Highway Safety

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Section 1 — General

Overview

As the number of motor vehicles and vehicle-miles of travel increases throughout the world, the exposure of the population to traffic crashes also increases. For example, vehicle miles of travel (VMT) in the United States increased from 2423 billion in the year 1995, to 2747 billion in 2000, and to 2990 billion in 2005. The number of traffic fatalities also increased from 41,817 in 1995, 41,945 in 2000, and to 43,443 in 2005. These numbers indicate that the fatality rates dropped from about 1.73 fatalities per 100 million VMT in 1995 to about 1.53 in 2000 and to 1.45 in 2005. This represents a drop of about 11 percent in fatality rate between 1995 and 2000, but only a drop of about 5 percent between 2000 and 2005. This indicates that the reduction in fatality rate between the years 2000 and 2005 is much less than that for the years 1995 to 2000. Highway safety is a worldwide problem; with over 500 million cars and trucks in use, more than 500,000 people die each year in motor vehicle crashes, where about 15 million are injured. In the United States, motor vehicle crashes are the leading cause of death for people between the ages of 1 to 34 years and rank third as the most significant cause of years of potential life lost—after cardiac disease and cancer. In the United States, between 1966 and 1997, the number of vehicle-miles traveled has increased from about one trillion to 2.6 trillion, whereas fatality rates have declined from 5 per 100 million vehicle-miles to less than 2 per 100 million vehicle-miles. In 1998, there were approximately 40,000 fatalities on the nation's highways—compared with 55,000 in the mid-1970s.

Traffic and highway engineers are continually engaged in working to ensure that the street and highway system is designed and operated such that highway crash rates can be reduced. They also work with law-enforcement officials and educators in a team effort to ensure that traffic laws, such as those regarding speed limits and drinking, are enforced, and that motorists are educated about their responsibility to drive defensively and to understand and obey traffic regulations.

States develop, establish, and implement systems for managing highway safety. There are five major safety programs that are addressed by states in developing a safety management program. They are:

- Coordinating and integrating broad-based safety programs, such as motor carrier-, corridor-, and community-based safety activities, into a comprehensive management approach for highway safety.

- Identifying and investigating hazardous highway safety problems and roadway locations and features, including railroad–highway grade crossings, and establishing countermeasures and priorities to correct identified or potential hazards.
- Ensuring early consideration of safety in all highway construction programs and projects.
- Identifying safety needs of special user groups (such as older drivers, pedestrians, bicyclists, motorcyclists, commercial motor carriers, and hazardous materials carriers) in the planning, design, construction, and operation of the highway system.
- Routinely maintaining and upgrading safety hardware (including highway–rail crossing warning devices), highway elements, and operational features.

Issues Involved in Transportation Safety

Overview

Several issues are involved in transportation safety. These include whether accidents should be referred to as crashes, the causes of transportation crashes, and the factors involved in transportation crashes.

Crashes or Accidents

“Accident” is the commonly accepted word for an occurrence involving one or more transportation vehicles in a collision that results in property damages, injury, or death. The term “accident” implies a random event that occurs for no apparent reason other than “it just happened.” Have you ever been in a situation where something happened that was unintended? Your immediate reaction might have been “sorry, it was just an accident”. In recent years, the National Highway Traffic Safety Administration has suggested replacing the word “accident” with the word “crash” because “crash” implies that the collision could have been prevented or its effect minimized by modifying the driver behavior, the vehicle design (called “crashworthiness”), the roadway geometry, or the traveling environment. The word “crash” is not universally-accepted terminology for all transportation modes and is most common in the context of highway and traffic incidents. In this chapter, both terms— “crashes” and “accidents”—are used because while “crash” is the preferred term, in some situations the word “accident” may be more appropriate.

Causes of Transportation Crashes

The occurrence of a transportation crash presents a challenge to safety investigators. In every instance, the question arises, “What sequence of events or circumstances contributed to the incident that resulted in injury, loss of lives, or property damage?”

