and quality control representatives). Superpave centers also conduct research, but they must compete against other competition; set-asides are not generally available.

One significant aspect of the Superpave concept is that technicians and other personnel must be *certified* in order to participate in a paving project in a technical task. The FHWA requires certification as a requirement for federal funding. While states can opt out, none do. This is a missing link in the safety field. There is no current requirement for certification in the safety field, for engineering or safety management functions. One interesting aspect of 100% certification in Superpave is that there have been minimal efforts to evaluate the "benefits" or "savings" attributable to the program; *everyone uses the certification!*

An additional benefit of the Superpave centers has been the development of user-producer groups to discuss common problems. These are organizations which bring together the producers of the pavement technologies (e.g. asphalt and concrete paving companies) and the users (e.g. states, counties and municipalities).

Another precedent is the numerous centers in the area of public health and injury prevention. Review of two university web sites indicated that the use of centers for outreach and education is very widespread (Johns Hopkins University and University of North Carolina web sites, July 1, 2010). The schools of public health at these universities contain 30-40 public health centers for outreach and implementation support. While public health is a broader and much more well-funded area than road safety the comparison is quite startling. While we have many university-based centers in transportation, few focus on safety alone and the breadth and depth of programming is considerably less than in public health.

Given these examples and precedents for the Center concept, what lessons are provided for road safety?

Implications for Safety Center of Excellence

Taken as a whole the needs for regional Safety Centers of Excellence have strong congruence to the needs in paving technology after the original SHRP program. Science is available through research to improve an important aspect of transportation: safety in our case; pavement performance, reliability and ride quality in the other case. There is a need to provide a structure for implementation of the best ideas on an on-going basis for a period of 15-20 years.

Safety investments such as median barriers and road realignments can be expensive, similar to pavement projects. Regional Safety Centers of Excellence would support existing SHSP actions and provide the technical support needed for implementation of the best strategies and evaluation of the strategies to support development of AMF's (a process recommended in the new Highway Safety Manual).

It is important to note that the scientific review of safety plans and implementation can be thought of as a replacement for the "certification" required in the paving area. However, safety certification has been discussed by several authors in the last few years (Hauer, 2005; Transportation research Board, 2007). There have been suggestions for legislation in this area, but no firm action to date (Transportation Research Board, 2007).

These references tell us that the concept of safety centers has been with us for several years. What are the challenges that must be overcome to provide support for this concept?

Challenges and How to Overcome Them

Experience indicates it may be difficult to generate support for an education/technical support function. Some of the comments received for the earlier draft outline revealed this bias. During the webinars for the TZD program, many professionals commented that it is better to "do something" than to wait to do the right thing. It is precisely this type of myopic vision that the superpave folks sought to overcome; furthermore, it was mandated to be changed through the certification process. This paper does not advocate for certification, but it should be seriously considered.

When teaching Safety 101 as part of NCHRP project 17-40, one of the first analysis discussions is the need to define the problem. This must occur before the professional charges off to "do something." For the purposes of the course, the first step is the identification of "sites with promise" (or equally, drivers with promise). One possible way to overcome the bias is to provide clear examples of the cost of the inappropriate actions. An internal review of SHSPs could be a first step in such a process. A few "success stories" could help convince the skeptics.

The center should involve several organizations regionally across the US. Selection of the regional locations should be based on competitive bid, not earmarks. This is the critical first example of the value of "doing things right".

One should expect that the need for review of material in support of SHSP will generate demand for education programs; over the long run. Individuals learn through repetition; the implementation and outreach components of the proposed center are mandatory for the program to have any chance of success. If there is a required review, the consultants that states use will be forced to obtain required training; an attempt to redefine the floor knowledge need to function as a safety engineer. This has been the experience with the superpave centers: states and local professionals attend as well as consultants who regularly do work for the states. Rejection of material will provide a strong incentive for the plans to be developed correctly and substantively.

