SAFETY ENGINEERING EDUCATION COURSE DEVELOPMENT

FINAL REPORT

SOUTHEASTERN TRANSPORTATION CENTER

N. STAMATIADIS

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EXECUTIVE SUMMARY

Highway safety has been the focus of the research and practicing community for several decades. Several academic programs have attempted to address the need for increased awareness and education of engineering students on the issues of highway safety. Practitioners agree that it is imperative for professionals entering the workforce to be familiar with the highway safety issues and concepts as well as be aware of recent advances in highway safety.

The Southeastern Transportation Center has been an advocate for highway safety in education and the higher fatality rates of the Southeastern states point to the need for the development of a college level course that could educate future professionals on the issues of highway safety and ensure that graduates have at least a basic background on highway safety and associated issues.

The main goal of this activity is to develop a web-based safety course appropriate for graduate students. The course material was developed in a modular fashion allowing instructors to select those appropriate with their curriculum providing instructors with flexibility in selecting appropriate modules to fit their students.

The course contents include an understanding of the multidisciplinary nature of highway safety, comprehension of the various contributing factors to crashes, ability to identify potential countermeasures, comprehension of data sources and potential issues with their use, and understanding of the institutional settings for safety management decisions. Practices and procedures used in the Highway Safety Manual are also included.

The teaching package developed as part of this effort includes lecture notes in PowerPoint presentation format accompanied with instructor notes that identify the main points in each slide and frequent provide questions to stimulate student participation and interaction.

INTRODUCTION

Highway safety has been the focus of the research and practicing community for several decades. The American Association of Highway State Transportation Officials (AASHTO) has established a Strategic Highway Safety Plan and AASHTO in cooperation with several other agencies have developed the Towards Zero Deaths (TZD) vision (TZD 2014). It is therefore imperative that professionals entering the workforce are familiar with these concepts as well as recent advances in highway safety.

Several academic programs have attempted to address the need for increased awareness and education of engineering students on the issues of highway safety. NCHRP Report 667 (Cambridge Systematics et al. 2010) has produced training materials on highway safety targeting a broad audience of professionals that could be involved in highway safety. However, this course is not well suited for academic use.

The recent edition of the Highway Safety Manual ([HSM] AASHTO 2010) has collected and documented the most up-to-date knowledge on highway safety. It is critical that future engineers be cognizant of the HSM approaches as well the appropriate methods for evaluating safety in order to be able to address future safety needs and improve roadway safety.

An issue of concern for the region of the Southeastern Transportation Center (STC) is the fact that more than a third of fatalities (34.1 percent) occur in the region (NHTSA 2014). Several states have a fatality rate higher than the national average indicting the severity of highway safety in the Southeastern USA.

These elements point to the need for the development of a college level course that could educate future professionals on the issues of highway safety and ensure that graduates have at least a basic background on highway safety and associated issues.

The main goal of this activity is to develop a web-based safety course appropriate for graduate students. The course material will be developed in a modular fashion allowing instructors to select those appropriate with their curriculum.

The development of the educational materials will advance the current state of the practice in the various schools not only in the Southeastern USA but the entire nation, since there are no such materials available as of today. The products of this work will provide the valuable link needed to further advance the educational objectives of STC and provide the opportunity to enhance safety through knowledge of basic concepts and information.

COURSE CONTENT

A review of prior efforts as well discussions with faculty in the various STC universities resulted in identifying key competences for the course as well as specific modules to address them. NCHRP Report 667 and NCHRP Digest 302 (Gross and Jovanis 2006) have identified a set of such competencies that were followed in this effort as well. These include an understanding of the multidisciplinary nature of highway safety, comprehension of the various contributing factors to crashes, ability to identify potential countermeasures, comprehension of data sources and potential issues with their use, and understanding of the institutional settings for safety management decisions.

In addition to these topics, the current HSM contents need to be included in any safety course in order to expose students in the current approaches and procedures and provide them with an understanding of their application. Therefore, this competency along with an understanding of basic statistical modeling and processes used in highway safety were included in this course.

The teaching package developed as part of this effort includes lecture notes in PowerPoint presentation format accompanied with instructor notes. The notes discuss some of the major issues to be addressed in each slide and they also provide questions that the instructor can use to stimulate discussion on the topic presented. The entire set of notes is included in Appendix A.

The course was developed with modularity in mind in order to allow instructors to select the elements they seem more fitting to their curriculum and embed them within their current courses. This approach does not require the need for following the entire course and thus provide the ability to address safety within the existing curriculum and course structure without increasing number of courses. However, the course materials are complete and instructors can follow all modules to be delivered during a 16-week semester.

The general topics covered in the course include the following:

1. Introduction to highway safety
2. Highway design and safety
3. Crash factors
4. Fundamental statistics
5. Statistical methods and models
6. Highway Safety Manual
7. Countermeasures and safety evaluations

Table 1 presents the objectives and details for each topic.

Table 1 Course topics and content

Topic	Subtopic	Content
Introduction to highway safety	Transportation safety history	Covers beginning of highway safety legislation in the1950s through MAP-21 and identifies key players and contributors to highway safety
	General crash trends	Covers basic trends of crashes over the last 20 years and presents general efforts (governmental) to reduce crashes
Highway design and safety		Presents basic crash statistics as they relate to the highway design elements, identifies design policies aiming to improve safety, discusses potential effect of future design trends on safety, and draws relationships between elements and safety through an introduction of HSM
Crash factors	Human factors	Presents basic crash statistics as they relate to human factors, identifies special groups of concern (young and older drivers, alcohol use), explores risk-taking behavior trends and discusses possible efforts to address them
	Vehicular factors	Presents basic crash statistics as they relate to vehicular factors, identifies efforts to improve vehicle design to address safety concerns and discusses issues of future trends in vehicle design and their impact on safety
Fundamental statistics	Statistics review	Reviews fundamental statistics related to safety analysis and presents basic statistical approaches for highway safety
	Crash data uses	Discusses types of available crash data and identifies their uses in highway safety in order to improve safety management and decision making
Highway Safety Manual		Presents different statistical approaches used to address and evaluate safety questions including regression models, Empirical Bayes, basic hypothesis testing and procedures used in HSM (also covers biases found in techniques)
Countermeasures and safety evaluations	Countermeasures	Identifies possible countermeasures for addressing safety, discusses the level of effectiveness of each effort and presents the cost-effectiveness of each possible solution, presents the CMF clearinghouse and approaches for assessing and using the various CMFs
	Road safety audits	Discusses the basic approach for RSA, presents examples of audits, and demonstrates efforts for selecting appropriate countermeasures based on RSA
	4Es	Covers the highway safety management process from network screening to countermeasure evaluation and also presents information on collaboration, leadership and need for safety champions

The contents shown here aim to address the primary purpose of this course, which is to develop an understanding of the various aspects of transportation safety by seeking answers to general questions and issues and explore the methods used to quantify safety.

The course has three main components:

1. Understanding traffic safety issues through a review of current trends and seeking answers to general safety questions and concerns.
2. Reviewing statistical analysis techniques required to measure safety indicators.
3. Identifying safety countermeasures employed to improve traffic safety.

Students who will complete the course should be able to accomplish the following course objectives:

1. To become familiar with the issues in highway safety, factors impacting safety levels, the effectiveness of countermeasures and the methods used to quantify safety.
2. To be able to perform the appropriate statistical tests on real world data to answer safety hypotheses.
3. To be able to improve written communication skills through development of short position papers.
4. To explore the issues affecting safety for heavy trucks, bicycles, pedestrians and rail/highway crossings.

As part of this packet, homework sets are provided in Appendix B.

COURSE EVALUATION

The course was piloted in the Spring 2016 semester at the University of Kentucky. Dr. Chen and Dr. Stamatiadis co-taught the course. Dr. Chen has not delivered a course on highway safety before or had developed any research in the highway safety area. The idea was that if a person not very familiar with the topic could rely on the instructor notes and deliver the material with some preparation, then the course content could be used by any other faculty, with or without any experience in highway safety. The pilot delivery also served as a test for the completion of the material to be covered as well refinement of both content and notes for the instructors.

Dr. Chen's assessment of the course material is presented in Appendix C. Her overall assessment is that the course provides a comprehensive picture of highway safety and some topics could be expanded to provide a greater background and information to students.

FUTURE STEPS

The course notes and content developed could improve over time with the addition of other modules and expansion of content in the developed modules. It is recommended that the course contents should be piloted by other STC universities and feedback to be solicited in order to improve the content and complete the course. To achieve this, a four-step process is envisioned:

1. Faculty workshop: a one-day workshop is proposed where faculty dealing with highway safety education in the STC universities will be invited to attend and the material developed will be presented. This will allow for a quick overview of the modules and presentation of the topics covered. A work session will be conducted to identify possible areas and topics for future inclusion and development.
2. Faculty delivery: faculty interested in the modules will be asked to incorporate them in their curricula and deliver either the entire course or specific modules. Periodic feedback will be solicited while the modules are delivered to ensure timely response addressing comments.
3. Faculty symposium: a half-day symposium will be held where faculty who have used the material will present their review and evaluation and identify future areas for development. This will complete the review process and provide the required feedback for improving and completing the course content.
4. Course update: the final step will ensure a review of the comments collected and develop the appropriate responses, i.e., adjustment of module content, development of additional modules, and inclusion of additional material in the already developed modules.

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Gross, F. and Jovanis, P. *NCHRP Research Results Digest No. 302*, National Cooperative Highway Research Program, Washington, DC, 2006.

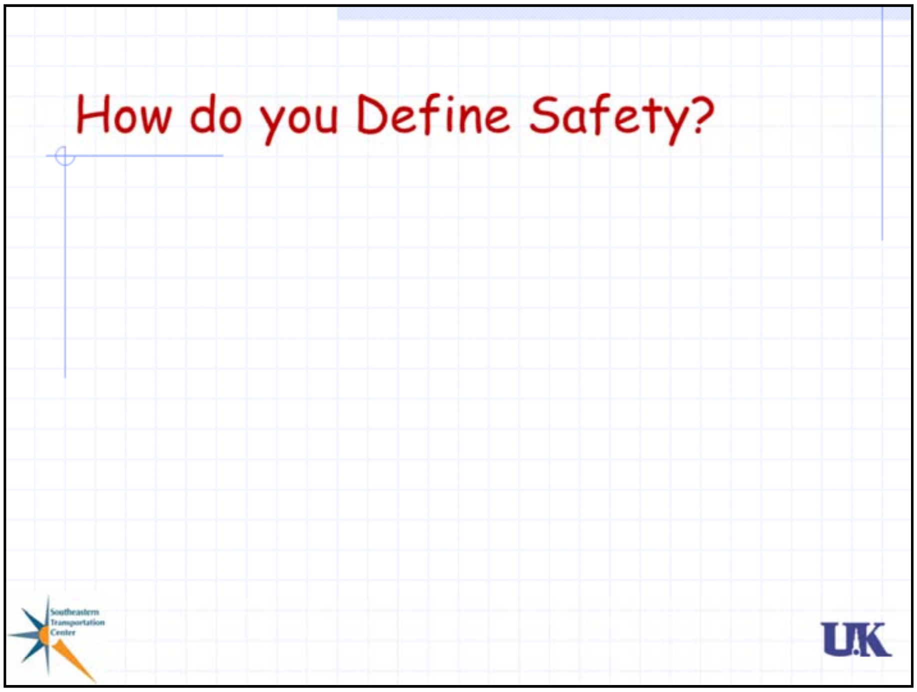
NHTSA, *Traffic Safety Facts: 2013*, National Highway Traffic Safety Administration, Washington, DC, 2014.

TZD, *Towards Zero Deaths*: *A National Strategy on Highway Safety,* http://www.towardzerodeaths.org/strategy/ Accessed May, 2016.

APPENDIX A

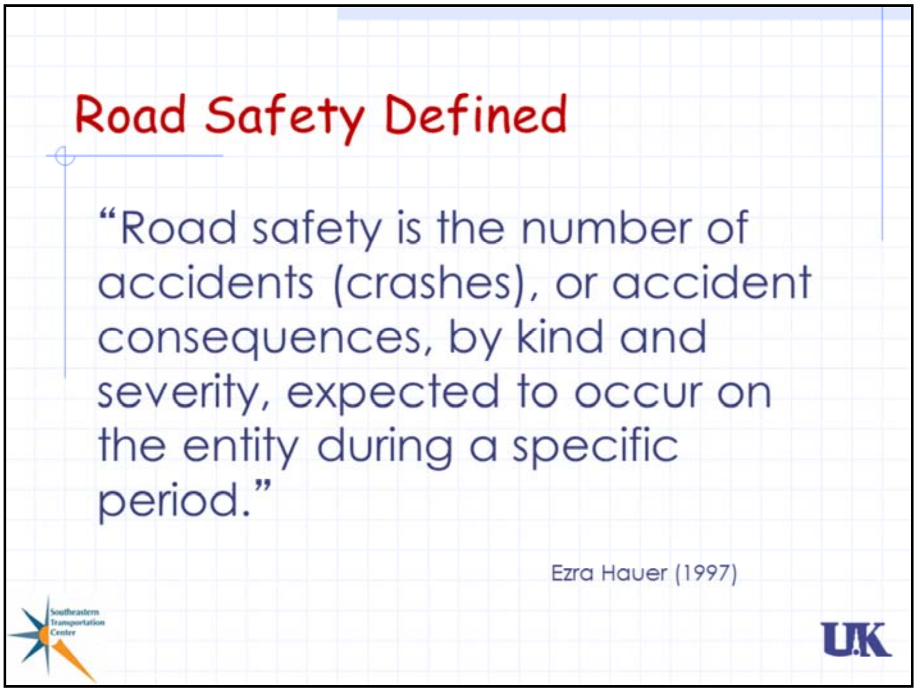
Teaching Modules

This course has been designed to provide a basic understanding and fundamental knowledge of safety issues and concerns. Upon completion of the course, participants should be able to articulate the safety issues as they relate to highway safety and be capable of understanding the implications of the various factors and choices affecting safety. An understanding of contributing factors to crashes is provided along with possible countermeasures (to date) to address safety concerns. Concepts of crash prediction and the components fo the Highway Safety Manual are also discussed.



Question: How do we define safety?

The idea here is to generate discussion and point to the need of understanding that various disciplines may have different perspectives. For example, a highway engineer may define it as the number of crashes while a transit operator may see it as the safety of passengers. We do not have a fundamental definition of safety due to its complexity.

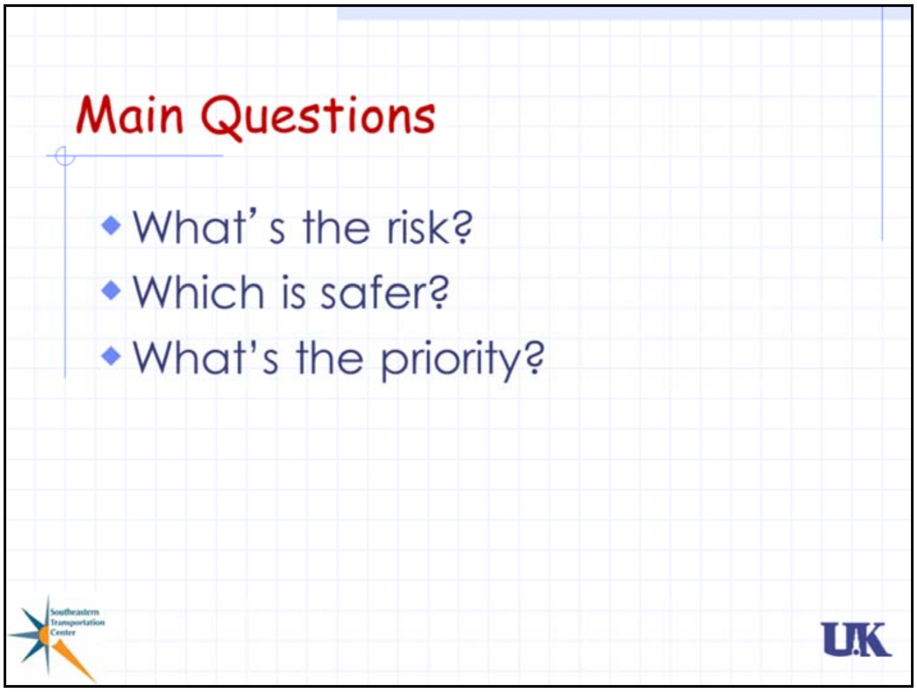


Road safety is the study of crashes and their impacts on the surface transportation system. The focus of road safety is the number of crashes over a period of time for a roadway unit or a group (entity in the above definition). The roadway unit could be a highway segment, an intersection, a freeway ramp, driver group (e.g., age or gender) or vehicle group (automobiles, trucks, etc.).

Ezra Hauer defined “Roadway Safety is the number of accidents (crashes), or accident consequences, by kind and severity, expected to occur on the entity during a specific period.” (Observational Before-After Studies in Road Safety, Pergamon. 1997).

The preferred measure for road safety is the number of crashes and their severity, i.e., fatalities, injuries and property damage only. Over time, surrogate measures of safety have been developed and they will be discussed in module X. these measures can provide a generic estimate of safety but it should be emphasized that the preferred measure of safety is one that characterizes the outcome of the event.

A terminology issue to be addressed here is the difference between “accident” and “crash”. The term “accident” implies that the outcome is unintentional. On the other hand, the term “crash” implies a preventable outcomes. It should be noted that both terms define a collision among vehicles as well as other roadway users, i.e., pedestrians and bicyclists.

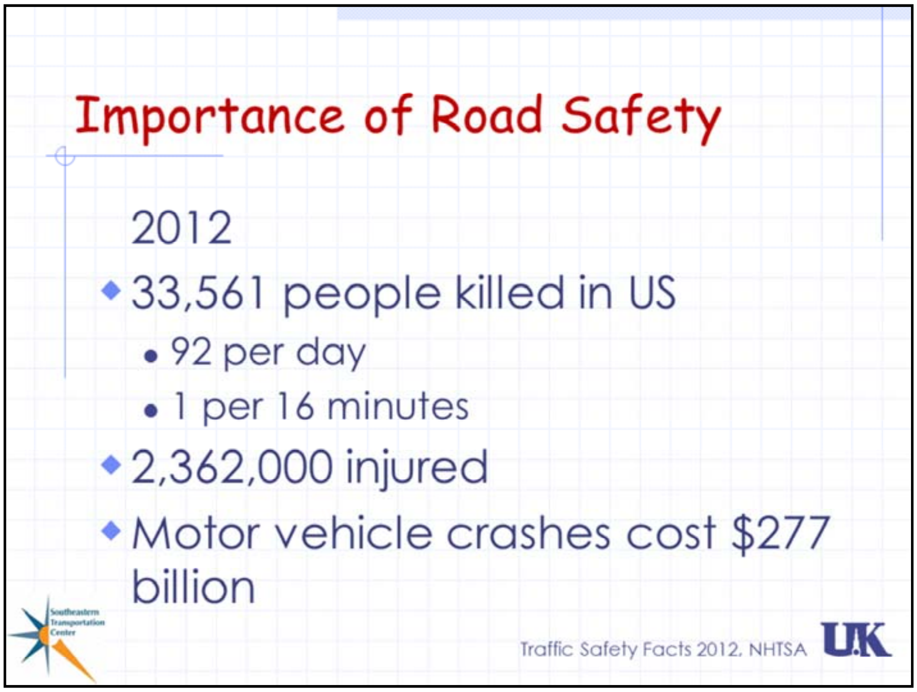


These are some of the questions that a person dealing with roadway safety may seek answers.

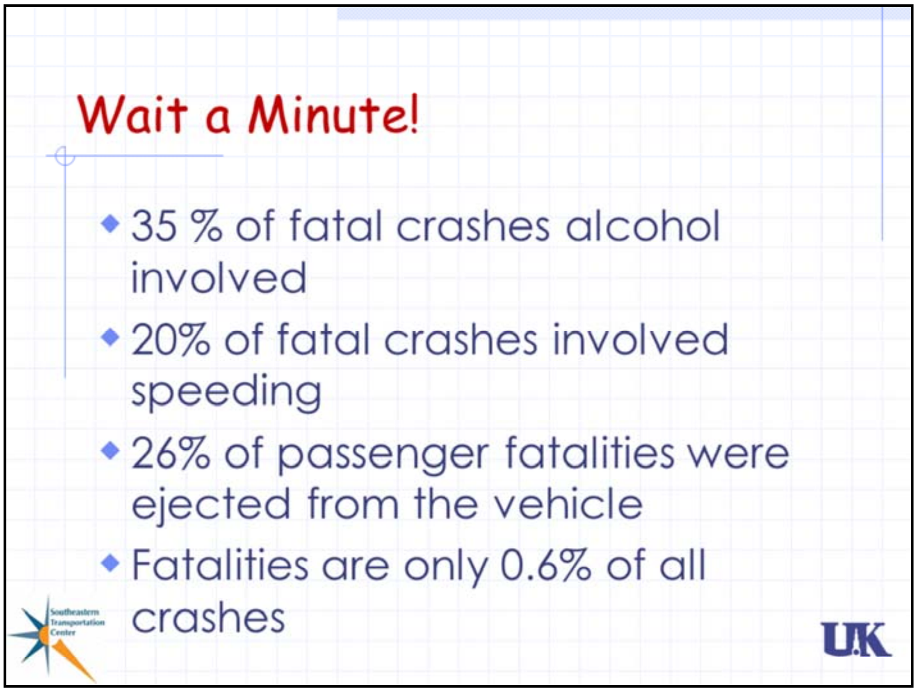
For example, one may want to identify how risk perceived in the highway environment. One may consider risk as overtaking vehicle in a two-lane rural road while a vehicle is approaching while others may simply consider risk the mere act of driving. There is a wide level here and the systematic evaluation of risk in the highway safety arena is a fundamental issue.

Another issue that safety professionals have to deal with is how to compare different scenarios or countermeasures in order to determine the safety impacts of an intervention or a condition. Again the systematic analysis with sound scientific approaches and appropriate data is the answer to this question. Developing models aiming to understand and explain crashes and their associate factors can assist in answering this question.

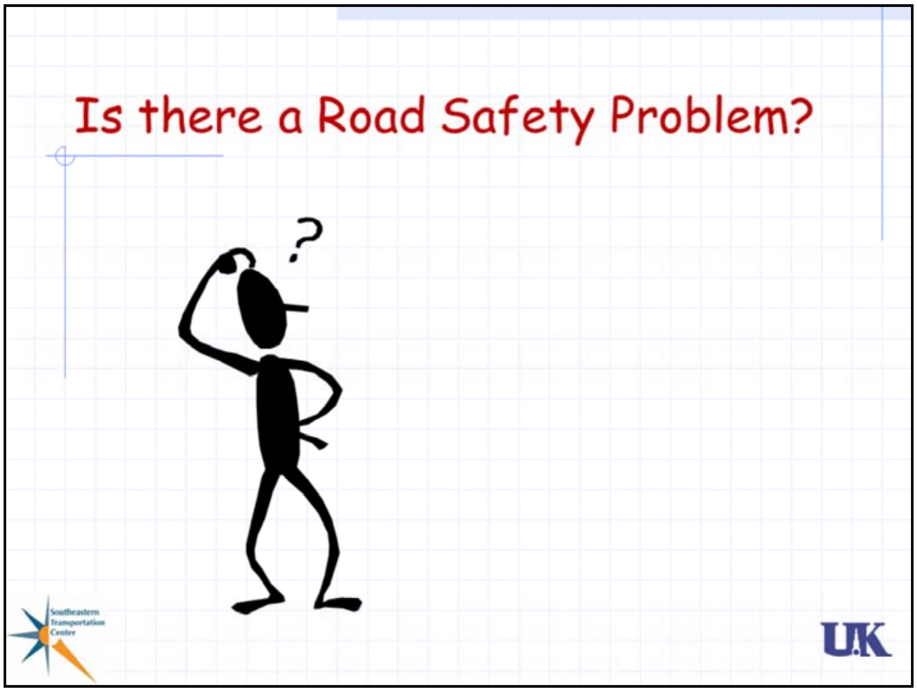
Finally, establishing priorities for addressing safety issues and concerns is central to the entire highway safety approach. Understanding the various risks and relative safety of factors involved and countermeasures proposed provides decision makers with adequate data to identify the relative order with which funding can be used to address safety issues.



These are some recent statistics for the US. Based on these data, there is a significant impact both on lives and monetary values. One may consider the number of fatalities on a per day basis and this is approximately equal to a CRJ-900 plane. The number of injuries is also high and this points to a significant health issue. Finally, the total costs of crashes in the US is close to $300 billions (this includes all associated costs from lost productivity, health costs and all other costs).



One may pose though these questions to ask whether the numbers before are a result of incorrect policies or simply human errors that a society may need to revisit. For example, over a third of fatal crashes involve intoxicated drivers and one in five involve drivers driving at speeds higher than allowed! One in four fatalities are for a person ejected from the vehicle indicating that he/she was not wearing a seat belt.



So one can ask "Is there a road safety problem?"

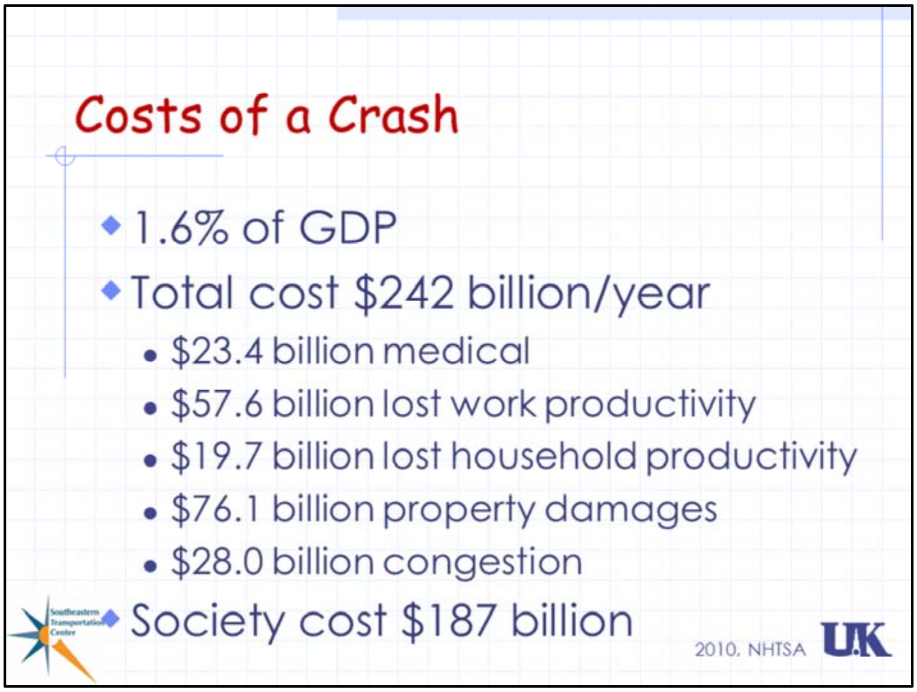
Ask participants to discuss this in the context of the previous slide. Additional questions to spark discussion may include:

•Are the issues here more human errors and how to prevent them or something else?

•What indicators would one use to demonstrate that there sis a safety problem, if we believe this to be the case?

These are some of the reasons as to why there is still a road safety problem:

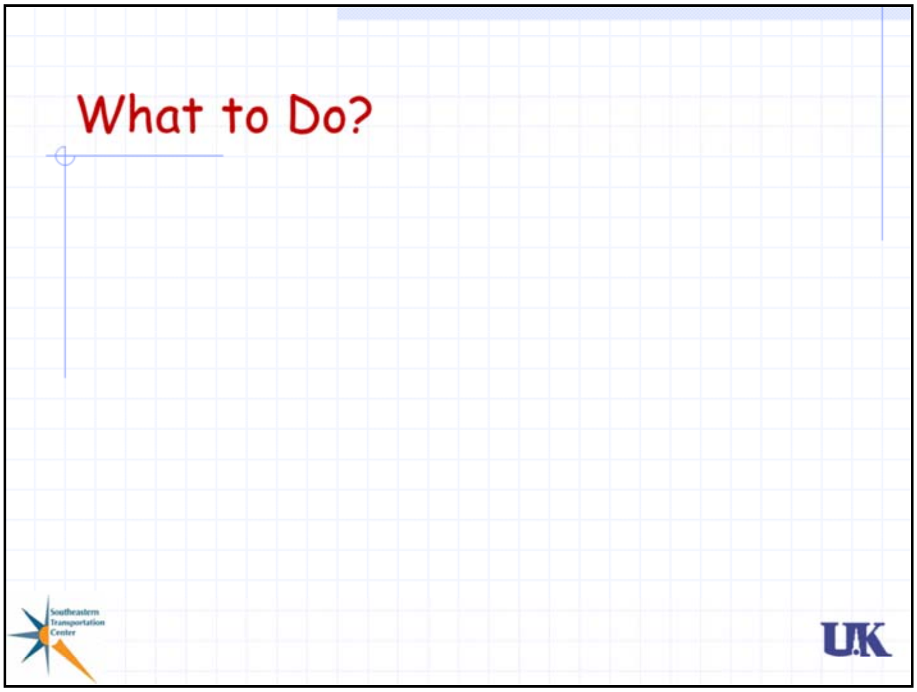
- There are roadway users that simply happened to be in the wrong place at the wrong time; those are defined as the innocent party in the crash. Think along the lines of a pedestrian crossing a street at a crosswalk being hit by a right turning vehicle because the driver focused his/her attention to the oncoming traffic and failed to acknowledge the pedestrian crossing in front of their vehicle.
- There is a large percentage of elderly drivers and aging has demonstrated effects that could affect the driving task (this will be discussed further in module X).
- There is a number of safety devices installed in vehicles that could have a significant impact in safety but there is the potential for drivers to change their risk taking behavior (increase) due to false perceptions of the safety afforded by these devices.
- Road design over the past decades has improved and several efforts have been undertaken to make roads safer. However, there are still locations that could be improved but budgetary constraints may limit the number of sites and improvements to be implemented.
- Young drivers with their inexperience pose one of the largest issues to be addressed in road safety. Moreover, they typically have a higher risk-taking behavior that may contribute to their increased crash involvement.
- Pedestrians and bicyclists are the most vulnerable road users due to lack of any protection in collisions. Crashes between vehicles an these users typically result in fatalities or injuries and they may often be the innocent party in a crash.



In 2010 NHTSA conducted a study to determine the economic and societal costs of motor vehicle crashes (DOT-HS-812-013). The report (revised in 2015) indicates that:

- The economic cost of crashes for 2010 was about $242 billion representing 1.6 of the Gross Domestic Product. This also represents a cost of $784 for every person living in the US.
- The work productivity costs are also high. $57.6 billion are estimated to be lost due to workplace related losses. There is also a $19.7 billion loss of household related productivity which accounts for lost taxes and other revenue sources.
- Property damage also accounts for 31% of the total cost. Most of this is due to property damage only crashes, i.e., those without an injure, which account for $71.5 billion.
- Congestion costs, which include travel delay, adverse environmental impacts, and extra fuel used, account for $28 billion.

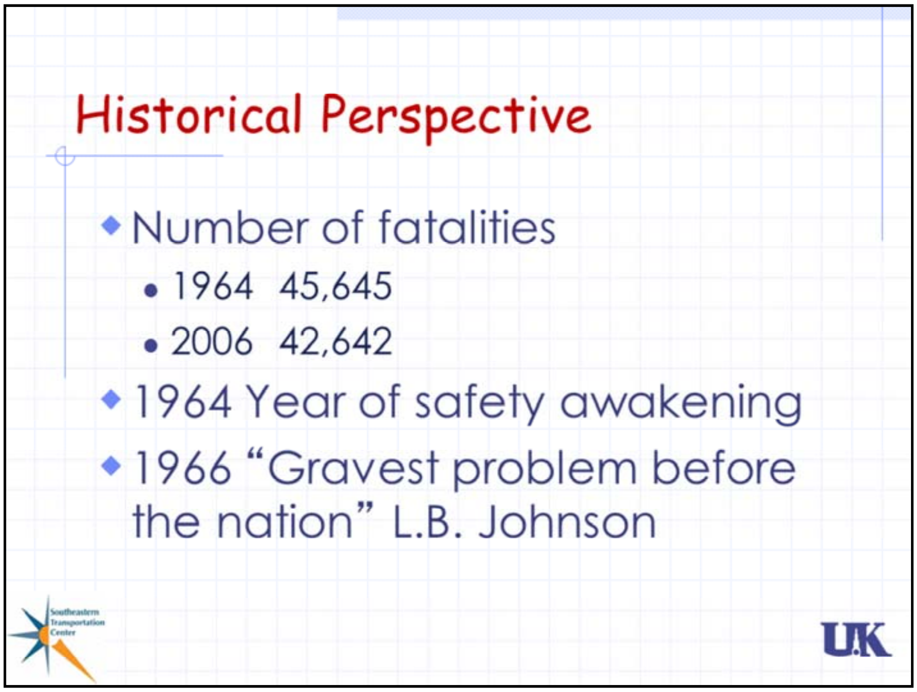
The total costs is covered though payments from public revenue (both federal and local government) and this accounts for about 7% of the total cost. Even though persons involved in crashes pay a large amount of these costs through their insurance, those not directly involved in crashes end up paying a significant portion f the bill though increase insurance premiums, taxes and congestion related costs, increased environmental degradation, and excess fuel consumption accounting for about $187 billion in 2010. Therefore, the society is paying for approximately 75% of the total bill.



So the question of the day is what one can do to improve road safety? What actions would we need to take to address the issues road safety professional face?

May want to develop a short list of options that could spark discussion. This list could include typical efforts, such as graduated license, efforts to curb drunk driving, wider roads (lanes and shoulders) or increased enforcement, or non-traditional efforts, such higher license fees, helmets in cars or mandated safety devices in vehicles.

This module discusses the history and institutional structures of road safety. Safety professionals should be familiar with the legislation that resulted in the current structures of road safety management and the institutional structures that shape road safety management practices. The purpose of this module is to develop an understanding of some of the many influences that have shaped the policy and structure of road safety management in the U.S. including key events and legislation, federal programs established in the 70's and 80's, and current legislation.



Safety is considered an integral part of any transportation project development but its role and significance in transportation policy has evolved over time. If one considers that in the 1964-2006 period were able to reduce fatalities only by 3,000 people and that during the 1995-2007 period the U.S. fatality rate remained essentially flat.

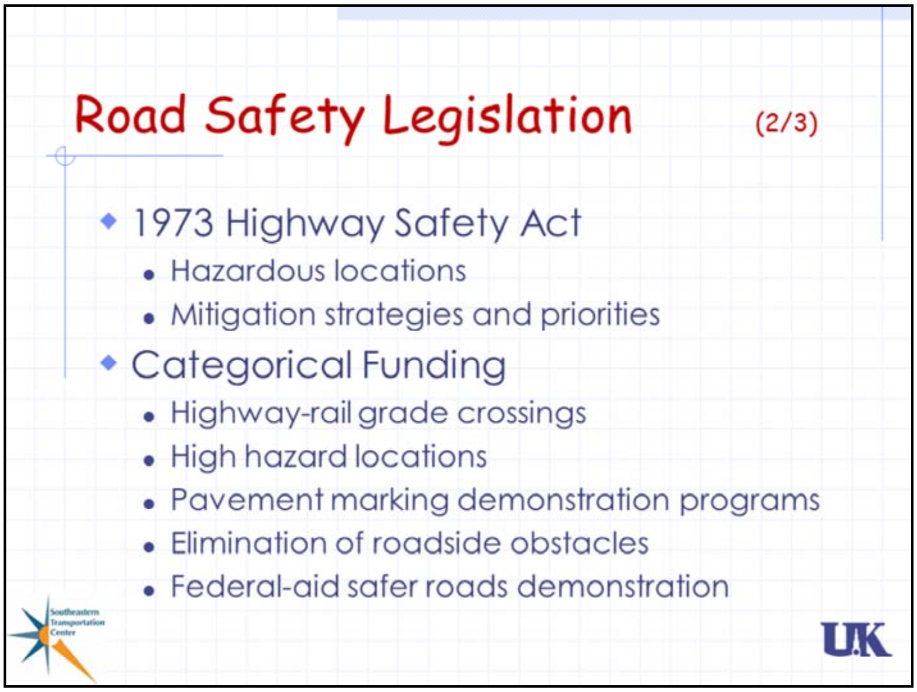
1964 was also the year that started the discussion about safety, since there were recorded 10 percent more fatalities than in 1963 prompting the nation to take a hard look at road safety efforts. [*Actually about 8%, but after a couple of years of 5+% annual increase*.] This resulted in a number of Federal hearings in 1965 to raise public awareness on this growing problem.

In 1966 President Lyndon Johnson declared highway deaths second only to the Vietnam War as the "gravest problem before the nation." This was the first time that the need to reconsider design and address road safety became national issues and it was time to pass some pivotal legislation that provided funds, resources, and policy direction.

The first safety act that congress developed was in 1966 and it focused in three areas: 1. Development of the Federal Motor Vehicle Safety Standards (FMVSS) that outline the regulations that motor vehicle manufacturers are required to follow; 2. Authorization for funded research and development on safety; and 3. Establishment of the National Driver Register that had as goal to track individuals whose licenses had been denied, terminated, or withdrawn. It should be noted that the first standard required under this Act was the one dealing with safety belt (FMVSS 209) and it became effective on March 1, 1967.

In addition, the Highway Safety Act of 1966 focused on specific state actions requiring states to develop and maintain a highway safety program in accordance with uniform standards established by the Secretary of Transportation (note that these standards have since been replaced by priority program areas). Road user behavior was targeted specifically with Section 402 of the Act and funding was provided to reduce crashes; this has been the foundation for state highway safety programs. Finally, the governors of each state were directed to appoint a Governor's Highway Safety Representative (GR) who was responsible for administering the program.

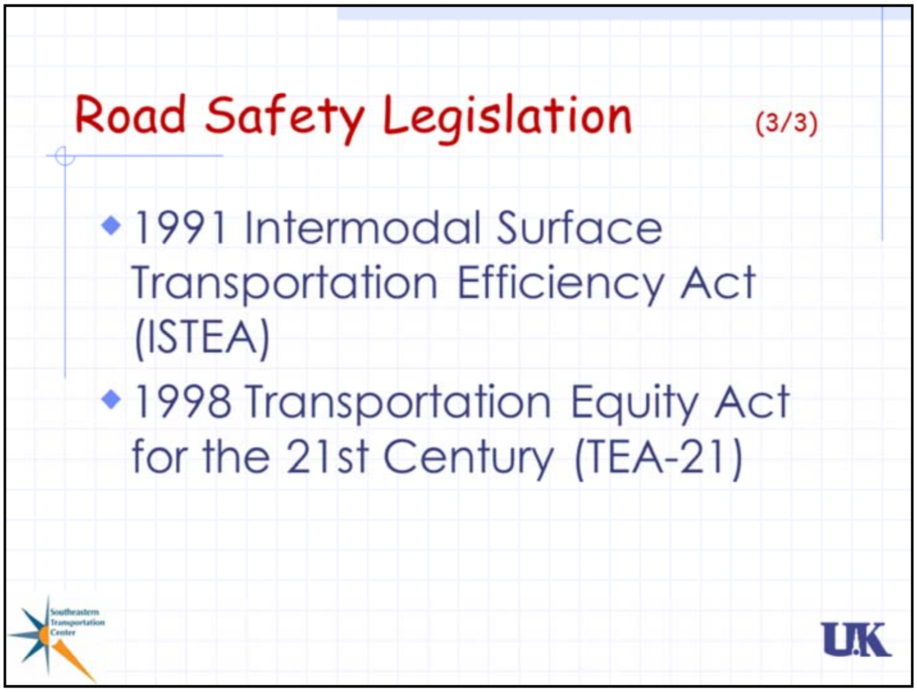
Funds under Section 402 are allocated to the states by a formula based on population and highway miles. This established the relationship between state and federal government, where the policy is at the federal level and the implementation is at the state level.



The 1996 Acts established the framework of roadway safety addressing the vehicular and road user issues but the 1973 Act created the federal mandate for roadway safety. The combined Acts provided the foundation for a complete coverage of highway safety including highway-vehicle-roadway interactions.

The 1973 Act identified a specific engineering-based methodology for improving roadway safety requiring states to identify their hazardous locations through a survey, study the causes of crashes at those locations, identify possible mitigation strategies to address these issues and conduct a benefit/cost analysis; and prioritize the improvements based on the results of the benefit/cost ratio analysis.

It also established categorical funding for five specific program areas including:
1. Highway-rail grade crossings;
2. High hazard locations;
3. Pavement marking demonstration programs;
4. Elimination of roadside obstacles; and
5. Federal-aid safer roads demonstration.



ISTEA required states to develop a safety management system (SMS) where it was going to be a process where safety projects could be identified and prioritized. This required the development of crash databases, identification of performance measures to monitor safety improvements, and establishment of a broad-based coalition of safety experts to be involved in the decision-making process. In reality, most states developed the databases to identify high crash locations and the absence of any federal mandates for interagency collaboration rendered these SMSs ineffective and they became optional after 1995.

ISTEA also gave greater power to Metropolitan Planning Organization (MPO) requiring them to develop long range transportation plans and transportation improvement programs (TIPs) since they receive federal funds as DOTs. (Note: The Federal Government assigns the MPO status to urban areas with a population of 50,000 or more.)

In 1998 TEA-21, reduced the number of transportation planning priorities to seven including “safety and security” for the first time and thus placing safety prominently in transportation planning activities. Until that point, safety may have been incorporated into the vision or goals of a state or MPO long-range transportation plan, but specific strategies to increase safety were seldom included in statewide and metropolitan planning processes or documents. The integration of safety into the transportation planning process became known as “safety conscious planning” or SCP. This approach encouraged state and local transportation planners to work collaboratively with engineers, law enforcement, and other safety practitioners and advocates on highway safety, data management and analysis, commercial vehicle safety, emergency response, and other areas to improve overall safety.

The 2005 Act was significant because it gave safety its own place in transportation planning by separating it from security. The Highway Safety Improvement Program (HISP) was established as a core funding program and Section 148, nearly doubled the funds for infrastructure safety, allows increased flexibility in program funding, and requires a focus on results.

Each state also had to develop a strategic highway safety plan (SHSP) as part of the HSIP requirements. The SHSP must be data driven utilizing crash data and other data to allow for identification of high crash locations, include broad range stakeholder collaboration including GRs, MPOs, major transportation modes, state and local law enforcement, Operation Lifesaver, MCSAP, DMVs, and others, address the **4Es of safety** – **E**ngineering, **E**nforcement, **E**ducation, and **E**mergency response, identify and adapt performance-based goals to properly allocate resources on the areas of greatest need, and coordinate all state highway safety programs.

Several entities conduct safety related research. The Transportation Research Board (TRB) is considered the main forum of research (not only on safety but transportation in general) and it acts as the clearinghouse of the research accomplished in the USA. Its publication also covers research findings worldwide. TRB is a unit under the National Academies of Science and is headquartered in Washington, DC. TRB manages the National Cooperative Highway Research Program (NCHRP), which was formed in 1962 and is considered a key sponsor of developing tools and products that shape policy and decision making processes.

The American Association of State Highway Transportation Officials or AASHTO, state DOTs, and other organizations (both national and international) adopt many NCHRP recommendations to enhance the safety, mobility, and productivity of the transportation system.

NCHRP operates under a three-way agreement involving AASHTO, FHWA, and TRB. TRB administers NCHRP, while state DOTs sponsor the program through AASHTO and in cooperation with FHWA. States provide funding each year based on a percentage of their federal-aid highway apportionments. FHWA also provides funding support. The ideas for research projects are developed by individual states, AASHTO committees, and FHWA.

The private sector also sponsors and conducts research. Perhaps the best known among private sector research institutions is the Insurance Institute for Highway Safety or IIHS, a nonprofit research and communications organization funded by auto insurers. The Institute's research focuses on vehicles, road users, and roadway factors and is aimed at preventing losses to their clients; however, any program that reduces insurance claims also obviously prevents crashes.

In 1992 IIHS opened the Vehicle Research Center (VRC). This center, which includes a state-of-the-art crash test facility, is the focus of most of the Institute's vehicle-related research. The Institute's affiliate organization, the Highway Loss Data Institute, gathers, processes, and publishes data on the ways in which insurance losses vary among different kinds of vehicles.

AAA Safety Foundation is another organization that is sponsored by AAA insurance company and supports research that addresses safety issues dealing with drivers and vehicles.

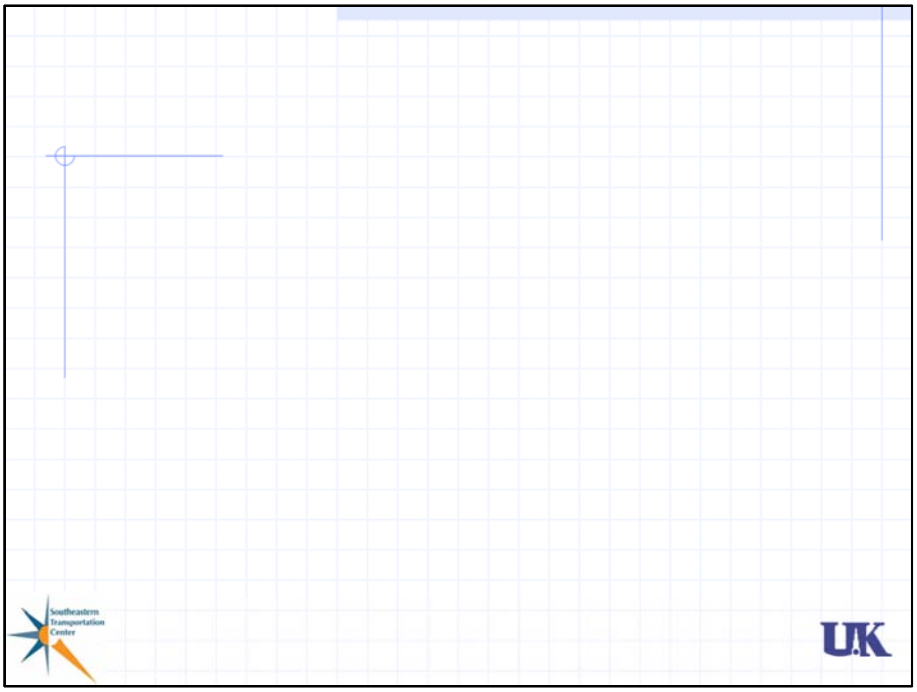
The federal agencies sponsor research to demonstrate and evaluate effective strategies, countermeasures, and techniques in support of their individual missions. All of the agencies, e.g. FHWA, FMCSA, FTA, and NHTSA, include safety in their missions. They simply have different mandates to implement.

FHWA's Turner Fairbank Highway Research Center's highway safety research program focuses on intersections, pedestrian and bicyclist safety, roadside safety, run-off-the-road prevention, and speed management.

NHTSA’s research and evaluation program focuses on vehicle regulatory factors and the behaviors and attitudes of all road users. Specifically, the Agency focuses on occupant protection, impaired driving, speeding, pedestrian safety, and data in addition to other areas. Laboratory and field studies are conducted to identify and behaviors involved in crashes or those associated with injuries. Scientific research is conducted to develop and refine countermeasures to deter unsafe behaviors and promote safe alternatives.

The mission of FMCSA's Office of Research and Analysis is to reduce the number and severity of commercial motor vehicle crashes and enhance the efficiency of CMV operations by adopting, testing, and deploying innovative driver, carrier, vehicle, and roadside best practices and technologies.

FTA also conducts research aimed primarily at the safety and security of transit employees, e.g. bus drivers, and transit systems. Some effort is also directed toward the safety of transit users.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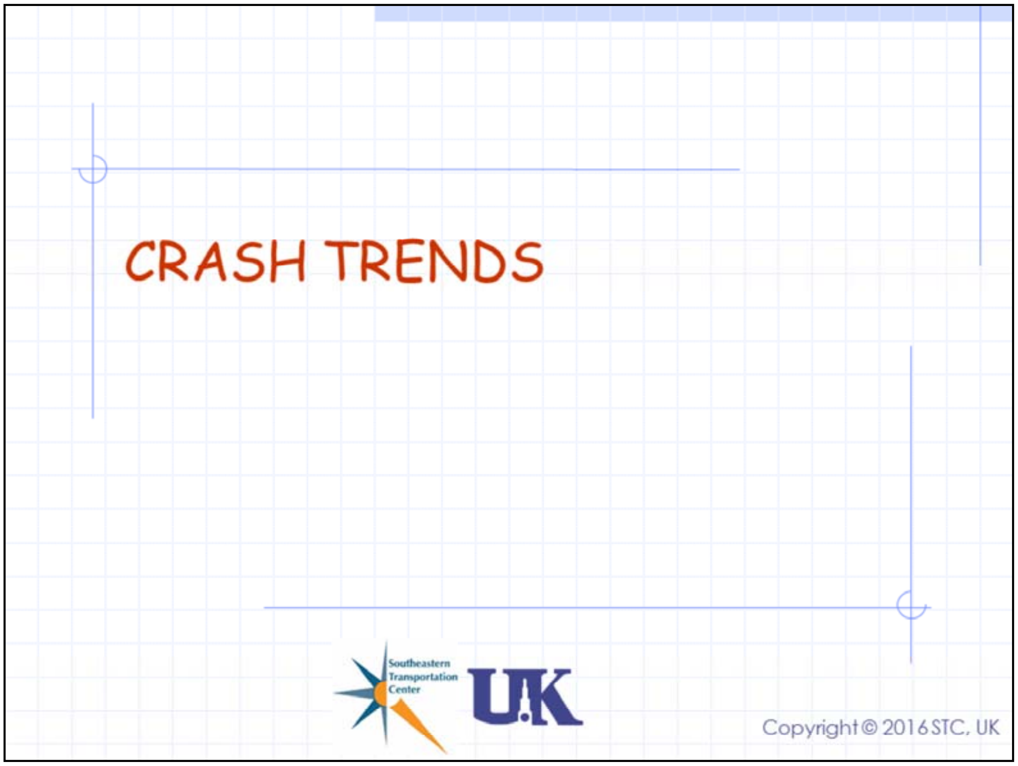
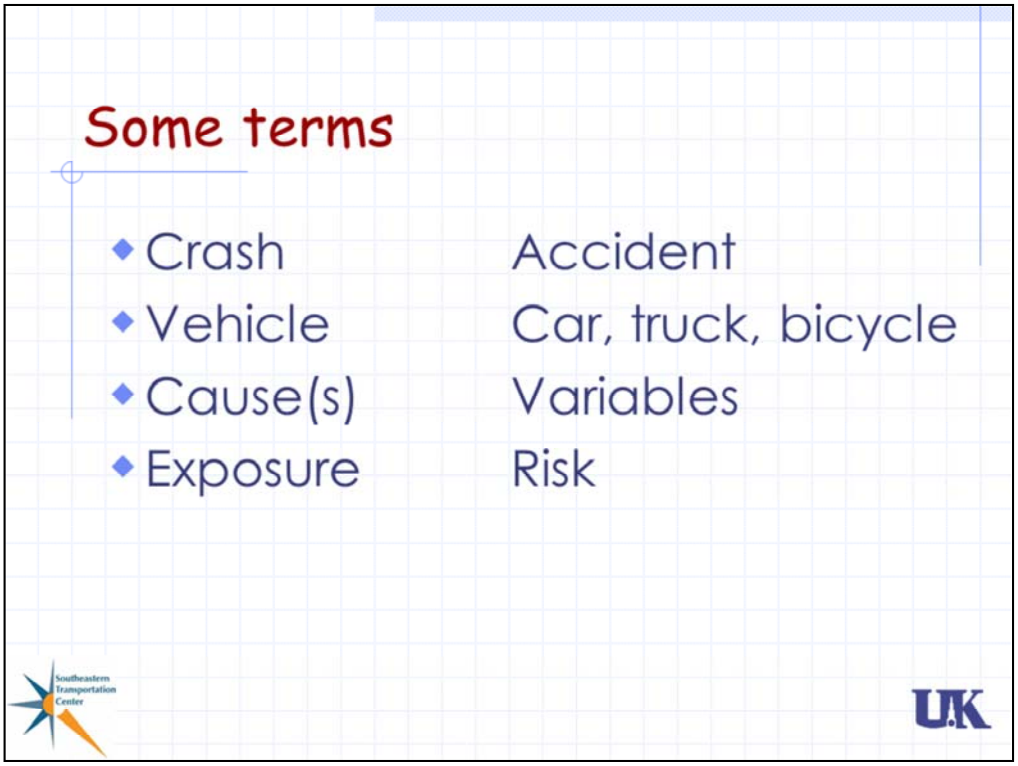


This module presents an overview of historical crash statistics and raises questions that could relate to both policy and design elements to address roadway safety.

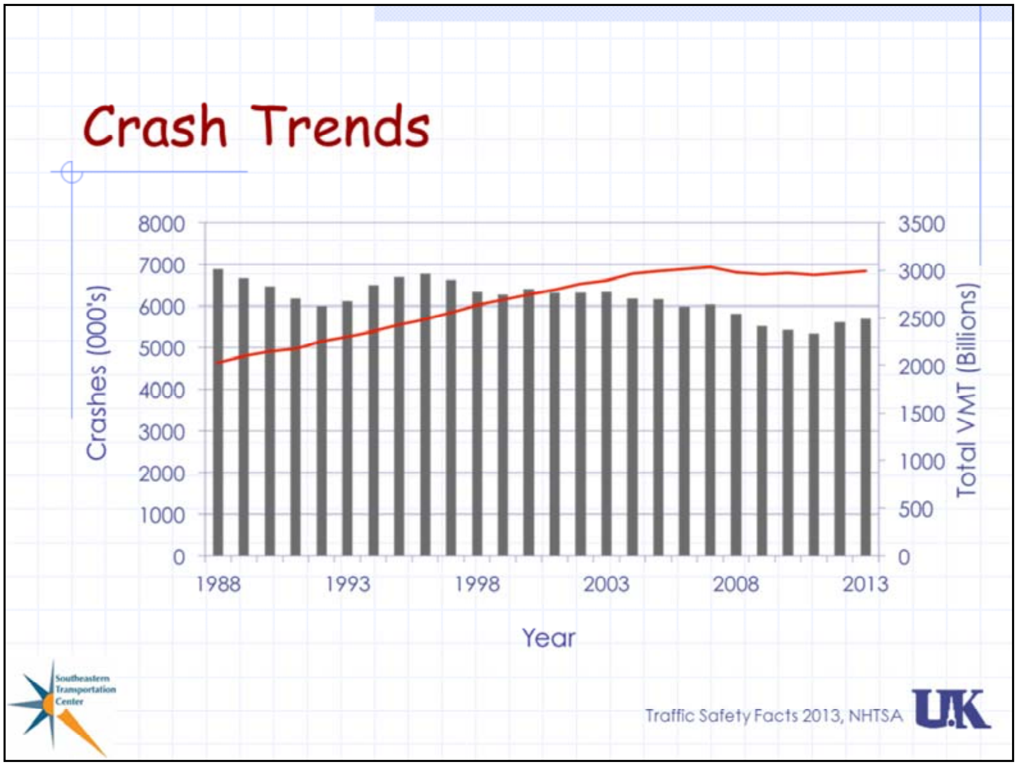


The terminology to be used here is identified to allow for the participants to have a uniform understanding of the terms presented. As noted in the previous module, the term “crash” implies the potential of avoiding a collision (preventable outcome) as opposed to the term “accident” which implies an unintentional event. Even though one can use these terms interchangeably, they have a significant different meaning.

The term “vehicle” describes all vehicles present in the roadway including motor vehicles, i.e., cars, pick up trucks, trucks, buses, motorcycles, and motorhomes, as well bicycles, since they are also considered vehicles.

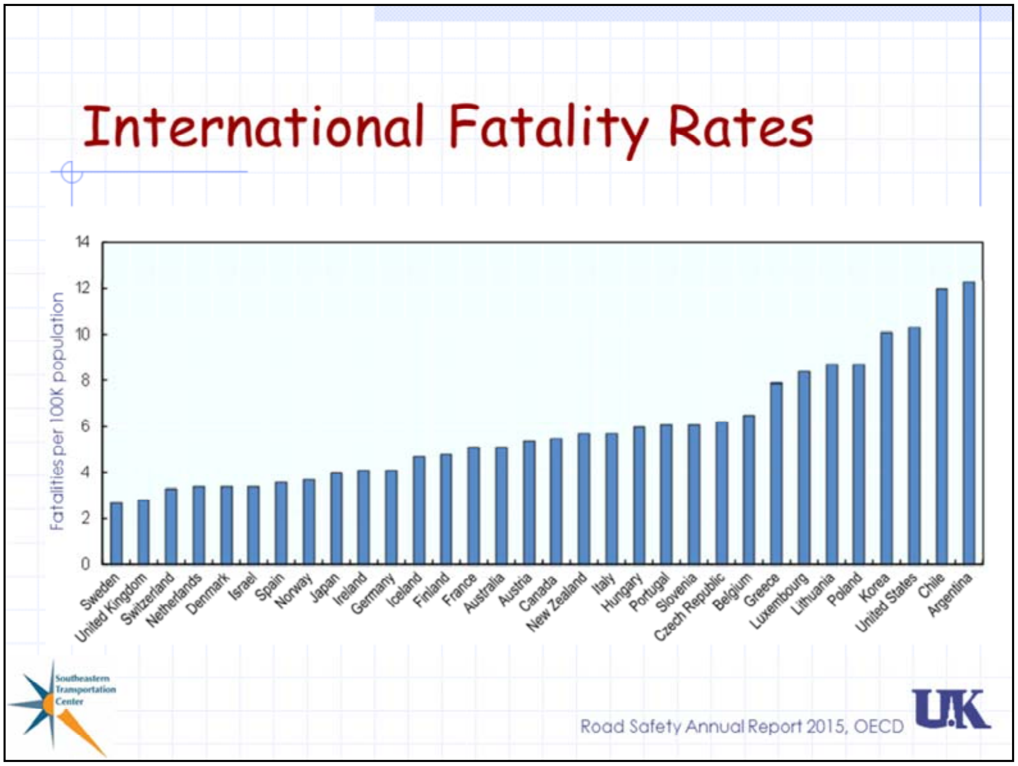
The term “cause” as it relates to crashes identifies the contributing factors to a crash and they will be the variables to be considered in a statistical analysis. In this case, if the cause for contributing to a crash is wet pavement, then the variable to be examined will be the pavement condition, i.e., wet or dry.

The term “exposure” defines the potential to be involved in a crash and it could be directly translated to the users’ risk.

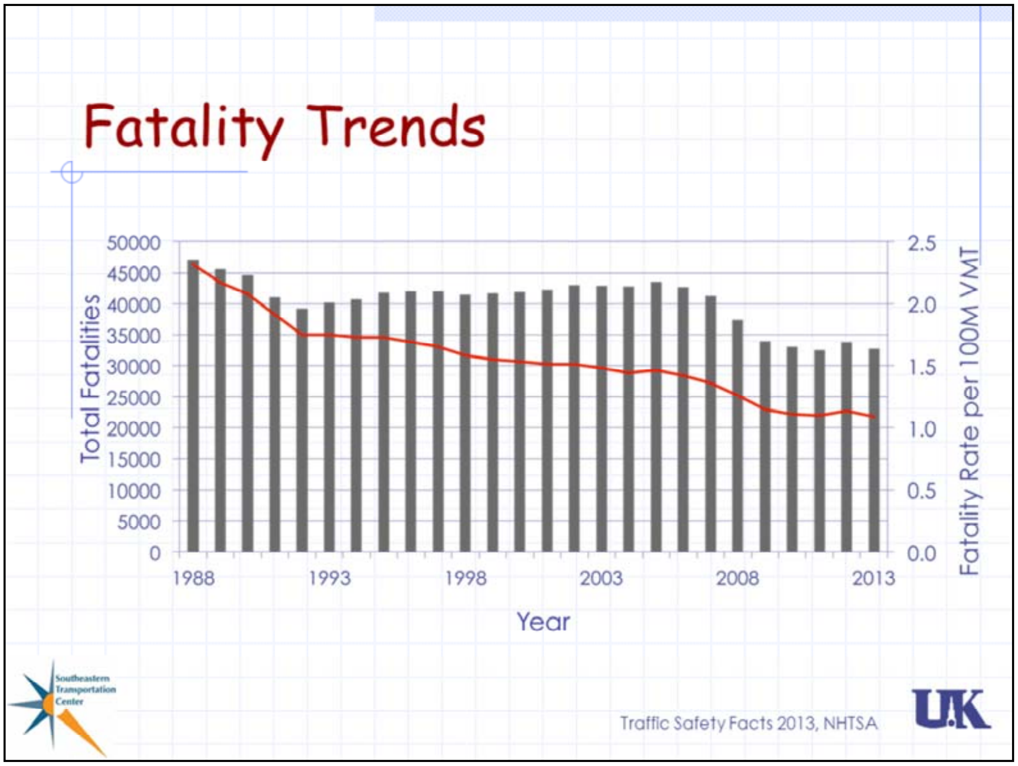


The data here demonstrates the crash trends over the past 25 years (1988-2013). There is an overall decreasing trend, especially after 1996 and a somewhat increasing trend for the last few years (from about 2011). The larger drop was observed during the 2007-2008 period when there was an economic crisis in the US and the price of gas was significantly higher than today.

One should also consider this in the context of the amount of driving in the US during the same period (red line). The data shows a continuously increasing trend with a somewhat leveling off since 2007 (the year of the economic issues). The combination of increased vehicle-miles of travel (VMT) and the reduced number of crashes could signify an improvement on the safety levels in the US.



High fatality rates is not a US only problem but a global one. However, US has one of the highest fatality rates per 100,000 population when compared to other countries. One may argue that this may be misleading due to the higher VMT in the US as compared to other countries. Unfortunately, even when normalizing for the amount of travel, the US is still among the countries with the highest rates where the same report indicates that the US has the sixth highest rate even in this case (preceded by Korea (highest), Czech Republic, Slovenia, Belgium and Japan).

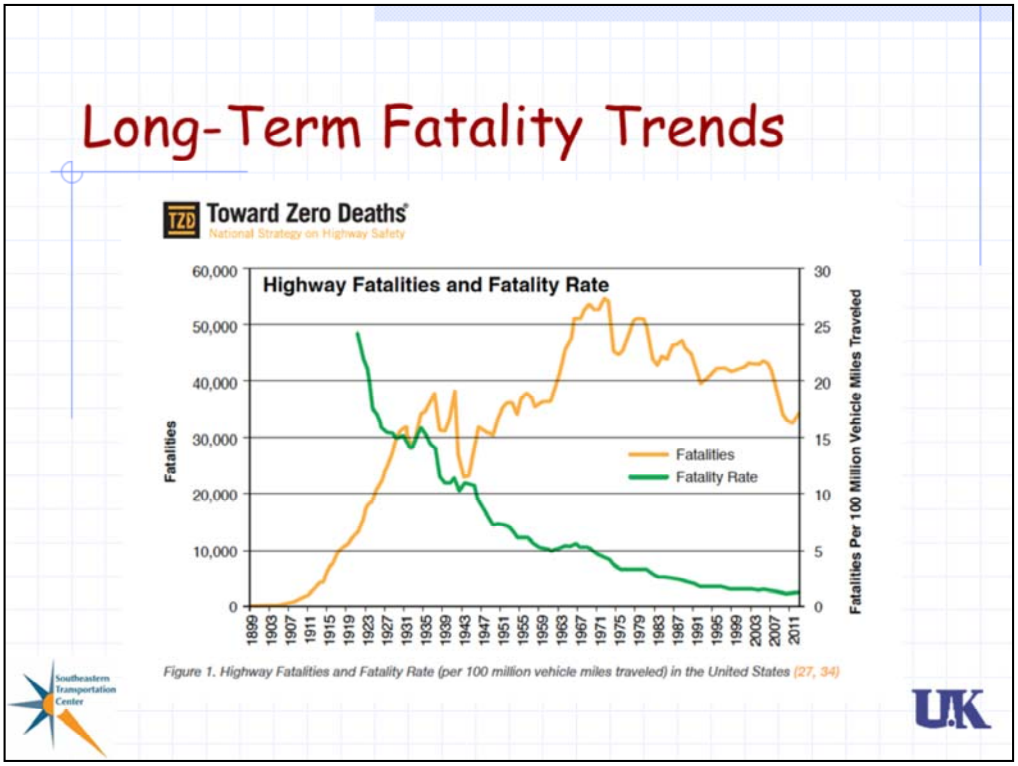


This slide presents the fatality trends for the 1988-2013 period. Fatalities is one of the measures typically used to represent safety levels in the US. Considering the fatality rate data, one can conclude that progress has been made in the last 25 years. However, the actual number of fatalities has remained somewhat constant since 2009 hovering at about 32,000 fatalities per year.

Question: Why do we observe this difference?
Answer: VMT has increased more than the fatalities over the same time so the rate goes down even though the actual number may not have changed much (think in terms of the numerator stays the same while the denominator gets bigger).

There is a portion in the highway safety community who argue that the fatality numbers are those to be used when setting goals. There are other countries (Sweden for example) who have set a zero fatalities goal for their safety program and they measure progress using the number of fatalities instead of the rates. The reason for this is that the actual magnitude of the problem is masked when normalizing the numbers with the exposure and some could argue that *one death is one too many.* (Iowa's tagline)

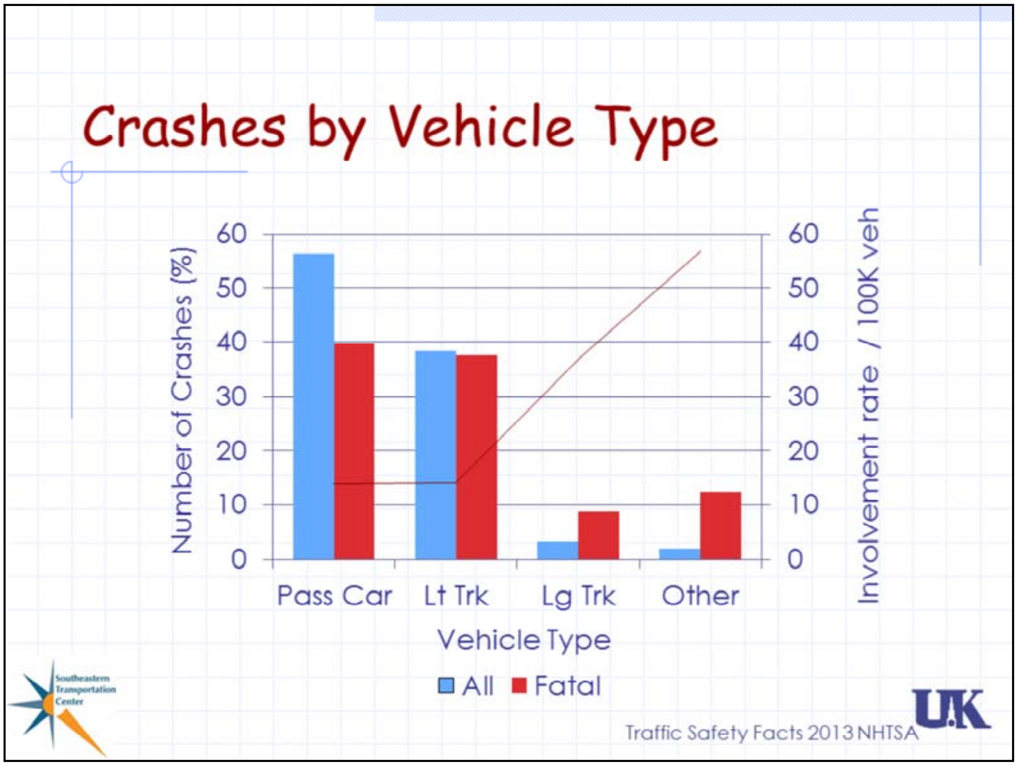
One should not forget the drop in the VMT during 2007 and 2008, when gas prices increased significant and there was a decline in the economy resulting in 3.6% in VMT. During the same period there was a decline in fatalities as well (9.1%) but the entire decline cannot be solely attributed to the reduced VMT due to the difference in magnitude.



This is chart shows a long-term (over a century) overview of the fatalities, both numbers and rates in the USA. The discussion on the previous slide regarding the value of crashes and rates is more apparent here.

Question: What trends can one observe here and conclusions may be drawn?

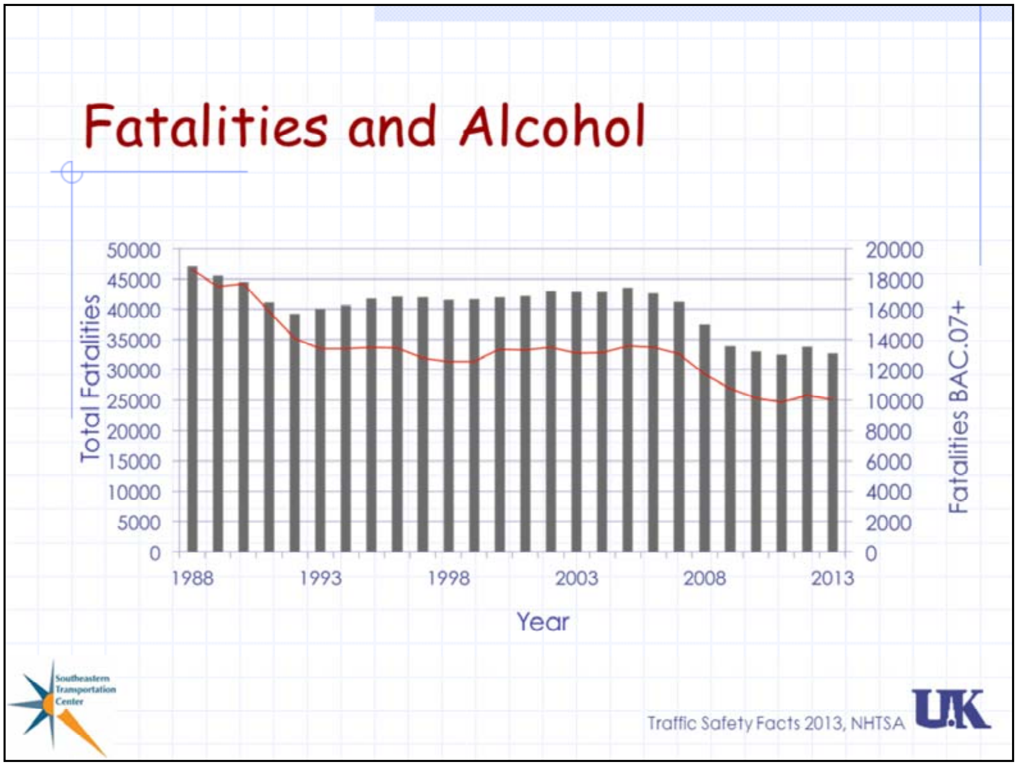
1. Fatalities peaked around late 1960s, 8% increase after a couple of years' of 5+% annual increase. One should not forget that this was the time that legislation was introduced to reduce fatalities in the USA.
2. Largest drop in recent years was during the 2007-2008 recession, which may indicate that in order to decrease fatalities other factors need to be in play.
3. Fatality rate drops steadily even though the number of crashes fluctuates (and is actually going up in the last few years). This could be considered as a positive trend even though it has the tendency to mask problem (as discussed in the previous slide).



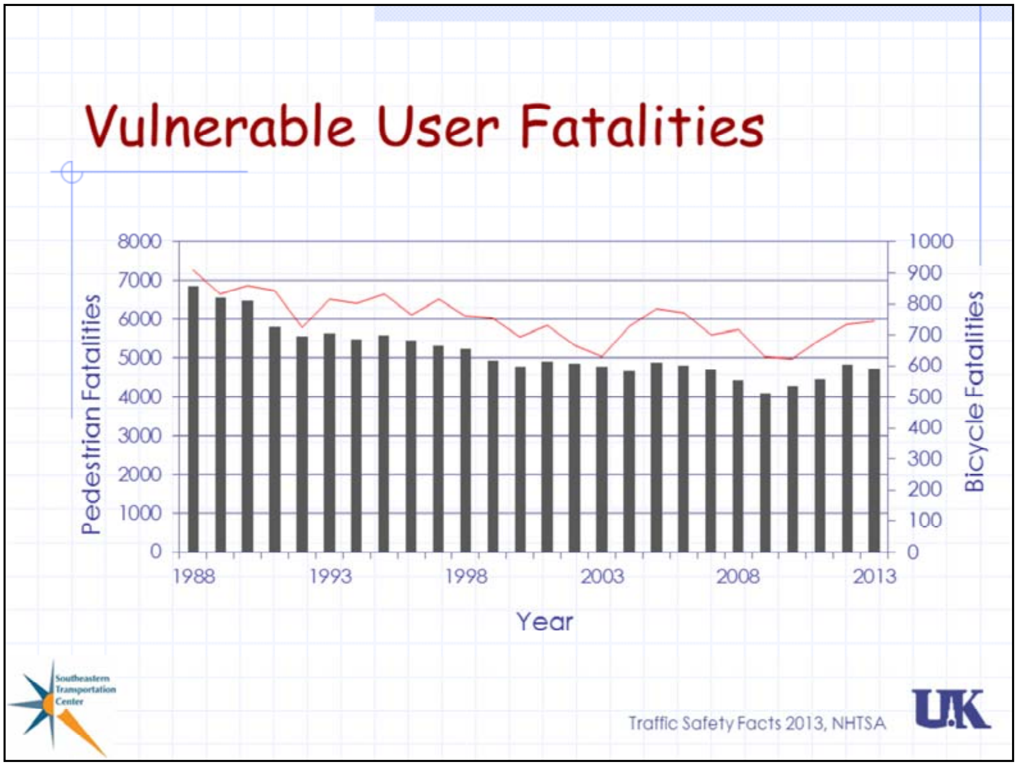
The data here shows the vehicle type involvement in all crashes. The largest portion is for passenger cars (56.3%) but at the same time one needs to consider that they also make up the largest potion of the vehicle fleet. There are approximately 129 million registered passenger cars, 121 million light trucks (pick up trucks, vans and sport utility vehicles), 275,000 large trucks and 21,000 motorcycles in 2013. The involvement rate and fatality crashes show a slightly different picture with passenger cars and light trucks sharing a similar number while the rates of large trucks and motorcycles increases significantly. It should be noted that when fatality rates are concerned, then motorcycles also have the highest rate.

One should point out that this does not necessarily imply that passenger vehicles and light trucks are "safer" than the other types of vehicles. While passenger vehicles have low rates, they tend to be involved in more injury and property damage crashes. On the other hand, crashes with large trucks and motorcycles often result in more serious injuries and fatalities.

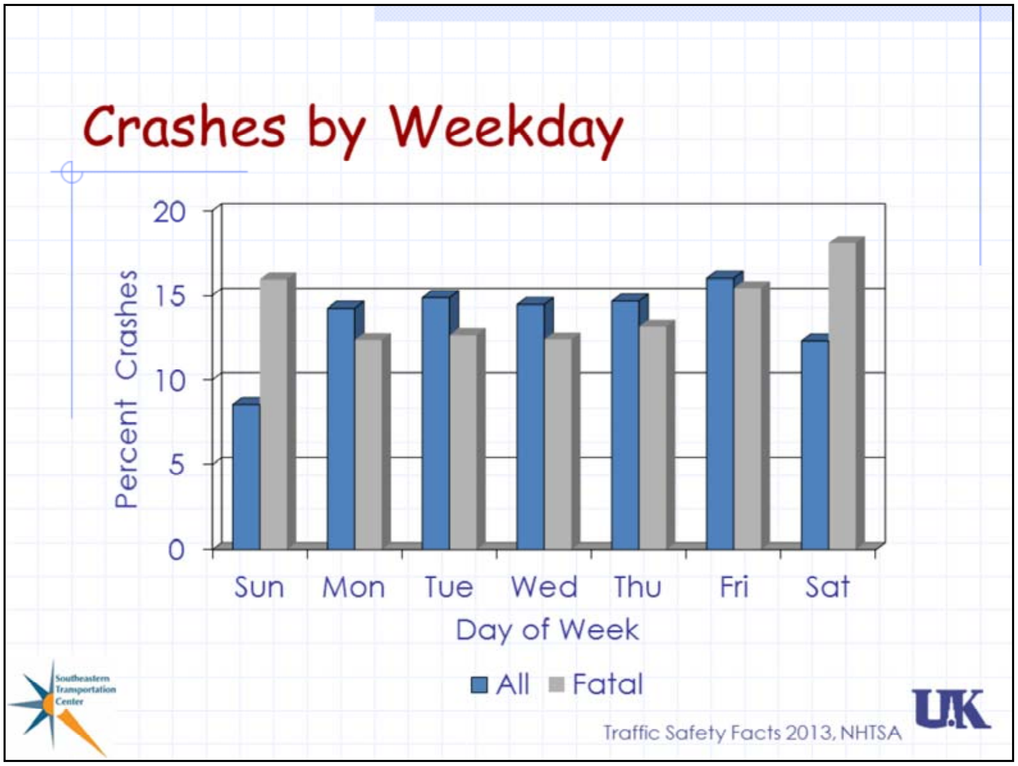
Question: why do motorcycles have a higher fatality rate?
Answer: lack of protection when involved in crash.



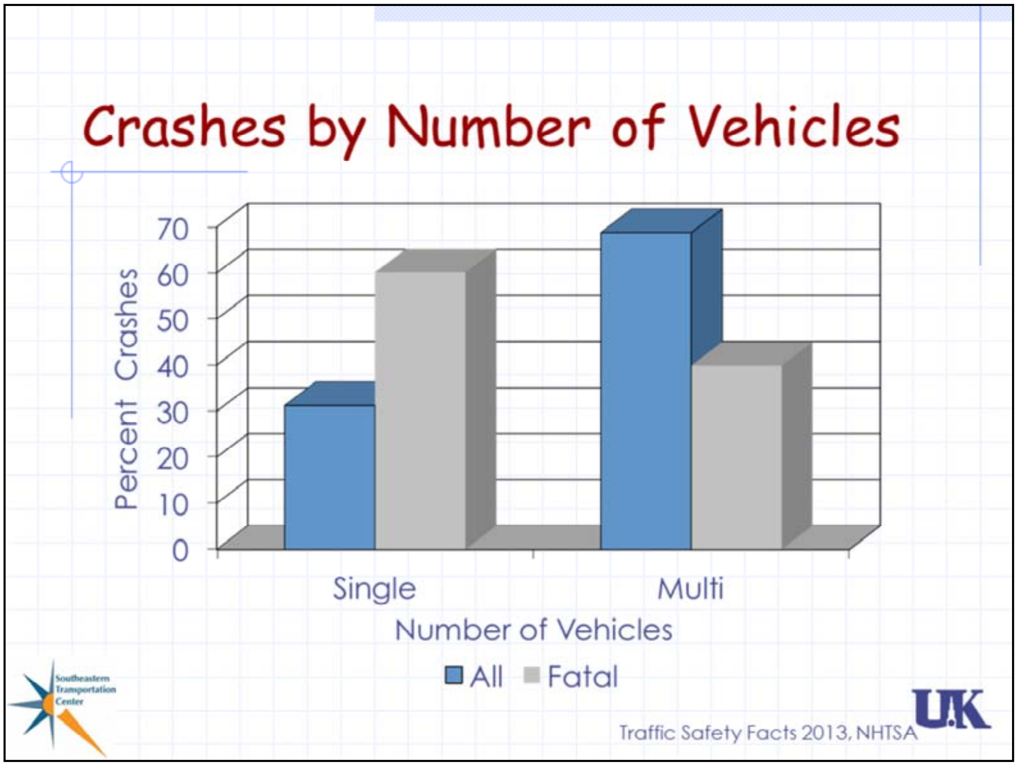
This slide shows again the fatality trends for the 1988-2013 period. The red line represent the number of fatalities where alcohol was involved and it is for persons with a blood alcohol concentration (BAC) greater than 0.07 (which is the legal limit for all states). There is a decreasing rend in numbers of fatalities that is somewhat corresponding to the trend of the overall fatalities. However, it should be pointed out that the persons with over the limit BAC still constitute approximately one-third (36%) of the total fatalities and this percentage has remained somewhat constant for the past 15 years. This may be indicative that even though the numbers re reduced, drunk driving may still be an issue (a longer discussion of BAC and safety is presented in module 3-2).



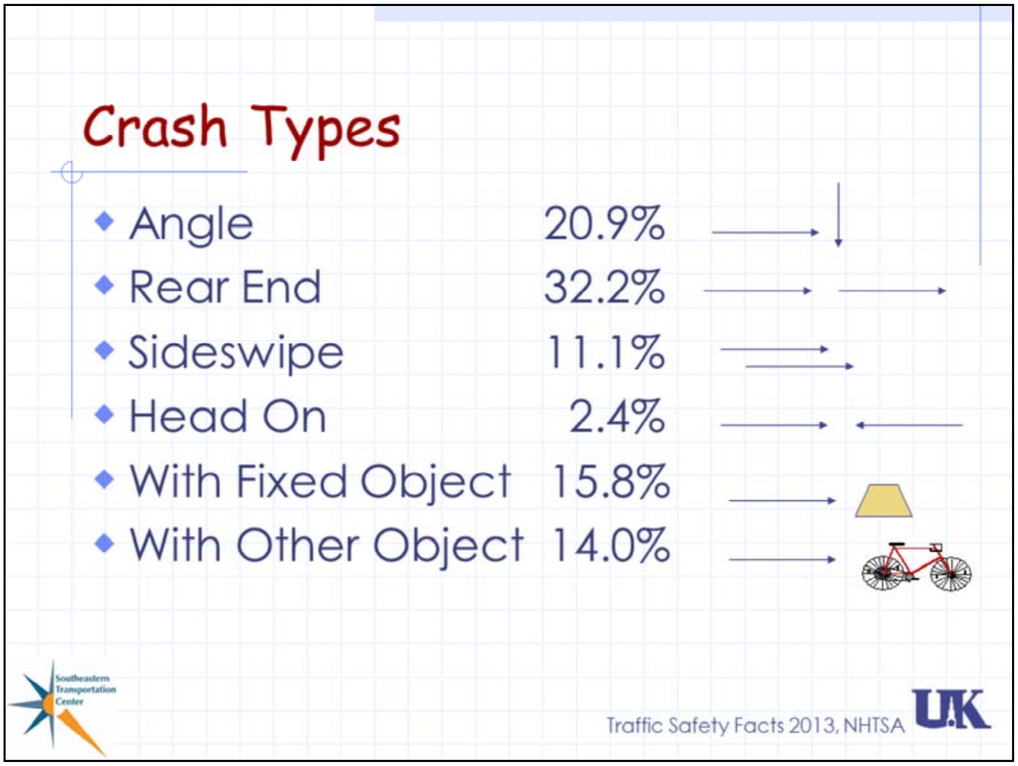
The number of fatalities for vulnerable users (pedestrians and bicyclists) follows a similar pattern as all crashes. There is general decreasing trend over time and the number of pedestrian fatalities is between 4,000 and 5,000 for the last decade. However, there is a somewhat increasing trend in the last few years (since 2009), that may either reflect an increase in the number of pedestrians (think along the economic issues discussed earlier) or simply a higher number of pedestrian deaths. It should be also noted that there is an increase of the pedestrian fatalities as a percentage of the total fatalities since 2005 from 11.2% to 14.5% in 2013. Similar changes are observed for bicycle fatalities, shown here in the red line. The recent upwards trend observed may be attributed to the potentially larger number of cyclists in the roads (either due to modal changes from economic-related issues or to increased bicycling as a the life-changing habit).



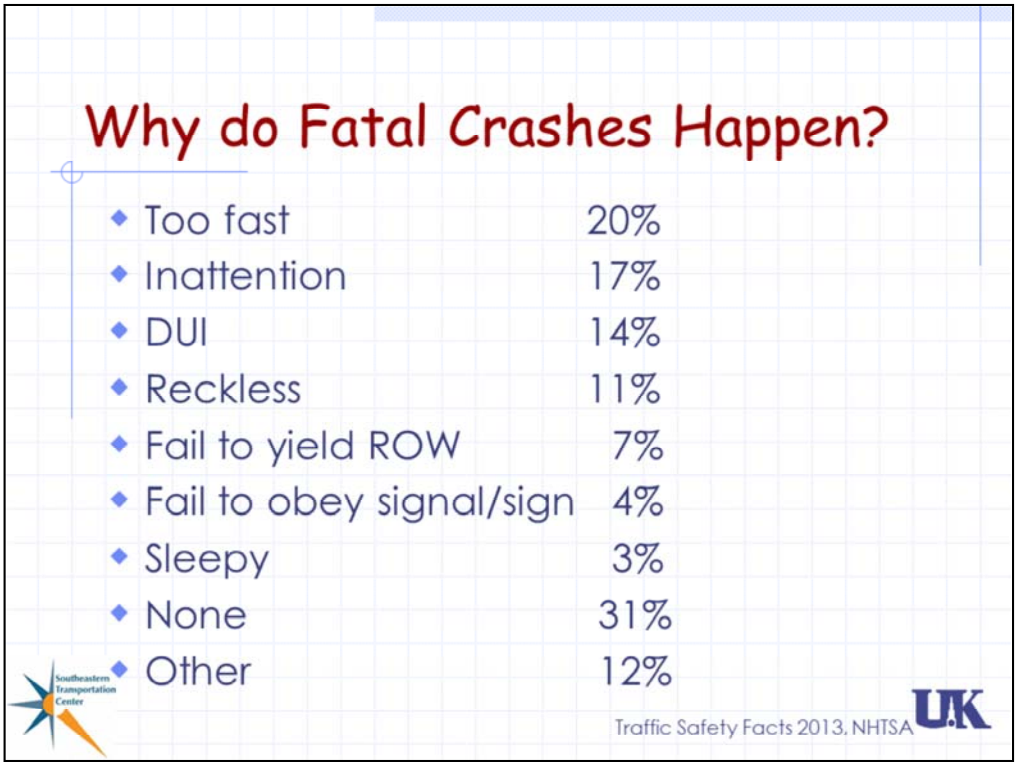
The data here shows an anticipated pattern: most crashes occur in the weekend (Friday through Sunday) and during weekdays (Monday-Thursday) the number of crashes remains the same. By comparison, fatal crashes are more frequent in weekends, accounting for almost one-half (49%) of the fatal crashes. This may be associated with the possible higher alcohol consumption (discussed before) and maybe reflective of general driver behaviors during the weekend, i.e., higher drunk driving occurrences that may lead to a fatal crash.



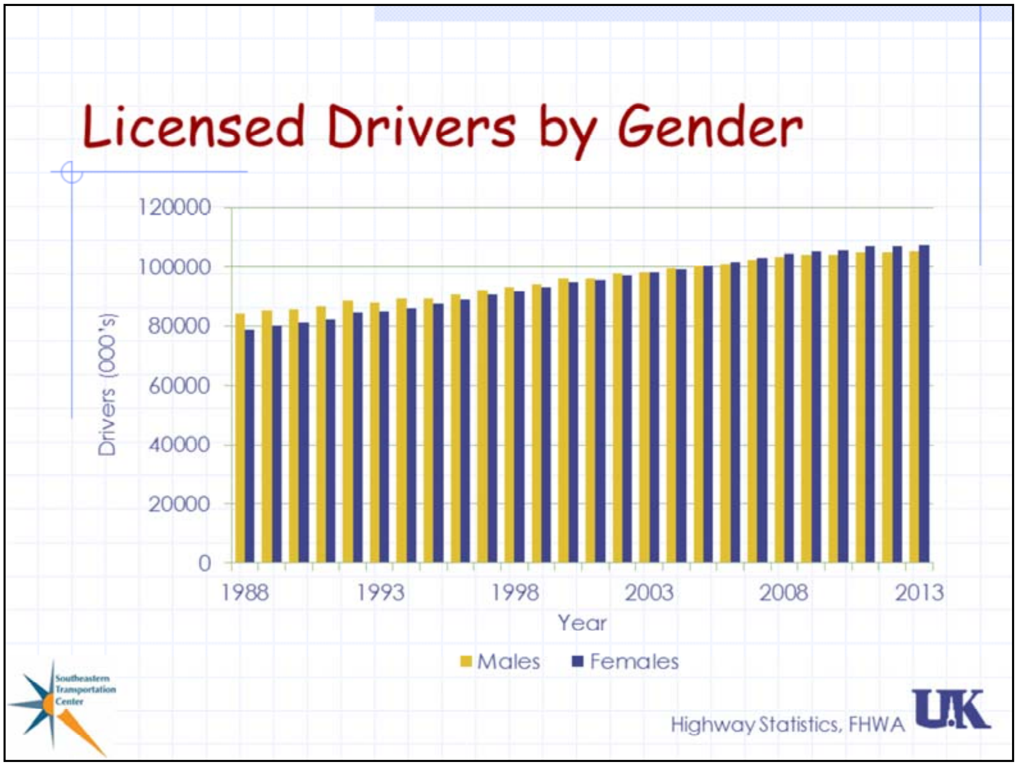
The data here shows that there is a significant difference in the number of crashes by vehicles number. The majority (69%) of all crashes are multi-vehicle indicating the greater risk of running into another vehicle due to higher congestion rates and larger number of vehicles present in the roadways. On the other hand, the picture is reversed for fatal crashes where they are predominantly single-vehicle crashes. The possible explanation here is the greater speeds at which vehicles traveling when typically involved in single vehicle crashes and that drivers are typically more attentive when they are in areas with more vehicles.



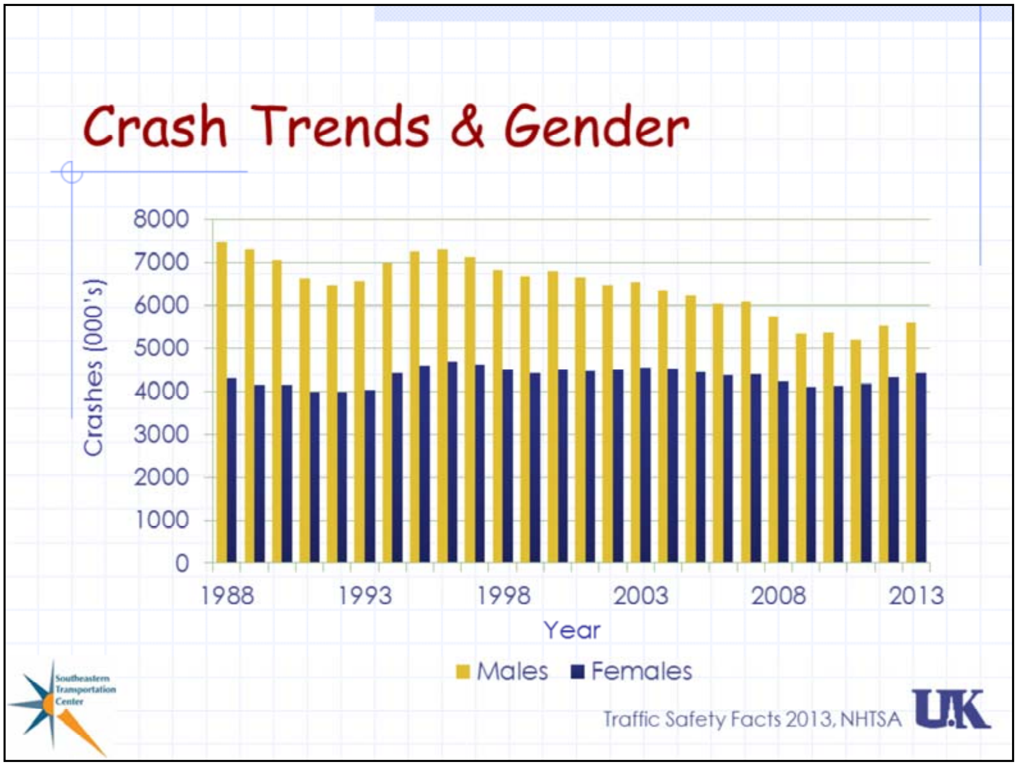
Most of the crashes are rear end crashes and collisions with an object (fixed or other). Each type accounts for about a third of the crashes. Angle collisions and sideswipe complete most of the remainder of the crashes. Of note her is the fact that **head on** collisions account for 9.3% of the total fatal collisions, while they represent only 2.4% of the total number of crashes. This signifies the severity level of these crashes that they often result in a fatality. The collisions with other object also show a similar trend when only fatalities are concerned. In this case, pedestrians are the highest number of fatalities in this category accounting for ¾ of the fatalities within this category. Among the collisions with a fixed object, the highest occurrence is for crashes with a pole and a culvert (5% of crashes) representing approximately half of the fixed object crashes and about a third of the fatal crashes.



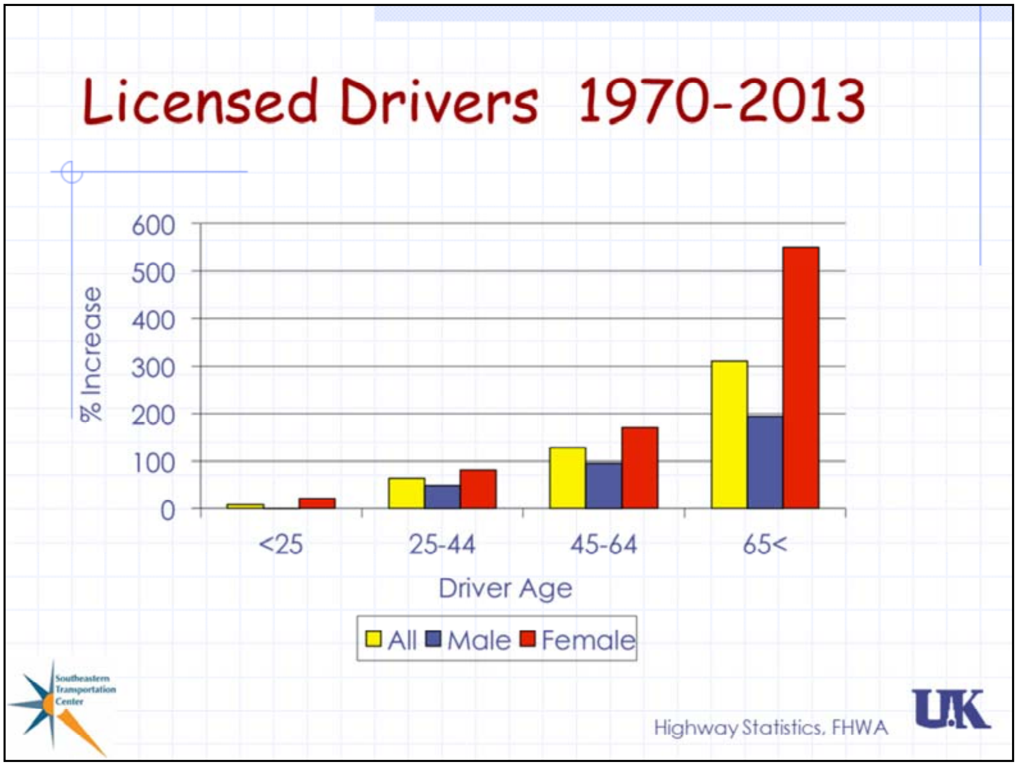
When one considers the reasons why fatal crashes occur, the most frequent contributing issue is driving too fast for the conditions. This is followed by inattention, including distracted driving, failure to stay within the lane, and making an improper maneuver (turn or driving the wrong way). Driving under the influence of alcohol follows third and reckless driving is the next highest category. Approximately one-third of the fatal crashes had no contributing related human factors. It should be noted that the total is greater than 100%, since there may be more than one factors present in a crash.