In some cases, the answer may be a simple one. For example, the cause of a single car crash may be that the driver fell asleep at the wheel, crossed the highway shoulder, and crashed into a tree. In other cases, the answer may be complex, involving many factors that, acting together, caused the crash to occur. Most people know that the Titanic, an "unsinkable" ocean liner, went to the bottom of the sea with nearly 1200 passengers and crew. Common belief is that the cause of this tragedy was that the ship struck an iceberg. However, the actual reason is much more complex and involved many factors. These include too few lifeboats, a lack of wireless information regarding ice fields, poor judgment by the captain, an inadequate on-board warning system, overconfidence in the technology of ship construction, and flaws in the rivets that fastened the ship's steel plates. Based on these illustrations and other similar cases, it is possible to construct a general list of the categories of circumstances that could influence the occurrence of transportation crashes. If the factors that have contributed to crash events are identified, it is then possible to modify and improve the transportation system. In the future, with the reduction or elimination of the crash-causing factor, a safer transportation system is likely to result.

Factors Involved in Transportation Crashes

While the causes of crashes are usually complex and involve several factors, they can be considered in four separate categories: actions by the driver or operator, mechanical condition of the vehicle, geometric characteristics of the roadway, and the physical or climatic environment in which the vehicle operates. These factors will be reviewed in the following sections.

The Driver or Operator Action

The major contributing cause of many crash situations is the performance of the driver of one or both (in multiple vehicle crashes) of the vehicles involved. Driver error can occur in many ways, such as inattention to the roadway and surrounding traffic, failure to yield the right of way, and/or traffic laws. These "failures" can occur as a result of unfamiliarity with roadway conditions, traveling at high speeds, drowsiness, drinking, and using a cell phone or other distractions within the vehicle.

The Vehicle Condition

The mechanical condition of a vehicle can be the cause of transportation crashes. Faulty brakes in heavy trucks have caused crashes. Other reasons are failure of the electrical system, worn tires, and the location of the vehicle's center of gravity.

The Roadway Condition

The condition and quality of the roadway, which includes the pavement, shoulders, intersections, and the traffic control system, can be a factor in a crash. Highways must be designed to provide adequate sight distance at the design speed or motorists will be unable to take remedial action to avoid a crash. Traffic signals must provide adequate decision sight distance when the signal goes from green to red. Railroad grade crossings must be designed to operate safely and thus minimize crashes between the highway traffic and the rail cars. Highway curves must be carefully designed to accommodate vehicles traveling at or below the design speed of the road.

The Environment

The physical and climatic environment surrounding a transportation vehicle can also be a factor in the occurrence of transportation crashes with the most common being weather. All transportation systems function at their best when the weather is sunny and mild and the skies are clear. Weather on roads can contribute to highway crashes; for example, wet pavement reduces stopping friction and can cause vehicles to hydroplane. Many severe crashes have been caused by fog because vehicles traveling at high speeds are unable to see other vehicles ahead that may have stopped or slowed down, creating a multivehicle pile-up. Geography is another environmental cause of transportation crashes. Mountain ranges have been the site of air crashes. Flooded river plains, swollen rivers, and mud slides on the pavement have caused railroad and highway crashes.

This course deals with the efforts and the methodology through which the highway and traffic engineers evaluate crash data, then redesign and reconstruct the highway system where the potential for high crash rates exists.

Section 2 — Strategic Highway Safety Plans

Overview

The Safe Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) legislation of 2005, that authorized the five-year federal surface transportation program for highways, highway safety and transit, requires that each state develop a Strategic Highway Safety Plan (SHSP).