STRATEGY C: DEVELOP AND IMPLEMENT PERFORMANCE-BASED DESIGN PARADIGM

Background

The Green Book, Roadside Design Guide, and the MUTCD are policy documents used by state and local transportation agencies throughout the U.S. to design the transportation infrastructure – safety performance is implied in these policies. With a few exceptions (e.g., traffic signal warrant in MUTCD), the frequency and severity of traffic crashes has been evaluated after a highway or street has been designed and constructed. Designers have relied on published research to assess safety while considering the trade-offs in accessibility and mobility. The prevailing thinking was that roadways designed to meet minimum or limiting criteria, or standards, would be safe. Several tools and supplemental guidance documents have recently been developed to enable safety performance evaluations in the project development process – each are described below.

The first edition of the Highway Safety Manual (AASHTO 2010) provides crash reduction factors for a variety of infrastructure-based treatments. In this case, treatments are defined as safety countermeasures that are installed on an existing roadway. Those that appear to provide the largest crash reduction benefits, when installed on existing roadways, include those shown in Table 1. Installing shoulder and centerline rumble strips produce significant crash reduction benefits on several roadway types. Similarly, the installation of pavement markings and changeable warning signs appear to offer substantial crash reductions on a variety of roadway types. To reach the Towards Zero Deaths goal, these treatments should continue to be installed on roadways throughout the U.S.

While infrastructure-based treatments have been shown to provide significant crash reduction benefits, several crash reduction factors related to physical changes to the infrastructure (e.g., modifications to lane width, shoulder width, median type/width, etc.) are provided in the first edition of the HSM. These can be broadly classified as cross-section, horizontal alignment, vertical alignment, and roadside changes. Many of the crash reduction factors for these roadway and roadside features take the form of a crash modification function. Readers are referred to the HSM for a complete list of the crash reduction estimates for various physical infrastructure changes; however, several are worth noting here. These include the following:

- Increasing the distance to roadside features: expected total crash reduction of 44% ± 1% when increasing the distance to roadside features from 16.7 to 30 ft on two-lane rural roads and freeways;
- Converting signalized and two-way stop-controlled intersections to modern roundabouts: expected total crash reduction ranges from 78% ± 7% to 19% ± 10% at most intersection locations.

Table 1. Proven Safety Countermeasures Installed on Existing Roadways.

Treatment	Setting	Traffic Volume (veh/day)	Crash Type	Expected Crash Reduction (% ± SE)[a]
Install edgeline and centerline markings on roads without markings	Rural two-lane and multi-lane undivided highways	Unspecified	All types (injury)	24% ± 10%
Install edgelines, centerlines, and post-mounted delineators on roads without markings	Rural and urban two-lane and multi-lane undivided highways	Unspecified	All types (injury)	45% ± 10%
Install continuous milled-in shoulder rumble strips on roads without rumble strips	Rural multi-lane divided	2,000 to 50,000	All types (all severities)	26% ± 10%
	Rural and urban freeways	Unspecified	Single-vehicle run-off road (all severities)	79% ± 7%
	Rural and urban freeways	Unspecified	Single-vehicle run-off road (all severities)	18% ± 10%
	Rural freeways	Unspecified	Single-vehicle run-off road (all severities)	21% ± 20%
Install centerline rumble strips on roads without rumble strips	Rural two-lane highways	5,000 to 22,000	All types (all severities)	14% ± 5%
Provide highway lighting on roads without lighting	All roads	Unspecified	All types (nighttime injury)	28% ± 6%
Install changeable accident ahead warning signs on roads without warning sign	Urban freeways	Unspecified	All types (injury)	44% ± 20%
Install changeable speed warning signs on roads without warning signs	Unspecified	Unspecified	All types (all severities)	46% ± 20%

[a] SE = standard error

To achieve the Toward Zero Deaths goal, the myriad safety countermeasures and physical infrastructure improvements that have been proven to reduce fatalities should continue to be implemented throughout the U.S., on a prioritized, cost-effective basis. To this end, the first edition of the HSM provides a safety management process that should be used to identify sites with potential for safety improvement, methods to diagnose safety problems, countermeasure selection guides, economic assessment methods, and countermeasure evaluation processes. The safety management process should be implemented by all transportation agencies throughout the U.S., and supported by the FHWA Interactive Highway Safety Design Model (IHSDM) and SafetyAnalyst. These tools implement the crash prediction algorithms and safety management process described in the HSM.