Over the past decades there has been a continuous increase in the number of licensed drivers. In 1988, there were 162 million licensed drivers and there were slightly more (51.7%) male than female drivers. The numbers of both male and female drivers have been increasing and in 2013 there were 212 million drivers. Female drivers have been increasing at a faster pace than male drivers and in 2013 they are the majority (50.5%); females have been the majority of drivers since 2005. Female longevity, greater numbers of females in the workforce and changes in the traditional family roles are the reasons for these changes.



The trends over time for crashes for male and female drivers is shown here. While in the early years (1988-1995) males were the majority of drivers involved in crashes, the trends have changed. In recent times, female involvement has risen and it now accounts for 45% of the total number of crashes as compared to 38% in the early years. This may be due to the increased number of licensed drivers (as shown in the previous slide) and a greater amount of driving from females in the most recent years.



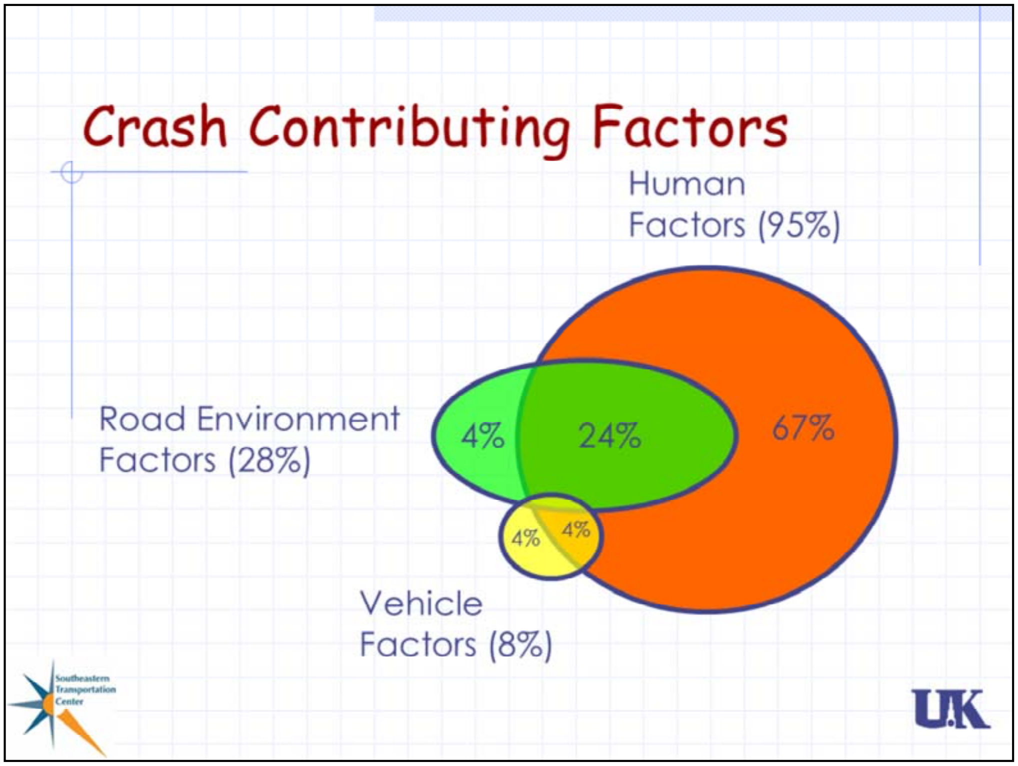
The data here shows the relative increase of the driving population by gender for the 1970-2013 period. Over the span of two generations, there have been significant changes in the composition of the driving population both by gender and age. There has been a negligent population increase for the young drivers(overall 8% change). The greatest change has been for older drivers, those over 65 (note here that 65 is considered the old driver age due to this being the age of retirement). Female drivers increase more that fivefold during this period reflecting societal changes (more females in the workforce, women's movement and changes in the household roles, and increased automobile dependence for addressing mobility needs). Current trends show this change to be lower (for example the increase was only about double the number of older females from 1988 to 2013) indicating that such great changes are not likely to happen in the future.

The white vehicle was overtaking the brown vehicle but the driver of the brown vehicle veered towards the path of the white vehicle while attempting to overtake another vehicle in front without realizing that he was overtaken by the white vehicle. The police record notes ”Driver inattention” as the contributing factor. However, many more factors could have also played a role here

Question: what are the elements that could have contributed to this crash?

The idea here is to pose the question and try to guide the audience to see the interaction of contributing factors and identify the human, roadway and vehicle interplay in a crash. In this case, there is some driver error (probably too fast for he conditions, bad judgment or not paying attention to the other drivers’ movements), some vehicle issues (bad tires or not working turning signal), environmental (vehicle and roadway combination) since it seems that the pavement was wet. The presence of the curb did not allow for an evasive maneuver. The main idea here is to demonstrate that most often there is NO single factor that can lead to a crash but rather a combination of factors.

Another concept to be noted here is that looking at a crash, then one can understand possible countermeasures that could affect safety.



This diagram emphasizes the issues discussed before. It is apparent that the majority of crashes are due to human factors but there is a significant interaction of the factors contributing to a crash. In the previous case, the collision could have been partially resulted from faulty brakes ("vehicle factor"), the driver failed to observe the actions of the other drivers or was driving too fast for the wet pavement ("human factor") or there was escape area to avoid the passing vehicle ("road environment").

(Note: The proportions in the diagram exceed 100 percent because crashes are very often attributed to more than just one of the causes.)

Road safety audits focus on the road environment and therefore they have the potential to address 28 percent of the crashes. It should be noted that even with collisions attributed purely to driver error or vehicle faults, a well-designed road can help to reduce the collision severity.

Contributing Circumstances
(C = correctable, N = Non correctable)

• **Driver-Related** -Unsafe speed (C). - Failed to yield right-of-way (C). - Following too close (C). -Improper passing (C). - Disregard traffic controls (C). - Turning improperly (C). – Alcohol involvement(C/N). - Drug involvement (C)(N). - Sick, (N). - Fell asleep (C)(N). - Lost consciousness (N) - Driver inattention (C /N). - Distraction (C)(N). - Physical disability (N). - Other. - None detected	• **Vehicle-Related** (N labels generally indicate the highway agency could not directly correct these) - Brakes defective (N). - Headlights defective (N). - Other lighting defects(N). - Steering failure (N). - Tire failure/inadequate - Tow hitch defective (N). - Over or improper load(N). - Oversized load on veh.(N) - Other. - None detected
• **Roadway-Related** - View obstructed/limited (C). - Improper/non-working traffic controls (C). - Shoulders defective © - Holes/deep ruts/ bumps©	• **Environment-Related** - Road construction/ maintenance (C). - Improperly parked vehicle(s) (C). - Fixed object(s) (C). - Slippery surface (N/C). - Water ponding (C). - None detected -debris in roadway (C).

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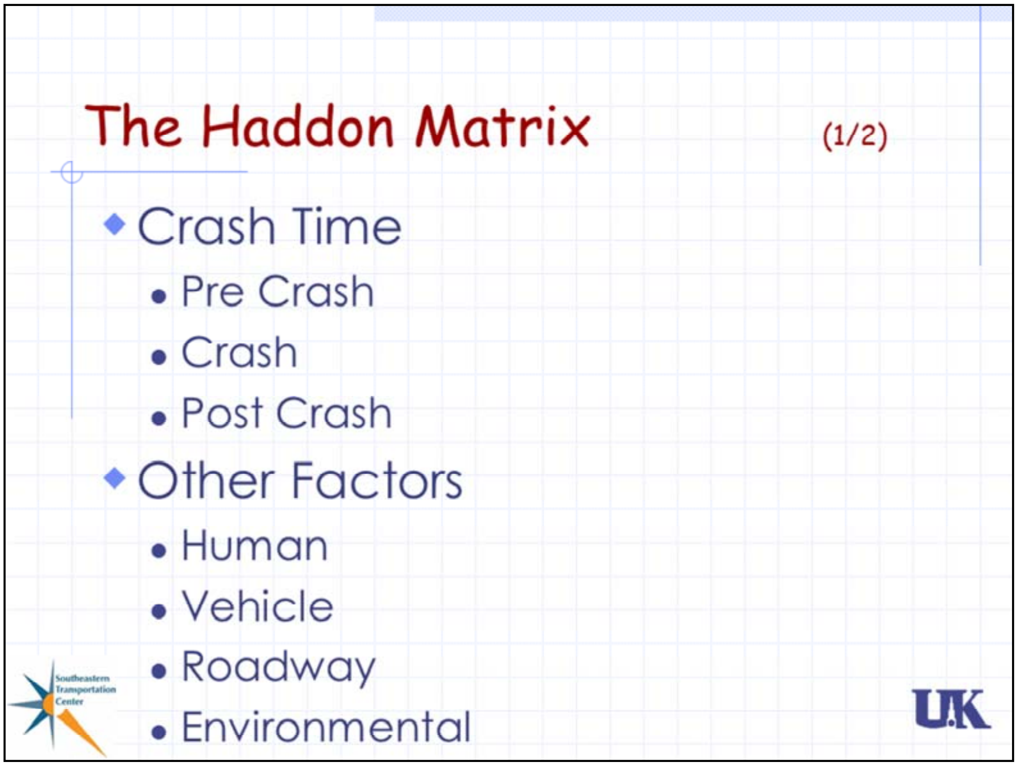
The above list of contributing circumstances are typical items an on-scene police officer may identify as related circumstances for an crash.

UK

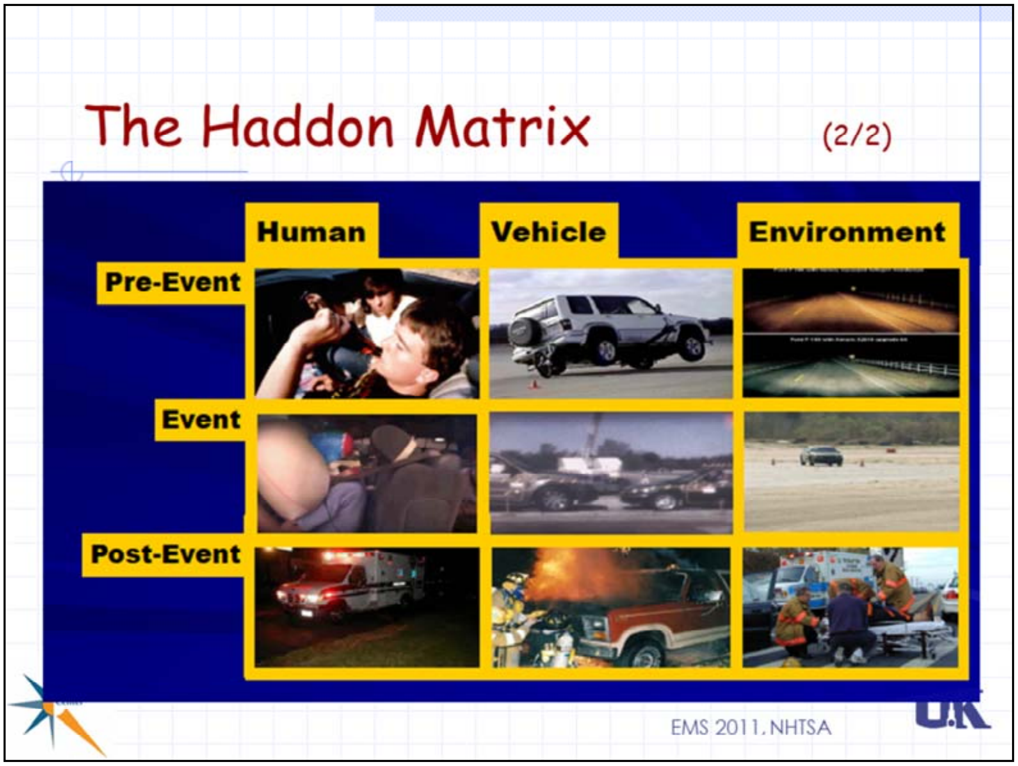
This table shows the various contributing factors to a crash and whether they are correctable. Most of the ones related to driver (human) are correctable through education or training while others are more increasing awareness. On the other hand there are a few (physical abilities for example) that are not correctable and they can be addressed either with limited driving or modifications within the vehicle.

A discussion here can be generated based on the distinction between correctable and non correctable in order to identify the actions and remedies for the ones that are correctable or to determine whether any of the characterizations are inappropriate.

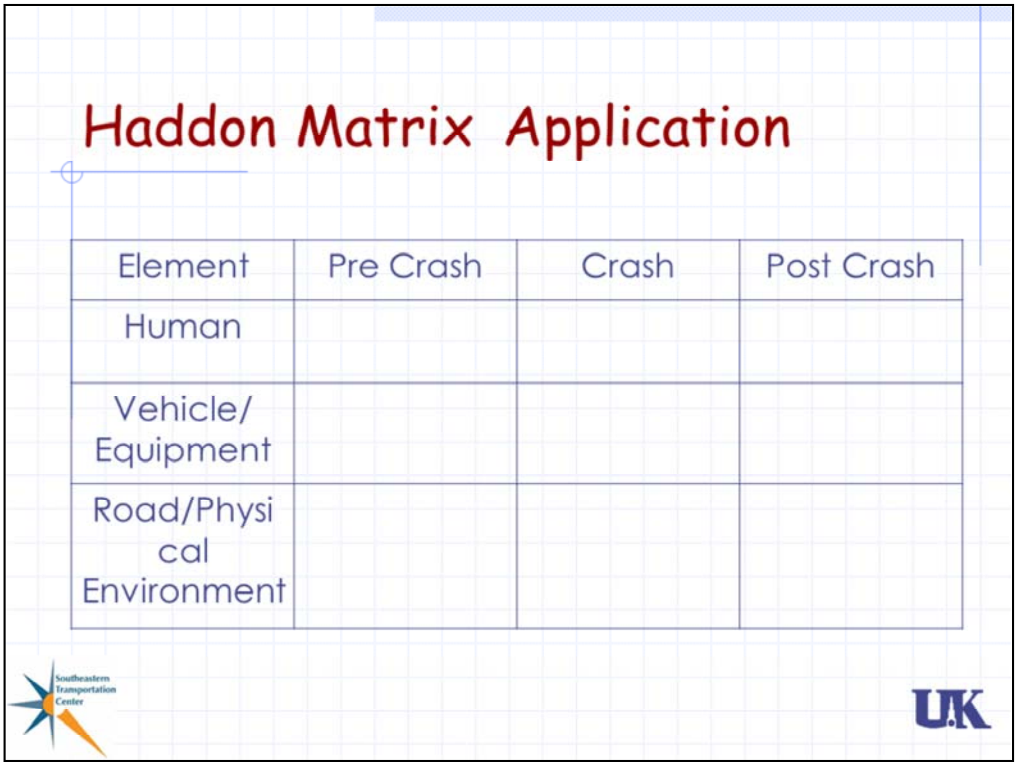


William Haddon Jr. developed a conceptual model in 1969 in an effort to apply concepts of epidemiology to highway safety. He developed the Haddon matrix, which has been used as a tool to approach safety analysis in a systematic manner. The matrix provides a structured framework for understanding the origins of safety issues and aid in identifying countermeasures to address those problems. The matrix contains nine or more elements for possible focus for road safety.

Haddon, W. Public Health Rep. 1980 Sep-Oct; 95(5): 411–421



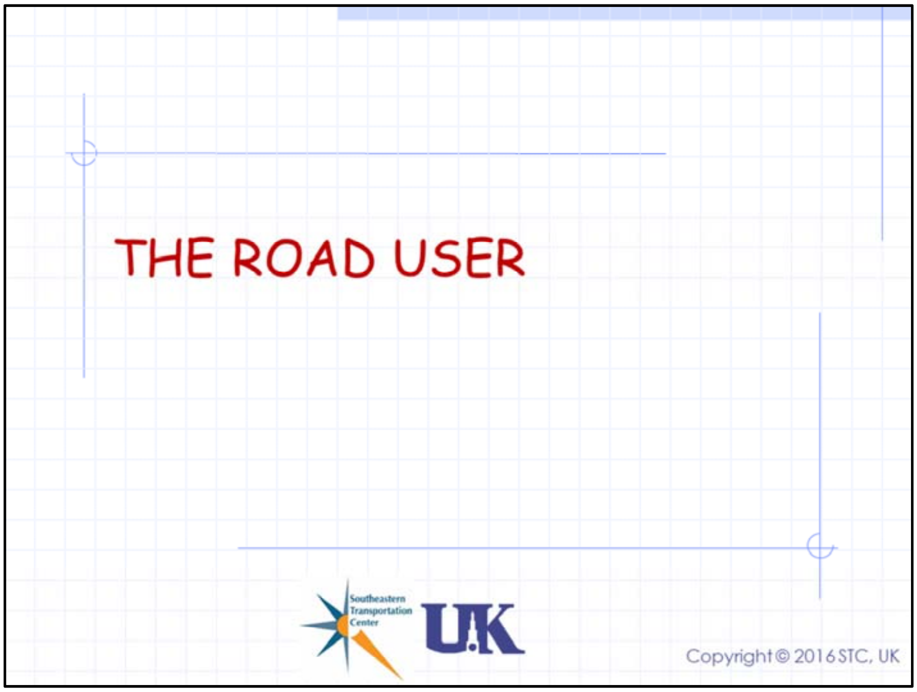
The matrix is set to reflect pre-crash, crash and post-crash elements as they would relate to the factors contributing to the crash occurrence. The columns represent time phases of the crash in addition to human, vehicle, and road factors related to the event. It is common to add a fourth row element that represents environmental conditions such as weather, etc., socio/economic conditions, etc. The Haddon matrix is completed through the evaluation of sites and/or crash details associated with a site or sites. When completed, it provides insight into the range of possible safety issues and concerns as well as possible solutions.



Consider the crash presented in slide 16 and identify some of the cells in the matrix.

Some possible answers:

- Human pre-crash could be inattention, attitude, impairment (alcohol or age), use of cell phone, conversation with passengers; crash could be use of restraints, vulnerability; and post-crash access to first aid and medical attention (for example the crash turned to a fatality due to late arrival of ambulance).
- Vehicle pre-crash braking, bad tires, roadworthiness; crash occupant restraints, crash protection cage; post-crash ease of getting out of the vehicle, fire risk.
- Road pre-crash speed limit, sight distance, wet pavement; crash pavement friction, presence of curb; post-crash rescue facilities, congestion to arrive at site.

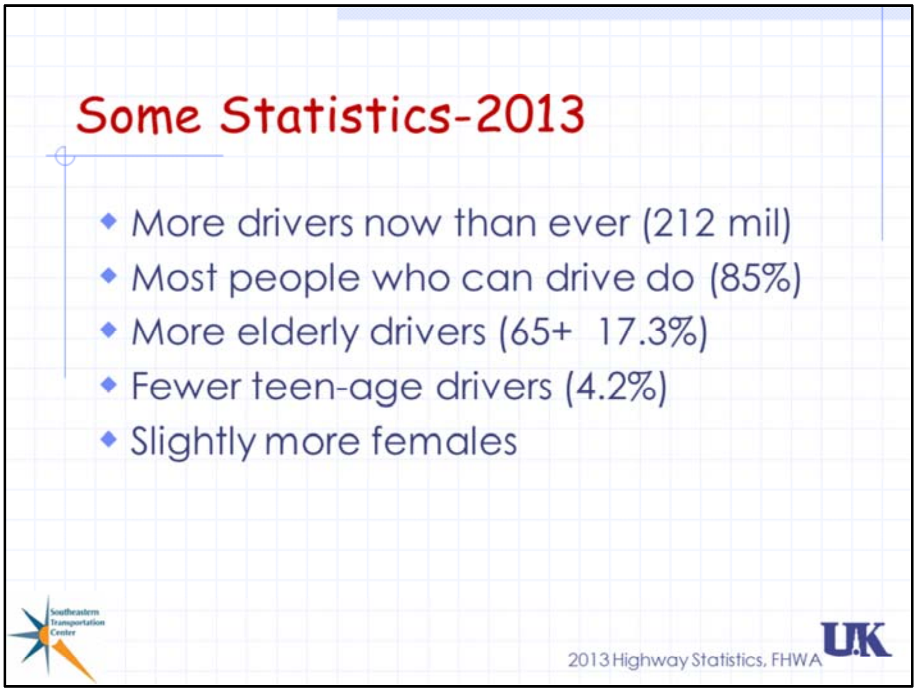


The purpose of this module is to identify the characteristics of the road users and understand the factors that influence their decisions. There are several modules within the “Road User” theme. First, general information is presented dealing with trends and statistics of the driving population. Next, an overview of attitudes and behaviors is discussed relating them to highway safety. The third section deals with age and gender issues as they affect highway safety. The effects of alcohol use on highway safety are discussed as well. Finally, licensing issues are presented to provide current efforts that could have an impact of safety.

The first section of the module will present the basic statistics and road user demographics and provide an overview of the issues that may influence road user safety behavior. The various demographic trends are presented and discussed in order to understand their potential influence in shaping how to address safety in the US. During the presentation, the discussions will focus on identifying how demographics, societal changes and social trends could influence road safety needs.

Question: In what ways do age and gender influence road safety?

Answer: Three ways demographic factors influence safety are physical ability; physical vulnerability; and risk-taking behavior



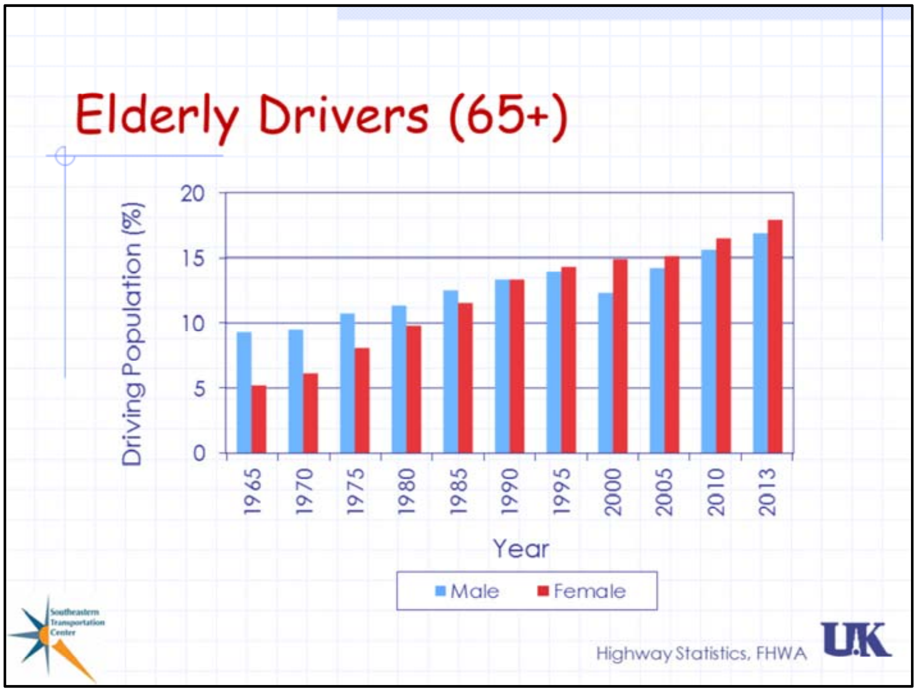
Current statistics indicate that in 2013 there were more drivers in the US than ever. Based on the Bureau of the Census statistics, of the 251 million population of driving age, approximately 85% have a driver's license. One should be careful here, since this does not necessary mean that all drive but rather they hold a driver's license. This percentage is lower than in the past (when in 2000 it was 88% and in 2010 86%) and it may indicate a shift in attitude changes towards less driving.

The population of elderly has increased as it compares with past trends (more discussed in the next slide) and it now occupies 17.3% of the driving population. This is also coupled with a lower percentage for teenagers (19 and under) may present a significant change in demographics and may have impacts both on driving habits as well as crash rates.

Finally, there are more female than male driver license holders than in the past (105 million males and 107 million females). As a comparison, in 2001 the numbers were 96 million males and 95 million females.

Question: What may be the reasons for this shift?

Answer: Females live longer than males and there are also more females in the population (2013 statistics show that females were 51% of the population).

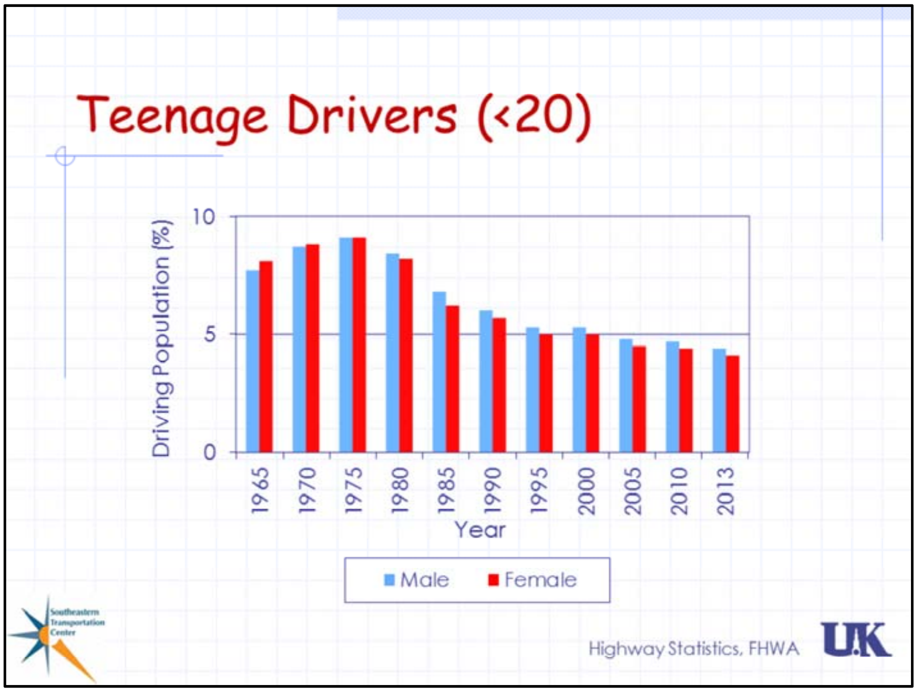


The shift and increase of female licensed drivers over time is apparent in the graph. The share of elderly females drivers over time has increased and this reflects a number of temporal and societal trends. According to he Bureau of the Census, it is anticipated that by 2030 people over 65 will account for 20% of the population.

The larger number of older drivers could impact road safety. For example, past research shows that older drivers are involved in higher proportions than other drivers at intersections especially when dealing with a left-turn maneuver.

Question: What are the reasons for this change?

Answer: Changes in traditional family roles (driving was done by the male in the 50's), increased presence of females in the labor force in the 60's translate into more older drivers in the 80's and 90's, and longevity of females (typically 3-5 years more than males).



Teenage driving population has declined over the same period and is steadied at approximately 4.5% for both males and females. This reduction is both in the percentages as a proportion of the driving population as well as in numbers. For example, in 2000 there were 5.0 million males and 4.7 million females, while in 2013 they were 4.5 and 4.4 male and female drivers, respectively.

Question: Why do we observe this trend?

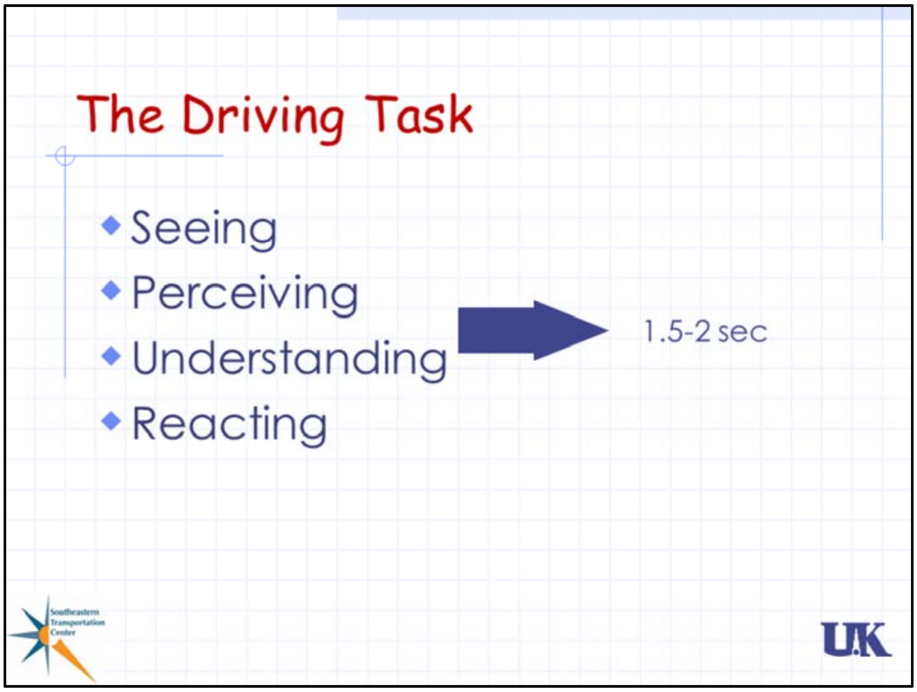
Answer: This could be attributed to: 1) reduced birth rates, 2) the "graying" of the US society as a whole, and 3) changing attitudes towards driving.

The question one may pose is why we need to focus on the road user. The answer is simple: they are the ones suffering from crash involvement.

In addition, the driver license is probably the most valued ID that one may posses: it signifies entry in the adult society and it can be considered an exit card (for elderly) if it is removed. Moreover, there are licensing issues that need to be considered that deal both with the early and late stages of driving.

Aging plays a significant role in the proper completion of the driving task (discussed in the next slides) and as such can have a significant influence on road safety. Moreover, population predictions place the elderly population at about 20% of the US population by 2030 (US Department of Health and Human Services) as opposed to approximately 15% in 2015.

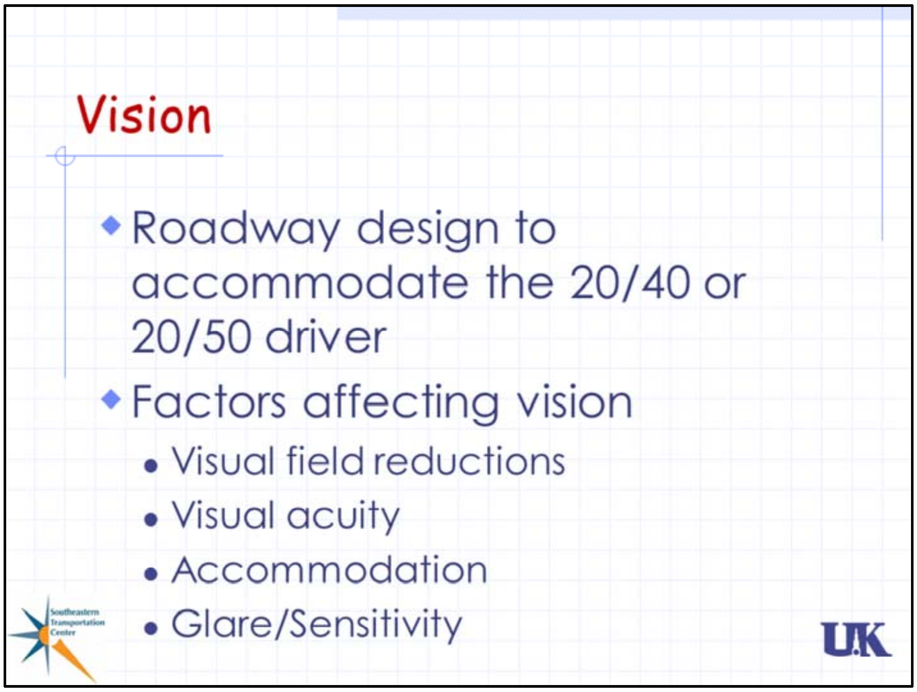
Finally, new technologies have been introduced that can have an influence on the driving task and road safety. One can simply consider the potential impact of cell phones (distracted driver) or presence or antilock brakes (increased risk taking behavior) to understand their influence on driving behavior.



Even though the driving task components are discussed here, this sequence of perceptual process is one that all users (drivers, pedestrians, and bicyclists) are constantly engaging in.

The user first visually perceive cues, such as traffic signs, traffic signals, or pedestrians crossing the road. Then, they process the meaning of the cue and upon understanding its connotation, they react to the cue. This in highway design is called the Perception-Reaction time and is typically 1.5-2.0 seconds.

This is a fairly quick process and roadway users have to continuously evaluate situations and make decisions. Age affects all stages of this perceptual process. For elderly drivers, vision may affect their ability to see while for young drivers inexperience may affect their understanding of the situation. These differences in physical and perceptual ability increase the risk of crash involvement.

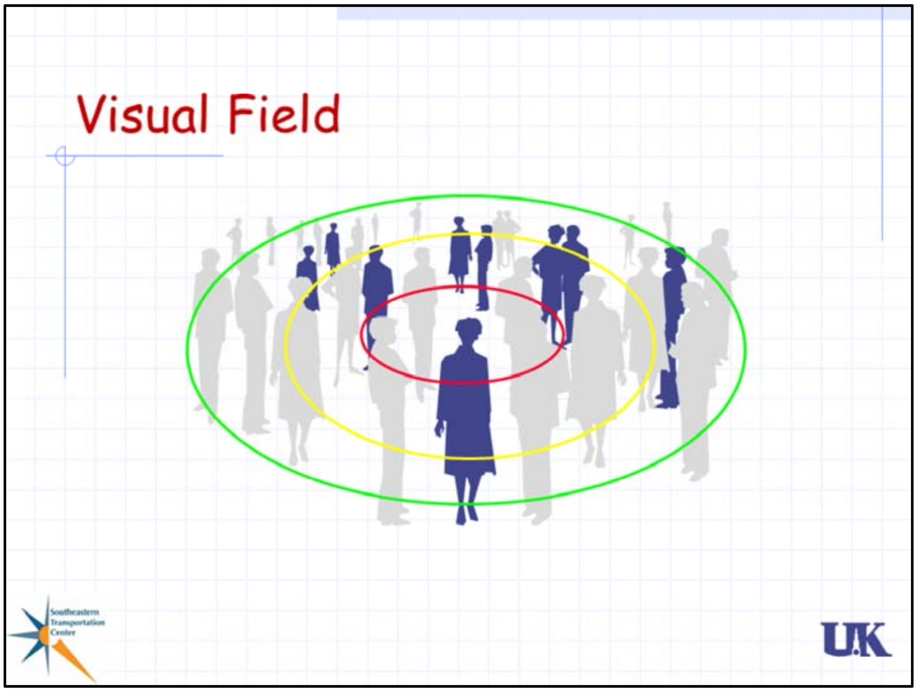


Vision plays an important role in gathering information from the environment and could have a significant impact in the decision-making process. Typically, road users get about 80-85% of their cues from visual stimuli. A driver with perfect vision has a 20/20 vision, i.e., can see at 20 feet the letter sizes intended to be seen at that distance. A 20/40 driver can see at 20 feet what a person with no visual problems can see at 40. Roadway design is developed to accommodate drivers who may not be aware of their visual deficiencies.

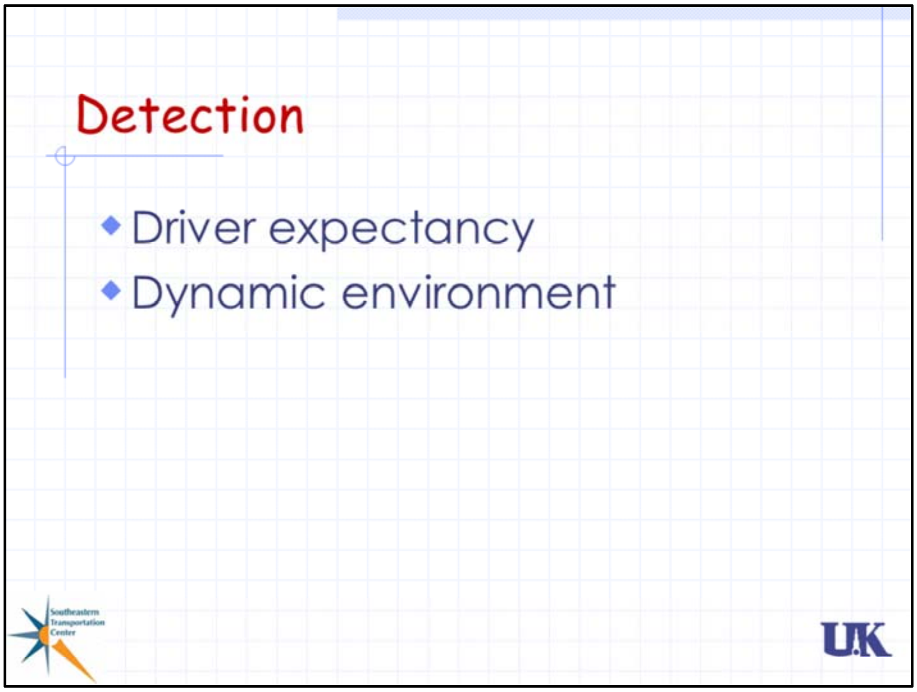
Vision factors that are affected by age include:

- Visual field: the ability to see at a field of approximately 160º focusing at a point without turning the head
- Visual acuity: which is defined as the ability to see fine details, such as lettering on road signs.
- Accommodation: which is the ability to understand how far an object is and how quickly it approaches the driver and changes size.
- Glare/Sensitivity: ability to recover vision during nighttime when opposing vehicles approach the driver.

Roadway designers need to address these issues with a proper understanding and provide for potential accommodation for elderly drivers with elements such as signs with bigger letters, brighter signs, etc.



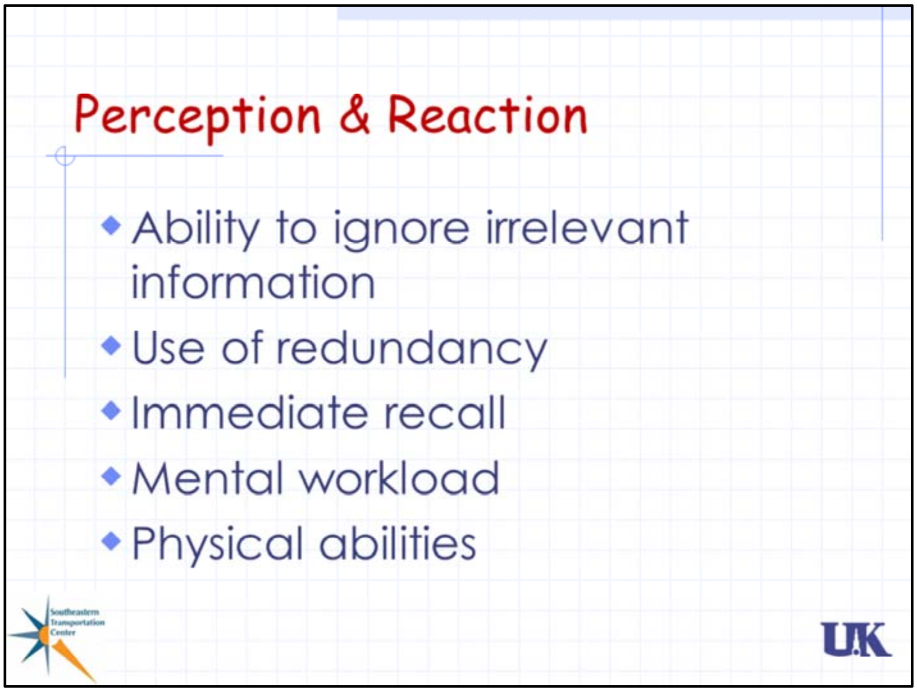
This is an example of how peripheral vision changes with age. The green line indicates a normal 160º field of view. Age affects this range requiring persons to turn their head to accommodate any loss which may result in not seeing objects if they were looking straight ahead.



The physical layout of the roadway along with its traffic control devices provides the required clues to drivers and as such it must be designed to provide the driver with information necessary to react to hazards; to predict what lies ahead; to select appropriate speeds, and so on.

Drivers rely on prior knowledge and form their reactions typically based on expected scenarios. Drivers expect signs and road markings to provide advice as to required changes and rely on them to make their decisions. Without this information, the driver's ability to make appropriate decisions is impaired. Moreover, the roadway design itself provides drivers with cues as to what lies ahead and what is expected from them. Drivers rely on their prior knowledge to to associate and influence their behavior. For example, drivers anticipate that freeway exits are on the right side and designers need to take significant care to inform drivers for exits on the left side of the freeway. In general, road designers strive for predictability and consistency in design so drivers can effectively anticipate what lies ahead.

The driving environment is dynamic and as such requires drivers to exercise their ability to judge how far away an object is and how fast it is moving by determining the change in its size as it approaches. This coupled with aging deficiencies and possible slower reaction times may hamper older drivers and reduce their effective reaction to a hazard.

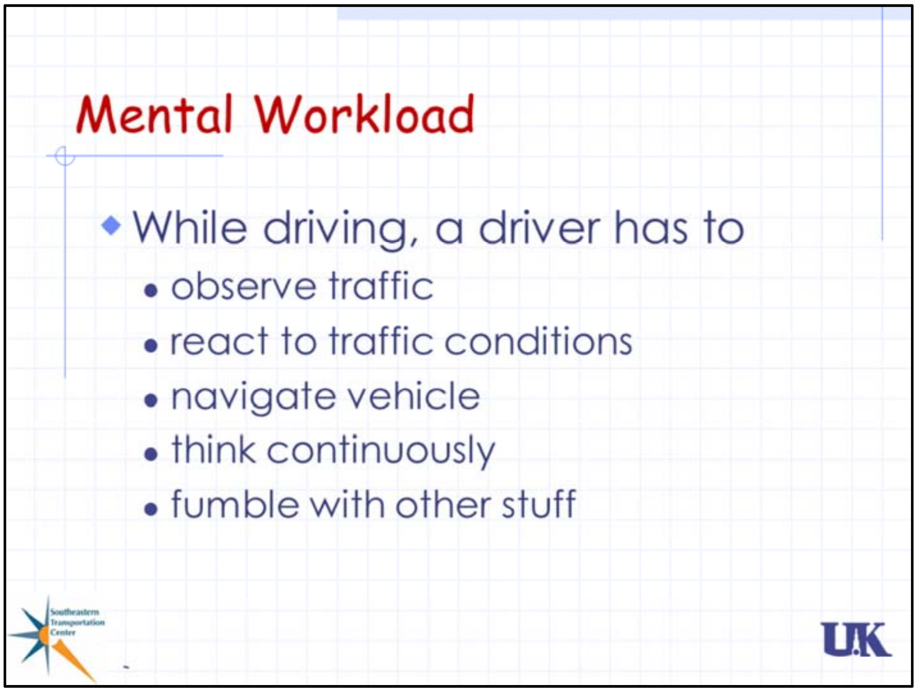


Once the road user has seen and detected a situation, then it has to determine whether the information received is relevant to the task at hand. For example, reading an exit sign that is not their destination is irrelevant and it could be processed and ignored. On the other hand, a STOP Ahead sign could be relevant, since a STOP sign is coming up. Both young people and older adults may have difficulty in sifting through information to determine their relevancy to what they are performing. Though not conscious of it, drivers constantly filter out a large amount of sensory information.

Road users use redundancy to understand a situation. This means that they are using prior experiences to evaluate the condition and determine the appropriate reaction. Familiar information is recalled from the immediate recall and new information is stored for future scenarios and reactions to them.

All this continued process of information increases the mental workload of the road user and can affect the rate with which decisions are made. An overloaded road user may ignore relevant information to the situation at hand or may not consider it as relevant as needed to be. In this case, this could lead to a safety issue and could result in inappropriate reaction. Young drivers maybe overloaded because they do not have adequate rules for ignoring irrelevant information while older drivers may have a tendency to process all information received.

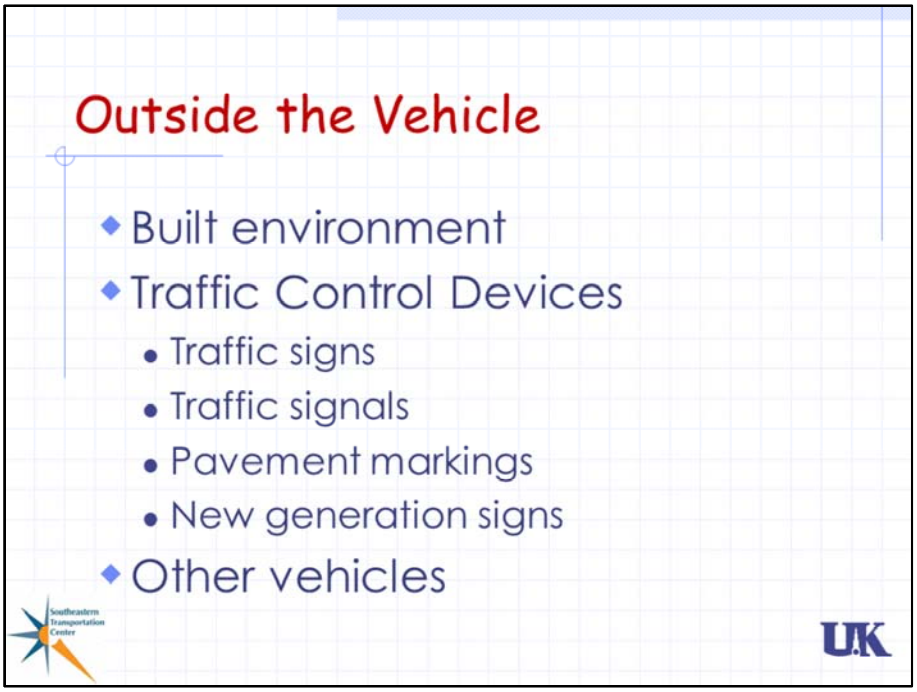
Once the stimulus has been seen, perceived and a reaction is determine, the driver must carry out the decision through physical motion. The reaction requires drivers to use their physical abilities to complete the reaction. For example, the driver must have the ability to steer the vehicle to a new direction, turn their head to see traffic coming from the side, brake with the required force, and so on. Aging plays a role in this as well with the deteriorating physical abilities of older drivers and this can further compromise their safety.



Mental workload is defined as the work required by the brain to process stimuli and information. For drivers, this can be very demanding, since the driver needs to :

- Observe and monitor multiple sources of information. For example, a driver approaching a signalized intersection going though must evaluate the signal display, ensure that no vehicles are turning right from the side street, there are no vehicles turning left from the oncoming traffic and check for vehicles in the in other lanes while simultaneously maintaining adequate spacing with the leading and following vehicles.
- React properly to traffic conditions and understand and react to changes in the road environment.
- Remember and apply navigational instructions while controlling the vehicle.
- Deal with other elements, such as other persons, mobile phones, radios, navigational displays, etc.

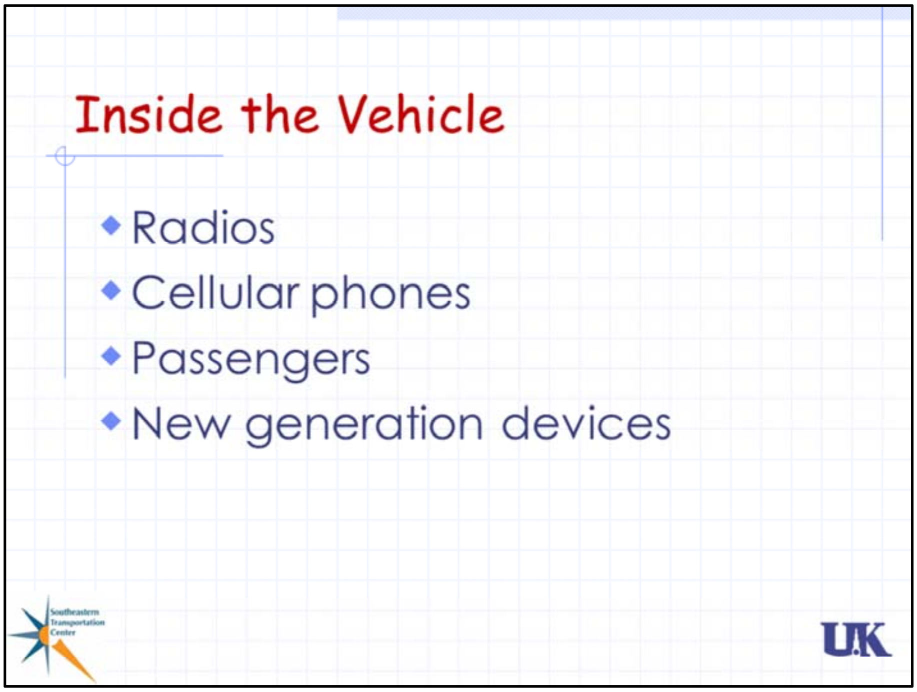
It should be noted here that not all drivers can perform these tasks successfully and they often exhibit limitations while completing these skills. It is therefore imperative that roadways are designed in a manner that would allow enough time for individuals to recognize and process all these stimuli. For example, in deciding where to place warning signs in advance of a hazard, engineers take into account the amount of time needed to observe the warning signs, cognitively process the information, and react appropriately.



In addition to dealing with the vehicle, a driver needs to deal with elements outside the vehicle, i.e., with the built environment. The term "built environment" refers to all of the built features of the human environment including buildings, roads, fixtures, parks, and all other human-constructed improvements.

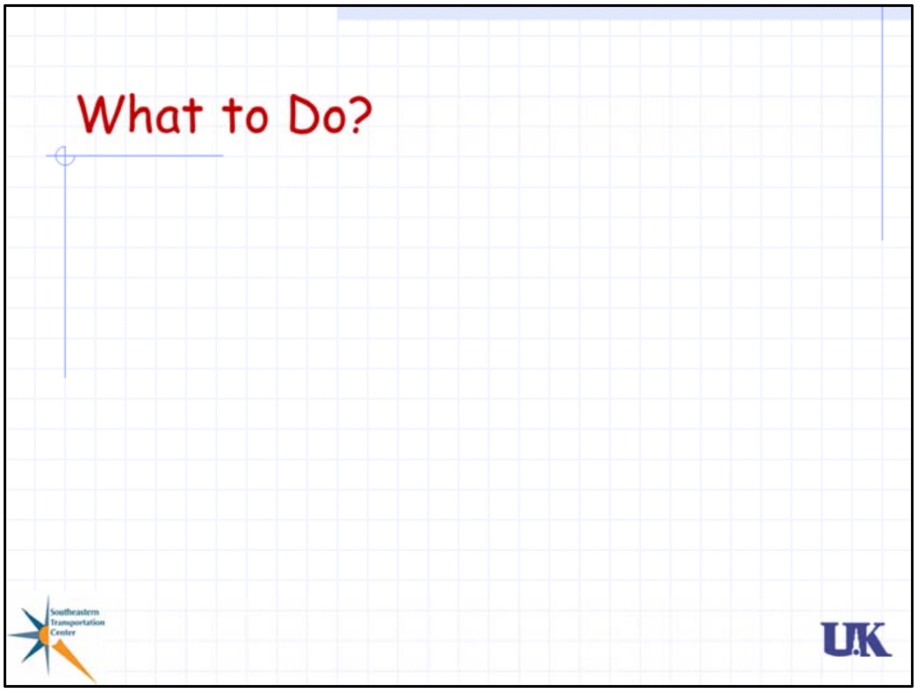
As previously noted, the built environment affects road user decisions while it provides cues to drivers and other travelers about how they should behave. Traffic control devices aid in this and assist drivers and roadway users in interpreting correctly the intended message and properly reacting to the stimuli.

Drivers also need to deal with the other vehicles in the roadway and thus understand their intentions and behaviors. The combination of the mental workload within the vehicle and the built environment with its distractions can affect the safety of the road users, since it has the potential to overload them and lead them to improper interpretation or disregard of stimuli resulting in incorrect reactions and thus compromising safety.



The driver has to deal with a number of potential distractions inside the vehicle that can detract from the driving task on various levels. Radios and cellular phones can provide a distraction that can lead to inattention to the task at hand. Passengers can act both as a negative and as a positive influence. Drivers involved in conversations or dealing with children can be a distracted and miss relative information while passengers can also act as a set of extra eyes and assist in navigational guidance or increased awareness of upcoming situations.

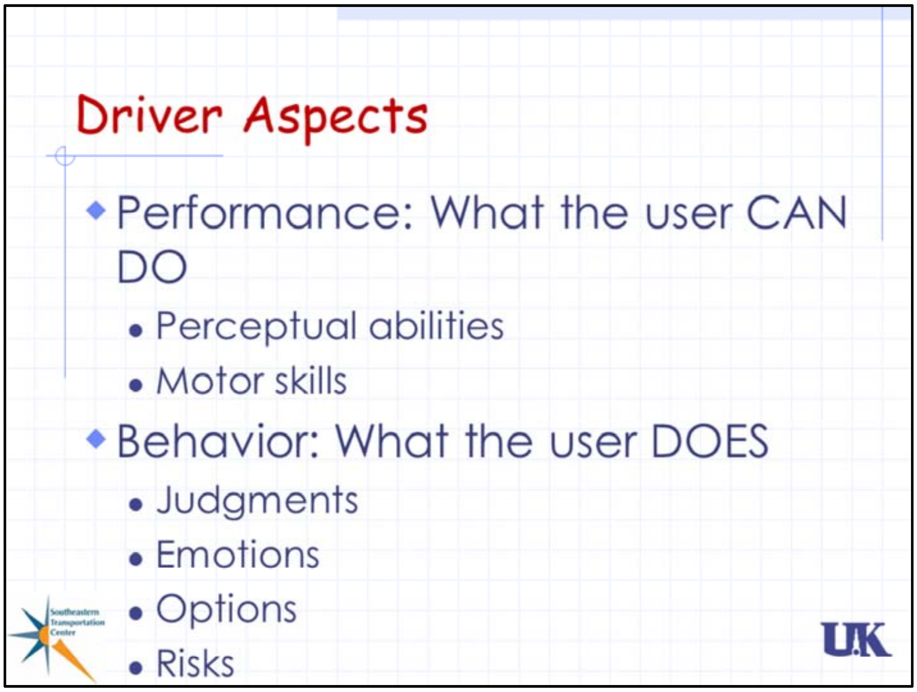
Modern passenger vehicles are equipped with a wide range of new devices that can help drivers by assisting their navigation, actively prevent drivers from becoming involved in a crash or passively reduce the severity of a crash once it occurs. However, these devices may also have a negative effect since it is possible to confuse drivers and affect their safety.



So the question of the day is what one can do to improve safety and deal with these issues?

Possible answers: revisit licensing programs (graduated license, restrictions for elderly drivers); increased training during licensure and license renewal;

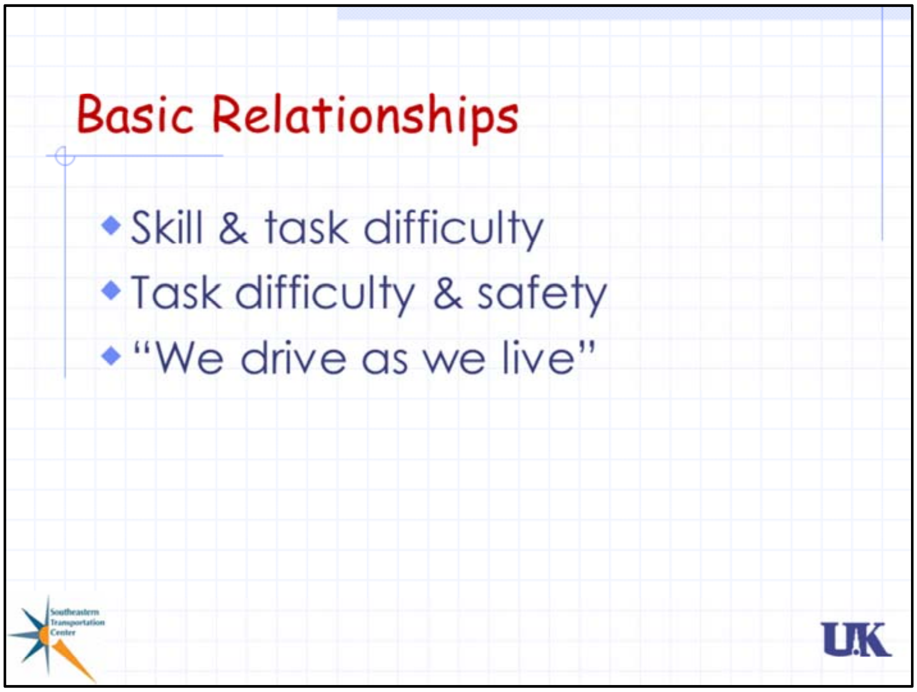
This module focuses on attitudes and behaviors of road users and how these can affect safety. Understanding the influences of these behavioral is essential for anyone interested in improving road safety. The discussion presented here can assist road safety professionals to understand and address the root cause of safety problems. For example, knowing that young drivers have a higher risk-taking behavior, one can then address this through education, enforcement, and engineering efforts specifically designed for this group.



There is a basic distinction between performance and behavior. Performance is defined as the ability of the road user to perform specific tasks. The perceptual abilities and motor skills are those elements that can affect performance and thus impact their performance. For example, elderly drivers have reduced motor skills (as discussed in the previous module) that can impact their ability to perform effectively certain tasks (such as visual search) and thus may require some compensatory actions.

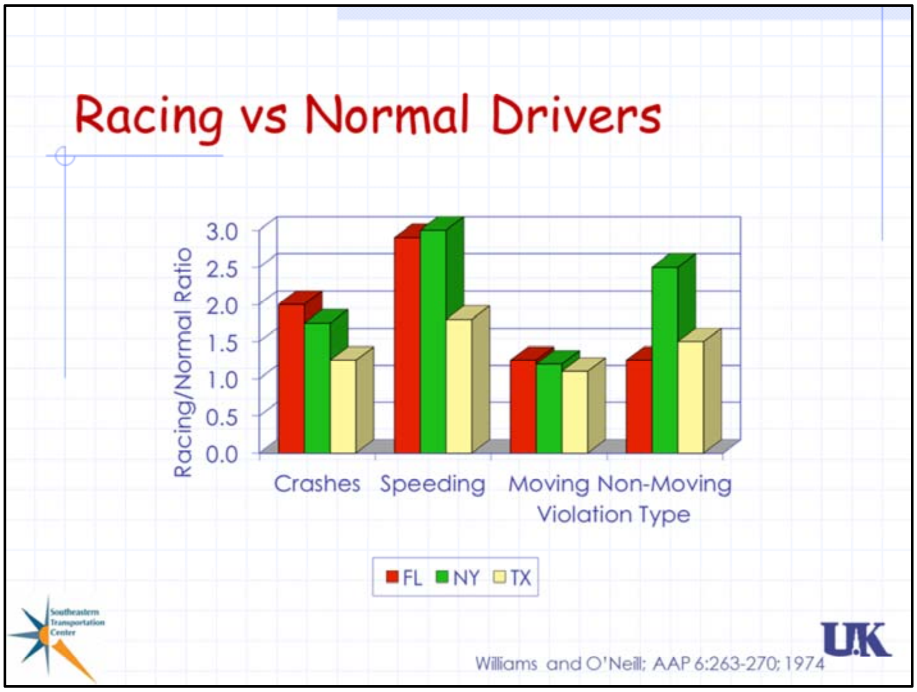
On the other hand, behavior is defined as the actual acts the users completes and these are affected by their:

- Judgments, where they could interpret a situation based on the available information and situational awareness;
- Emotional status, where this could to distractions or different reactions based on this emotional status;
- Options to resolve the situation, where these shape the eventual action of the road user (think in terms of same scenario but with limited or different options to react); and
- Risk taking levels, where different groups of road users can react differently based on their willingness to take risks (as an example, mid-block crossings without crosswalks).



When it comes to driver performance, there are some relationships that need to be addressed. It should be also noted that driving is a "self-paced" task and as such there are certain concepts that influence individual behavior.

- There is a distinct relationship between driver skill and task difficulty. It is clear that more difficult tasks require a greater level of skill to be completed properly. In general, drivers choose the task with desired level of difficulty based on their skills. For example, the task of keeping the vehicle within the lines on a straight roadway segment is easier than when a curve is involved, since this one requires both attention to vehicle placement and speed. Another example could be merging on a freeway, where younger drivers with limited skill may not be willing to undertake this more difficult task.
- Difficult tasks could have a safety implication if not performed correctly. For example, during the taking of a curve (task noted above) improper speed can result in a ran off the road crash. The more difficult the task, the greater the chance is for creating a safety issue. For example, intersections pose a greater difficulty in the tasks required (observing others, vehicle placement and navigation, and completing maneuvers) and therefore the potential for safety concerns is greater.
- A final aspect that should be noted is that lifestyles shape (and affect) driving styles. For example, persons who are greater risk takers in life are more willing to take risks while driving. Similarly, traits of caution, patience, tolerance, foresight, consideration, etc. also have an impact on driving behavior.

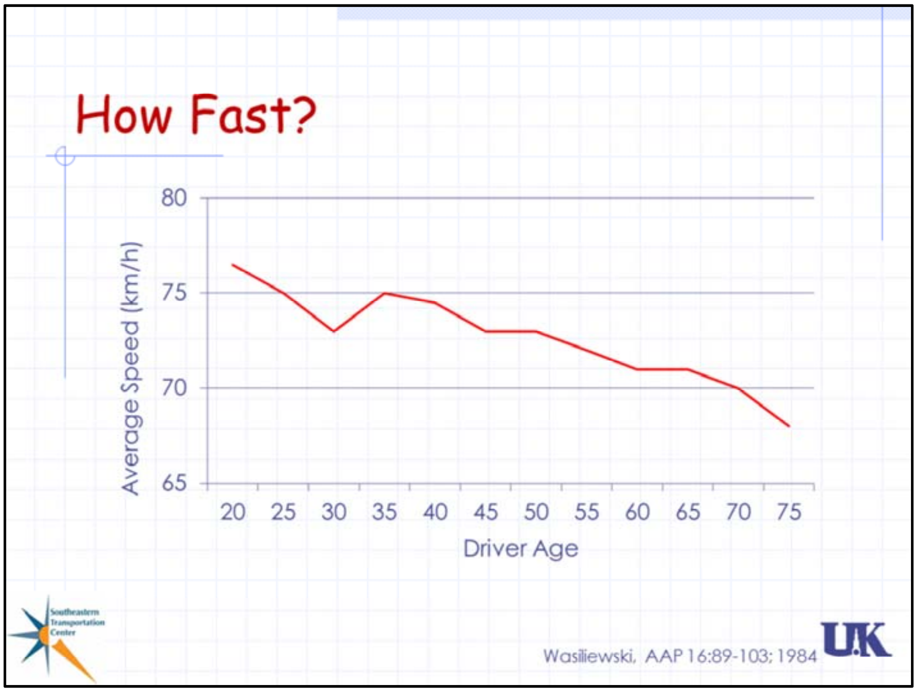


The idea that drivers with higher training, especially in crash avoidance techniques, would have a safety impact and could reduce the number of crashes. The idea of a national Master Driver's License was developed in the 19070's based on the concept that these drivers could be specifically trained to avoid crashes and be more familiar with vehicle behavior resulting in better safety records than those without the license. One could presume that car racing drivers are trained in such situations and have some experience in crash avoidance techniques. A study examined the on street performance of car racing drivers and compared their records with those of normal drivers in three states (where most of the car racing drivers resided at the time).

The findings indicate that in all violation types examined, the racing drivers have a greater number that the normal drivers. The results here indicate that the additional skills do not guarantee a safer performance.

Question: What may be the reason for these differences?

Answers: Greater confidence in skills could result in riskier behaviors (higher speeding violations); level of anticipated reaction from other drivers (i.e., in a race track all have similar skills and all behave a certain way which is not true for normal drivers wit different skills and experience).

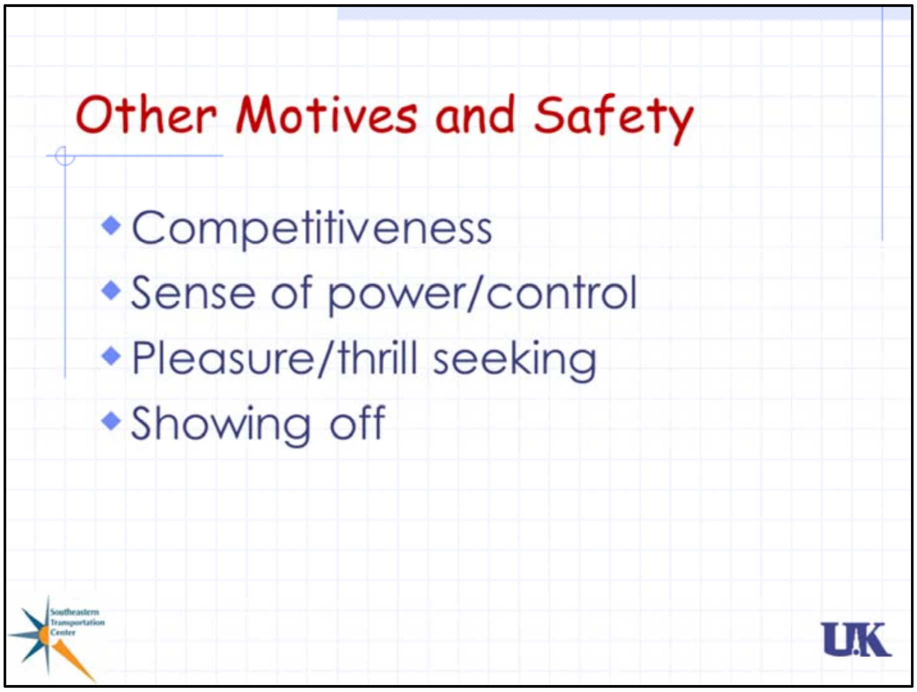


People over their lifespan exhibit a changing behavior when driving speed is concerned. Young drivers have a tendency to drive faster than any other age group and over the lifespan, there is a reduction of about 10 km/h (6 mph) in average (overall) speeds. The higher speeds of young drivers could be attributed to their inexperience and greater risk-taking behavior. On the other hand, the lower speeds for older drivers could be considered as a compensating technique for their aging abilities and their reduced risk-taking behavior. A potential explanation for the dip in the graph at the age of 30 could be interpreted as the entry in the workforce indicating a greater income and possibly a newer vehicle and thus an increase in speeds.

There are several factors that could influence driver personality and their behavior in traffic situations and could have an impact on safety. Psychological factors can affect the way that one reacts to traffic conditions. These include:

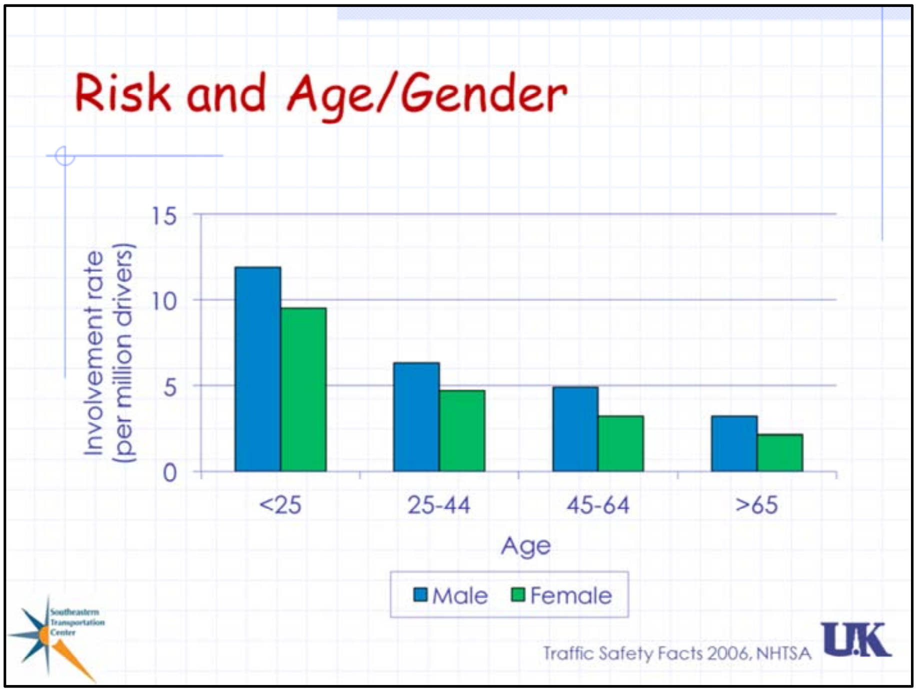
- Tension tolerance, where one can diffuse situations or accept more stressful conditions;
- Stress, where one can depart from normal driving behaviors due to work or other related influences;
- Personality disorders, which can influence driving behavior; and
- Immaturity, when chronological age may have little to do with how one drives.

Social factors can also affect driving behavior. Such factors include levels of maturity, similar to the psychological immaturity, as well as attitudes against the law, where one may disregard signs and traffic control devices or existing rules (seat belt or helmet use for example).



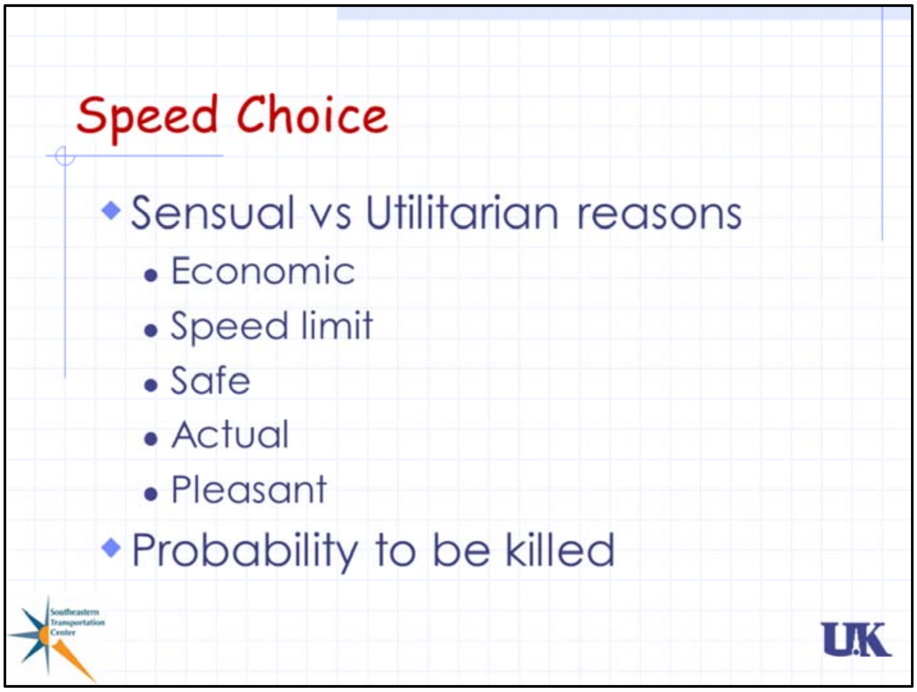
Additional factors that could also have an impact on safety and can contribute to improper behavior include:

- Competitiveness, where the feeling of "winning" every situation may pose threat in proper reactions. For example, overtaking other vehicles because one wants to be the first in line is a result of such behavior.
- Sense of power is a situation where one is feeling powerful due to their ability to control a vehicle. For example, the sense of being able to control a four-wheel drive vehicle in inclement weather could lead to incorrect behavior and result in a crash.
- Thrill seeking is another motive that could be detrimental to safety. This behavior can lead to taking higher risks than required and thus increasing the potential for a crash.
- Showing off is a behavior that is typically noted among peers where the need to demonstrate one's abilities becomes critical. This could lead into taking improper actions (driving faster than the conditions allow or braking at high rates) that can be detrimental to safety and lead to a crash.



Age and gender have a role in determining one's propensity to take risks on the roadway. Young drivers, especially young men, are much more likely to be involved in in a crash not only because of lack of experience, but also because of increased willingness to engage in risky behaviors such as drinking and driving, not wearing a safety belt, and speeding. For example, in 2004, the motor vehicle death rate for male drivers and passengers aged 16 to 19 was more than one and a half times that of their female counterparts (19.4 per 100,000 compared with 11.1 per 100,000). Recently, young women drivers have shown increases in crash involvement, but this phenomenon is not well understood and may be related to greater exposure.

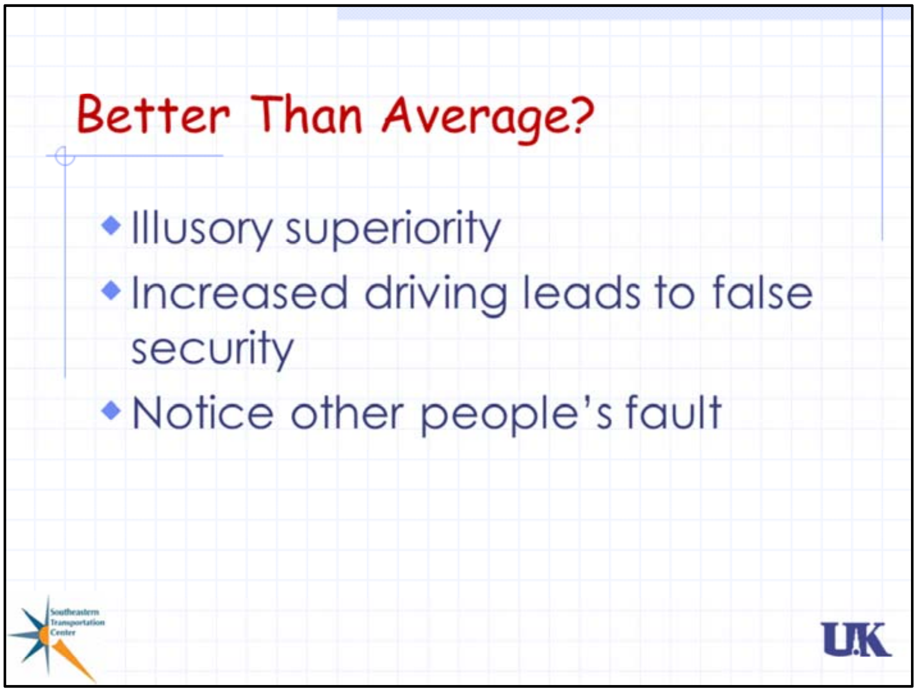
As a result of in engaging these risky behaviors, a disproportionate number of young drivers die in car crashes. In fact, the risk of motor vehicle crashes is higher among 16- to 19-year-olds than any other age group. Per mile driven, teen drivers ages 16 to 19 are four times more likely than older drivers to crash.



There are several reasons that one selects the speed they drive and they also based on both economic and behavioral aspects. People may drive fast simply because they have to get places within a certain timeframe or save time (utilitarian) while others feel better by driving fast (sensual). A NHTSA survey of drivers' speeding attitudes and behaviors (NHTSA 2013) indicates that young drivers more often admit enjoying driving faster than older drivers; this is also true for males over females.

An issue that needs to be considered here is that often unconsciously, people select their driving speeds based on the likelihood of being involved in a crash and get killed. The same NHTSA survey on speeding attitudes noted that all drivers (regardless of age) consider the speed choice as a function of being involved in a crash.

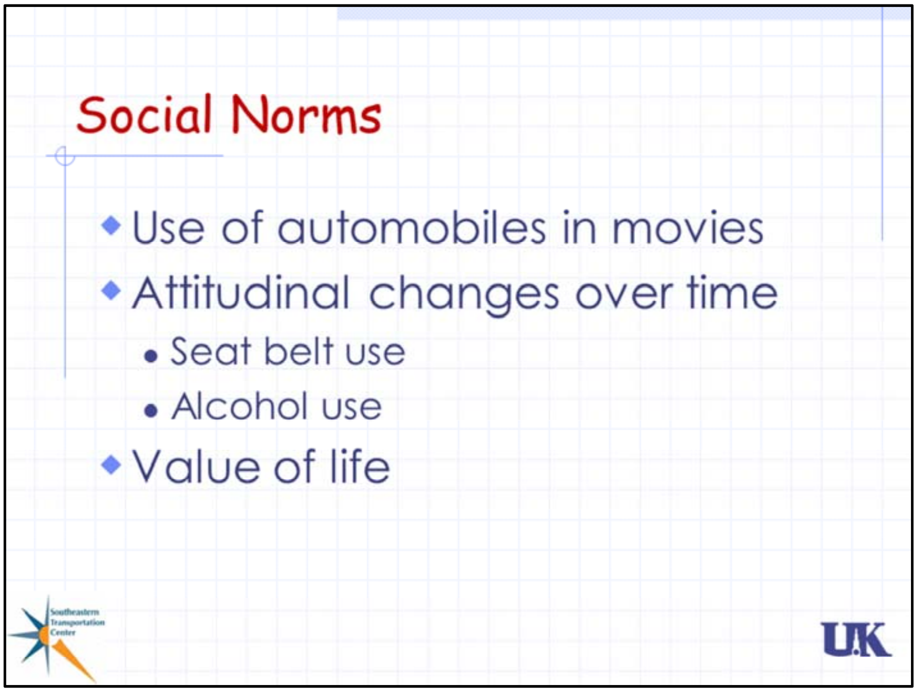
NHTSA, 2011 National Survey o Speeding Attitudes and Behaviors, DOT-HS-811-865, 2013



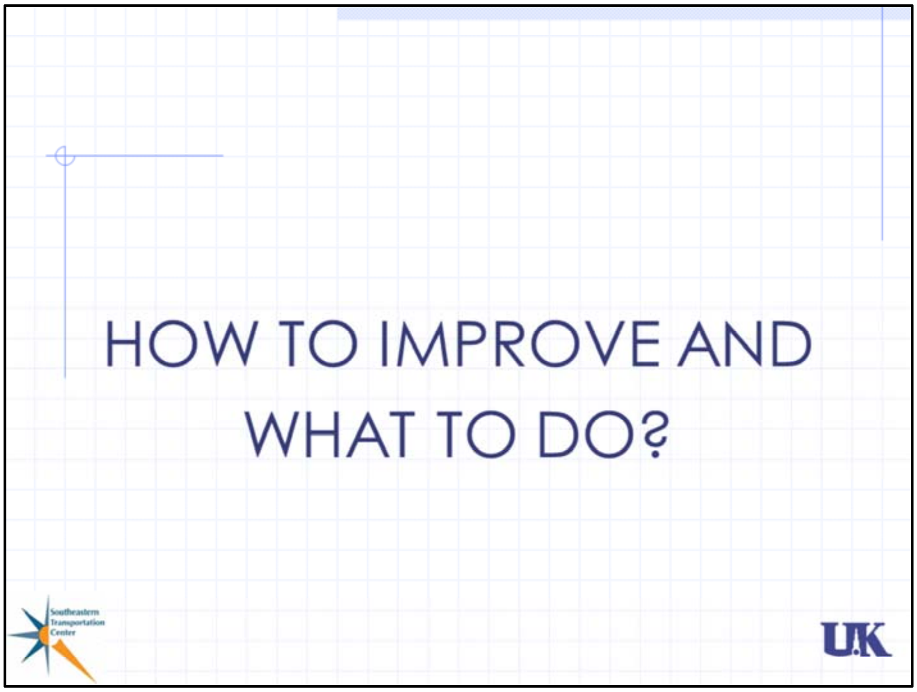
People have a tendency to believe that they are better than the average person in a variety of aspects including driving behavior and skills. Svenson (Acta Psycologica 47:2; 1981) noted that 93% of the U.S. sample and 69% of the Swedish sample put themselves in the top 50% for driving skills as compared to the average driver; 88% of the U.S. and 77% of the Swedish put themselves in the top 50% for safe driving.

An issue of concern is the belief that more driving may lead to improved skills. However, this may not be true due to the fact that drivers may perpetuate wrong behaviors that remain uncorrected until a safety issue arises. Increased driving has the potential to improve one's behavior and understanding by providing additional situations to be dealt with but those need to be reacted properly to avoid creating false impressions of appropriate behavior.

People have a tendency to note others' mistakes than their own. It is always easier to point the wrong driving behavior when observing a situation even though drivers may not always recognize that they behave in the same manner as well.

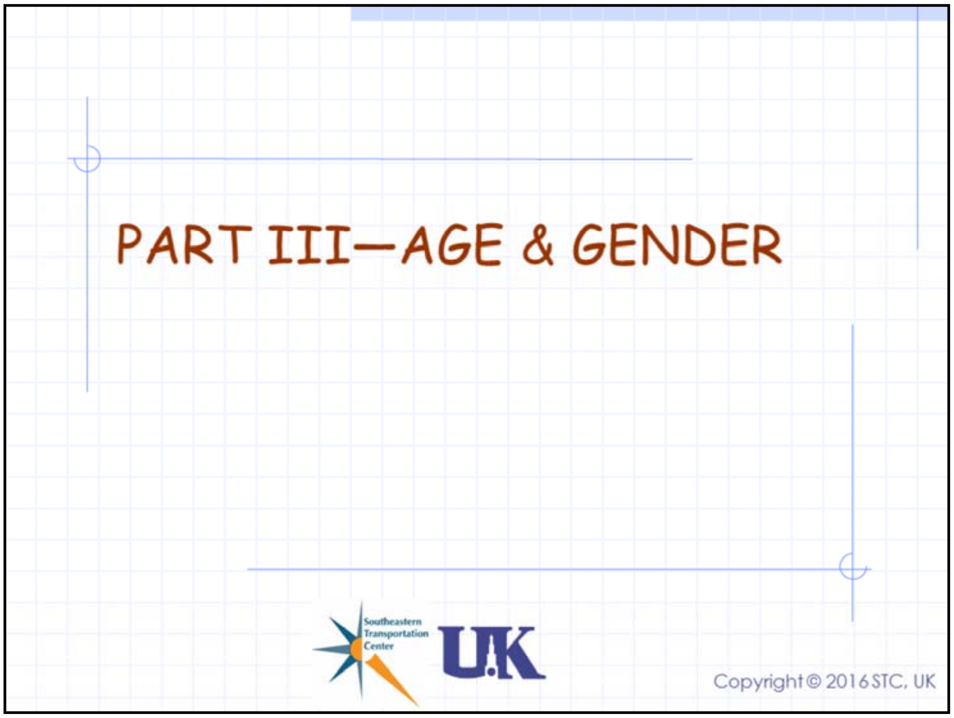


There are social norms that affect driver behavior and impact driving choices and decisions. The use of automobiles in movies and the relatively lack of serious consequences after a crash paint an unrealistic picture of the consequences of a crash. Attitudes over time have also changed and these can have an impact on safety. People nowadays wear their seat belts more frequently, are more award of the safety features of vehicles and often seek them out when purchasing a new vehicle, and alcohol consumption while driving has been significantly reduced. A final point to be made is the changing idea of the value of life. It is possible that the modern era with the desensitization through video games and movies may have created a lower value of life which may also transfer in driving behavior where defensive driving is practiced due to inability to see its benefits.

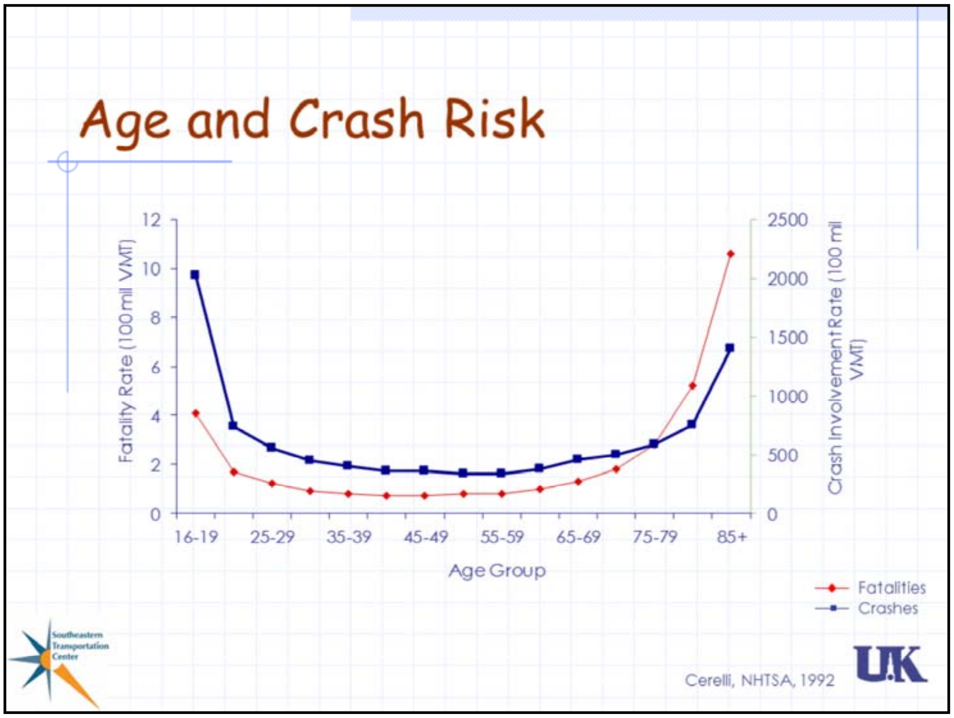


Question: How would one improve this? What actions can one take to ensure better driving behavior?

Answer: Education to provide facts and behaviors that could lead to crashes; driving habits that include greater headways and avoidance of aggressive driving (tailgating); improving braking habits by understanding situations and reacting appropriately; improving visual search techniques; and changing one’s attitude towards safety and defensive driving in general.



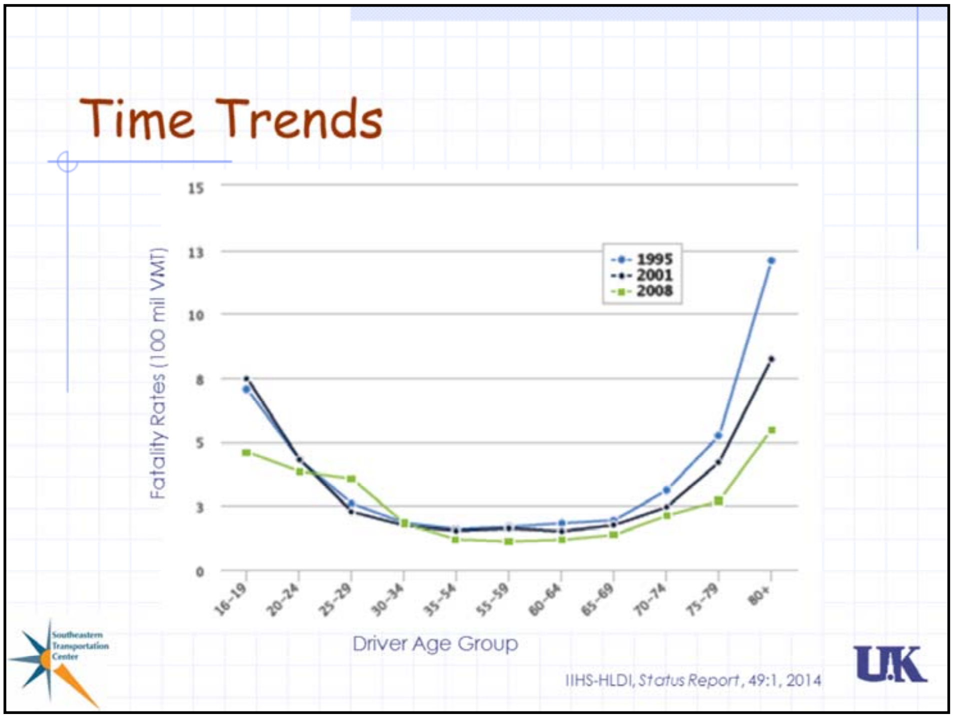
This module further explores the relationships between various aspects of road safety and demographics and closely examines the effects of age, gender, and alcohol consumption. The module provides insight in these issues and identifies potential contributing effects as well as trends that may have affect safety. Current efforts to address these are also discussed along with countermeasures tried that had an effect on road safety.



The graph shows the fatality rate by age and gender. It is clear drivers in the 16-19 and 75+ age groups have higher fatality rates. Risk taking and failure to recognize hazardous situations contribute to this trend among younger drivers. Physical and perceptual limitations put older drivers at greater risk. In both cases, women experience a lower fatality rate than men but they also have less exposure (e.g. miles traveled).

A similar trend is also noted for the crash involvement rates where both young and older drivers exhibit higher rates than the other age groups. The same reasons noted above could be cited here as well. A difference between these rates is the shape of the curve, where for the fatalities, the curve is skewed towards the older drivers where for the crash involvement, higher rates for the young drivers are noted. This difference can be attributed to the greater likelihood of frailty for older drivers and larger inexperience for young drivers' involvement in crashes as compared to other age groups.

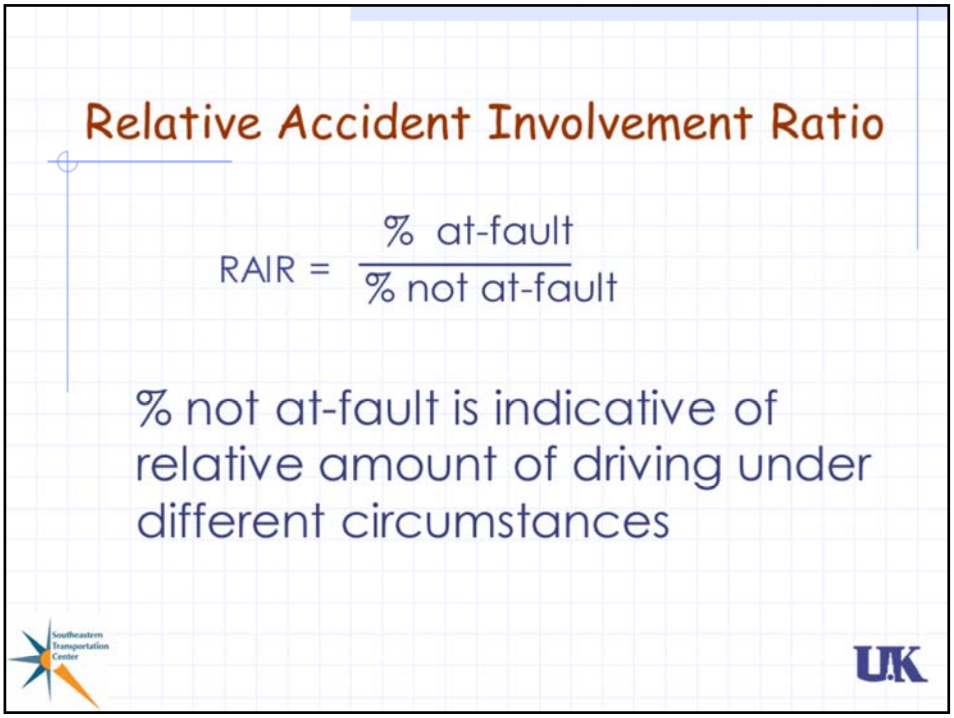
Cerelli, *Crash Data and Rates for Age-Sex Groups of Drivers, 1990* NHTSA, May 1992



The data here shows that over time the rates of the older drivers are dropping. Today's older drivers are less likely to be involved in crashes and fatalities. There is an overall improvement in fatal crashes for all driver age groups but those over 75 experience the greater reduction in such rates as the graph here shows. More recent statistics indicate a reduction of 36 percent for the 70-74 group, 46 percent for 75-79 and 49 percent for the over 80 during he 1997-2012 period. Better vehicles, more active and fit elderly and greater automobile dependence may be contributors to these changes. Pairing this with the larger number of vehicle-miles traveled for the older drivers during the 1997-2012 period as compared to the past may indicate that they are more comfortable with the driving tasks both physically and mentally.

Question: What could be the factors or reasons behind these figures?

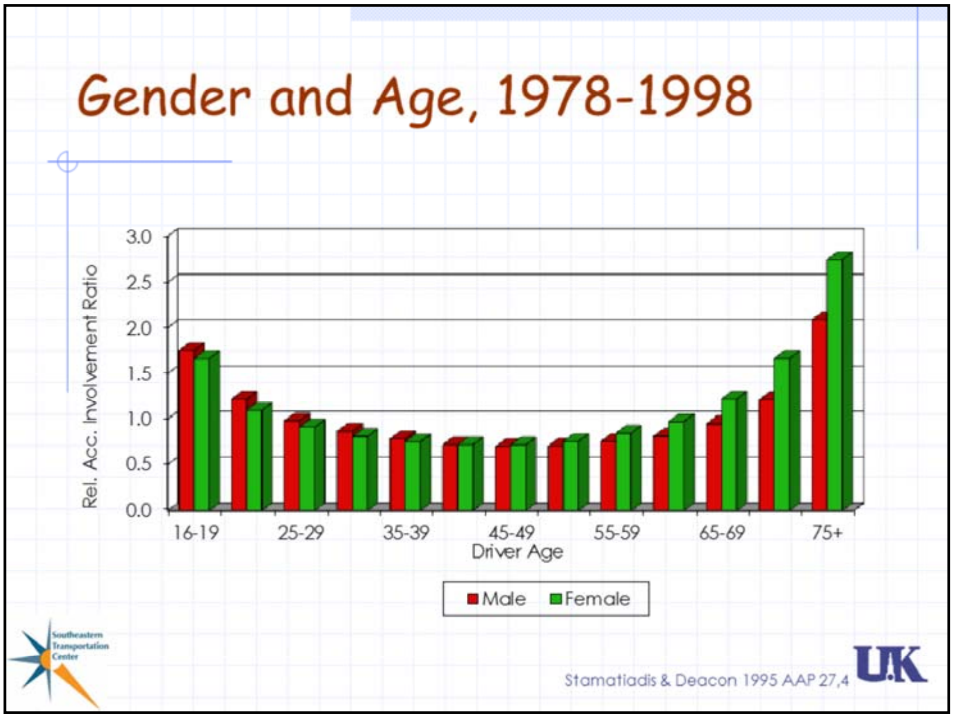
Answers: better vehicles with performance that could improve safety (ABS, third brake light, headlamps, etc.); increased number for older licensed drivers and population (greater number of them are living longer and are driving more); more travel for all groups (in 2008) resulting ion lower rates.



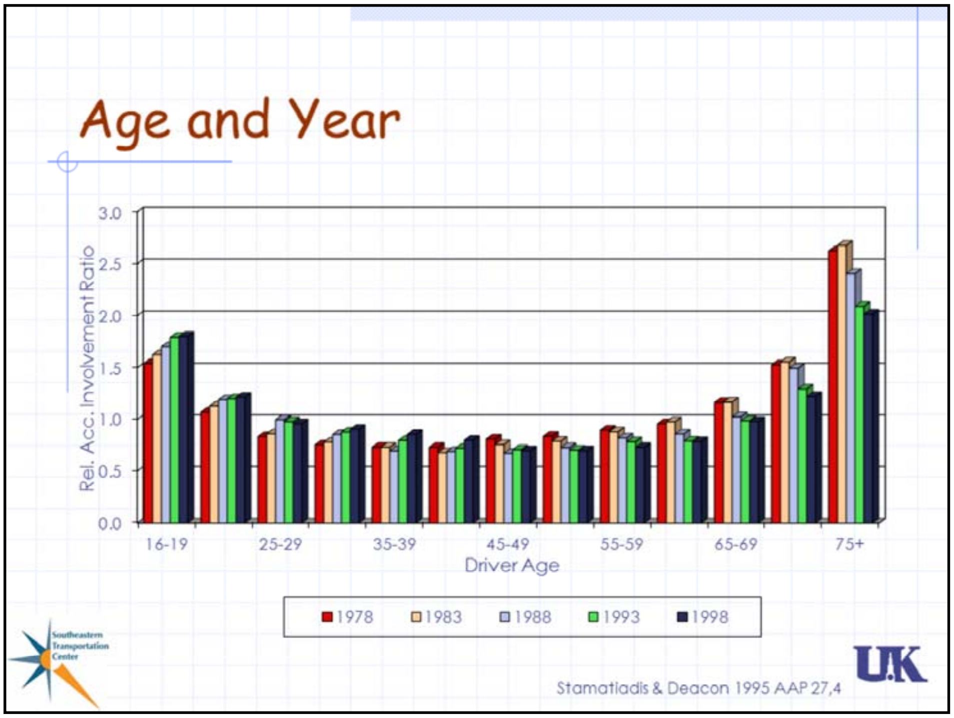
Crash rates are typically used to normalize data and account for driving frequency. For example, if one wants to compare crashes in two-lane to four-lane highways cannot simply sue the numbers of crashes in each roadway type but also needs to account for amount of traffic in each road (most likely greater in four-lane roads) and mileage (most likely greater in two-lane roads). This disparity in "use" can be remedied with the use of a normalizing factor that accounts for exposure and in this case the amount of travel, or vehicle miles of travel (VMT), is used. The problem with this approach is the frequency with which traffic counts are collected as well as the lack of continuous counts, since most are periodic counts. Moreover, VMT does not provide any information regarding drivers and vehicles and thus it cannot be used as an exposure metric in such evaluations.