The purpose of this plan is to develop a process through which each state would identify its key safety needs such that investment decisions can be made that will result in significant reductions in highway fatalities and serious injuries on public roads. Suggested activities that could be included in this plan are:

- Gain Leadership Support and Initiative
- Identify a Champion
- Initiate the Development Process

- Gather Data
- Analyze Data
- Establish Working Group
- Bring Safety Partners Together
- Adopt a Strategic Goal
- Identify Key Emphasis Areas
- Form Task Groups
- Identify Key Emphasis Area Performance-Based Goals
- Identify Strategies and Countermeasures
- Determine Priorities for Implementation
- Write SHSP

Discussion of each of these activities is beyond the scope of this course. The activities discussed below are those normally included in a Highway Safety Improvement Program (HSIP). In partnership with individual states, FHWA has developed the Highway Safety Improvement Program (HSIP) with the overall objectives of reducing the number and severity of crashes and decreasing the potential for crashes on all highways. The HSIP consists of three components:

- Planning
- Implementation
- Evaluation

The planning component of the HSIP consists of four processes as shown in Figure 1. These are:

- Collecting and Maintaining Data

- Identifying Hazardous Locations and Elements
- Conducting Engineering Studies
- Establishing Project Priorities

Figure 1 shows that the information obtained under the planning component serves as input to the two other components, and that results obtained from the evaluation component may also serve as input to the planning component.

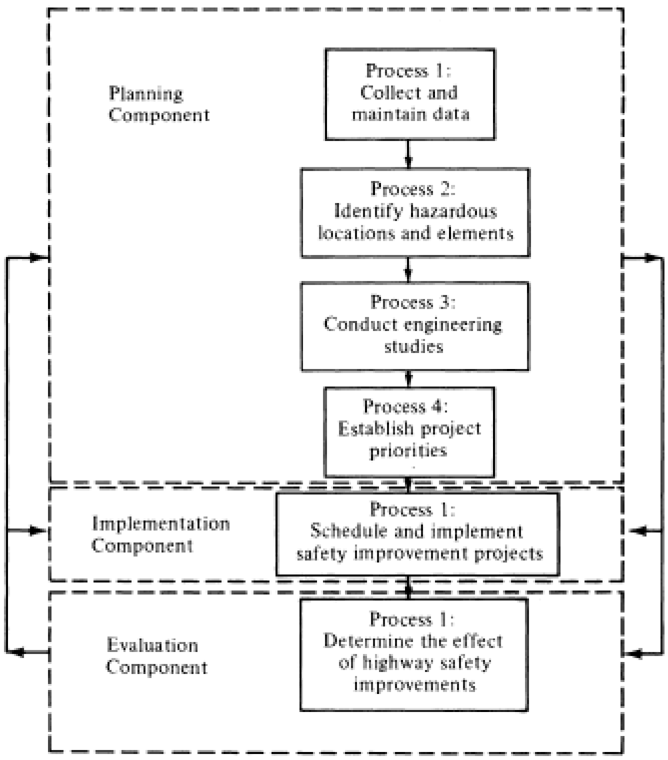
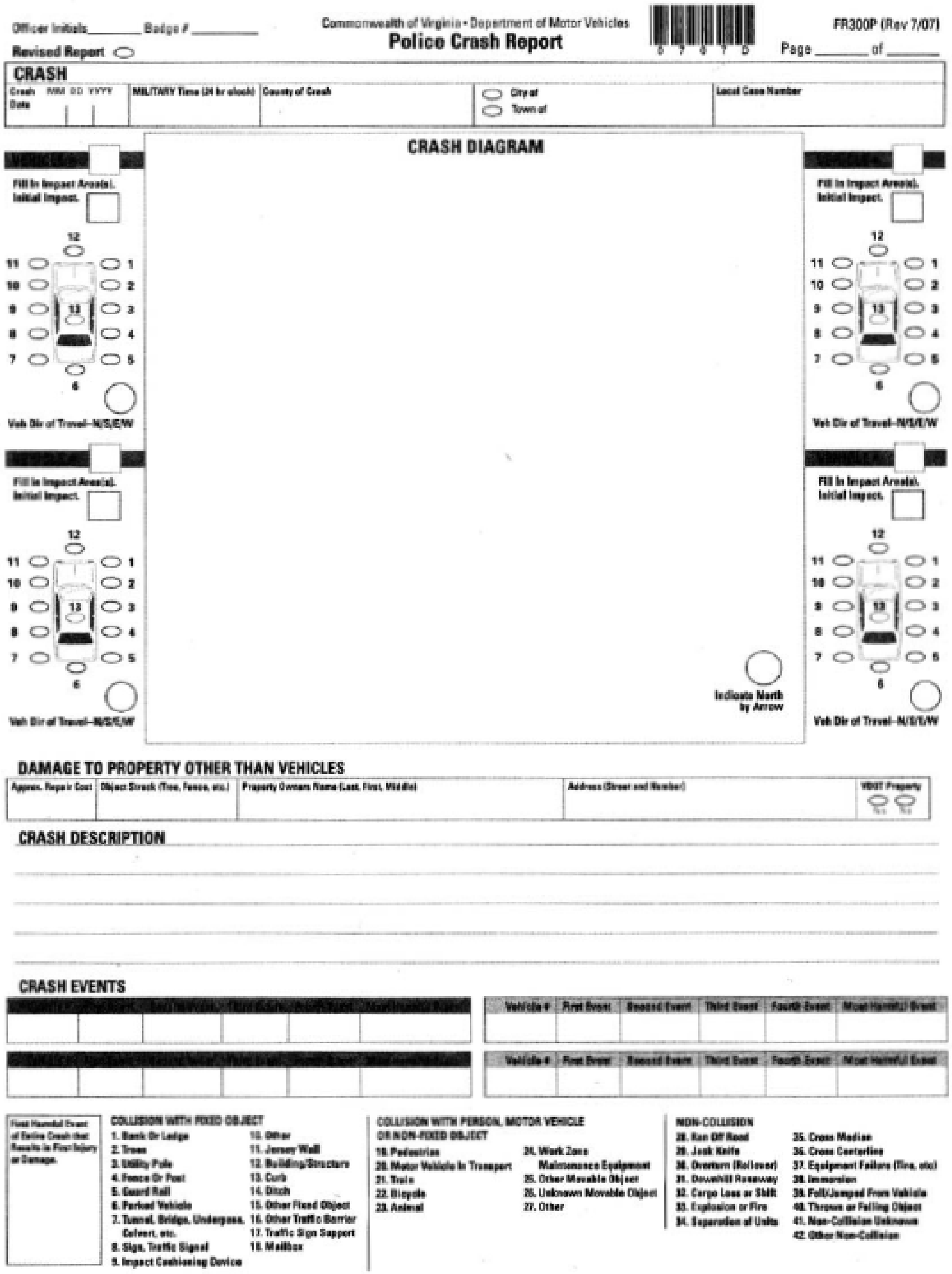