The Roadside Safety Analysis Program (RSAP) is a software program that can be used to evaluate trade-offs associated with roadside designs to reduce the impact severity of single-vehicle run-off-road crashes. The program is intended to complement the AASHTO Roadside Design Guide by incorporating a series of algorithms to estimate the frequency of roadside encroachments, crash frequency, and crash severity to compare the benefits and costs associated with alternative roadside designs. It is not clear if RSAP has been widely-implemented by transportation agencies in the U.S., but the program is the most comprehensive roadside design and safety evaluation tool available, and should be integrated into the HSM, IHSDM, and SafetyAnalyst. This would ensure that both roadway and roadside design decisions are considered concurrently during the safety management process, rather than as separate or independent functions.

While the HSM, IHSDM, SafetyAnalyst, and RSAP provide opportunities to evaluate the safety performance of existing and planned highway designs, all have limitations with respect to infrastructure safety. For example, the HSM contains accident modification factors for very few roadway and roadside design criteria (e.g., radius of horizontal curve, lane width, shoulder width, superelevation, roadside hazard rating, etc.), primarily for two-lane rural highways. The Crash Prediction Module of the IHSDM includes a two-lane rural highway crash prediction algorithm, and a current beta version of the module includes crash prediction algorithms for rural multi-lane highways and urban/suburban arterials based on the HSM. For each roadway type, several roadway and roadside design criteria are not included in the prediction algorithm because safety performance data are not well-documented. SafetyAnalyst is a safety management evaluation tool based on processes outlined in the HSM. It, too, contains few roadway and roadside design variables. HSM, IHSDM, and SafetyAnalyst have all been developed in a coordinated manner, while RSAP has been developed independent of these tools. The performance-based design strategy outlined in this white paper proposes to implement a roadway and roadside design process that builds on the knowledge-base included in these tools, and proposes to expand the capabilities of these tools so that they can be used in an integrated manner to reduce infrastructure-based fatalities.

Current Design Paradigm

The design process begins after long-range transportation plans have been developed, and projects have been programmed (i.e., prioritized, selected and funded). Safety is an important component of this process, and available tools should be used assist agencies in selecting infrastructure projects that offer the greatest potential for safety improvement. The HSM and SafetyAnalyst are tools that can be used to assist in project selection based on the safety management process for an existing roadway network. Washington et al. (2006) outlines a process for incorporating safety into long-range transportation planning.

With regards to design, the project development process includes many steps, beginning with project planning, and concluding with construction, management, and operations, safety-based infrastructure decisions are primarily performed during alternatives analysis, prior to selecting a preferred alternative. This process is illustrated in Figure 6. Many of the existing tools described previously can be used during this phase. The extent to which these tools are utilized is not clear, but is likely after establishing minimum or limiting values of design criteria based on accepted guidelines or standards. Figure 7 is a microscopic view of alternatives analysis process, and further illustrates this concept.

The transportation design process in the U.S. is based on the design speed concept. Designers are encouraged to consider land use, anticipated operating speeds, highway functional class, and topography prior to selecting a design speed. Once the design speed is selected, minimum or limiting values of design criteria are established based on the design speed. These minimum or limiting values are published in design guidelines or standards; safety performance is implied if complying with established design policies. Explicit consideration of safety performance is most commonly completed after applying design policy guidelines and assessing cost and environmental impacts.