An alternative approach has been developed that allows for such comparisons and is called the Quasi-Induced Exposure Method (Thorpe 1967; Carr 1970; Stamatiadis and Deacon 1997). The basic assumption here is that in a two-vehicle crash, the driver responsible for the crash will not select the other vehicle to crash into but rather it will hit whichever vehicle is in his/her path. Therefore, the not at-fault driver/vehicle can be used as a metric of exposure of this population and form the required exposure estimate. The key assumption is that the distribution of not-at-fault drivers is assumed to be a sample of the total population exposed to the particular crash hazard. The ratio of the at-fault to not at-fault drivers provides for a relative measure of their crash involvement propensity with ratios greater than 1 indicating a greater tendency to cause tan to be involved in a crash.

Carr, B.R., 1970. A statistical analysis of rural Ontario traffic accidents using induced exposure data. Proc. of the Symposium on the Use of Statistical Methods in the Analysis of Road Accidents, OECD, Paris France, 86-72.
Stamatiadis, N. and Deacon, J.A., 1997. Quasi-induced Exposure: Methodology and Insight. Accident Analysis & Prevention, 29 (1), 37-52.
Thorpe, J.D., 1967. Calculating relative involvement rates in Accidents without determining exposure. Traffic Safety Research Review, 11 (1), 3-8.



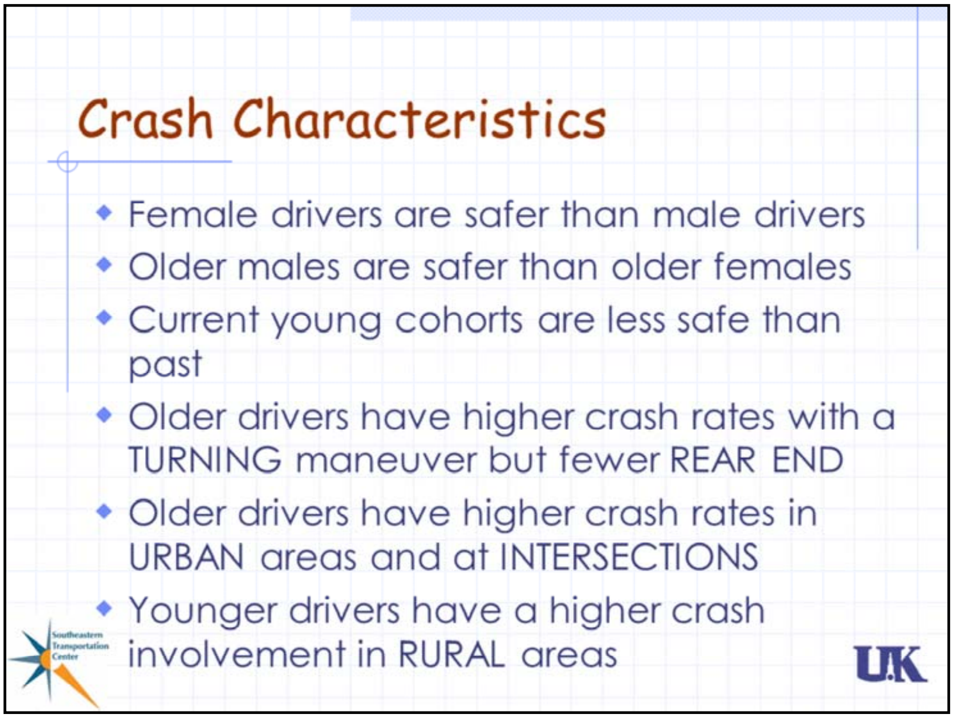
There is a gender effect that should be also considered when one examines crash trends and issues for older drivers. The figure here shows that the gender effect is complex and intimately related to driver age. For the best drivers, those of middle age, gender has little influence on accident propensity. The relative advantage of female drivers reverses between younger and older drivers. When younger, female drivers perform better, it is presumably because of lower risk-taking and different attitudinal factors than their male counterparts and perhaps as well because of when and where they drive. When older, males are considered better drivers than females, it is presumably because they have more lifetime driving experience and began accumulating it at an earlier age. This difference between older males and older females argues rather convincingly for the existence of a cohort effect.



Crash propensities are also affected by driver cohorts. The notion of cohort identifies a population group born within a certain period whose attitudes and behaviors reflect societal concepts and norms of the period they were growing up. One such example could be the level of motorization of the society. In 1940 approximately 25% of all drivers in the U.S. were aged 40 years or older and approximately 2% were over 65. Similar data for 1990 indicate that approximately 43% of drivers were over 40 years old, and that approximately 13% were over 65. Based on these trends, today's middle-aged and elderly drivers have a significantly greater familiarity with and dependence upon automobiles than those of the past.

Gender differences noted in the previous slide could be also attributed to the cohort effects. were younger. Today's elderly population grew up in a patriarchal period in which males dominated the driving task. Even though women have been in the labor force for a long period, they make shorter work trips than men do. In the 1940s and 1950s when significant numbers of women entered the labor force, certain societal factors imposed limits on the location of their workplaces in relation to homes. Such factors, including family obligations as shoppers and homemakers as well as commitments to raising children, influenced the amount of driving women did. Therefore, older female drivers may not have gained as much driving experience as male drivers when they were younger, and older women are now faced with the necessity to drive to fulfill their mobility needs.

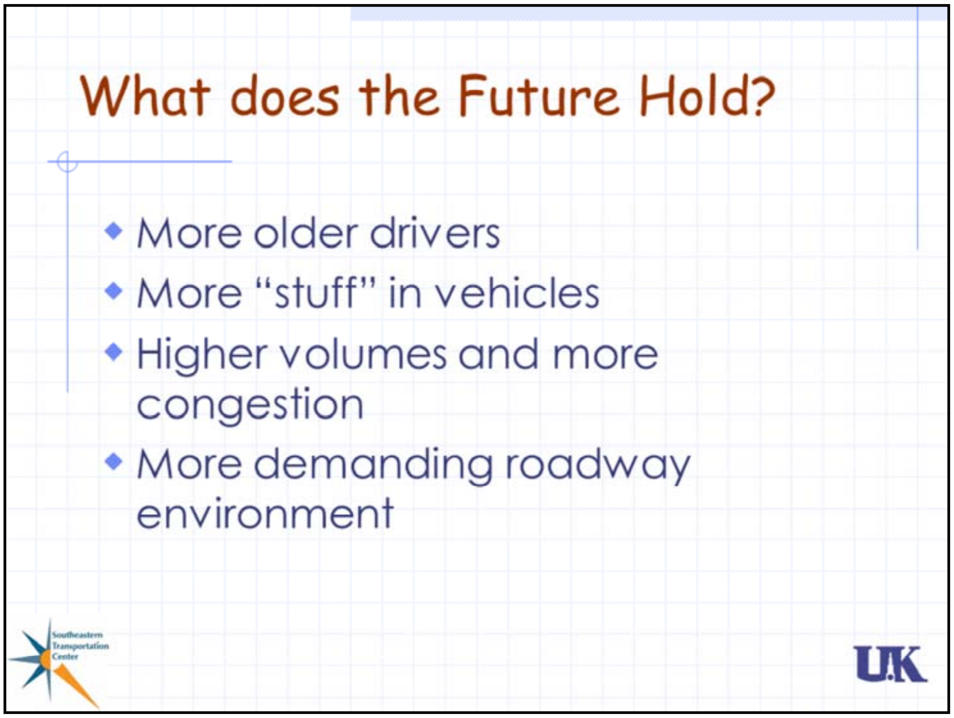
The data here indicates that older cohorts exhibit an decreasing crash propensity risk, which could be attributed to cohort and temporal effects. One could argue that safety improvements in the driving environment between 1978 and 1988 would also have contributed to improvements in older driver performance. But safety improvements in the driving environment would likely beneficially affect younger as well as older drivers: the crash statistics suggest a deterioration in the relative safety of younger drivers between 1978 and 1988. This supports the cohort explanation for these trends.



Past research has identified a series of findings in relation to the crash involvement of older drivers. Overall, female drivers are safer, i.e., have a lower involvement rate, than males. This could be attributed to the lower risk-taking behavior that females exhibit. On the other hand, older males have lower involvement rates than older females. This could be due to differences in in the amount of driving that females did when they were younger. The elderly population of the 1990's grew up in a patriarchal period in which males dominated the driving task and thus, older female drivers may not have gained as much driving experience as male drivers when they were younger.

Current young cohorts exhibit higher crash involvement than their peers in the past which may be indicative of a greater risk-taking behavior.

Older drivers have a higher crash involvement in crashes where a turning maneuver is required which may be indicative of their reduced visual capabilities (ability to correctly estimate speed of oncoming traffic) and a lower in rear end crashes, which may be indicative of applying compensatory means to offset slower reaction times. Similarly, older drivers have higher crash rates at intersections and in urban areas, where metal workload may be higher and thus could possibly create slower or improper reactions. Finally, young drivers have higher crash rates in rural areas which may be indicative of the higher risk-taking behavior when there are few other vehicles present.



The number of older drivers is expected to increase in the near future. As noted previously, forecasts of the Bureau of the Census indicate that over 20 percent of the population in 2030 will be over 65. The current trends of motorization and dependence on the automobile indicate that the number of older drivers will continue to increase at least at the same rate as the population.

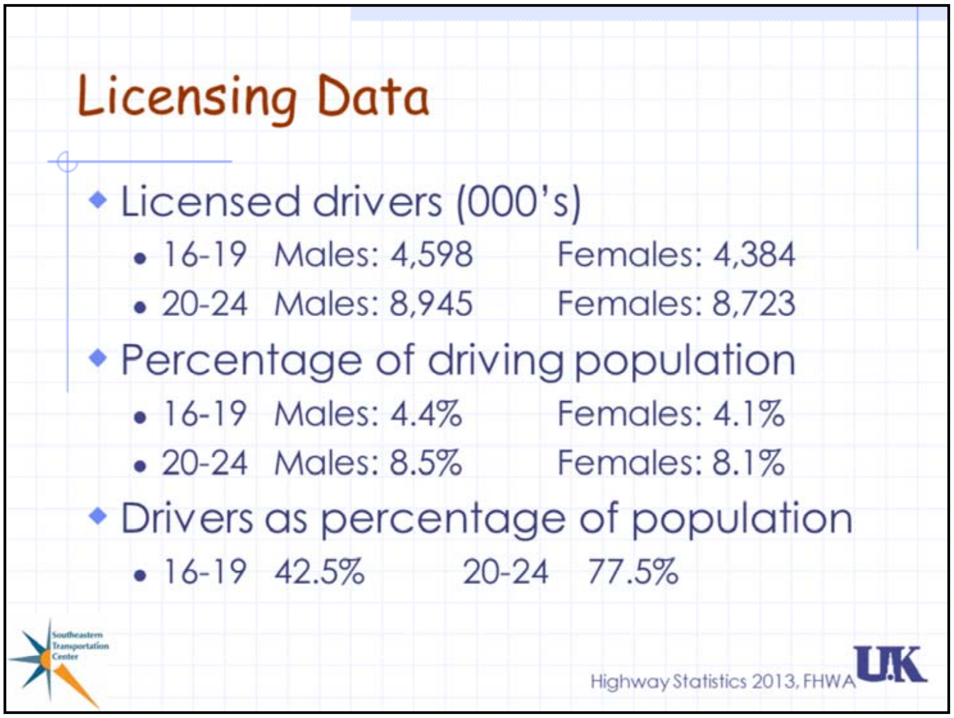
Over the past decades significant improvements have been achieved in the motor-vehicle industry with respect to vehicular safety. A number of safety devices have been introduced, such as antilock brakes, which have contributed to a reduction in the number of crashes. At the same time, navigation displays, mobile phones and other devices may detract the driver from the driving task and could potential reduce their ability to properly react to a traffic situation.

At the same time, the number of vehicles on U.S. roadways has increased, and continual future increases are possible. Drivers must deal with congested roadways and must spend significant time being delayed by congestion. Increased travel and large vehicle fleets are more conducive to crash occurrences and reduced roadway safety.

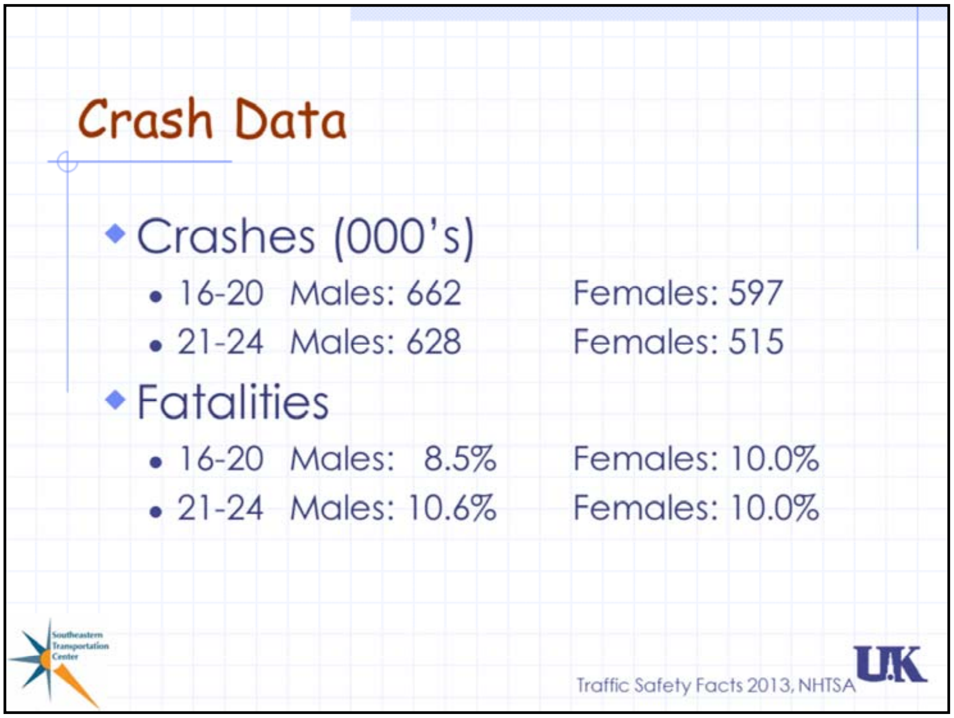
There are also changes in the roadway environment that may affect older drivers as well. The increased used of electronic messages, construction zones with reduced lane widths and alternative routes, new traffic devices (roundabouts for example), signs and signals could have an influence on older drivers to properly recognize them and react to them.

Question: How can we address these future challenges?

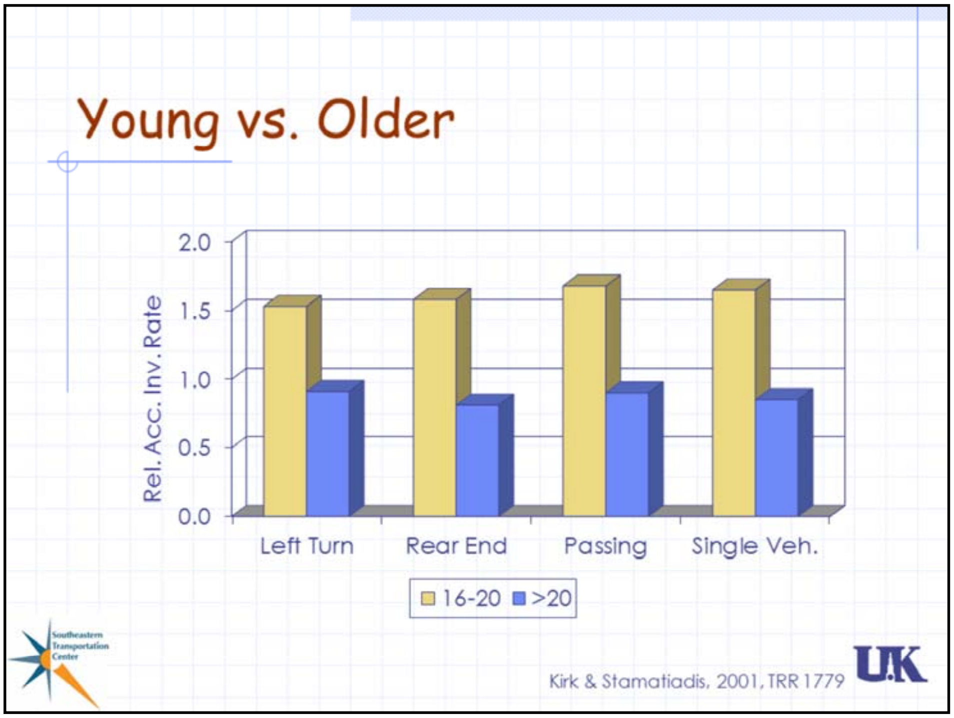
Answer: Education has seemed to be a tool used in the past mainly to inform older drivers about their changes and how to cope with possible limitations and implement techniques to avoid difficult situations. www.SeniorDriving.AAA.com is such a program that can help older drivers understand their limitations and what techniques may work for them.



The 2013 licensing data indicate that young drivers are a small fraction of the driving population (under 13 percent). These numbers have been in a small decline for the past decades. In 1994, they accounted for 14.6 percent of the driving population and the numbers were approximately the same (about 24 millions). Of interest though is the percentage of drivers within the 20-24 age group where in 1994 this was 87.2 percent. This may indicate shift in driving habits for young drivers and possibly a lower reliance on automobiles to meet their mobility needs.

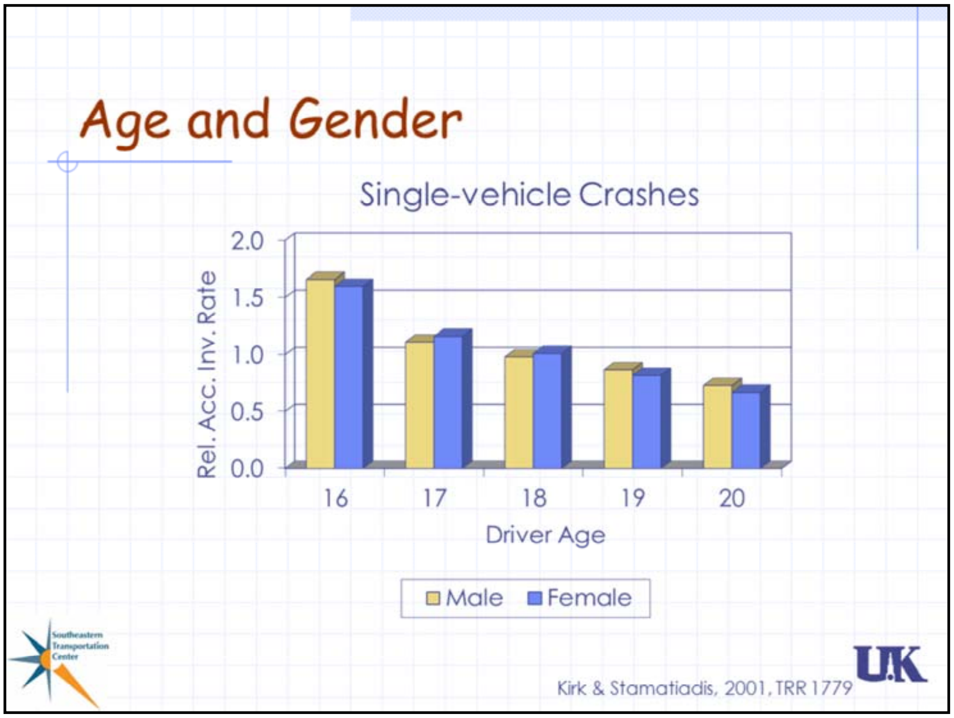


The crash data of young drivers also reveals some gender differences. In general, young novice drivers (16-20) make up 4.3% of the driving population but they are involved in 12.5% of all crashes and 8.7% of fatal crashes. This presents a serious issue for teenage drivers, since they seem to cause almost three times more crashes per driver when their licensing numbers are concerns (12.5/4.3). In a quarter of the fatal crashes, the young driver had a BAC of .08 or above. Motor vehicle crashes are the leading cause of death for this age group. These figures improve for the next group of young drivers (21-24) where they represent 8.3% of the driving population and they are involved in 11.4% of the crashes and 10.3% of the fatal crashes.

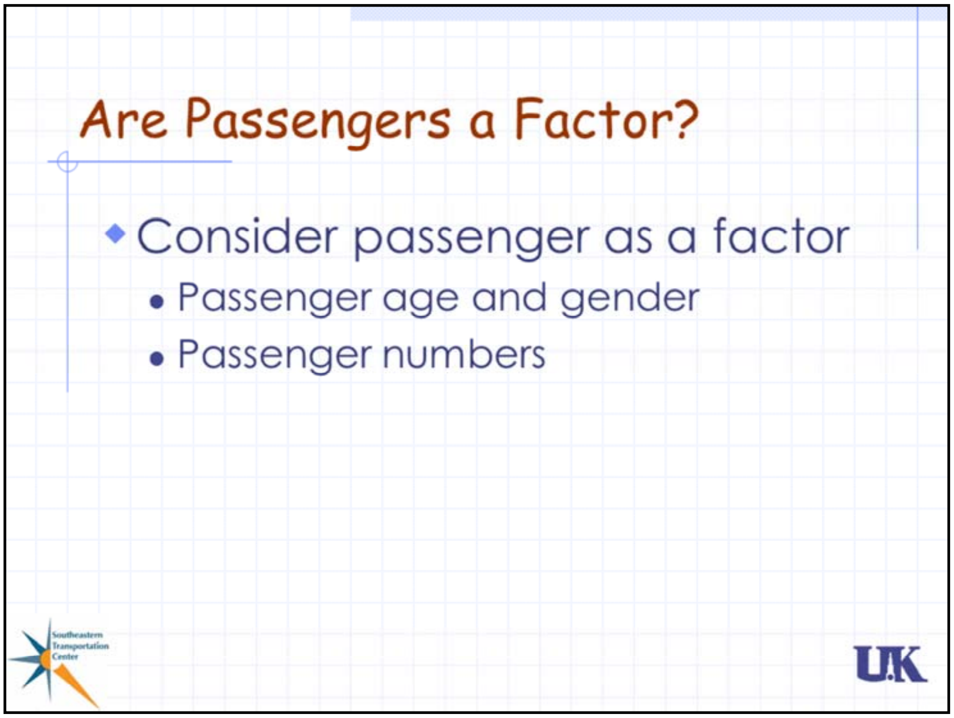


A study using Kentucky crash data and comparing young drivers' specific crash patterns against drivers over 20 showed the following:

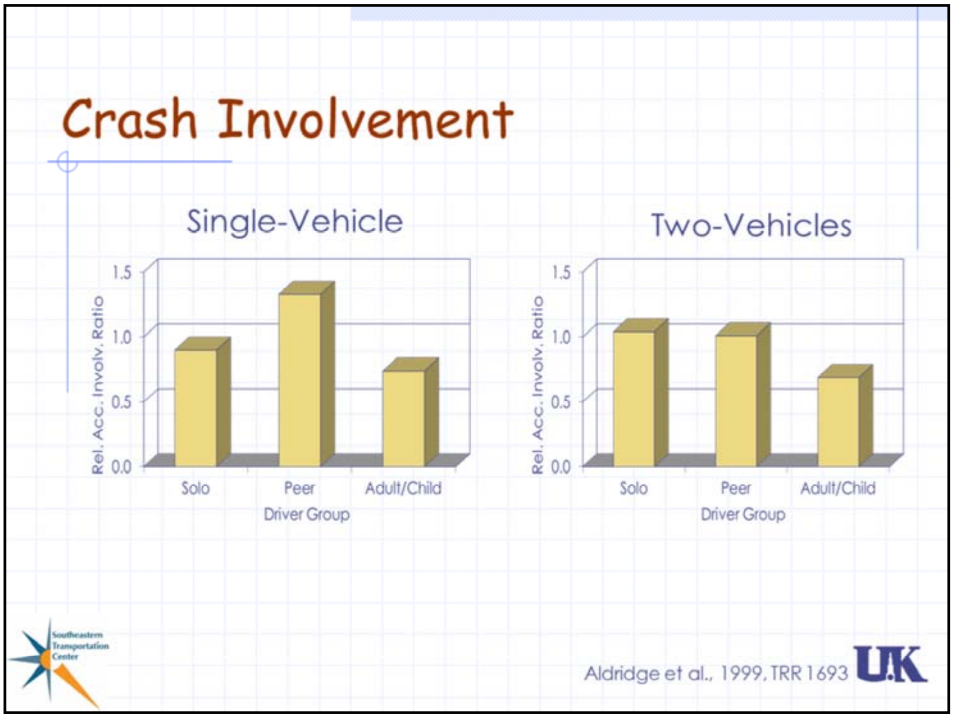
- Left turning movements exhibit a crash characteristic affected mainly by the ability of the driver to handle the demands of maneuvering a vehicle through the traffic. This factor is consistent with the trend of decreasing crashes with increasing age, since drivers gain experience with the passing of time. Young drivers exhibit a higher crash involvement rate as older drivers mainly due to their reduced experience-related abilities to estimate gaps and handle and maneuver the vehicle.
- Although the general trend of decreasing involvement coincides with increasing age, it is unclear as to whether ability, experience or maturity governs youth involvement in rear end crashes. Due to significance found regarding the period of the day it may be hypothesized that motivational factors are the overriding factors in this type of crash.
- While it is obvious that motivational factors are responsible for the initial engagement and decision to pass another vehicle, they may not be responsible for the final execution of the maneuver. The increased crash involvement of younger drivers may be more reliant on the ability of drivers to differentiate between safe and unsafe passing conditions.
- Increased involvement of young drivers in single vehicle crashes could be mainly attributed to their inexperience and limited abilities to properly control a vehicle.



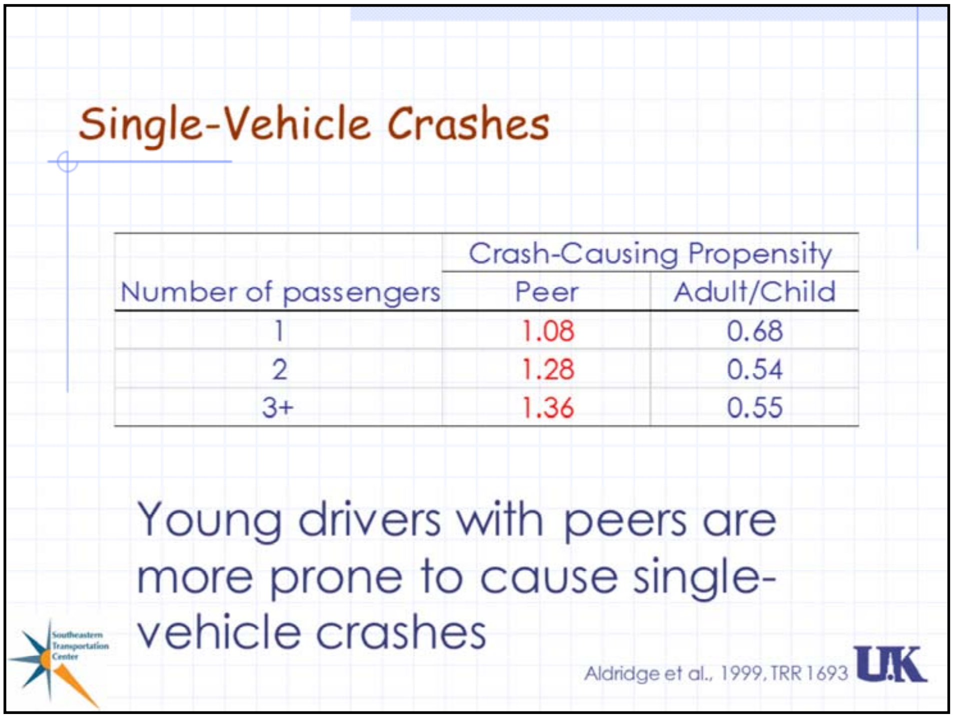
The figure here shows that females in the 17 and 18 year old age groups have a higher involvement in single vehicle crashes than males from the same ages. This may indicate a different maturing period between genders, where males may curb their risk-taking behavior after their first year of driving. This difference may also reflect a different starting point in driving behavior, where females start driving more frequently at a later age than males. Another possibility is that the female driving population is becoming more comfortable after the initial year of driving and thus engaging in higher risk driving, closely paralleling the trend of the younger males.



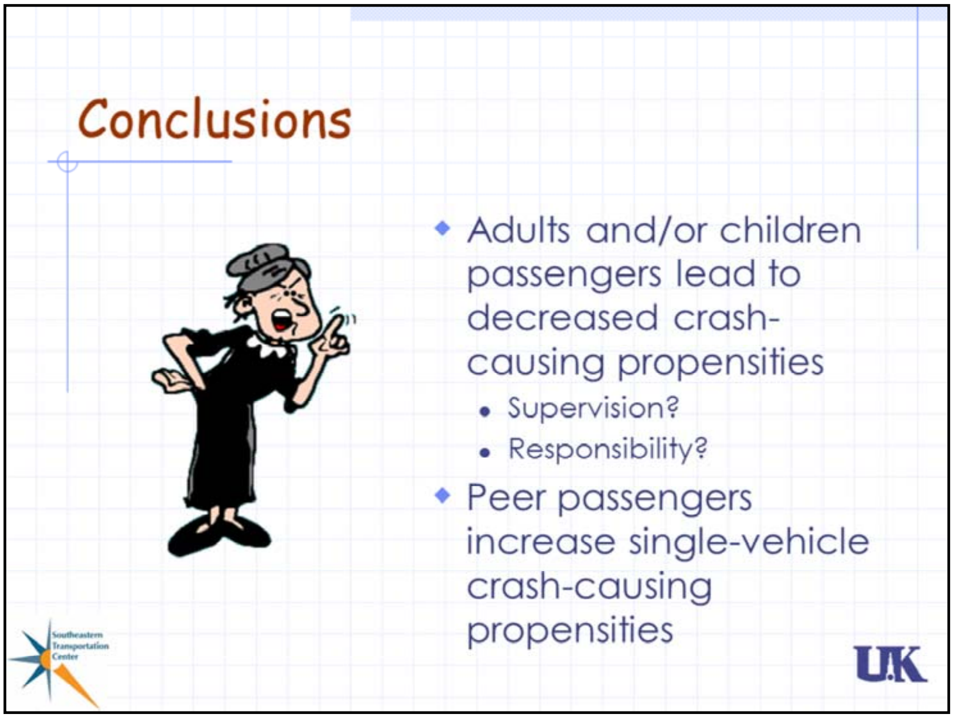
There is the possibility that passengers can have an impact on driving performance of young drivers. Recent studies have documented that increased passenger occupancy increased the likelihood of crashes of drivers 16-19 years old with a dramatically increased risk when there are 3 or more passengers in a car. Young drivers were two times as likely to be involved in a crash when there were one or more passengers, and 16-19 year old males remained the population at greatest risk in all categories. In a study of young Swedish drivers, risky driving (i.e. speeding and dangerous maneuvering) was shown to coincide with the fact that peer and societal pressures made younger drivers feel the need to engage in these types of activities. Peer pressure is obviously more pronounced when there is a high peer occupancy rate, and it increases significantly in the presence of passengers.



Overall, the young drivers are safest when traveling with an adult or child for both single and two-vehicle crashes. When traveling with peers, the propensity to cause a single vehicle crash is greater than the two-vehicle accident, with a RAIR value of 1.3. This suggests possible distractions by the peer group or peer pressure contributing to risk-taking. This is further supported by the fact that 31.4% of the peer group crashes involved travel at an unsafe speed. This compares to just 23.7% and 17.7% for the solo and adult/child passenger groups, respectively. Moreover, the adult/child category is the lowest of the three, suggesting that driver attitude does indeed change for the better when there is some form of supervision or responsibility in the car. The RAIR values are close to 1.0 when the young driver is alone for both single and two-vehicle accidents suggesting that the youths are relatively responsible when alone.

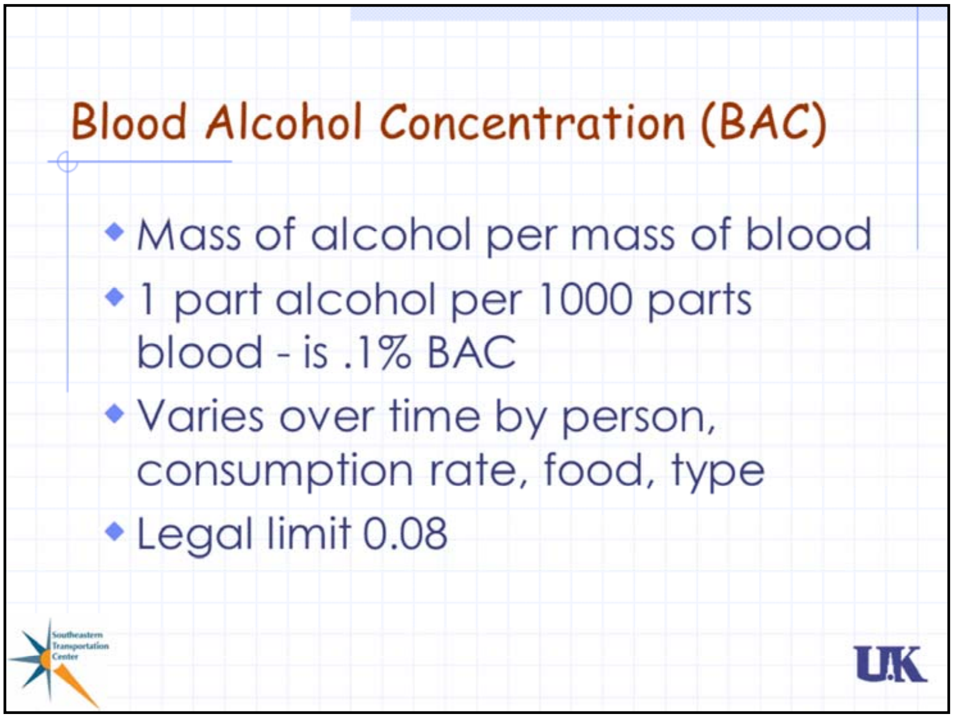


The number of passengers could affect the crash-causing propensity of the young drivers with different passenger groups. The number of passengers may reasonably affect peer pressure or distraction for younger drivers increasing their likelihood to cause an accident with more passengers. The RAIRs values for the peer group demonstrate that crash propensity increases with an increase in the number of passengers, which may be indicative of the fact that the driver must deal with increased peer pressure and distractions, thus compromising driving safety. The adult/child category shows an opposite trend; it decreases with the increase in the number of passengers. This may be attributed to the fact that increased supervision, or an increased sense of responsibility for multiple passengers, causes young drivers to be more cautious.



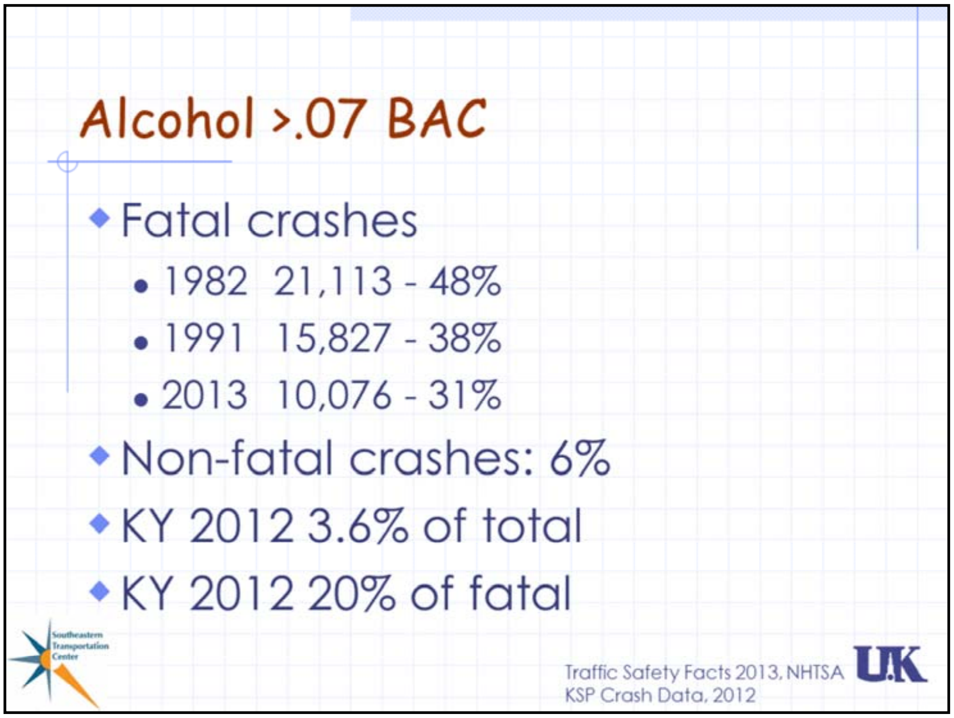
Passenger group was found to have a significant effect on young driver crash propensities. Young drivers have the lowest propensity to cause single or two-vehicle crashes when traveling with either adults and/or children. They have increased propensity for causing single vehicle crashes while traveling with peers. The relative accident involvement ratios for both single and two-vehicle accidents for young drivers traveling alone were close to 1.0. The results suggest that risk-taking is a factor (as opposed to only skill or experience) in young driver safety. These results support the Graduated License requirements for the presence of an adult for teenage drivers.

This module will discuss the effects of alcohol on crashes and identify current trends and issues as they relate to crash involvement due to alcohol consumption or use of alcohol while driving.



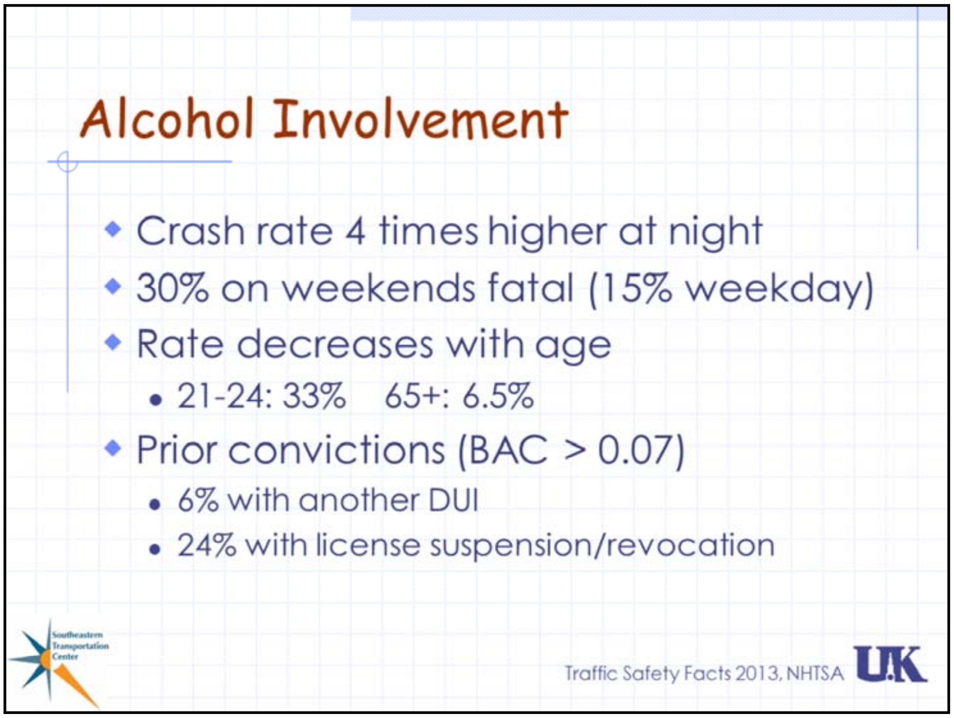
Blood Alcohol Concentration is the amount of alcohol that is contained in the blood. This is measured as the ratio of the two masses and is typically expressed as percentage of BAC. It should be noted that the concentration is highly dependent on various factors including size of person (heavier and larger people typically display lower BAC for the same consumption when compared to thinner and smaller people), consumption rate (drinks spread over time will have a lower BAC due to absorption than if consumed in very short time), food accompanying drinks (different foods accelerate or reduce the rate with which alcohol is absorbed in the body), and type of alcohol (alcohol content is different in beer, wine or hard liquor).

Legal limits for been considered intoxicated vary by state and driver age. All 50 states have a legal limit for driving under influence 0.08 BAC (i.e., one can be ticketed for BAC of 0.08 and above) and 0.04 BAC for truck drivers. Most states have an additional limit for underage drivers ranging from 0.00 to 0.02 BAC.



There is a reduction of crashes over time that involve drunk driving. There has been a reduction of approximately 37% over the past 20 years in the numbers of drunk driving related crashes and they now represent a smaller percent of the total number of crashes 931 vs 38 in 1991). Overall, this represents a significant reduction from 1982 where these were 21,113 fatalities representing 48% of the total number of fatalities!

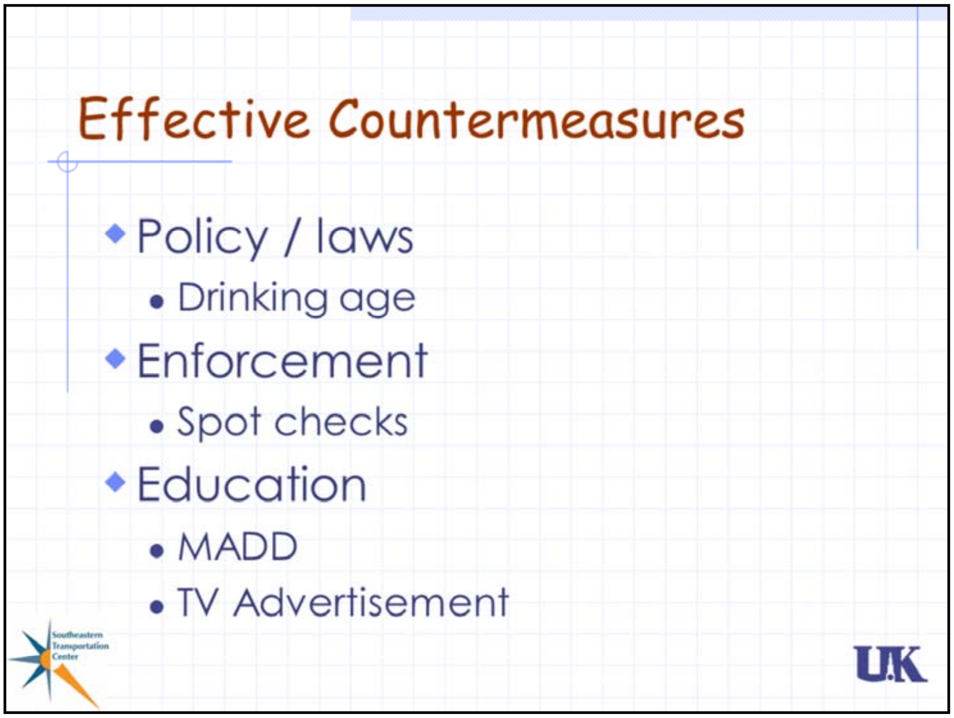
The number of drivers with high BAC involved in all crashes is relatively small (6%). The numbers for Kentucky are lower than the national averages with an overall crahs involvement of drivers with BAC >0.07 at 3.6% of all crashes and 20% of fatal crashes.



Most of the crash statistics verify the higher level of crash involvement of drivers impaired by alcohol and they follow typical patterns of alcohol consumption. The rate of alcohol impairment among drivers involved in fatal crashes in 2013 was nearly 4 times higher at night than during the day (35% versus 9%). Weekends also show a higher involvement rate of driving under the influence drivers with a 30 percent involvement in fatal crashes as compared to 15 percent of all drivers involved in fatal crashes during the week. Both of these are indicative of social norms of higher alcohol consumption typically at night (here is 6:00 pm to 5:59 am) and weekends.

In fatal crashes in 2013 the highest percentage of drivers with BACs of .08 or higher was for drivers 21 to 24 years old (33%), followed by ages 25 to 34 (29%). The proportion of drivers involved in fatal crashes with BACs of .08 or higher is reduced with age and drivers over 65 have an involvement rate of 6.5 percent.

Of interest is also here to note that there is a large number of drivers with BAC 0.08 that had prior convictions and license related issues as a result of driving while intoxicated (DWI). The data shows that 24 percent of the drivers involved had a their license suspended or revoked for some time as a result of a DWI and 6 percent had another DWI in the past. It should be noted though that this reflects only the prior three years of the drivers' records, since this is available in the FARS database.

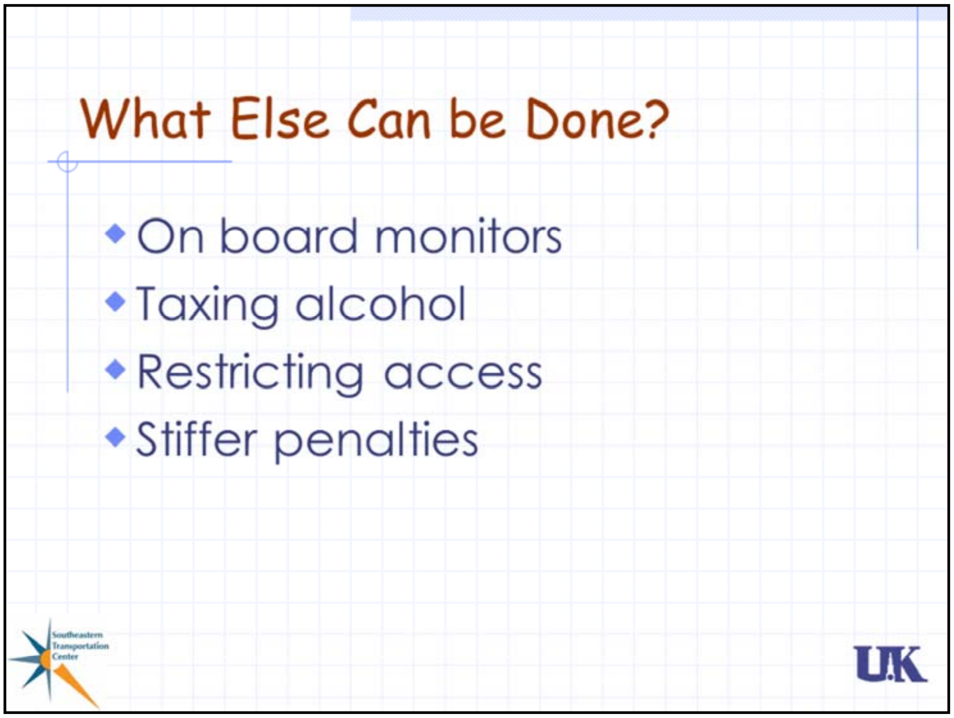


Since the 1980's a number of efforts have been initiated to combat the drunk driving problem in the US. The countermeasures that have been effective in reducing the number of fatalities according to the Insurance Institute of Highway Safety (IIHS) have been a combination of public policy and laws, increased enforcement and education. In 1984, the national Act of Minimum Drinking Age was passed establishing the age of 21 as that when one can legally buy and consume alcohol. The Act also included provisions for states to initiate programs to reduce drunk driving. As a result, after the passage of the Act several states have revised their drunk driving laws and have changed the penalties and licensing restrictions associated with DWI. To date, 42 states (excluding KY, MT, MI, NJ, PA, SC, SD and TN) have initiated an Administrative License Suspension (ALS) after the first DWI and all states have some type of ignition interlock, in which judges require all or some convicted drunk drivers to install interlocks in their cars to analyze their breath and disable the engine if alcohol is detected.

Enforcement has also increased over time and sobriety checkpoints are a common event at certain times (weekend nights and holidays are more common occurrences). IIHS noted in 2001 that sobriety checkpoints are effective but they are not used as often as needed to become more effective.

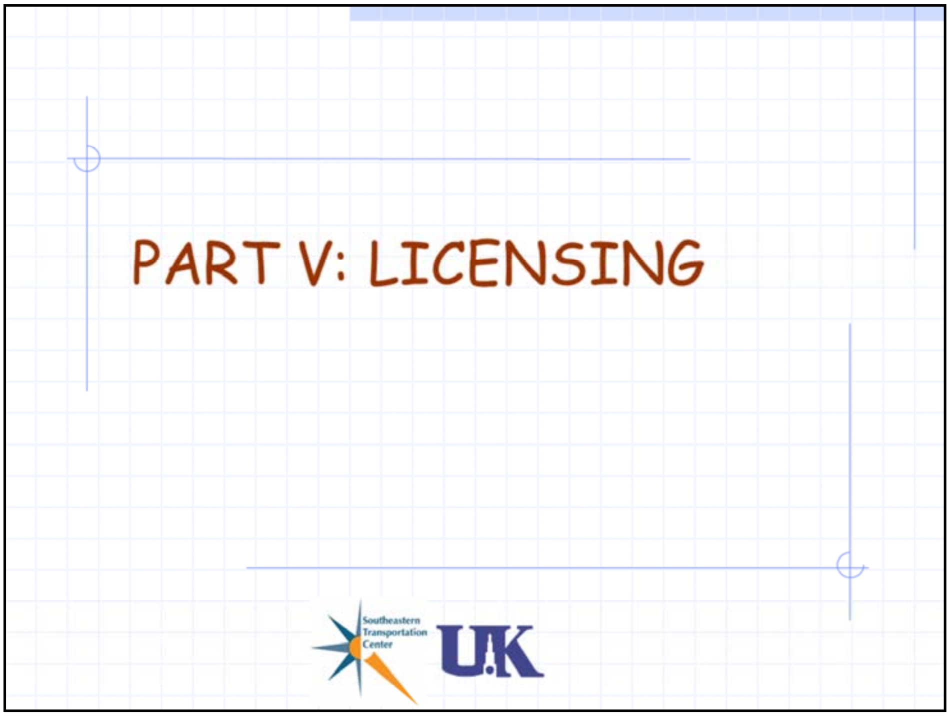
Education has also been very effective in changing attitudes and perceptions regarding drunk driving and its effects. The Mothers Against Drunk Driving (MADD) was started in 1980 after the daughter of Candy Lightner was killed by a drunk driver with several prior DWI convictions and releases. The initial focus of the organization was to reduce drunk driving and deal with the associated issues. However, recently the focus has been shifted to reducing alcohol use overall, which has lead to criticism of the organization.

Until 1996, there were almost no television advertisements for alcohol. It should be noted that there has never been a law prohibiting this. Since then, several companies advertise alcohol but they have to adhere to the rule that no alcohol should be ingested during the advertisement.

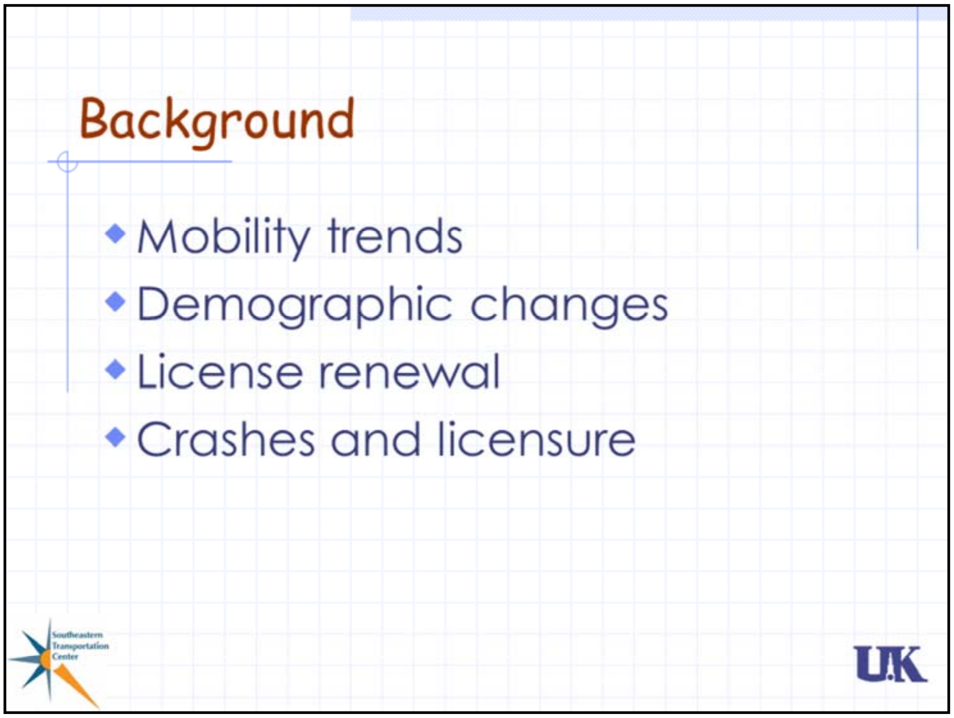


These are some ideas that may assist in curbing drunk driving and possibly reducing the number of fatalities due to high BAC.

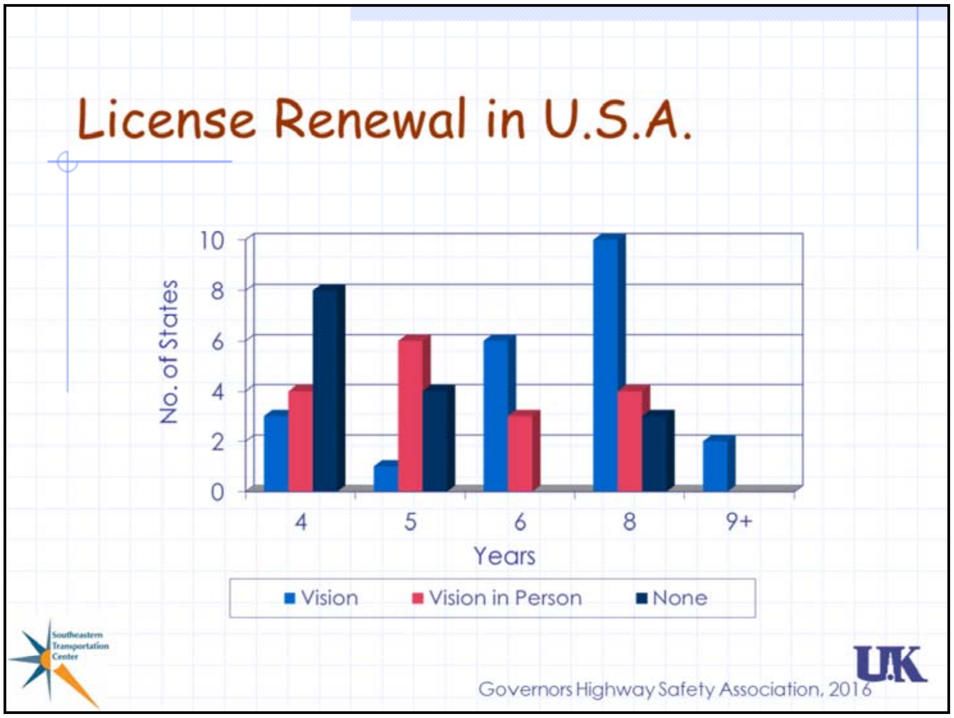
- On board alcohol monitors is an effort under way that could automatically detect alcohol levels in the driver's breath and lock vehicle from driving. According to an IIHS survey, 64 percent of the public supports such a system.
- Higher taxes for alcohol has also been considered a deterrent for consumption. This coupled with restricted access (locations or time of sales) has been viewed as means for curbing its availability. Both practices are in effect in Scandinavian countries where alcohol is highly taxed (for example, tax on liquor in Sweden is about 40%) and there are sate controlled selling points which are often difficult to access by car and they have limited hours of operation (again Sweden has such a system). However, these measures do not deter alcohol consumption, since there are always ways to go around the prohibitions. For example, Swedes are traveling to Denmark to purchase alcohol at significant reduced prices or stock up to avoid running out during closing periods.
- Another approach is to introduce stiffer penalties for DWI and this is the concept of the Administrative License Suspension (ALS) after the first DWI . The suspension length varies among states from 90 days to 1 year and there are several states that also confiscate or impound the vehicle and license plates.



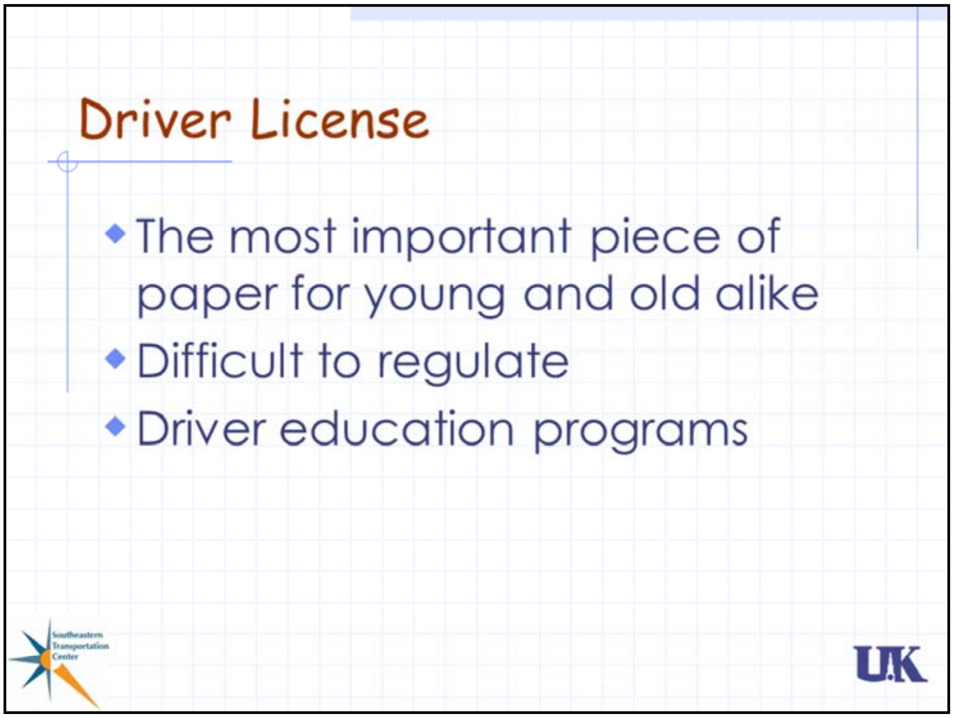
This module discusses current efforts with regards to licensure and how they may affect crash rates.



The greater dependence of people of all ages on automobiles to fulfill their mobility needs over the past years has generated a larger than ever number of licensed drivers. In 2013, there were 212 million licensed drivers representing 83 percent of the population who can drive. The demographic changes discussed earlier (larger expected number of older drivers and an overall aging of the population) has lead some states to reconsider licensing procedures and frequency for drivers over a certain age. Most states have a periodic license period varying between 4 to 6 years and some require specific tests (vison and/or roadway) as part of the renewal. There have been a few studies that attempted to correlate crash involvement with prior infractions as those reflected though historical traffic records. These studies attempted to identify potential crash-prone drivers based on historical infractions and their results have shown mixed promise.



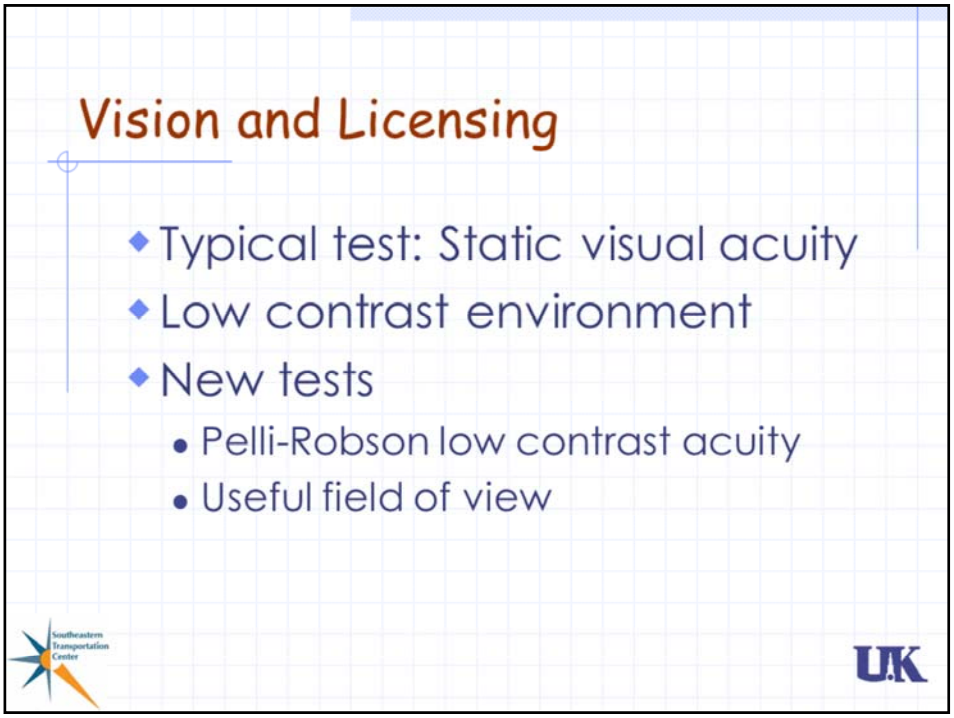
The license renewal procedures vary among states but they all follow a similar pattern. First time applicants are generally required to provide proof of identity and take vision, written and road tests. Drivers renewing their license are typically asked to take a vision test or provide proof of a recent test. What mainly varies among states is the length between renewals with a current trend of longer times and providing the opportunity for online or via mail license renewal. These changes reduce administrative costs in addition to making the process more convenient for the public. The majority of states (18) have an 8-year period or longer (Arizona has a 12 year period and South Carolina 10) and most states (39) require a vision test or proof. Most states (23) require this for every renewal while the remaining require it when renewal is in person (in this case they allow renewal via mail or online but require every other renewal in person).



Driver license is considered as the most significant identification that a person can hold. For young persons, this signifies their entry in the adult society while for older persons holding on to their license indicates continued active membership in the society. Studies have shown that older drivers who lost their license suffer from psychological problems and they fight before they surrender their license. Moreover, the current dependence on automobiles and lack of other real transportation alternatives exacerbates the significance of the driver license.

Driver licensure is typically difficult to regulate. While it is easier to impose rules and the Graduated Driver License (GDL) system for young drivers, it is extremely difficult to impose an age restriction for older drivers due to the diversity of the rate with which deteriorations due to aging are manifested. It is commonly understood that inexperience is a common factor among young drivers and as such the use of the GDL program can assist in gradual gaining of experience. On the contrary, the aging effects vary among individuals and establishing a universal age beyond which restriction could be applied is not possible.

Driver education has been recently reintroduced as part of the GDL that has been implemented throughout the USA. NHTSA and other agencies are promoting driver education as an integral part of crash prevention for young drivers and are developing a curriculum for teenage drivers to address various issues to improve their safety performance. An issue that has been recently discussed is the content and delivery of the driver education programs and the need for a balance between classroom and practical applications.



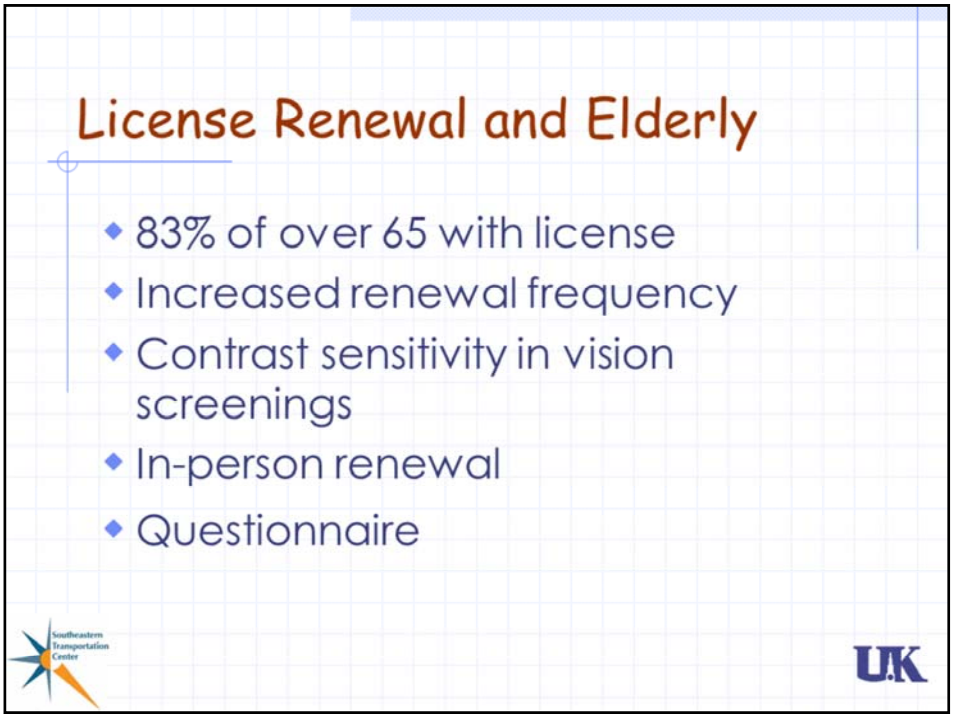
Typically, static visual acuity tests, which measure the ability of drivers to discriminate high contrast targets, are conducted for license issuing and renewal. However, low contrast environments (e.g. fog, rain, dusk) actually pose significantly more problems for drivers and their visual search. Therefore, current vision tests may not adequately identify drivers with visual problems.

Typical visual acuity tests consist of reading letters from a Snellen chart with high contrast letters. Other charts which evaluate visual acuity for low contrast letters have recently been tested for implementation in license renewal in California (Hennessy 1995). The study showed that the use of a Pelli-Robson low-contrast acuity test can identify drivers with potential vision problems that could contribute to unsafe driving practices. This test uses charts similar to Snellen charts but the letters progressively fade out as if they were being read in increasingly thicker fog conditions. The research also pointed out that this test requires additional investigation to compare it with existing practices and to verify its impact on identifying at-risk drivers.

The size of the useful field of view (UFOV), a test of visual attention, has been found to have high sensitivity and specificity in predicting which older drivers had a history of crash problems. Older adults with substantial shrinkage in the UFOV were six times more likely to have caused one or more crashes within the previous five years (Ball et al. 1993) . Also, the types of crashes in which older drivers were over-represented seemed to implicate visual difficulties. Moreover, a large-sample study reported that the small subset of drivers with severe visual field loss in both eyes had crash and conviction rates twice those in the general population.

Ball, K., Owsley, C., Sloane, M., Roenker, D., and Bruni, J. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science*, Vol. 34, No. 11, pp. 3110-3123.

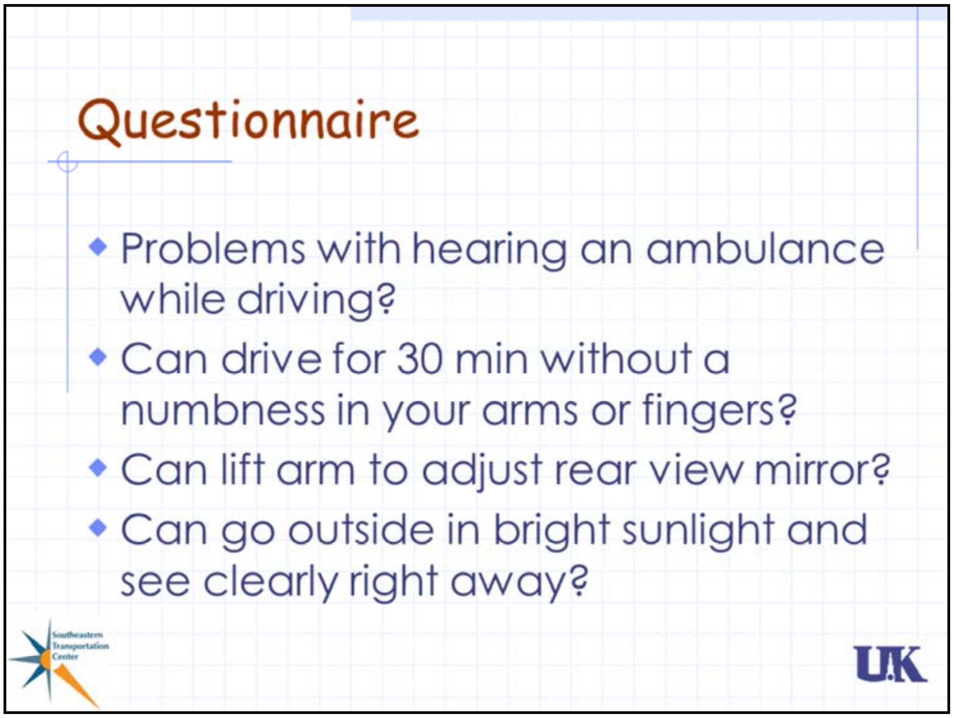
Hennessy, D. F. (1995). Vision testing of renewal applicants: Crashes predicted when compensation for impairment is inadequate. RSS-95-152, California Department of Motor Vehicles, CA.



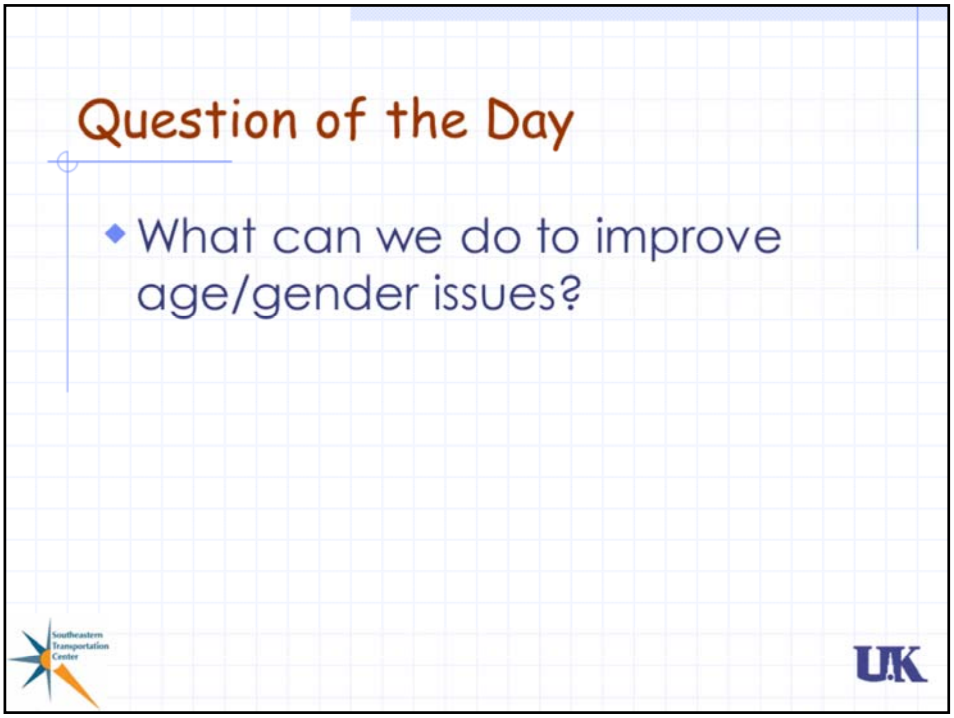
The demographic statistics indicate a significant increase in the number of licensed older drivers in the future. In 2013, 83 percent of those over 65 are holding a driver license as compared with only 73 percent in 1993. Currently, there are 20 states with shorter renewal periods required for drivers over a specified age and 19 of them require more frequent vision screening/testing for older drivers. Moreover, 15 of the states that allow online or by mail renewal do not allow this option for older drivers. In addition, Maryland and the District of Columbia require a physician's approval for drivers 70 and older to renew their licenses and Illinois requires applicants older than 75 to take a road test at every renewal.

Contrast sensitivity measures how the eye and brain respond to both sharply defined black-on-white targets with clear boundaries and those with fuzzy edges in varying shades of grey. This is amore appropriate measure of the range of targets and objects a driver may have to decipher and this is more critical for nighttime conditions. It is therefore important to consider including such tests during renewal to properly address the driving needs.

As noted above, in person renewal is a practice that several states have initiated for persons over a specified age and this could be used as visual observation of the overall physical abilities of a person. “In-person” driver license renewal allows for the licensing agent to visually observe the driver and evaluate his/her general physical and cognitive abilities for driving. While several states provide guidance and/or training to their licensing agents regarding the identification of potentially hazardous signs and symptoms of drivers while they renew their licenses, a simple line of questioning at the time of renewal could allow the agents to perform a basic screening regarding mentally impaired drivers.



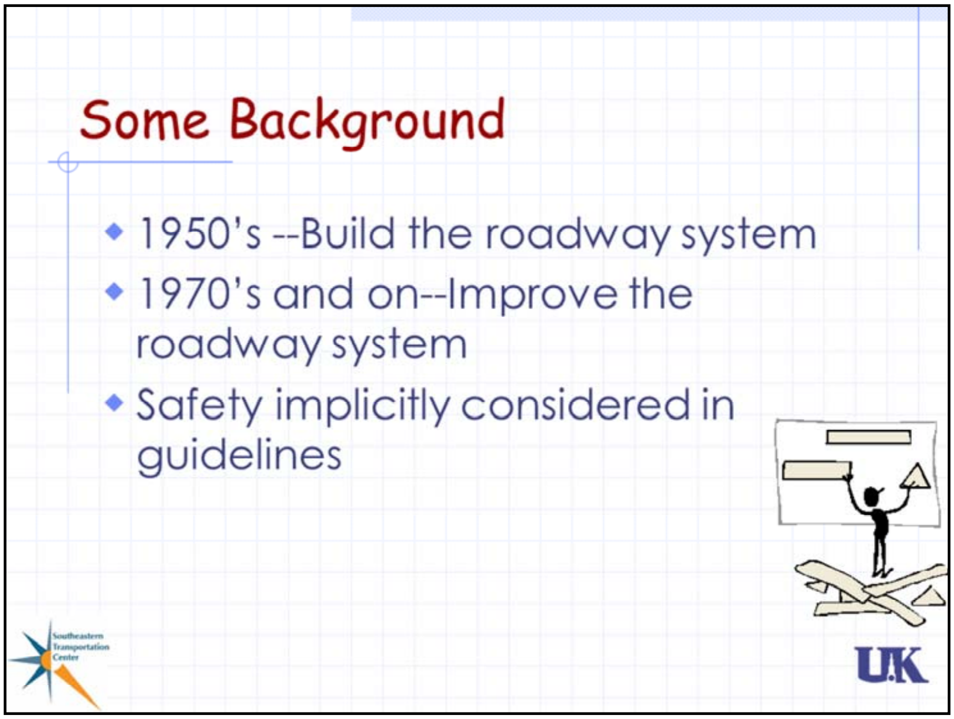
Medical conditions and symptoms have been shown to affect the driving task and elderly drivers are more susceptible to a variety of medical problems related to aging. The inclusion of a questionnaire during the driver license renewal process identifying possible medical problems for the elderly has been examined and suggested in previous research, and it is currently used in a few states. This issue has also been legally cleared by Americans with Disabilities Act (ADA), and it has been recommended to include a standardized form of simple medical questions that could determine whether an applicant may have certain medical problems that would affect his/her driving abilities. This questionnaire would be of higher significance for areas where reporting by physicians is not mandatory or is not widely publicized, and it could be completed at the time of renewal by the licensing agent. The questions above are a sample of questions that could be asked in the questionnaire. The objective of the questions is to identify potential issues without been blunt in asking questions such as can you see or do you have any physical limitations. The indirect approach is more appropriate because it will also put participants at ease and provide the opportunity to extract the information easier.



Question: What are some of the areas where changes can be implemented to improve the issues that have been discussed here to address gender and age concerns?

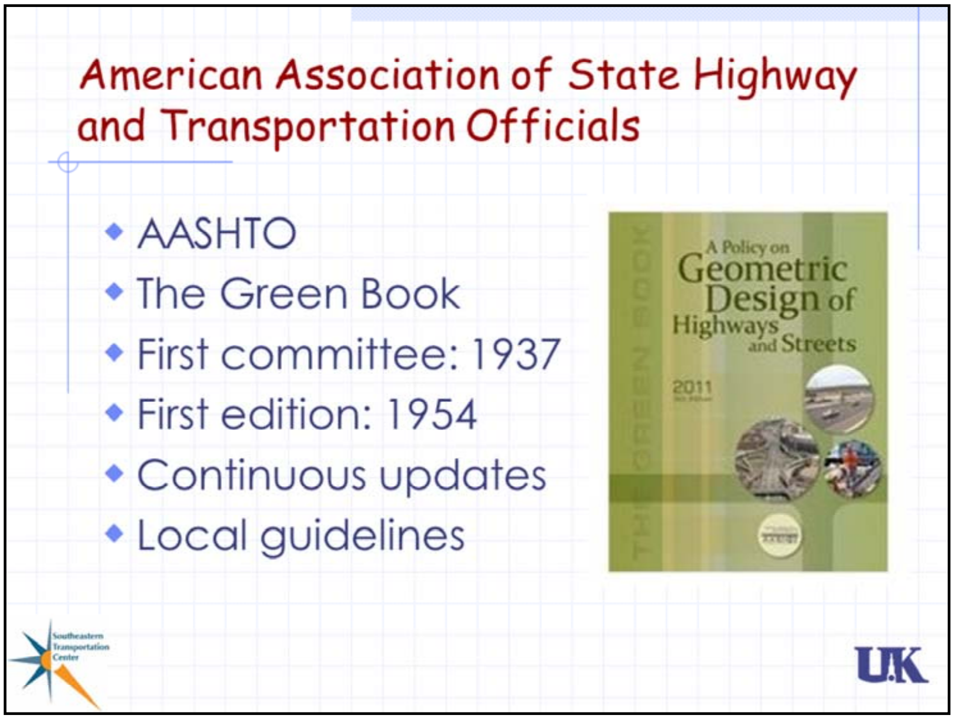
Answers: Targeted roadway improvements for older drivers (brighter signs and with higher reflectivity; introduction of advanced warning signs; wider edge lines; symbol signs; improved pedestrian crossings); examining licensing practices, and improving driver education content and frequency for both young and older drivers.

In this module we will discuss various aspects of highway design and their potential effects on roadway safety. As noted in the introduction, factors contributing to a crash can be related to human, roadway and vehicle failures. Frequently human and roadway factors interact contributing to a crash during and can influence the severity of the crash. For example, a distracted driver running of the road after hitting a pavement-shoulder separation. Prior research identifies the roadway contribution to about 10 percent of the crashes. The module will discuss such issues and how they could be alleviated and provide insights on possible countermeasures to improve roadway safety.



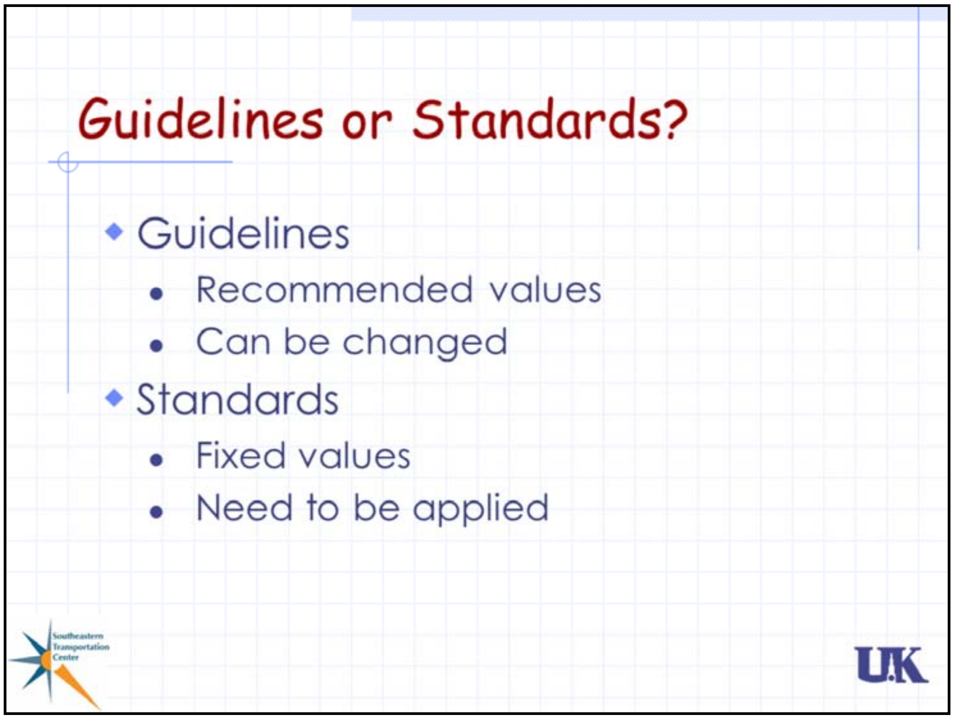
In the early stages of roadway network development, the focus was on developing and building a network system. In 1950s when highway mobility was the main issue, concerns are mostly on getting people from one place to another. Most of the guidelines developed were based on rudimentary safety studies, if any, and safety was a secondary thought in the development of the system. The first time that the US government realized that there is a safety issue was after a study in 1966 where it was determined that 50,900 people were killed in the nation's highway resulting in 5.5 fatalities per 100 million VMT. This resulted in the *Highway Safety Act of 1966,* which required states to develop and implement a highway safety program. As a result, in 1995 the fatality rate was down by 69 percent (to 1.73 fatalities per 100 million VMT).

In the 1970's, AASHTO started considering the safety of the highway system and in 1974 they defined that "A safe roadway is one in which none of the driver-vehicle-roadway interactions approaches the critical level at any point along its length" (AASHTO , Highway Design and Operational Practices Related to Highway Safety, 2nd ed., 1974). In 1995, AASHTO also develops a strategic highway safety plan with a goal of reducing fatalities to 37,000-39,000 by 2004 (the actual number was 42,836). Even though the goal was not reached, significant gains were made towards the desired reduction and efforts continue to date.



AASHTO is an organization made of representatives from all 50 states and has the responsibility of developing guidance for roadway design in the US. This guidance in reported in the *Policy on Geometric Design of Highways and Streets*, often nicknamed as the *Green Book.* The first edition of the guidelines was in 1954 and periodic reviews and updates to reflect current knowledge have resulted in the most recent edition of 2011. Older editions started as a collection of state practices and later research findings were incorporated as they became (or are becoming) available.

The goal of the Green Book is to provide guidelines for a safe and efficient roadway network system. Design guidelines often identify minimum acceptable design criteria that, if adhered to, are intended to provide a safe highway design. However, strict adherence to the minimum values may result in situations where the abilities of the driver will be stretched resulting in an unintended unsafe situation.



The notion and differences between guidelines and standards need to be addressed here. Guidelines are recommended values that can be used as the basis for initial design and can be varied as needed to fit the context of the roadway. On the other hand, standards are established values that cannot be changed and have to be applied during the design process. If one considers the lane width as an example, the Green Book provides guidance as to the width to be used based on the functional classification of the road and allows the designer to select a value from a range (say 10-12 feet). However, for freeways, the lane width is viewed as a standard value of 12 feet and thus freeways have to be designed with 12-foot lanes.

An issue of concern is that many designers have viewed the suggested values of the Green Book as rigid standards instead of guidelines to be used in roadway design to achieve a reasonable degree of flexibility based on the roadway surroundings. This can lead to the erroneous assumption that the roadway will perform safely (see notes on nominal and substantive safety slide 8). Hauer examined the belief that adherence to design standards is directly linked to safe roadways and he found that design guidelines have an inherent safety level but there is little known of what will be the impacts of using flexibility in applying them in roadway design.

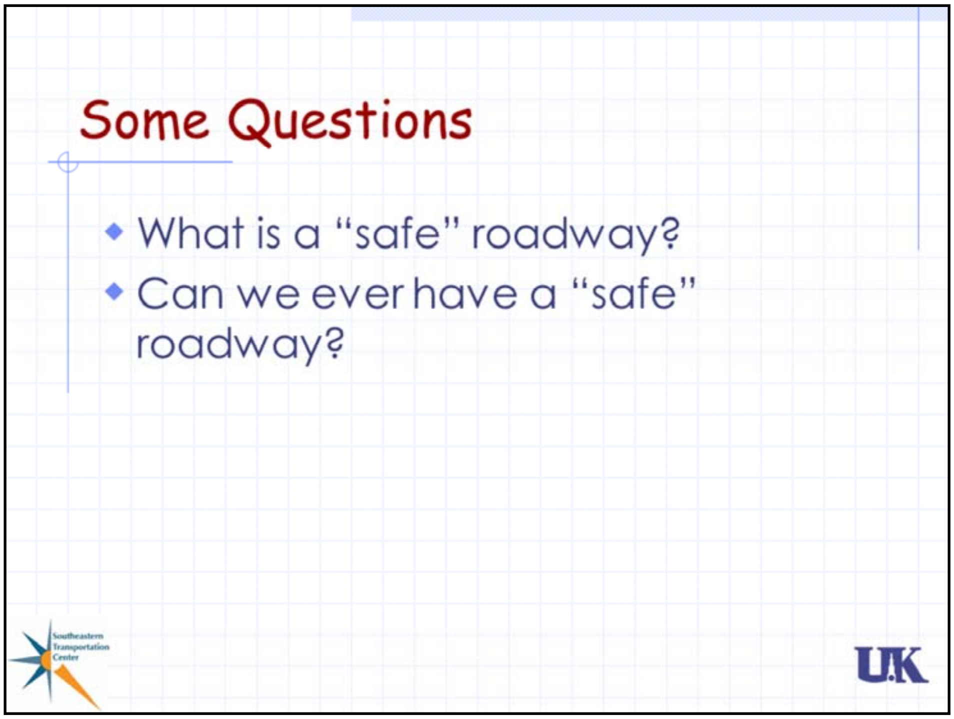
Hauer, E. Safety in Geometric Design Standards I and II, in *Conference Proceedings of 2nd International Symposium on Highway Geometric Design*, Mainz, Germany (2000).

The need to develop roadway guidelines stems from a variety of issues. The AASHTO Green Book represents the common wisdom and collective knowledge of the profession as it has been developing based on prior experience and research findings. The guidelines developed allow for sharing the up to date expertise on roadway design and other related issues, such roadside design and bicycle facilities, and form the basis for roadway design. Even though every state has the option to develop their own guidance, all agencies either adopt the Green Book as their guide or develop some additional guidelines aiming to simplify the process and assist their designers in developing solutions customized to their local issues. This approach ensures that there common design aspects throughout the country and promotes design consistency among various jurisdictions. The common guidance also allows for consistent driver expectations, especially for those traveling at different areas and jurisdictions.

It should be noted form the outset that each design assumes a safety level. The main goal of the final design is to achieve a “reasonable” level of safety & service. This is also noted in the Title 23 of the US Code, Section 109, where safety is one of the key features that needs to be addressed when developing a design and needs to be balanced against other competing project priorities.

Every design assumes tradeoffs among costs, safety and operations and this is done continuously consciously or unconsciously. Examples of such trade offs could be considered the following:

1. Safety vs Operational efficiency: Often right turn on red is allowed to improve operational efficiency at the expense of safety
2. Safety vs Budget: Divided highways are frequently safer than other roadways but not all roadways are constructed with medians.



There are two basic questions on can ask at this point:

1.What makes a roadway safe?

The main focus of this question is to make the audience to identify elements that may make a road safe. Possible answers may be divided highways, wide shoulders and clear zones, straight roads, good pavement, roads with adequate capacity, and roads with no cars. This would play well in the next slide where each of these could be questioned.

2. Can we ever have a safe roadway?

The answer here is no. Even if we design a roadway to perfect dimensions, there are always elements that we can control including driver errors, weather conditions, and vehicular failures. What we are trying to do is design a roadway that will provide for reasonable safety and eliminate driver errors based on roadway failure.

The first picture shows a 4-lane divided highway with wide lanes, shoulders and adequate clear zones. The question posed here is whether this is a safe highway. The second picture shows a 2-lane facility with narrow shoulders and obstacles 4 feet from the travel lane. The same question is posed here as well.

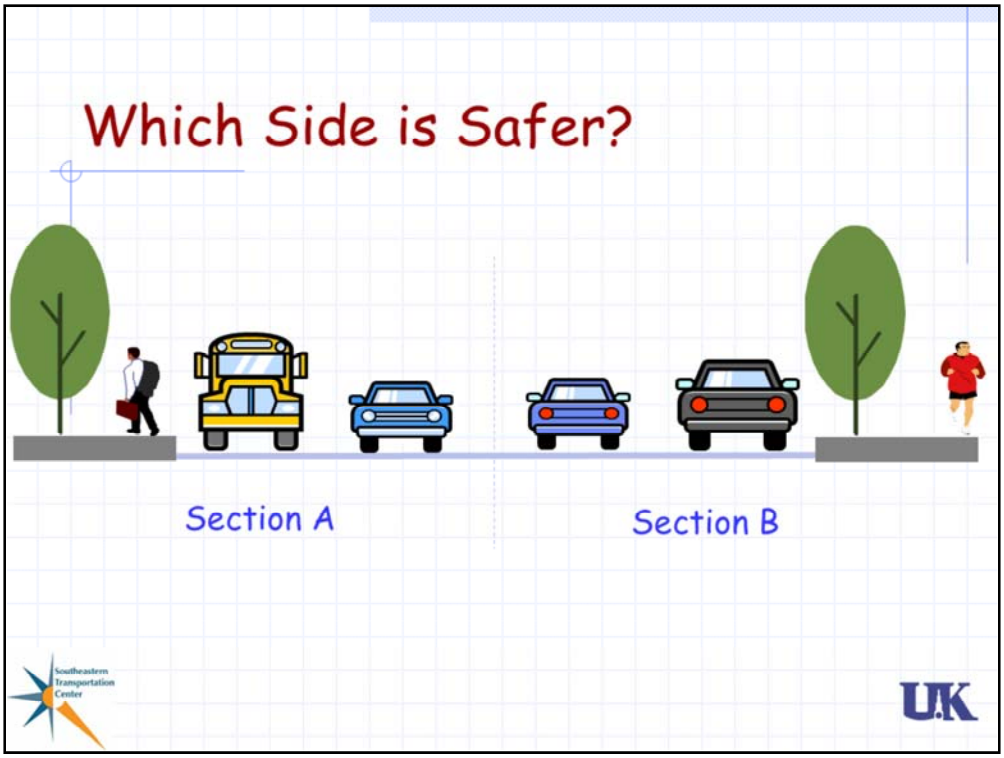
Question: Which of these two roads is safer?

Tying this with the questions in the previous slide, one may start considering the notion of a gray scale when determination of safety levels is considered. Possible questions from the audience could include: what is the crash rate for each section, what are the speeds for each section, and what are the traffic volumes. All these demonstrate the need for additional information to make the decision and the absence of a yes/no answer. The first segment has a crash rate of 62 crashes per 100 million VMT (24 crashes, AADT 35,000 over 3 years) and the second 61.5 crashes per 100 million VMT (2 crashes AADT 2950 over 3 years). Therefore, there are factors that one needs to consider when determining safety levels.

The previous discussion leads to the need for a different approach in roadway safety. According to Hauer, there are two levels of safety. The first, called nominal safety, identifies whether a system has been designed and constructed based on a set of criteria or standards. Compliance to the standards ensures safety and lack increases failure. An example of this could be the codes used for concrete and steel where lack of providing what the standards require (with respect to slab height or steel size and amount) will eventually result in a failure.

However, in roadway safety this is not the case. The fact that a roadway segment has been designed and constructed based on the guidelines (or standards) does not automatically ensure safety. In roadway, the concept of safety is called substantive that is based on the roadway's actual safety performance measured along a continuous scale and is expressed in crash frequency and severity of crashes. This reflects the notion that incremental changes in geometric design element values will result in incremental changes of safety and thus providing a continuum instead of an absolute yes/no as nominal safety dictates.

Hauer, E. *Safety in Geometric Design Standards* University of Toronto, Toronto, Canada. 1999.



Another aspect that should be noted regarding safety and determining the potential safety effects, especially when applying countermeasures, is the relative perspective of safety. Given the example above, both options could be viewed as viable alternatives but each could be considered different (or less safe) depending the users' perspective. For the drivers, Section A is "safer" since there are no trees by the side of the road that an errant vehicle may hit. On the other hand, for a pedestrian, Section B is "safer" due to the presence of a buffer between vehicles and them. This is an issue that further complicates safety and introduces the notion of targeted evaluation and designs that may require a more detailed examination of multiple impacts for each user.

Tort liability stems from violations of the legal duties and could result in a punishment. Tort liability has been a controlling factor for highway designs in the past where designers were afraid to deviate from the guidelines. The belief was that designing a facility according to standards will absolve them from any liability. However, this is not the case and a more appropriate manner to address liability is the documentation of all decisions made throughout the project development process, maintenance of decisions records, and following a clearly defined process for reaching decisions (AASHTO 2004).

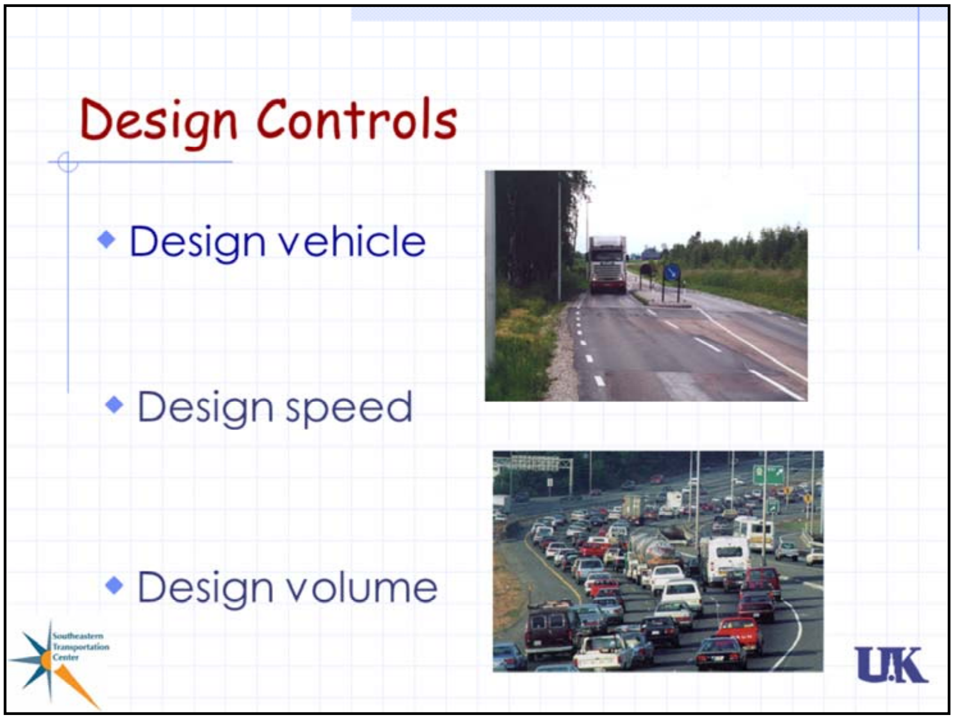
The Kentucky Transportation Cabinet's responsibility is to provide reasonably safe travel and warn the public as needed. This could be viewed as an effort to provide an as safe as possible system that is properly signed to provide information about potential unsafe situations. Kentucky is a state with sovereign immunity, which implies that the state is exempt from suit and any liability (or in plain words, the state cannot do wrong).