Figure 1 Highway Safety Improvement Program at the Process Level

Collecting and Maintaining Data

Overview

Crash data are usually obtained from state and local transportation and police agencies. All relevant information is usually recorded by the police on an accident report form. The type of form used differs from state to state, but a typical completed form will include information on the location, time of occurrence, roadway and environmental conditions, types and number of vehicles involved, a sketch showing the original paths of the maneuver or maneuvers of the vehicles involved, and the severity (fatal, injury, or property damage only). Figure 2 shows the Virginia report form, which is completed by the investigating police officer. Information on minor crashes that do not involve police investigation may be obtained from routine reports given at the police station by the drivers involved, as is required in some states. Sometimes drivers involved in crashes are required to complete accident report forms when the crash is not investigated by the police. Figure 3 shows an example of such form.



Officer Initials________ Badge # __________

Revised Report

Commonwealth of Virginia • Department of Motor Vehicles

Police Crash Report

FR300P (Rev 7/07)

Page ________ of ________

CRASH

Crash Date MM DD YYYY	MILITARY Time (24 hr clock)	County of Crash	City of / Town of	Local Case Number

CRASH DIAGRAM

Fill In Impact Area(s). Initial Impact.

12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 13

Veh Dir of Travel–N/S/E/W

Indicate North by Arrow

DAMAGE TO PROPERTY OTHER THAN VEHICLES

Approx. Repair Cost	Object Struck (Tree, Fence, etc.)	Property Owners Name (Last, First, Middle)	Address (Street and Number)	VDOT Property
				Yes / No

CRASH DESCRIPTION

CRASH EVENTS

Vehicle #	First Event	Second Event	Third Event	Fourth Event	Most Harmful Event

Vehicle #	First Event	Second Event	Third Event	Fourth Event	Most Harmful Event

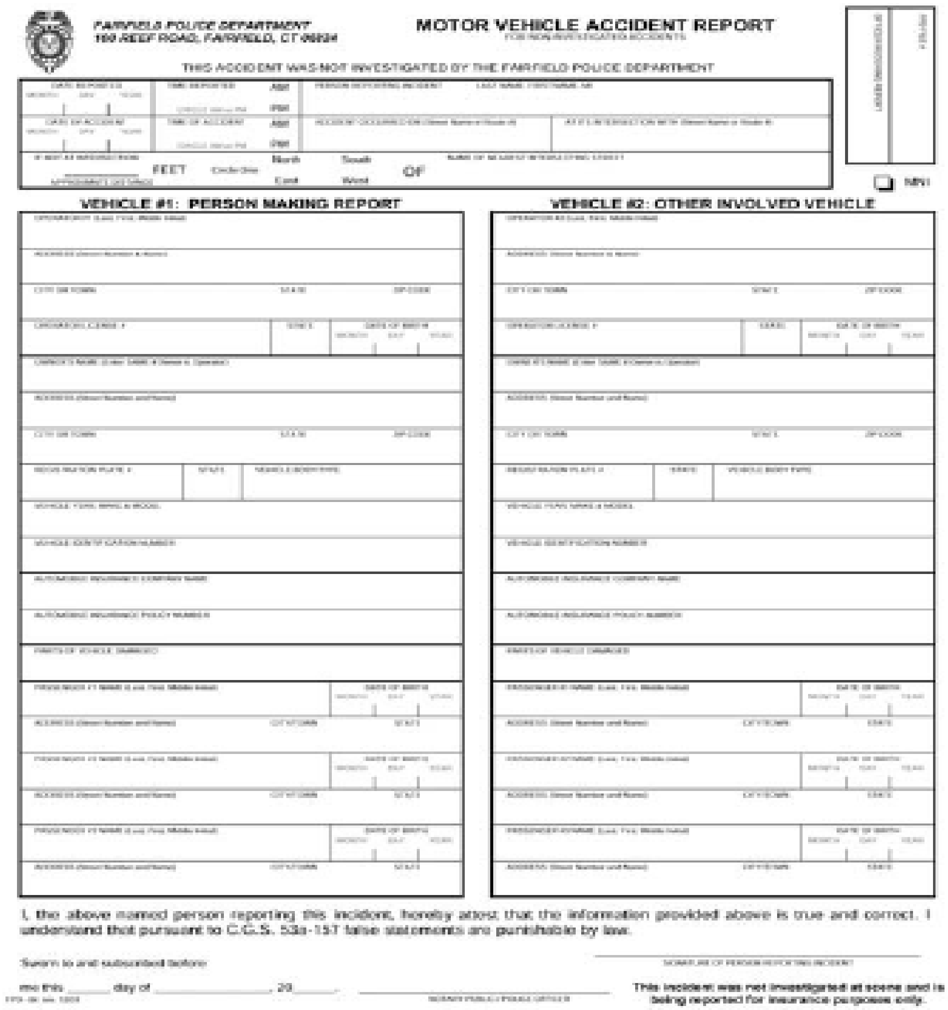
First Harmful Event of Entire Crash that Results in First Injury or Damage.