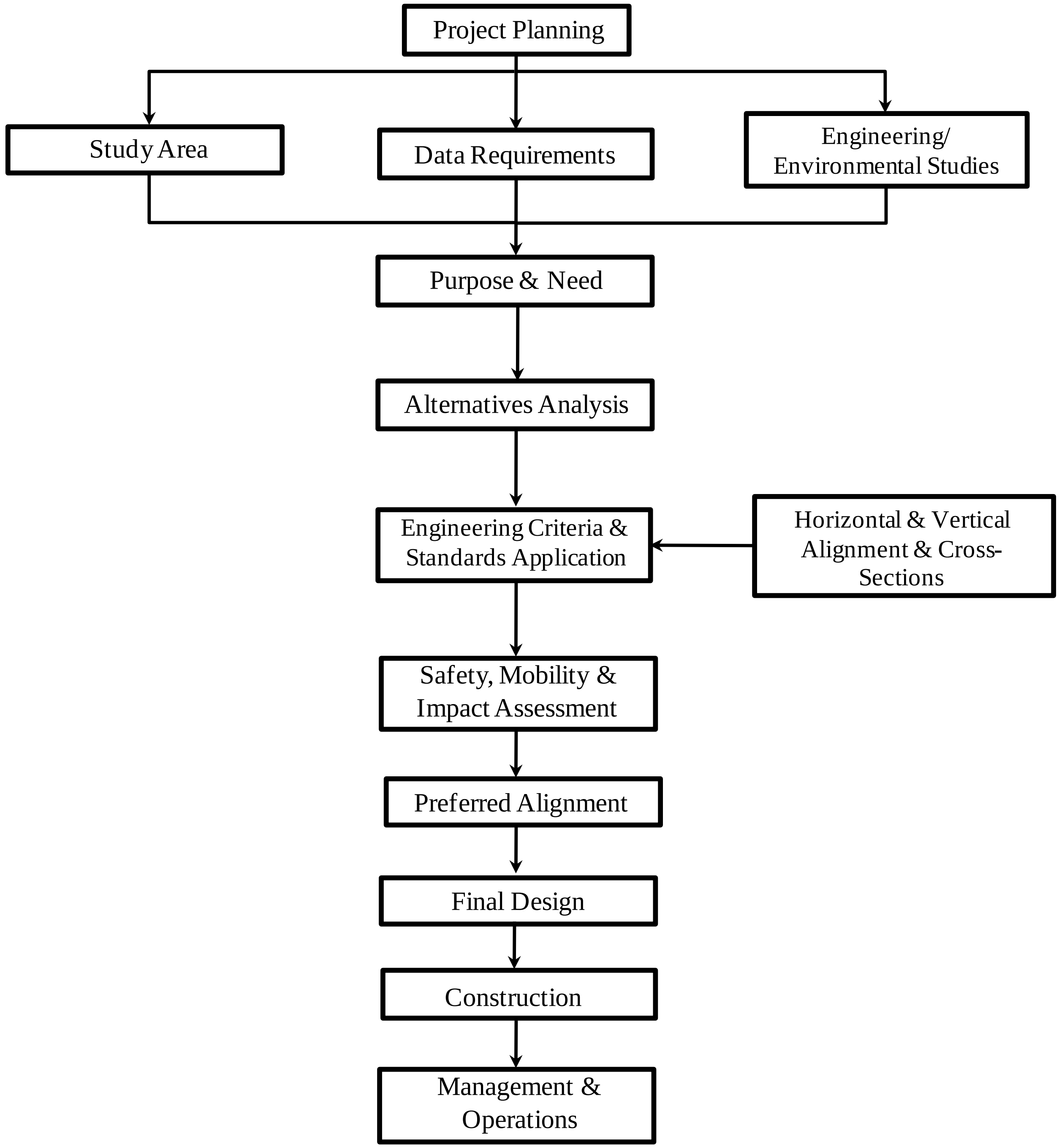

Figure 6. Project Development Process.