There are also two levels of negligence:

- Contributory: If the plaintiff contributed at all, then they are totally to blame
- Comparative: If the plaintiff contributed, then they are responsible for the percentage of blame assigned to them.

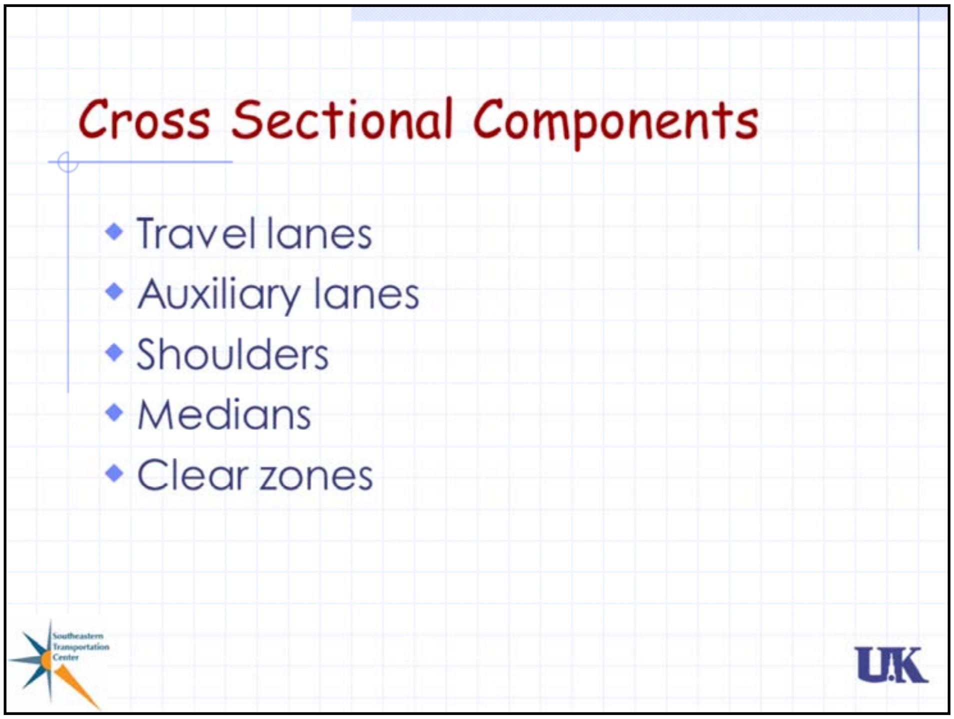
A Discretionary Function is defined as "one which requires exercise in judgment and choice and involves what is just and proper under the circumstances." A Ministerial Function is defined as "that which involves obedience to instructions, but demands no special discretion, judgment, or skill." (Black 2009).

AASHTO *A Guide for Achieving Flexibility in Highway Design*, 2004.
Black's Law Dictionary, Ninth Edition, 2009



There are a number of elements that a designer needs to deal with and those control the final design developed.

- Design vehicle is defined as the largest expected vehicle to use the roadway with considerable frequency. Physical and operational performance characteristics of the vehicle affect several elements of design (such as radius, grades, underpass clearance, driver's eye height, etc.). Selection is based on the context of the roadway and location and designers are urged to select a vehicle that represents a cost-effective choice for the project. For example, in an urban setting selecting a bus as a design vehicle instead of a semi-trailer (even if those can be seen on the road) may be more appropriate due to potential impacts on sidewalks and buildings and properties adjacent to intersections.
- Design speed is probably the most fundamental input to design. The current Green Book approach establishes most of the dimensions of the various design elements based on design speed and thus its selection affects all design aspects. Traditional practice has been the development of designs with as high a speed as possible. This conforms to the idea of high mobility but may be at the expense of safety. i.e., higher speeds may result in more crashes. The choice should be based on the context of the roadway, the intended operating speed, and the vehicular and non-vehicular traffic.
- Design volume defines the amount of traffic to be accommodated in the facility. Research has shown that traffic volume is the single greatest contributor to the risk of a crash. An issue of concern here is that a facility is designed based on future traffic and as such it may not be a very accurate estimate of traffic demand. The design volume has implications on the size of the roadway, since each design aims to accommodate traffic at a certain operational level. Balancing costs with safety and community needs is central in utilizing design volumes during the design process.



Various roadway components could impact safety and their implications are presented here:

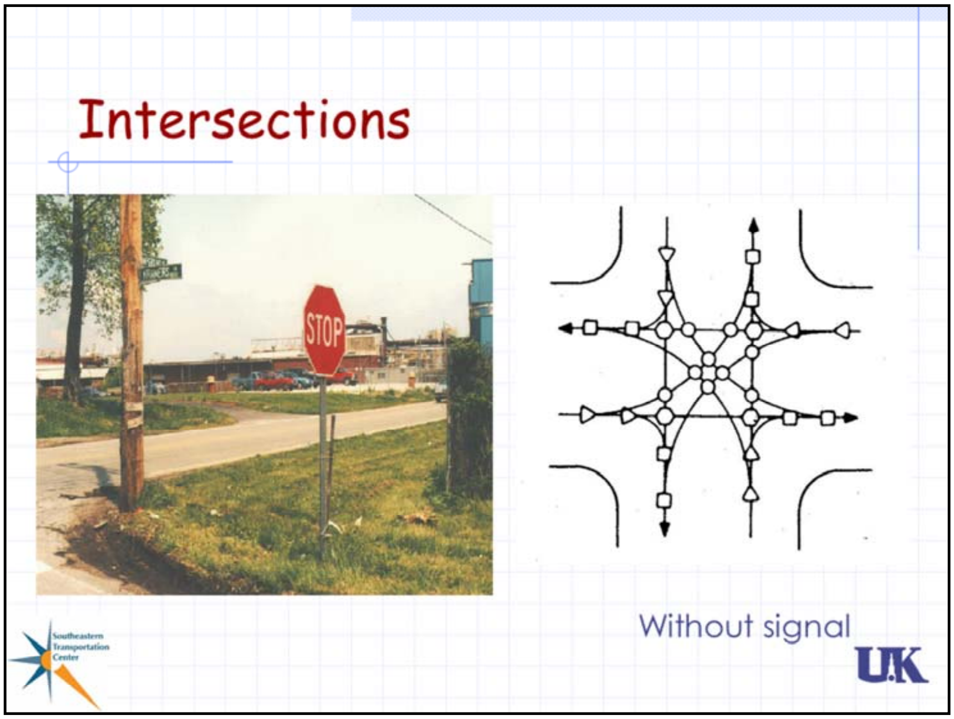
- Travels lanes: this deals both with the number of lanes as well as their width. Typically, wider lanes are associated with higher speed roadways and in general, wider lanes are safer than narrower lanes (HSM 2010). However, lane widths should be balanced though a cost-benefit analysis where the benefits from reduced number of crashes need to be evaluated against the cost of wider and more lanes.
- Auxiliary lanes: their presence at intersections has shown to improve safety (HSM 2010). The advantage is that they remove the turning traffic form the mainstream and allow for completing turning maneuvers as the drivers see fit.
- Shoulders: this deals both with the shoulder type and width. Typically, wider shoulders provide more room for drivers to correct any mistakes especially in situations where they run off the road. Similarly, paved shoulders have shown better safety performance than unpaved shoulders. The choice of width and type should be based both on anticipated safety performance as well its function (AASHTO 2004).
- Medians: this deals with median width and type as well. Medians provide for the separation of traffic and their presence has a positive safety effect, since it can reduce crossing over the opposite side of travel (HSM 2010). Median width should be balanced against other roadway elements and right of way requirements. Selection of median barrier type (if used) is also critical due to the addition of an element that can affect safety severity (concrete barriers are less forgiving than cable barriers).
- Clear zones: this mainly deals with the width provided beyond the end of the travel lanes. Keeping the adjacent are free of obstacles is essential in order for errant vehicles to avoid hitting them. This is another element where costs (right of way) need to be balanced against potential safety issues and appropriate remedies (removal, relocation, modification, shielding and delineation).

Current research efforts examine the combined effect of these treatments to determine what these implications are, i.e., multiplicative or additive, or which of these factors may be the most critical for highway safety.

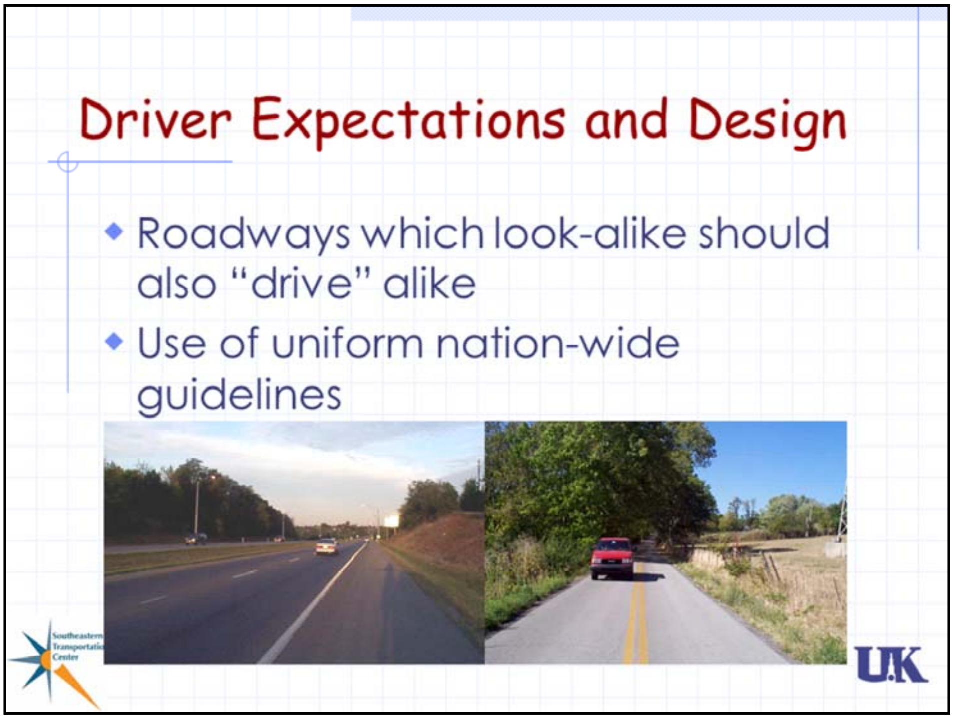
Design exceptions are a process utilized by state transportation agencies when there is a need to develop roadway designs that require deviation from the prevailing guidelines and policies. Designers rely on design guidelines and policies, which aim to address safety, mobility and economic goals. Sometimes, however, it may not be practical to conform to all these guidelines. For example, it is possible that adherence to a certain geometric specification may create environmental implications, affect historical structures, be economically unfeasible or affect a community in an undesirable way. In these cases a design exception can be used to address these deviations.

FHWA has identified 13 design elements that are considered appropriate for consideration when design exceptions are requested. These include cross sectional elements, such as lane and shoulder with, cross slope and bridge width, alignment concepts, such as vertical and horizontal alignment, superelevation, and vertical and horizontal clearance, and stopping sight distance and structural capacity. It should be noted here that these are the criteria that FHWA requires a formal process for requesting deviations from the guidelines of projects in the National Highway System (NHS) and it does not preclude the need to alter other design elements if such deviations from policies are needed.

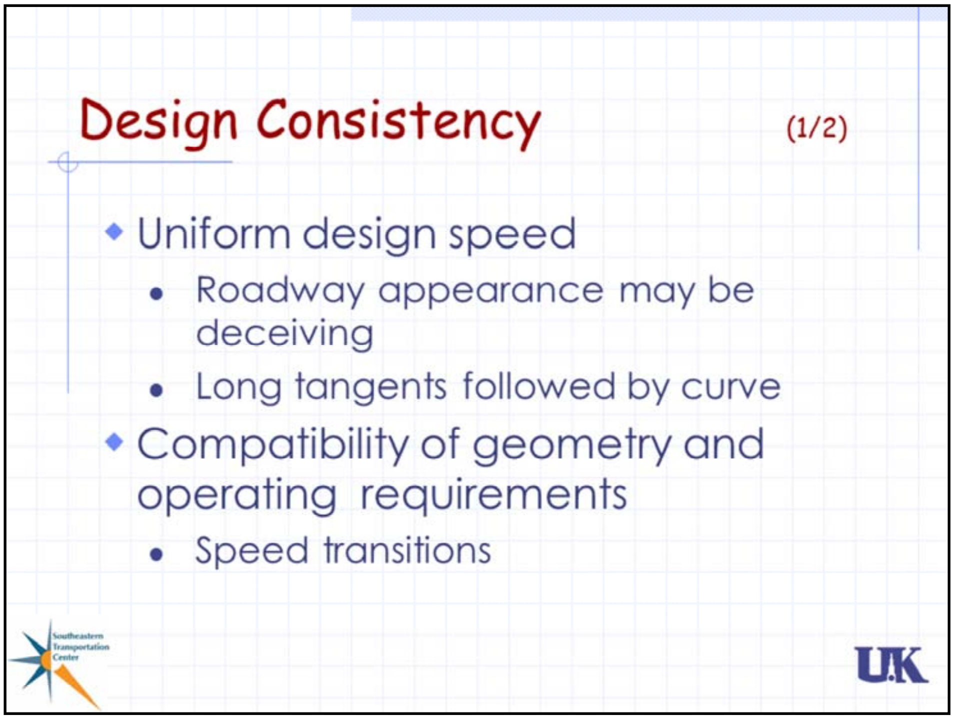
Design exceptions require a formal process where the need for the deviation is identified and explained. Most states have developed a form that identifies required and proposed values for the elements to be altered and require a short write up to justify the need for the exception. Recent efforts have also included the need to attempt an estimate of the potential impacts of the design exceptions where safety, operational, and economic impacts need to be identified.



Intersections are the most complex roadway element because it requires roadway users to make simultaneously multiple decisions. The user needs to be aware not only of the traffic next to them but also traffic coming from all other directions as well as traffic controls that could pose restrictions to their movements. A typical 4-leg intersection controlled by a stop sign has 32 points of potential conflict (places where streams of traffic cross paths) as opposed to three or four conflict points on an access controlled highway. Left turns at an intersection are the most difficult maneuver (16 of the 32 points are left-turn related) and as such efforts to improve safety have concerted in the use of signalization (protected left turn phases) and presence of exclusive left-turn lanes.



Drivers form expectations of a roadway with respect to how to drive on it based on their visual cues. The notion that roads that look alike should also drive alike is paramount in providing a safe environment. For example, the road in the left picture gives the impression that it can be driven safely with high speeds due to the wide lanes and shoulders and presence of a median. In this case it looks like a high-speed facility and the driver expects to be bale to drive it as such. On the right side, the restricted cross section indicates the need for lower speeds and the driver should conform to the road environment and adjust speeds accordingly. Problems may arise when the way the road looks does not coincide with the manner with which drivers can drive. For example, a very sharp curve on the left picture is not expected and it may lead to unsafe operating speeds, while a sharper curve could be easier negotiated in the right picture due to presumably lower speeds. The use of the uniform nation-wide guiltiness aids in this aspect.

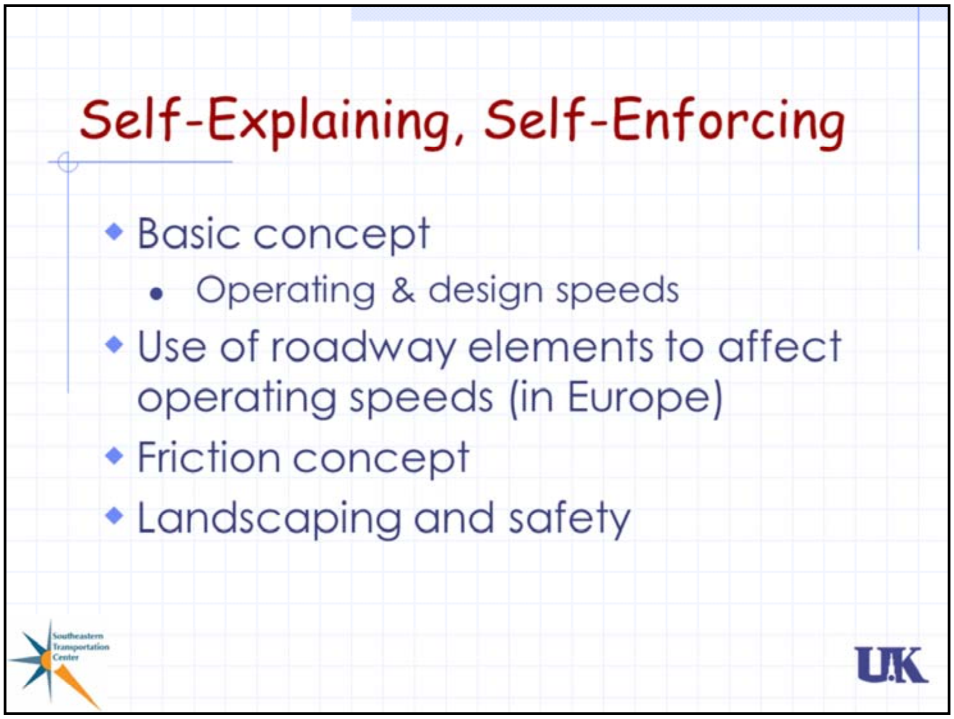


Design consistency is central to roadway design and safe performance. The notion of using the same design speed throughout the roadway does not guarantee that the roadway has been designed in a consistent manner. The ideas noted in the previous slide about driver expectancy have an immediate application here. Roadway appearances may be deceiving and provide drivers with a false sense of security and operating performance. For example, long tangents followed by sharp curves are not considered a good and safe design practice and as such should be avoided. Another element that needs to be considered is how one transitions from one element to another (for example from a straight segment to a curve). Current models allow for the estimation of the speed differential in such transitions and provide values that render them unacceptable and unsafe requiring attention to be paid in such locations.

This picture highlights the concept of design consistency. The preceding tangent was designed at 45 mph and the posted speed limit was also 45 mph. At the far end of the road shown here there is a fairly sharp curve (deflection angle of 100^{o}). Driver operating speeds at the leading segment are fairly high resulting in unexpected braking when approaching the curve. Signing is not very helpful (or effective given the tendency of drivers to misunderstand or ignore signing due to proliferation of warning signs) and safety concerns have been raised at this location requiring some remedy.

The picture shows a 4-lane divided roadway segment with a 45 mph speed limit with curb and gutter in an urban area. The roadway conveys an image of a fairly open roadway where speeds can easily exceed the posted speed limit. The driver perceives that there is ample space to correct any mistakes and thus can drive at speeds that feel comfortable and may exceed the posted speed limit.

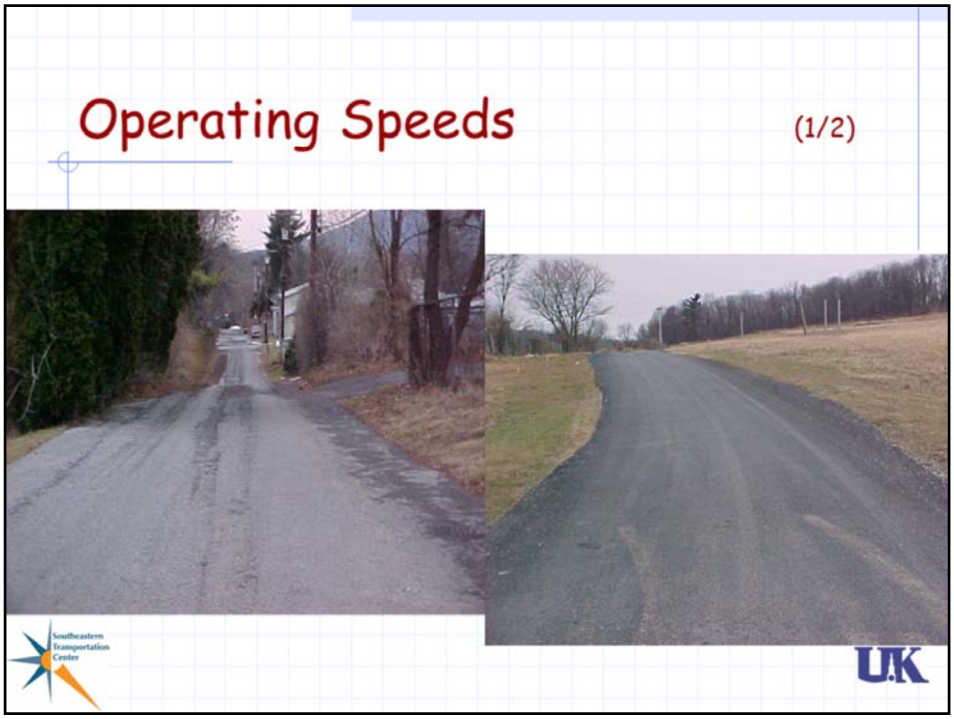
This is a location less than 2,000 feet away from the previous picture. The speed limit has been changes to 35 mph without any additional changes to the cross section that may encourage drivers to reduce their speeds. This is also a similar phenomenon noted in transitions from high speed rural to built up areas where we rely on posted speed limit signs to change the operating speeds. As noted above, reliance in signs to enforce speeds and inform drivers may need to be revisited, since drivers tend to ignore them.



A new idea is taking root mainly in Europe for developing roads that are self-explaining and self-enforcing. The concept was initiated in Europe (Denmark, Netherlands and Germany) and its focus is on developing a roadway design consistent with desired operating speeds. The self-enforcement part of the design comes from the introduction of design elements that will prohibit the user to exceed the desired operating speed.

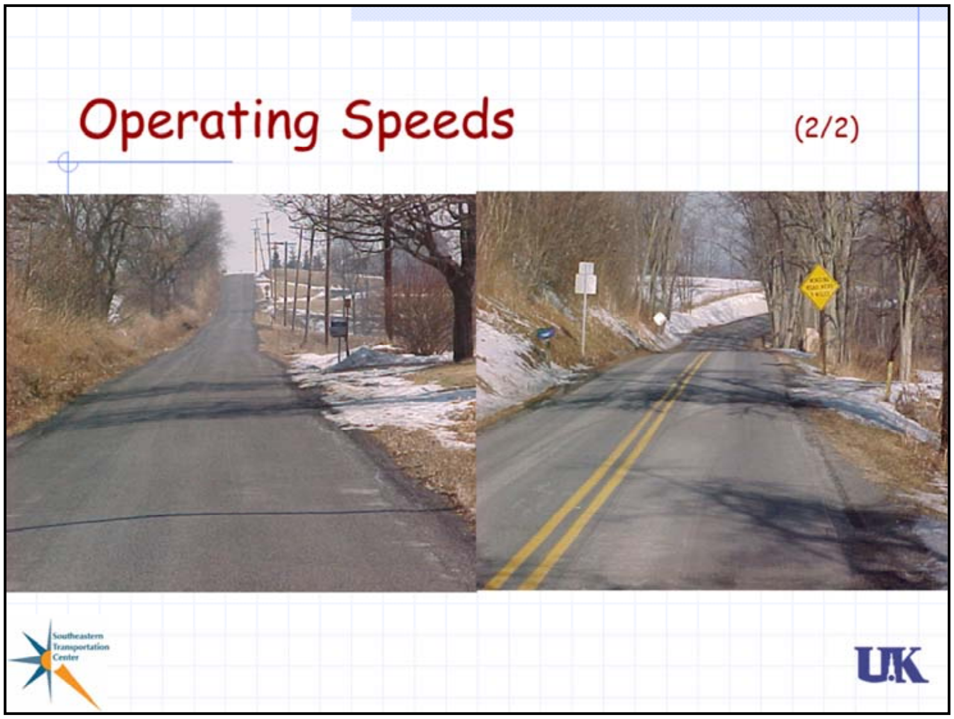
The concept applied here is that of friction among the various users that could result in slower speeds and allow for target operating speeds. An additional benefit of the lower speeds is the lower severity levels of crashes, since crashes will occur at lower speeds. Landscaping, especially trees, has long been viewed as a roadside obstacle and a detriment to safety. Trees adjacent to the roadway can pose such a safety concern but at the same time can be an issue with communities and stakeholders and thus their location and placement needs to be viewed under this scope. Using low shrubbery can provide for a separation between vehicles and pedestrians and tat the same reduce the severity of the potential impact from errant vehicles.

This is an example of a self-enforcing, self-explaining roadway in the Netherlands. This was originally a 2-lane, 2-way facility retrofitted with a median to address head-on collisions, a wider overall paved section where lanes were narrowed form the original width but with some additional shoulder, and pull off areas to allow for passing. The narrower lanes encourage lower speeds, since drivers attempt to keep the vehicle within the edge lines, thus enforcing the desired lower operating speeds, i.e., self-enforcing. The horizontal curvature and the median provide for the self-explaining part limiting passing and dictating also lower speeds.



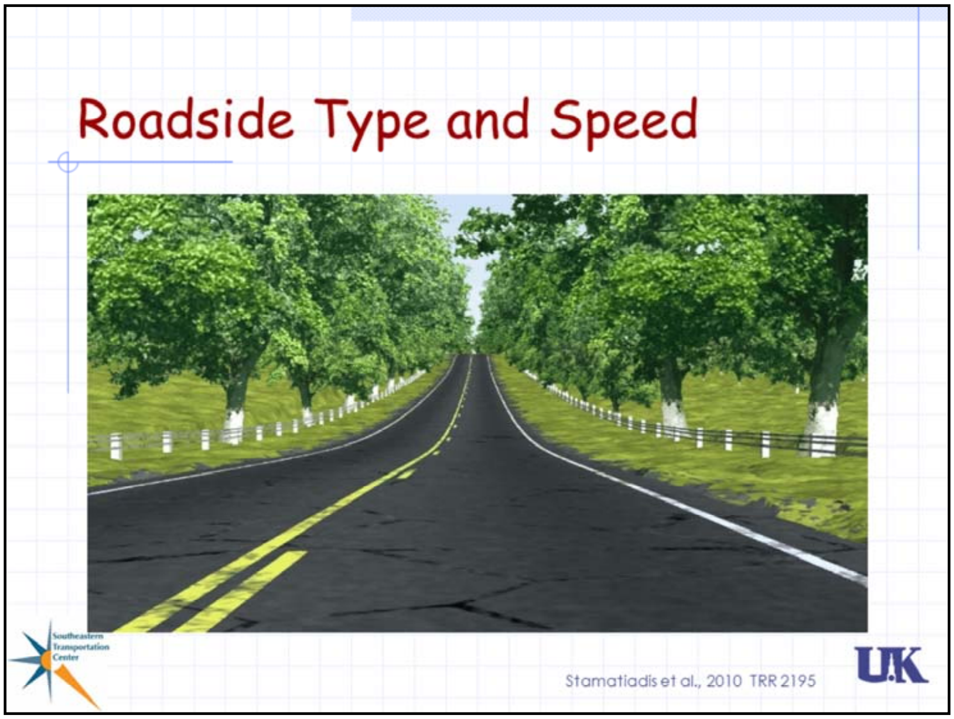
Question: In which roadway section will you drive faster and why?

Answer: the most probable answer is the right, since the open terrain does not prohibit drivers to reduce their speeds. Both roadways have the same pavement width, approximately 20 feet. The presence of trees and other elements by the side of the road in the left picture would result in slower speeds than those in the right side.



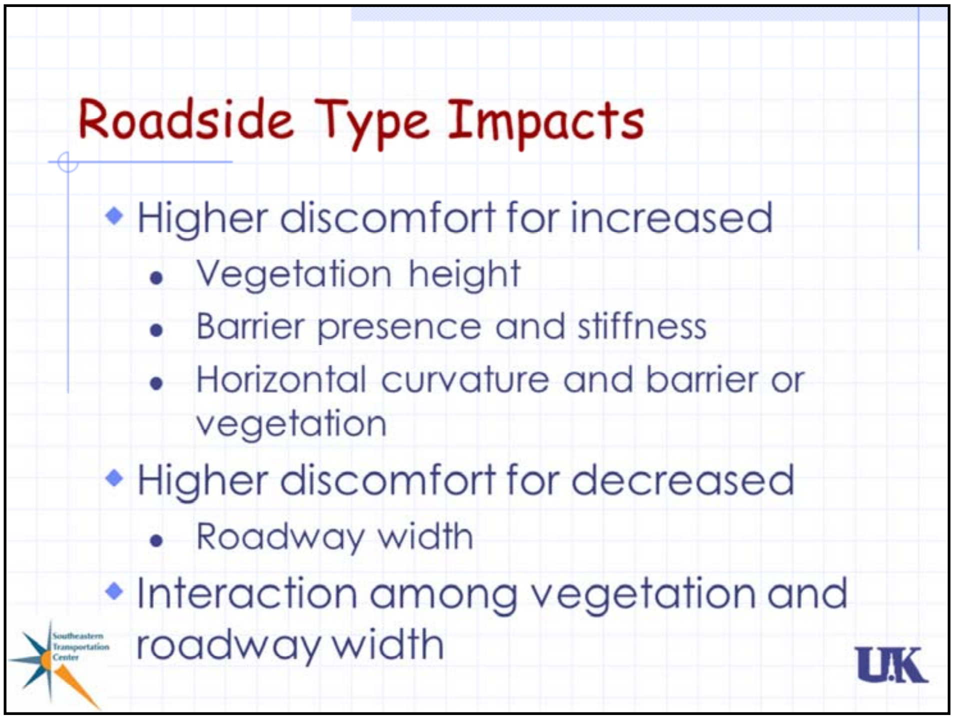
Question: In which roadway section will you drive faster and why?

Answer: the most probable answer is the right, since the presence of the centerline markings delineate the proper vehicle location and provide for a sense of security, i.e., stay within the lines and it will be OK. Both roadways have the same pavement width, approximately 20 feet. The lack of centerline striping creates some ambiguity and could result in lower speeds due to driver uncertainty for placing their vehicle in the right spot.



A recent study examined the effects of altering the roadside elements type and proximity to the road on the operating speeds. The objectives were to identify elements or features of the roadway environment that could influence drivers' operating speed through visualization animations and the use of fuzzy set analysis for modeling.

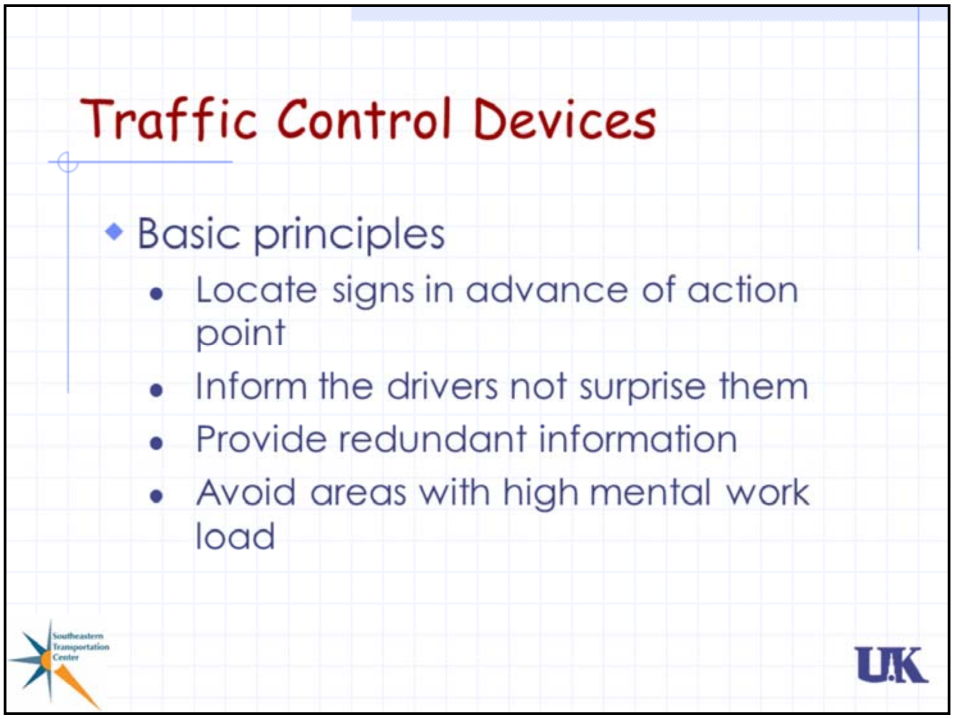
The study examined the effects of roadway width (<16, 16-19, >16 ft), horizontal curve radius (500, 750, 1000 ft), vertical grade (Level, Rolling, Mountainous), plant density (Grass, low plants, shrubs, trees), and barrier type (None, cable, steel, wood, stone, rock wall). Some sample scenarios are shown here.



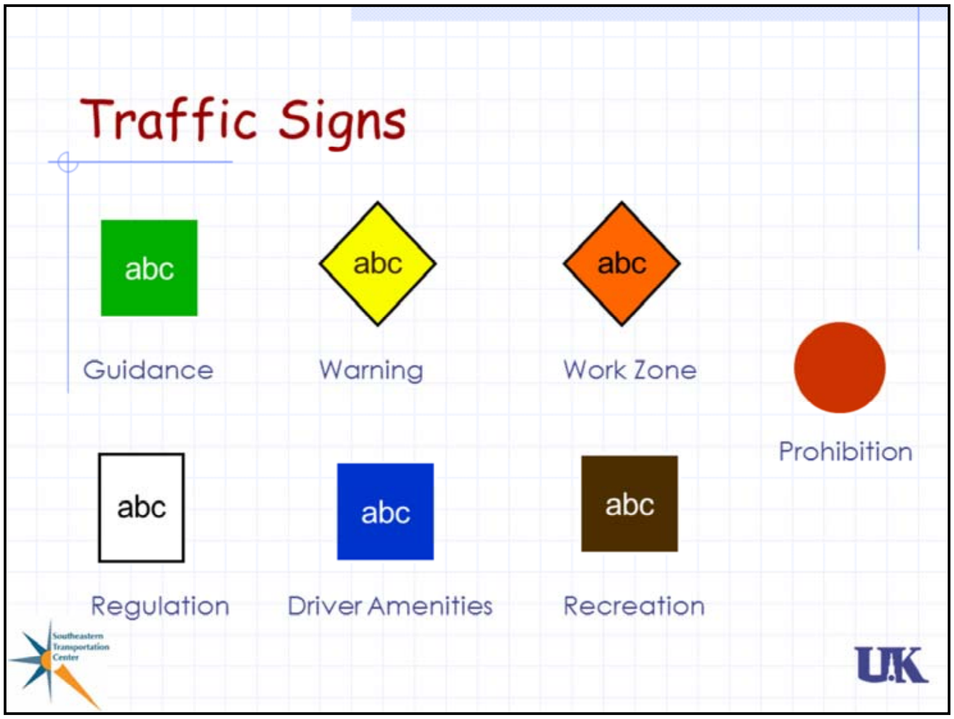
The results of the study indicated that there is an influence of the plant density on the driver's discomfort, i.e. operating speed, which could be used in roadway designs aiming to influence these speeds. The plant intensity showed some influence that was more apparent for narrower roadways with narrower clear zone widths and for roadways with sharper horizontal curves and low grades. The results showed that discomfort increased with narrower roadways indicating the potential for impacting operating speeds by adjusting roadway width according to the desired speed.

The results of the study indicate that the use of vegetation type and density and barrier type has the potential to influence driver operating speeds. These roadside features can be used in designing roadways aiming at achieving desired operating speeds. The results show that discomfort increases when trees are present or when guardrails are added. It is therefore possible to envision that the placement of such devices will have an effect on operating speeds, i.e. reduce them.

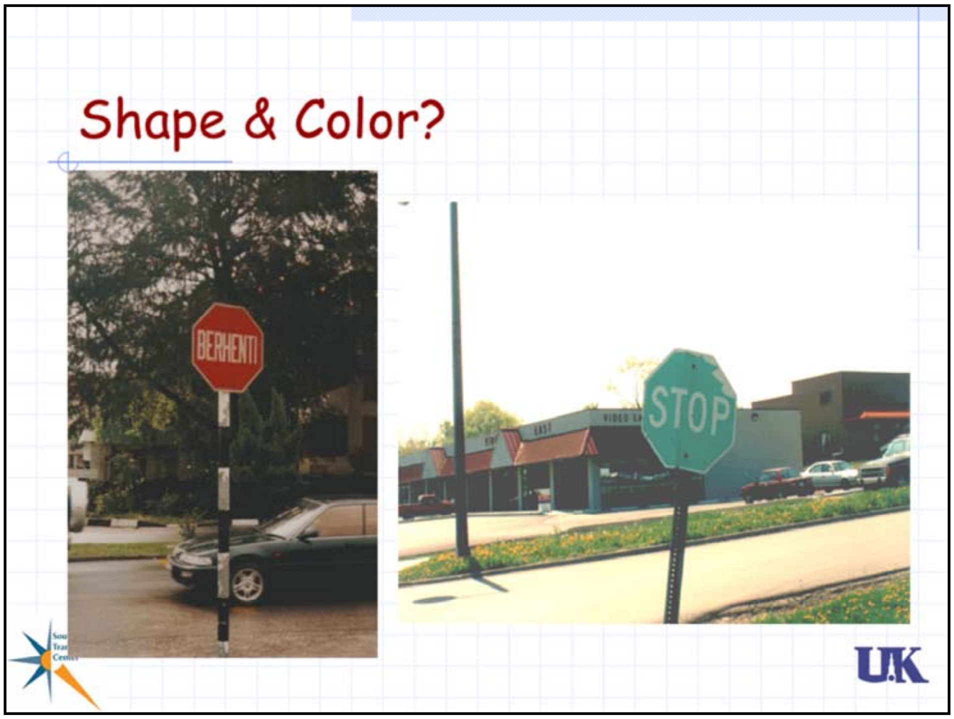
Stamatiadis, N., Baily, K., Grossardt, T, and Ripy, J. 2010 "Evaluation of Highway Design Parameters on Influencing Operator Speeds through Casewise Visual Evaluation", *Journal of the Transportation Research Board,* Record 2195, pp. 143-149.



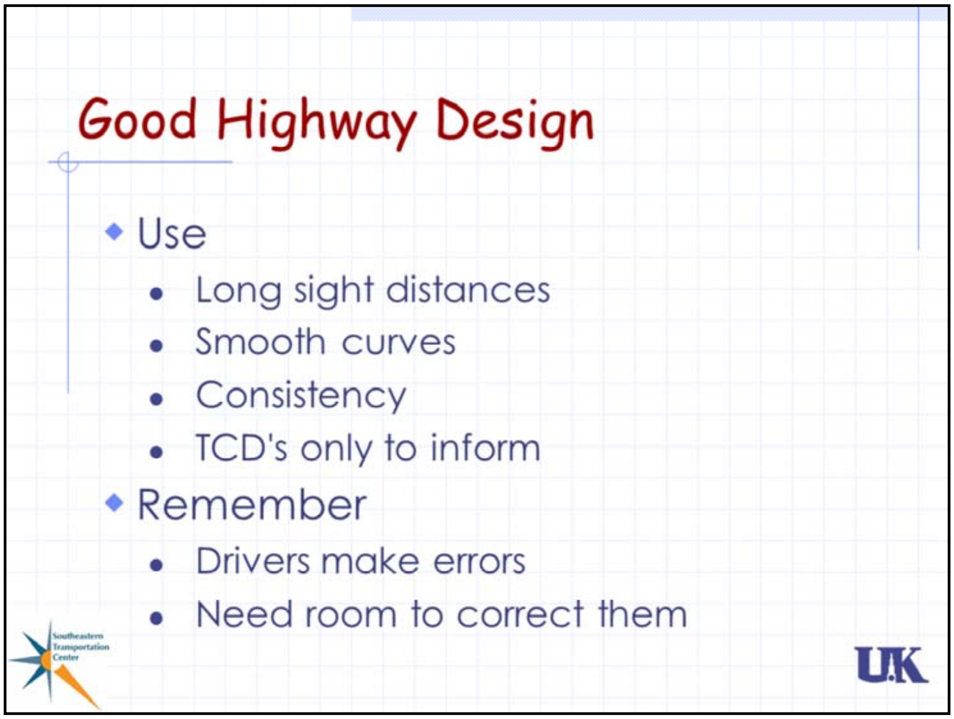
Traffic control devices assist drivers in anticipating and reacting properly to unexpected elements as well as aid in their proper placement and assignment of right of way. These devices need to be placed properly and well in advance of the action point and they need to provide adequate information to the road user to properly react to the situation. For example, a curve warning sign needs to be placed well in advance of the curve to provide the driver with adequate time to adjust speed and negotiate the curve appropriately. The devices should also provide redundant information to ensure compliance with the desired action. In the curve example, a second sign prior to the curve may be used to emphasize the proper speed for taking the curve or the warning sign may be coupled with chevron arrows that delineate the curve. The devices need to be placed at locations where drivers are not overloaded and typically they should be placed in a manner requiring the driver to make one decision at a time.



Signs have associate shapes and colors to indicate appropriate information.

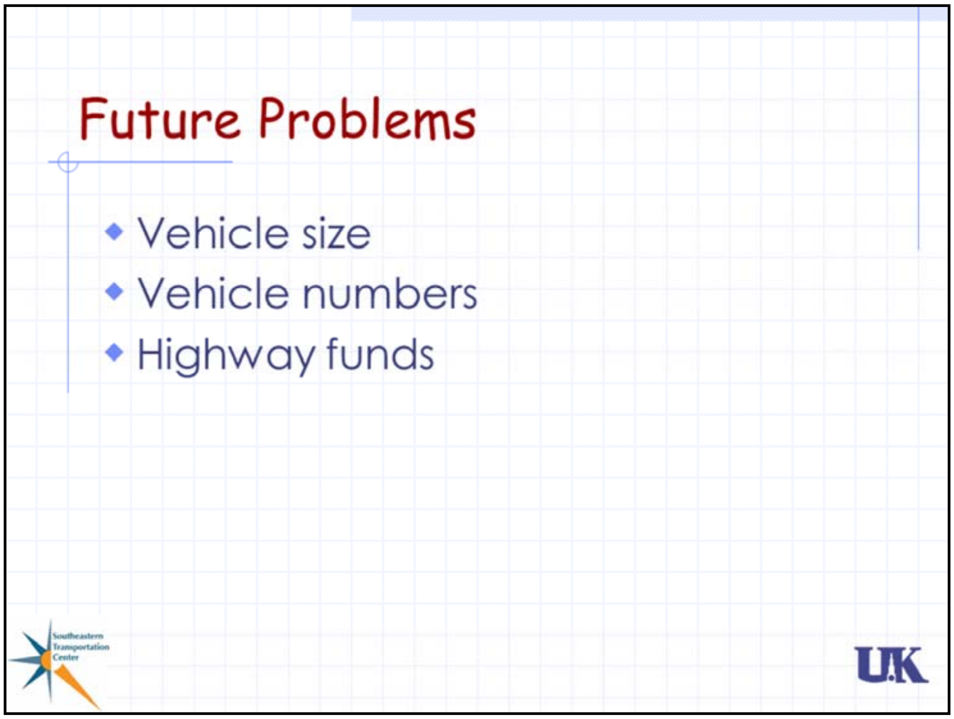


Drivers associate shape and color of the sign with a priori knowledge. For example, red octagonal signs are always associated with a STOP sign and lack of language understanding the word in the sign can be overcome with the basic shape and color. On the other hand, shape by itself can also provide the basic message even if the color is not the correct one (as the case in the right side picture).

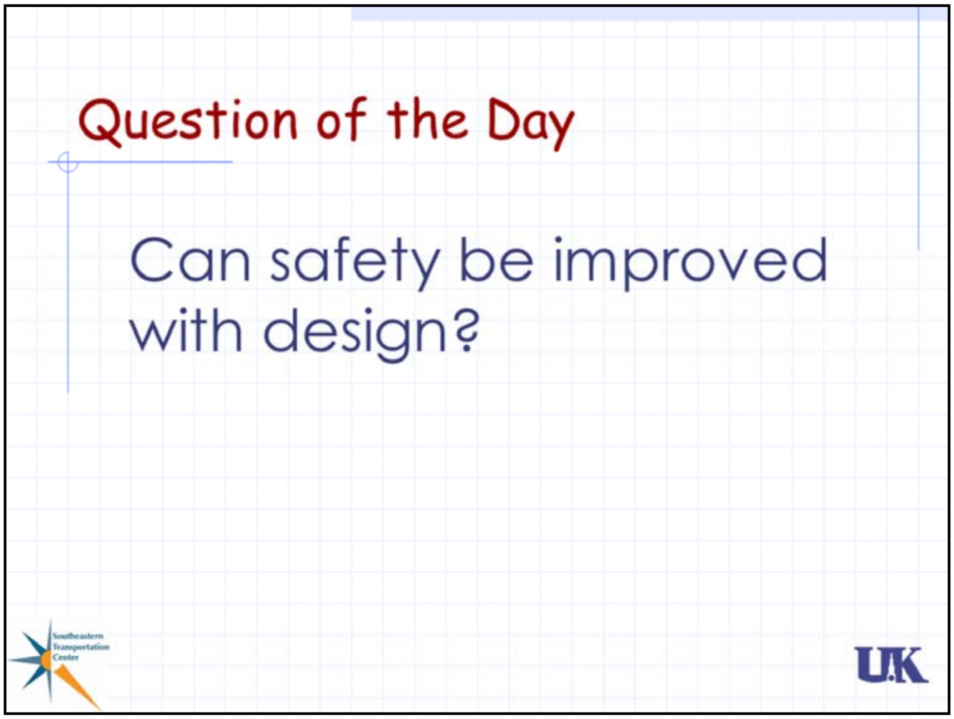


Good highway design utilizes a series of principles that rely on providing adequate sight distance and avoiding surprises to the driver. Alignments that allow for drivers to see ahead and anticipate situations are preferred to those with limited sight distance and other obstructions. Design consistency and ability to transition between elements without significant speed changes are also essential. Traffic control devices should be used sparingly and only to inform the driver rather than impose operating speed. Drivers tend to ignore warning signs due to sign proliferation and this may be detrimental when the signs need to be adhered to.

One needs to never forget that in any roadway, drivers will make mistakes and there should be adequate space to correct any error. The concept of the clear zone is central to a safe highway but this needs to be examined within the greater scope of a benefit-cost analysis where construction costs are to be evaluated as a function of the safety benefits gained.



Over the past decades there have been significant changes in the vehicle fleet that have affected highway design and safety. The trends of bigger automobiles (pick up trucks and sport utility vehicles) required the consideration of wider lanes and superelevation rates on ramps (stability of sport utility vehicles). Performance characteristics also change and these have to be accounted for in the highway design. The larger number of vehicles and the associated congestion could affect safety. Studies have shown that congestion increases the number of crashes, simply because there are more vehicles in the road. At the same time, continued roadway widening is not feasible and therefore alternative solutions should be sought. Funds for highway construction have been reduced in the last decades, resulting in the need to address safety and mobility issues in a more critical manner. This has introduced the notion of cost-benefit analyses where the costs of the improvements need to be balanced by the safety gains.



Question: Can we improve safety with design?

Answer: Up to a certain extent, since the deign can address roadway deficiencies but cannot deal with driver, vehicle or environmental issues.

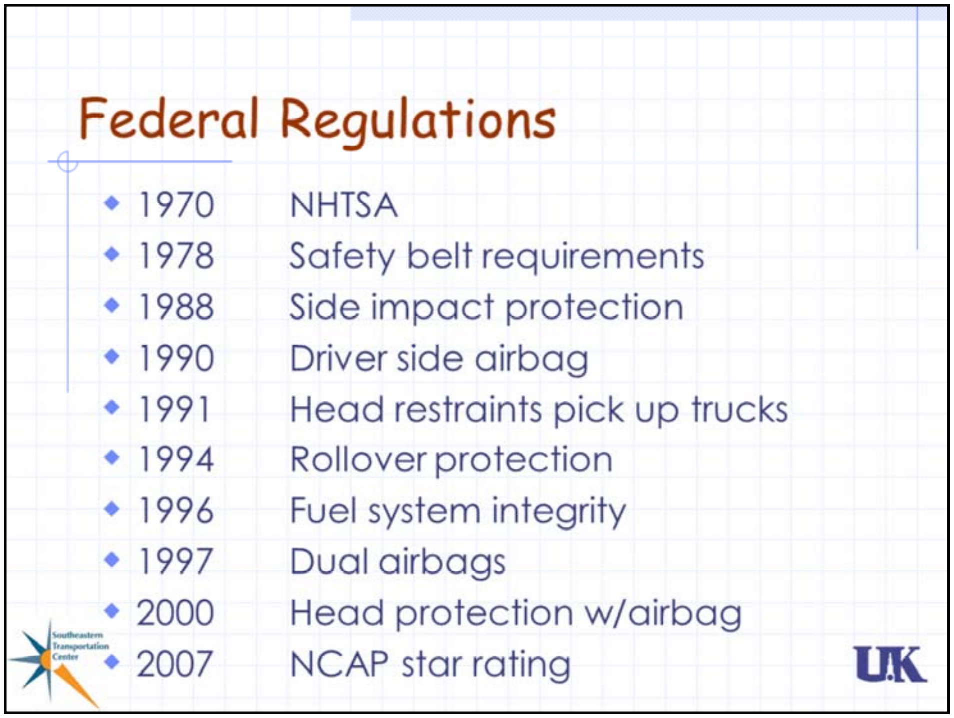
This module discusses the issues of safety as they pertain to vehicles. The module will provide some background statistics on vehicle crashes and identify areas of research where advances have benefited roadway safety.

One may consider vehicle safety under two basic concepts. The first deals with the ability of the vehicle to avoid a crash and the second deals with the ability of the vehicle to protect its occupants in a crash.

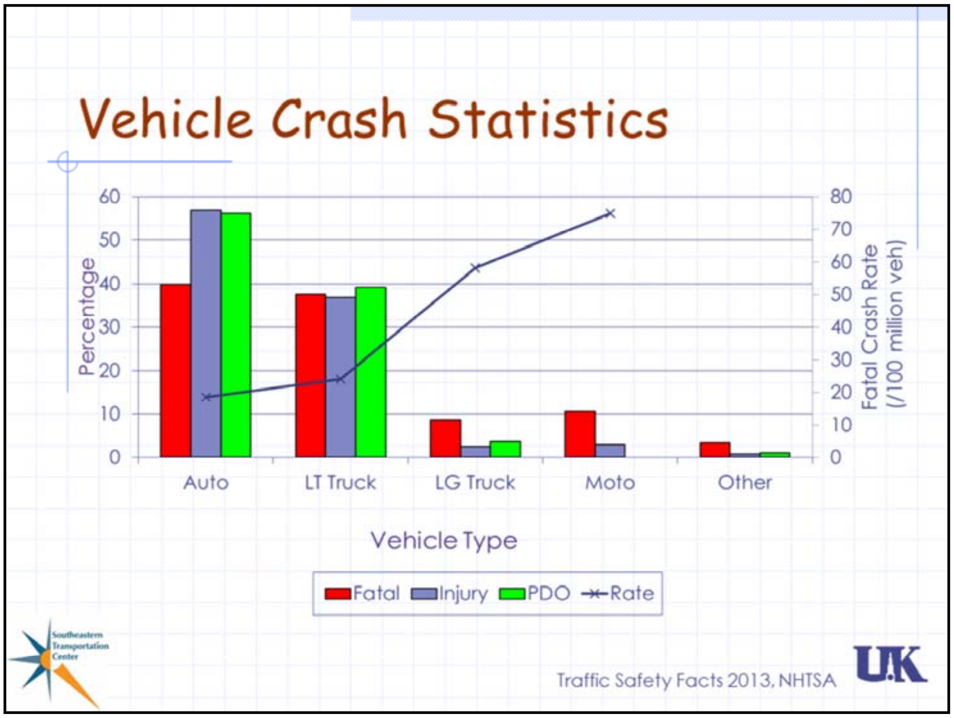
The major factors that can help to prevent a crash include braking, stability and visibility. The braking ability of the vehicle is critical in ensuring appropriate stopping within the available distance. Antilock Braking Systems (ABS) typically assist the braking of most newer vehicles resulting in reduced braking distances and avoidance of wheel lockup. However, ABS may result in increased risk due to the understanding that an extra safety has been added that could allow for greater risk-taking actions.

The stability of a vehicle is very important as well and it is manifested in its ability to prevent rollovers. Vehicles that rollover typically result in greater injuries than those that do not. Rollover probability is related to center of mass as well as other vehicle dimensions and attributes. The problems that Sport Utility Vehicles (SUVs) had in the early 1990's with rollover on or off freeway ramps were a result of a high center of gravity that in such situations resulted in rollover crashes. That was resolved with lowering the vehicle height and adding stabilizing bars in the suspension system. Visibility is also very important, especially for reducing blind spots. Appropriate windshields that do not interfere with the peripheral vision are required to ensure that the driver can see the entire field of lateral view.

The crashworthiness of the vehicle identifies the ability for a vehicle to withstand a crash and how well it can protect its occupants. Obviously size and weight matter in this case. The key to crash survivability is the ability of the vehicle to absorb energy over a long period of time (scale of milliseconds). All else being equal, more massive vehicles have more energy absorbing potential than less massive vehicles. Safety equipment present in the vehicle can protect passengers and the driver in the event of a crash. These equipment include airbags, safety belts and child car seats, crumple zones, ABS, energy absorbing designs, forgiving interiors, etc.

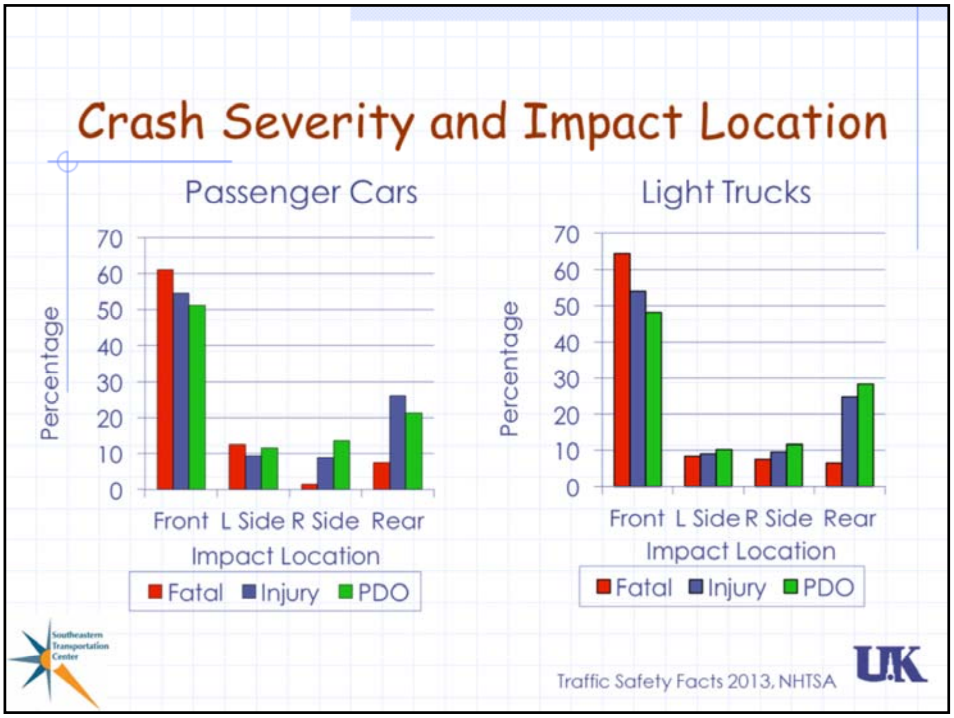


Over the past 45 years, there has been a series of Federal Motor Vehicle Safety Standards (FMVSS) dealing with vehicular safety. In 1965, Ralph Nader published the book “Unsafe at Any Speed” starting a major discussion about the lack of auto manufacturers to improve automobile safety features due to their reluctance to spend money on improving safety. The 1970 Highway Safety Act established the National Highway Traffic Safety Administration (NHTSA) with the goal of achieving the highest standards of excellence in motor vehicle and highway safety. Since then, a series of standards and regulations have been developed and adopted aiming to improve vehicle crashworthiness and passenger protection. The rules noted here are some prime examples of the legislation that has affected roadway safety. For example, in 1978 it was mandated to change to a three-point safety belt in front seats for all passenger vehicles, in 1988 side impact protection requirements went in effect, in 1990 driver side airbags became mandatory, in 1994 the issue of rollover was addressed (as noted in previous slide), in 1996 as a result of the Ford pick up location of the fuel tank a fuel system integrity ruling was developed and in 1997 and 2000 regulations regarding airbags were developed. As of 2007, all new cars are required to post the New Car Assessment Program (NCAP) star rating indicating their relative safety performance based on the NHTSA crash testing protocol.



This current statistics indicate that passenger vehicles (autos and light trucks) are involved in many more crashes than any other types of vehicles. However, one may consider that there are a lot more passenger vehicles and they also travel more than the other types. The right axis considers the number of registered vehicles within each category and it shows that passenger vehicles are the least likely to be involved in serious crashes. The crash rates per VMT are also the lowest for passenger cars as well (1.55 per 100 million VMT as compared to 43.2 for motorcycles in fatal crashes). Does this mean that passenger vehicles are “safer” than other types of vehicles? Not necessarily. We have to consider who is driving; where they are driving; and break the data down much further to answer this question. For example, the fatal and injury rate for large trucks is higher than passenger vehicles; however, it is generally not the truck occupants who are injured or killed but rather the passenger vehicle occupants.

Note: light trucks are considered pick up trucks, sport utility vehicles (SUVs), and vans.



The data here shows the distribution of crashes by impact location and severity level. The majority of crashes involve a hit in the front side of the vehicle and this holds true for all vehicle types. The highest percentage of fatalities is for head on impacts and this is reflected in the data here. This emphasizes the need for better vehicle protection for frontal crashes and ability of vehicles to better protected passengers and drivers in such crashes.

Vehicle Safety Features (1/2)

- Research started in late 1960's
- Safety was not a major issue
- Several vehicle features were cosmetic

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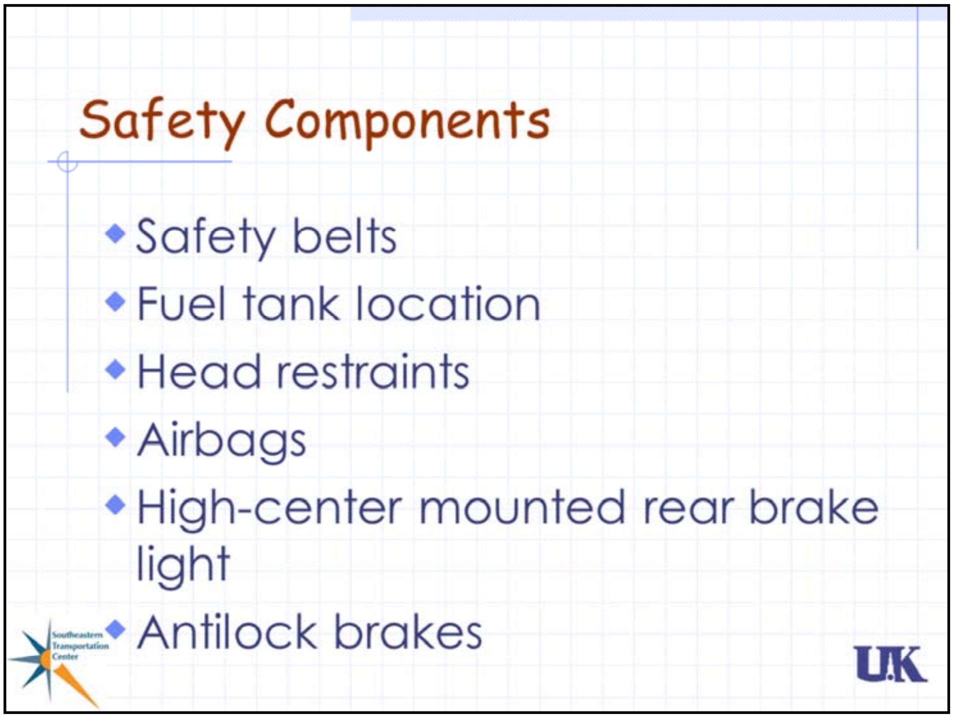
The effect of vehicle design and its components in safety was not a significant issue in the early stages of motor vehicle manufacturing. Ralph Nader published the *Unsafe at Any Speed* in 1965 that is considered the beginning of automobile safety research. The book criticized Corvair (General Motors) for a various fatal crashes. The book lead to the Highway Safety Act of 1966 and the eventual creation of NHTSA.

Several of the elements included in the vehicles were mainly cosmetic and there was no systematic effort to address their impact on safety. Elements such as chrome bumpers or tail lights were placed mainly to accent the vehicles and had no special ability to reduce and absorb the energy during a crash (bumpers) or provide warning for stopping (brake lights).

The interior design of older vehicles created similar problems. The type of seat belts used in the past were only lap belts and could result in severe internal injuries during a crash. The currently used three-point seat belt was designed with the intention of keeping the driver and passengers on their seat and reduce any potential internal injuries. The interior also has been padded to cover all the steel and metal parts and reduce secondary injuries from these elements. For example, the area below the glove box in this picture is open and not protected. In a crash, a passenger sliding forward could have had their knees and lower legs severely damaged due to the other items that could have penetrated them.

The introduction of various FMVSS has resulted in a reduction of crashes and especially fatalities and the development of vehicle crashworthiness. A point to be noted her is that the various FMVSS become mandatory only when a benefit-cost analysis indicates that the cost to implement the measure will be outweighed by the safety benefits. An example where the cost-benefit consideration has been used is the usage of red instead yellow tail lights as signal indicators, even those NHTSA and European studies indicate that there safety gains from their use instead of the red lights used in the US.

A point to be noted here is the need for a cost-benefit ratio to be less than 1 in order for a feature to be mandated for implementation in the US. For example, rear turning lights in the US are still red, while all international models have a yellow light. Even though there is a safety gain (i.e., easier to detect) from converting to yellow turn lights, the cost-benefit ratio is over 1 indicating that the costs are greater than the perceived benefits and thus these lights are not mandated.



This is a list of safety components aiming to improve safety and have been mandated through various FMVSS. Safety belts was one of the first standards in place and nowadays requires three-point belts both in the front and rear of vehicles. The use of automatic three-point seat belts has also been allowed but this has been phased out over time in favor of the manual type. Compliance with seat belts has increased throughout the US (86 percent in 2012) and NHTSA estimates that their use saved 12,174 lives in 2012.

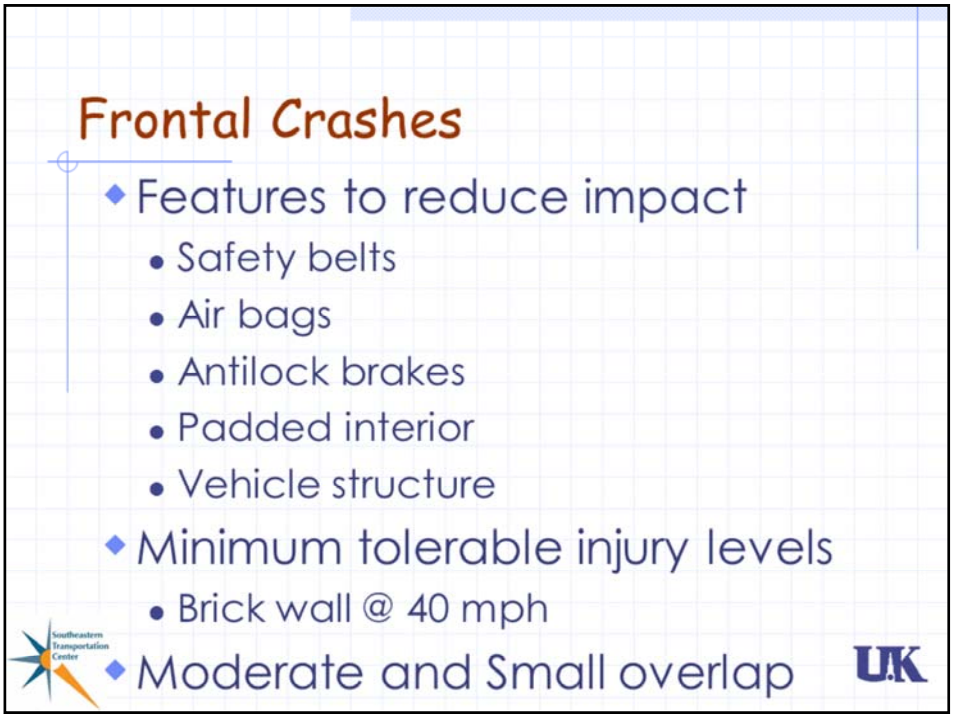
Fuel tank integrity is another are where improvements have been made to improve vehicle safety. The FMVSS for this focuses on avoiding fires due to fuel ignition during a crash and it stared in 1967. Attention was also paid in recent issues with pick up trucks where if they were struck in the middle of their bed, then exposed fuel tanks could ignite.

Head restraints are used to reduce whiplash mainly during rear end crashes. Early vehicles had a very small, cosmetic restraint that did not prevent the head rolling back and pick trucks recently (1991) were required to have them as standard equipment.

Airbags have been in place in select models since 1975 (GM models) and in the 1980's became more common in luxury vehicles. The purpose of the airbags is to complement the seat belt and moderate the impact during a crash. They became mandatory for vehicles after 1998 and NHTSA estimated that there were 2213 lives saved in 2012 with the sue of airbags.

The use of the high-center mounted rear brake was introduced in 1986 and aimed at reducing rear end crashes. The use of the lights has shown to reduce rear end crashes by about 4 percent (NHSTA, DOT-HS-808-696).

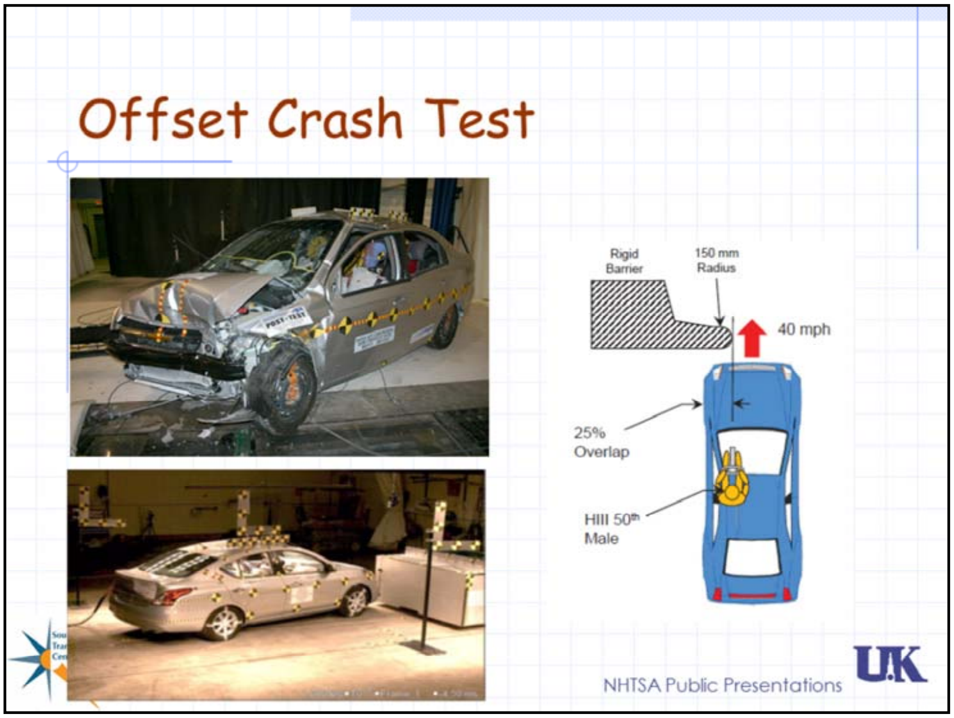
Antilock brakes is a means of reducing braking distance by eliminating locking of the wheels during braking. Research findings indicate that the overall effect on ABS is close to zero for both fatal and all crashes. Evans (1996, AAP 28:3) indicates that there is greater chance for vehicles with ABS to not rear end the vehicle in front of them but greater chance of them to be rear ended if the following vehicle does not have an ABS.



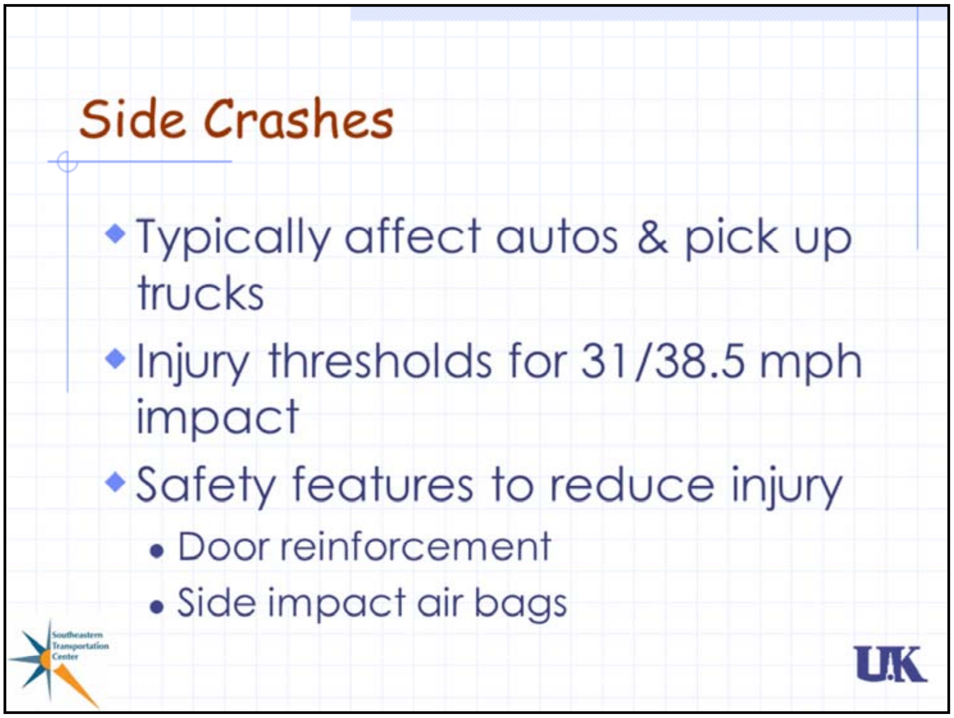
Frontal crashes are a significant problem due to the higher fatality rates that other areas of impact. The features that can reduce the impact on the drivers and passengers include:

- Safety belts and airbags that aim to keep the driver within the vehicle and lessen the impact of the crash on the steering heel and dashboard
- Antilock brakes resulting in shorter breaking distances
- Padded interior that can soften the impact on the vehicle frame and objects
- Vehicle structure with reinforced door pillars, enhanced front bumpers to absorb greater forces and reinforced side frames tied to the main frame of the vehicle to better protect passengers

Vehicles are tested on how well they are able to withstand a crash and what will be the impacts to the passengers after a crash. Current tests require minimum injury levels when a vehicle hits a fixed obstacle at 40 mph. There are two tests that are typically used in rating vehicles. The first is called Moderate Overlap test (formerly known as Frontal test) where a vehicle strikes a wall simulating a frontal crash of vehicles with similar size and mass hitting each other at about 40 mph. The Insurance Institute for Highway Safety (IIHS) performs this with an overlap of approximately 50 percent of the front of the vehicle, while NHTSA preforms the same taste where the entire front of the vehicle hits the wall at 35 mph. IIHS believes that a moderate overlap forces the vehicle to absorb similar forces with a smaller are than when the entire front hits the wall. In the Small Overlap, the vehicle hits a fixed object at 40 mph only in its front corner simulating crashes with trees, poles and other fixed objects with a small diameter.

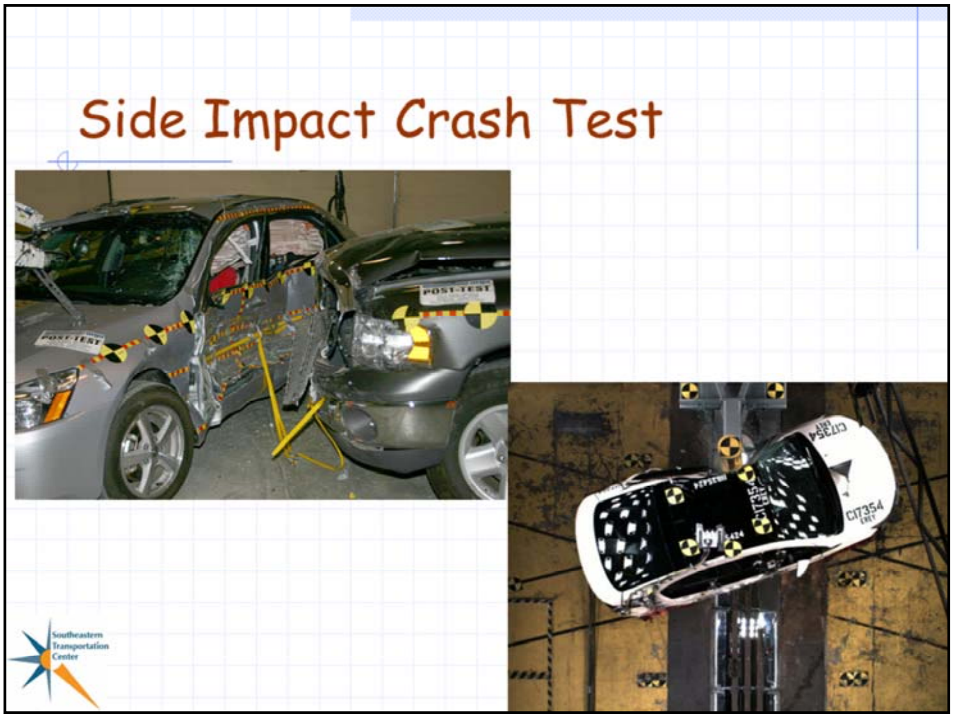


The images here depict various tests and their results for frontal crashes. The top left picture shows the results from a moderate overlap test demonstrating the results after the crash. The bottom left picture shows the instrumentation for a small overlap crash and the diagram depicts the overall layout for the test. The results evaluate injuries occurred to the dummies and the examine head, neck, chest, knee, thigh, leg, and foot impacts. The structural problems of the vehicles are also examined to determine potential improvements required to improve the vehicle's ability to withstand the crash.

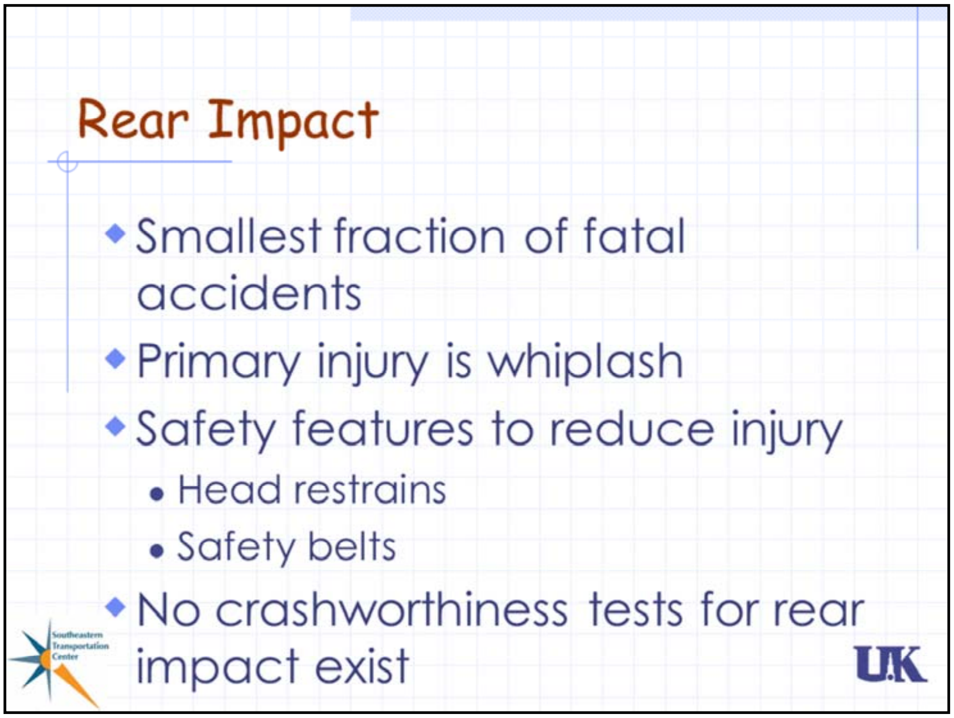


The second crash type evaluated for vehicles is their ability to withstand been hit on the side. This test typically affects passenger cars and pick ups, since trucks and buses usually do not have any problems been hit on the side. There are different tests performed to evaluate the crashworthiness of the vehicle depending on the agency preforming the tests. NHTSA conducts two tests, where in the first simulates a hit on the side of the vehicle by a 3000 lbs. vehicle traveling at 38.5 mph. The second test measures the injuries to the driver from a side impact to a pole at 20 mph. IIHS performs one side test where an SUV-like barrier hits the vehicle at 31 mph.

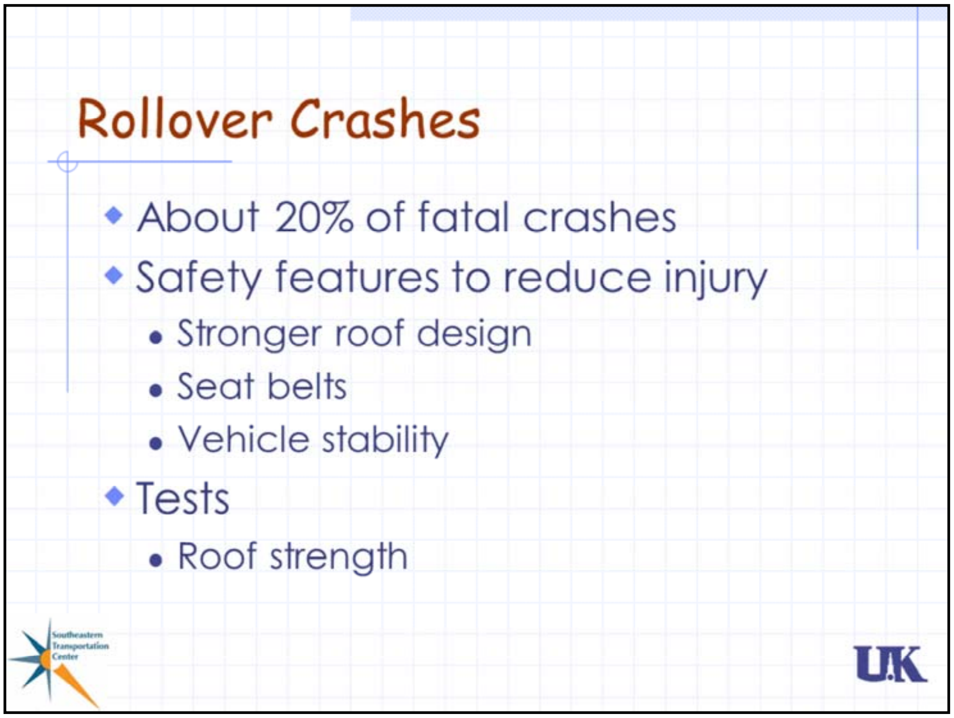
Both tests aim at improving the ability of vehicles to withstand such crashes and they have resulted in reinforced doors and the development and inclusion of side impact air bags (required for all vehicles produced after 9/1/09 and manufactures have a 4-year window to comply).



These images demonstrate the side impact tests that NHTSA conducts. The upper left picture shows the after test results of the side crash where a 3,000 lbs. vehicle hits another at the side. The side airbags have been deployed as a result of the crash protecting the driver. The lower right picture shows the second test where a vehicle is pushed on a pole to determine its crashworthiness in such a crash. Focus areas of performance include injuries to head, neck, chest, abdomen, pelvis and femur. Structural strength is measured by measuring the intrusion of side towards the driver.

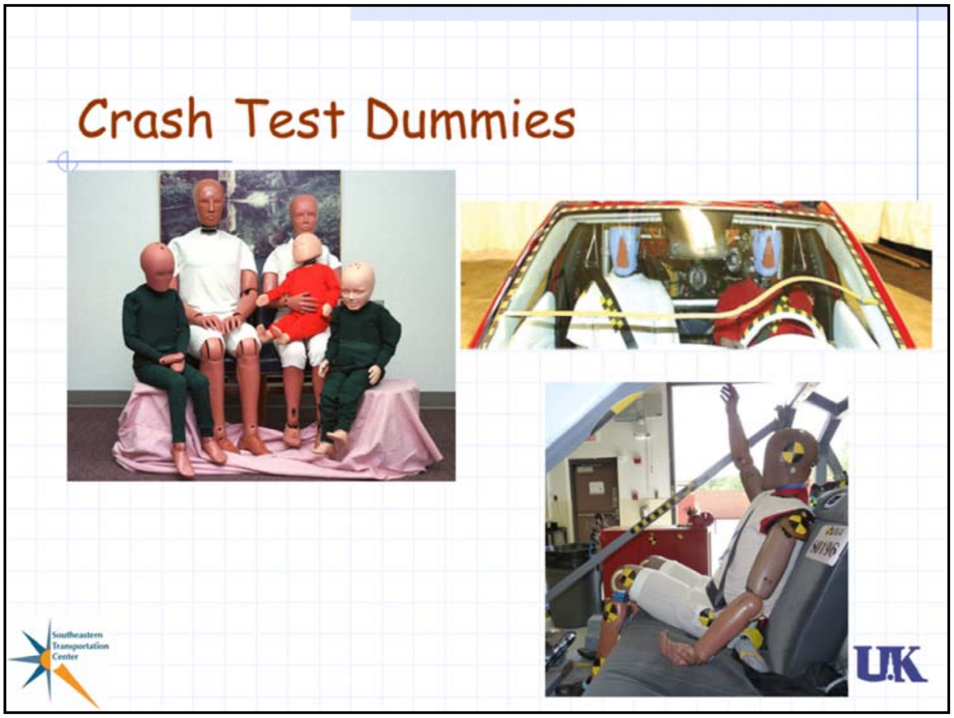


Rear impact crashes represent a small fraction of fatalities and the primary injury is whiplash. Head restraints are the primary safety measure that can reduce the injury level and safety belts can act complimentary to hold the passengers in place after the crash and reduce the amount of body swaying back and forth. There are no crashworthiness tests as of now that can evaluate vehicles. IIHS has a test that determines the ability of the seat to hold the head during a simulated crash where the vehicle is hit by another traveling at 20 mph. IIHS also has a rear bumper test, where vehicles are rated by determining the damage resulted from a 5 mph hit of a stationary pole.



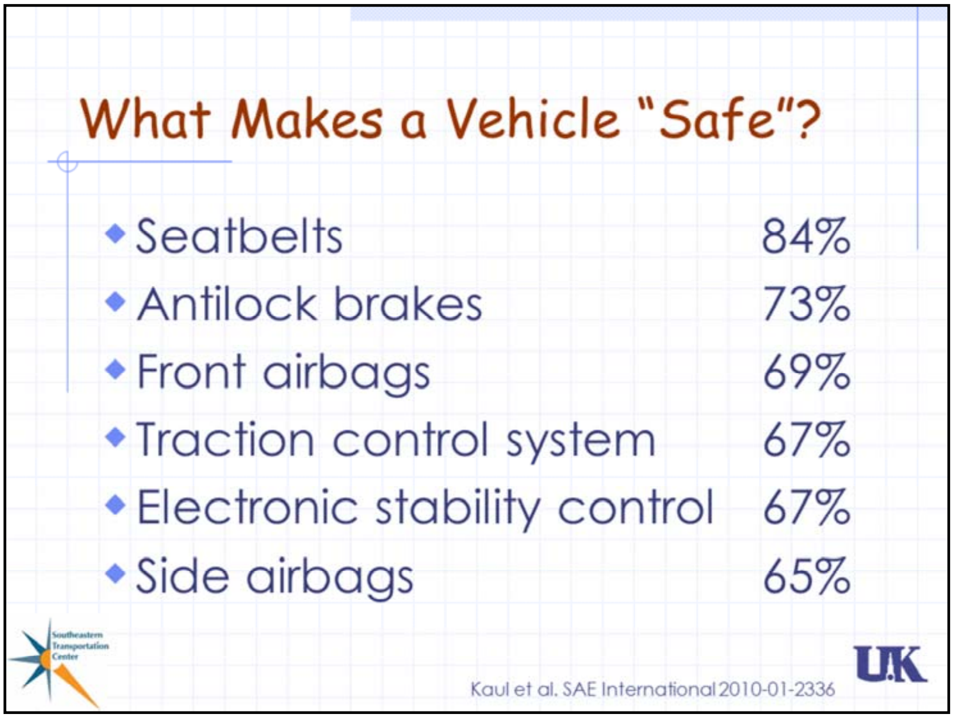
Rollover crashes resulted in approximately 20 percent of the fatal crashes in 2013. A safety feature that has been implemented over the past include improved and reinforced roof design to reduce the risk of a fatal or incapacitating injury when a vehicle rolls over, mainly because stronger roofs reduce the chance of being ejected from a rolling vehicle. Seat belts also prevent ejection from the vehicle, since this is the most common reason for a fatality in a rollover crash. Improving vehicle stability (several vehicles equipped with electronic stability controls nowadays) has also assisted in reducing rollover crashes and is mandatory for all vehicles since 2012.

The only test currently in place for rollover crashes is that of IIHS which tests the ability of a vehicle's roof to withstand a metal plate been pushed against one side of the roof before the roof is crushed 5 inches. The force applied relative to the vehicle's weight is known as the strength-to-weight ratio.



Crash test dummies are a full-scale anthropomorphic test device (ATD) that simulates the dimensions, weight proportions and articulation of the human body. Dummies are typically instrumented to record data about the dynamic behavior of the ATD in simulated vehicle impacts. Dummies were introduced in 1949 and since then they have been improving and becoming more capable to simulate the impacts of a crash and measure impacts on very specific body areas. Dummies represent a typical person (i-th percentile of the population). For example, the left picture depicts the Hybrid III family with a 50-percentile man and 5-percentile female and children of ages ten, six and three years old.

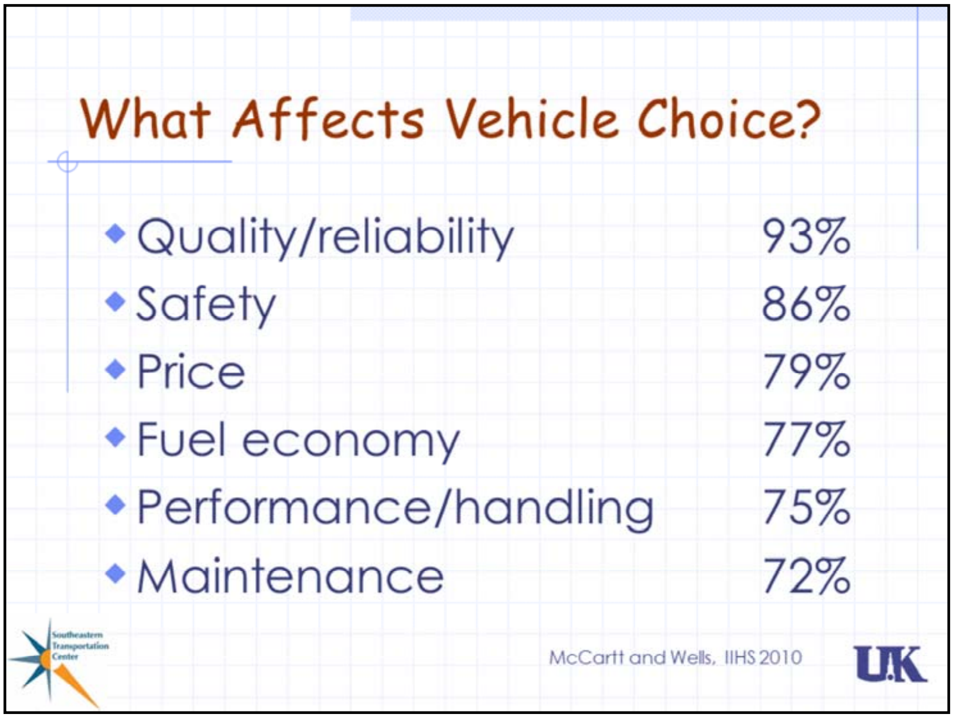
The right bottom picture shows the successor of the Hybrid III ATD, THOR which has a more human-like spine, pelvis and spine and the face contains a number of sensors that can improve and increase data collection. The top left picture shows the placement of THOR ATDs in a vehicle prior to a NHTSA frontal test.



This a review aimed at defining the consumers' attitudes towards safety elements to be included in a vehicle. The percentages noted here indicate the overall ranking when the safety feature plays an important role in vehicle safety. Most of these are already mandated to be in vehicles and demonstrate the importance of both passive (seatbelts, stability control and airbags) as well as active safety systems (antilock brakes and traction control). This also demonstrates that consumers rate occupant protection systems and braking systems fairly high.

Some additional considerations include:

- ABS not only reduces breaking distance, but also reduces speed when impact occurs.
- Traction control system is another word for four wheel drive. The purpose is to balance traction when in wet or slippery condition.
- Stability control is to balance weight (using swaybar in old mechanical system and electronically measure spring extension to gauge vehicle tilting) to vehicles to make sure the gravity center is balanced once it senses vehicle weight starts to tilt to an unsafe level when vehicles travel on superelevated roads.



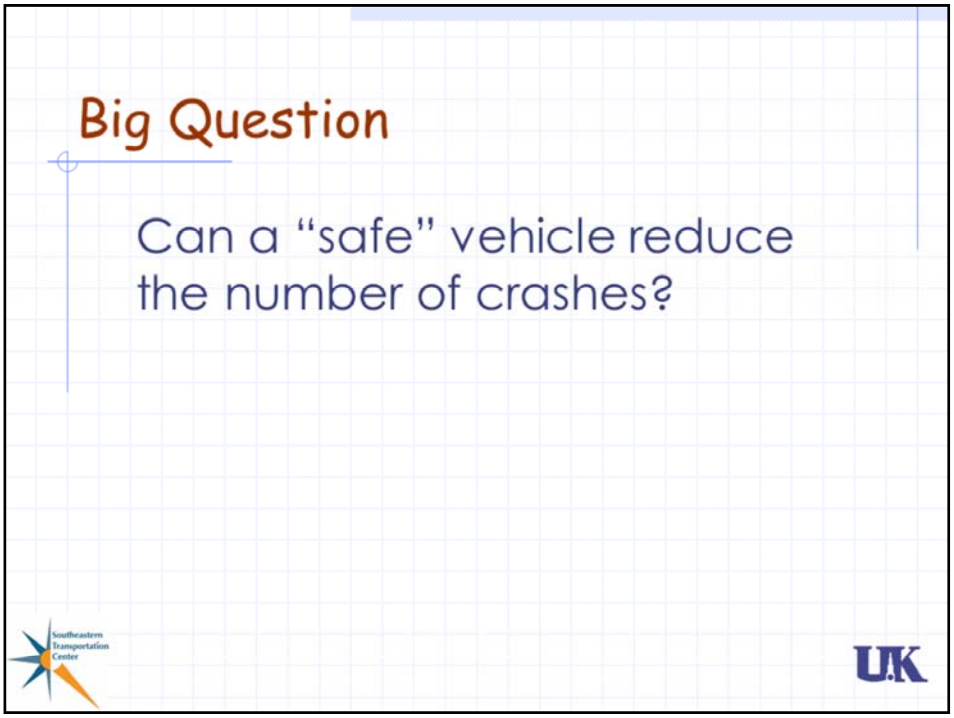
A study conducted for IIHS aimed at identifying the factors consumers consider when selecting a vehicle and it was based on a nationally representative sample of drivers. The findings suggest that safety is one of the most important factors. The percentages shown here reflect the ranking of importance of the specific factors in choosing a vehicle. Safety was the second most important consideration after quality/reliability. Economic factors are also featured in the list high (price, fuel economy and maintenance) and are reflective of recent financial issues.

Over the past decades, manufacturers have improved their compliance with mandated standards aiming at improving safety. There is a tendency to understand the importance of safety and the safety rating systems of NHTSA and IIHS have contributed towards compliance. Current advertisement campaigns emphasize the safety ratings and attempt to attract consumers based on these rankings. Smaller cars are fighting an uphill battle in the US market. Americans do not value fuel efficiency as much as others. To battle this, manufacturers started to market safety features of their vehicles (e.g. Volvo and this ad for Mini). Still most of the commercials for vehicles are for promoting image and performance aspects (e.g. Mazda theme of Zoom, several GM models for excitement, and trucks for carrying ability and roughness in four-wheel environments).

There is a need for additional testing to be included in evaluating vehicle safety. These tests include rollover and rear end crash testing. There is an effort to develop a dynamic crash test protocol for rollover by NHTSA and this would have the ability to evaluate crashworthiness of vehicle sin such situations. There has been no real rear end crash test developed and the IIHS efforts in evaluating seat reactions at a rear end crash are a good step in this direction. Tests in Europe have demonstrated that rear end protection and testing is needed due to similar effects and issues as those observed in frontal crashes. This may be more critical for passengers in the back of the vehicle.