COLLISION WITH FIXED OBJECT
1. Bank Or Ledge
2. Trees
3. Utility Pole
4. Fence Or Post
5. Guard Rail
6. Parked Vehicle
7. Tunnel, Bridge, Underpass, Culvert, etc.
8. Sign, Traffic Signal
9. Impact Cushioning Device
10. Other
11. Jersey Wall
12. Building/Structure
13. Curb
14. Ditch
15. Other Fixed Object
16. Other Traffic Barrier
17. Traffic Sign Support
18. Mailbox

COLLISION WITH PERSON, MOTOR VEHICLE OR NON-FIXED OBJECT
19. Pedestrian
20. Motor Vehicle In Transport
21. Train
22. Bicycle
23. Animal
24. Work Zone Maintenance Equipment
25. Other Movable Object
26. Unknown Movable Object
27. Other

NON-COLLISION
28. Ran Off Road
29. Jack Knife
30. Overturn (Rollover)
31. Downhill Runaway
32. Cargo Loss or Shift
33. Explosion or Fire
34. Separation of Units
35. Cross Median
36. Cross Centerline
37. Equipment Failure (Tire, etc)
38. Immersion
39. Fell/Jumped From Vehicle
40. Thrown or Falling Object
41. Non-Collision Unknown
42. Other Non-Collision

Figure 2 Virginia Accident Report Form–Crash Diagram Sheet



FAIRFIELD POLICE DEPARTMENT
100 REEF ROAD, FAIRFIELD, CT 06824

MOTOR VEHICLE ACCIDENT REPORT

THIS ACCIDENT WAS NOT INVESTIGATED BY THE FAIRFIELD POLICE DEPARTMENT

FEET North South East West OF

VEHICLE #1: PERSON MAKING REPORT

VEHICLE #2: OTHER INVOLVED VEHICLE

I, the above named person reporting this incident, hereby attest that the information provided above is true and correct. I understand that pursuant to C.G.S. 53a-157 false statements are punishable by law.

Sworn to and subscribed before

me this ______ day of ______________, 20____.

This incident was not investigated at scene and is being reported for insurance purposes only.

Figure 3 Example of a Driver Accident Report Form

Storage and Retrieval of Crash Data

Two techniques are used in the basic storage of crash data. The first technique involves the manual filing of each completed accident report form in the offices of the appropriate police agency. These forms are usually filed either by date, by name or number of the routes, or by location, which may be identified by intersection and roadway links. Summary tables, which give the number and percentage of each type of crash occurring during a given year at a given location, are also prepared. The location can be a specific spot on the highway or an identifiable length of the highway. This technique is not commonly used nowadays but is suitable for areas where the total number of crashes is less than 500 per year and may be used when the total number is between500 and 1000 annually. This technique, however, becomes time-consuming and inefficient when there are more than 1000 crashes per year.

The second technique involves the use of a computer where each item of information on the report form is coded and stored in a computer file. This technique is suitable for areas where the total number of crashes per year is greater than 500. With this technique, facilities are provided for storing a large amount of data in a small space. The technique also facilitates flexibility in the choice of methods used for data analysis and permits the study of a large number of crash locations in a short time. There are, however, some disadvantages associated with this technique such as the high cost of equipment and the requirement of trained computer personnel for the operation of the system. The advent of microcomputers has, however, made it feasible for relatively small agencies to purchase individual systems. Several national data-banks use computerized systems to store data on national crash statistics. These include the following:

- The Highway Performance Monitoring System (HPMS) which is compiled by the Federal Highway Administration (FHWA) of the U.S. Department of Transportation. The system contains data on the extent, condition, performance, use, and operating characteristics of the nation's highways. Data relating to these characteristics are compiled on each of a representative sample of road sections. The sample is a stratified random sample, based on the geographic location (rural, small urban, and urbanized), the roadway functional system, and traffic volume. Crash data are obtained as part of the operational characteristics and include information on the number of fatal crashes, the number of non-fatal crashes, and the number of fatalities, etc.

- The Fatality Analysis Reporting System (FARS) which is compiled by the National Highway Traffic Safety Administration of the U.S. Department of Transportation. The system contains data on all fatal traffic crashes occurring within the50 states, the District of Columbia, and Puerto Rico. The information on each of these fatal crashes is recorded and coded in a standard format by trained personnel of the different states' Departments of Transportation. The criterion for including a crash in the database is that the crash must involve a motor vehicle and result in at least one fatality within 30 days of the crash.