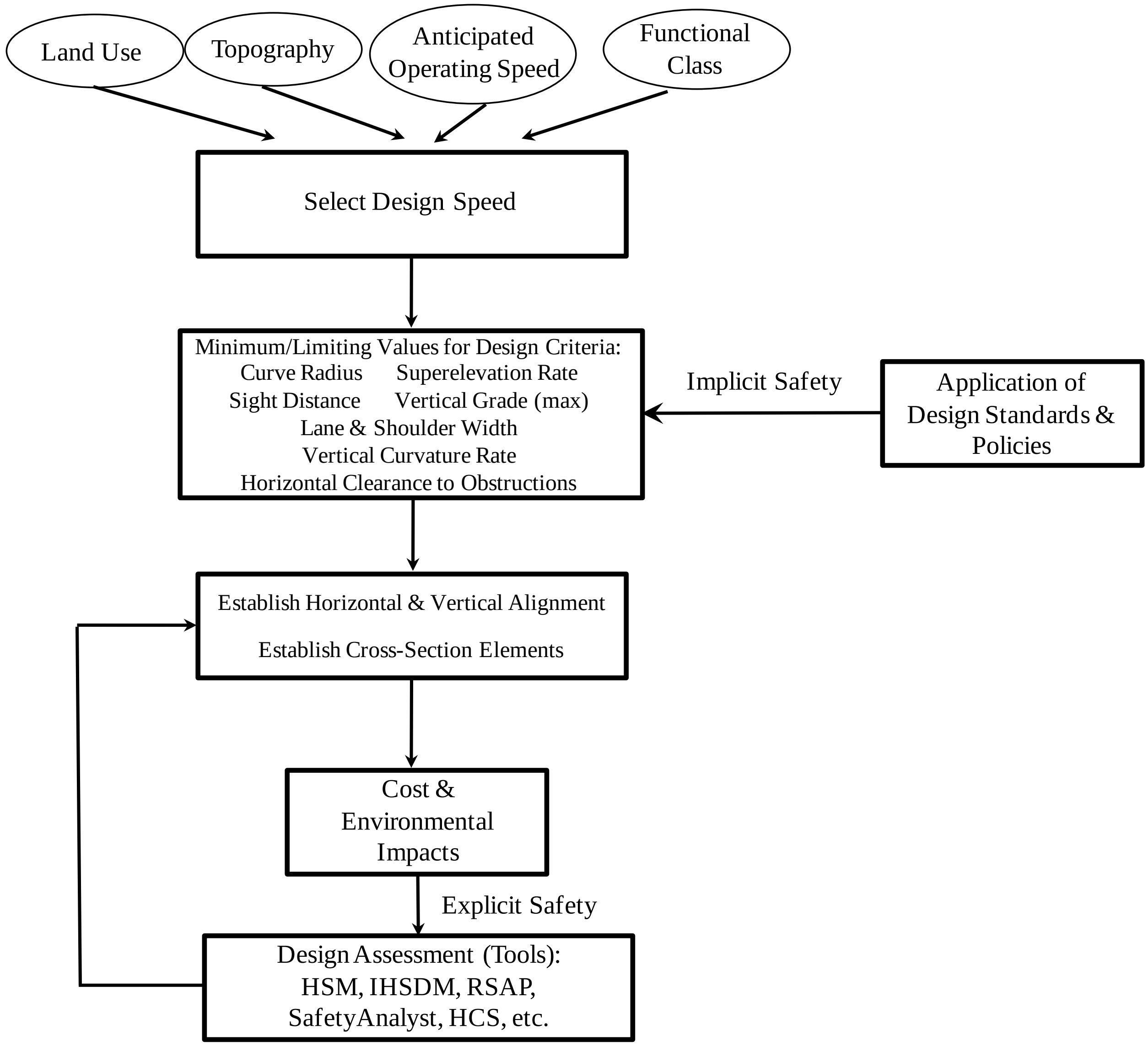

Figure 7. Current Design Process.

What is Performance-based Design?

Performance-based design, as proposed in this white paper, is the explicit consideration of safety in establishing design criteria, and the holistic application of tools and processes to evaluate the performance of roadway and roadside design decisions. The goal of a performance-based design process is to incorporate objective safety metrics in the project development process, rather than implicitly relying on the application of design policies, criteria, or standards.

Opportunities

In the current design process, the following roadway and roadside criteria are based on the design speed:

- Radius of horizontal curve
- Superelevation
- Sight distance (stopping, intersection, passing, and decision)
- Horizontal sightline offset
- Length of vertical curve
- Lane and shoulder width
- Horizontal clearance to obstructions

The relationship between safety and some of these design elements is known (i.e., radius, superelevation, lane and shoulder widths for rural highways). Opportunities exist for safety-based data to be developed for all criteria across all roadway types. Thus, the design speed concept currently used to establish speed-based criteria could be either replaced by quantitative safety-based criteria, or supplemented by safety performance data. Roadway and roadside design based on minimizing the frequency and severity outcomes of crashes, given a set of objectives and other constraints (e.g., cost, environmental impacts, mobility, etc.) will not only reduce fatalities attributed to the roadway, but will likely also reduce those attributed to the combination of the driver and roadway (see Figure 1).