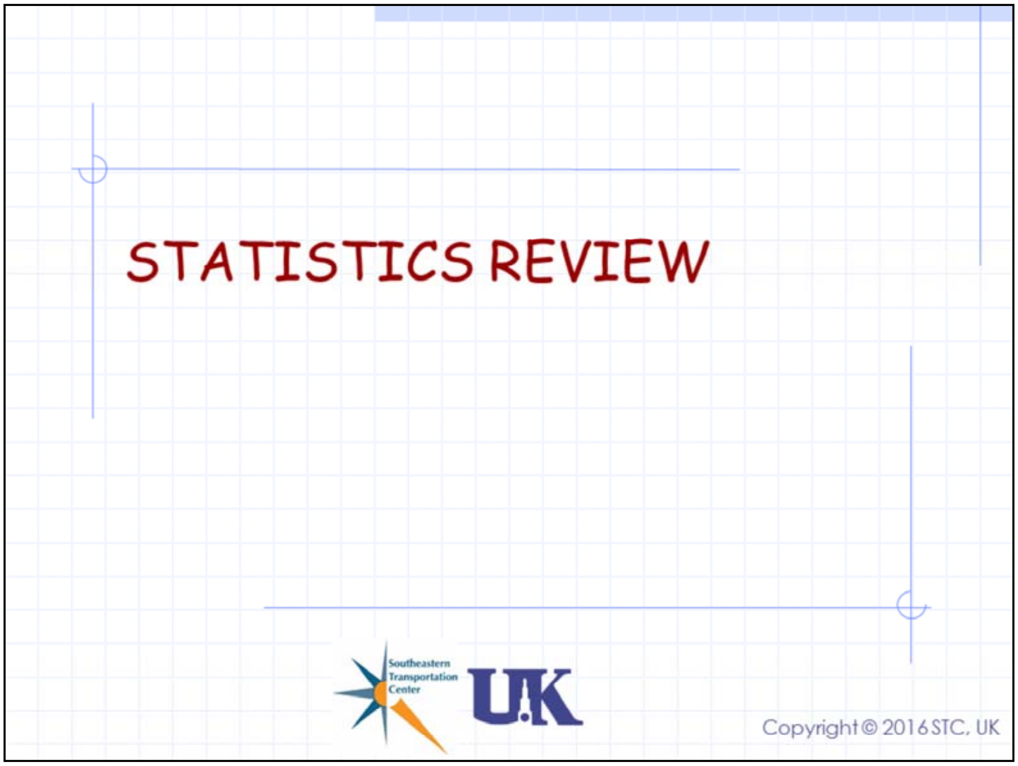
Safety belt usage has been increasing over the past decades (86 percent nationwide) but the percentage needs to increase further to become a more effective safety feature. An issue of concern here is that there are still 16 states that they do not have a primary seatbelt law (i.e., a driver can be stopped simply because are not wearing their seatbelt) and this could increase compliance and usage. However, an issue still of concern is the lack of seatbelt use for rear seat passengers. National statistics estimate that about 80% do not use their seatbelts.

Increased public information on safety ratings and safety campaigns is another area where attention needs to be paid. Consumers need to become aware of the safety rankings for vehicles and use them when making decisions on what vehicle to purchase. Similarly, manufactures should start using these more and advertise vehicles with high rankings, since studies have shown that consumers value safety as clos as to quality and reliability.

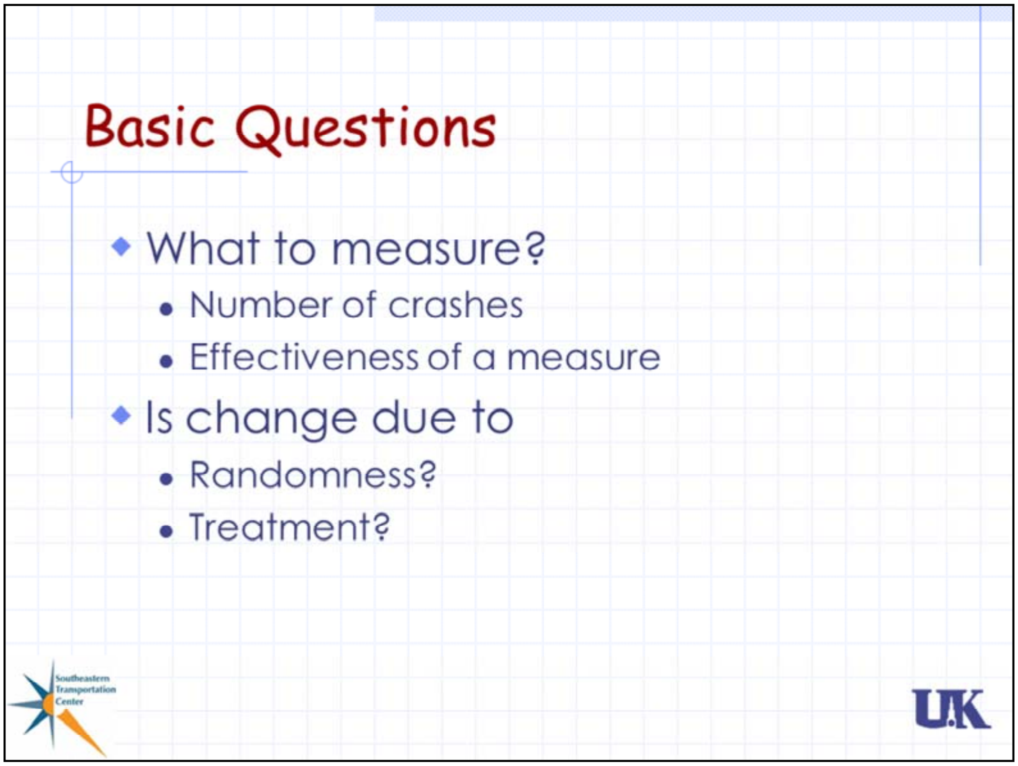


The question of the day: Can a safe vehicle reduce crashes?

The answer is obviously yes, since modern technologies can alert drivers about vehicles in their blind spots, can brake and reduce vehicle's speed if approaching another vehicle and assist them in traction and barking. However, the driver needs to be aware of these technologies and how they impact driving and should not attempt to override them when are in effect.

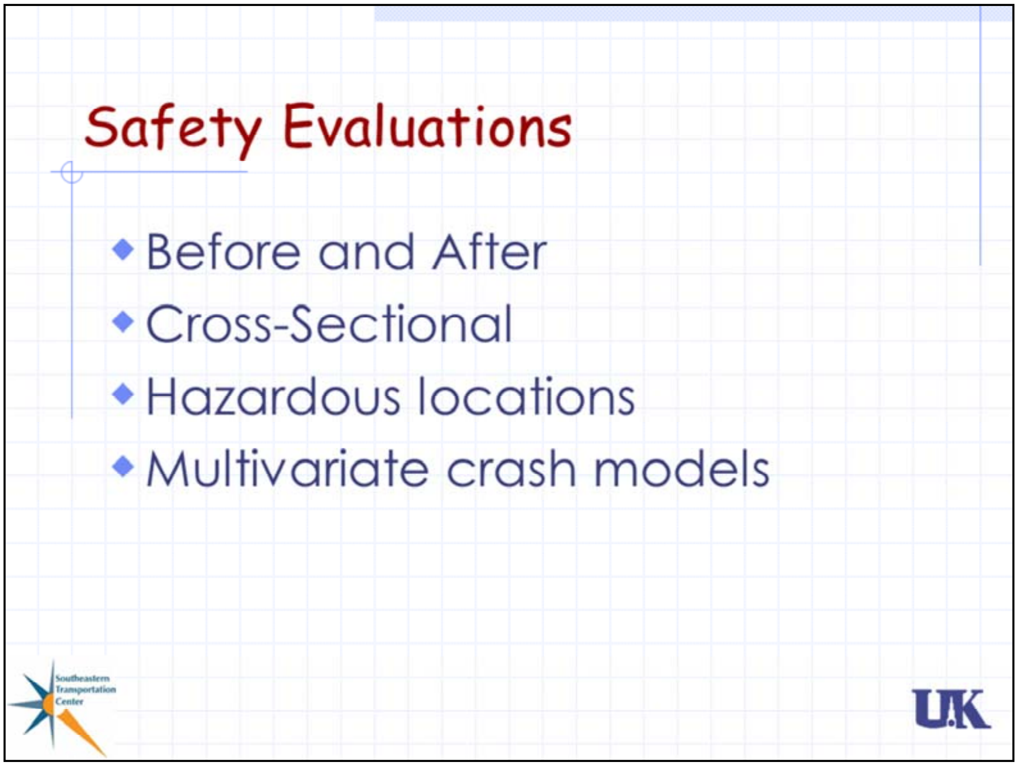


This module reviews fundamental statistics related to safety analysis. It is critical to have a basic understanding of the models to be developed in order to apply the statistical methods and tools correctly for safety analysis. Even though current highway safety analysis techniques have moved beyond basic statistics, an understanding of statistical fundamental concepts can be useful in any analysis.



There are two basic questions that one has to deal with when concerned with statistical analysis in highway safety. The first deals with the identification of the safety measure to be evaluated. A metric of interest could be the level of risk expressed as a number of crashes at a particular location, for a particular group of drivers or for a specific crash type and level of severity. Another metric could be the relative effectiveness of a countermeasure as it relates either to the existing conditions or as compared to other countermeasures.

Another fundamental question for highway safety is the identification of whether the resulting change observed is due to randomness of the treatment implemented. It is possible that a change in crashes (or safety level) is completely due to randomness, since crashes are random and rare events. Moreover, crashes have shown to vary with time and there is a phenomenon called regression to the mean, where data fluctuates over time around its true mean. It is therefore imperative to be able to distinguish whether the change would have happened with or without the treatment implemented.

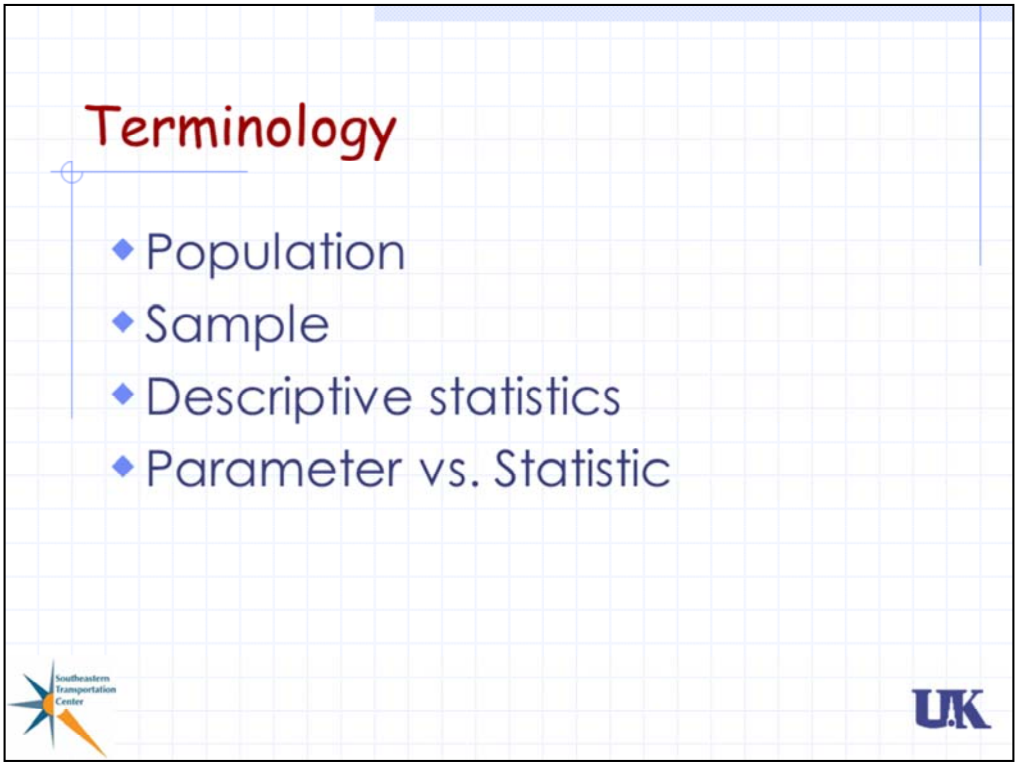


Before and after evaluations compare the safety performance of an improvement through an examination of the safety performance before and after the intervention. The information can be used to guide future safety improvements. These evaluations can be simple before/after, with or without control sites studies or take the form of more complicated empirical Bayes (EB) approaches. A major issue with this approach is the fact that simple (naïve) before/after do not account for other factors hat could have an influence on the changes observed and need to separate them from the improvement effect. These factors include traffic volume changes and random fluctuation in accident counts (also known as regression to the mean that will be discussed later).

Cross-sectional evaluations aim to estimate the safety effects of various possible improvements. Simple approaches include the evaluation of crashes considering other factors to determine whether a specific treatment had an effect while considering several locations with and without the treatment. More complicated approaches can take the form of regression models using a variety of highway features, including traffic volume and then can estimate the safety effect of making a change in one or more variable using the equation to calculate the resulting change in crashes.

Identification of hazardous locations is a process through which locations are ranked based on their safety record to identify those that should be investigated for safety deficiencies and possible treatment of these deficiencies. The process is sometimes known as "blackspot identification" or "identification of sites with promise". An important issue here is the proper use of a method to identify the sites, since simple crash rates or number of crashes may suffer from the random fluctuation of crashes.

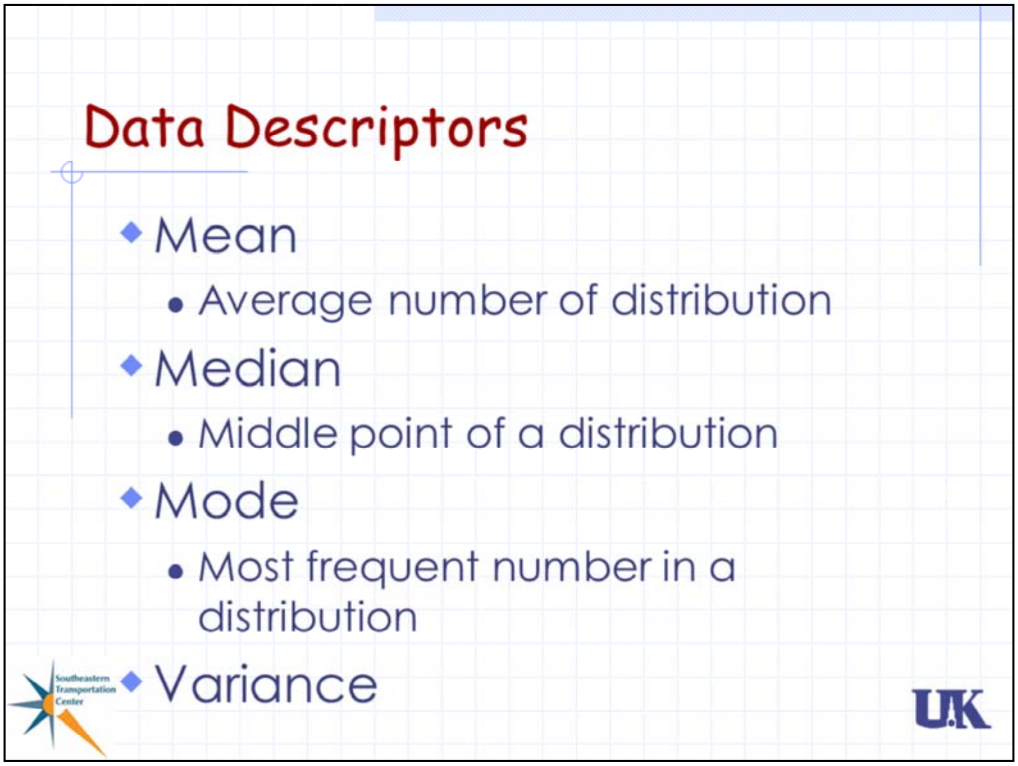
Multivariate models are regression equations that relate crash experience to the traffic and other characteristics of locations to develop a prediction for crashes or understand the causation of factors contributing to crashes. In prediction models, the safety of a location is estimated as a function of variables that are deemed to be the best predictors while in causation models, crashes are related to factors that could explain crash causation and the coefficients of the various factors can be used to estimate the change in safety that would result from a change in that factor.



Let’s refresh our memory with some basic terminology in order to be able to understand the terms to be used in this section.

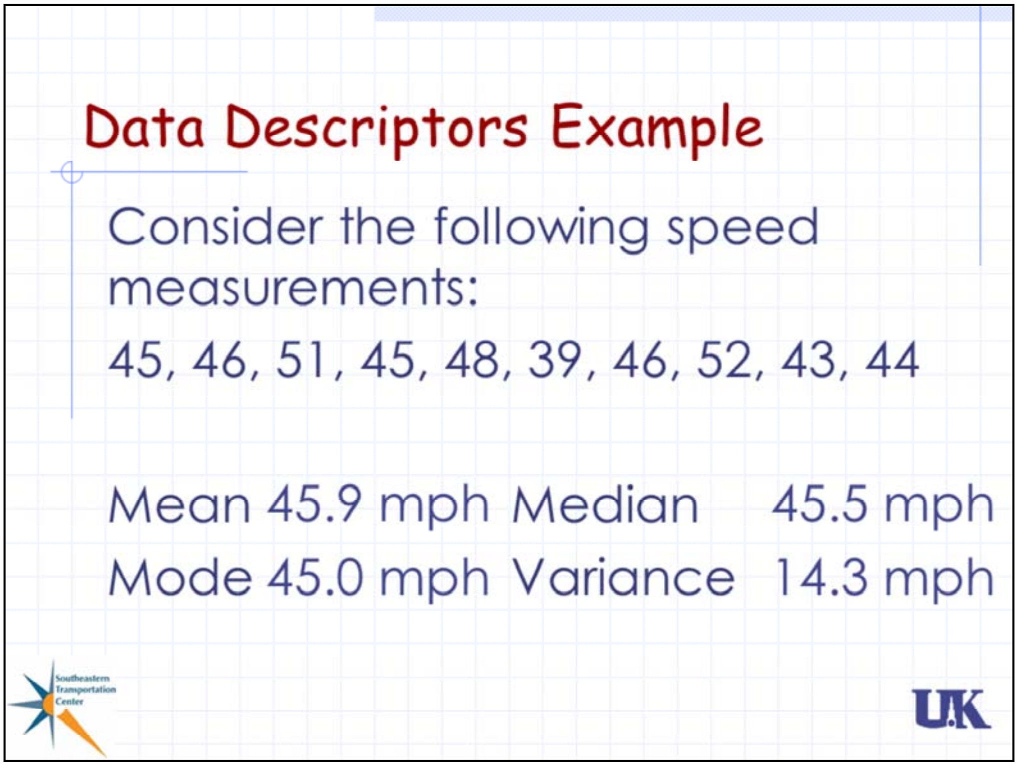
•Population refers to the entire universe of a particular group. For example, if one wanted to know the average number of points per licensed driver in Kentucky for the entire population, she needs to account for every single driver.

- Collecting population data can be a cumbersome approach and hence the concept of a sample has been developed. With the same example in mind, now the researcher can identify a smaller group of licensed drivers and consider this a representative sample of the licensed drivers in Kentucky. Note that there are certain rules and guidelines as to how one may develop this “representative” sample that is beyond this basic review (please review statistical procedures for this).
- Descriptive statistics are the metrics used to describe a population or a sample. In this example, such statistics could include the average number of points, the standard deviation, the average age of the drivers and so forth.
- Parameters and statistics are descriptors of a group characteristic. The difference is that parameters describe the population while statistics describe a sample. In our example, the statement “the average number of points per driver is 2.5” is a parameter if it is based on the entire population and it is a statistic if it is based on a sample of drivers.



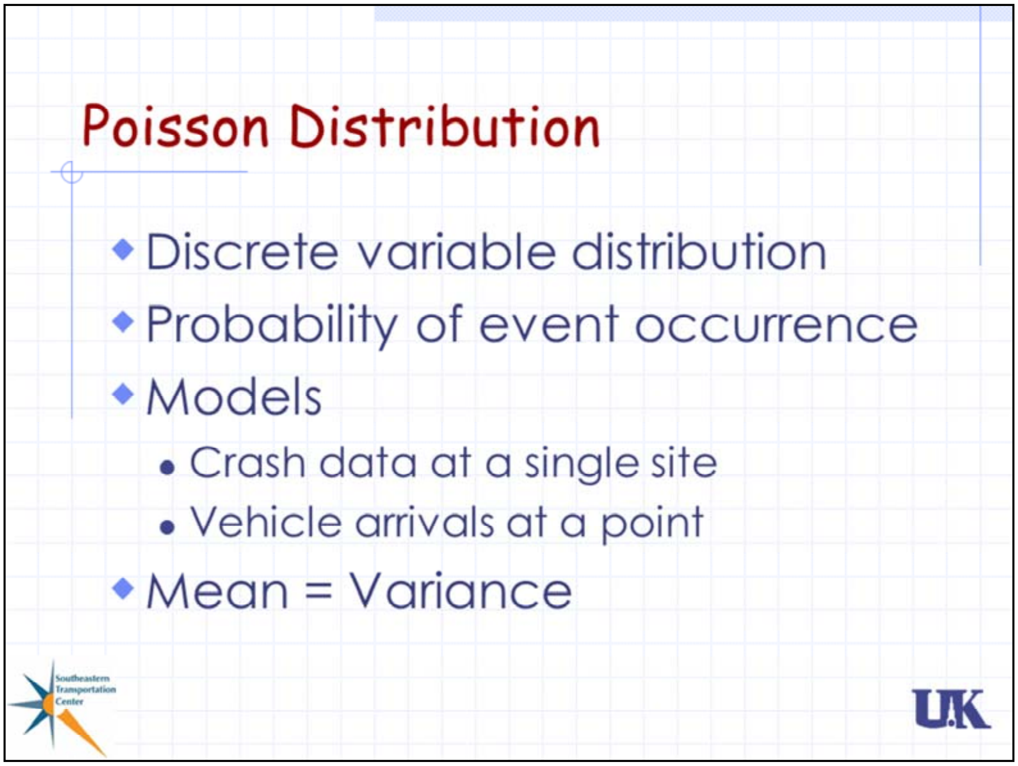
The differences between these three terms. Each describe a statistic of a sample and can provide meaningful information about the distribution. Medians and modes are not sensitive to outliers of the data and sometimes may be more accurate descriptors of the data at hand.

The variance is a measure of dispersion of the data. It is estimated by averaging the squared distance of the values form the expected value (mean).

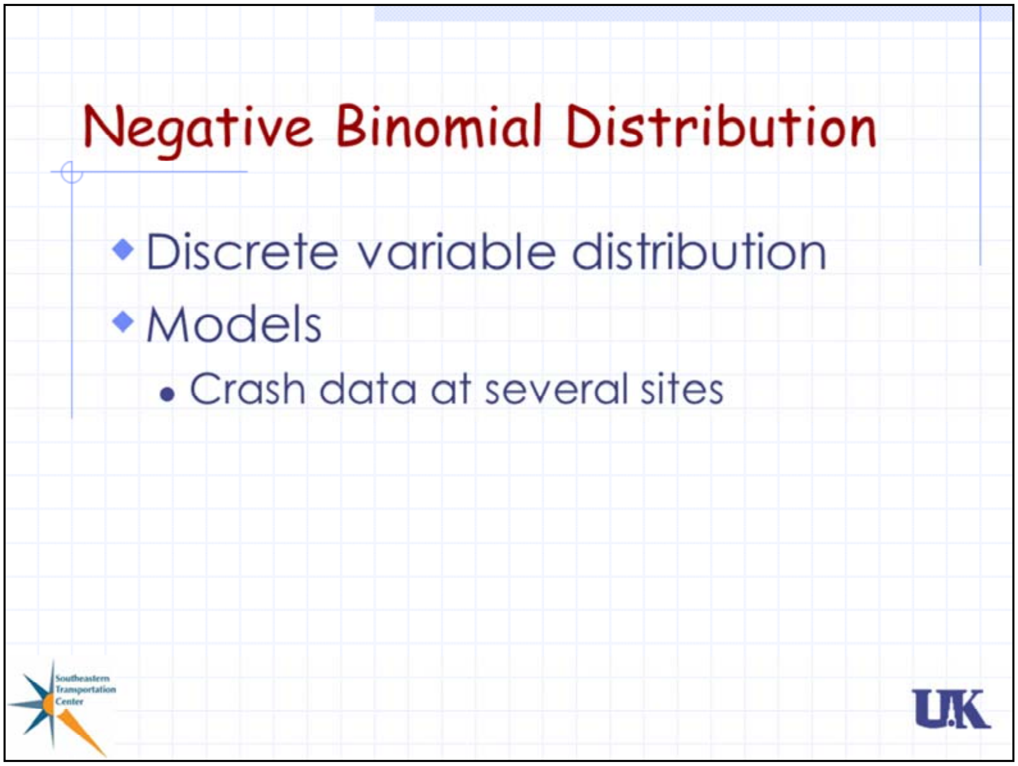


As an example, consider the following speed data collected for a roadway segment. 45, 46, 51, 45, 48, 39, 46, 52, 43, and 44.

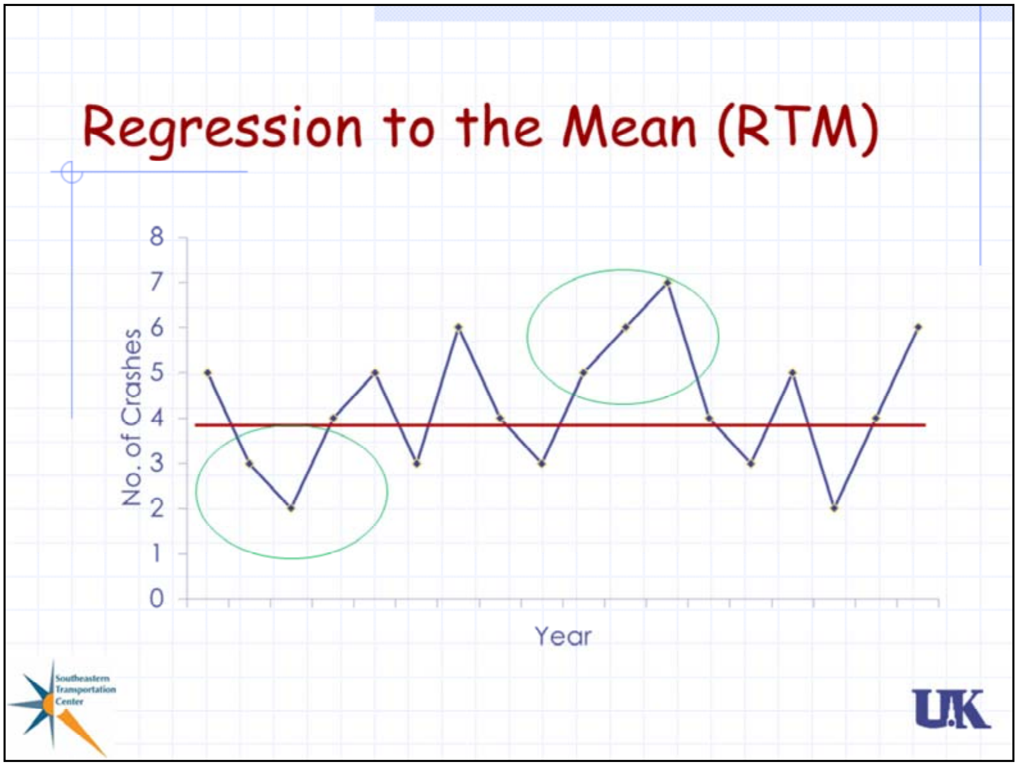
In this case, one can estimate the average speed of the distribution as 45.9 mph; the median to be 45.5 mph; the mode is 45 mph; and the variance is 14.32 mph.



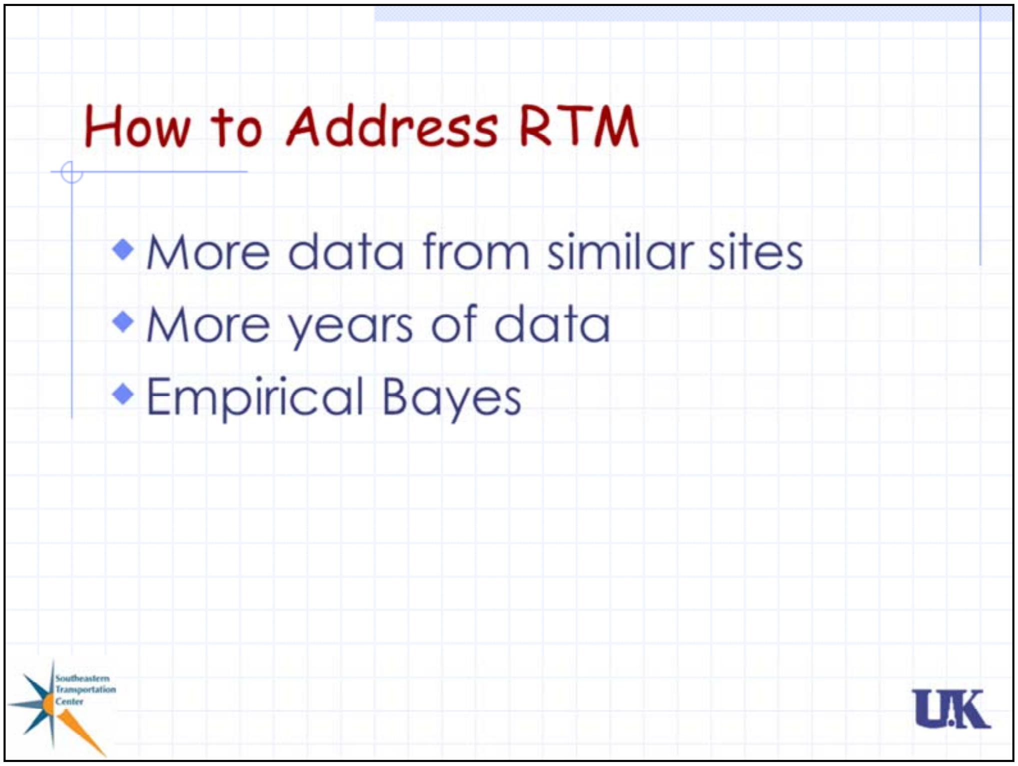
Poisson distribution is a discrete probability distribution that expresses the probability of events occurring in a fixed time assuming that the average rate of occurrence is known. The distribution also assumes that each occurrence is independent of the time since the last event. The distribution models the probability of the exact occurrence and can be used to model various elements in highway. Most typical uses are crashes at a single location and number of arrivals at a highway point (intersection arrivals within a cycle length). The distribution has only a single parameter to be estimated since its mean is equal to its variance.



As noted in the previous slide, the Poisson distribution can be used to model crash counts at a given location. The Poisson distribution has been shown to be reasonable to model crash data at a given one site. However, one often wants to evaluate more than one locations and in this case the crash data will often exhibit a large variance and a small mean, and display over-dispersion with a variance-to-mean value greater than one. To address this issue, the negative binomial distribution, also known as the Poisson-Gamma distribution, has become the most commonly used probabilistic distribution for modeling crashes. The negative binomial distribution is considered to be able to handle over-dispersion better than other distributions and has been widely used in many fields in addition to transportation.



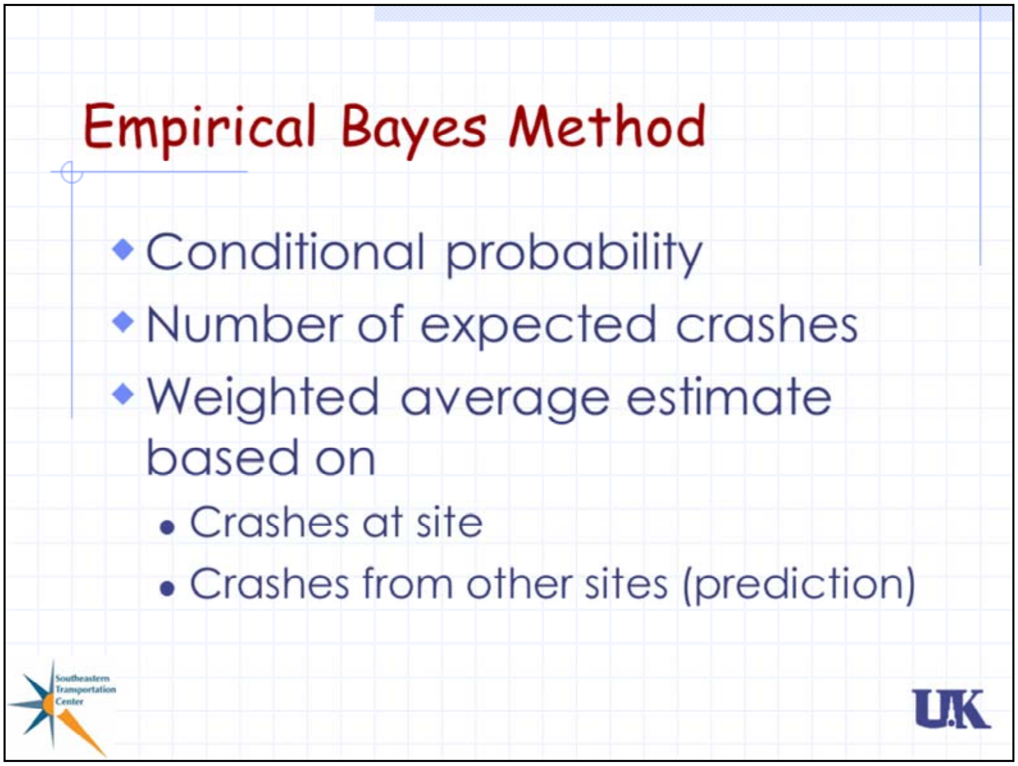
Crash frequencies vary naturally from one time period to the next and therefore, a site that has an above-average crash frequency one year is likely to have a below-average crash frequency the next. This phenomenon is called “regression to the Mean” and is observable in various scientific fields (first was introduced by Sir Francis Galton in 1887 who was studying pea genetics and observed that large peas will produce smaller peas and small peas will produce large ones). It is a statistical phenomenon resulting from repeated observations of the same subject occurring with random error around a “True Mean”. Statistical methods can be used to assure that these changes are not mistaken as the effects of roadway enhancement project.



There are a couple of possible ways to address the regression to the mean issue identified before. One approach is to include more data from similar sites, since there are a number of sites that could have a low number of crashes. This may skew the data to sites with no problems and thus represent an inaccurate picture of the safety situation. Another approach would be to increase the number of years considered in the analysis. This could be problematic as well, since a longer period may include other factors that may influence crashes. For example, consider the effect of an oil crisis that could affect the amount of travel and the potential influence that it may have on crashes. Moreover, both approaches need to consider the change in traffic over time and across sites and this could be problematic for large data sets.

Recently, the concept of Empirical Bayes approach has been used to address the RTM phenomenon (Hauer 1997). The objective of the approach is to estimate the number of crashes that would have been expected in the after period had there been no treatment.

Hauer (1997) *Observational Before-After Studies in Road Safety*, Pergamon.



The Empirical Bays method is an approach utilizing empirical data to evaluate or estimate the conditional probability of an occurrence and it is based on the Bayes Theorem, which describes the probability of an event based on conditions that might be related to the event. The objective of the approach is to estimate the number of crashes that would have been expected after the implementation of the treatment had there been no treatment. The difference between this estimate and the number of crashes actually recorded after the treatment is the estimate of the treatment effect.

The estimated number of crashes is obtained through a weighted average from two sources: 1) the number of crashes before the treatment at the location of concern; and 2) the number of crashes at other locations with similar traffic and physical characteristics based on the prediction model developed.

Basic Equations

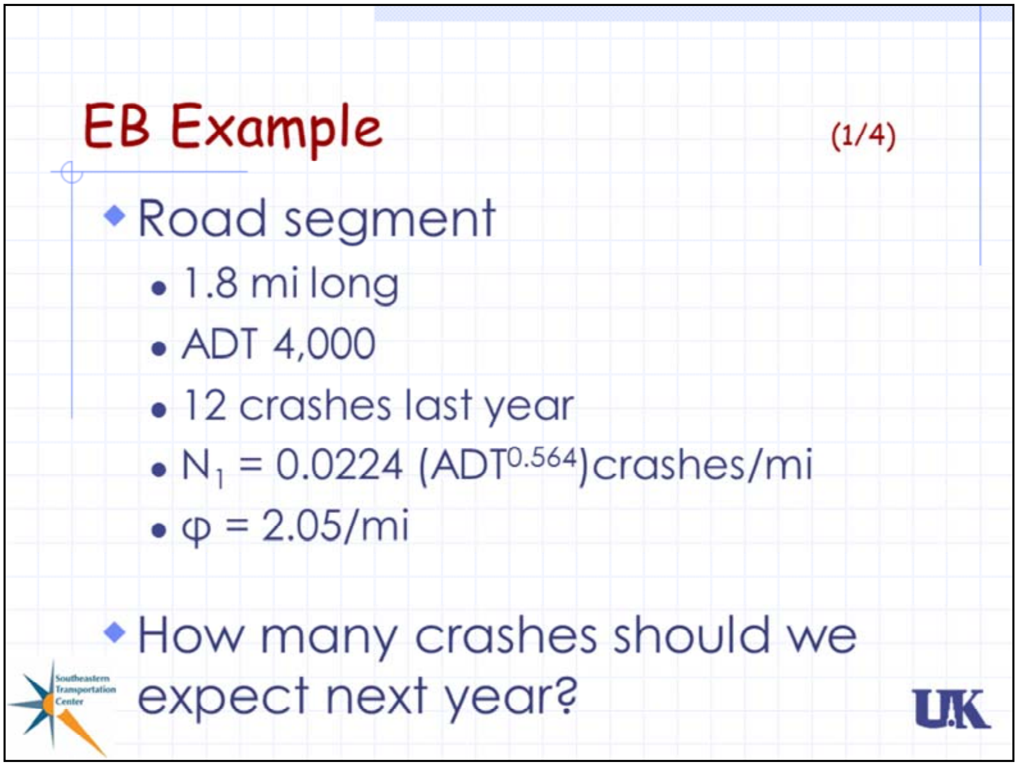
$$N = N_1 w + N_2 (1\text{-}w)$$

where: N: estimated expected crashes
N_1: crashes from other similar sites
N_2: observed crashes at site
w: weight factor

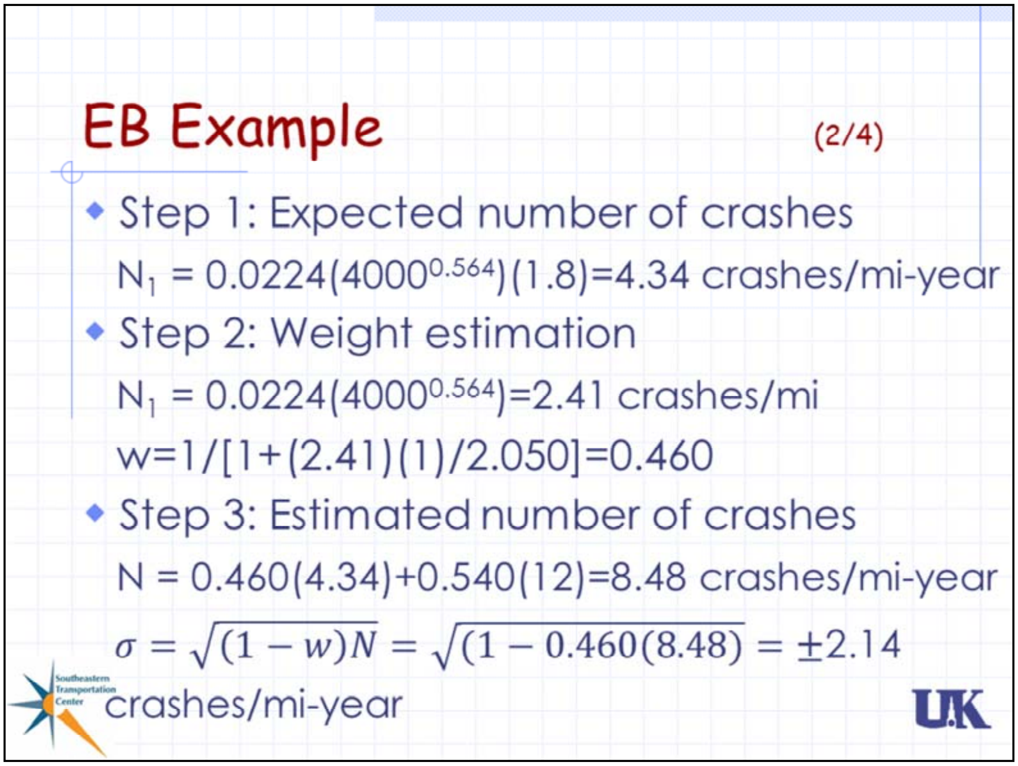
$$w = 1/[1+(N_1 Y/)\varphi]$$

where: Y: timeframe in years for crash counts
φ: overdispersion parameter

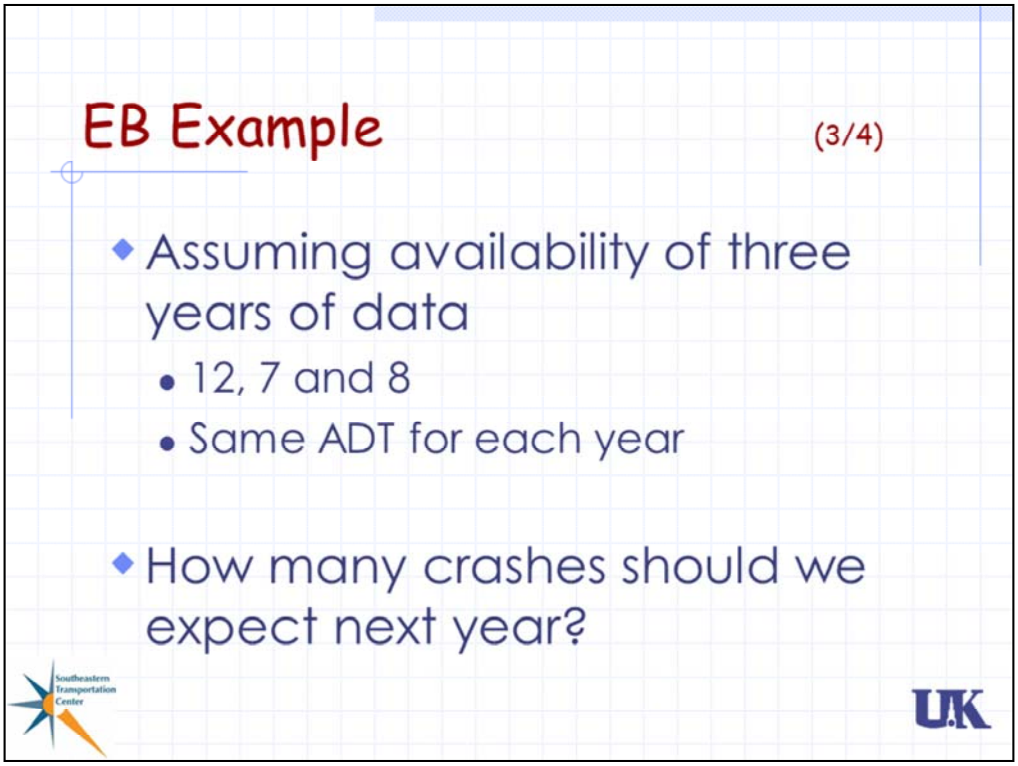
The basic equation form is as shown above. The weights assign the relative importance between crashes from other similar sites (the population in this case) and the specific site where the treatment was implemented. The key here is to determine the weight to be associated with crashes in similar sites (N_1) and the Highway Safety Manual (AASHTO 2009) has defined this a function of the crashes from other sites and the overdispersion parameter the estimate which is calculated from the negative binomial distribution of the crashes. Typically, the number of crashes from other sites is a regression model (safety performance function) that relates crash experience to traffic and other physical characteristics of sites in the other similar sites group. It should be noted that the weight is based both on logic and real data.



Given the roadway data here, the question required is to estimate the number of crashes next year. The SPF noted here is the safety prediction function that can be used to estimate the number of crashes in similar locations.



The steps required for answering the question are noted here. Step 1 estimates the number of expected crashes at the site for the given year based on the SPF from similar sites. Step 2 calculates the weight for the function based on the estimate from other similar sites (converted on a per mile basis) and the overdispersion parameter given. The number of crashes is estimated in Step 3, where the weight is used. The expected number of crashes is between the anticipated from similar sites (4.34) and the actual (12). The standard deviation of the estimated number of crashes is also calculated.



In this case, a 3-year period is utilized to demonstrate the effect of the larger number of years in the analysis.

EB Example (4/4)

- Step 1: Expected number of crashes

  $N_1 = 0.0224(4000^{0.564})(1.8)(3) = 13.01$ crashes 3 yrs

- Step 2: Weight estimation

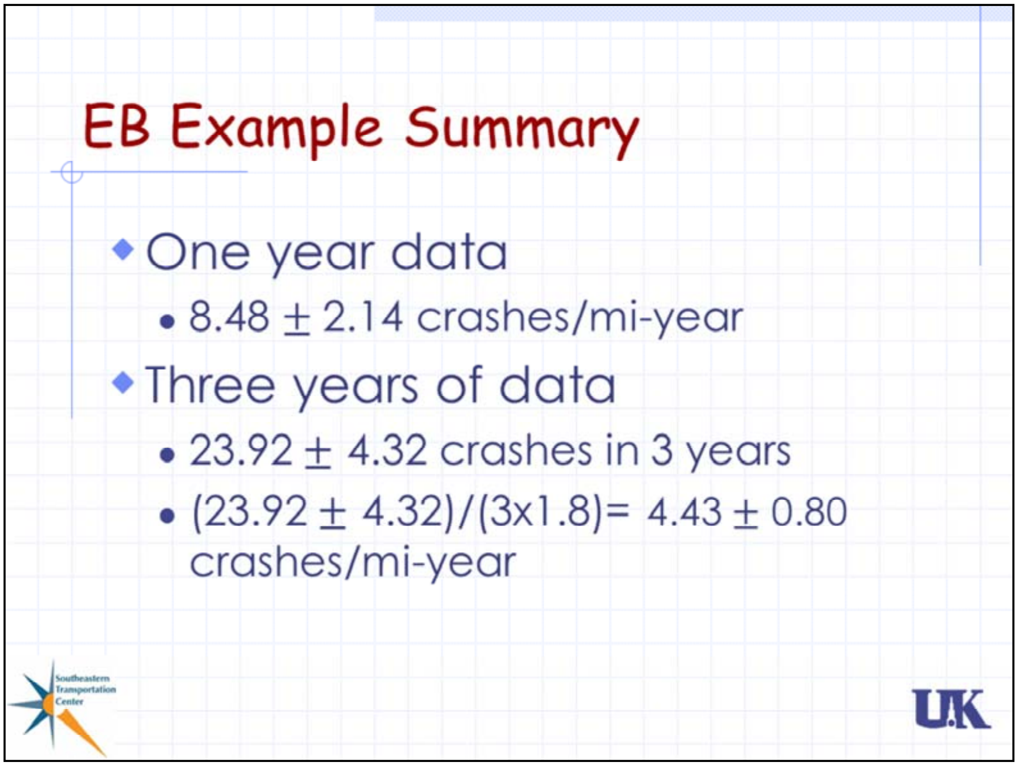
  $w = 1/[1+(2.41)(3)/2.050] = 0.220$ crashes/mi

- Step 3: Estimated number of crashes

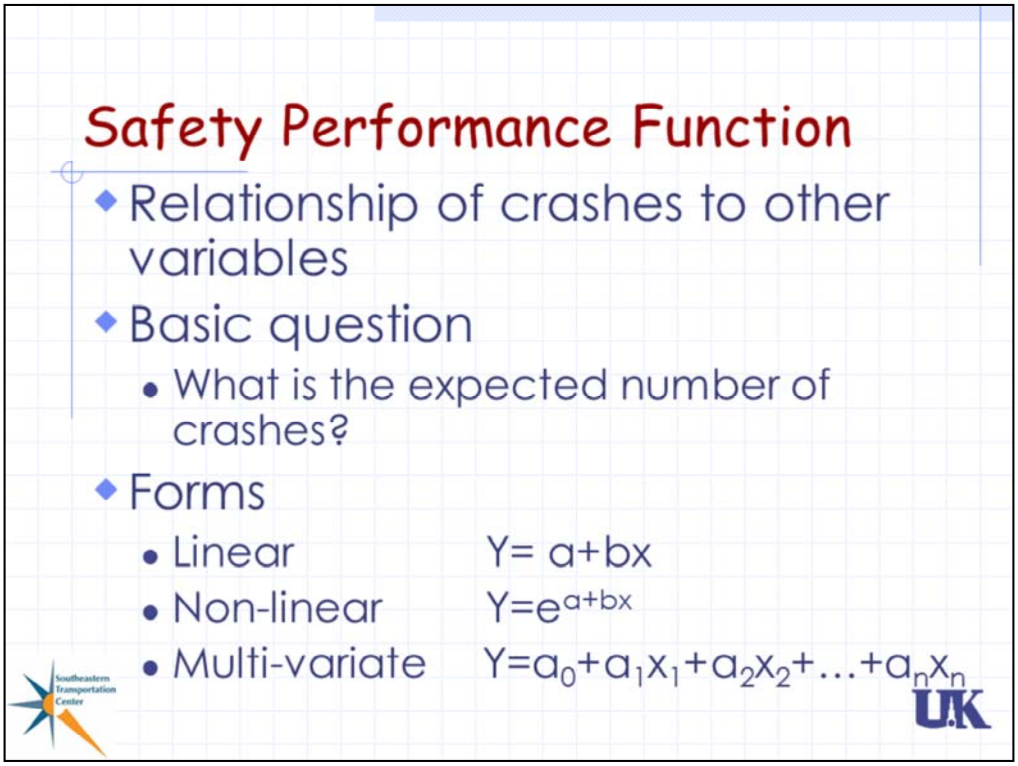
  $N = 0.220(13.01) + 0.780(27) = 23.92$ crashes 3 yrs

  $\sigma = \sqrt{(1-w)N} = \sqrt{(1-0.220(23.92)} = \pm 4.32$ crashes/mi-year 3 yrs

The same steps as in the previous example are taken here as well. The only difference is that a 3-year value is used in the calculations for N_1 and φ. It should be also noted that the number of observed crashes is 9, which is the average of the three years of data obtained. In this case, the estimated number of crashes for a 3-year period is 23.92 crashes, which lies between the estimated value (13.01) and the actual (27). This example also demonstrates the impact of multiple years of crashes. The weight associated with model prediction is reduced (0.220 vs. 0.460 in the one-year data) thus placing more emphasis on the estimate from the observed data.

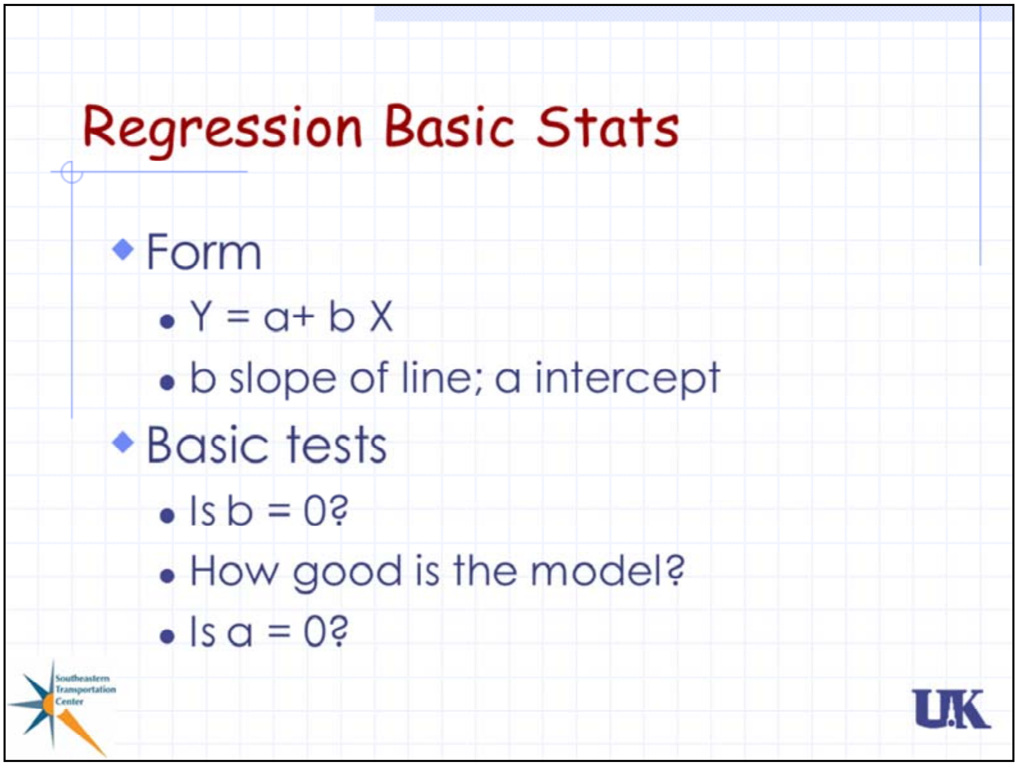


The effect of multiple years of data is noted here where greater emphasis is placed on actual data than the predicted numbers. Also, the standard deviation is getting smaller. The larger number of years also allows for a more accurate prediction and regression to the mean can be eliminated. For the 3-year data, the final estimate is converted into an annual estimate, since the original question is “How many crashes should one anticipate next year in this site?”.



The SPFs identify the relationships of crashes to other variables of concern. These typically contain offset variables, including length and volume to account for the importance of the exposure, as well as explanatory variables that identify the potential contribution of various factors on a crash. Such variables typically include roadway geometry elements (e.g., lane and shoulder widths, presence of median and type, curvature, grade, etc.).

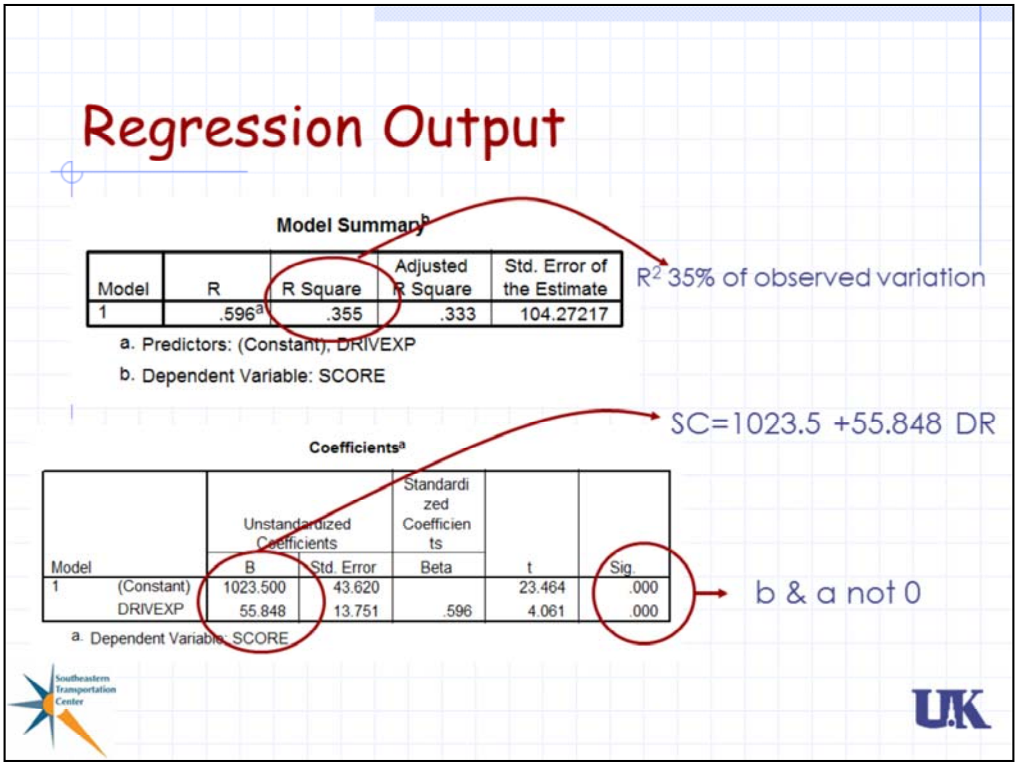
The basic effort here is to predict the expected number of crashes at a site given its features. An SPF can assist in this and determine the anticipated number of crashes based on historical data (as seen in the EB example before). The SPF can take a variety of forms, including linear, non-linear or multi-variate. Typically, a number of forms are examined in order to develop the most appropriate model for the available data.



The linear regression basic form is shown above. In this set up, the slope indicates a corresponding increase between the estimate and the predictor with a positive sign and a decrease when the sign is negative.

The issues of concern with a linear regression focus on whether the parameters a and b are not zero. The basic idea here is that a slope of zero will indicate complete randomness of the data and lack of any model fit. An intercept of zero indicates that the prediction will be equal to zero when all predictors (X in this case) are set to zero. However, this is difficult to achieve and frequently the intercept is different than zero.

The model needs to be examined for goodness of fit and in this case various statistical metrics can be used (as discussed in the following). In addition to the statistical metrics, one needs to consider also the rationality of the model and examine the sign of the slope for reasonableness. A priori knowledge of anticipated variables should be examined in order to determine whether their signs are reasonable.



Regression Output

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.596[a]	.355	.333	104.27217

a. Predictors: (Constant), DRIVEXP

b. Dependent Variable: SCORE

R^2 35% of observed variation

Coefficients[a]

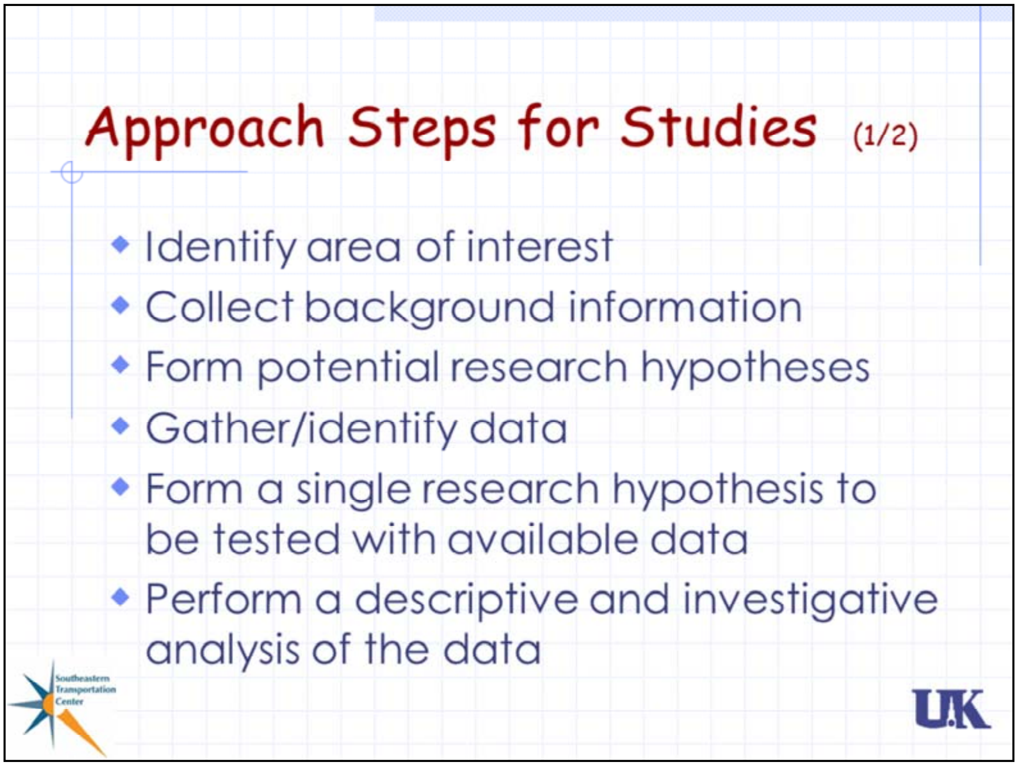
Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	1023.500	43.620		23.464	.000
	DRIVEXP	55.848	13.751	.596	4.061	.000

a. Dependent Variable: SCORE

SC=1023.5 +55.848 DR

b & a not 0

These are the results of an example regression that examined the number of years of driving experience to the scores of a driving knowledge test.

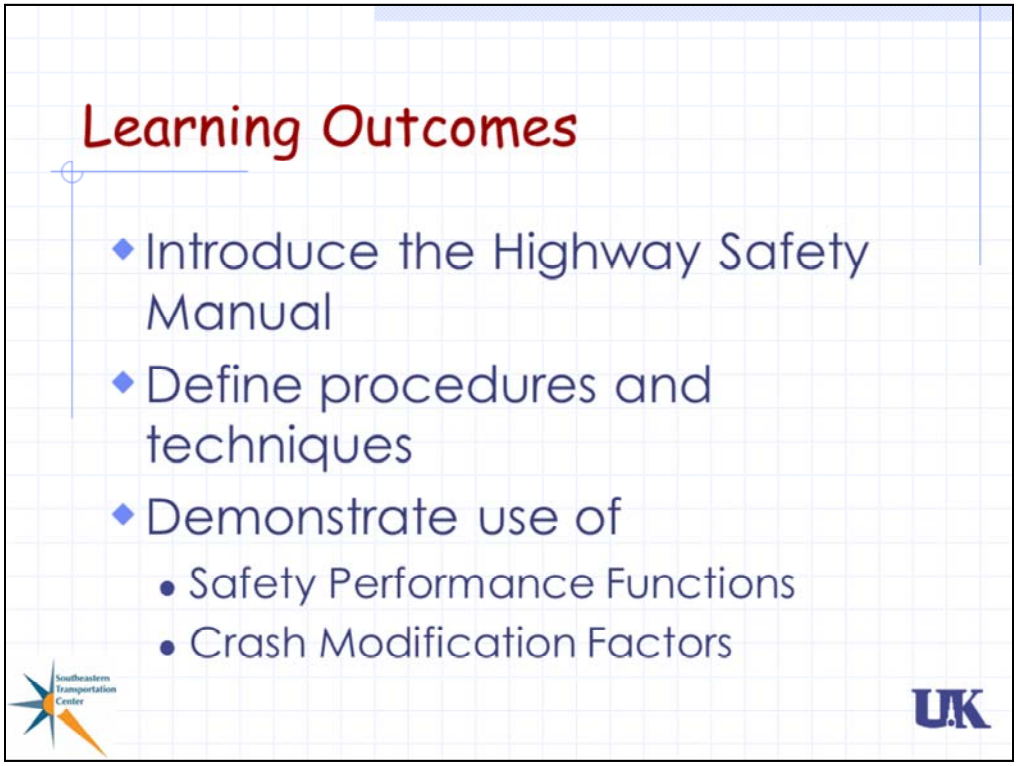


These two slides demonstrate the steps required for a study and follow basic engineering concepts and principles.

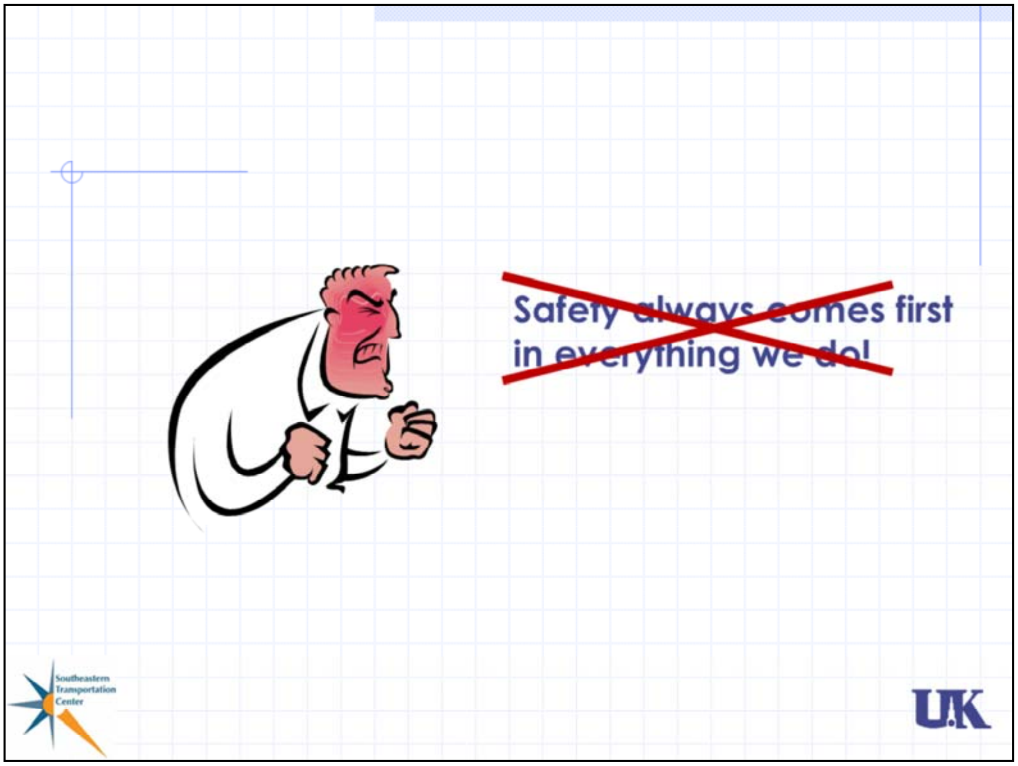
Approach Steps for Studies (2/2)

- Perform the test(s)
- Compare results to past results
- Develop potential explanations
- Discuss limitations of the findings
- Discuss applicability of findings
- Determine future research

This module reviews fundamental statistics related to safety analysis. It is critical to have a basic understanding of the models to be developed in order to apply the statistical methods and tools correctly for safety analysis. Even though current highway safety analysis techniques have moved beyond basic statistics, an understanding of statistical fundamental concepts can be useful in any analysis.



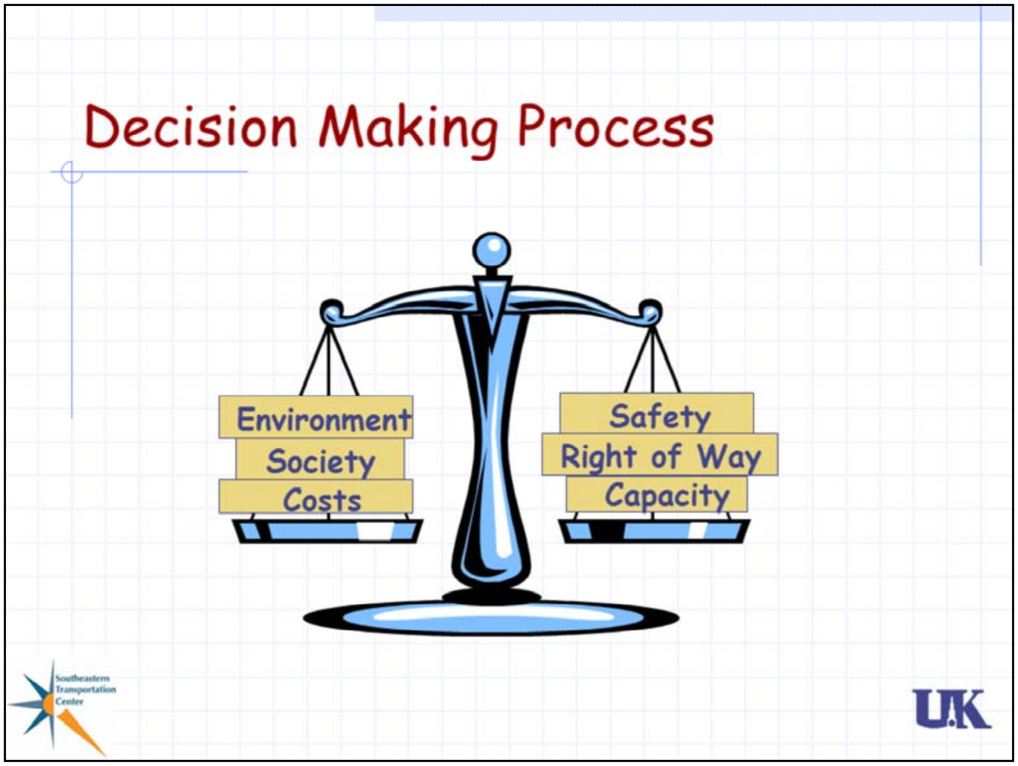
The main objective of the session is to familiarize workshop participants with the Highway Safety Manual procedures and applications. Participants will be able to use the technical information presented and apply the tools of the Highway Safety Manual effectively upon completion of this workshop. Examples and exercises are included to demonstrate concepts.



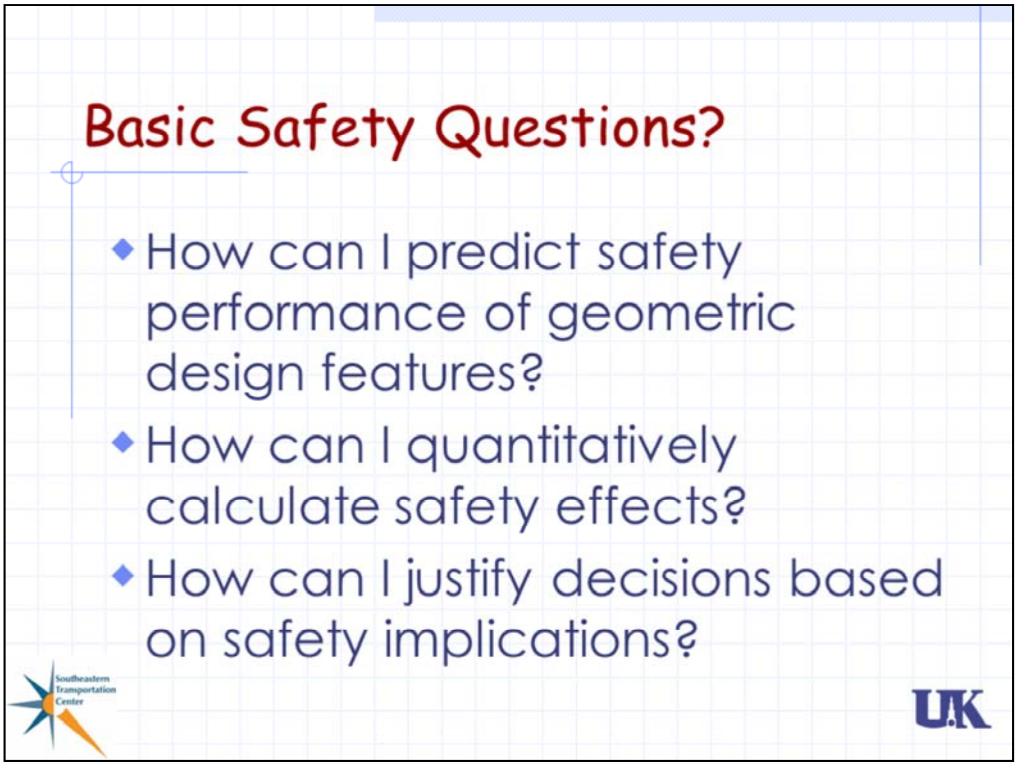
This may be true but most times, there is a need to trade off between various competing project issues and attributes.

Examples of such trade offs could be considered the following:

1. Safety vs Operational efficiency: Often right turn on red is allowed to improve operational efficiency at the expense of safety
2. Safety vs Budget: Divided highways are frequently safer than other roadways but not all roadways are constructed with medians.



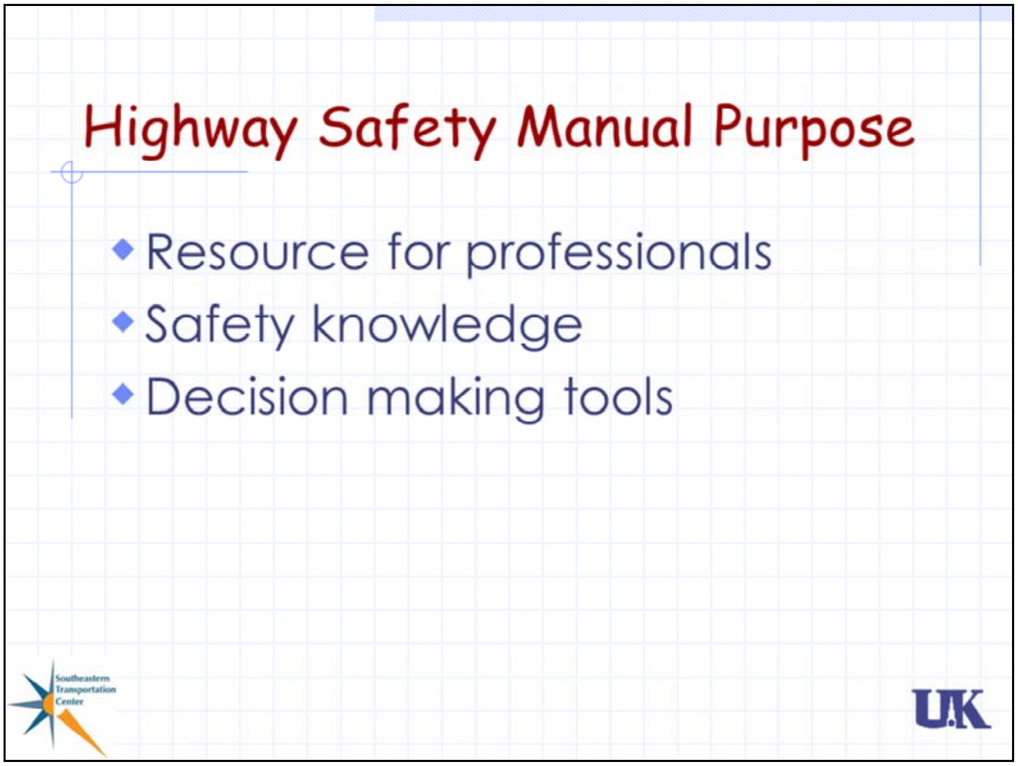
Until recently, transportation professionals did not have a single national resource to use in estimating safety performance. The HSM provides professionals with a much needed resource where current knowledge, techniques, and methodologies to estimate future crash frequency and severity are presented. Professional now have a set of predictive methodologies that can use in predicting crashes and quantitatively evaluate alternative designs. The new methods in the HSM are more statistically rigorous and reduce past issues of random variations of crash data.



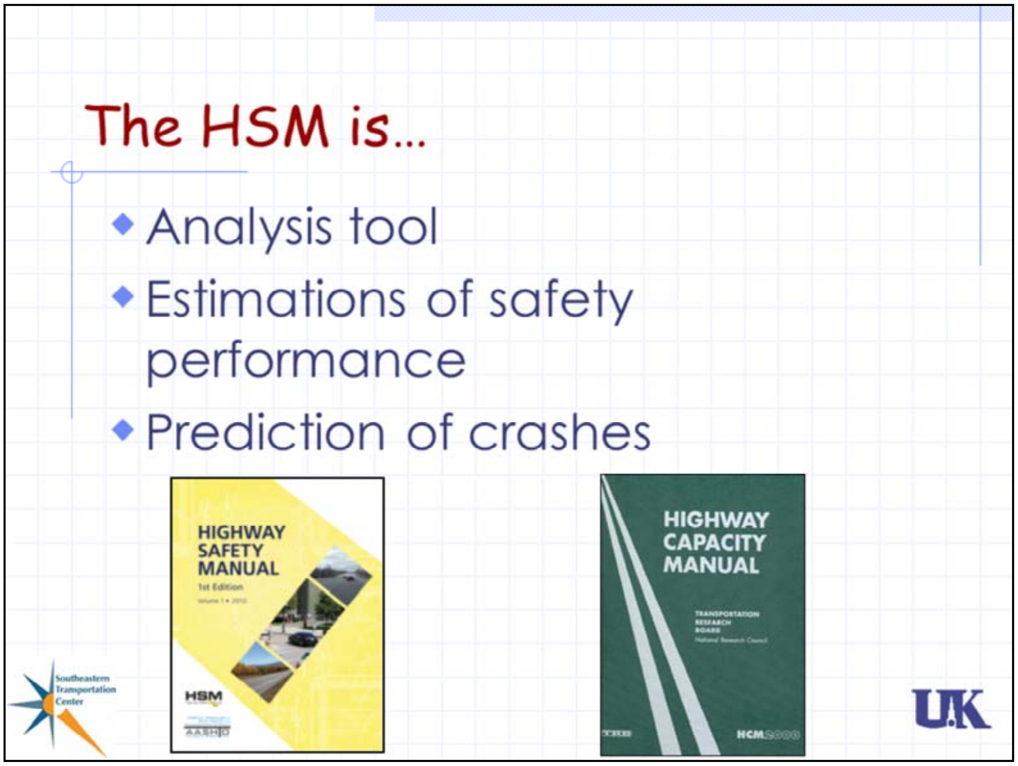
An agency or a practitioner, typically requires answers to these questions. For example, one may need to know what will be the safety performance for a horizontal curve and what may be the tradeoffs between a larger radius and the its associated costs and its safety gains. Similar questions can be posed for decisions regarding any geometric feature in evaluations of design elements and the selection of the appropriate value in order to balance costs and benefits.

The HSM can answer these questions by:

- Providing proven and vetted science-based approach to quantifying safety effects of decisions and actions a professional contemplates
- Providing common knowledge base, language and basis for reasoned safety judgments
- Allowing incorporation of safety to same level of importance as other factors
- Not increasing risk of tort liability



The Highway Safety Manual (HSM) is a resource for professionals that provides safety knowledge and decision making tools in order to allow for a systematic evaluation of safety impacts in highway design. The HSM organizes these tools in a useful form to enable improved decision making based on safety performance. The HSM fills the gap of lacking quantitative information that could aid decisions. Moreover, the HSM is a platform for assembling current information and methodologies on measuring, estimating and evaluating roadways in terms of crash frequency and severity.

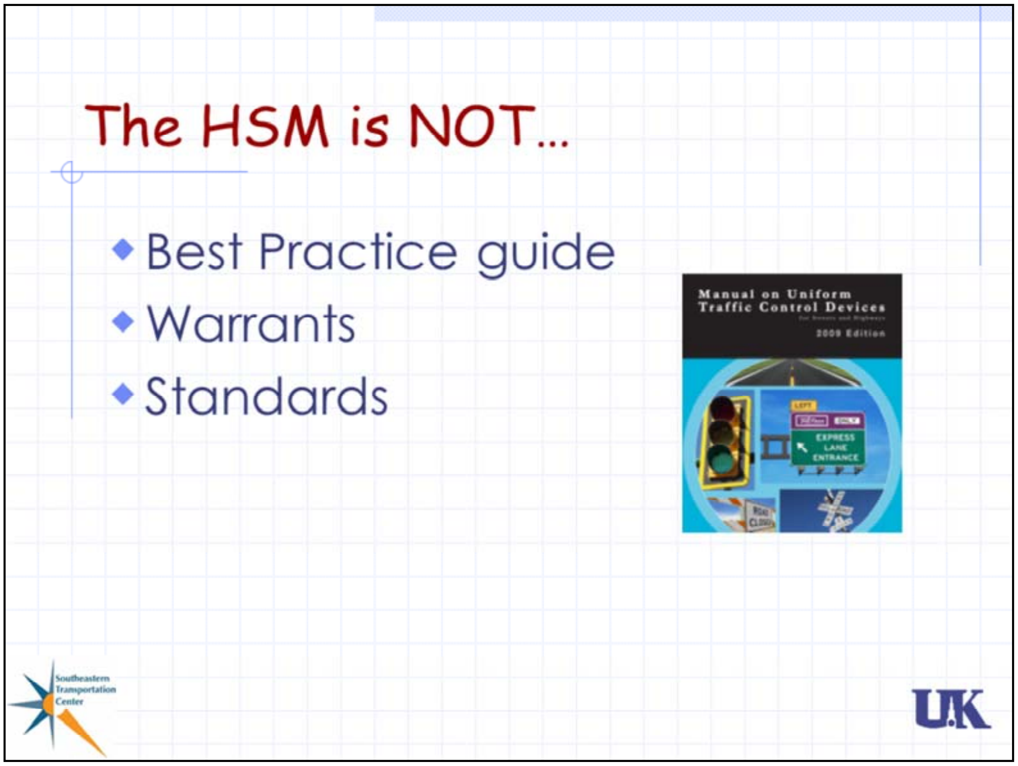


The HSM is a toolbox that professionals can use to evaluate or estimate the safety performance of a facility and in this respect is very similar to the Highway Capacity Manual.

The HSM provides users with a process on how to use the tools provided along with direction on which tools are appropriate to use in estimating safety performance.

The HSM provides the user with safety estimates of alternative choices and allows for the development evaluating design options and treatments to improve safety performance.

The HSM provides the required quantitative data for a decision maker to determine the most appropriate solution for a given scenario and support their judgment.

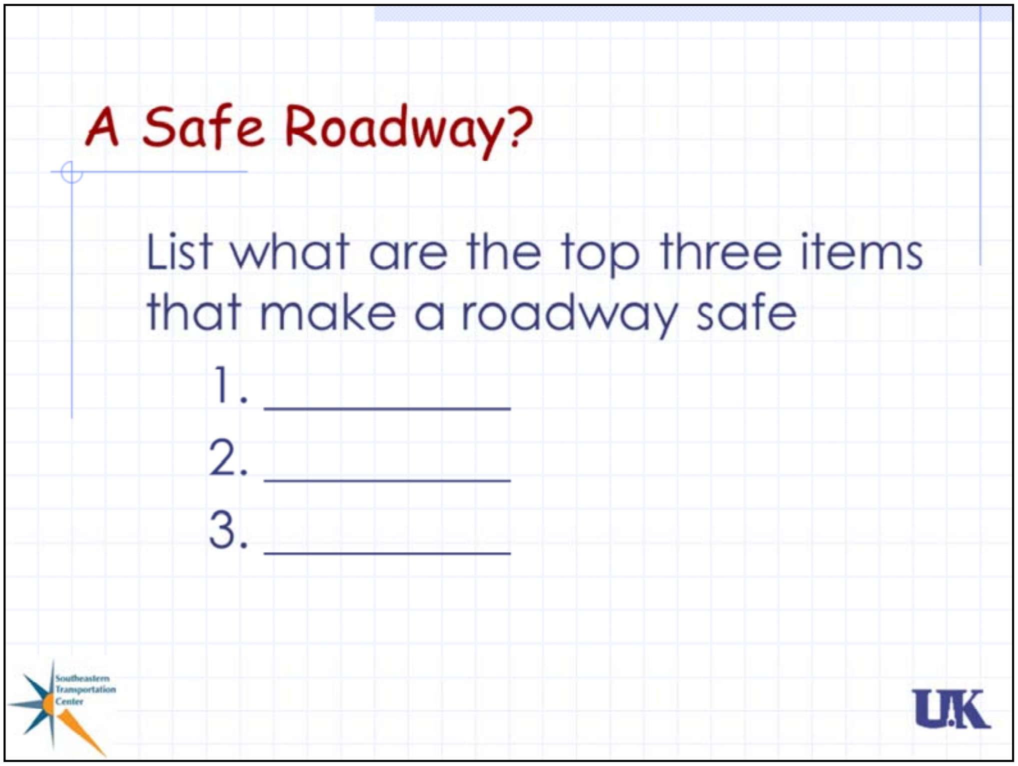


The HSM is NOT like other AASHTO publications, such as the MUTCD, that provide user with definitive requirements, i.e., standards and warrants.

The HSM does not require any user obligations to follow a particular design or warrant but rather provides a process for a quantitative decision.

The HSM will NOT tell the user that a particular option should be adopted.

The HSM 2010 is a compilation of past research that was sponsored by AASHTO and FHWA and provides the user with current trends in highway safety. The HSM provides a state-of-the-art information and is the definitive resource for such collection of knowledge. It is also anticipated that the HSM will be updated periodically to reflect future research findings and present future trends in safety analysis and evaluation.



The idea for this is to identify elements that the students may consider as safe feature for a highway. Answers could include wide lanes, wide shoulders, clear zones, medians, guardrails, proper vertical and horizontal alignment, good pavement condition, available sight distances, provision of stopping sight distances greater than the minimum, and placement of proper barriers around immovable obstacles. You may also indicate that a road with no vehicles could be safe☺

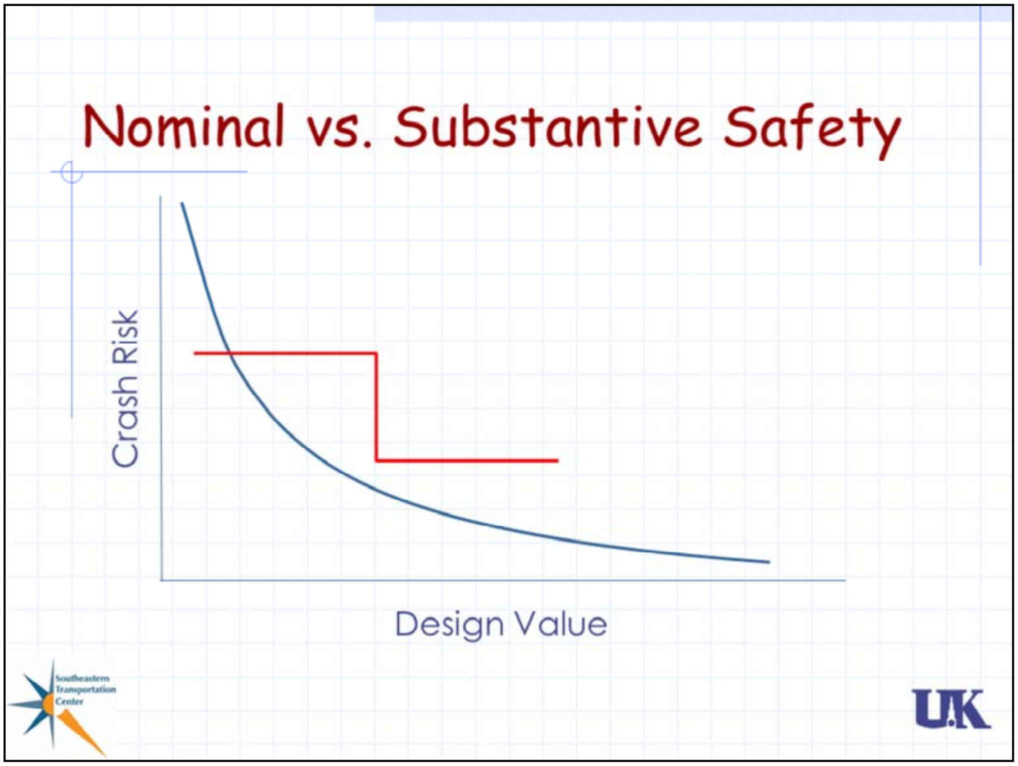
The discussion should lead towards the next few slides, where the point is to identify the relativity of safety features (nominal and substantive safety) and the fact that roadway geometry has the potential to influence driving behavior (curvy roads typically lead to slower driving than straight ones).

Question to be posed here is “Which roadway is safer?” The answer should focus on the concept that we need more information to reach a decision and we need a systematic approach to do this. Also, the idea that roads do not always perform as intended when it comes to safety should be raised. In this case, designs of straight and wide roads may result in more unsafe roads. Drivers may compensate for what is perceived more dangerous and thus safety is not a black and white issue but rather one that requires other factors to be considered as well. For the photographs shown here, the first one had 25 crashes in 2014 with an ADT of 40,000 and a rate of 1.71 crashes per million vehicle-miles of travel (MVMT) and the second had 3 crashes with 6,000 ADT and rate of 1.37 per MVMT. In this case, the crash experience of the first road is “worse” than the second, even though the first one gives the impression of a “safer” roadway.

Nominal safety is a term coined by Dr. Ezra Hauer that describes whether a design adheres to design standards and practices. Under this approach, a road is "nominally safe" if it meets the required standards and guidelines.

On the contrary, substantive safety (or perhaps quantitative safety) is its actual or expected performance in terms of crash frequency and severity. Substantive safety is not only affected by the basic characteristics of the road, but it is also affected by all other resources (e.g. maintenance, law enforcement, etc.) devoted to the road.

Hauer, E. *Safety in Geometric Design Standards* University of Toronto, Toronto, Canada. 1999.

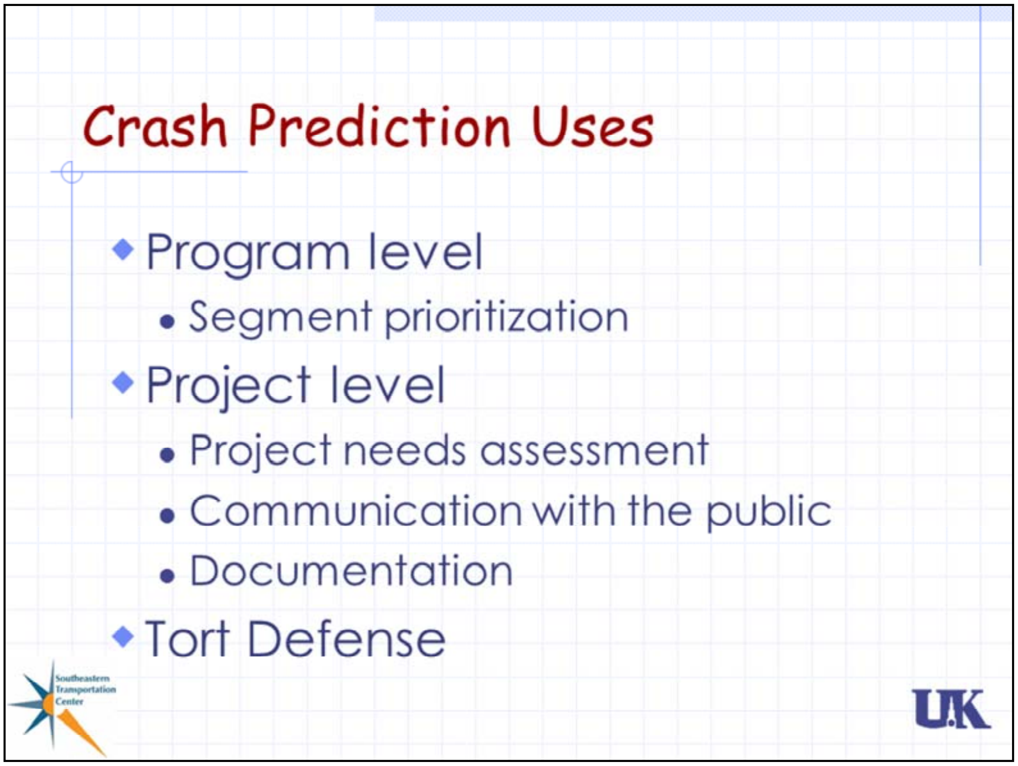


In the nominal safety concept, there is a simplistic approach evaluating whether the facility complies with the prescribed standards or guidelines. In this case, any choice outside the value will be considered unsafe and in this case the road either meets the standard or not.

Professionals frequently are called to make decisions and evaluate incremental effects of a design value. For example, one may want to know what are the safety effects of reducing the lane width by 1 foot or increasing shoulder width by 2 feet. The nominal safety approach does not allow for this estimation. In this case one needs to estimate these changes and approach the project under the substantive safety model.

The HSM provides the tools to estimate such incremental differences and provide professionals with a needed tool to characterize the shape and values of the substantive safety curve for the range of highway types and conditions they would typically encounter.

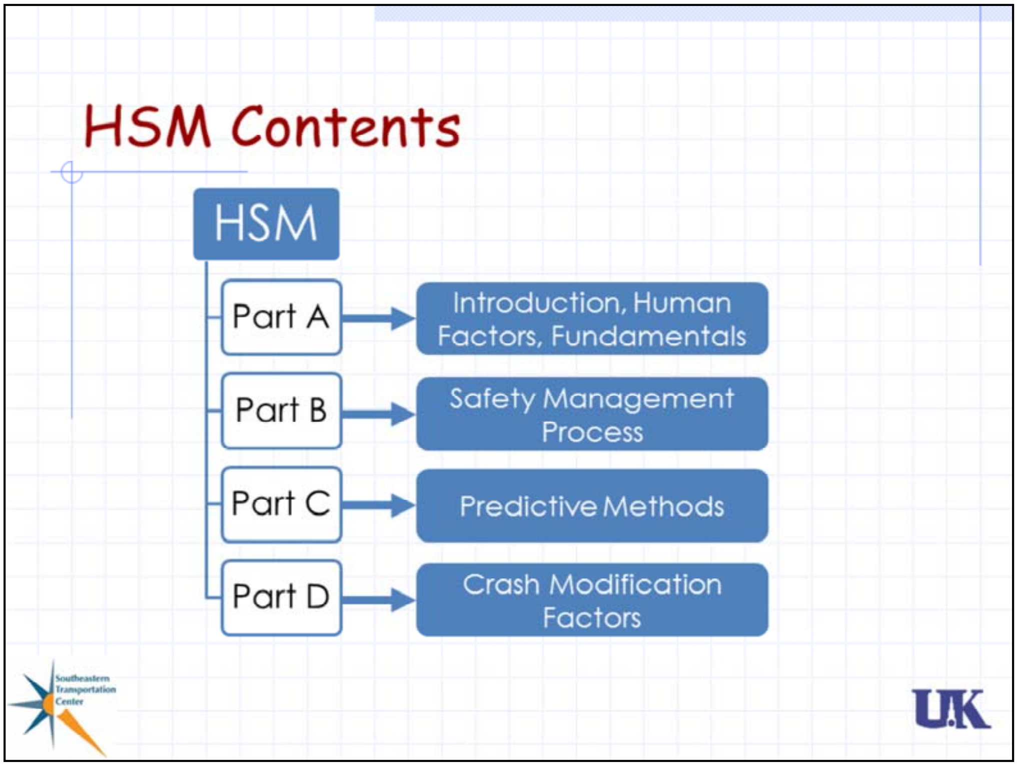
HSM can help professionals decide on whether an alternative design option is feasible and what are the safety effects from such choices. For example, when considering upgrading a 2-lane rural road with no shoulders one can identify what will be the benefits of increasing only shoulder width or increasing only lane width or converting to a super 2. These benefits then can be quantified based on crash values and compared to costs of construction to determine a benefit/cost ratio.



Transportation agencies can use crash prediction in various levels. At the program (planning) level, these predictions can be used to identify hazardous locations/segments and prioritize them in order to address the most pressing needs.

At the project level, crash predictions can assist in establishing and assessing the needs of the project (can be utilized in the purpose and need statement), to demonstrate the impacts of alternative designs during public meetings and communicate these choices to the public, and to document decisions reached during the design of the project justifying choices.

The latter can be very useful in tort defense, since all decisions could be documented and readily available.



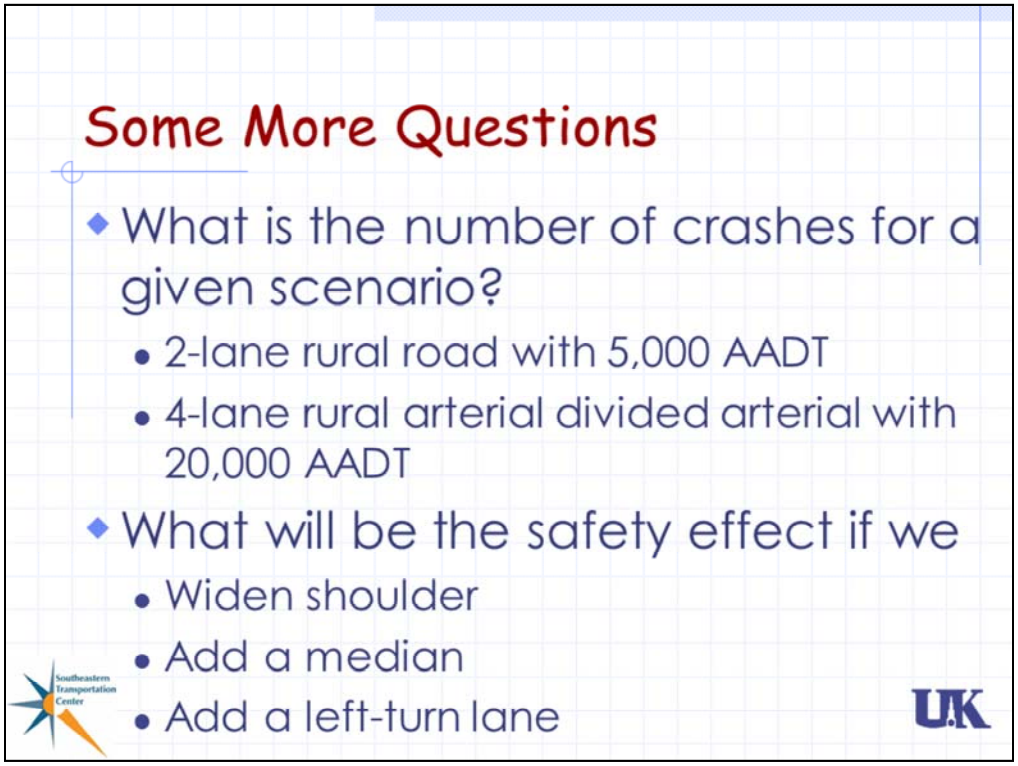
The HSM is divided into four parts. In part A the user is provided with an introduction to the HSM, knowledge about human factors and the fundamentals of highway safety. Part B covers the roadway safety management process. In Part C predictive methods are introduced for different facility types. And, last but not least, Part D provides Crash Modification Factors (CMFs) for use with Part B. It is important to keep in mind that Part D can only be used with Part B – Part C has its own AMFs for each facility type. This issue is further addressed later in the presentations.