- The National Electronic Injury Surveillance System (NEISS) which is compiled by the Consumer Product Safety Commission (CPSC) and consists of data obtained from emergency departments of 100 hospitals, representing a sample of over5300 U.S. hospitals. The data on the injury of each patient brought into the emergency room of each of the selected hospitals are collected by a staff member of the hospital's emergency department, who obtains information on how the injury occurred. With this information, traffic-related injuries can be identified.

- The Motor Carrier Management Information System (MCMIS) which is compiled by the Federal Motor Carrier Safety Administration and contains summaries on the national safety performance of individual carriers. This summary is known as the Company Safety Profile (CSP), and contains information on several aspects of the carrier's safety performance including a crash summary of four years and individual crashes of one to two years. Information provided by these databanks may be retrieved by computer techniques for research purposes. The technique used for retrieving specific crash data depends on the method of storage of data. When data are stored manually, the retrieval is also manual. In this case, the file is examined by a trained technician who then retrieves the appropriate report forms. When data are stored on computer, retrieval requires only the input of appropriate commands into the computer for any specific data required, and those data are given immediately as output.

Collision Diagrams

Collision diagrams present pictorial information on individual crashes at a location. Different symbols are used to represent different types of maneuvers, types of crashes, and severity of crashes. The date and time (day or night) at which the crash occurs are also indicated. Figure 4 shows a typical collision diagram. One advantage of the collision diagrams is that they give information on the location of the crash, which is not available with statistical summaries. Collision diagrams may be prepared manually either by retrieving the data filed manually or by a computer when the data are stored in a computer file.

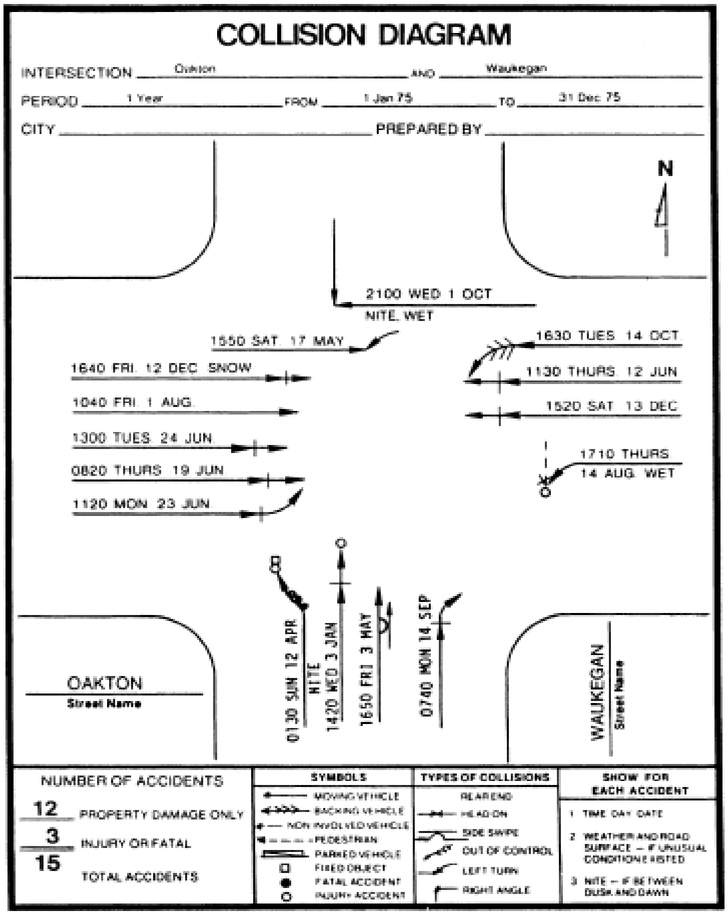


Figure 4 Collision Diagram

Analysis of Crash Data

The reasons for analyzing traffic data are to:

- Identify patterns that may exist.
- Determine probable causes with respect to drivers, highways, and vehicles.
- Develop countermeasures that will reduce the rate and severity of future crashes.