A similar opportunity exists when considering the 13 controlling criteria designated in the Federal-Aid Policy Guide for application to projects along National Highway System (NHS) routes. These criteria are as follows:

- Design speed
- Lane width
- Shoulder width
- Bridge width
- Structural capacity
- Horizontal alignment
- Vertical alignment
- Grade
- Stopping sight distance
- Cross-slope
- Superelevation
- Vertical Clearance
- Horizontal Clearance

When the minimum or limiting criteria are not met, a design exception is required. An important consideration when documenting a design exception is the safety performance of the proposed design. While nearly all state transportation agencies in the U.S. indicate that safety is a principal consideration in documenting design exceptions (Mason and Mahoney, 2006), little is known about the safety performance of many of these 13 controlling criteria, thus an opportunity exists to develop it so that design decisions are based on the expected safety performance.

The AASHTO Roadside Design Guide and RSAP provide design decision-making tools for the roadside infrastructure. Both have limitations. The Roadside Design Guide contains barrier selection and placement guidelines that are based primarily on the results of physical crash testing. These tests are typically performed in controlled facilities, under a set of well-defined conditions (i.e., vehicle type, impact speed and angle, etc.) as described in NCHRP Report 350 (Ross et al., 1993). The authors of RSAP (Mak and Sicking, 2003) acknowledge the following limitations of the program: (1) the encroachment model is based on data that are more than 30 years old, (2) vehicle and driver inputs are not considered in the vehicle path algorithm, (3) roadside slopes and roadway and roadside geometries are not adequately addressed in the lateral encroachment module, and (4) the impact severity is not based explicitly on severity outcomes resulting from a roadside crash. An opportunity exists to develop comprehensive in-service performance data for implementation into the Roadside Design Guide and RSAP. Data elements such as the barrier type, location, performance (e.g., deflection) during a crash, crash impact angle and speed, roadway and roadside geometrics at the time of the crash, driver and vehicle inputs prior to the crash event, and other relevant run-off-road crash data should be collected and used to update these tools. Then, each could be re-developed with safety performance explicitly considered in the design decision-making process.

Finally, the MUTCD contains a series of standards, guidelines, and options for traffic control devices. With few exceptions, many of the implementation guidelines are based on traffic volume and visibility. While the manual provides important information related to standards of size, shape, color, and message of traffic control devices for use on public roadways, little is known about the safety performance of most devices. The HSM contains a collection of accident modification factors for several traffic control devices, but more safety performance data are required. As this scientific knowledge is developed, the MUTCD should be developed with explicit consideration of safety performance.

Challenges

A significant investment and a cultural change in the design profession are the two principal challenges to implementing the performance-based design strategy. With regards to cost, there is a considerable amount of research required to develop safety-based relationships for all design decisions. While the aforementioned tools (HSM, IHSDM, SafetyAnalyst, RSAP) are a positive step in this direction, a critical assessment of the design process is needed to identify decisions that are not related to safety. An attempt should then be made to quantify the decisions with an unknown relationship to safety. Developing a strategic design-safety research agenda may provide the roadmap to achieve a safety-based design paradigm.

As more design decisions are linked to safety performance, a cultural shift in the design paradigm is required to achieve the Toward Zero Death goal. The design speed concept has been used for nearly 70 years to establish design criteria – future design policies should be developed with explicit consideration of safety.

Expected Benefits and Cost of Strategy

A strategic research effort to develop and implement a performance-based design paradigm is expected to cost approximately $10 million. Reduction of all fatalities solely attributed to the “roadway” is the expected by implementing this strategy. It is also possible to expect that a proportion of the fatalities attributable to the combination of the "roadway" and the "driver" may result from a performance-based design strategy.

SUMMARY AND CONCLUSIONS

The Penn State team has carefully considered the very broad range of infrastructure strategies that are available while seeking to adhere to FHWA guidance to identify breakthrough strategies that are "outside the box". As described in our introduction, tremendous progress has been made in infrastructure safety management in the last 20 years; many useful treatments have been identified, installed and either fully or partially evaluated. As a result, we have chosen not to develop a bibliographic type of document which summarizes the literature in infrastructure countermeasures. Instead, we have chosen three strategies which, we believe, can substantially reduce serious injuries and fatalities.