The first edition does not cover driver education, enforcement, and vehicle safety, even though it is recognized that these are important elements which can help reduce injuries and fatalities from motor vehicle crashes.

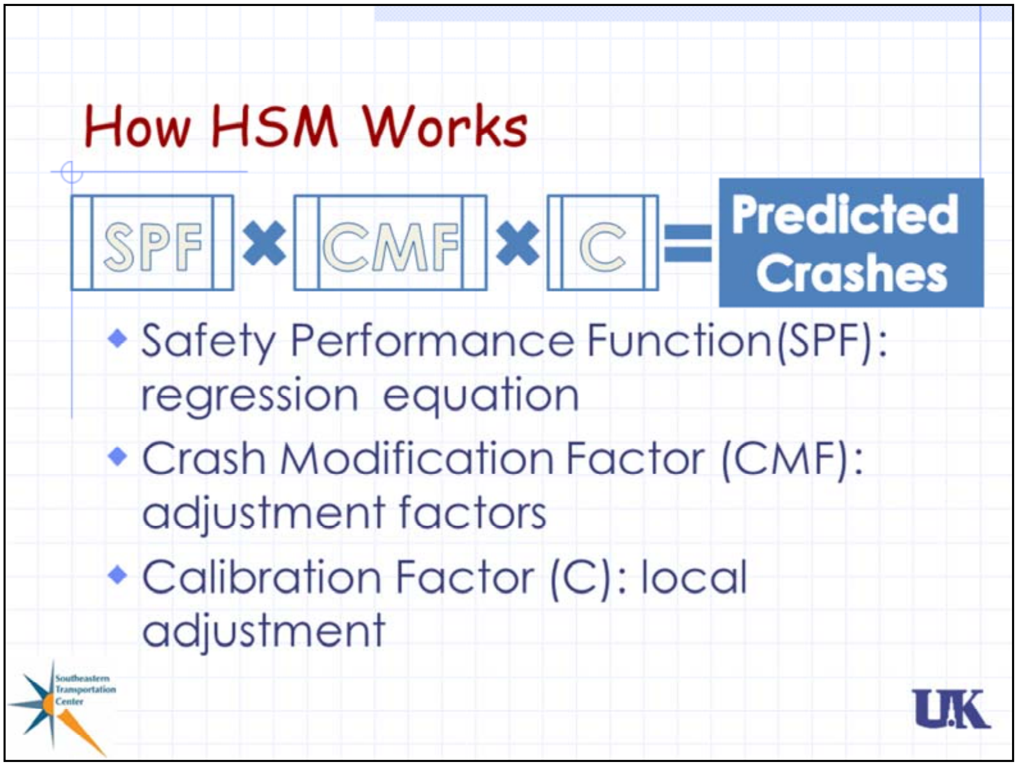
HSM Companion Software

HSM Part	Supporting Tool
Part B: Roadway Safety Management Process	SafetyAnalyst www.safetyanalyst.org
Part C: Predictive Methods	IHSDM www.ihsdm.org
Part D: Crash Modification Factors	FHWA CRF/CMF Clearinghouse www.cmfclearinghouse.org

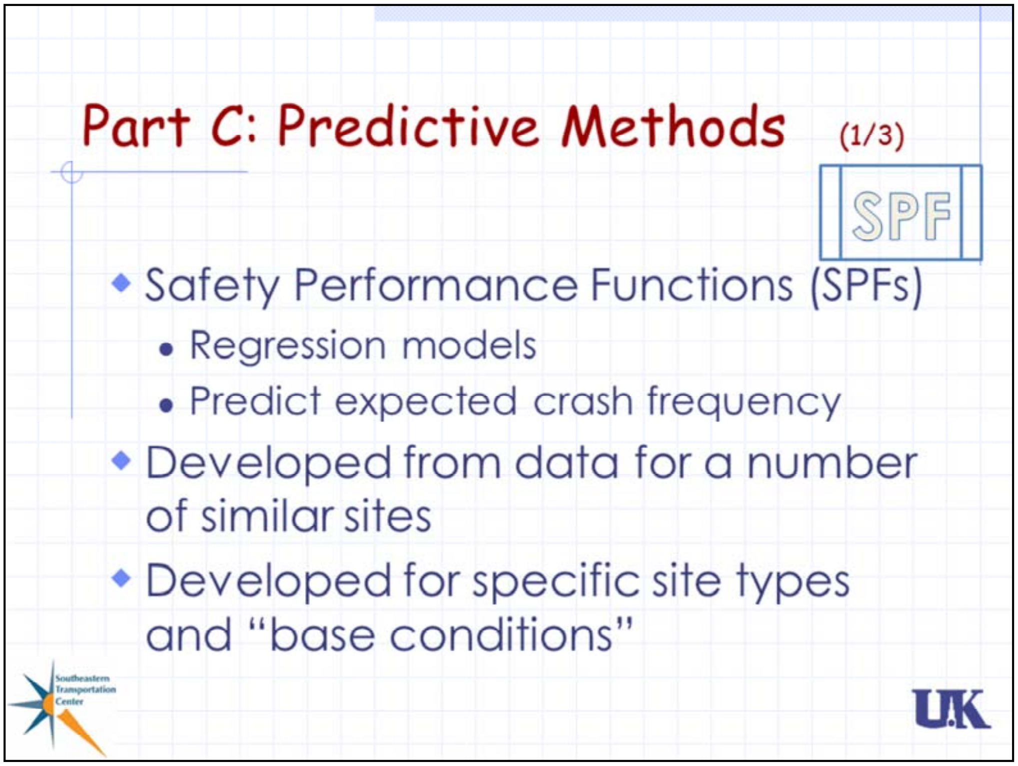
Current software (as of August 2015) is noted here. The Safety Analyst can assist with the safety management process at the state level. IHSDM can assist in estimating safety impacts from design choices and assess compliance with existing policies. Finally, the Clearinghouse provides up to date information on CMs and CRFs and ranks them based on their robustness.



The goal in this process is to be able to quantify the anticipated crashes for any given scenario. This is the critical question that any person involved in any stage of the project development process is trying to address. The answer will provide quantifiable results and allow to decisions to be made through a well-documented process.



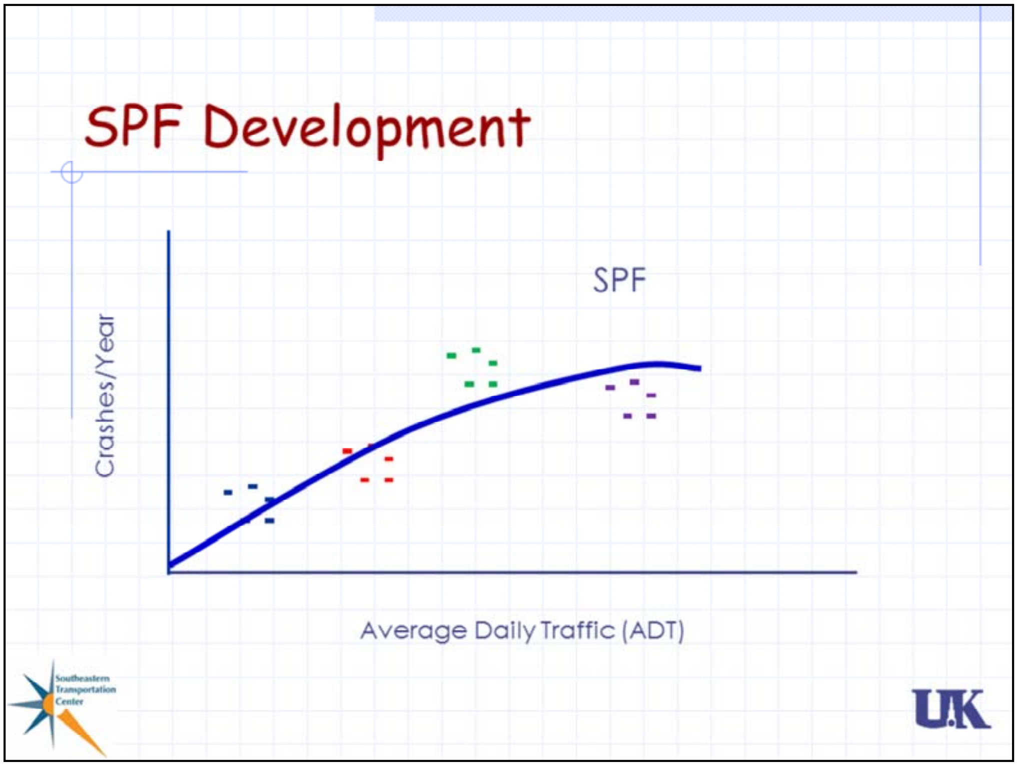
The predicted crashes are the "expected average number of crashes". The use of the SPF indicates the application of a statistical method and the answer is not an exact number, as is frequently the case in engineering, but rather a statistical estimate. This means that if we record crashes in several sites with similar characteristics, then, on average, we can expect to measure that particular number.



SPFs are regression models that are developed using historical data from a set of sites with similar characteristics. Sites can be aggregated based on lane width, shoulder width and type, degree of curvature, presence of median or any other geometric features that could provide for such classification.

The model developed could predict the expected number of crashes for these sites and can be used to estimate crash performance for sites with similar features. The models establish the base conditions based on the common features of the sites used in the prediction. The models are typically a function of ADT.

It is desirable to use a 3-5 year historical data, if available, when developing these models per HSM recommendation. It should be also noted that "base" conditions could vary from state to state and this should be evaluated if one wants to use the HSM models.



Here is an example of how an SPF can be developed.

Assuming that the four data sets depict the crash experience over 5 years for a set of sites with similar features. It can be assumed that the all sites are 2-lane roads with 12-foot lanes, 8-foot shoulders, and no curves.

A curve is fitted through these 4 entities using a negative binomial regression formula. The line is the “best fit” of all the data and is the Safety Performance Function (SPF). The line represents the change in the mean expected number of crashes at all similar entities as ADT (or other exposure measure) increases, while all other factors affecting crash occurrence are held constant. It should be noted that this is an example and typically SPFs are based on a far greater number of sites for greater accuracy.

Sites that lie above the SPF indicate a mean expected crash frequency in excess of the average for comparable sites. One can think about sites with mean risk above the SPF as those with higher than average risk and those below the line as those with lower than average risk. SPFs have been compiled into safety analysis tools, such as Safety Analyst and the Highway Safety Manual (HSM). However, since crash patterns may vary in different geographical areas, SPFs must be calibrated to reflect local conditions (e.g., driver population, climate, crash reporting thresholds, etc.).

SPF Example: 2-Lane Rural Roads

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)} \quad \text{(Eq. 10-6)}$$

Table 10-2. Safety Performance Functions included in Chapter 10

Chapter 10 SPFs for Rural Two-Lane, Two-Way Roads	SPF Equations and Figures
Rural two-lane, two-way roadway segments	Equation 10-6 , Figure 10-3
Three-leg stop controlled intersections	Equation 10-8 , Figure 10-4
Four-leg stop controlled intersections	Equation 10-9 , Figure 10-5
Four-leg signalized intersections	Equation 10-10 , Figure 10-6

10.6. SAFETY PERFORMANCE FUNCTIONS

The appropriate safety performance functions (SPFs) are used to predict average crash frequency for the selected year for specific base conditions. SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. The SPFs, like all regression models, estimate the value of a dependent variable as a function of a set of independent variables. In the SPFs developed for the HSM, the dependent variable estimated is the predicted average crash frequency for a roadway segment or intersection under base conditions and the independent variables are the AADTs of the roadway segment or intersection legs (and, for roadway segments, the length of the roadway segment).

The SPFs used in Chapter 10 were originally formulated by Vogt and Bared (13, 14, 15). A few aspects of the Harwood et al. (5) and Vogt and Bared (13, 14, 15) work have been updated to match recent changes to the crash prediction module of the FHWA *Interactive Highway Safety Design Model (3) software. The SPF coefficients, default* crash severity and collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (12).

The predicted crash frequencies for base conditions are calculated from the predictive models in Equations 10-2 and 10-3. A detailed discussion of SPFs and their use in the HSM is presented in Chapter 3, Section 3.5.2, and the Part C—Introduction and Applications Guidance, Section C.6.3.

Each SPF also has an associated overdispersion parameter, *k. The overdispersion parameter provides an indication of* the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the EB Method discussed in Part C, Appendix A. The SPFs in Chapter 10 are summarized in Table 10-2.

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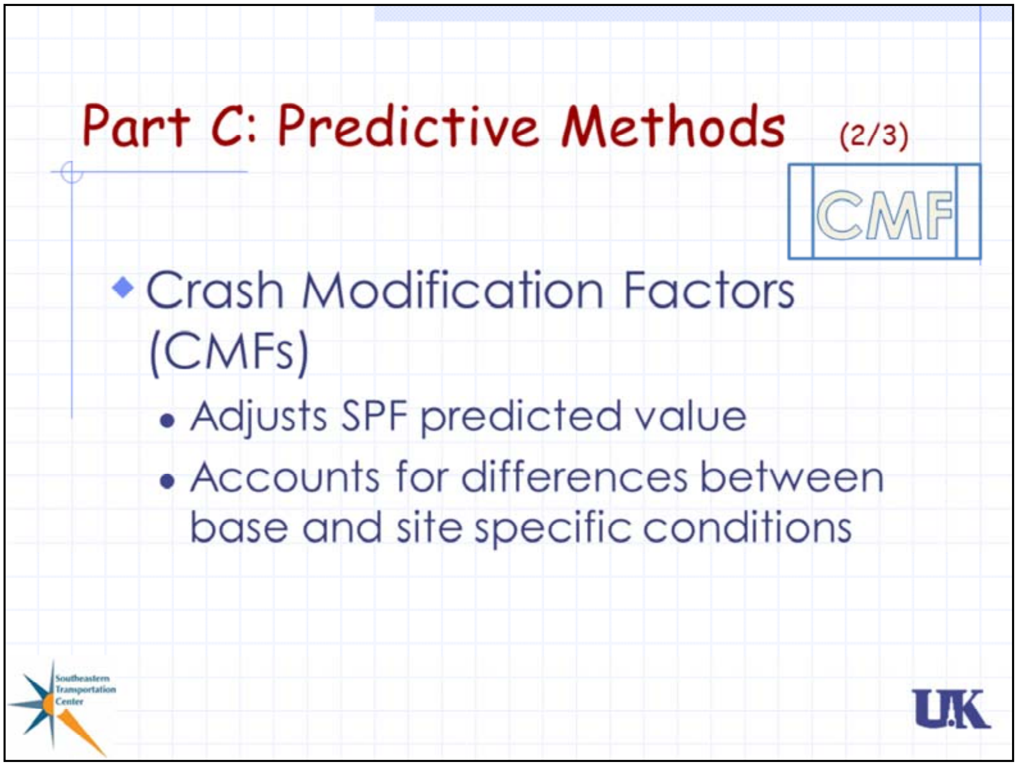
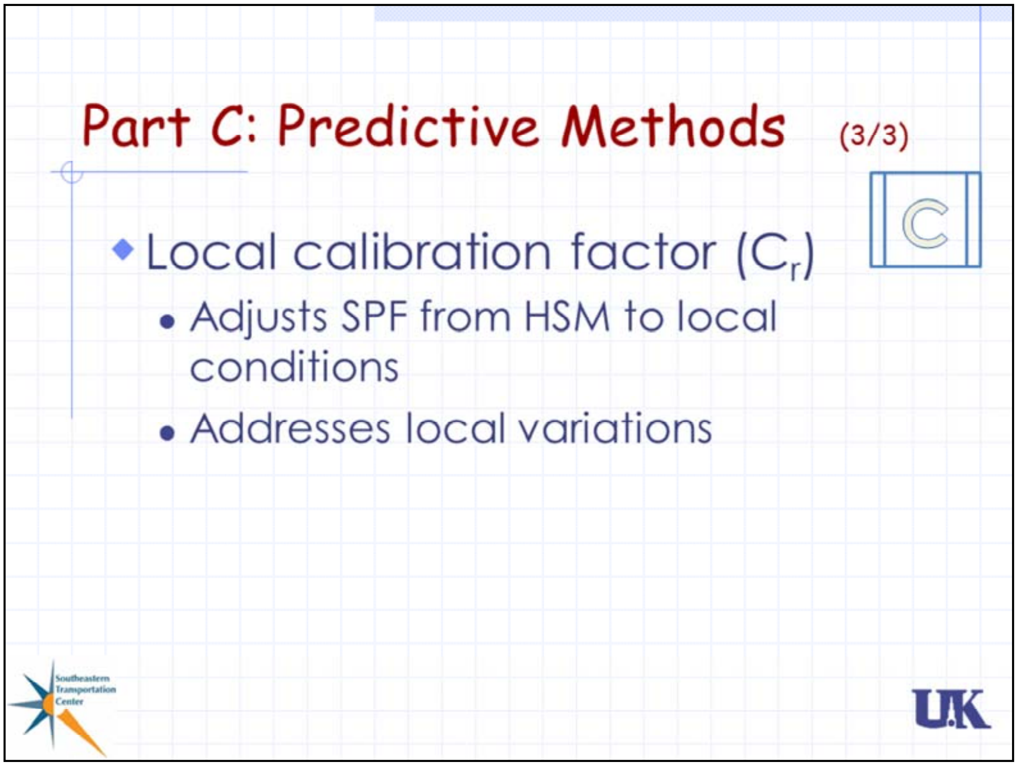
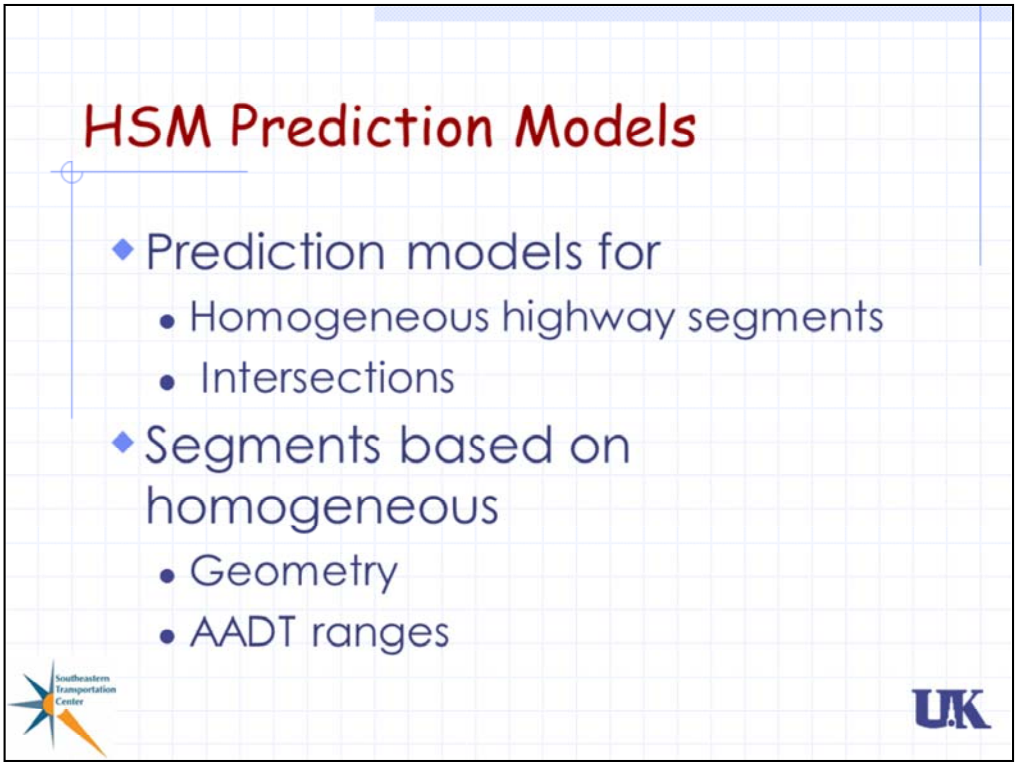


Crash Modification Factors allow for estimating the impact of a change in the value of a design element. This allows designers to estimate the relative change in the predicted number of crashes for deviating from the selected design value and determine the potential implications from a design choice. These factors are similar in nature to those used in the Highway Capacity Manual for adjusting from the base conditions for lane and shoulder width, presence of median, access frequency, etc.



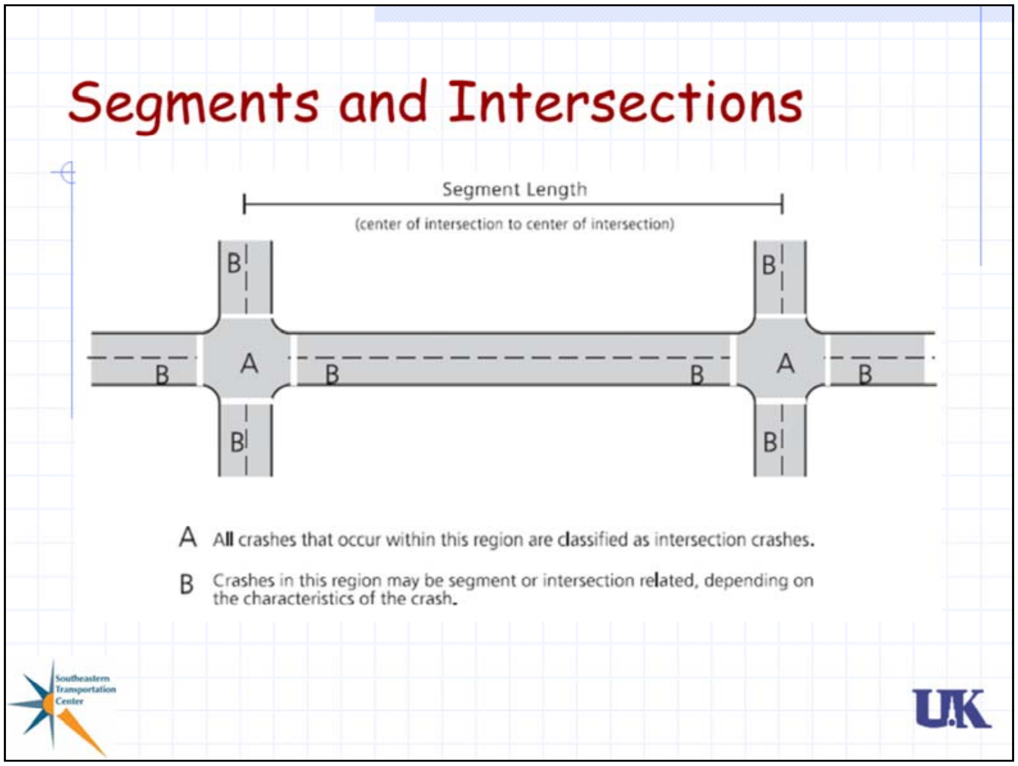
Typically, local conditions will vary from those where the SPFs n the HSM have been developed. Calibration factors are developed to adjust the SPFs to the local conditions.

The SPFs included in the HSM (Part C) have been developed base do on data from select states in the USA. However, there are several areas where differences that could be noted between the local conditions and those of the model development areas including climate, driver populations, crash reporting thresholds, and crash type and severity distributions. In these cases, a calibration factor is recommended to be developed to address these differences when the HSM SPFs are used.



The Analysis divides the highway into homogeneous analysis sections based on whether they are intersections or roadway segments. Each analysis section is homogenous with respect to geometry and traffic conditions.

- Homogeneous highway segments have uniform horizontal, vertical, cross section, traffic characteristics, and roadside geometry. At any location where there is a change in geometry (e.g., changing from a horizontal curve to a tangent or a change in shoulder width) or a change in traffic volume, a new highway segment begins.
- Each intersection is also defined as a separate, homogenous analysis section.



10.5. ROADWAY SEGMENTS AND INTERSECTIONS

Roadway segments begin at the center of an intersection and end at either the center of the next intersection or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in the figure above. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapters 10, 11 and 12 (multilane) provide predictive models for stop-controlled (three- and four-leg) and signalized (four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the curb line limits of an intersection (Region A of figure above) and intersection-related crashes that occur on the intersection legs (Region B in figure above).

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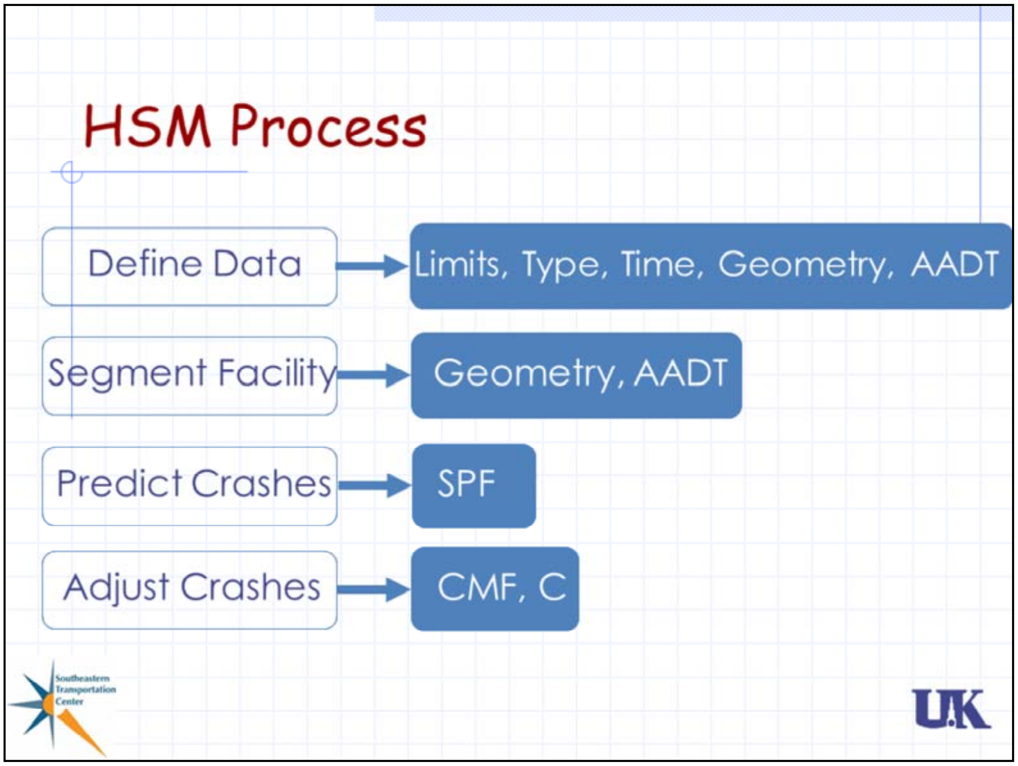


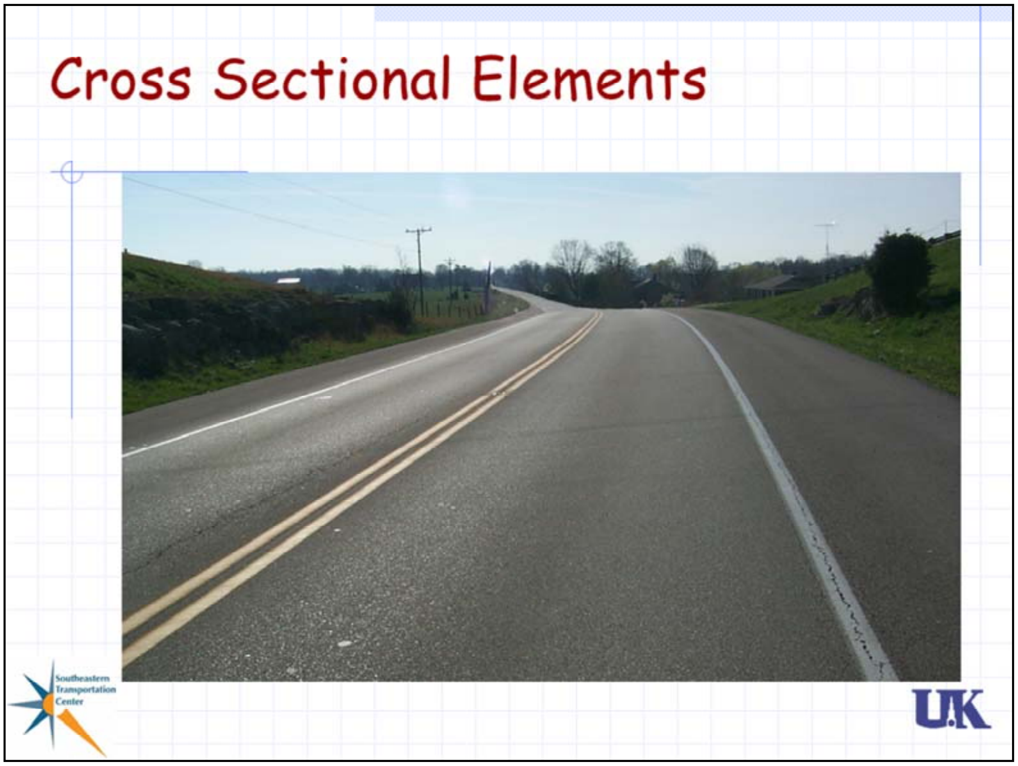
HSM Process

The predictive method for each facility can be summarized as shown above. The first steps involve the collection of required input data including:

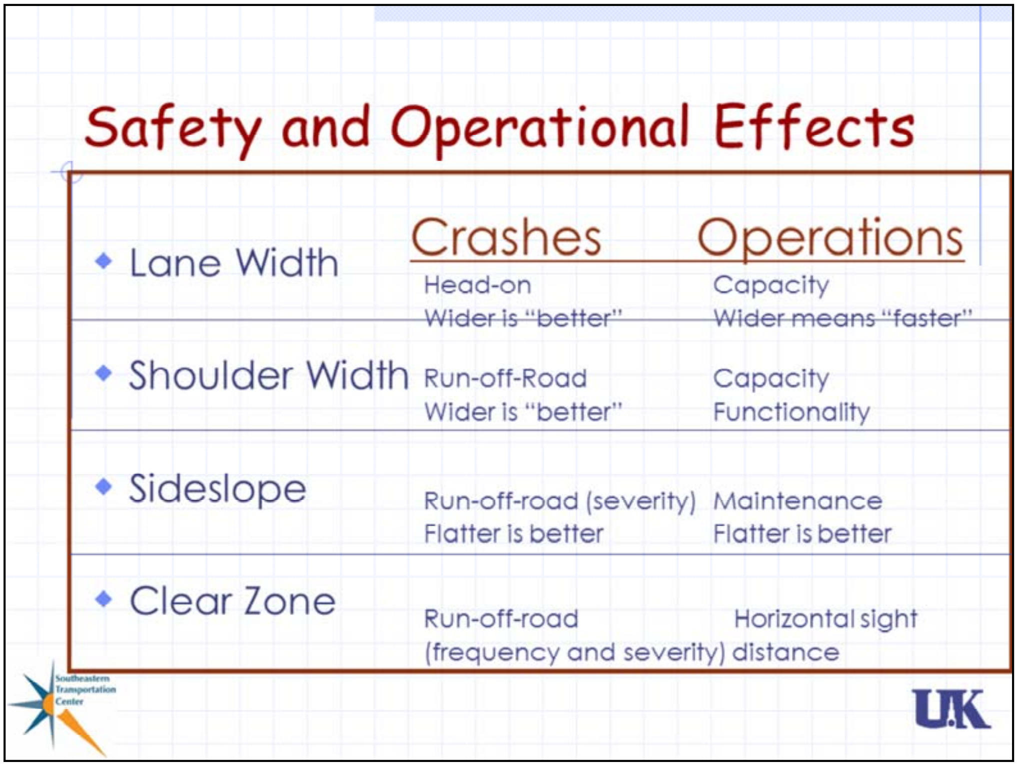
- Limits of the roadway and facility type in the study;
- Period of interest;
- Geometric design features, traffic control, and site characteristics;
- Availability of traffic volume for the study period;
- For intersections, AADT volumes are needed for both the major and minor streets; and
- If the EB Method is used, AADT traffic volumes are needed for each year for which observed crash data are available.

The next step requires the segmentation of the facility into individual homogenous (or similar) roadway segments or intersections. For roadway segments, the recommended site length is equal to or greater than 0.10 miles. Smaller segments would result in excessive and needless calculations. Boundaries can be defined based on cross section, AADT, and alignment changes as well as with the presence of intersections. The HSM includes recommendations for rounding variables that then helps clarify the boundaries of homogeneous segments. This information is located on pages 10-12 to 10-13 (for rural two-lane segments), pages 11-12 to 11-13 (for rural multilane highway segments), and page 12-15.

The next steps involve the estimation of the predicted crashes through the SPF (by using the appropriate function for the roadway type evaluated) and the adjustment to the local conditions though the use of CMFs and the calibration factor.

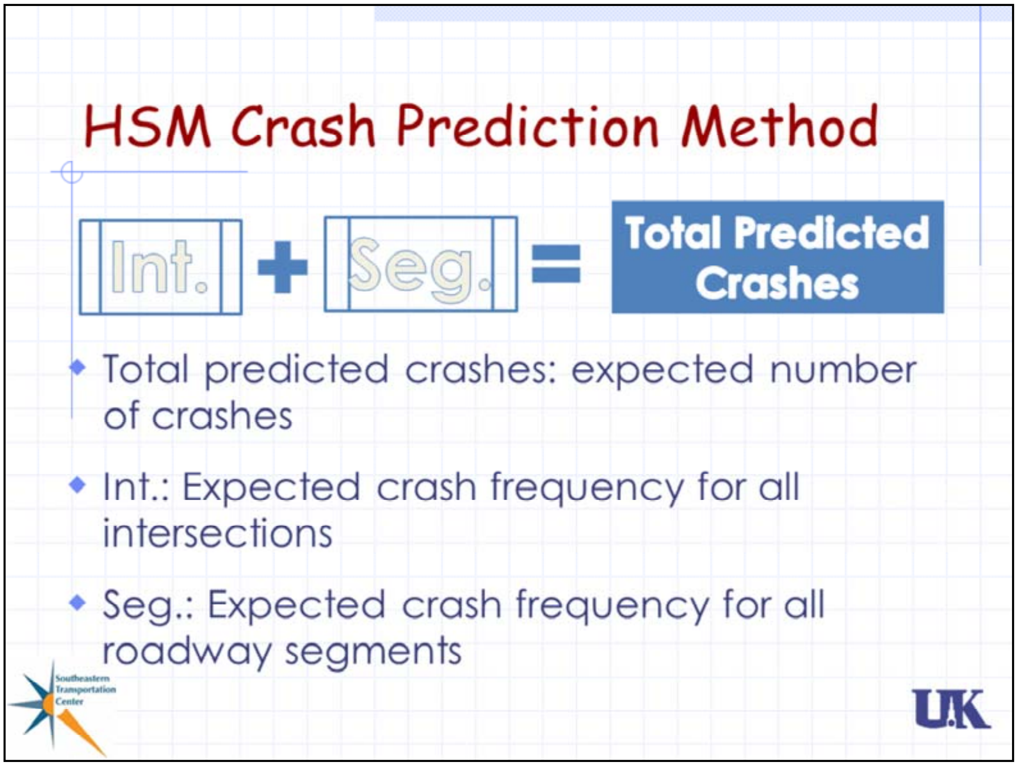


The entire cross section is of interest when one considers safety. This includes lanes and shoulders, as well as the roadside. The effects fo each component need to be considered when evaluating safety.



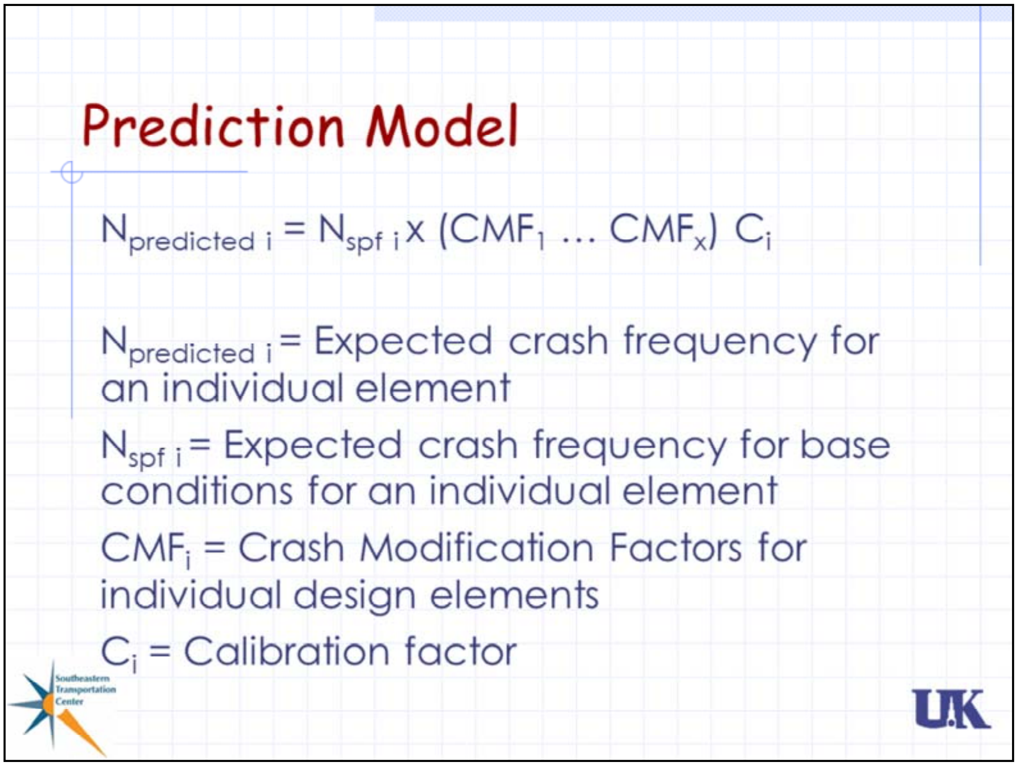
There are safety and operational effects for each cross sectional element. Some are positive and some are negative and there are interactions. For example wider lanes may improve safety but they encourage greater speeds, which could be impacting safety negatively.

This module presents a basic overview of the processes used in the HSM and provide participants with an example application.



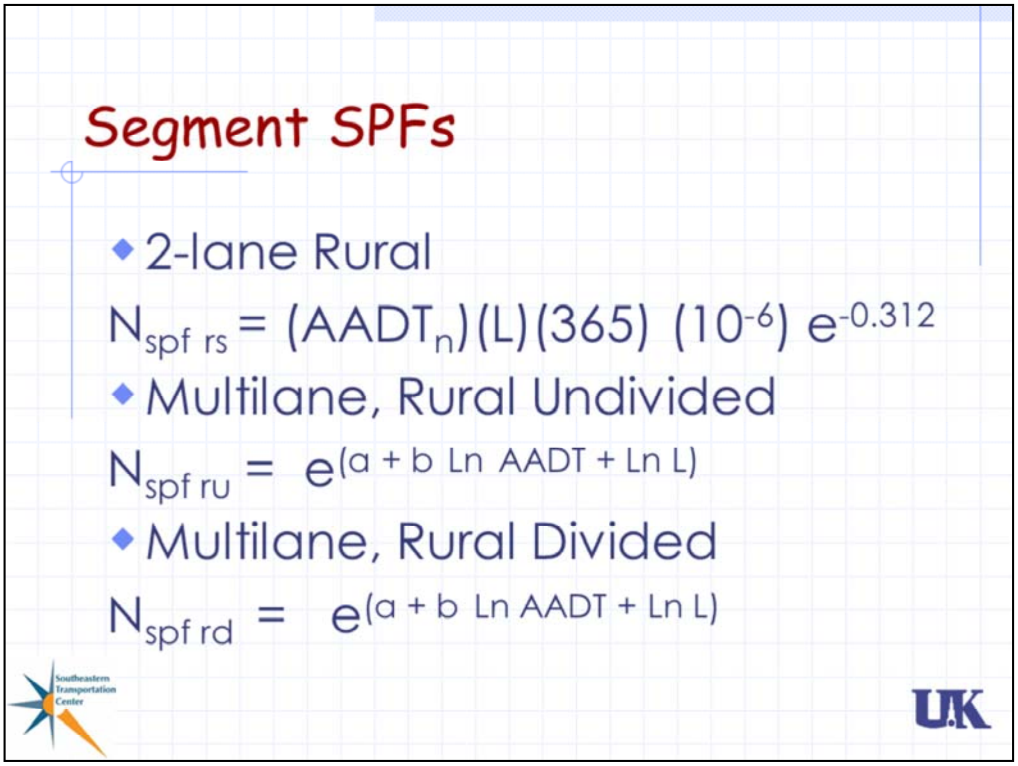
In general, the total number of predicted crashes for a facility will be equal to the sum of predicted crashes for roadway segments and intersections.

$$N_{\text{total}} = \sum_{\substack{\text{all} \\ \text{roadway} \\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all} \\ \text{intersections}}} N_{int}$$



The equation for predicting the expected total crash frequency, $N_{predicted\ i}$ on a particular homogenous highway segment, where i is a roadway segment or an intersection.

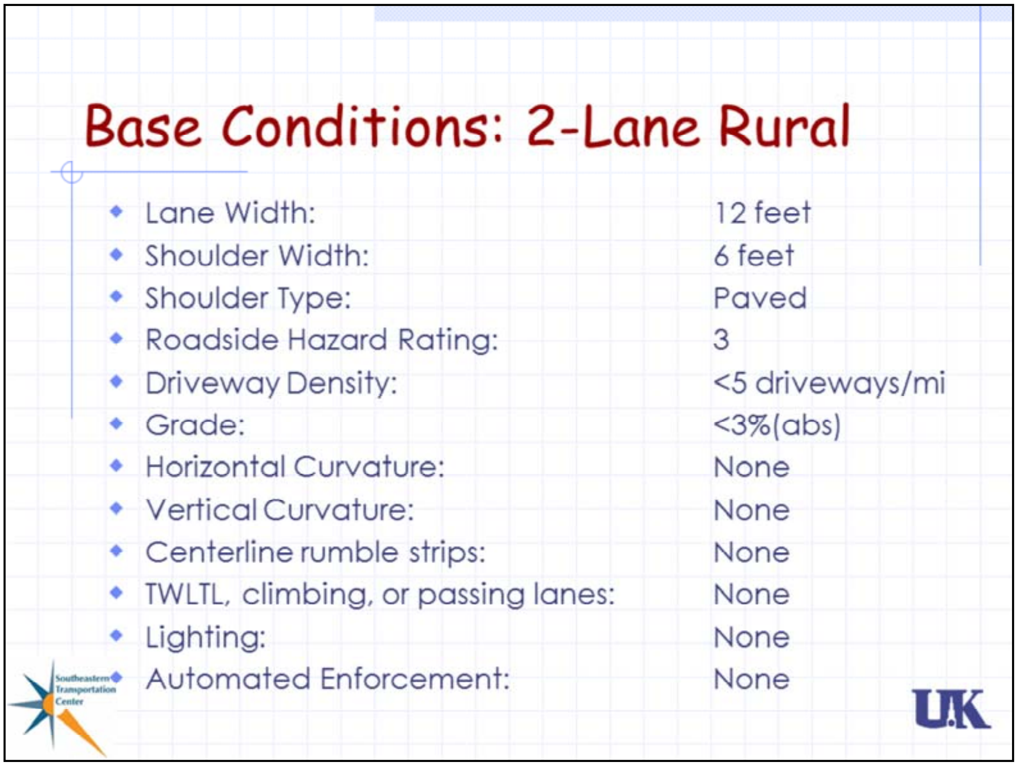
This model can be used to estimate total predicted average crash frequency or average crash frequency of specific crash severity types or specific collision types depending on the SPFs and CMFs utilized.



The equations shown here are for rural road segments and represent the base conditions. The equations are used to predict the expected crashes per year on individual highway segments based upon traffic volume and segment length. Each assumes the appropriate base conditions for geometric and traffic control elements, which are discussed next.

For 2-lane roads, the only inputs to the base model are traffic volume and segment length. For the multilane roads, the parameters *a* and *b* are defined based on the type of crash severity predicted, i.e., they are different for total and fatal and injury predictions. These values are defined in Tables 11-3 and 11-5 for undivided and divided segments, respectively.

Each equation has a usable range of AADT that is based on the data utilized to develop the models. For example, the SPFs for roadway segments on 2-lane rural roads are applicable to the AADT range from zero to 17,800 vehicles per day. Application to sites with AADTs substantially outside this range may not provide reliable results.



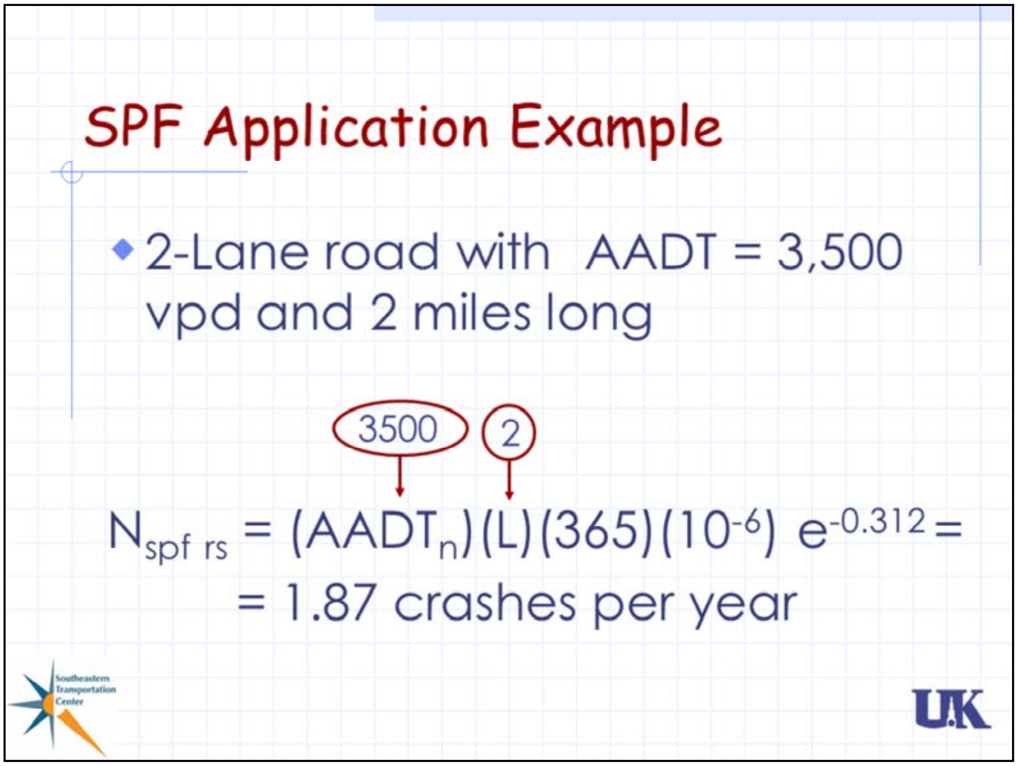
These are considered the nominal geometry or base conditions represented by the base model.

It should be emphasized that the values shown here do NOT represent the “safest” values. The reason for selecting these dimensions as the base conditions is statistical. These values are the approximate the mean values for these variables in the database used to fit the base model. This implies for example, that the average lane width for the database used to develop the model is approximately 12 feet. Moreover, the regression models developed have the least standard error near the mean values of these independent variables in the model.

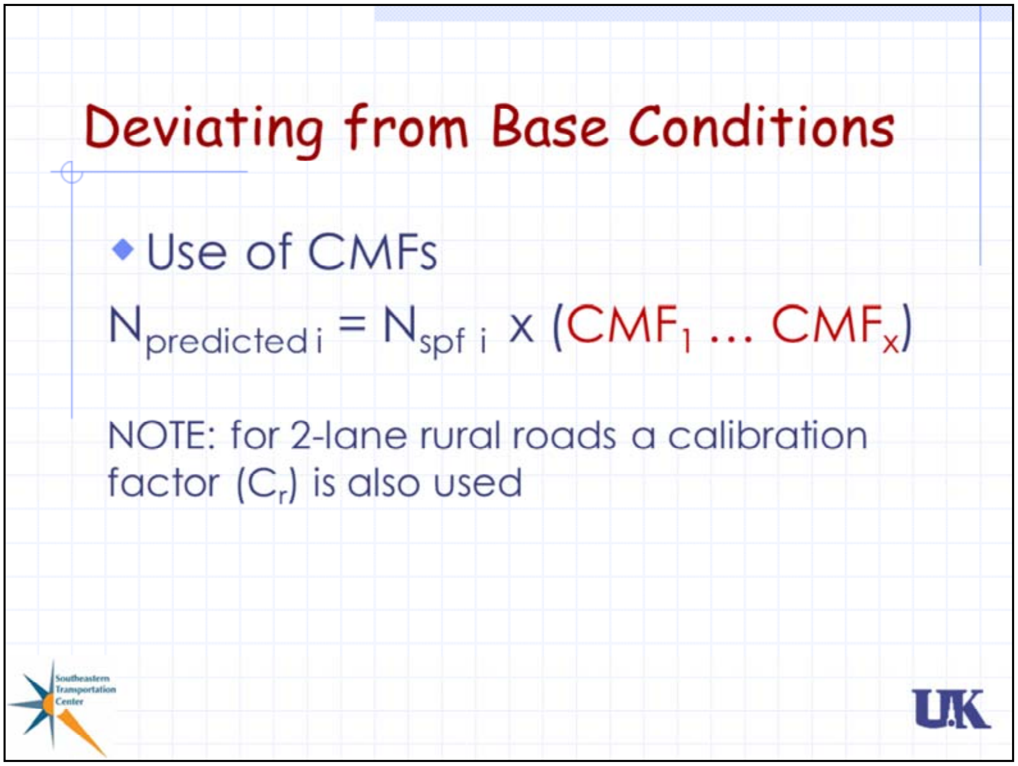
Base Conditions: Multilane Roads

- All
  - Lane width 12 feet
  - Shoulder type Paved
  - No lighting or automated speed enforcement
- Undivided
  - Shoulder width 6 feet
  - Sideslopes 1V:7H or flatter
- Divided
  - Shoulder width 8 feet
  - Median 30 feet

The same notes apply for these values regarding the reason for the selection of the values. An additional note is that the shoulder width used for both divided and undivided is that of the RIGHT shoulder.



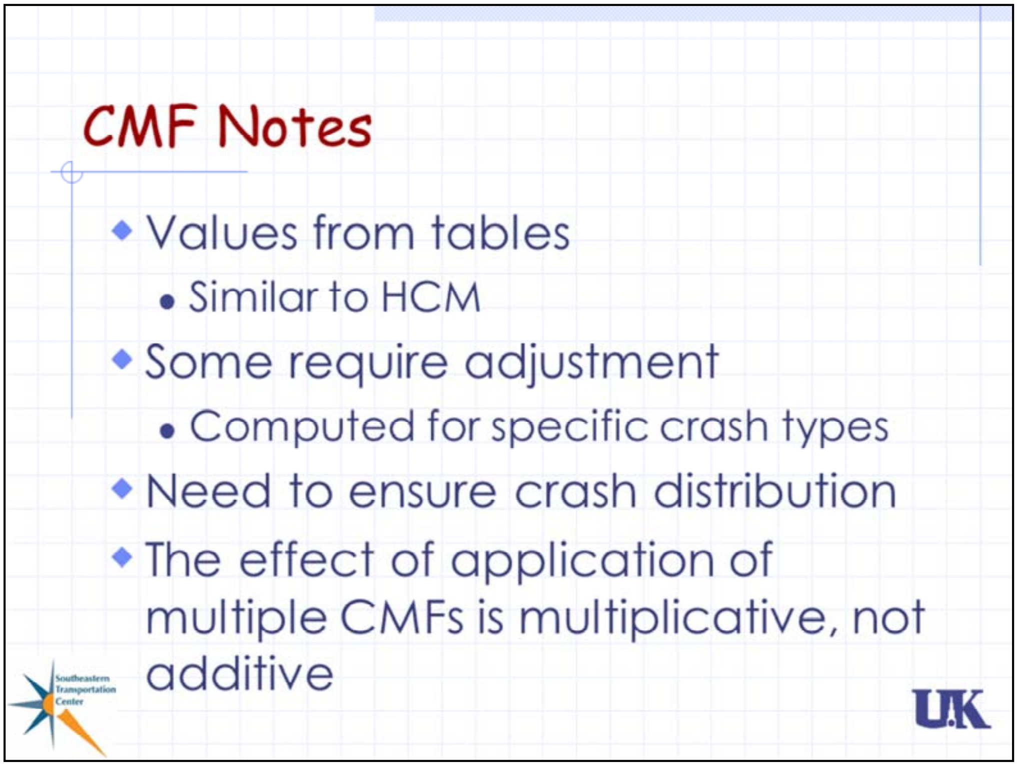
Example calculation using the SPF base model for 2-lane rural highway segments. Note that the estimate is the number of crashes per year. It is assumed that the segment geometry complies with the base conditions.



Most times the base conditions will not reflect the actual roadway geometry. In this case, the next step involves the use of the appropriate Crash Modification Factors to the predicted crash frequency in order to account for those conditions that are different that the assumed base conditions.

This model estimates the predicted average crash frequency of non-intersection related crashes (i.e., crashes that would occur regardless of the presence of an intersection).

CMFs are used to adjust the SPF estimate of predicted average crash frequency for the effect of individual geometric design and traffic control features. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher crash frequency than the base condition has a CMF with a value greater than 1.00. Likewise, any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.



For most CMFs, the values are simply taken from the corresponding tables. Attention should be paid to those that vary by AADT, since different values are used in this case.

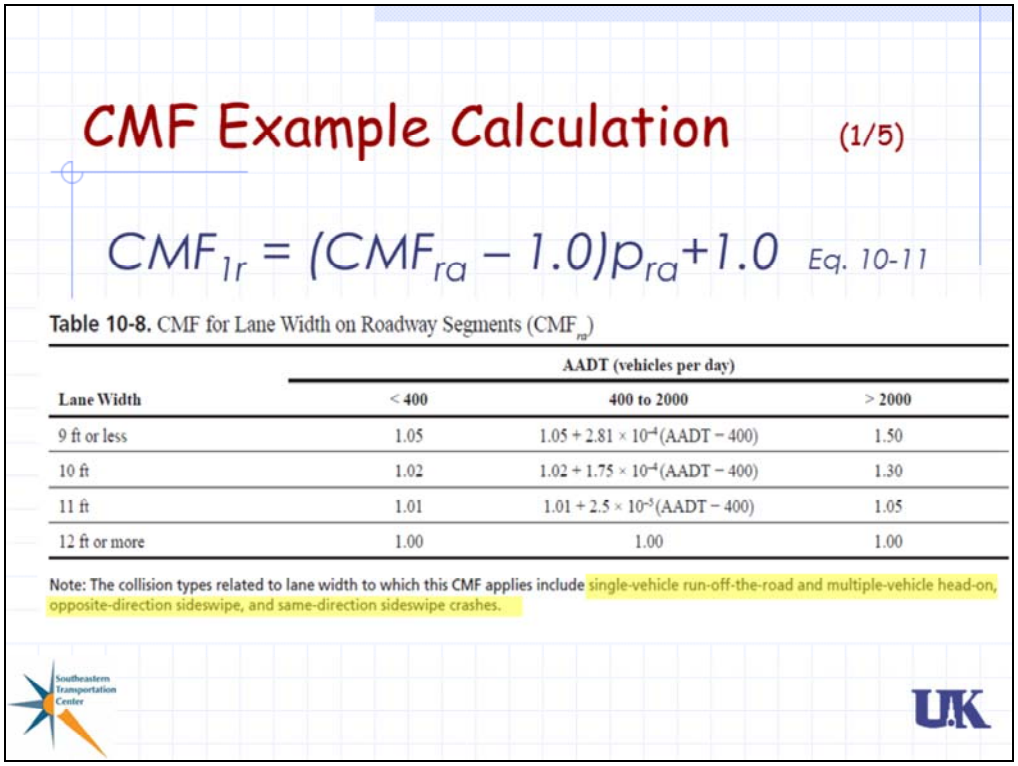
The CMFs presented in the tables are for the specific crash types associated for the element adjusted. For example, when computing the CMF for lane width, the associated crashes are single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. This default crash type distribution, and therefore the value of the percent of associated crashes, may be updated from local data as part of the calibration process.

2-Lane Rural Segment CMFs

Table 10-7. Summary of Crash Modification Factors (CMFs) in Chapter 10 and the Corresponding Safety Performance Functions (SPFs)

Facility Type	CMF	CMF Description	CMF Equations and Tables
Rural Two-Lane Two-Way Roadway Segments	CMF_{1r}	Lane Width	Table 10-8, Figure 10-7, Equation 10-11
	CMF_{2r}	Shoulder Width and Type	Table 10-9, Figure 10-8, Table 10-10, Equation 10-12
	CMF_{3r}	Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions	Table 10-7
	CMF_{4r}	Horizontal Curves: Superelevation	Equation 10-14, 10-15, 10-16,
	CMF_{5r}	Grades	Table 10-11
	CMF_{6r}	Driveway Density	Table 10-11
	CMF_{7r}	Centerline Rumble Strips	See text
	CMF_{8r}	Passing Lanes	See text
	CMF_{9r}	Two-Way Left-Turn Lanes	Equation 10-18, 10-19
	CMF_{10r}	Roadside Design	Equation 10-20
	CMF_{11r}	Lighting	Equation 10-21, Table 10-12
	CMF_{12r}	Automated Speed Enforcement	See text

Here is an example of how CMFs are determined to estimate the effect of deviating from the base conditions. Similar tables are available for all road types and both segments and intersections.



CMF Example Calculation (1/5)

$$CMF_{1r} = (CMF_{ra} - 1.0)p_{ra} + 1.0 \quad \text{Eq. 10-11}$$

Table 10-8. CMF for Lane Width on Roadway Segments (CMF_{ra})

	AADT (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.05	$1.05 + 2.81 \times 10^{-4}(AADT - 400)$	1.50
10 ft	1.02	$1.02 + 1.75 \times 10^{-4}(AADT - 400)$	1.30
11 ft	1.01	$1.01 + 2.5 \times 10^{-5}(AADT - 400)$	1.05
12 ft or more	1.00	1.00	1.00

Note: The collision types related to lane width to which this CMF applies include single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

In this example, the CMF for 2-lane rural roads is presented. It should be noted that the CMFs shown in Table 10-8 apply only to the crash types that are most likely to be affected by lane width: single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. These are the only crash types assumed to be affected by variation in lane width, and other crash types are assumed to remain unchanged due to the lane width variation.

CMF_{ra} = crash modification factor for the effect of lane width on related crashes (i.e., single-vehicle run-off-the road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), such as the crash modification factor for lane width shown in Table 10-8; and
p_{ra} = proportion of total crashes constituted by related crashes.
The proportion of related crashes, p_{ra}, (i.e., single-vehicle run-off-the-road, and multiple-vehicle head-on, opposite direction sideswipe, and same-direction sideswipes crashes) is estimated as 0.574 (i.e., 57.4 percent) based on the default distribution of crash types presented in Table 10-4. This default crash type distribution, and therefore the value of p_{ra}, may be updated from local data as part of the calibration process.

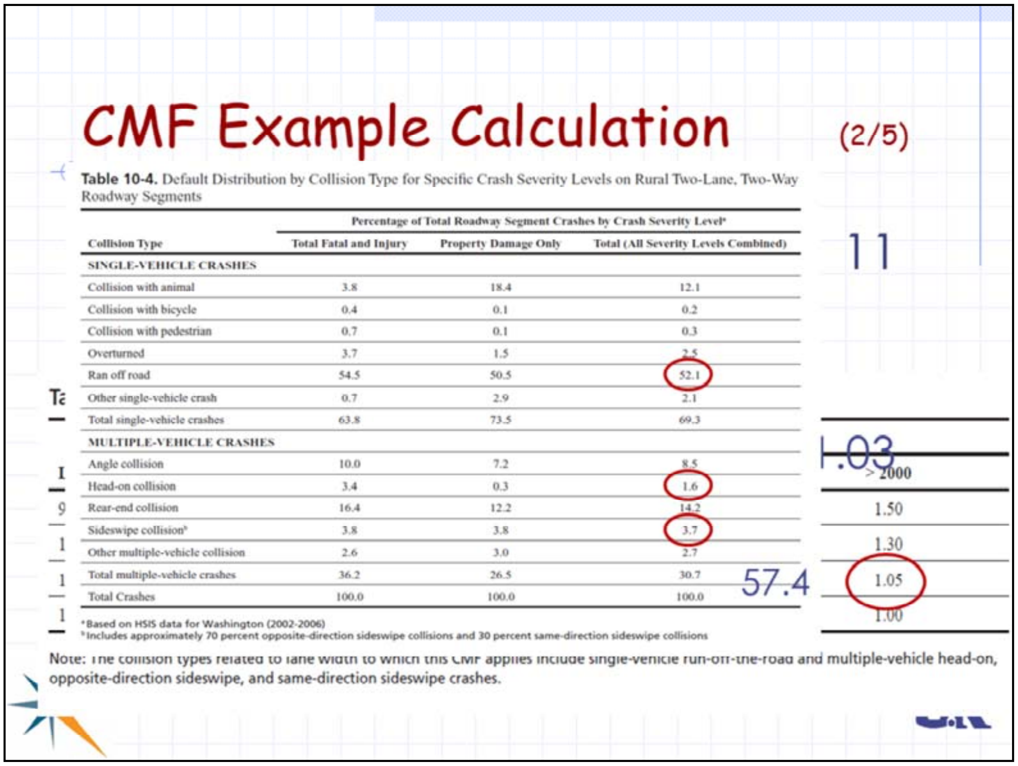
Crash Distribution

Table 10-4. Default Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane, Two-Way Roadway Segments

Collision Type	Percentage of Total Roadway Segment Crashes by Crash Severity Level[a]		
	Total Fatal and Injury	Property Damage Only	Total (All Severity Levels Combined)
SINGLE-VEHICLE CRASHES			
Collision with animal	3.8	18.4	12.1
Collision with bicycle	0.4	0.1	0.2
Collision with pedestrian	0.7	0.1	0.3
Overturned	3.7	1.5	2.5
Ran off road	54.5	50.5	52.1
Other single-vehicle crash	0.7	2.9	2.1
Total single-vehicle crashes	63.8	73.5	69.3
MULTIPLE-VEHICLE CRASHES			
Angle collision	10.0	7.2	8.5
Head-on collision	3.4	0.3	1.6
Rear-end collision	16.4	12.2	14.2
Sideswipe collision[b]	3.8	3.8	3.7
Other multiple-vehicle collision	2.6	3.0	2.7
Total multiple-vehicle crashes	36.2	26.5	30.7
Total Crashes	100.0	100.0	100.0

[a] Based on HSIS data for Washington (2002-2006)
[b] Includes approximately 70 percent opposite-direction sideswipe collisions and 30 percent same-direction sideswipe collisions

In the absence of local data, this table can be used to determined the percent of crashes to be considered for lane width calculations. As noted in the previous slide, the only crash types affected are single vehicle ran off the road (ROR), head-on collisions and sideswipe collisions.



CMF Example Calculation (2/5)

Table 10-4. Default Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane, Two-Way Roadway Segments

Collision Type	Percentage of Total Roadway Segment Crashes by Crash Severity Level[a]: Total Fatal and Injury	Property Damage Only	Total (All Severity Levels Combined)
SINGLE-VEHICLE CRASHES			
Collision with animal	3.8	18.4	12.1
Collision with bicycle	0.4	0.1	0.2
Collision with pedestrian	0.7	0.1	0.3
Overturned	3.7	1.5	2.5
Ran off road	54.5	50.5	52.1
Other single-vehicle crash	0.7	2.9	2.1
Total single-vehicle crashes	63.8	73.5	69.3
MULTIPLE-VEHICLE CRASHES			
Angle collision	10.0	7.2	8.5
Head-on collision	3.4	0.3	1.6
Rear-end collision	16.4	12.2	14.2
Sideswipe collision[b]	3.8	3.8	3.7
Other multiple-vehicle collision	2.6	3.0	2.7
Total multiple-vehicle crashes	36.2	26.5	30.7
Total Crashes	100.0	100.0	100.0

[a] Based on HSIS data for Washington (2002-2006)
[b] Includes approximately 70 percent opposite-direction sideswipe collisions and 30 percent same-direction sideswipe collisions

Note: The collision types related to lane width to which this CMF applies include single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

Example calculation on determining an CMF_{1r} for Lane Width for total crashes when the CMF_{ra} is given for a particular crash type or severity level.

Here CMF_{ra} is for crash types relating to ROR, Head-On and Sideswipe Crashes.

CMF Example Calculation (3/5)

$$CMF_{2r} = (CMF_{wra}\ CMF_{tra} - 1.0)p_{ra} + 1.0$$

Table 10-9. CMF for Shoulder Width on Roadway Segments (CMF_{wra})

Shoulder Width	AADT (vehicles per day) < 400	AADT (vehicles per day) 400 to 2000	AADT (vehicles per day) > 2000
0 ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT − 400)	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT − 400)	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT − 400)	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 + 6.875 \times 10^{-5}$ (AADT − 400)	0.87

Note: The collision types related to shoulder width to which this CMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

The CMF for 2-lane rural road shoulder is presented here. This CMF accounts for the shoulder width (CMF_{wra}) and the shoulder type (CMF_{tra}). The base value of shoulder width and type is a 6-foot paved shoulder, which is assigned a CMF value of 1.00.

It should be noted that the values in Table 10-8 are only for shoulder related crashes: single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

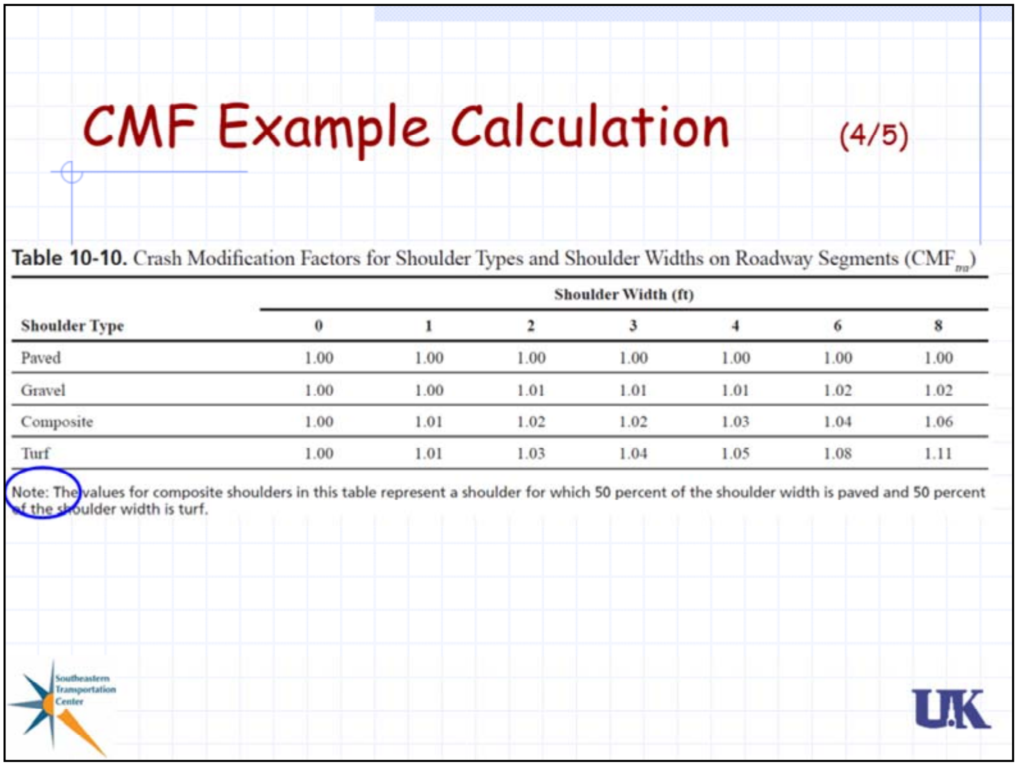


Table 10-10. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra})

Shoulder Type	Shoulder Width (ft) 0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

This table shows the effect of the shoulder type and estimates the CMF_{tra} which adjusts for the safety effects of gravel, turf, and composite shoulders as a function of shoulder width.

If the shoulder types and/or widths for the two directions of a roadway segment differ, the CMF are determined separately for the shoulder type and width in each direction of travel and the resulting CMFs are then be averaged.

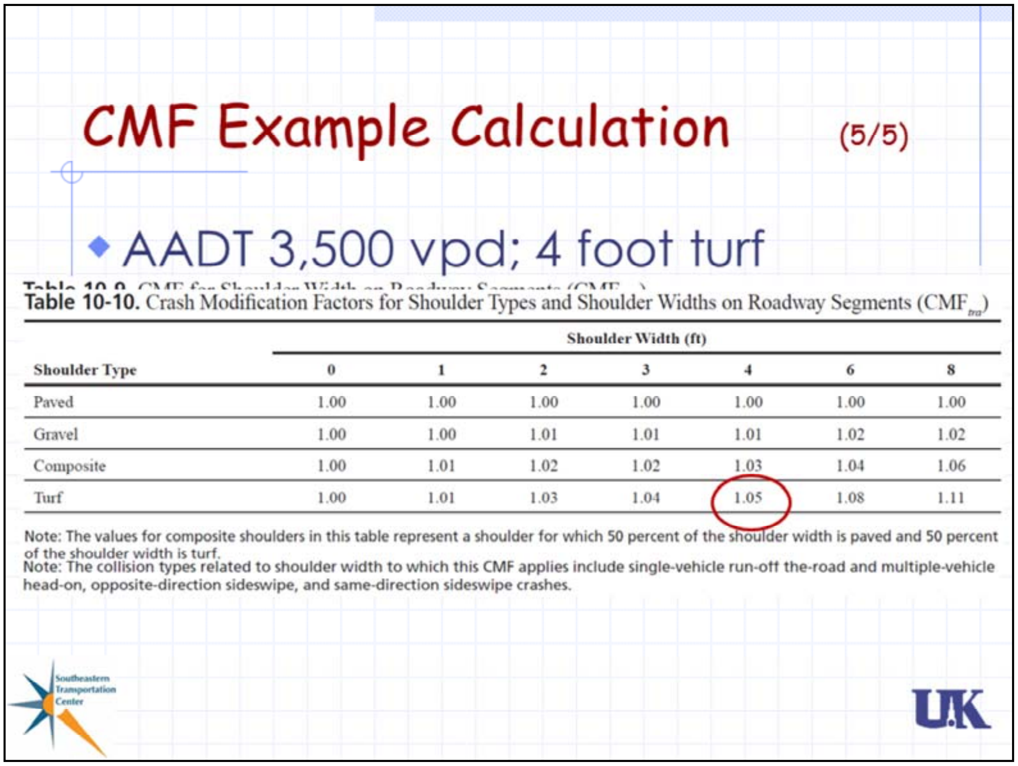


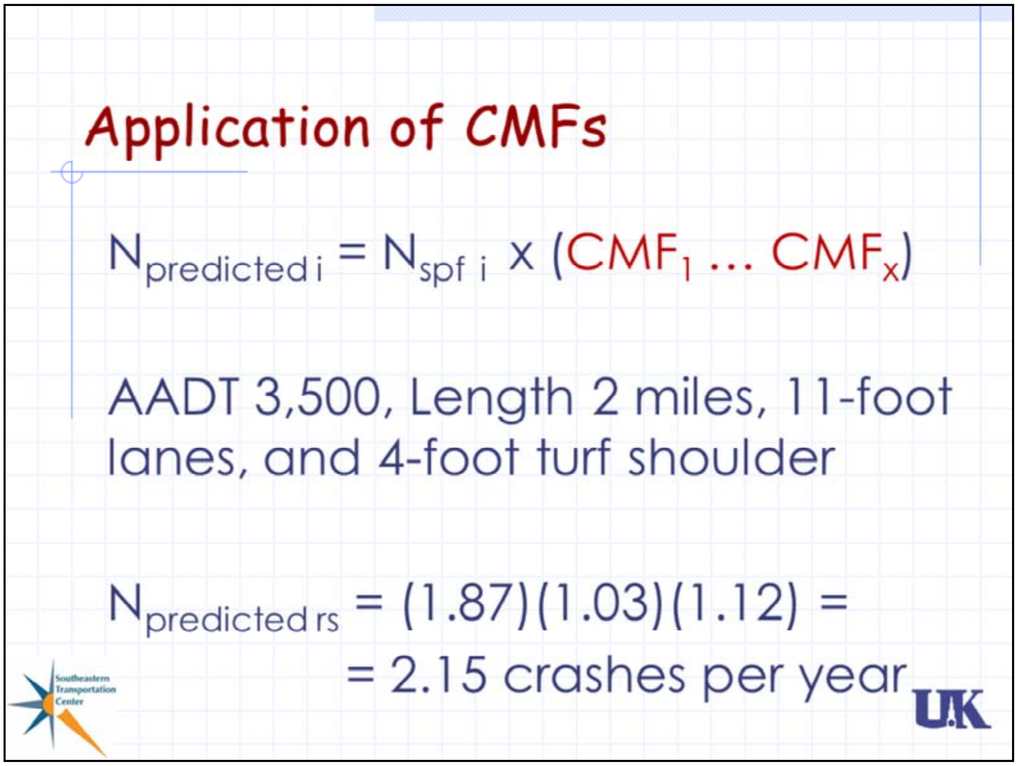
Table 10-10. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra})

	Shoulder Width (ft)						
Shoulder Type	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

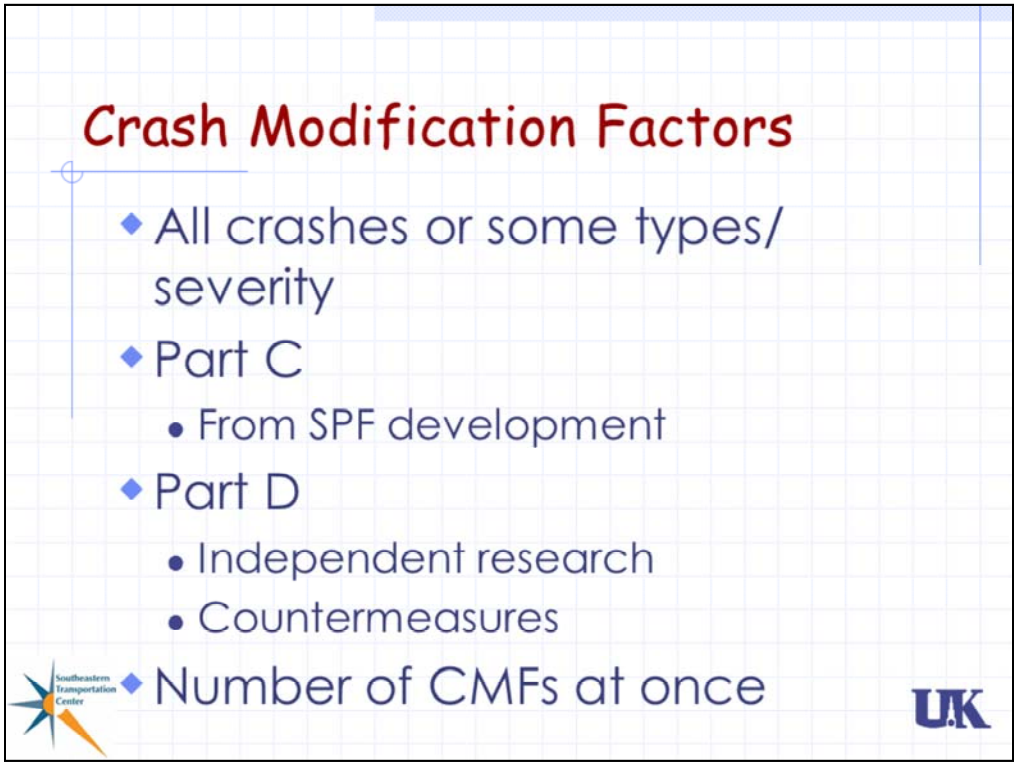
Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.
Note: The collision types related to shoulder width to which this CMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

Example calculation on determining an CMF_{2r} for Shoulder Width and Type for total crashes when the CMF_{wra} and CMF_{tra} are given for a particular crash type or severity level.

Here CMF_{wra} and CMF_{tra} are for crash types relating to ROR, Head-On and Sideswipe Crashes.



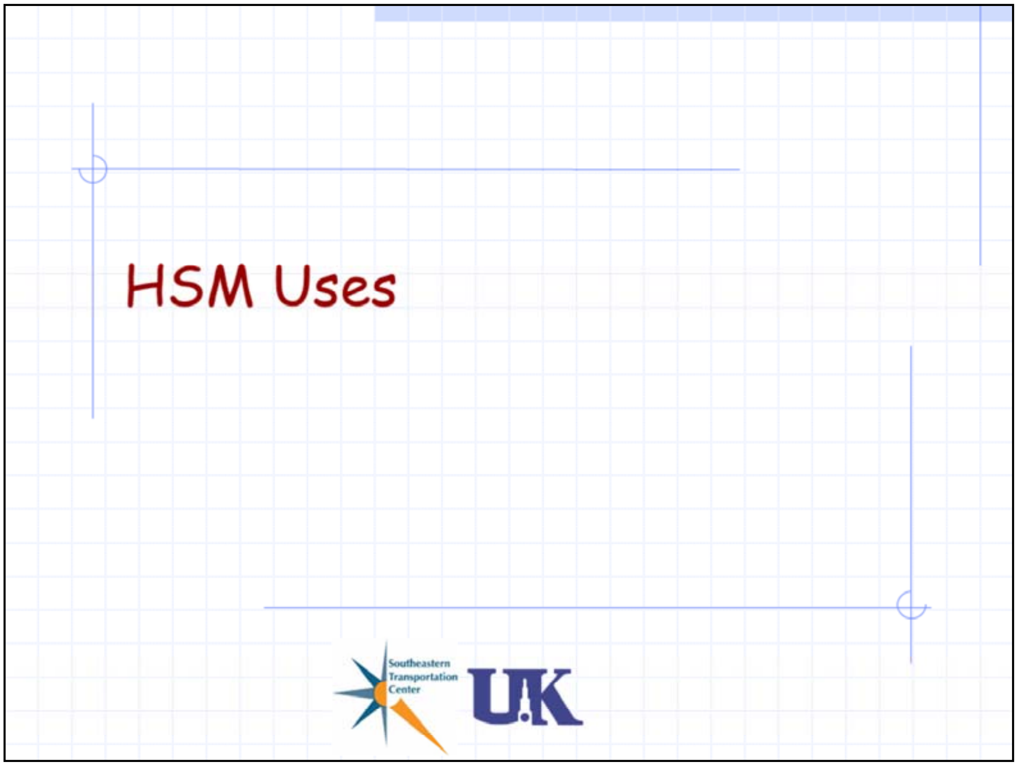
As previously noted, the CMFs are used to adjust the base model SPF to the local conditions. In this case, they are used as multiplies to adjust the predicted number of crashes to existing conditions.



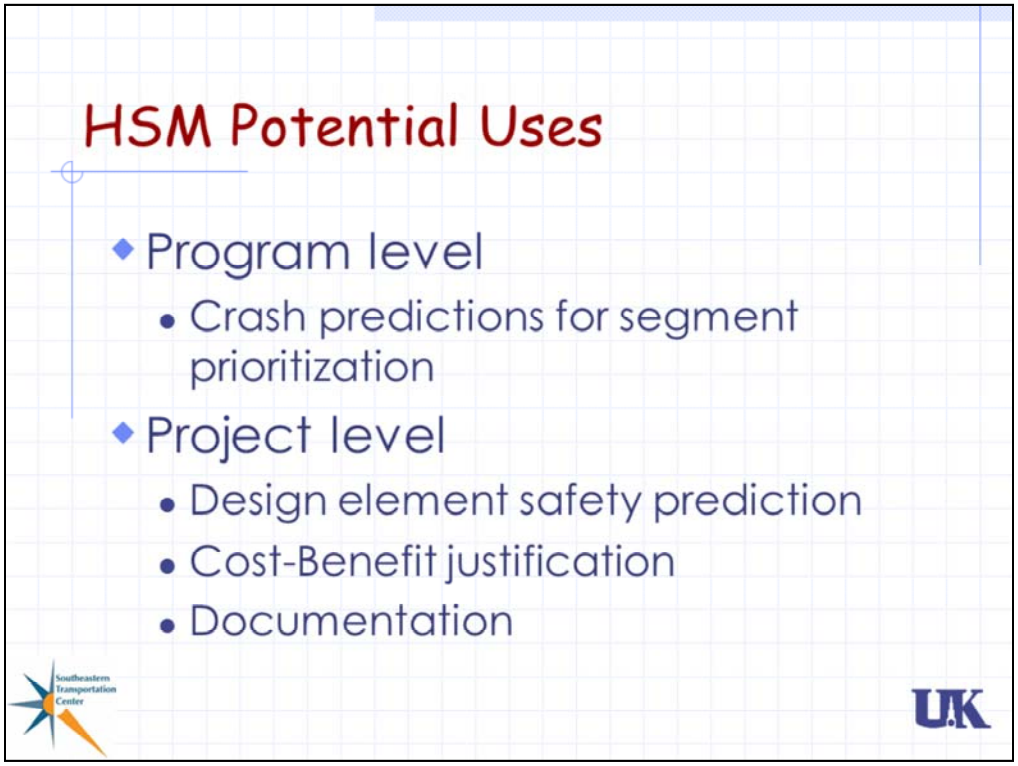
It should be noted that CMFs may be applicable to all crash types or certain types and/or severity. Caution should be exercised when using them.

Another notable difference is the use of CMFs in Part C and Part D. Part C CMFs were developed in conjunction with the model development whereas Part D CMFs are based on actual countermeasures. The CMFs from Part D can be used to adjust the SPFs used from Part C.

The user needs to be aware of the fact that using several CMFs simultaneously is not recommended due to the potential interactions among CMFs.

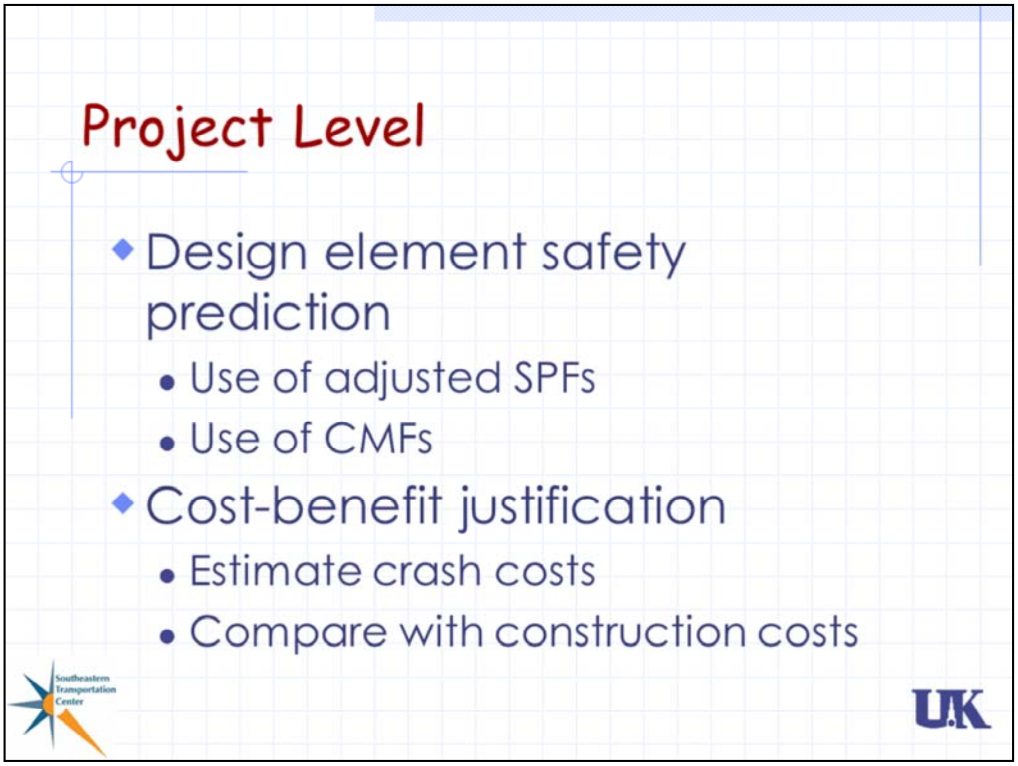


This section presents examples of HSM uses and how the processes could be used in estimating cost-benefit impacts from design options and evaluating alternatives.



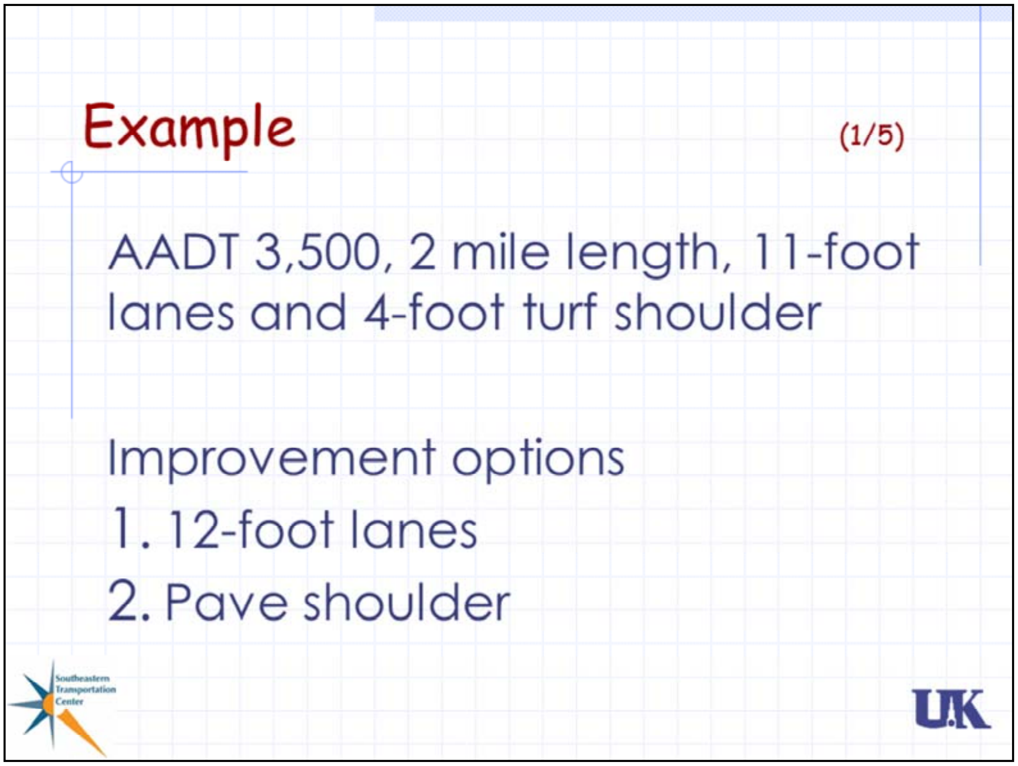
Transportation agencies can use the HSM methods and tools in various levels. At the program (planning) level, these predictions can be used to identify hazardous locations/segments and prioritize them in order to address the most pressing needs.

At the project level, HSM can assist in estimating the relative safety changes among different values for design elements as well as design elements, justifying choices based on cost-benefit analysis of the alternatives evaluated, and to document decisions reached during the design of the project justifying choices. The latter can be very useful in tort defense, since all decisions could be documented and readily available.



Designers can use the HSM procedures at the project level in two ways. The fists involves the use of SPFs where the number of crashes for each alternative design can be estimated and compared. The second approach relies on the use of CMFs where comparisons for specific elements can be made to justify choices. In this case, the relative change from one value to another can be obtained comparing the corresponding CMFs.

The cost-benefit justification of the choices is essential to finalize the selection of the alternative. The costs are base don the expected number of crashes and they can be estimated on an annual basis. Obviously the difference between crash costs of alternative designs could be considered as the benefits and these need to be compared against the relative construction costs for each alternative. An issue that needs to be pointed out here is that these costs and benefits need to be considered for the entire life cycle of the project.



This example presents the use of the HSM methods to evaluate project level decisions. There are two alternative improvement options for the roadway in concern and the decision maker needs to define the one that is more appropriate.

Example – Option 1 (2/5)

1.00 0.574

Table 10-8. CMF for Lane Width on Roadway Segments (CMF_{ra})

	AADT (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.05	$1.05 + 2.81 \times 10^{-4}(AADT - 400)$	1.50
10 ft	1.02	$1.02 + 1.75 \times 10^{-4}(AADT - 400)$	1.30
11 ft	1.01	$1.01 + 2.5 \times 10^{-5}(AADT - 400)$	1.05
12 ft or more	1.00	1.00	1.00

The first step in evaluating each option is to determine the appropriate CMF assuming that only the specific option will be applied. In this case, the new CMF is calculated for the lane width adjustment and the difference between the two CMFs is used to determine the potential safety effect from the option.

Example - Option 2 (3/5)

Table 10-10. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra})

Shoulder Type	Shoulder Width (ft) 0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

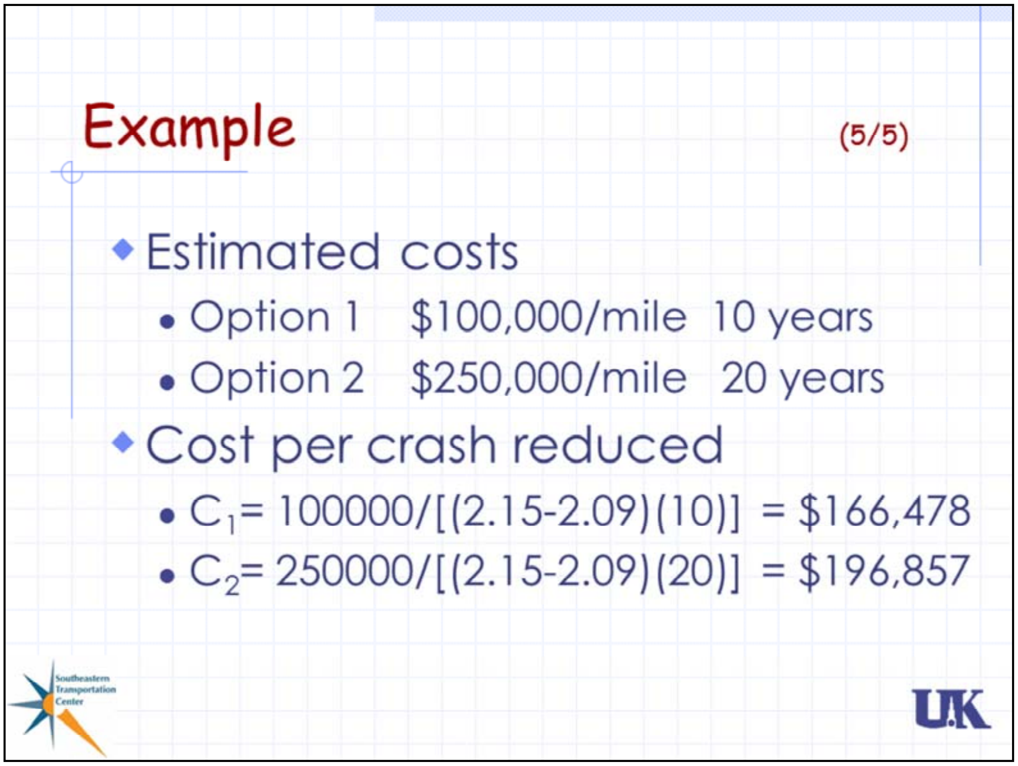
Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

Anticipated crash reduction: 4%

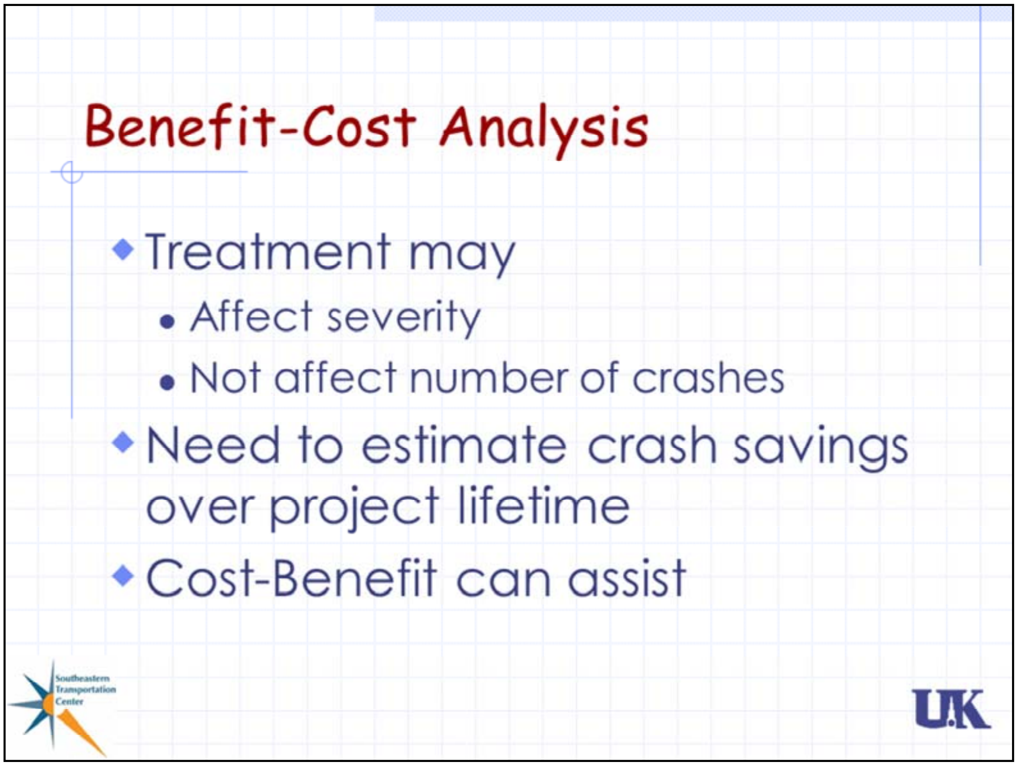
Example (4/5)

- Anticipated crash reductions
  - Option 1 3%
  - Option 2 4%
- Crash predictions
  - $N_o = (1.87)(1.03)(1.12) = 2.15$
  - $N_1 = (1.87)(1.00)(1.12) = 2.09$
  - $N_2 = (1.87)(1.03)(1.08) = 2.09$
- Which one to use?

The decision maker has the required data to select the option to implement. In this case, both alternative options will result in similar safety gains and therefore, one may need to consider the associated costs for each option to determine the most beneficial application. The predicted number of crashes is per mile per year and they are the total number of crashes anticipated in the segment.

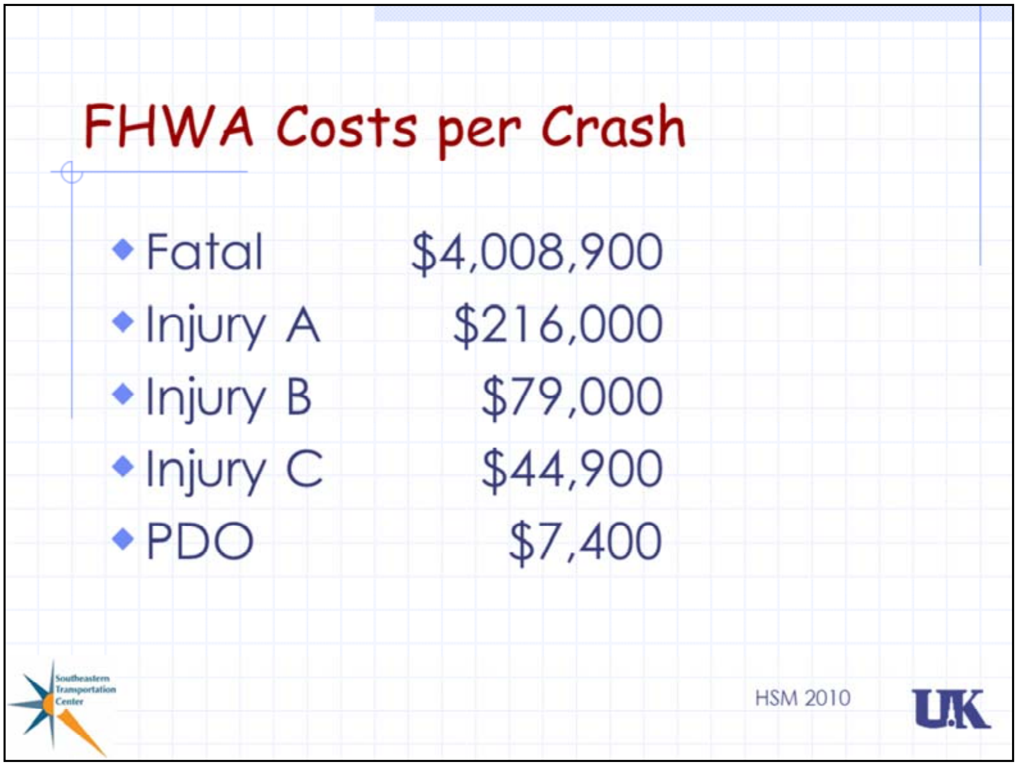


The costs for each option were obtained from the KYTC databases. The cost per option is estimated and this can assist the decision maker to select the option to implement based on both crash reductions and costs per crash reduced.
It should be noted that a simplistic approach was undertaken here to estimate the costs for the life time of the project. In this case, the lane widening will be for 10years while the shoulder paving will be for 20 years and this difference should be accounted for. A more detailed analysis using Present Worth Value and estimated interests for the life of the project should be underatken.



It is possible that a specific treatment aimed to improve safety may not reduce the total number of crashes but have an effect on the crash severity distribution. For example, the installation of a median cable barrier will not reduce the number of run off the road crashes but it will reduce the number of sever crashes. In this case, the cost-benefit analysis will account for the estimated monetary benefits of reduced sever crashes and allow for a more appropriate estimation of the potential gains.

Another issue of concern is that benefits need to be considered over the lifetime of the project and their value should be converted to their net present value using appropriate methods.



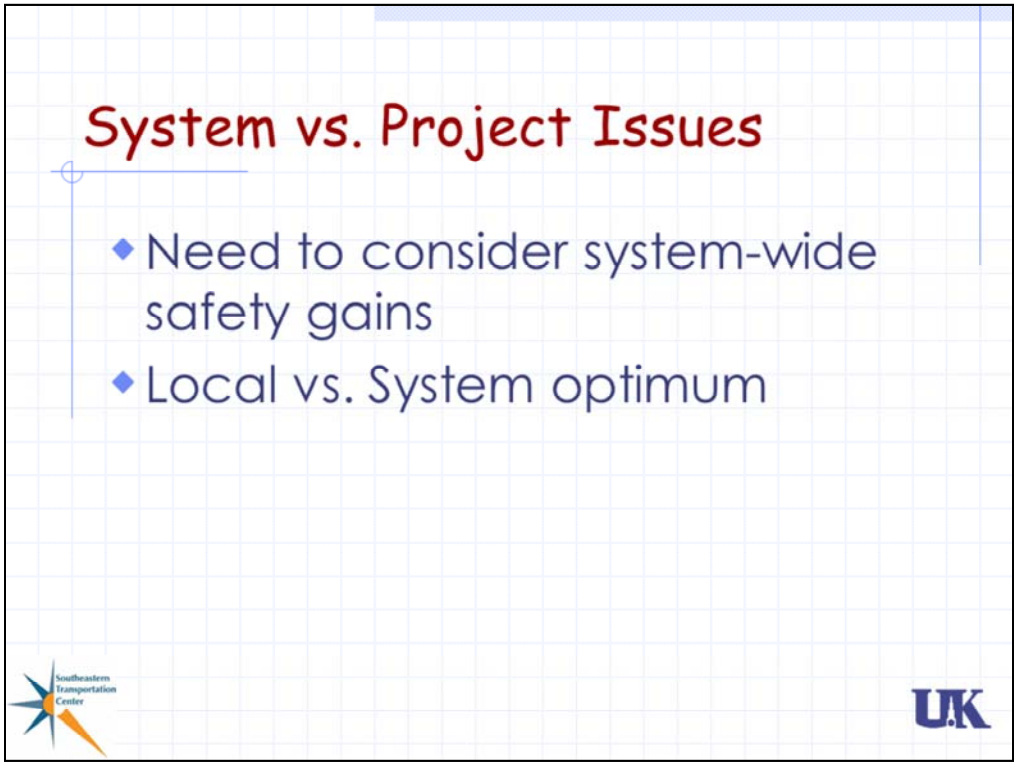
FHWA has developed associated comprehensive costs for each severity level and those are shown above. The values can be used to estimate the average crash cost based on the severity distribution of the crashes or can be used to estimate the benefits from reduction in one specific (or combination) of crash severity level(s).

Average Crash Cost Estimation

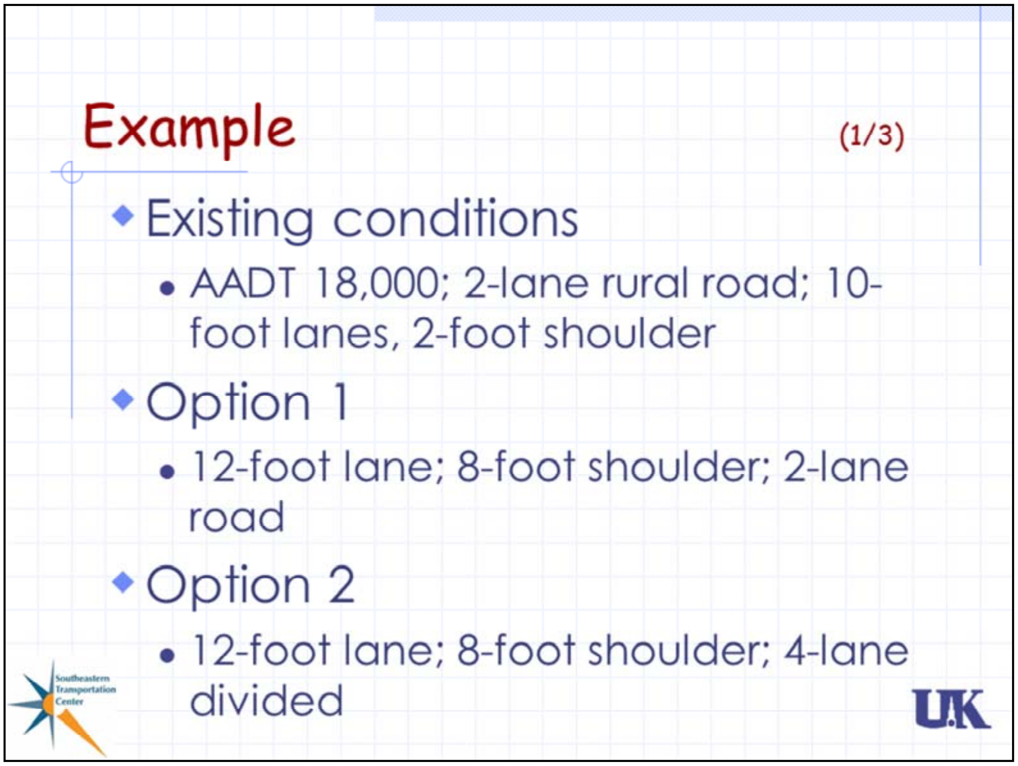
Crash Severity	Distribution	Cost ($)	Average Cost ($)
Fatal	0.02	4,008,900	80,178
Injury A	0.05	216,000	10,800
Injury B	0.10	79,000	7,900
Injury C	0.15	44,900	6,735
PDO	0.68	7,400	5,032
Total	1.00		110,645

Option 1 monetary gains: (0.06)(110645) = $6,646 per year

In this example, the distribution of crash severity for a site is used to estimate the average crash cost for the site. Using the gains in safety by utilizing option 1 in the previous example and assuming no change in severity distribution, the annual gains per mile can be estimated. This value can be converted to the net present worth over the lifetime of he project to estimate the actual benefits from the improvement.



Some times what maybe the best option for a project needs to be balanced against the system optimization. This means that frequently, one could address many small projects instead of a big project in one location. In this case, best safety improvement may not be appropriate if it requires a significant amount of resources. In this case this needs to be evaluated with respect to its impacts on the system.

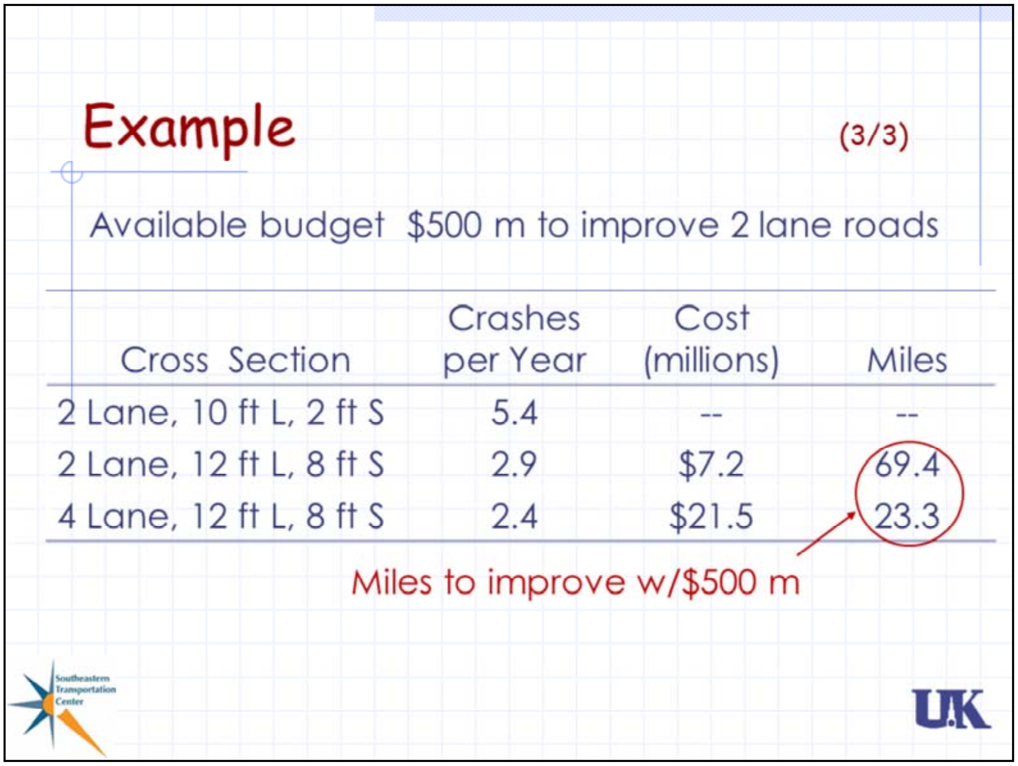

Example
(1/3)
Existing conditions
AADT 18,000; 2-lane rural road; 10-foot lanes, 2-foot shoulder
Option 1
12-foot lane; 8-foot shoulder; 2-lane road
Option 2
12-foot lane; 8-foot shoulder; 4-lane divided
Southeastern Transportation Center
UK

Example (2/3)

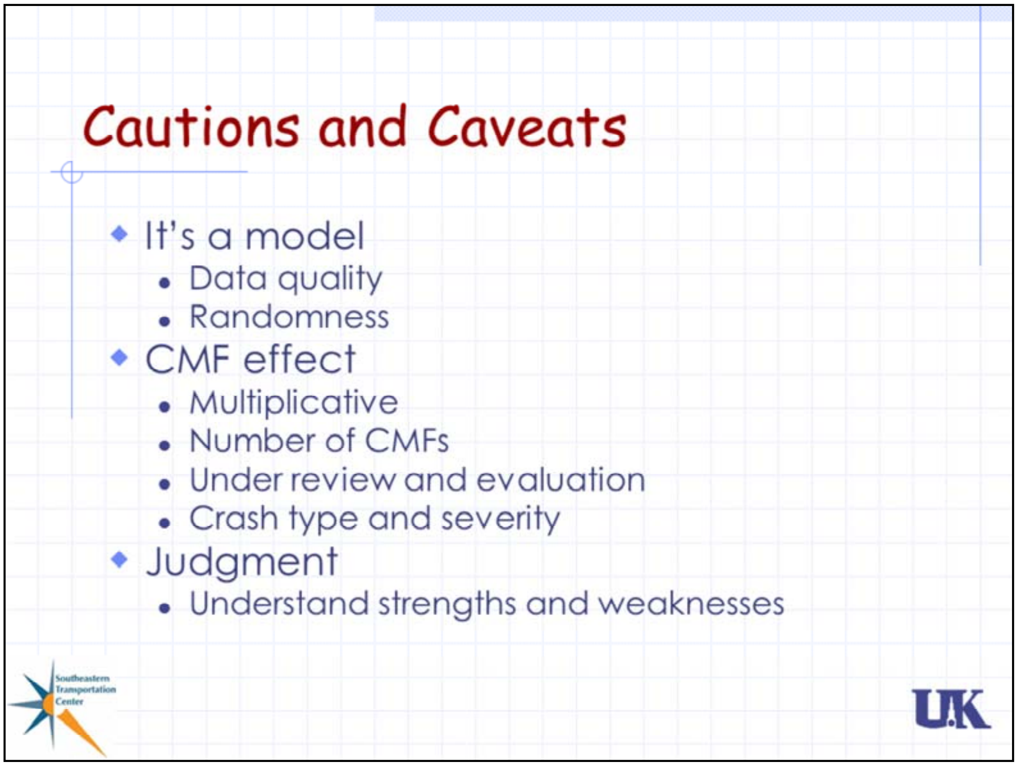
Condition	Crashes
Existing	5.4
Option 1	2.9
Option 2	2.4

Costs
Option 1 $7.2 mil/mile
Option 2 $21.5 mil/mile

These are the estimated number of crashes per mile per year for each of the alternatives considered. It is apparent that the 4-lane option will result in the larger number of crash reduction. However, one needs to consider the associated costs with each solution and determine the system wide implications.



If one compares the system-wide effect of each alternative, then the “less” safe option allows for a greater number of miles to be improved. In this example, the $500 million budget will allow for improvements in 69.4 miles if the lanes and shoulders are widened instead of 23.3 miles if the ultimate safety is achieved. If one further considers the overall safety gain, there will be 173.5 ((5.4-2.9)(69.4)) fewer crashes with the 2-lane option as opposed to 69. 9 ((5.4-2.4)(23.3)) crashes with the 4-lane option.

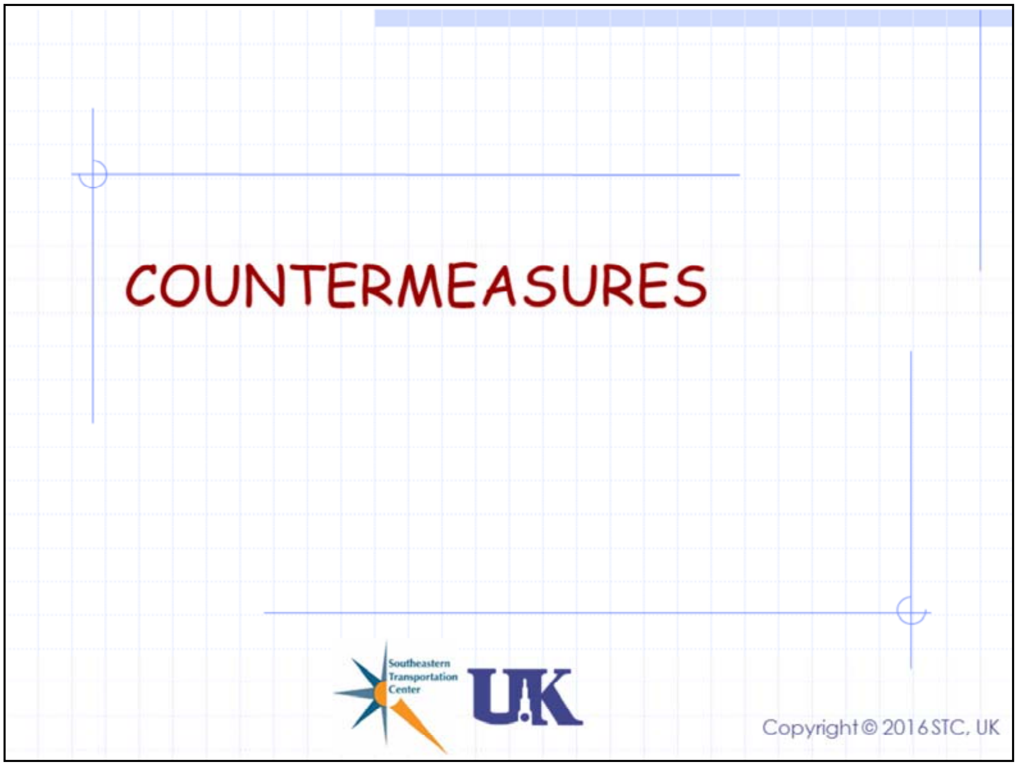


One should never forget that the HSM is simply a model and as such it can suffer form data quality and the randomness of the crashes. The important aspect here is that we now have a tool that can help us answer several questions quantifiably and be able to address potential safety impacts on design choices.

An issue of concern is the effect of multiple changes on the same section and how to utilize multiple CMFs. The maximum number of choices is under review and in future updates, some guidance is anticipated. Another issue relative to CMFs is their applicability on specific crash types and severity levels and this needs to be noted when CMFs are utilized.

Central to the entire HSM approach, is the need to understand the strengths and weaknesses of the approach and try to exercise appropriate judgement when results are obtained and used in design evaluations and policy development.

This may be true but most times, there is a need to trade off between various competing project issues and attributes.



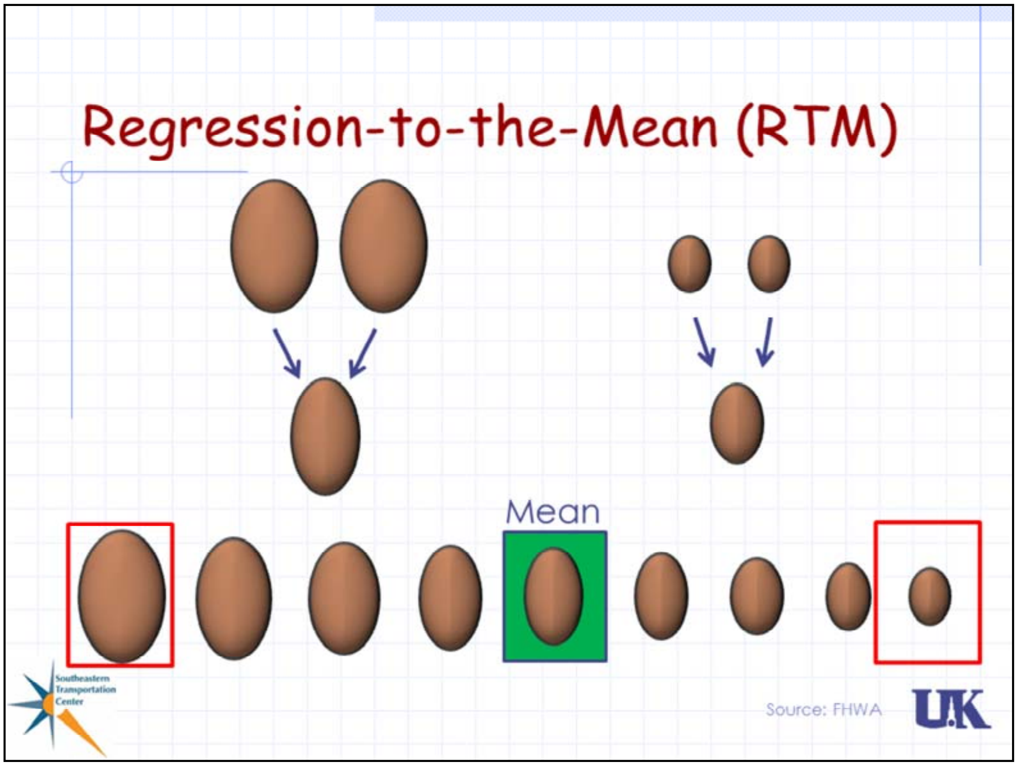
The previous presentations provided the background for understanding the factors that contribute to a crash occurrence and identified methods with which one can evaluate options. Module 7-2 provided some basic evaluation of alternatives considering economic aspects and system-wide evaluations. The focus of this module is to discuss methods and resources for selecting effective countermeasures and identify strategies for prioritizing countermeasures. The necessity of outcome evaluation will also be discussed.

Rational vs. Pragmatic Analysis

Rational	Pragmatic
Data and analysis	Lay beliefs
Factual experience	Personal anecdotal experience
Estimates based on the effect on safety	Meeting standards means "safe"

Countermeasure evaluation should be based on sound science and follow a rational approach. Only until recently we have started moving towards the direction of scientific and rational approaches in evaluating safety options based on available data and analysis, since most of prior analyses were based on lay beliefs and personal anecdotal experience. The future is described as rational because it is founded on understanding the expected consequences of actions based on factual experience and involves learning from experience. The concepts of substantive and nominal safety discussed earlier point to the need for a rational rather than pragmatic approach. As noted before, the assumption that meeting the standard is necessarily safe in not true. For example, we generally know that longer radii could improve safety but the effect of the radius on both safety and economics of the roadway could only be recently quantified though the Interactive Highway Safety Design Manual (IHSDM). It should be noted that this is not feasible using only the Green Book, since such tradeoffs are not discussed.

The rational style emphasizes estimates of the effect on safety (data and analysis), not adherence to standards based on personal experience, beliefs and intuition.



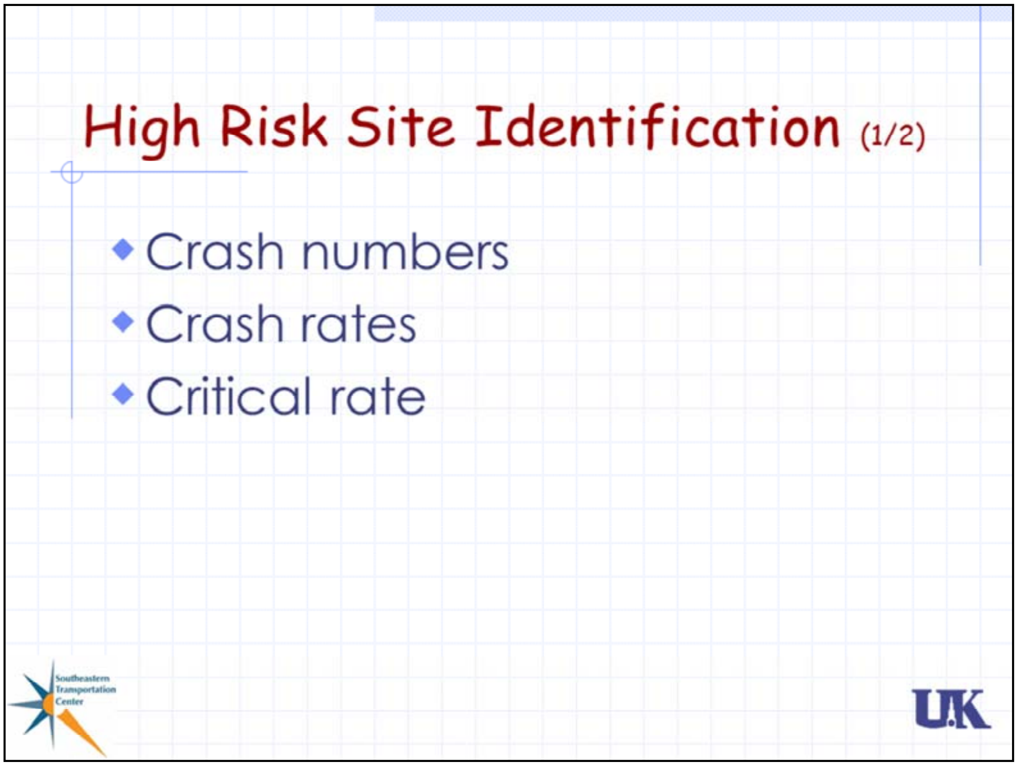
The concept of the regression to the mean (discussed in Module 6) needs to be considered when evaluating potential alternative countermeasures. As noted before, there is a random crash variation and the concept of “regression to the mean” (RTM) could result in locations having a relatively high number of crashes one year, and then a drop in the next year.

This phenomenon was observed as early as 1877 in a study by Galton in which, “. . . the offspring of tall parents are generally found to be shorter than their progenitors (and vice versa)”. In this sense the heights tend to move or “regress” back toward the underlying mean, e.g. average height. The specific concern in road safety is that one should not select sites for treatment based on a high count in one year because the count will tend to “regress” back toward the mean in subsequent years.

The RTM affects both the selection of the alternative and the evaluation of its effectiveness. Alternatives chosen and implemented when the crash count is randomly high could show artificially high improvements and vice versa thus resulting in a wrong estimate of its effectiveness.

Safety improvements are typically based on determining and prioritizing high risk sites. There are several ways that such sites can be identified based both on quantitative information (data) and political will directed from top officials which can be based on a variety of factors (pragmatic as discussed above) and not necessarily based on crash data. Funding sources often tie investments to specific focus areas or activities. A careful analysis of crash data is essential in determining areas requiring attention. FHWA after reviewing the state highway safety plans has identified a series of common problems including run-off-the-road crashes, intersection-related crashes, impaired driving, occupant protection, and pedestrian safety.

The idea behind high risk site identification is to determine the exact locations where improvements can be useful and effective. For example, the knowledge that high-friction pavement can improve run of the road crashes does not mean that a DOT should implement it on all roads but rather identify locations that this could reduce these crashes. In such an approach, the high risk sites are identified and the countermeasure is applied in a targeted manner. By starting with "high risk" site identification and then determining the specific crash factors at those locations, safety investments stand a far better chance of affecting the root safety problems and reducing fatalities and serious injuries.

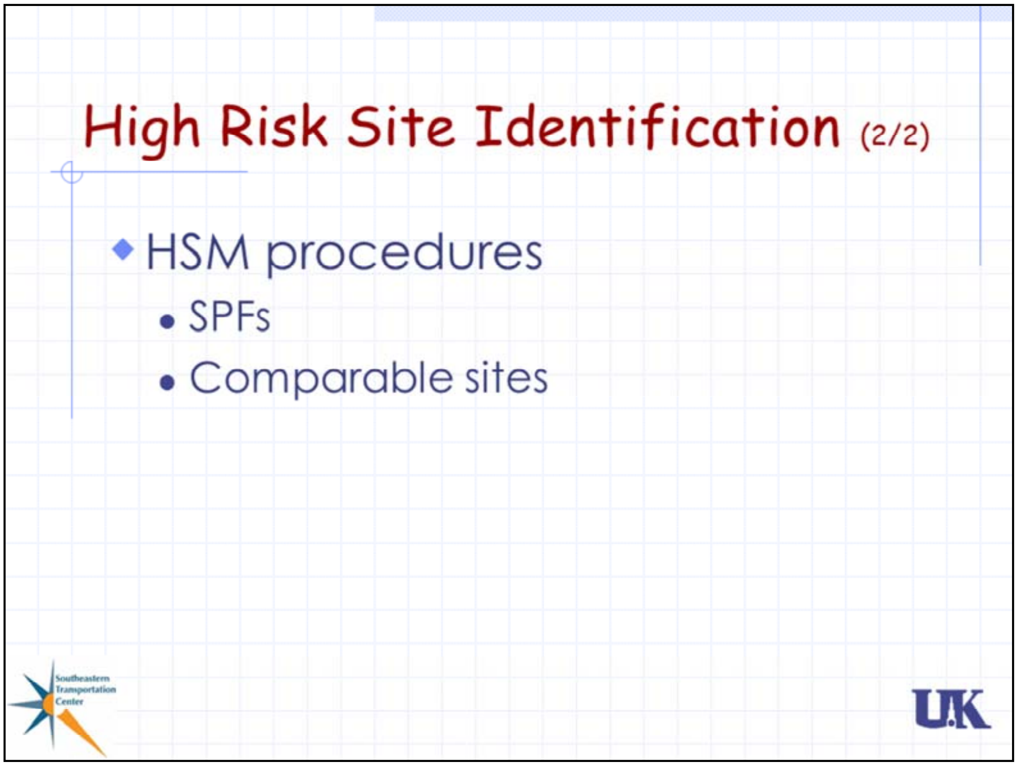


Ask the students the following question prior to showing the possible approaches and try to generate some discussion.
Question: How do we identify high risk sites?

One of the simplest approaches is to use the number of crashes per year averaged over several years. The appeal of this measure lies in its simplicity, since the more crashes at a location, the generally higher level of injuries and fatalities expected. A variation on this theme would be to conduct the analysis using only mean numbers of injury and fatal crashes per year, but this does not fundamentally change the argument. A limitation of using crash frequency is the high expected number of crashes may be a primary manifestation of high traffic volumes, which may not be easily changed.

To avoid the issue of exposure inequality, one can develop crash rates per year (number of crashes divided by an exposure measure such as million vehicle miles for road sections or millions of entering vehicles for intersections or other junctions). This can also lead to not reflecting the actual ranking, since exposure measures may not be accurate and there are several other factors that can influence crash occurrence.

Some, having reflected upon this situation, have decided that a combination of crash rates and numbers should be used. This is referred to as the “number-rate” method. First a minimal number of annual crashes are selected to initially screen sites to a smaller number, and then the rate is used to generate another ranking. The difficulty is that the selection of the cut-off number for inclusion is arbitrary and there is still no assurance that the sites identified will have promise for improvement



The HSM procedures also allow for the identification of the high risk sites through the use of SPFs. This approach allows for identifying the performance of the site in comparison to what is expected at similar sites. The difference between what is expected at similar sites and what is experienced at a specific site can be used to determine the potential for improvement and identify the high risk sites with promise.

The use of considering and using information about comparable sites is valuable in this scenario. Sites that seemed to hold promise using the crash frequency can be identified.

Once high risk sites are identified, the specific information regarding crash types and factors for the site should be examined. This will allow for understanding the particular performance of the site and identify specific elements that could be addressed to improve the site performance. The documentation of contributing factors is crucial in identifying potential effective countermeasures. The specific crash types can also contribute in the understanding of the potential issues and aid in the identification of the countermeasures.

These crash factors and types are generally obtained through road safety engineering studies and audits (as is discussed in Module 9). Screening by crash type should identify those types of crashes over-represented with respect to the group as a whole, thus further refining the high risk sites for identifying appropriate countermeasures. Another aspect of crash type evaluation is the potential for contrasting effects in a single countermeasure. Note that these are not all crash types that one should consider but a sample for discussion purposes.

As an example ask students: at an intersection, will the installation of a signal have a positive or negative impact on all crashes?

Answer: the signal can reduce left-turn related and crossing crashes but may increase rear end crashes, hence some types can go up while others can go down.

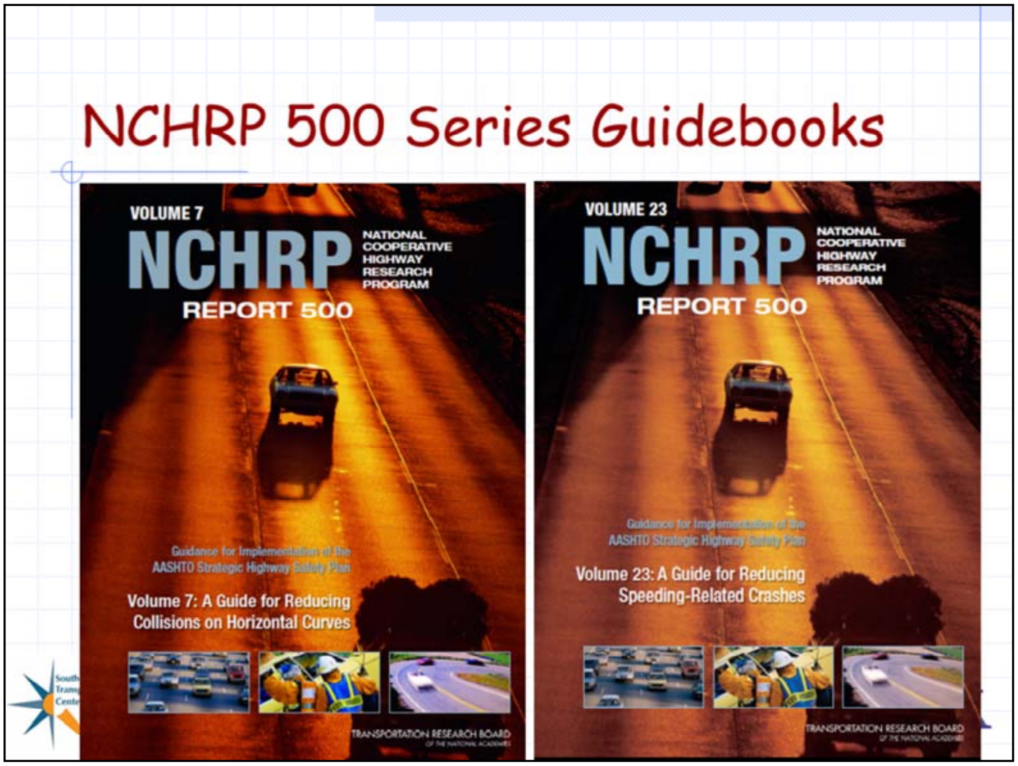
There are three motives for considering countermeasures and those include economic efficiency, professional responsibility, and fairness.

It is imperative to consider economic efficiency to determine whether the a treatment would be cost-effective. This would provide an understanding of the effectiveness of specific countermeasures and allow for determining the potential of the countermeasure for application at each specific site. There is also professional and institutional responsibility to identify and address high risk sites. Finally, fairness to all system users is required to ensure that specific user groups are also addressed. The issue here is that typically such sites will not be routinely identified and once specific crash types and factors are identified users can be targeted to improve their safety levels.

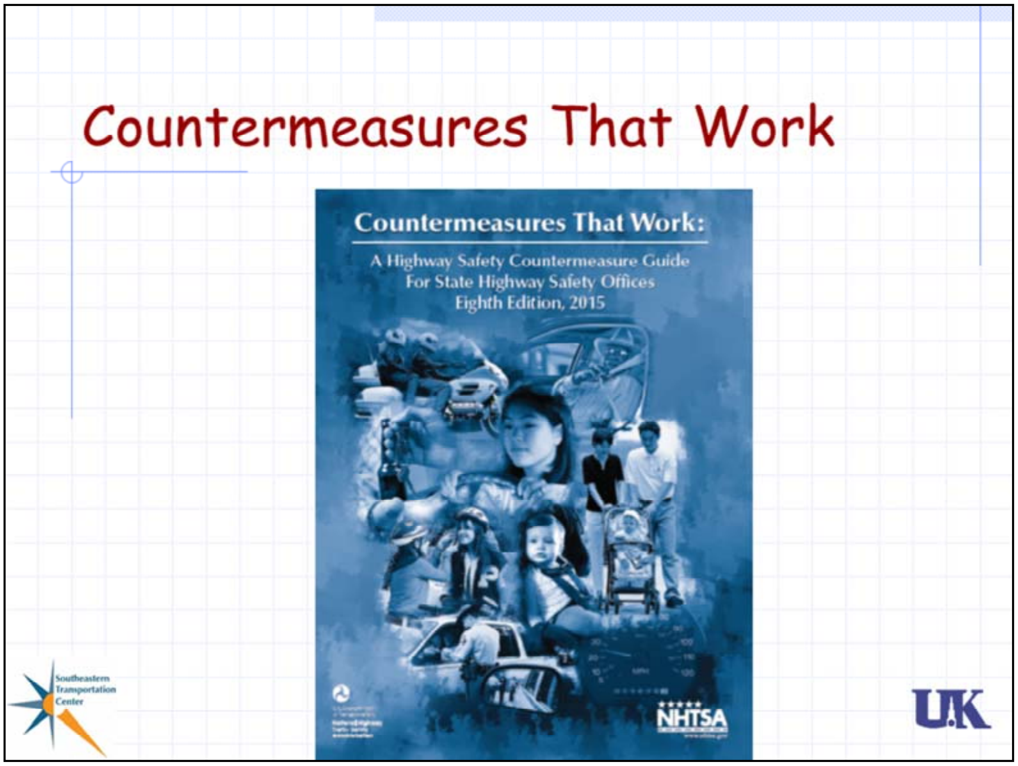
Once a high risk site has been identified, some review of the site is needed to identify the various issues that can point to the reasons for the site been identified in the first place. A typical review approach is an engineering study that considers the available data and determines whether any infrastructure interventions will result in addressing the issues. These studies typically review roadway features and geometry along with crash data and attempt to correlate crashes to the features of concern. In recent years, road safety audits typically accompany engineering studies since they have the potential to provide a multidisciplinary and multimodal perspective regarding road safety. These audits (see module 9) when conducted during the design phase of the project can provide a systematic review. Road safety audit reviews are conducted at existing locations and thus are different in nature trying to identify areas, elements and road features that may contribute to a crash occurrence. The results of these reviews can be used to identify alternatives and countermeasures that could improve safety at the site in question.

The reviews could recommend actions that could be considered as immediate safety improvements indicating actions that can be implemented immediately (e.g. clearing vegetation and sight obstructions), low-cost improvements such as signing, and high-cost improvements where significant investment may be needed.

An issue to be emphasized here is the need to consider human factors and all other users in such reviews and steer away from the one-dimensional engineering only countermeasures. This is the main reason for the prevalence of road safety audits and reviews focusing on multidisciplinary and multi-modal efforts.



The NCHRP 500 series guidebooks were developed to support implementation of the AASHTO Strategic Highway Safety Plan. Each volume of the series presents information about a specific safety problem (e.g., horizontal curves, aggressive driving, teenage drivers, run-off-road crashes, etc.). Each report provides a process for addressing the problem and provides guidance in developing plans to address the issue. For each issue, several countermeasure that were identified from past research efforts are proposed and discussed. The countermeasures are classified as proven, including those that have demonstrated effectively addressing the issue; tried, including those that have been implemented but their effectiveness in not yet available; or experimental, including those that are considered and have been implemented on an experimental basis and with little or no field evaluation.

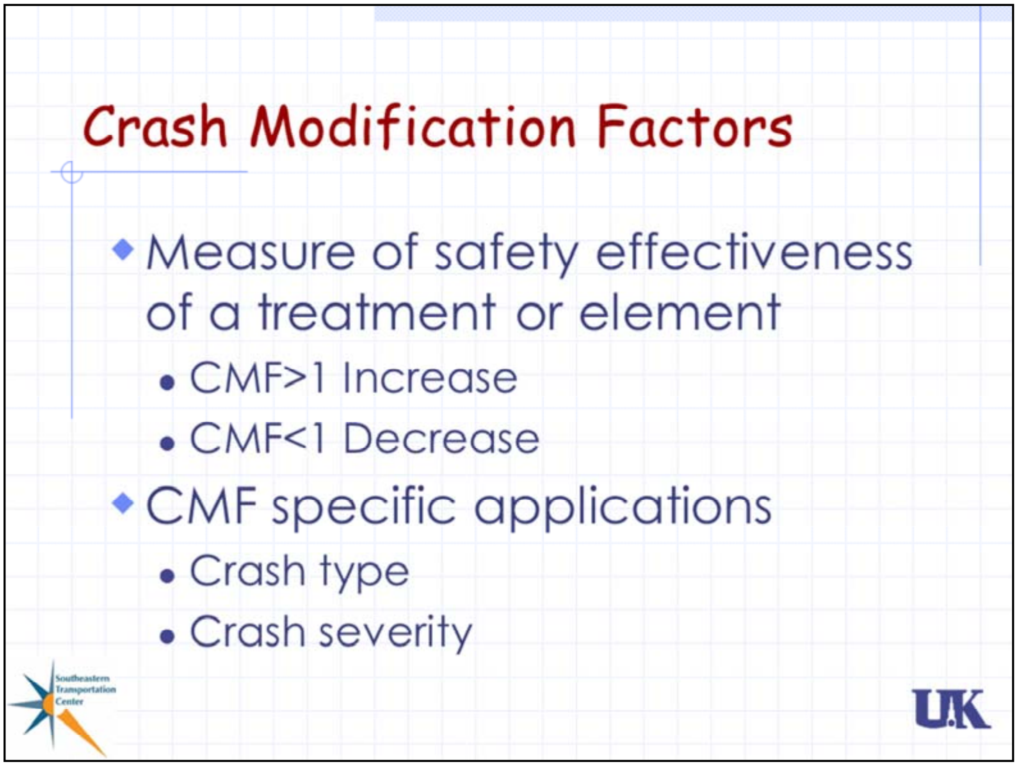


NHTSA's *Countermeasures That Work: A Highway Safety Countermeasure Guide For State Highway Safety Offices (8th Edition, 2015)* is a basic reference to assist in selecting effective, science-based traffic safety countermeasures relevant to road user crash factors. The guide summarizes major strategies and countermeasures, their effectiveness, costs, and implementation time, and provides references to research summaries and individual studies. The guide provides information on countermeasures for:

- Alcohol- and drug-impaired driving;
- Seat belts and child restraints;
- Speeding and speed management;
- Distracted and drowsy driving;
- Motorcycle safety;
- Young drivers;
- Older drivers;
- Pedestrians; and
- Bicycles

FHWA has also developed a list of proven safety countermeasures. This practice started in 2006 and every few years it is updated to reflect current thinking and research findings. The 2012 memorandum identifies these nine areas as proven countermeasures considering the latest safety research to advance a group of countermeasures that have shown great effectiveness in improving safety. FHWA also encourages safety practitioners to consider this set of countermeasures that are research-proven, but not widely applied on a national basis.

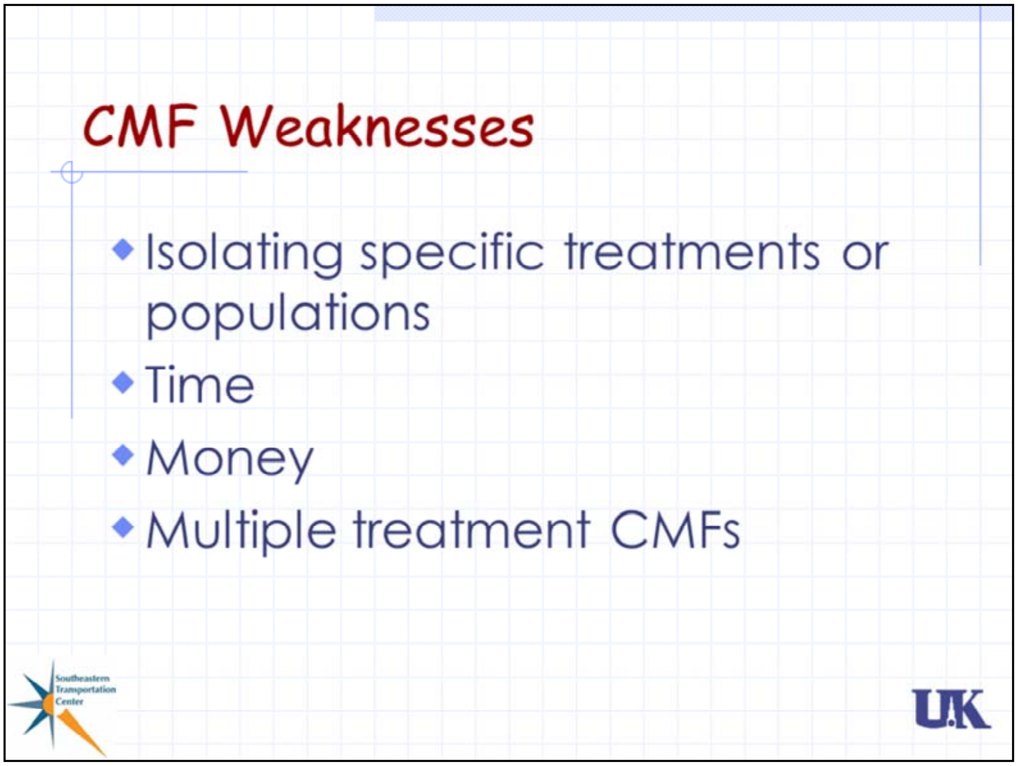
FHWA provides additional information on the effectiveness of each countermeasure in their web site (http://safety.fhwa.dot.gov/provencountermeasures/). For each countermeasure, a fact sheet is developed that provides more detailed descriptions, related research studies, and evaluations.



Crash Modification Factors (CMFs) allow for the assessment of the effectiveness of a countermeasure or treatment. The CMF is applied to the estimated crashes ***without*** treatment to estimate crashes ***with*** treatment (assuming the countermeasure of interest is implemented). It is therefore imperative to estimate the number of crashes ***without*** treatment before applying CMFs and this can be accomplished with the various methods described in the HSM module (7.1 and 7.2). As an alternative, one can estimate the crashes without treatment by computing the long-term (i.e., 5+ years) average crash frequency before treatment and thus use this as the future safety performance in the absence of changes. The Empirical Bayes method, described in the HSM, is a more rigorous method for estimating crashes ***without*** treatment as it combines information from the site of interest with information from other similar sites.

Mathematically stated, CMF = 1 - (CRF/100). For example, if a particular countermeasure is expected to reduce the number of crashes by 23% (i.e., the CRF is 23), the CMF will be 1 - (23/100) = 0.77. On the other hand, if the treatment is expected to increase the number of crashes by 23% (i.e., the CRF is -23), the CMF will be = 1 - (-23/100) = 1.23.

CMFs may apply to total crashes or to target crash types and severities. It is important to pay attention to the application range of the CMF, since several have been developed for specific crash types and severities. The user should be aware of this apply the CMF appropriately, since incorrect application may result in erroneous estimates of safety changes (a countermeasure may reduce certain crash types or severities while increasing other crash types and severities).



Research efforts have focused in isolating the effects of a a specific element and identify associated CMFs. However, countermeasures are often implemented in combination with other actions, and it is difficult to separate the effect of the countermeasure from the effect of additional actions. For example, installing a left turn phase at a signalized intersection may be accompanied by an installation of a left turn lane and thus the effect of the countermeasure may be not easily identified.

At the same time, one may have to wait for a long time to collect data regarding the effectiveness of a treatment installed in order to conduct with–without comparisons and this can also be costly. In response to these concerns researchers have tried a variety of approaches to expand our knowledge base of quantified CMFs.

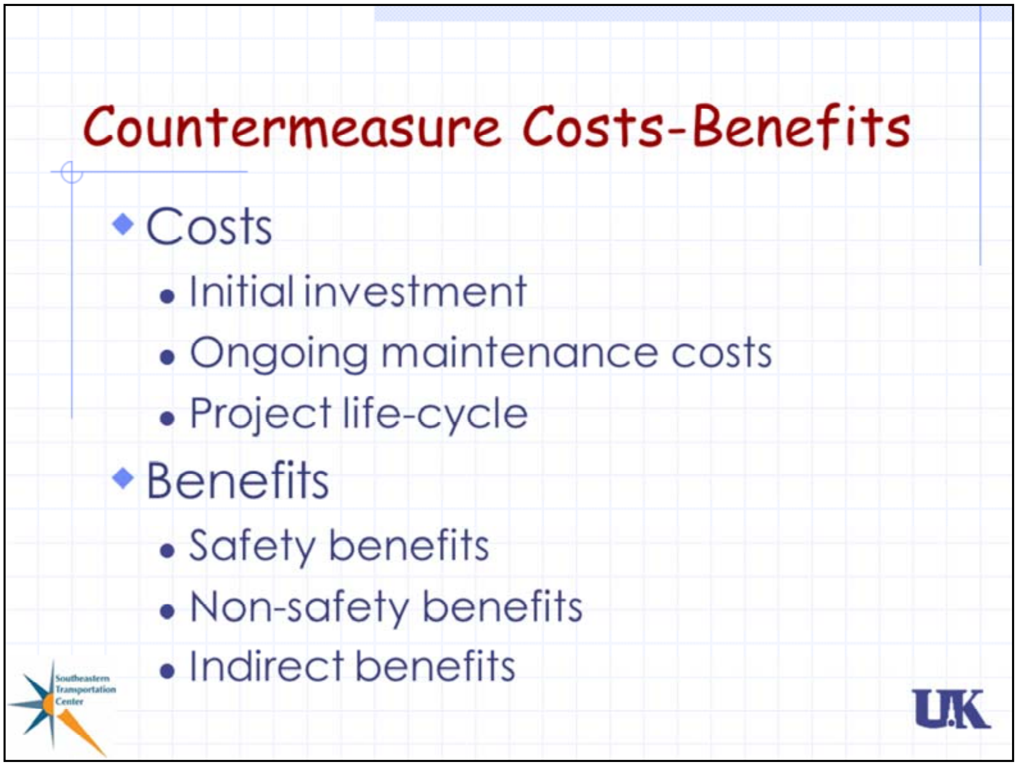
The CMFs for combined treatments are not widely studied, since most past research has focused on estimating those for individual countermeasures. The current practice for many agencies is to assume that CMFs are multiplicative; this is the current method presented in the *HSM* and the *CMF Clearinghouse.*

FHWA has developed and maintains the CMF Clearinghouse which is considered the repository of current research findings on CMFs. The webpage presents both CMFs and CRFs, or Crash Reduction Factors. The main difference between CRF and CMF is that CRF provides an estimate of the percentage reduction in crashes, while CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given improvement. Both terms are presented in the Clearinghouse because both are widely used in the field of traffic safety.

The CMF clearinghouse identifies and evaluates all CMFs developed using a 5-star rating system. One-star rating indicates a low reliability on the CMF either due to limited number of sites or low number of crashes. Higher ratings provide more reliable CMFs. The database is searchable with keywords and all known CMFs are identified from a search. The applicability of CMFS to crash type and severity is also noted.

It is important to note that a CMF represents the long-term expected reduction in crashes and this estimate is based on the crash experience at a limited number of study sites; the actual reduction may vary.

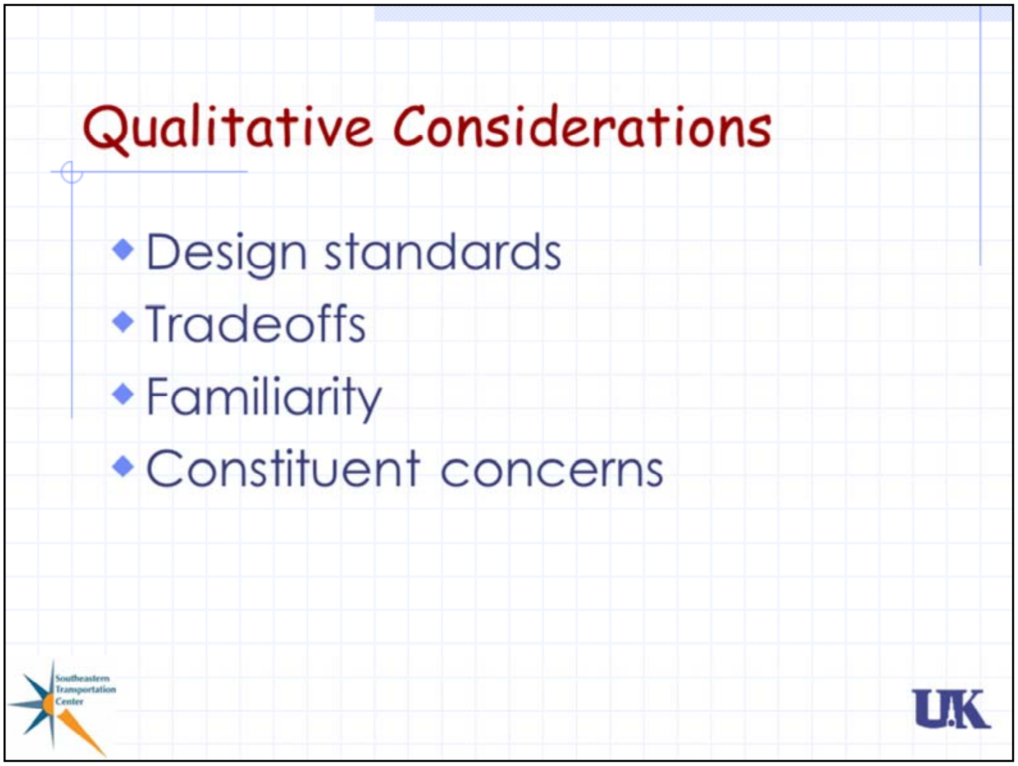
Source: http://www.cmfclearinghouse.org



Every countermeasure has associated costs and could result in safety benefits. Obviously, for a specific site, different countermeasures will have different costs. For example, dealing with safety issues on a horizontal curve, the low-cost solution will be additional signage while the high-cost will be a new alignment. Therefore, one needs to consider the relative costs of each treatment as a function of the benefits to be derived.

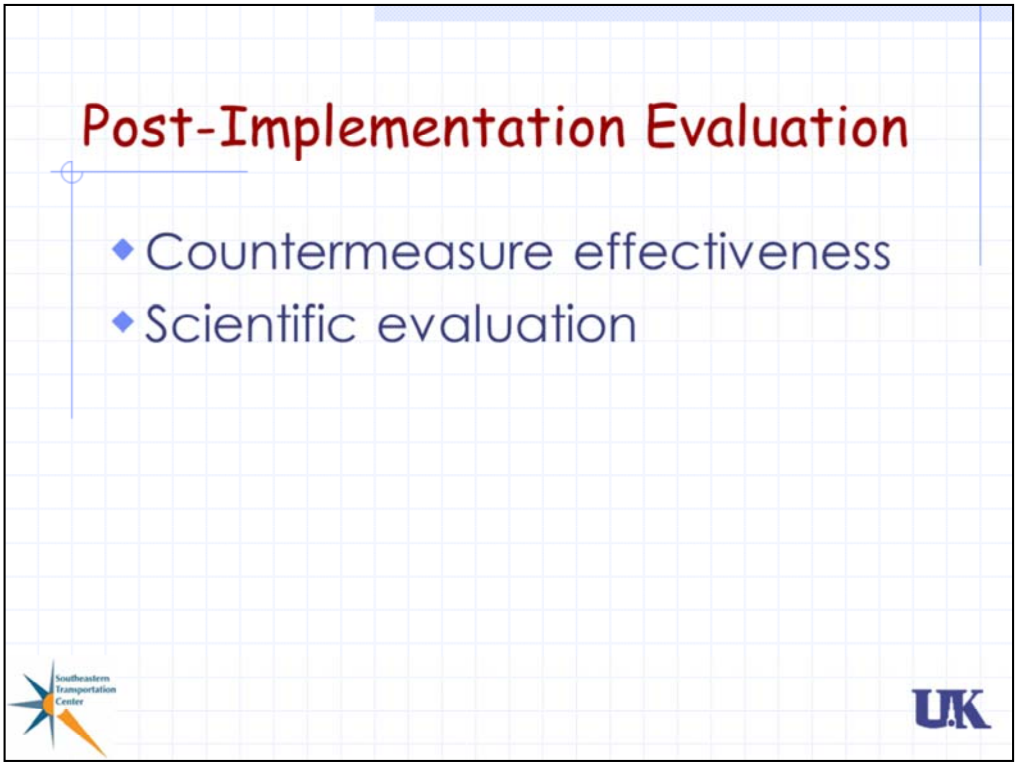
Costs need to consider not only the initial investment but also the ongoing costs required over the life-cycle of the project including maintenance costs, as well as the relative long-term effectiveness of the countermeasure. One countermeasure may be just as effective as another in the short term, but less cost-effective over a longer time horizon. For example, installing speed cameras along a corridor requires significant up-front cost, but over time may be less than the cost of paying for enforcement each year along the corridor.

All benefits resulting from the countermeasure need to be accounted for developing a proper cost-benefit evaluation. Obviously crash reduction can be monetized and this is an easily estimated benefit. An issue of concern here is the proper estimation not only of the changes in the number of crashes but the estimation of the severity of those crashes. It is possible that a countermeasure may reduce the total number of crashes but affect the severity distribution. For example, placing median barriers reduces the severity of head on collisions in run of the road instances but it does affect the number of crashes (they still run off the road but now hit the barrier). Sometimes a safety countermeasure will produce benefits beyond safety benefits, e.g. mobility improvements, reduced congestion, etc. With safer, less congested roadways, indirect benefits can also occur, such as improved environmental quality and economic prosperity.



A number of additional considerations may be required during the cost-benefit evaluation of a countermeasure. It is possible that untested countermeasures may conflict with existing design standards and as such agencies may tend to shy away from them. In these cases, efforts can be undertaken to establish testing procedures and determine the potential effectiveness of the countermeasure. There is a need for continuous balancing of mobility and safety needs and it is possible that these could conflict at times. It is conceivable that countermeasures perceived to conflict with other priorities may meet with resistance. As an example, the use of protected only left turn phasing could improve safety but at the expense of mobility and as such it may not be viewed favorable all the times. Proper evaluation of these tradeoffs is needed to determine the pros and cons of each option.

Another issue that can affect countermeasure implementation is the lack of familiarity with the countermeasure. In such cases proper discussion and communication with all decision-makers and stakeholders is needed to address and alleviate any such concerns. Finally, elected officials may be in favor of or oppose certain countermeasures due to the concerns of their constituents and often politicians may support or oppose a countermeasure regardless of its cost-effectiveness. This is a very difficult case to alter and public information and education efforts are important in ensuring proper dissemination and understanding of the issues.



An integral part of each countermeasure installation should be its evaluation. This is essential because it is the best mechanism for determining the effectiveness of the countermeasure. Without it, there is no information on the actual benefit of the countermeasure and no data to justify its future use. However, post-implementation evaluations are often neglected because all funds are consumed in implementing the countermeasure itself. Enough funds should be set aside to allow a proper, scientific evaluation of the countermeasures whenever possible. Lack of funds may lead to a simple comparison of the number of crashes that occurred before and after the countermeasure was applied, which may not be accurate. A proper evaluation must take into account other variables that could affect the number and/or severity of crashes, such as any change in the number of vehicles using the corridor (e.g., exposure), changes in demographics (proportion of older or younger drivers in the area), and so on.

This module provides the basic concepts for a road safety audit and describes an example application.

“The road safety audit (RSA) is an effective tool for proactively improving the future safety performance of a road project during the planning and design stages, and for identifying safety issues in existing transportation facilities. “ (FHWA-SA-06-17, 2006). The roadway design strives to balance all competing needs in a project (costs, community needs, mobility, safety, environmental, etc.) in order to develop an acceptable design. The RSA is conducted by an independent team that is not related to the design team and its goal is to evaluate the design developed to ensure the adequacy of safety in the proposed design. RSAs can be conducted during the planning stages of the project as well as during and after the design stage. In addition, evaluations of existing roadways are also conducted to identify potential safety issues that can be remedied to improve safety.

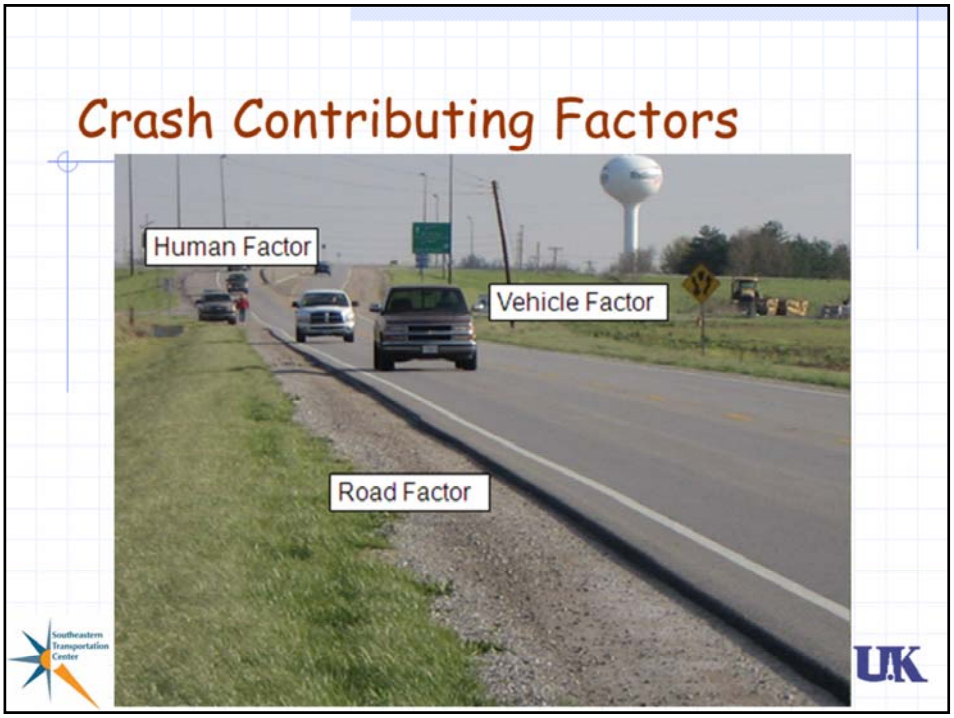
RSAs are a formal investigation and evaluation of a roadway segment that focuses only on the safety issues of the roadway as they could affect all users. It is very important to develop an all-user encompassing review in order to address potential safety interactions among users.

RSAs have a structured approach and they follow a specified process. This implies that in addition to the evaluation of the section itself, the team needs to address the connections of the segment to the remaining network and identify possible issues for he users entering and exiting the segment. For example, is signing adequate for drivers approaching from adjacent road segments (are approaching drivers correctly positioned for turn-only lanes, and is signing consistent with similar facilities upstream and downstream)? An RSA does not simply identify potential problems – it may also identify potential solutions. An RSA can identify possible mitigation measures to address these risks.

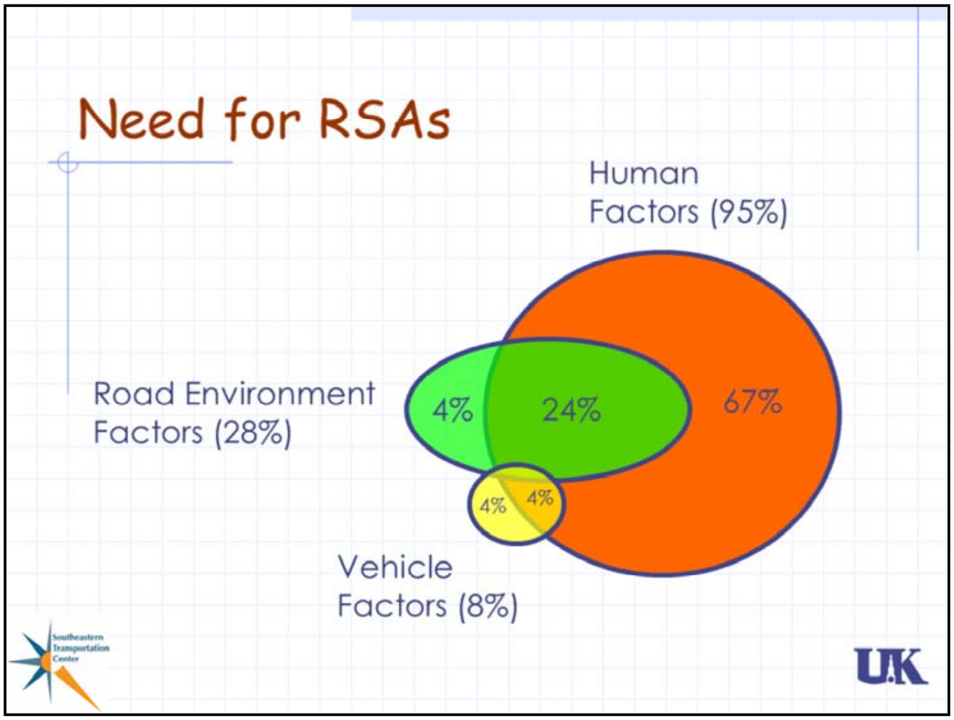
It should be emphasized that an RSA is not a simple check off of adherence to existing design guidelines and standard to ensure that they were met. The idea is to evaluate the implications of the design on safety rather than whether the design team has followed the specific standards and guidelines available. Comparisons of the design proposed with the standards is possible but more from the perspective of identifying how the combination of specific design elements may interact to generate a potential hazard.

The RSA team has no mandate to change a design they are auditing. RSAs are very frequently conducted at advanced stages in the design process, when design changes would be costly in terms of fees and delays. The RSA team is charged with reviewing a project for its safety implications, and suggesting measures that can be taken to reduce collision risks within the project's limits. The earlier a pre-construction RSA is conducted, the more potential it has to identify potential safety issues and address them before the final design and construction. RSAs are not a tool to evaluate alternative designs or to rate alternatives. An RSA is simply an evaluation of the proposed design and how the choices for each design element will affect the safety performance of the roadway.

It is important to note that a well-run RSA is not a critical review of the designer's work, but rather a review of the design with a focus on how safety can be incorporated into it. RSAs in which the designer and audit team work together in a spirit of cooperation are generally the most productive in terms of ensuring that the audit team fully understands design issues and challenges (as described by the designer in the pre-audit meeting), with the result that suggested mitigation measures to address safety issues are practical and reasonable.



A closer look of this picture can identify the potential contributing factors to an unsafe roadway environment. The stopped vehicle by the side of the road creates a human factor that can lead to a crash (driver walking by the side of the vehicle and be struck by an errant vehicle). Any vehicle with defective equipment could also contribute to a crash occurrence. There is a road factor here too due to the large roadway-shoulder drop off that can lead to a crash if an errant vehicle leaves the roadway and the driver overreacts in an effort to bring the vehicle back on the road.



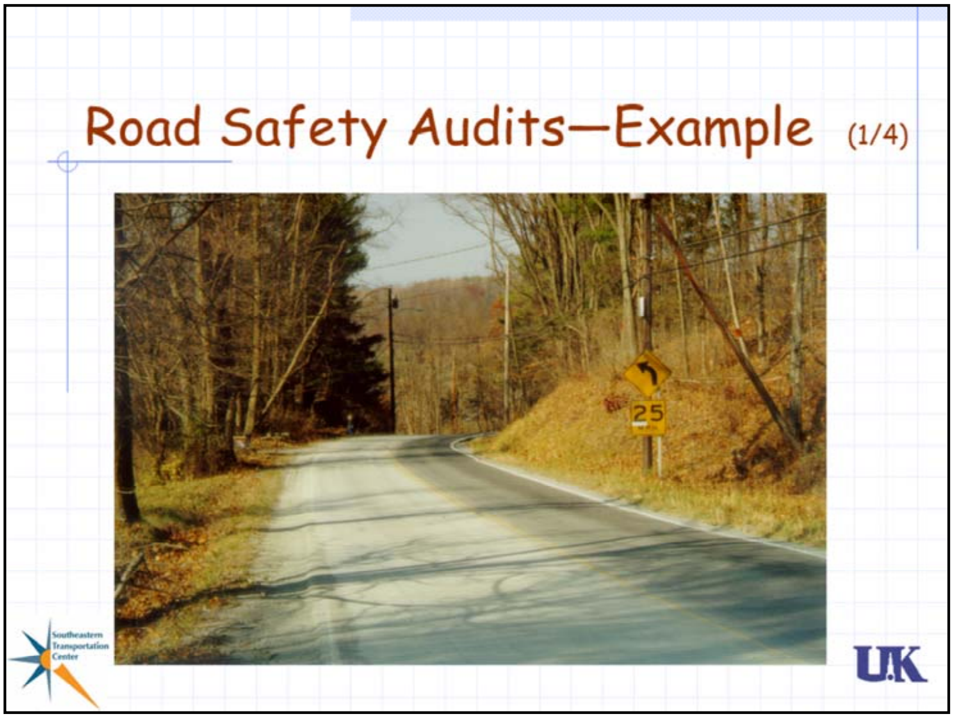
We have seen this diagram before and we want to emphasize the interaction among the contributing crash factors. For example, a collision may result from faulty brakes (“vehicle factor”), a driver who fails to observe a properly-functioning traffic signal (“human factor”), or a road segment with inadequate sight distance (“road environment”).

(Note: The proportions in the diagram exceed 100 percent because crashes are very often attributed to more than just one of the causes.)

Road safety audits focus on the road environment and therefore they have the potential to address 28 percent of the crashes. It should be noted that even with collisions attributed purely to driver error or vehicle faults, a well-designed road can help to reduce the collision severity. A good road design is one that can anticipate and accommodate common driver errors and the concept of the “forgiving roadside” has been fundamental in how roads are designed since the 1960’s. An RSA focuses on this part (i.e., roadway) of the safety area and identifies means with which driver errors are considered and efforts are made to minimize them.

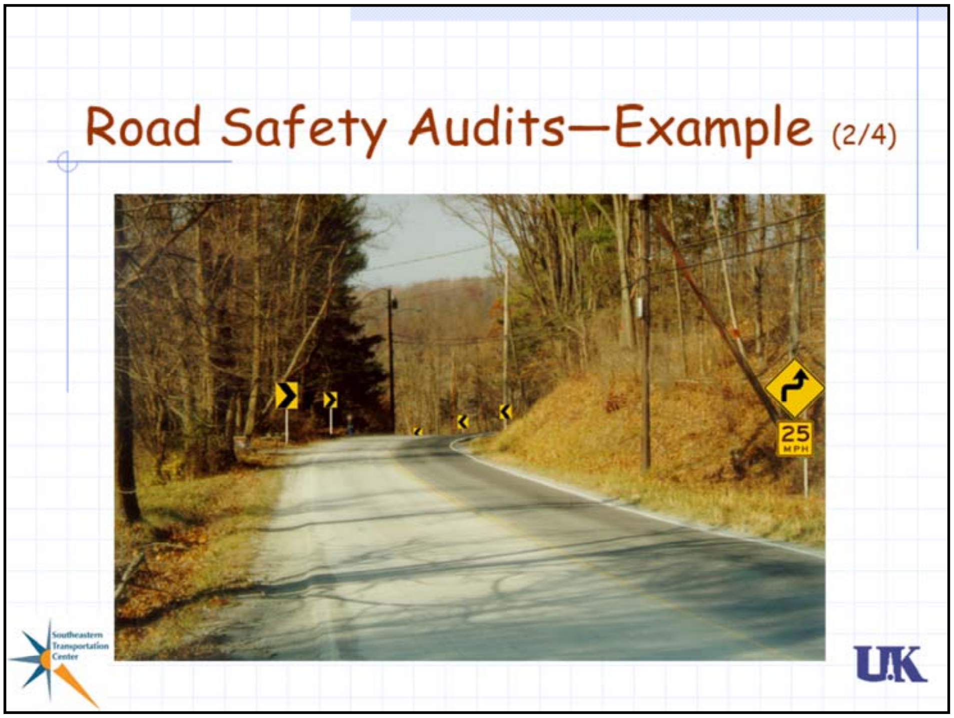
RSAs are typically focusing on areas beyond the design of the roadway and they focus in other areas beyond the roadway design. A focal point is to also consider how the human factors are treated within the segment and what issues may require additional attention in order to ensure proper driver behavior and reaction. RSAs focus on:

- Signing, in order to ensure that proper and adequate signing is present;
- Delineation, to emphasize proper lane usage and edge of pavement;
- Fixed objects, in order to identify potential issues with run of the road crashes and location of objects close to the roadway edges;
- Pavement drop offs, to identify areas where errant vehicles may not be able to recover and get back on the road; and
- Inadequate superelevation, to address potential run off the road or head on crash potential.

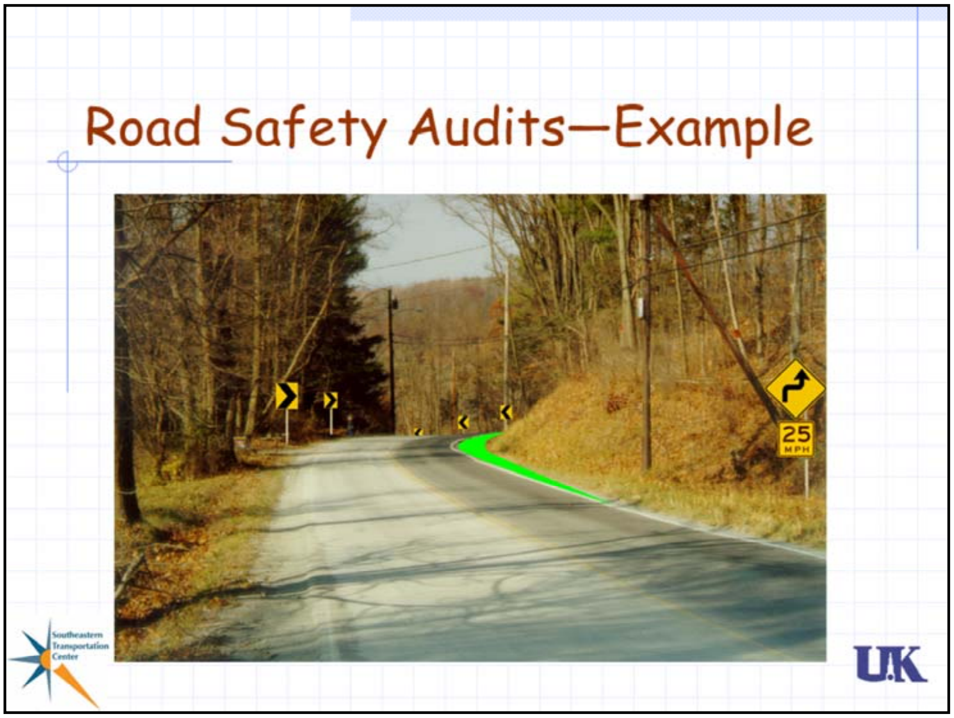


Here is a roadway segment that may pose some issues for drivers based on how it has been signed.

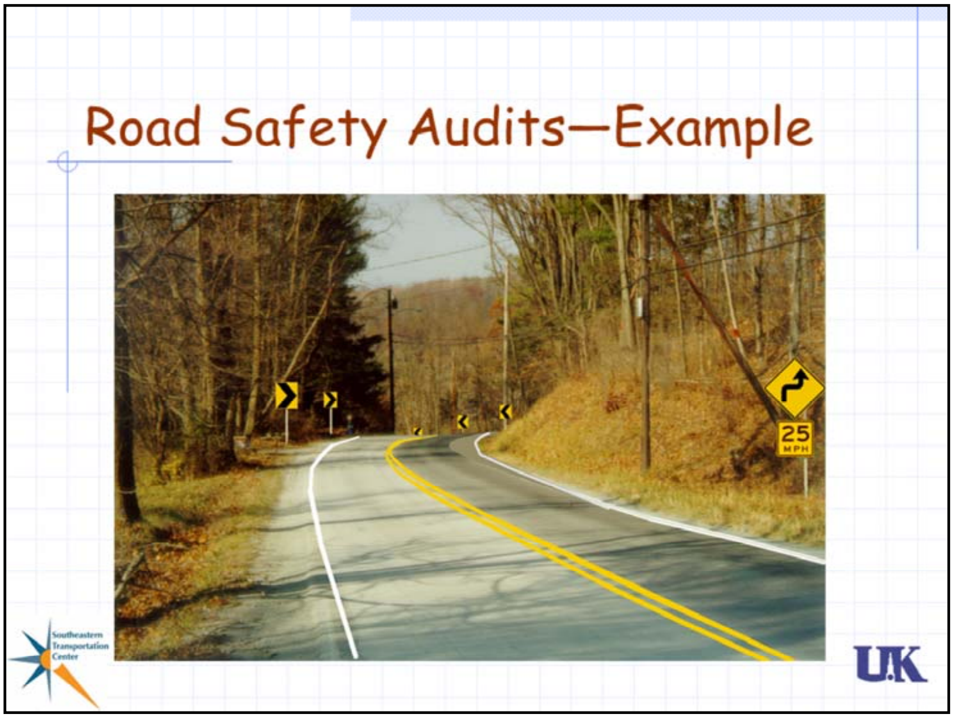
Question: What may be some issues for this roadway?
Answers:
1. Warning sign shows a left hand curve while to road indicates an immediate right hand curve.
2. Additional curve delineation may be useful to mark the roadway.
3. Pavement markings are not clearly visible especially left side of the road.
4. Drop off at shoulder could be problematic for returning an errant vehicle on the road; indications of need for a wider shoulder are also present.



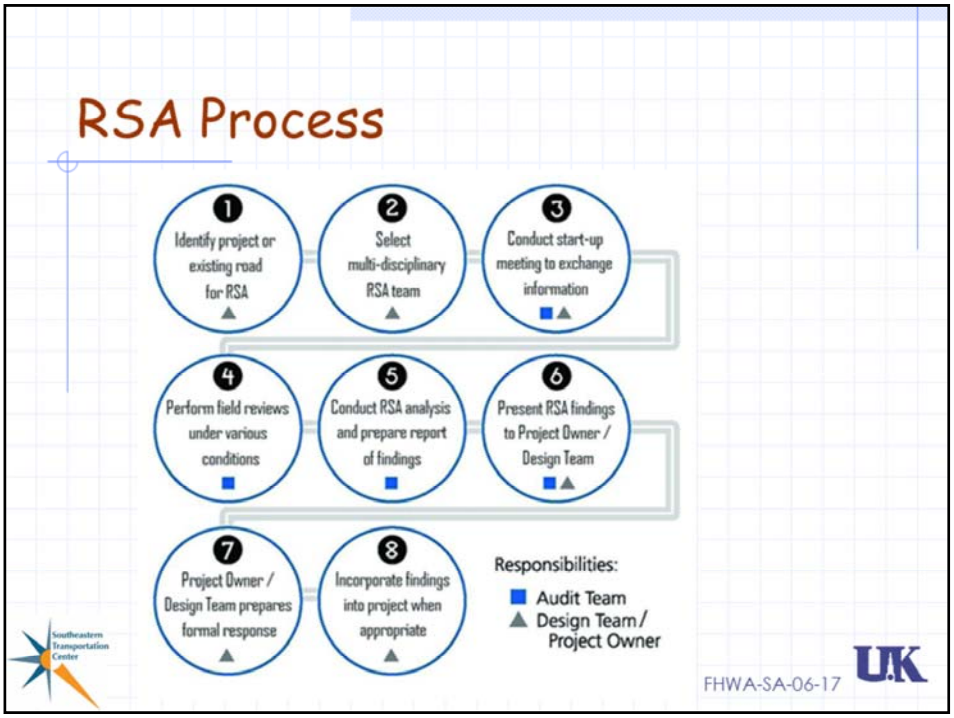
The S-curve warning sign is more appropriate and the use of chevrons clearly marks the curve.



The shoulder has been rebuilt to eliminate the drop off and it has been widened to address off tracking issues.

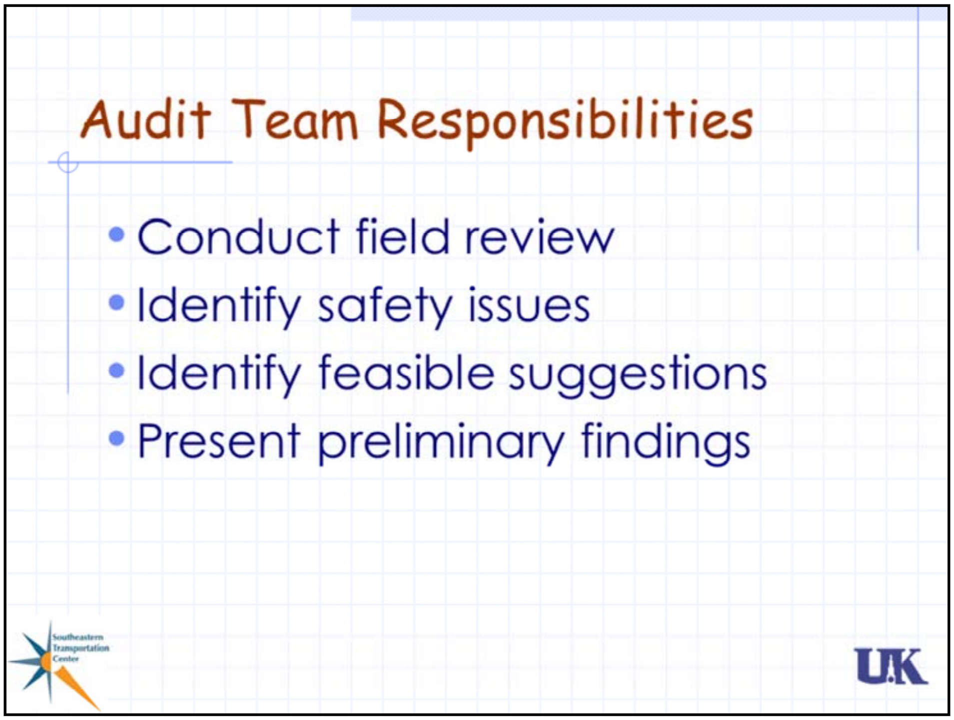


Pavement markings make the road edges more visible.

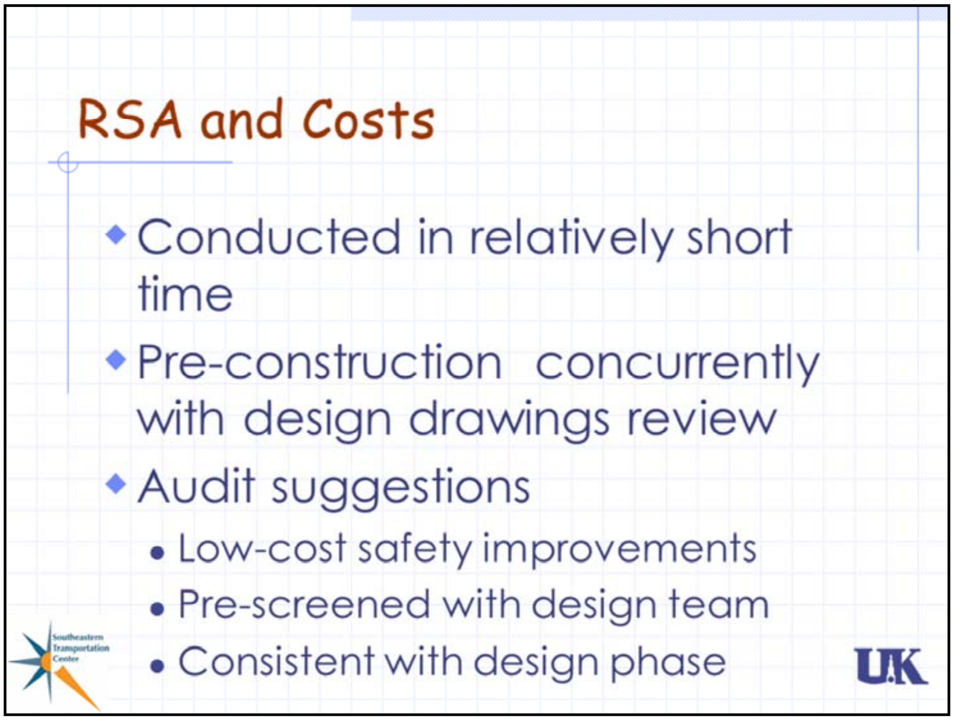


FHWA has developed an eight-step process for conducting an RSA (FHWA-SA-06-17, 2006). In this process, the activities of the design and RSA teams are delineated to provide the final safety review. The design team identifies the project to be examined (Step 1) and selects the independent expert team to conduct the SRA (Step 2). A meeting is typically held between the two teams to identify the reasons for the RSA, describe the design elements used and overall design, and for the RSA to identify and explain its scope (Step 3). The RSA team performs a field review (if this is an existing roadway) or reviews plans and existing roadway conditions to understand the operating parameters of the project (for design-stage projects) (Stage 4). This will allow to identify any external factors that may need to be considered at this stage. The RSA team conducts a systematic safety analysis through a review of design drawings (to examine features such as road geometry, sight distances, clear zones, drainage, signing, lighting, and barriers) and considers any human factors issues, such as road “readability”, sign location and sequencing, and driver perception of geometric features. (Stage 5). A report is prepared and presented to the design team (Stage 6). The design team reviews the report sna provides responses to the RSA team (Stage 7) and finally addresses the issues as needed and appropriate (Stage 8).

The most critical responsibility of the local agency is commitment to the RSA process. Typically, support from senior management in the road agency is vital to the success of individual RSAs and the RSA program as a whole. Commitment of resources is essential and this is manifested though allocating time within the project schedule for conducting the RSA and incorporating any improvements resulting from it, dedicating funds to perform the RSA, and providing staff to represent the road agency in the RSA process. Traditionally, the road agency selects the audit team, which may be composed of road agency staff (from the owner's road agency or in a reciprocal arrangement with another road agency), consultants, or a mix of the two. Prior to the start of the audit (or at the start-up meeting), road agency staff should provide required information such as traffic volumes and collision records. For pre-construction (design stage) audits, the design drawings and reports should be provided. Within the RSA process itself, the local road agency should attend the start-up meeting and the wrap-up meeting. At the start-up meeting, road agency staff should be prepared to describe issues, challenges, and constraints. At the wrap-up meeting, the local road agency is invited to consider any suggested mitigation measures identified by the audit team, but can suggest alternative measures or adopt no measures.

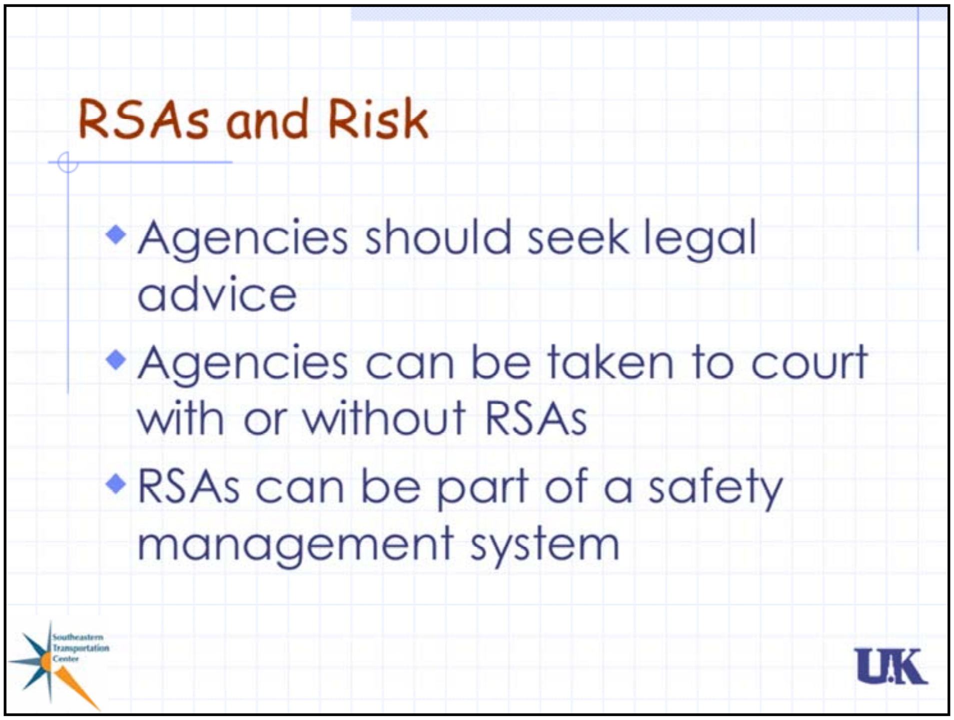


In a similar manner, the RSA team has responsibilities that needs to meet The audit team should conduct a field review to understand the context of the road and to identify safety issues. Practical suggestions for mitigating all safety issues need to be identified. For pre-construction (design stage) audits, these suggestions must be consistent with the design stage. Mitigation measures can be finalized with input from the local road agency (and designer, if applicable). At the post-audit meeting, the audit team presents a summary of safety issues and potential mitigation to address them.



A central question that agencies have is what will be the costs (both in time and money) for an RSA. For preconstruction audits, the required time to conduct such a review is typically short once the required items have been submitted to the RSA team. Medium- or large-size projects usually require 2 to 3 weeks to complete the RSA (from start-up meeting to submission of RSA report); smaller projects require less time, though usually not less than a week. A further investment of time is then required for the local road agency to consider the items in the RSA report and formulate a response to them. These times are within the same time frame that an agency typically expands when reviewing plans and drawings and if the RSA is conducted concurrently with this review then no additional time delays will be noted.

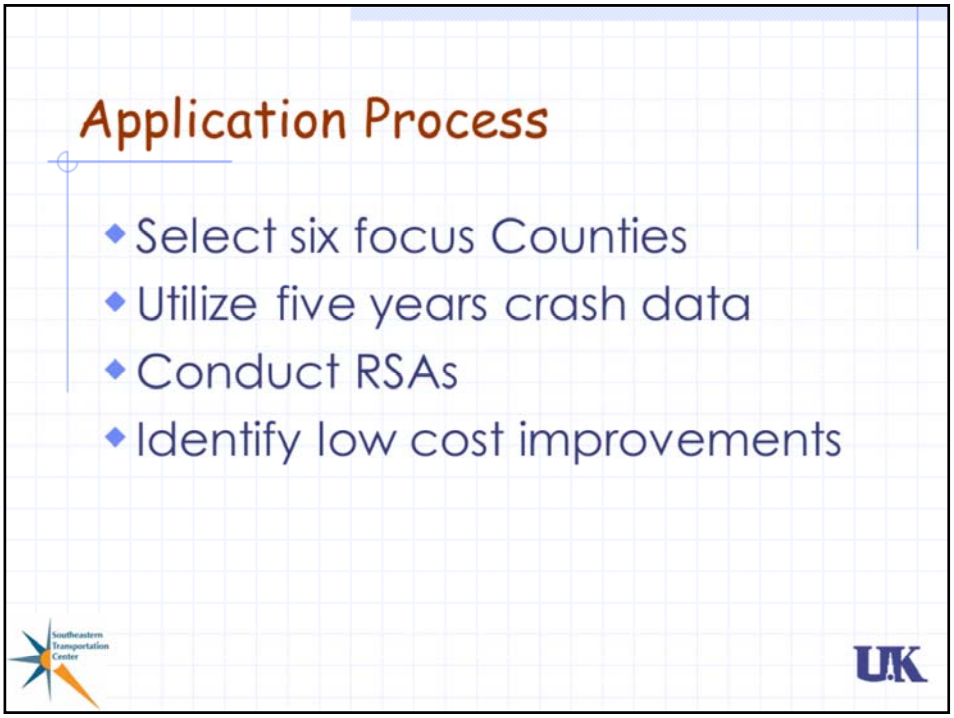
Another way that costs can be limited could be the focus on low-cost safety improvements, such as signing, pavement markings, delineation, access consolidation, enhanced signal displays, and pedestrian improvements. These will not increase the cost of the project and will typically not require redesign of the project. The presumed continued interaction between the RSA and design team can also assist in cutting costs through pre-screening potential mitigation measures to advise on whether they are considered technically and financially feasible. Is should be noted though, that the RSA team should identify all issues and mitigation measures, even if those are not considered feasible by the agency. Finally, suggestions should be consistent with the stage of the audit. For example, major alignment changes are *not* consistent with the detailed design stage, by which time the alignment is a “given”. If safety issues related to the alignment elements are identified, suggestions can focus on measures such as signing and delineation, rather than alignment changes.



The liability issue also is a factor that an agency needs to consider, since the results from an RSA create a record of potential safety issues and put the agency on notice. It is therefore imperative that agencies should consult the road agency's attorney for the legalities specific to their jurisdiction. However, it should be emphasized that agencies may be taken to court with or without a road safety audit. In this case, the well documented process followed though an RSA can be of assistance in developing an defense for a lawsuit. RSAs demonstrate that an agency is taking extra steps to ensure that the safety of a project is considered. The road safety audit (the RSA report and the agency's response letter) can constitute part of a safety (or risk) management system that shows that the road agency is exercising good faith in managing its liabilities and risks. Moreover, this identifies the reasonable choices made and how the decisions were reached and thus provide the agency with a record of decision that can be easier to defend in courts than simple adherence to the Green Book or other design standards. "We did not know" is not a legal defense!

In 2005, the Kentucky Local Technical Assistance Program (LTAP) was chosen to administer the Safety Circuit Rider Program that had as an objective to provide assistance to local agencies for improving safety on **low volume** roads using **low cost** improvements. Kentucky's Program gained national recognition for excellence and funding has continued through the Federal Highway Administration and the Kentucky Transportation Cabinet.

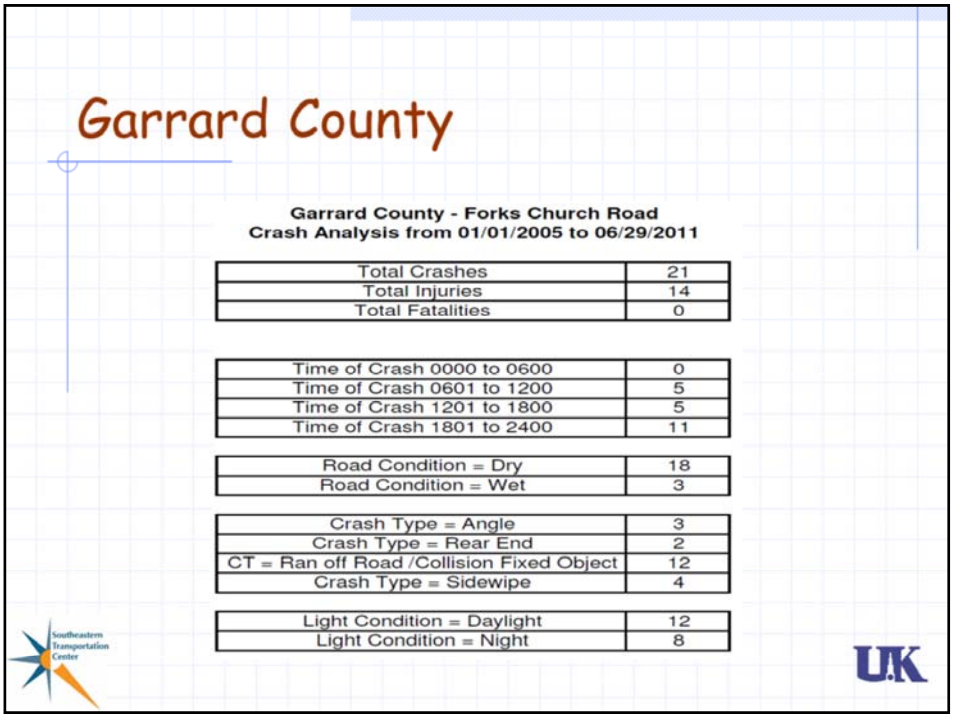
The program provides free technical assistance to local agencies for improving safety and it focuses in identifying high incident sites and assisting communities in finding low-cost roadway safety improvement. There are three focus areas for crashes of roadway departures and collisions with fixed objects, crashes at intersections, crashes with pedestrians.