Safety Centers of Excellence

The Safety Center of Excellence is aimed at doing a better quality job in virtually all areas of road safety management, particularly infrastructure countermeasures. There is an excellent starting point for infrastructure management with the publication of the Highway Safety Manual (HSM) and other tools such as the IHSDM and Safety Analyst. There is also strong process and institutional support for safety with the initiation of Safety Conscious Planning. An important gap is that there is virtually no way that one can assure that the Manual will be used, used correctly, or that the processes of SCP and SHSP will yield strategies that are the most effective. The Safety Center of Excellence responds to all these concerns by providing education and technical assistance to those in implementation roles.

Using the SuperPave Centers as a model and accounting for inflation, one would estimate a cost of $1.5 million per year for each of 5 years to start ($25 million total). After 5 years, the Centers should be self-supporting. The expected benefit can only be estimated with some intuition: let's say that 30% of the safety investments are mis-guided and confounded by regression-to –the-mean. The benefit would be a 15-20% reduction in serious crashes per year, primarily through better selection of sites for treatment and more effective selection of countermeasures. Part of the payoff of the safety centers should be much improved evaluation of effectiveness after implementation, so FHWA should know fairly directly about the success of the program.

Automated Speed Enforcement

The team believes that much can be gained through the persistent pursuit of automated speed enforcement on a large scale. We focus on speed enforcement because red-light running, while effective in most studies, does not have the "big bang" that is sought for TZD. Safety improvements of 10% or so in angle crashes partially counterbalanced by 2% or so increases in rear-end collisions would not seem to be a strategy that will drive us to TZD goals. As a result, we recommend broad-scale automated speed enforcement as our second infrastructure strategy. There are a great number of infrastructure design decisions that need to be made in the potential deployment of such systems including covert/overt speed camera placement; tolerance for speed over the limit and emphasis on fines vs. demerit points.

Experience shows that benefits of such automated enforcement are in the range of 20% reduction in fatalities and serious injuries and may be as high as 30-40% in some areas. The economic value of the benefit was estimated to be $16 million per year in the Scottsdale, Arizona study (Shin et al. 2009); larger scale area-wide deployment should yield even larger benefits. We were not able to find cost information, but are sure that the breakeven point for such systems would be 3-5 years.

Performance-based Design

Performance-based design, as proposed in this white paper, is the explicit consideration of safety in establishing design criteria, and the holistic application of tools and processes to evaluate the performance of roadway and roadside design decisions. The goal of a performance-based design process is to incorporate objective safety metrics in the project development process, rather than implicitly relying on the application of design policies, criteria, or standards.

The team believes the implementation of performance-based design offers systematic advantages for managing road safety. It will require a change in the safety culture of transportation organizations, from how they deal with the public, other DOT's and manage planning, design, construction, operations and maintenance within their own organization.

A strategic research effort to develop and implement a performance-based design paradigm is expected to cost approximately $10 million. Reducing all fatalities solely attributed to the "roadway" is the expected benefit by implementing this strategy.

The team believes that the three proposed strategies, if pursued over the 10-15 year horizon of the TZD initiative, will profoundly change the manner in which safety is managed on our road system. We have tried to estimate costs and benefits as best we could. While the cost estimates proved difficult, the benefit estimates, we believe, are clearly achievable. This is not to minimize the difficulty of any of the strategies; each faces strong challenges. In some cases there is already formed political opposition (such as the "highway robbery" web site). In others, such as the Safety Centers and Performance-Based Design, there are imbedded cultural forces at play.

Lastly, we would like to remember that the focus of the recommendations was to seek strategies that would apply to run-off-road and intersection crashes in particular. We believe this priority can readily be accommodated through the detailed pursuit of each of the 3 strategies. For example, development of the Safety Centers (posed as 5 regional centers) can use selection criteria that focus on these problem areas. The automated speed enforcement can be emphasized in rural areas where the problems are the greatest. Performance-based design can be applied to the high risk roads first.

The team hopes that the reviewers find the strategies thought-provoking, interesting and useful.

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