The process followed in this program was to first selects six counties with high crash rates. The counties selected exhibited a critical crash rate on all crashes and injury/fatal crashes. The 2007-2011 crash data was utilized in the analysis and the counties selected were not included in any prior safety improvement programs. An RSA was conducted for two roadway segments in each county after a presentation of the crash data to the County Judge, Road Supervisor / County Engineer and Area Development District (ADD) representative. Once the review was completed, a set of countermeasures was identified for implementation. A one-day training workshop on low cost safety countermeasures was conducted for the county officials.

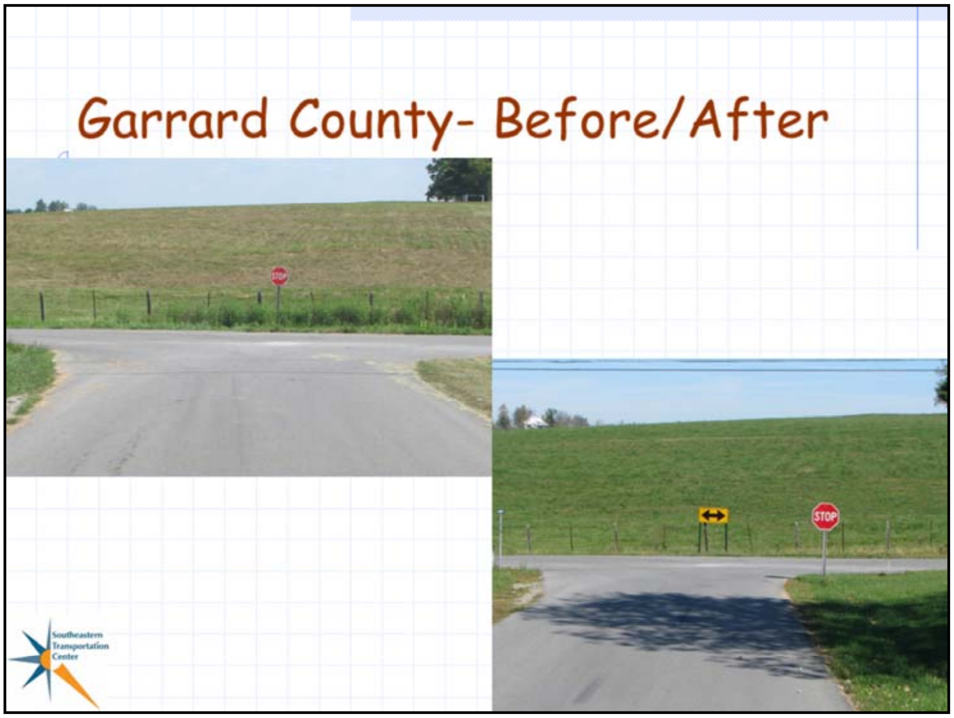
The RSA team consisted of the county officials, law enforcement representative and a Kentucky Transportation cabinet representative. The team rode in one vehicle to allow for discussions during the ride and after the visit and provide for possible exchanges of their view points.

These are some common low cost safety improvements that can be implemented to address safety concerns. Some are very basic and require periodic maintenance (clearing vegetation) while others require installation of signs. Others may require additional minimal construction, such as eliminating areas that can hold water resulting in vehicles running off the road or addressing shoulder drop offs that can force vehicles to overcorrect once they are off the roadway or not provide adequate space for recovery. It should be noted here that these measures are within the scope of the project, i.e., address the specific target crash types (roadway departures and collisions with fixed objects, crashes at intersections, crashes with pedestrians).



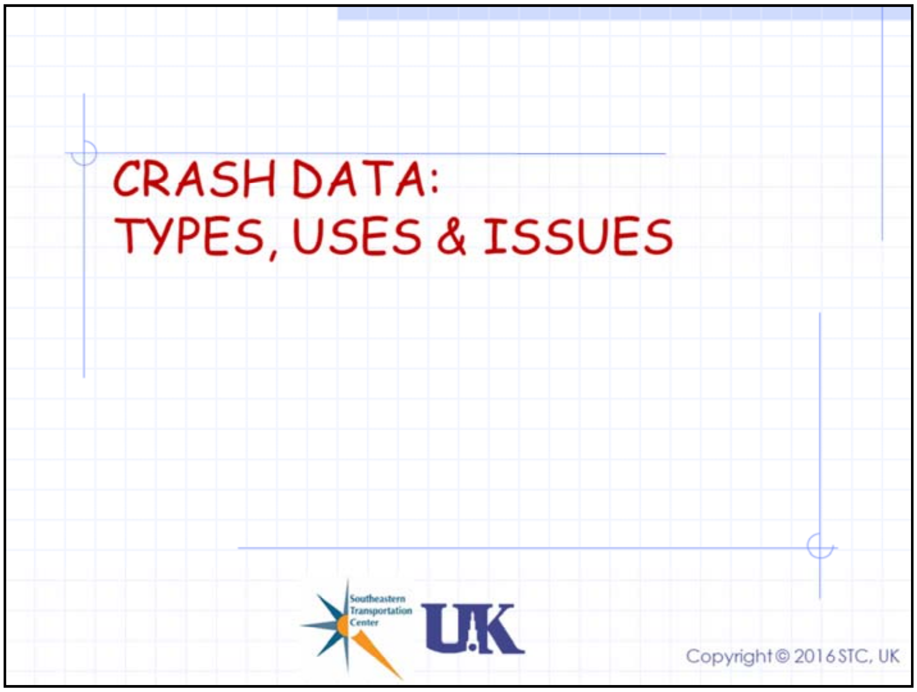
Total Crashes	21
Total Injuries	14
Total Fatalities	0
Time of Crash 0000 to 0600	0
Time of Crash 0601 to 1200	5
Time of Crash 1201 to 1800	5
Time of Crash 1801 to 2400	11
Road Condition = Dry	18
Road Condition = Wet	3
Crash Type = Angle	3
Crash Type = Rear End	2
CT = Ran off Road /Collision Fixed Object	12
Crash Type = Sidewipe	4
Light Condition = Daylight	12
Light Condition = Night	8

This is an example of the process for one county indicating a predominant issue was ran off road crashes (12 of 21) over the period examined (2007-2011)



The pictures here identify the before and after conditions of the roadway of concern. The STOP sign is at the far side of the intersection and the fence does not allow approaching drivers to clearly see the T-intersection. The solution was to move the STOP sign at the intersection corner and add a two-way warning arrow sign indicating the need for turning at the intersecting roadway.

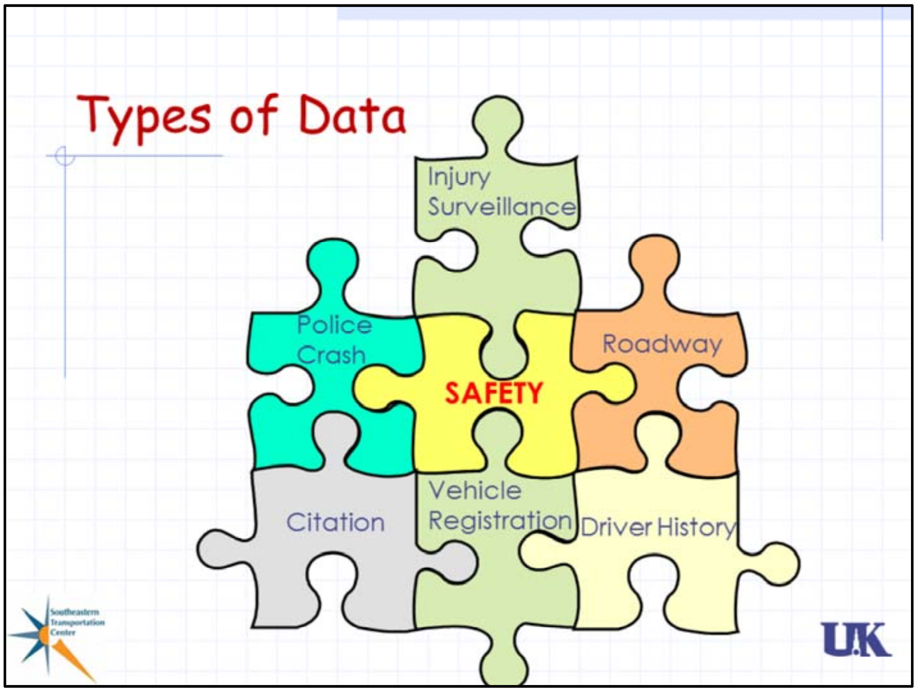
This is another example of the RSA results. The lack of any signage in the before conditions resulted in a number of ran off the road crashes and the installation of the curve warning sign and chevrons clearly marks the curve.



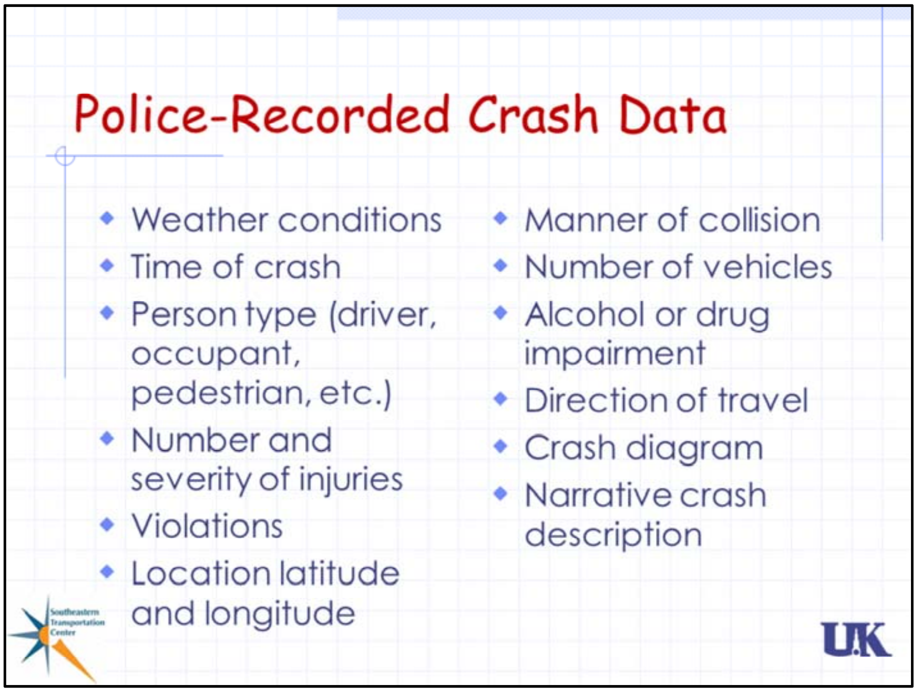
This module discusses the types of available crash data and identifies their uses in highway safety in order to improve safety management and decision making. It also provides an overview of data deficiencies and explains the limitations of crash data.

Question: How do we measure safety?

Answers: The idea here is to generate discussion and focus on the need for data in order to analyze, evaluate, compare and determine the issues surrounding highway safety. Any study undertaken requires some type of data in order for the researcher to be able to reach conclusions. The data could be simply crash data in order to identify potential trends and contributing factors, it could a combination of crash and roadway data in order to identify roadway related factors contributing to crashes, or it could be crash and socioeconomic data to evaluate their relationships. The availability of crash data becomes central to all such analyses. It is therefore imperative to ensure that data is first available and then reliable.

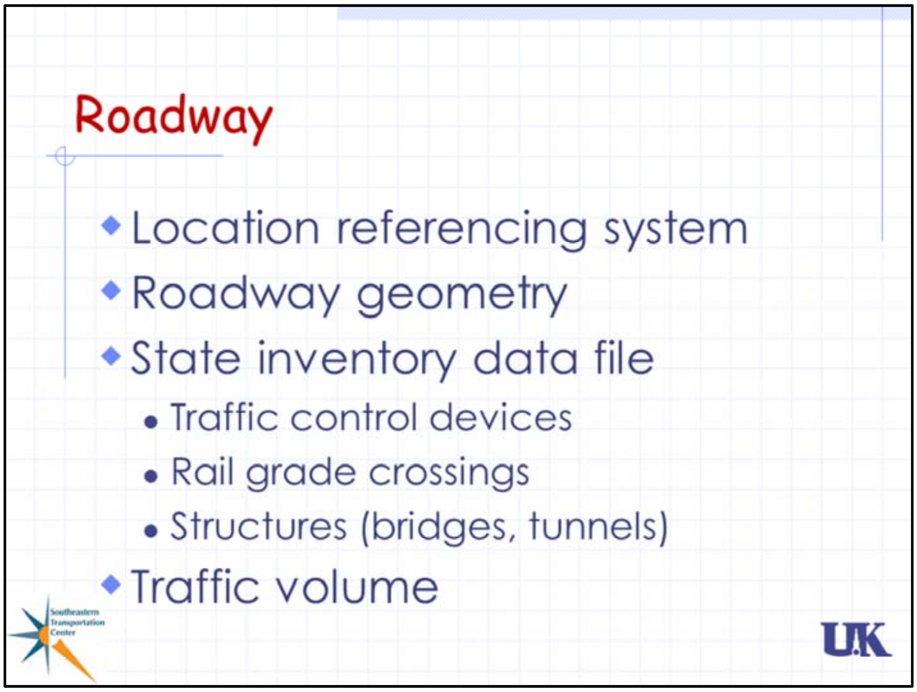


There is variety of data that is available and could be used in a safety analysis. Each one fulfills a specific need and addresses areas of needs. Transportation officials typically utilize a variety of data depending on their needs. Police crash data is typically available at the state and local level. There are also national efforts to ensure data transferability and these will be discussed later in the module. Roadway and traffic volume data is also often linked to crash data to allow for investigating the effects roadway geometry and features on crash occurrence. Vehicle registration and driver history could also provide additional information when specific human and vehicular issues are examined. Follow up of injuries and Emergency Management Systems (EMS) is another area where data is collected and tied to crash records to determine the level of crash severity aiming to address potential police information errors in such assessments (also to be discussed later in the module).



Over the years, the National Highway Traffic Safety Administration (NHTSA) has made concerted efforts to ensure that complete, accurate, and timely traffic safety data are collected, analyzed, and made available for decision-making at the national, state, and local levels. To ensure this, typical data to be collected includes the time, location, environment, and characteristics (sequence of events) of a crash. In addition to this basic information, data identifying the people and vehicles involved and the consequences of the crash are also provided. Finally, violations and citations are included to identify any infractions.

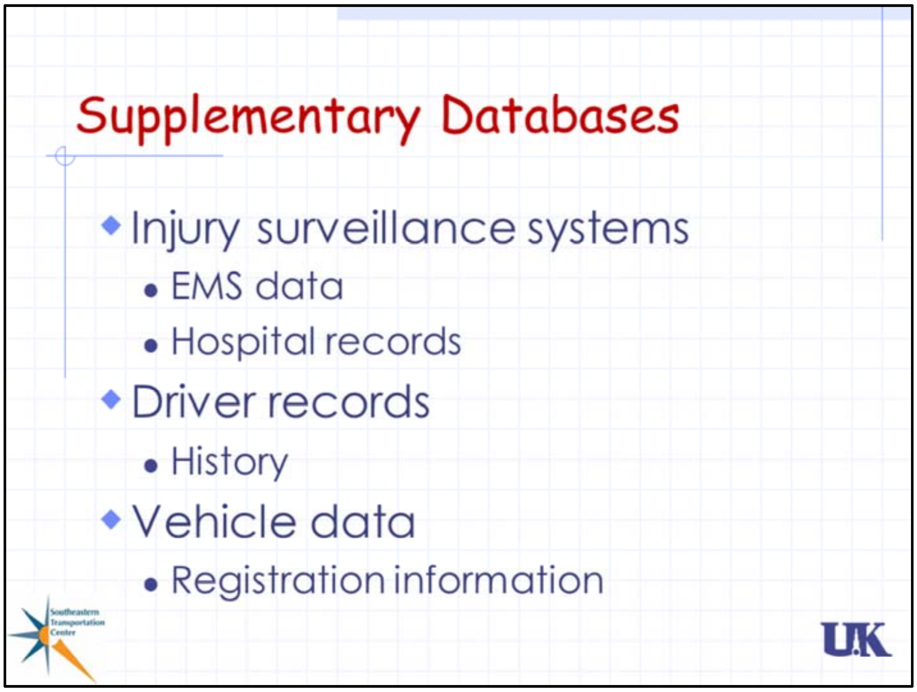
The crash data system is generally maintained by state departments of transportation, departments of motor vehicles or departments of public safety. Crash data are the most widely used type of data in road safety management. They provide guidance to decision makers within agencies and a powerful tool in support of safety legislation.



The main data provided in the roadway information is the location of the facility and its geometry. A variety of location reference systems are used throughout the country and most are dependent upon GPS information for accurately locating facilities.

The roadway geometry data typically provides cross section information on the roadway, e.g., number of lanes, lane width, shoulder type and width, median descriptors, pavement types, horizontal curvature, grades, etc. Most states also have supplemental files describing bridges (as part of the National Bridge Inventory) and railroad grade crossings (as part of the Federal Railroad Administration's Railroad Grade Crossing Inventory) that can usually, but not always, be linked to the basic roadway inventory file.

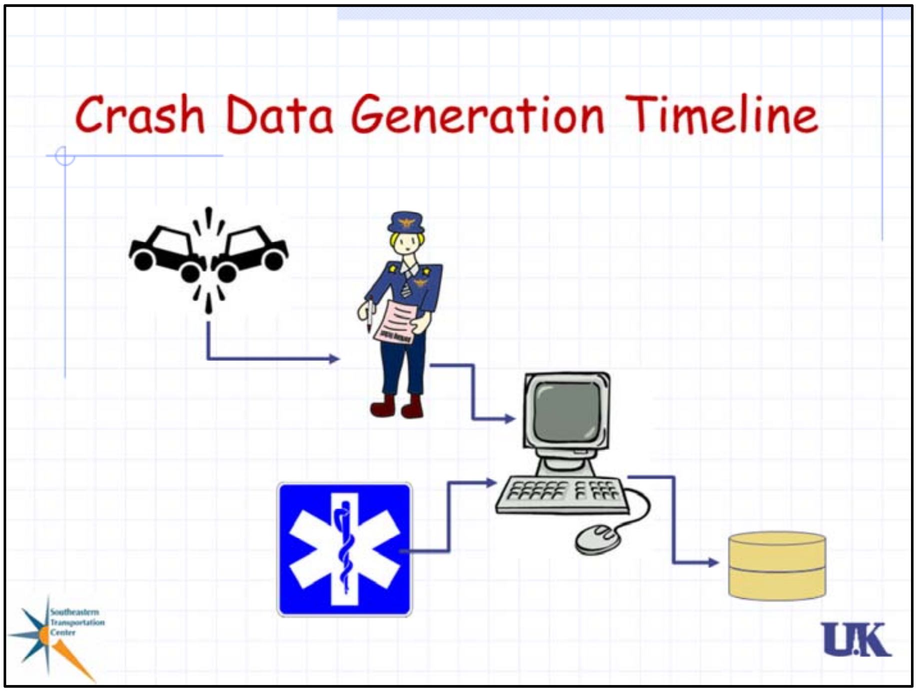
Another variable that is of interest in highway safety is the traffic volume of the facility and state highway agencies collect and maintain data on traffic volumes (Average Annual Daily Traffic – AADT). Traffic volume data may also include truck percentages. In general, traffic volume data are collected on the state-maintained system and traffic data in other roads may be obtained from local agencies. Most states conduct sample traffic counts on a periodic basis in addition to some permanent locations. The accuracy of traffic volume data should be ensured, especially if the Highway Safety Manual procedures are utilized for safety analysis.



Additional databases that can assist safety evaluations include the following:
Injury surveillance systems can be used to further assess the severity of the crash as well as costs associated with the consequences of the crash (medical bills, length of recuperation and healing, long-term rehabilitation). These systems rely on EMS and emergency department data and can be of great significance in bridging the gap between traditional traffic safety and public health issues.

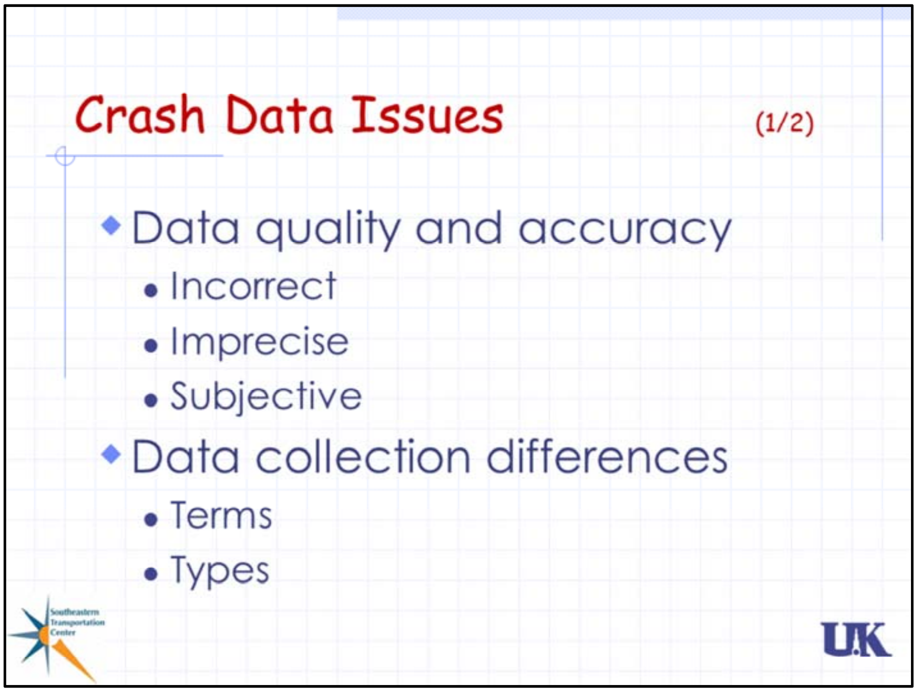
Driver records are maintained through department's of motor vehicles and include data on all licensed drivers in the state. The driver history file contains basic identifiers (e.g., name, address, driver license number), demographic information on the driver (e.g., age, birth date, gender), and information relevant to license and driver improvement actions (e.g., license issuance and expiration/renewal dates, license class, violation dates, suspension periods,, crash involvement).

Vehicle data provides registration information including owner information, vehicle license plate number, and vehicle make, model and year of manufacture. Vehicle information systems also contain information regarding commercial vehicles and carriers which may be registered in one state but are licensed to travel in other states. This information includes the U.S. DOT number, the carrier information, and any inspection or out-of-service information.



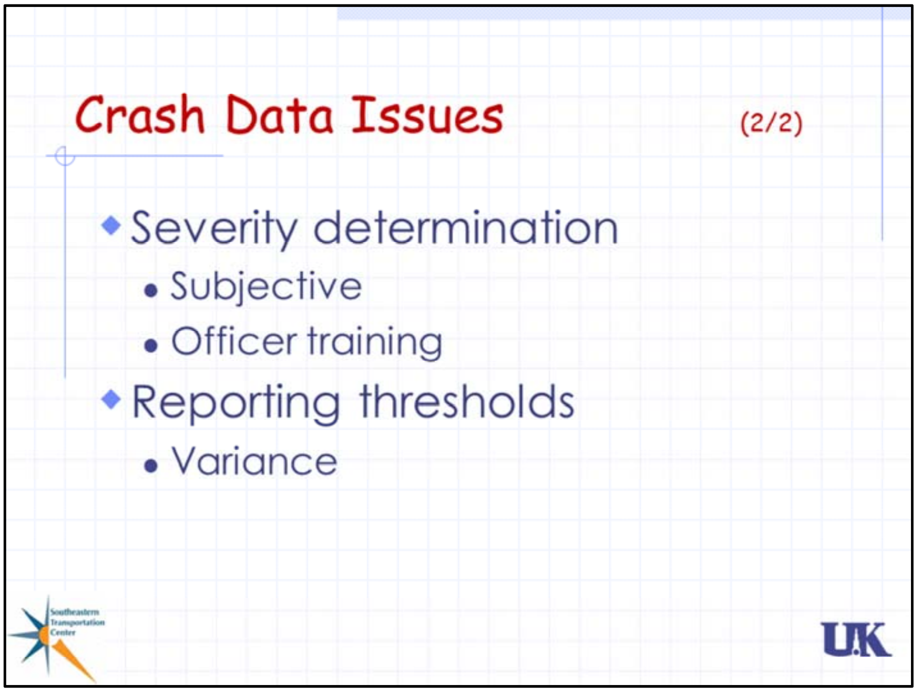
Crash data collection initiates when a crash occurs. At this point, the corresponding law enforcement unit (state patrol or local police) is notified and upon arrival at the location, the police officer completes short crash report documenting the crash specifics (location, time of concurrence, driver and vehicle data, pertinent violations and severity assessment). The officer then completes a more detailed report (full report or long form) in the office based on state- or local-specific requirements. This form is then coded and entered in the database by the law enforcement agency responsible for crash data collection. Typically all crash data (state or local level) is assembled into the state crash database that can then be used to data to identify and record the location of the crashes. Data is evaluated to ensure that it meets the state database requirements and once it is included in the database, it becomes available to the various agencies and entities for analysis and use. It is apparent that there is a time lapse between the crash occurrence and the time the data is available and this depends on state procedures and checks for the data. Typically, this time can be between 6 to 12 months. Crashes involving fatalities are reported to the NHTSA and investigated further for inclusion in the Fatality Analysis Reporting Systems (FARS).

It is apparent that there is a great potential for errors in this entire process from the point of collection to the point of analysis. The process is complicated, varies from state to state, and sometimes it even varies within states and among local governments.



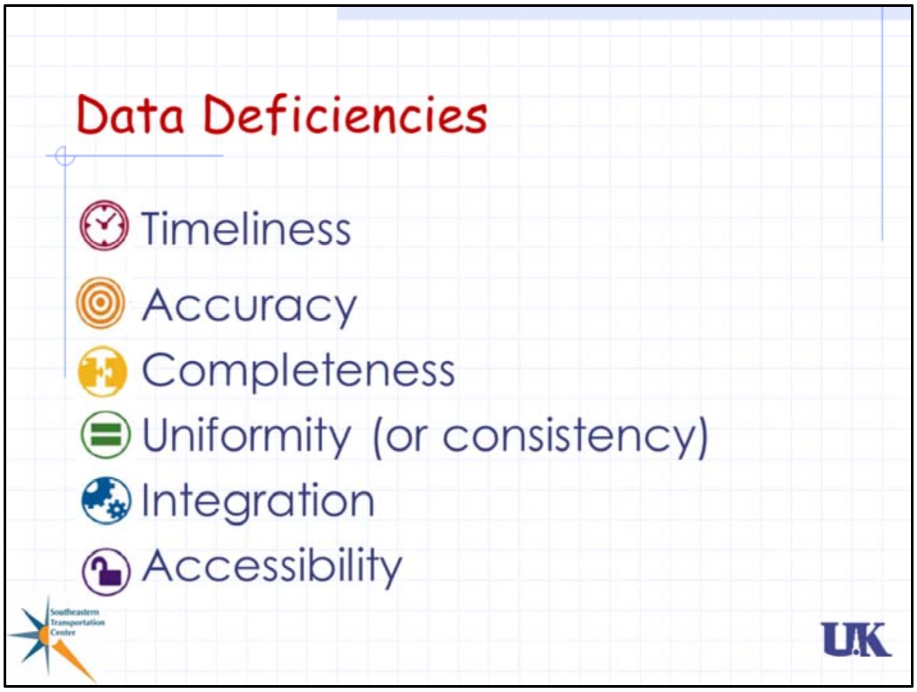
A number of crash data issues can affect the quality of the analysis. These issues can introduce bias and affect crash evaluation and analysis resulting in erroneous results and decisions. Data quality and accuracy is critical in any analysis undertaken in order to ensure that the reported crashes reflect the existing situation. The main sources of error for the data accuracy involve incorrect data entries, i.e., typographic errors or incorrect information regarding road designation, severity level, vehicle and driver information, etc., or imprecise data, such as use of generic terms to describe a location. Another form of error is the subjective nature of some data to be provided, such as level of severity of speeding (since he officer determines this after the fact as a potential contributing factor).

There may be different procedures followed between state and local agencies in crash reporting that could complicate the data analysis due to incompatibilities among the collected data. These procedures could be attributed to the use of different terms for the same data type or use of different types of data. For example, some agencies may record the Average Daily Traffic (ADT) as the volume while others may use the Annual Average Daily Traffic (AADT). It is possible that two agencies could simply call the same information differently, i.e., both use the AADT, while at other times each agency may be using a different metric. Such differences need to be identified and understood to avoid misuse of the data,



Additional issues that could affect the quality of the analysis include determination of severity levels and the threshold for reporting crashes. Severity assessment can be flawed, since police officers typically are not trained medical professionals to assess the level of injuries sustained in a crash. This could be a significant problem, since often countermeasures are evaluated not only on the changes they impact on the number of crashes but on the levels of severity as well. Studies indicate that crashes with high severity levels are reported more reliably (and more frequently) than crashes with lower levels, which may lead into bias towards countermeasures targeting improvements for crashes with high severity levels.

An issue of concern for comparative analysis across states and jurisdictions is the different reporting thresholds for a crash resulting in improper estimations if all are aggregated into one database. Changes in reporting thresholds to reflect inflation or cost of living adjustments need to be also acknowledged, since they will create different reporting levels between time periods. Another issue is also the number of unreported crashes. It is well recognized that not all reportable crashes are reported to eh police for a variety of reasons. This may also affect the development of countermeasures, since the true magnitude of the problem is not documented.

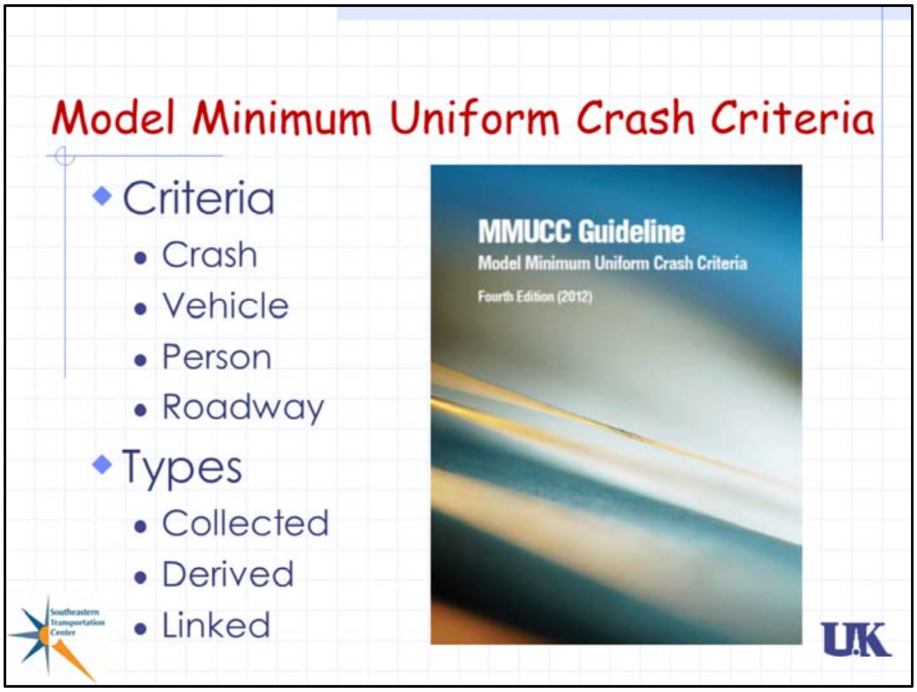


NHTSA identified the following six items as deficiencies that should be addressed to improve data quality. NHTSA identifies these as the data "six pack" to describe areas where data need to be improved.

1. Timeliness – Data needs to be provided in time in order to be relevant. This deficiency can result because the agency responsible for the crash data either does not receive the crash report forms in a timely manner from law enforcement, or the agency can not keep current with the volume of crashes being reported.
2. Accuracy – This probably the most critical element in the entire process. This can result because the information was incorrectly converted to electronic format; multiple people entered the data into an electronic database from a paper form; the form was hand written in poor conditions (lighting, weather, etc.) by an officer with other responsibilities at the time (e.g., attending to the victims, clearing the roadway, etc.).
3. Completeness – Uncertainty of codes during the coding process could result in leaving entries blank or incomplete and thus no information is entered into a required field on the crash report form.
4. Uniformity / Consistency – This could result due to lac of uniform codes and a single crash report form are not being used by all state and local police departments.
5. Integration – The crash database was created with incompatible versions of software and cannot be linked to spatial databases or other key fields such personal identifiers or vehicle data.
6. Accessibility – The agency does not provide access to the crash database fearing that "the wrong" person will get access to information that could possibly result in a misunderstanding or be used against the State in a court of law.

The National Safety Council developed an injury scale to allow for a better classification of motor vehicle crashes. The scale is called KABCO and each letter represents an injury level category defined as follows:

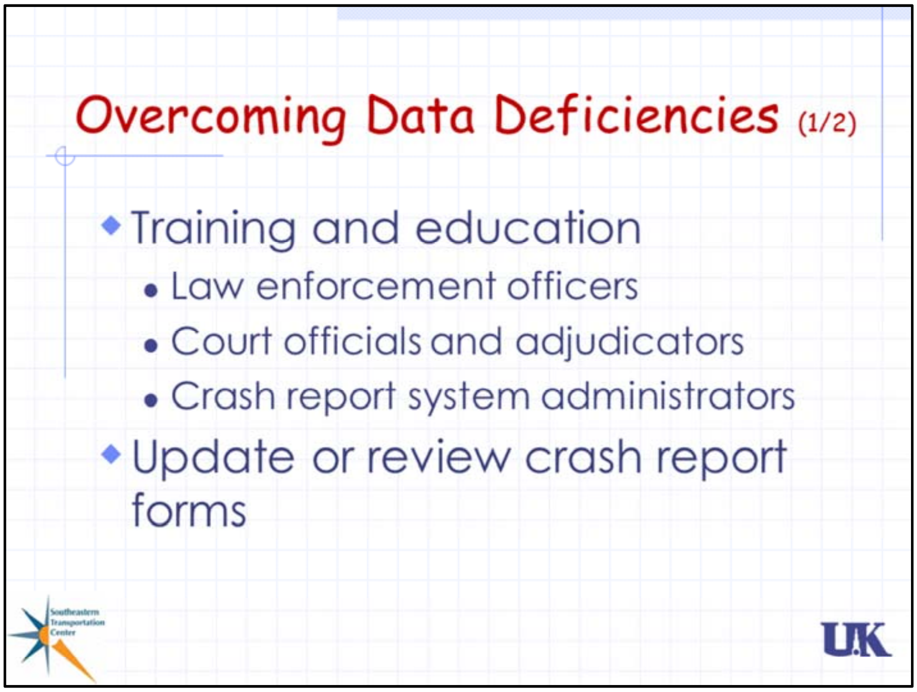
- K fatal injury is defined as an injury resulting in a death
- A incapacitating injury is defined as any injury other than fatal that prevents the injured person from walking, driving or normally conducting the activities the person was capable of performing before the injury
- B non-incapacitating injury is defined as any injury other than fatal or incapacitating injury evident to an observer at the crash scene.
- C possible injury is defined as any injury reported or claimed that is not fatal, incapacitating or non-incapacitating and it was immediately observable
- O no injury (or Property Damage Only - PDO) which is defined as a crash resulting in no juries and only property damage between vehicles.



NHTSA, FHWA, Federal Motor Carrier Safety Administration and Research and Innovative technology Administration developed in 2009 the Model Minimum Uniform Crash Criteria (MMUCC). This provides voluntary guidelines for states in order to improve and standardize their state crash data. MMUCC provides a minimum set of data elements that are accurate, reliable, and credible within states, among states, and at the national level. States could achieve "MMUCC-compliance" by the addition of data elements and attributes to their crash report form in the following four major groups:

- Crash – This describes the overall characteristics of the crash and consistency among the minimally reported data is required (similar to those presented earlier).
- Vehicle - The motor vehicle data elements describe the characteristics, events, and consequences of the motor vehicle(s) involved in the crash.
- Person - The person data elements describe the characteristics, actions, and consequences to the persons involved in the crash.
- Roadway - Roadway data elements are generated by linking crash reports to the roadway inventory and hardware data files when these data files exist in the state. The data elements used for linkage include crash roadway location and others as necessary depending upon the type of roadway inventory system implemented by the state.

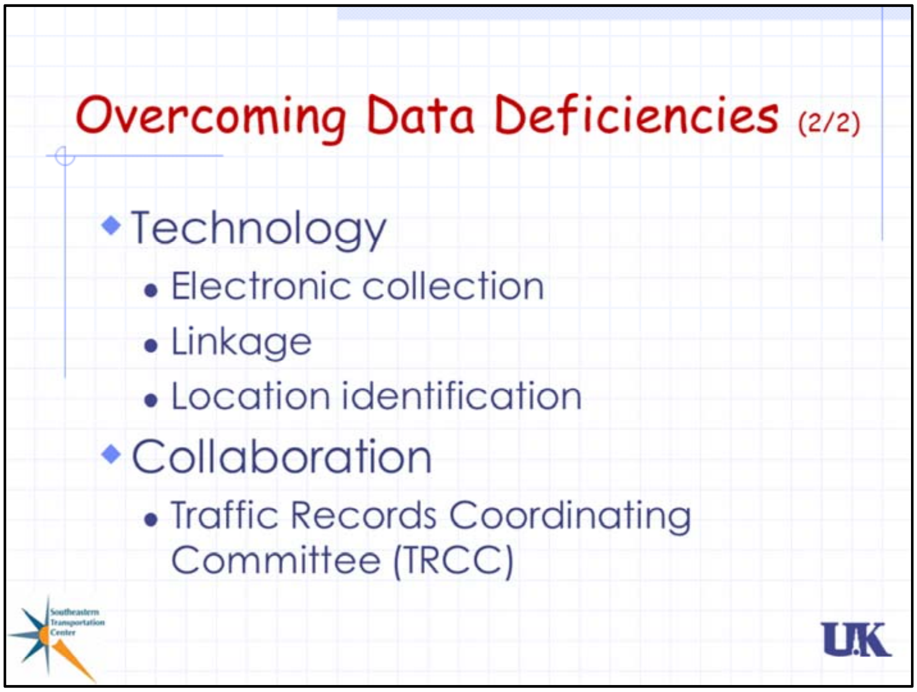
The data can be collected in the field (collected by police at the scene and recorded directly onto the crash report), derived (generated from computerized crash data) or linked (data generated when the crash data file is linked to injury, driver history, vehicle registration, roadway inventory, or other data files).



Efforts to address the data issues noted before have been undertaken in order to improve problem identification, needs assessment, priority setting, resource allocation, project selection, and countermeasure evaluation.

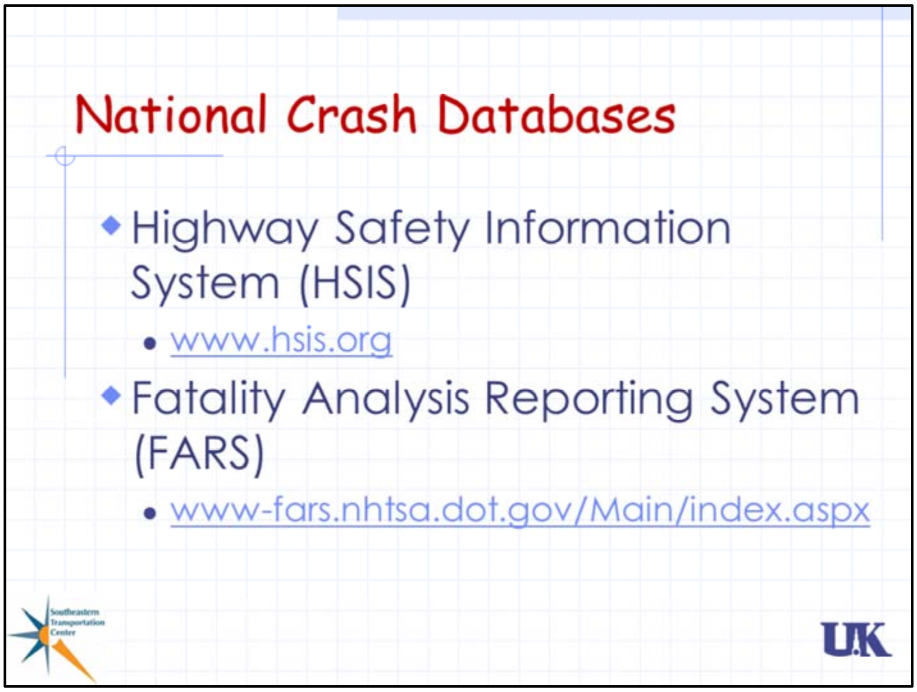
A basic effort to address some of the issues is focused on continuous training for police officers. Police reports completed at the crash site are the first source of potential errors and can create a variety of inaccuracies when data is coded and entered into the database. Such training efforts could also include information on the importance of the crash data collected and techniques to ensure accurate data collection. A good understanding of the various uses of the crash data is also important so police officers can see the value and importance of the crash data during the decision making process for safety improvements and investments. The notion that crash data is merely to serve and comply with insurance company needs should be dispelled. Training of court officials and adjudicators is also important as changes to safety legislation and penalties occur. Training crash report system administrators to properly handle reports with inaccurate or missing information can result in more accurate data.

In the past few years, several states as a result on MMUCC have reviewed and updated their crash report form. This should be considered as a continuous improvement effort, since analysis of crash trends may require additional information. For example, the use of cell phone was not previously recorded as a contributing factor and this has been added in the crash forms of several states to reflect this recent change.



The use of technology can also improve data deficiencies. Electronic crash report systems, GPS location devices, and barcode or magnetic strip technologies that collect vehicle and license data can reduce data entry errors and improve data accuracy. NCHRP Synthesis 367 Technologies for Improving Safety Data provides a comprehensive summary of crash data collection innovations.

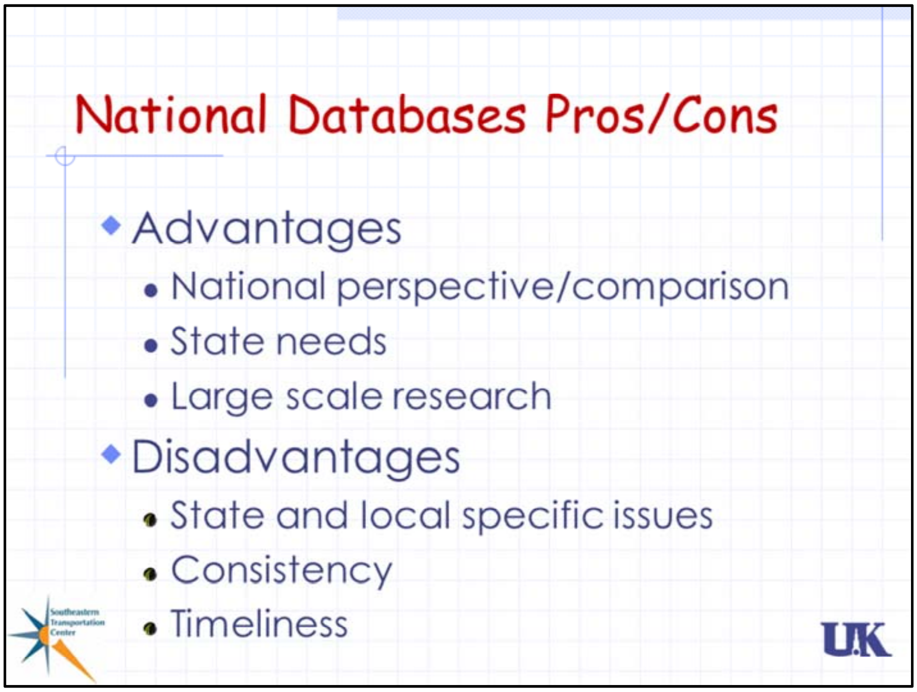
Safety data is collected through a variety of agencies and as such it requires collaboration among all parties involved. Many programs establish data collection task forces or committees to promote collaboration among safety stakeholders. The task force or committee holds regular meetings or workshops to highlight data sharing issues. In most states this function is performed by the Traffic Records Coordinating Committee or TRCC.



Various crash databases are maintained though a variety of national agencies that could provide for nation-wide analysis and research. The two most commonly used databases are:

The Highway Safety Information System (HSIS) database is maintained through FHWA and it provides the crash records for a number of states based on voluntary participation. The HSIS is a roadway-based system that provides quality data on a large number of crash, roadway, and traffic variables. The data are acquired annually from a select group of States, processed into a common computer format, documented, and prepared for analysis.

The Fatality Analysis Reporting System (FARS) database is maintained by NHTSA's National Center for Statistics and Analysis (NCSA) and contains data from 1978 through present. This database is updated annually and contains detailed information for crashes that resulted in at least one fatality. To be included in FARS, a crash must involve a motor vehicle traveling on a traffic way customarily open to the public, and result in the death of a person (either an occupant of a vehicle or a non-motorist) within 30 days of the crash. The FARS file contains descriptions of every fatal crash reported. Each case has more than 100 coded data elements that characterize the crash, the vehicles, and the people involved. General statistics are provided on the home page or through annual reports, and specific queries may be conducted from the FARS website. The queries allow the user to specify the variables of interest as well as the year of analysis to obtain various crash statistics.



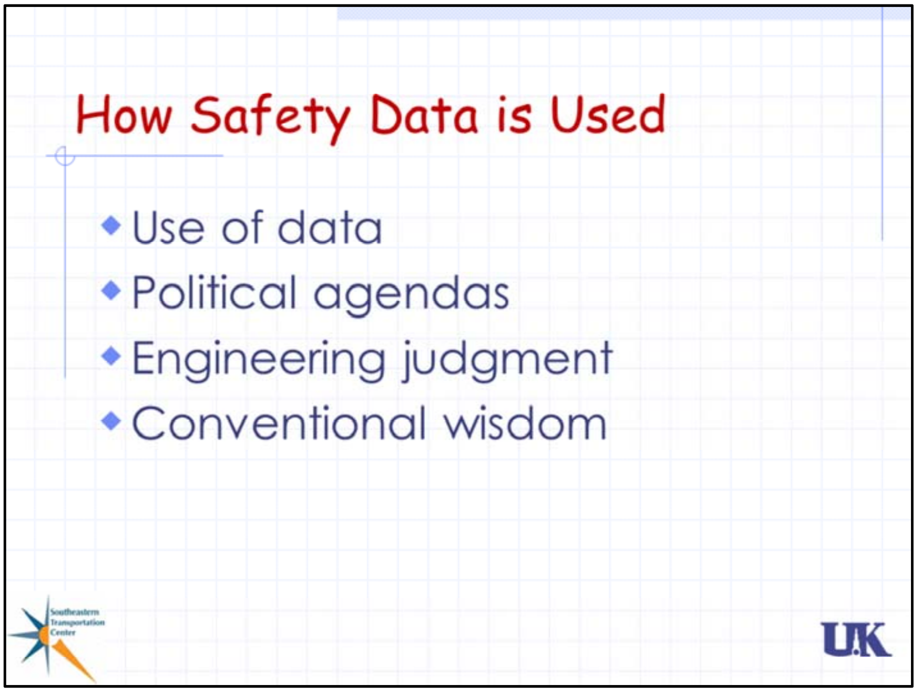
Federal databases can provide a representation of the nation status. However, data at this level could have distinct advantages and disadvantages.

Advantages

- Nation-wide data could be used as representing the entire nation either through inclusion of the entire population or an adequately representative sample. Such data can address national-level policies such as safety belt use, alcohol-related crashes, and young driver fatalities and then be used to develop programs to address them at the national level. The data can then be also used to determine the efficacy of the policies implemented.
- State needs can be also identified from national databases due to the potential for comparisons across states. National data can be used to identify states with greater than average crash and fatality rates for total crashes or for specific areas of concern and then be targeted for improvement.
- National databases can also be used to identify trends and conduct statistical analyses that could not be completed utilizing the smaller size state databases.

Disadvantages

- National data may not be able to capture local issues. The national databases would be bale to distinguish of specific location issues that may not show up in such databases.
- The fact that national databases rely on input from various states creates a potential issue of consistency and accuracy of the data provided. Even though most states collect the same information, there is a lack of commonality among the specific information provided or the level of detail within an entry. As noted earlier, there are different levels of reporting thresholds for each state and this alone could create significant issues for comparisons among states.
- Timeliness is an issue at all levels of database management, but the issue is compounded at the federal level. Federal data are often received from state and local agencies, and lags at the local level can significantly impact the timeliness of the federal database.

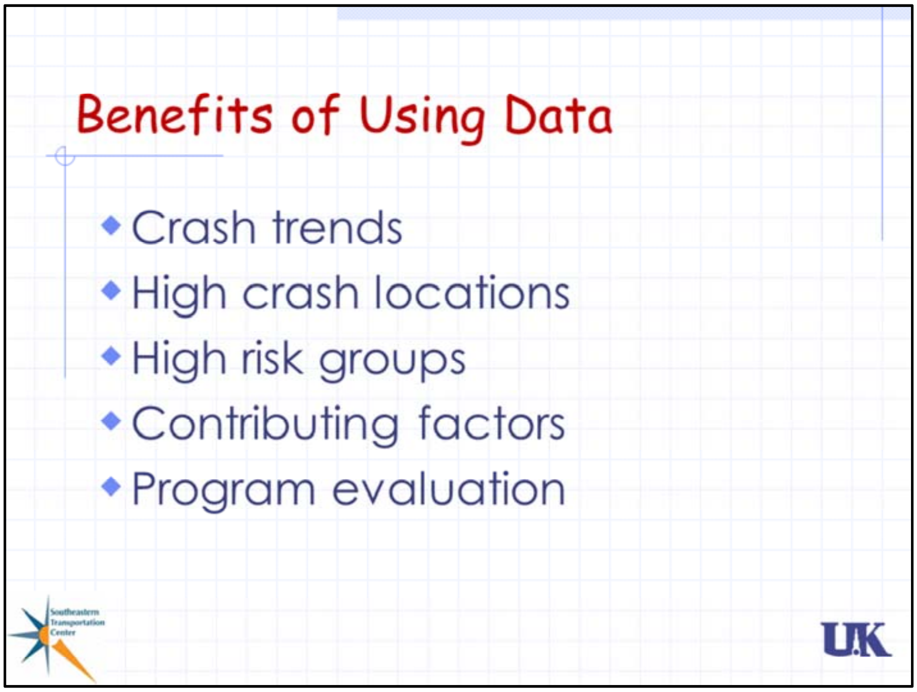


It is important to understand that safety data is an integral part of any decision-making effort. Decisions are improved and are more effective if they are based on comprehensive and accurate data. Frequently, decisions are not based on data due to complexity of safety issues, variety of agencies involved in the decisions, and historical crash data but rather formed based on political priorities, engineering judgment, and conventional wisdom.

Legislative bodies typically make the transportation investment decisions and therefore there is a large political influence on reaching them. Constituents can convince elected officials to press for investment in their areas and this can result in improper allocation of funds. A good example is congestion. The public often cites congestion as their number one transportation problem because it confronts them on a daily basis, when in fact, safety has a far greater impact.

Engineering decisions are often based on the implicit assumption that safety is built into the design guidelines and this can have safety implications that are unknown and most importantly, difficult to measure. Most engineers are not trained to consider the safety implications of their decisions outside of the traditional measures such as providing adequate stopping sight distance. However, recent tools (Highway Safety Manual, Interactive Highway Safety Design Model, Safety Analyst, etc.) can provide the tools to address this. And, by the way, the “judgment” of safety practitioners and law enforcement is often faulty as well.

Conventional wisdom can also affect safety especially since many safety countermeasures have not been evaluated. The use and potential effects of the implementation are often based on conventional wisdom. This means the effectiveness of the countermeasure is generally accepted as true, but no proof has been shown.



The uses of data can result in many benefits when safety issues are examined. Data can provide decision makers with systematic process to determine efforts to improve roadway safety. Data also allows for a quantitative description of the problem and provides means for evaluation of implemented countermeasures and interventions.

Data can assist in determining crash trends and can be used to determine crash rates in order to allow for comparisons among regions with varying environments. Data can also help managers identify high crash locations and identify high risk groups such as younger drivers, older drivers, impaired drivers, and motorcyclists. This can result in development of specific countermeasures targeting the high risk location or group.

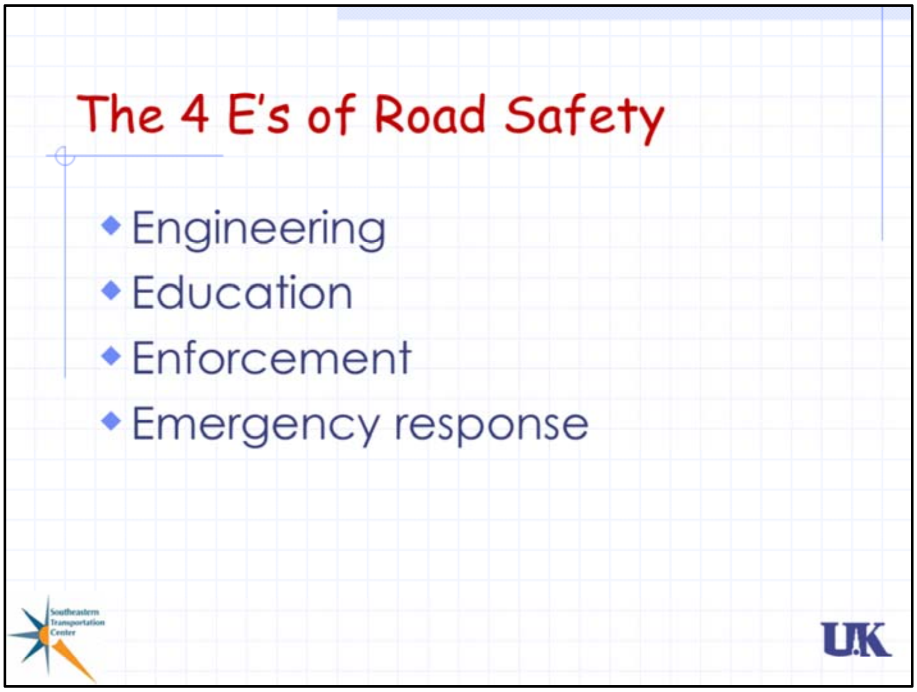
Data can also identify contributing crash factors. This examination can assist decision makers in developing programs that could combat these factors and improve roadway safety and reduce crashes. Safety programs are typically developed with an aim to identify safety goals and evaluate strategies. Data is critical in such efforts, since it provides for a comparison of a before-and-after conditions in order to evaluate efforts undertaken and countermeasures implemented. Using data to identify road safety problems allows planners and engineers to effectively communicate safety needs to decision makers in the form of lives saved and injuries prevented.

Safety improvements are the result of a coordinated effort across various fronts all targeting user behavior, roadway environment, and vehicle aspects. As we already noted before, road safety is a multidisciplinary profession including professionals with engineering, public health, public safety, education among the many other disciplines that could be involved. All these disciplines should work synergistically, since there is not a single discipline that could address the multitude of safety issues completely.

The variety of backgrounds and perspectives that each discipline brings into road safety creates a challenge when all need to work together to improve safety. Each discipline may address safety improvements from its own perspective but frequently all need to work in sync to achieve the desired goal of improving overall safety. This section identifies some of the efforts that can be implemented though various distinct disciplines aiming to improve safety.

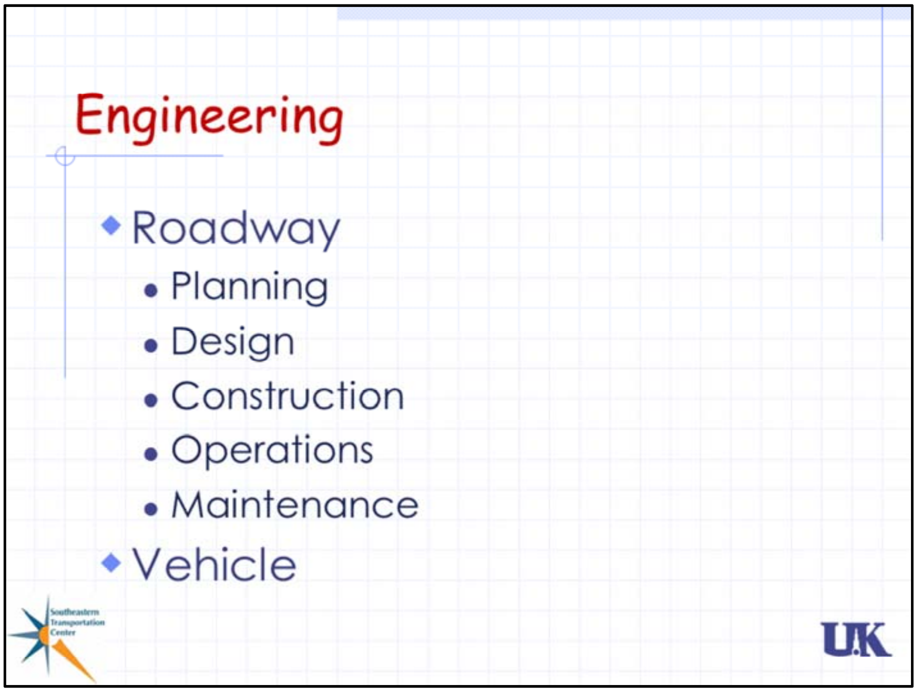
The complexity of improving road safety can be eliminated when various professionals break their silos and work with others. There are institutional boundaries that one needs to transcend, since developing independent plans addressing on one level may conflict plans developed by other jurisdiction. Working only on a specific level, limits any information exchange and data sharing and could lead to lack of coordination among agencies.

Each safety profession has worked over the past 40 years to improve their elements that could improve safety. Roadway designers have provided safer roads introducing a variety of countermeasures, vehicle designers have improved vehicles due to the safety devices introduced in their designs, education and law enforcement have contributed significantly in raising awareness and affecting user behavior, and emergency services have helped mitigate the severity of crashes. Safety professionals have worked within their respective environment and very rarely have crossed their boundaries to cooperate with other disciplines. Moreover, each of these efforts are effective only up to a point and the need for their coordination is apparent. It is therefore imperative to break these barriers and develop a coordinated effort from all professionals to realize the full potential of these efforts and improve roadway safety.



As noted at the beginning of this module, road safety is a multidisciplinary filed requiring professionals with varied and diverse backgrounds to work together to improve safety. There is not a single profession or approach that could address road safety completely or holistically. Four major categories are recognized among safety professionals as those with a potential impact on safety. These are typically referred to as the 4 E's of safety and they are: engineering, education, enforcement, and emergency response. The 4 E's have typically been used either as measures to correct existing road safety issues or as crash prevention strategies.

Historically, the 4 E's have been used as a means to address crashes and the related injuries and fatalities. It is apparent that safety requires a wealth and variety of professionals who have to work together. The idea of working in silos noted before should be eliminated in order for all to contribute in improving safety. In order for this to be realized, the 4E's need to start thinking of how to work together across their respective disciplines.



Engineering could impact road safety from two different fronts: roadway and vehicle.

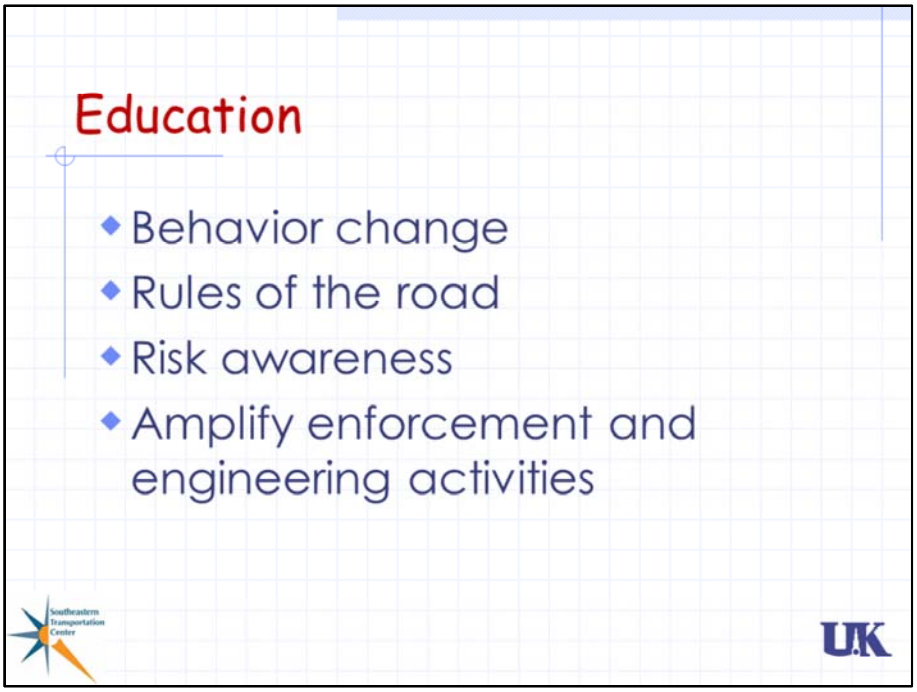
Roadway

The engineer's responsibility for the road safety covers the entire spectrum of the project development process, i.e., from planning to maintenance. Roadway design is critical in addressing safety needs of the user and current design manuals are based on user behavior and vehicle capabilities (there are questions however about the lack of updating design guidance to reflect current vehicle capabilities). Once a roadway is designed and constructed, safety studies can identify issues with operations and attempt to develop solutions to address them. Countermeasures are typically employed to address roadway design deficiencies (as those were described in modules 4 and 8). For example, crashes associated with a particular curve may require the evaluation of the curvature, the roadside elements and the pavement to determine the appropriate countermeasure to be implemented. Road Safety Audits (both during planning and design as well as after construction) could assist in developing the suitable engineering intervention. As noted previously, the entire cross section (roadway and roadside) needs to be evaluated in order to develop the most appropriate engineering solution.

Vehicle

Another area that engineering plays a role in road safety is though the design of the vehicle. As it was previously discussed (Haddon matrix and module 5), vehicle design can affect safety during all three stages of the crash, i.e., pre-crash, crash, and post-crash. Typical engineering improvements over the past decades regarding vehicle safety include:

- Antilock brakes, vehicle stability systems, and collision warning devices (pre-crash)
- Safety belts, airbags and vehicle integrity (crash)
- Emergency response notification system (post-crash).



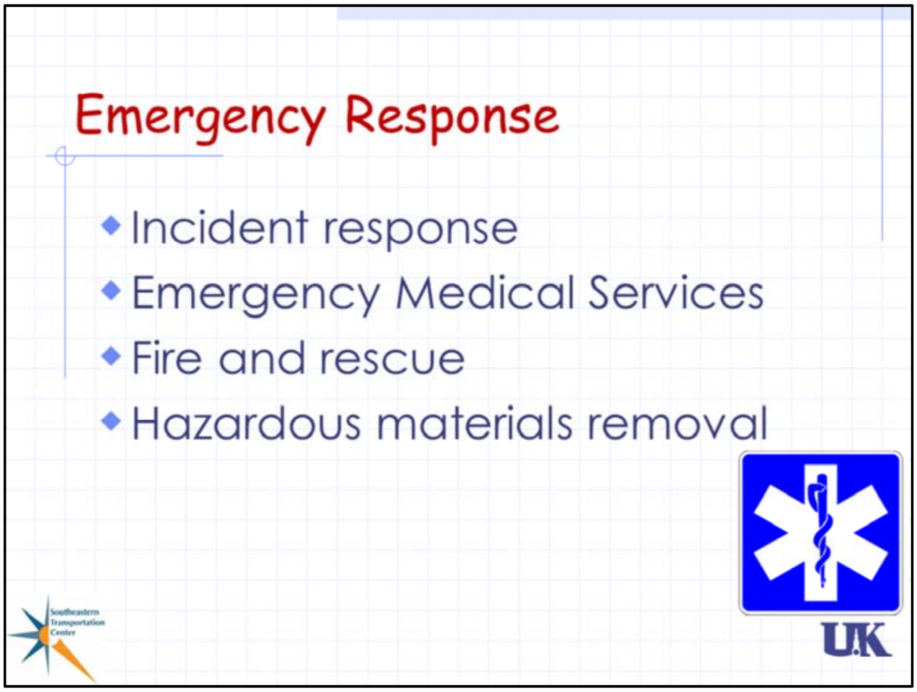
- The main focus of education in rod safety is to affect behavior change of the road users. The objectives of such education activities could be viewed as those targeting reduction of unsafe behaviors (speeding, tailgating, driving under the influence, etc.) while promoting corresponding safe behaviors (defensive driving, understanding and awareness of user limitations, etc.). As previously noted, human factors are the single largest contributing factor to a crash and education has a great potential to improve road safety through development of training and targeted educational activities aiming to alter user behavior.
- New roadway designs and schemes can be understood easier if coupled with a proper educational activities, such as public announcements or educational campaigns. Implementation of roundabouts and crossover diamond interchanges have greatly benefited from such activities, since proper driving techniques were introduced to the public. Educational campaigns can be used in conjunction with engineering and enforcement efforts to address policy changes or new legislation. Educational activities can also be used as a standalone effort targeting improvement of driving skills (such as defensive driving or teenage driver education), enhancing knowledge of the rules of the road or becoming more aware of various road safety related issues.
- Educational activities can benefit users also by simply providing information and making users aware of the various risks undertaken. Training courses such as those developed by AAA targeting older drivers or BMW targeting young drivers focus on identifying the various risks that each group could face and provide techniques to address and cope with their limitations. educational campaigns can also be targeted to address specific unsafe actions (e.g., driving under the influence, texting while driving, and not wearing a safety belt) or to address specific road user populations (e.g., teen drivers, motorcyclists, and pedestrians).
- Educational activities supporting engineering or enforcement actions can also be used to aid a wider acceptance and understanding of the effort. These activities can identify the reasons for he implementation and address how the road users could respond. For example, speed feedback signs could be considered both engineering and enforcement activities. In this case, it is critical for the public to understand the issue of speeding and the use of the speed feedback signs to address it.

Efforts on engineering and education alone cannot improve safety. These efforts require assistance from law enforcement units. It is reasonable to assume that an engineer can design a road in a manner that users will operate at a certain speed and to assure this, signs with the appropriated speed limit could be posted. Educational activities could be then initiated to ensure that users are familiar with the posted speed limits describing the problems with speeding and their safety consequences. However, these two activities cannot ensure that all users will travel at the posted speed limit and thus enforcement is needed to make sure that users behave appropriately. Enforcement can assist in user behavior through continuous presence and a variety of activities. NHTSA has been working closely with the enforcement community to develop toolkits and activities that can enhance enforcement. Such toolkits include the:

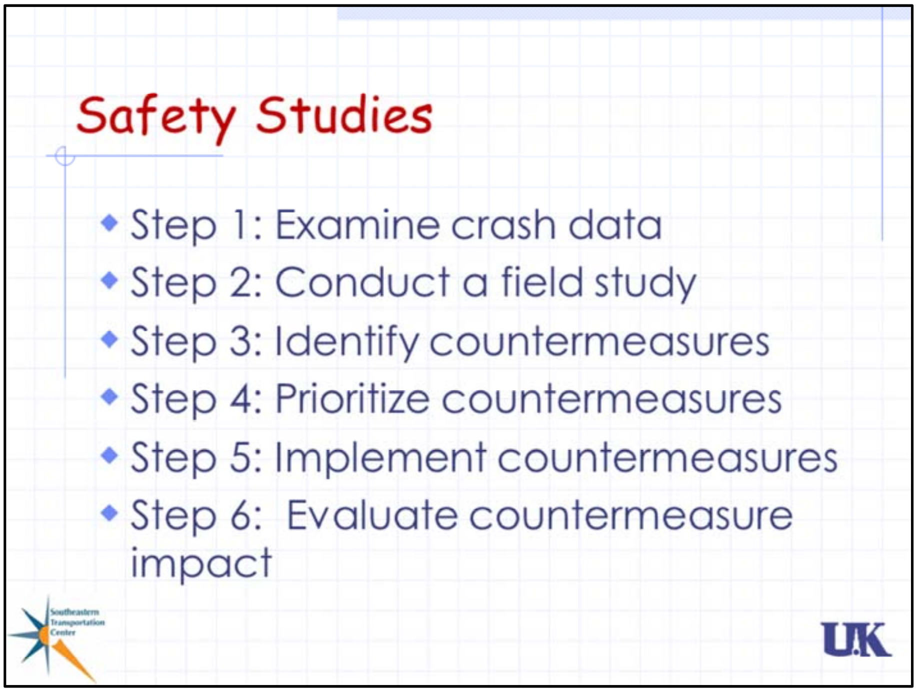
- High Visibility Enforcement, where enforcement, visibility elements, and a publicity campaigns (checkpoints and saturation patrols) are used to educate the public and promote voluntary compliance with the law. Publicity campaigns have accompanied safety belt use (click it or ticket), texting (U drive, U text, U pay), drunk driving (Buzzed driving is Drunk driving), etc.
- Speed prevention, where a variety of marketing tools are available for local enforcement to be used in speeding campaigns.
- Workshops and training activities aiming to increase understanding of traffic safety issues and cooperation among local agencies to increase efficiency of their efforts.

An issue of concern for enforcement is the view of other law professionals (prosecutors and judges) who sometimes they do not understand the seriousness of the issue and fail to ensure citations are followed by maximum penalties. It is therefore imperative that all enforcement professionals work closely together with other safety groups to ensure that proper treatment of violators is undertaken.

Effective enforcement must result in consequences that the users are aware of. Campaigns that advertise the consequences of actions undertaken while driving should not only present the issues to increase awareness but should also identify the penalties and consequences of the actions.



Emergency response is the typically the post-crash activities taking place in order to rescue crash victims, provide primary care to injured users, and protect other road users from additional involvement in the crash scene. Responders to a crash scene include police officers (who investigate the crash and control traffic at the scene), fire and rescue (for removing victims from vehicles, provide primary care, and address vehicle fires), and emergency medical services (who provide immediate care to crash victims and can be part of the fire and rescue responders). These responders some times also employ others as needed, including towing companies to remove inoperable vehicles, hazardous materials contractors to remove hazardous materials leaked form vehicles, and media who typically report on crashes. It is important to ensure the safety of the other users while the crash scene is investigated and cleaned up in order to avoid any additional crashes as well as to move traffic though the scene in order to minimize any traffic delays.



The goal of all those involved in safety is to identify effective countermeasures and implement them in order to improve roadway safety. The basic principles of an engineering study can be used here as well. In this case, one starts with an evaluation of the exiting conditions though a review of historical crash data and performs a field study to better understand the potential issues and layout of the location. Next, countermeasures to address the safety issues at hand should be identified, followed a prioritization of the potential countermeasures while considering their effectiveness and associated costs (i.e., develop a benefit/cost ratio). Highway safety professionals seek to identify the most effective countermeasures for improving road safety. After the selection of the appropriate countermeasure and its implementation, the countermeasure effectiveness should be evaluated in order to provide the basis for future uses and expand the database of implementations.

Public education is integral part of changing safety culture and user behavior. It targets the attitudes of individuals and attempts to point them in the right direction in order to affect changes in roadway safety. It is therefore important to continue communicating new knowledge and research findings and demonstrate the impacts such findings will have on safety. As noted before, enforcement is equally critical in improving roadway safety and enforcement professionals need to be included in such educational campaigns.

Changing user behavior is a life-long process and it can take several years until the results of the campaign are known or observed. For example, the efforts started in the 1980's about curbing drunk driving did not show significant changes until the late 1980's when rates for drunk driving fatalities were observed (module 2, slide 7).

Research also provides us with information on what does NOT work in the communications area. Ineffective public information and education or what is commonly referred to in the safety field as PI&E is associated with:

- Passive messaging communicated by signs, pamphlets, brochures and buttons;
- Slogans that give simple exhortations for people to behave in certain ways to avoid undesirable outcomes;
- Education programs that are lecture oriented and informative only; and
- Use of extreme fear or scare techniques, especially when directed at adolescents and without clear instruction of steps necessary to avoid the danger.

APPENDIX B

Course Homework Assignments

CE 635 Highway Safety Issues Spring 2016

SHORT PAPER #1

Using the data and information discussed in class, Evans book, and any other sources, prepare a one page position paper that answers the following question:

Is traffic safety more of a public or a private responsibility?

During the first presentation, we talked about where one would draw the line when aiming to improve traffic safety. The discussion we had was an indirect response to this question. So, relatively speaking is safety more a public or private responsibility? Who should be the main provider in this case? At what point has the state done all it can do? At what point would private agencies (manufacturers and individuals) be held responsible?

It is the insight and support you provide in this paper that will merit a good grade. **Remember that there is no right or wrong answer**. The impression, judgment and interpretation made by you are valuable. Your paper should follow the guidelines provided below. Create a unique piece that catches the readers' attention, interests them, and keeps them reading. Consider your target audience a group of transportation safety professionals--write with the format and tone that one would find in a short professional magazine article. Many engineers, planners and project managers find themselves producing this type of article for newsletters, company annual reports, company advertisements or magazines (i.e. this is not a totally useless exercise!).

Use the following guidelines for writing and be warned that the grading scheme on page 3 for style will comprise half your grade.

1. Use your introduction wisely. The first half of it should set the context of your paper, and state the main "point" you plan to make. The final sentences of the introductory paragraph serve as the "road map" for the remainder of the paper. They need to be explicit enough to tell a reader where you are going, yet must also be brief. The reader must know where you are going or they may not be interested enough to read on.
2. Subsequent paragraphs (3 to 4) should flow logically together. Each paragraph should expand on a single related idea or topic that supports your main position. In general, these paragraphs will provide the support to convince the reader of the main point of your paper.
3. A brief conclusion should be considered but a single concluding sentence that fits with the last paragraph might also be used. Conclusions should be more than just a repeat of previously made points. In a paper this short, there is rarely room to repeat yourself.
4. Try to avoid personal tense. Repetitive use of personal tense is disruptive to a professional document. Often personal tense is used where you want to stress or emphasize a point. (Students are welcome to challenge this point.)

5. In your mind, identify your reader / target audience first, before you write. With every sentence and paragraph ask yourself if your target reader would understand the point or information you are trying to convey. Try to imagine the questions they would ask you.
6. Beware of **PLAGIARISM.** All students are reminded of the seriousness of academic dishonesty of any form and particularly that of plagiarism. In this regard, a grade of zero will be given to any assignment in which plagiarism is found. If you do not know the finer points about plagiarism, find out! Use footnotes for references.
7. Minor errors (see page 3) include the following: spelling, typos, misuse of punctuation, and failure to close a quotation or parenthetical remark.
8. Major errors (see page 3) include subject and verb disagreement, incomplete sentences, and run-on sentences.
9. Find a proofreader who will actually be hard on you and your writing. Constructive criticism is the only way to improve. People who say "it's great" are of no help at all.

Guidelines for Student Grading

One quarter of your grade for this assignment will be based on your grading of the other student papers. **No one writes perfectly.** Ask the students who have worked with me, they point out my weaknesses (I'm bad with commas and passive sentences to name only two things).

The job of the grader is to point out where the overall logic of the paper is weak. Are you clear as the reader on what the main point of the paper is? Do you find the support for the points in each paragraph sufficient and convincing? Are the sentences constructed so you understand what is being said?

Identify weaknesses. Complement strengths. Make suggestions for improvement. Give a plus/minus letter grade.

GRADING CRITERIA FOR ASSIGNMENTS

A written report is graded both for its substance and style. Note that style can detract from substance, but not improve it. If the substance grade is greater than the style grade, the grade for the assignment will be the average of the two. If the substance grade is lower than the style, then the grade of the assignment will be that of substance.

SUBSTANCE

A
1. Your point or conclusion is clear and provides a complete answer to the problem posed;
1. The reasons supporting your point are clear;
2. The logic within your reasoning is valid; and
3. The support is sufficient to sustain the conclusion.

B
1. Your point or conclusion is clear and provides a complete answer to the problem posed;
2. The reasons supporting your point are clear;
BUT
3. the logic has minor errors, or
4. the substantive support is insufficient.

C
1. Your point or conclusion is clear and provides a complete answer to the problem posed;
2. The reasons supporting your point are clear;
BUT
3. there is bad logic, and/or
4. there is irrelevant support.

D
1. Your point or conclusion is clear, *but* the reasons supporting it are not clear;
2. Your point is never made explicitly, but it can be inferred.

E
1. It is not clear what point you are trying to make;
2. Failure to answer the specific question; and
3. Illegible answer.

STYLE

1. No grammatical errors;
2. Well organized and easy to follow;
3. Appropriate introduction and conclusion; and
4. Maximum of one spelling or typographical error.

1. Minor grammatical errors;
2. Overall organization is good, but within one section or sentence is hard to follow;
3. Multiple spelling errors;
4. Misuse or poor choice of a word or phrase;
5. Weak introduction; and
6. Improper paragraphing.

1. More than one of the errors listed above for B; or
2. Major grammatical errors; or
3. Lack of an appropriate introduction or conclusion.

1. Two or three of the errors listed above for C.

1. Four or more occurrences of the errors listed for C.
2. Lack of clear overall organization;
3. Failure to acknowledge a quotation; and
4. Illegible answer.

CE 635 Highway Safety Issues Spring 2016

SHORT PAPER #2

DUE DATE:

Using the data and information provided in class, Evans book or any other source, prepare a one page position paper that answers the following question.

Is there any way to minimize and/or eliminate human errors in traffic safety?

Improving roadway safety is a major target of the highway and traffic community and a large effort has been placed on enhancing roadway design to achieve this target. The existing literature points out that the largest contributing factor to a crash is human error. Is there any way that human errors can be minimized? If yes, how it can be done? If no, how can highway safety be improved? Moreover, what are some of the steps that may be taken (or need to be taken) to reduce the human errors?

It is the insight and support you provide in this paper that will merit a good grade. **Remember that there is no right or wrong answer**. However, there is a need to separate facts from fiction and include your references. The impression, judgment and interpretation made by you are valuable. Your paper should follow the guidelines presented in the previous assignment. Create a unique piece that catches the readers' attention, interests them, and keeps them reading. Consider your target audience a group of transportation safety professionals – write with the format and tone that one would find in a short professional magazine article. Many engineers, planners and project managers find themselves producing this type of article for newsletters, company annual reports, company advertisements or magazines (i.e. this is not a totally useless exercise!).

Use the same guidelines presented in Paper #1 for writing. The same rules apply for the student grading as before.

CE 635 Highway Safety Issues Spring 2016

SHORT PAPER #3

DUE DATE:

Using the data and information provided in class, Evans book or any other source, prepare a one page position paper that answers the following question.

Should we continue to improve traffic safety especially though highway design?

Improving roadway safety is a major target of the highway and traffic community and a large effort has been placed on enhancing roadway design to achieve this target. Regardless of the effort put forth, crashes will always happen and one may question the real value of time and money invested in roadway improvements. Moreover, technological advancements have significantly enhanced the safety level of current vehicles that could assist in avoiding several crash types that are often addressed by roadway improvements. In light of these concerns, is it reasonable to continue our efforts to improve roadway safety and why? What might be the reasons for continuing such an effort? Or, what might be the reasons for aborting these efforts?

It is the insight and support you provide in this paper that will merit a good grade. **Remember that there is no right or wrong answer**. However, there is a need to separate facts from fiction and include your references. The impression, judgment and interpretation made by you are valuable. Your paper should follow the guidelines presented in the previous assignment. Create a unique piece that catches the readers' attention, interests them, and keeps them reading. Consider your target audience a group of transportation safety professionals – write with the format and tone that one would find in a short professional magazine article. Many engineers, planners and project managers find themselves producing this type of article for newsletters, company annual reports, company advertisements or magazines (i.e. this is not a totally useless exercise!).

Use the same guidelines presented in Paper #1 for writing. The same rules apply for the student grading as before.

CE 635 Highway Safety Issues Spring 2016

SHORT PAPER #4

DUE DATE:

Using the attached paper, data and information provided in class, newspapers, magazines, personal experiences, the Internet or any other source, prepare a one page position paper that discusses the issue raised in the paper and address the following question:

Are oversized vehicles a safety improvement or a myth for increasing sales?

Traffic safety is important to everyone. Policies, devices, programs, investments and even taxes are often promoted and "sold" to the public in the name of safety. Sometimes however the relationship between traffic safety and the item promoted is somewhat weak and sometimes may be fraudulent and promoted only for "PR" purposes. Use your position paper to briefly describe your position relative to oversized vehicles.

It is the insight and support you provide in this paper that will merit a good grade. **Remember that there is no right or wrong answer**. However, there is a need to separate facts from fiction and include your references. The impression, judgment and interpretation made by you are valuable. Your paper should follow the guidelines presented in the previous assignment. Create a unique piece that catches the readers' attention, interests them, and keeps them reading. Consider your target audience a group of transportation safety professionals – write with the format and tone that one would find in a short professional magazine article. Many engineers, planners and project managers find themselves producing this type of article for newsletters, company annual reports, company advertisements or magazines (i.e. this is not a totally useless exercise!).

Use the same guidelines presented in Paper #1 for writing. The same rules apply for the student grading as before.

Work Session HSM Exercise

Setting

US 62 in Woodford County between mile points 10.548 and 11.363 has been identified as segment with a large number of crashes in the past 5 years. The segment should be reviewed to determine potential safety issues and evaluate possible countermeasures to improve them. Tables 1 and 2 present some of the crash summaries and could be used in the analysis.

Table 1. Crash Severity for US 62

Severity	Number
Fatal	0
Injury (A)	3
Property Damage Only	14

Table 2. Crash Types for US 62

Crash Type	Number
Sideswipe	2
Rear end	3
Fixed object	5
Head on	0
Ran off the road	3
Animal	1
Right angle	3

The roadway has an AADT of 4,239 vehicles per day, lane width of 10 feet, paved shoulder of 4 feet. The segment has grades less than 3% and no horizontal curves or lighting. The roadside design of the roadway could be classified as 4 (clear zone 10 feet, no guardrails, trees about 10-15 feet from pavement edge).

Possible countermeasures for the segment include widening the lanes to 11 feet ($100,000/mile @ 10 years) or 12 feet ($250,000/mile @ 10 years), widening the shoulders to 6 feet ($250,000/mile @ 20 years), increasing clear zone to improve roadside hazard to 3 (clear zone 10 feet, $25,000 @ 20 years) or 2 (clear zone 20 feet, $75,000/mile @ 20 years), and installing centerline rumble strips ($32,000/mile @ 10 years).

For this segment:

1. Predict the number of crashes for the level and on-grade segments.
2. Determine the CMFs required to be applied for the segment.
3. Estimate the total number of crashes for the segment.
4. Identify possible countermeasures to address the safety issues.

5. Estimate potential cost-benefits for each countermeasure suggested.

Table 10-2. Safety Performance Functions included in Chapter 10

Chapter 10 SPFs for Rural Two-Lane, Two-Way Roads	SPF Equations and Figures
Rural two-lane, two-way roadway segments	Equation 10-6, Figure 10-3
Three-leg stop controlled intersections	Equation 10-8, Figure 10-4
Four-leg stop controlled intersections	Equation 10-9, Figure 10-5
Four-leg signalized intersections	Equation 10-10, Figure 10-6

Table 10-3. Default Distribution for Crash Severity Level on Rural Two-Lane, Two-Way Roadway Segments

Crash Severity Level	Percentage of Total Roadway Segment Crashes[a]
Fatal	1.3
Incapacitating Injury	5.4
Nonincapacitating injury	10.9
Possible injury	14.5
Total fatal plus injury	32.1
Property damage only	67.9
Total	100.0

[a] Based on HSIS data for Washington (2002–2006)

Table 10-4. Default Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane, Two-Way Roadway Segments

	Percentage of Total Roadway Segment Crashes by Crash Severity Level[a]		
Collision Type	Total Fatal and Injury	Property Damage Only	Total (All Severity Levels Combined)
SINGLE-VEHICLE CRASHES			
Collision with animal	3.8	18.4	12.1
Collision with bicycle	0.4	0.1	0.2
Collision with pedestrian	0.7	0.1	0.3
Overturned	3.7	1.5	2.5
Ran off road	54.5	50.5	52.1
Other single-vehicle crash	0.7	2.9	2.1
Total single-vehicle crashes	63.8	73.5	69.3
MULTIPLE-VEHICLE CRASHES			
Angle collision	10.0	7.2	8.5
Head-on collision	3.4	0.3	1.6
Rear-end collision	16.4	12.2	14.2
Sideswipe collision[b]	3.8	3.8	3.7
Other multiple-vehicle collision	2.6	3.0	2.7
Total multiple-vehicle crashes	36.2	26.5	30.7
Total Crashes	100.0	100.0	100.0

[a] Based on HSIS data for Washington (2002-2006)
[b] Includes approximately 70 percent opposite-direction sideswipe collisions and 30 percent same-direction sideswipe collisions

Table 10-7. Summary of Crash Modification Factors (CMFs) in Chapter 10 and the Corresponding Safety Performance Functions (SPFs)

Facility Type	CMF	CMF Description	CMF Equations and Tables
Rural Two-Lane Two-Way Roadway Segments	CMF_{1r}	Lane Width	Table 10-8, Figure 10-7, Equation 10-11
	CMF_{2r}	Shoulder Width and Type	Tables 10-9, 10-10, Figure 10-8, Equation 10-12
	CMF_{3r}	Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions	Equation 10-13
	CMF_{4r}	Horizontal Curves: Superelevation	Equations 10-14, 10-15, 10-16
	CMF_{5r}	Grades	Table 10-11
	CMF_{6r}	Driveway Density	Equation 10-17
	CMF_{7r}	Centerline Rumble Strips	See text
	CMF_{8r}	Passing Lanes	See text
	CMF_{9r}	Two-Way Left-Turn Lanes	Equations 10-18, 10-19
	CMF_{10r}	Roadside Design	Equation 10-20
	CMF_{11r}	Lighting	Equations 10-21, Table 10-12
	CMF_{12r}	Automated Speed Enforcement	See text
Three- and four-leg stop control intersections and four-leg signalized intersections	CMF_{1i}	Intersection Skew Angle	Equations 10-22, 10-23
	CMF_{2i}	Intersection Left-Turn Lanes	Table 10-13
	CMF_{3i}	Intersection Right-Turn Lanes	Table 10-14
	CMF_{4i}	Lighting	Equation 10-24, Table 10-15

CMF_{7r}—Centerline Rumble Strips

Centerline rumble strips are installed on undivided highways along the centerline of the roadway which divides opposing directions of traffic flow. Centerline rumble strips are incorporated in the roadway surface to alert drivers who unintentionally cross, or begin to cross, the roadway centerline. The base condition for centerline rumble strips is the absence of rumble strips.

The value of CMF_{7r} for the effect of centerline rumble strips for total crashes on rural two-lane, two-way highways is derived as 0.94 from the CMF value presented in Chapter 13 and crash type percentages found in Chapter 10. Details of this derivation are not provided.

The CMF for centerline rumble strips applies only to two-lane undivided highways with no separation other than a centerline marking between the lanes in opposite directions of travel. Otherwise the value of this CMF is 1.00.

Table 10-8. CMF for Lane Width on Roadway Segments (CMF_{ra})

	AADT (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.05	$1.05 + 2.81 \times 10^{-4}(AADT - 400)$	1.50
10 ft	1.02	$1.02 + 1.75 \times 10^{-4}(AADT - 400)$	1.30
11 ft	1.01	$1.01 + 2.5 \times 10^{-5}(AADT - 400)$	1.05
12 ft or more	1.00	1.00	1.00

Note: The collision types related to lane width to which this CMF applies include single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

Table 10-9. CMF for Shoulder Width on Roadway Segments (CMF_{wra})

	AADT (vehicles per day)		
Shoulder Width	**< 400**	**400 to 2000**	**> 2000**
0 ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT − 400)	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT − 400)	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT − 400)	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 - 6.875 \times 10^{-5}$ (AADT − 400)	0.87

Note: The collision types related to shoulder width to which this CMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

Table 10-10. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra})

	Shoulder Width (ft)						
Shoulder Type	**0**	**1**	**2**	**3**	**4**	**6**	**8**
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

Table 10-11. Crash Modification Factors (CMF_{5r}) for Grade of Roadway Segments

Approximate Grade (%)		
Level Grade (≤ 3%)	Moderate Terrain (3%< grade ≤ 6%)	Steep Terrain (> 6%)
1.00	1.10	1.16

Rural, 2-Lane Arterials - Equations

$$CMF_{4r} = 1.00 \text{ for } SV < 0.01 \qquad (10\text{-}14)$$

$$CMF_{4r} = 1.00 + 6 \times (SV - 0.01) \text{ for } 0.01 \leq SV < 0.02 \qquad (10\text{-}15)$$

$$CMF_{4r} = 1.06 + 3 \times (SV - 0.02) \text{ for } SV \geq 0.02 \qquad (10\text{-}16)$$

Where:

CMF_{4r} = crash modification factor for the effect of superelevation variance on total crashes; and

SV = superelevation variance (ft/ft), which represents the superelevation rate contained in the AASHTO Green Book minus the actual superelevation of the curve.

CMF_{4r} applies to total roadway segment crashes for roadway segments located on horizontal curves.

$$CMF_{6r} = \frac{0.322 + DD \times [0.05 - 0.005 \times \ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(AADT)]} \qquad (10\text{-}17)$$

$$CMF_{9r} = 1.0 - (0.7 \times p_{dwy} \times p_{LT/D}) \quad (10\text{-}18)$$

Where:

CMF_{9r} = crash modification factor for the effect of two-way left-turn lanes on total crashes;

p_{dwy} = driveway-related crashes as a proportion of total crashes; and

$p_{LT/D}$ = left-turn crashes susceptible to correction by a TWLTL as a proportion of driveway-related crashes.

The value of p_{dwy} can be estimated using Equation 10-19 (6).

$$p_{dwy} = \frac{(0.0047 \times DD) + \left(0.0024 \times DD^{(2)}\right)}{1.199 + (0.0047 \times DD) + \left(0.0024 \times DD^{(2)}\right)} \quad (10\text{-}19)$$

Where:

P_{dwy} = driveway-related crashes as a proportion of total crashes; and

DD = driveway density considering driveways on both sides of the highway (driveways/mile).

The value of $p_{LT/D}$ is estimated as 0.5 (6).

Table 13-25. Quantitative Descriptors for the Seven Roadside Hazard Ratings (16)

Rating	Clear zone width	Sideslope	Roadside
1	Greater than or equal to 30 ft	Flatter than 1V:4H; recoverable	N/A
2	Between 20 and 25 ft	About 1V:4H; recoverable	N/A
3	About 10 ft	About 1V:3H or 1V:4H; marginally recoverable	Rough roadside surface
4	Between 5 and 10 ft	About 1V:3H or 1V:4H; marginally forgiving, increased chance of reportable roadside crash	May have guardrail (offset 5 to 6.5 ft) May have exposed trees, poles, other objects (offset 10 ft)
5	Between 5 and 10 ft	About 1V:3H; virtually non-recoverable	May have guardrail (offset 0 to 5 ft) May have rigid obstacles or embankment (offset 6.5 to 10 ft)
6	Less than or equal to 5 ft	About 1V:2H; non-recoverable	No guardrail Exposed rigid obstacles (offset 0 to 6.5 ft)
7	Less than or equal to 5 ft	1V:2H or steeper; non-recoverable with high likelihood of severe injuries from roadside crash	No guardrail Cliff or vertical rock cut

NOTE: Clear zone width, guardrail offset, and object offset are measured from the pavement edgeline.
N/A = no description of roadside is provided.

$$CMF_{10r} = \frac{e^{(-0.6869 + 0.0668 \times RHR)}}{e^{(-0.4865)}} \quad (10\text{-}20)$$

Where:

CMF_{10r} = crash modification factor for the effect of roadside design; and

RHR = roadside hazard rating.

$$CMF_{11r} = 1.0 - [(1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}] \qquad (10\text{-}21)$$

Where:

CMF_{11r} = crash modification factor for the effect of lighting on total crashes;

p_{inr} = proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury;

p_{pnr} = proportion of total nighttime crashes for unlighted roadway segments that involve property damage only; and

p_{nr} = proportion of total crashes for unlighted roadway segments that occur at night.

This CMF applies to total roadway segment crashes. Table 10-12 presents default values for the nighttime crash proportions p_{inr}, p_{pnr}, and p_{nr}. HSM users are encouraged to replace the estimates in Table 10-12 with locally derived values. If lighting installation increases the density of roadside fixed objects, the value of CMF $_{10r}$ is adjusted accordingly.

Table 10-12. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Type	**Fatal and Injury p_{inr}**	**PDO p_{pnr}**	**p_{nr}**
2U	0.382	0.618	0.370

Note: Based on HSIS data for Washington (2002–2006)

CMF $_{10r}$—Roadside Design

For purposes of the HSM predictive method, the level of roadside design is represented by the roadside hazard rating (1–7 scale) developed by Zeeger et al. (16). The CMF for roadside design was developed in research by Harwood et al. (5). The base value of roadside hazard rating for roadway segments is 3. The CMF is:

$$CMF_{10r} = \frac{e^{(-0.6869 + 0.0668 \times RHR)}}{e^{(-0.4865)}} \qquad (10\text{-}20)$$

Where:

CMF_{10r} = crash modification factor for the effect of roadside design; and

RHR = roadside hazard rating.

This CMF applies to total roadway segment crashes. Photographic examples and quantitative definitions for each roadside hazard rating (1–7) as a function of roadside design features such as sideslope and clear zone width are presented in Appendix 13A.

APPENDIX B

Course Homework Assignments

Highway Safety Class Notes Evaluation

By – Mei Chen

In Spring 2016, I was tasked to co-teach CE635 Highway Safety at University of Kentucky. This is a graduate level course offer by the Department of Civil Engineering. The course notes developed by Dr. Nick Stamatiadis as part of the STC grant was used for this class.

The notes cover a broad range of issues associated with highway safety. Major components include historical evolvement and trend of highway safety, user, vehicle and infrastructure factors, safety data and statistical analysis techniques, highway safety manual, countermeasures, road safety audits. I believe the breadth of the topics allows students to gain a broad understanding of highway safety issues and points them to sources for further investigation on aspects of interest. Given the limited amount of time in a semester, it is difficult to have in depth discussion on each and every topic. The notes put strong emphasis on road user issues associated with highway safety. Given the limited amount of time in a semester, it is difficult to have in depth discussion on each and every topic. The course achieves a balanced distribution among the various topics but instructors could emphasize topics as they see fit. In addition, the concepts and applications of the Highway Safety Manual can be expanded with more sample problems to enable better understanding of the analysis process.

From presenter's perspective, notes embedded with individual slide pages provide valuable assistance to lecture preparation. Many slides contain further elaborations and examples of the topics. Some provide cues to engage student in classroom discussion. These features are particularly helpful to instructors. Personally, I would like to see more examples given in the notes to help understanding. However, I must point out that I do not have extensive background on highway safety research.

Overall, I believe the course notes provide a comprehensive picture of issues related to highway safety.