To facilitate the comparison of the results obtained before and after the application of a safety countermeasure at a particular location, or the comparison of safety conditions among different locations, one or more of the following procedures have been used:

- Direct Comparison of the Number of Crashes

- Direct Comparison of the Crash Rates
- Crash Patterns
- Statistical Comparison

Direct Comparison of the Number of Crashes

This involves the computation of the number of crashes for the same duration before and after the implementation of the safety countermeasure or the computation of the number of crashes for the same time period at different locations. The comparison may be done by computing the percentage change in the number of crashes from which some inferences can be made. This procedure is biased to high volume sites, and has a major flaw as it does not consider several factors (exposure), such as the volume at the location or locations. This type of analysis may therefore lead to erroneous conclusions. Although this procedure is easy and simple to conduct, it is not usually recommended for use.

Direct Comparison of the Crash Rates

These rates are determined on the basis of exposure data, such as traffic volume and the length of road section being considered. Commonly used rates are rate per million of entering vehicles (RMEVs) and rate per 100 million vehicle-miles (RMVM). The rate per million of entering vehicles (RMEVs) is the number of crashes per million vehicles entering the study location during the study period. It is expressed as:

$$RMEV = \frac{A \times 1{,}000{,}000}{V}$$

Where:

RMEV = crash rate per million entering vehicles.

A = number of crashes, total or by type occurring in a single year at the location.

V = average daily traffic (ADT) x 365.

This rate is often used as a measure of crash rates at intersections.

Example 1:

The number of all crashes recorded at an intersection in a year was 23, and the average 24-hr volume entering from all approaches was 6500. Determine the crash rate per million entering vehicles (RMEV).

Solution:

RMEV = (23 x 1,000,000)/(6500 x 365) = 9.69 crashes/million entering vehicles.

The rate per 100 million vehicle miles (RMVM) is the number of crashes per100 million vehicle miles of travel. It is obtained from the expression:

$$RMVM = \frac{A \times 100{,}000{,}000}{VMT}$$

Where:

A = number of crashes, total or by type at the study location, during a given period.

VMT = vehicle miles of travel during the given period x ADT x (number of days in study period) x (length of road).

This rate is often used as a measure of crash rates on a stretch of highway with similar traffic and geometric characteristics.

Example 2:

It is observed that 40 traffic crashes occurred on a 17.5-mile long section of highway in one year. The ADT on the section was 5000 vehicles.

Determine the rate of total crashes per 100 million vehicle-miles.

Solution:

RMVMT = (40 x 100,000,000)/(17.5 x 5000 x 365) = 125.24 crashes/100 million veh–mi.

Note that any crash rate may be given in terms of the total number of crashes occurring or in terms of a specific type of crash. Therefore, it is important that the basis on which crash rates are determined is clearly stated. Comparisons between two locations can be made only using results obtained from an analysis based on similar exposure data. Although the use of crash rates considers the effect of an exposure, it does not take into consideration other factors, usually referred to as confounding factors, that may affect the occurrence of crashes. Research has also shown that it tends to be biased toward low volume sites. Care should therefore be taken in making conclusions by simply comparing crash rates.

Crash Patterns

Two commonly used techniques to determine crash patterns are (1) expected value analysis and (2) cluster analysis. A suitable summary of crash data also can be used to determine the patterns.

Expected Value Analysis: is a mathematical method used to identify locations with abnormal crash characteristics. It should be used only to compare sites with similar characteristics (for example, geometrics, volume, or traffic control), since the analysis does not consider exposure levels. The analysis is carried out by determining the average number of a specific type of crash occurring at several locations with similar geometric and traffic characteristics. This average, adjusted for a given level of confidence, indicates the "expected" value for the specific type of crash. Locations with values higher than the expected value are considered as over representing that specific type of crash.

Cluster Analysis: involves the identification of a particular characteristic from the crash data obtained at a site. It identifies any abnormal occurrence of a specific crash type in comparison with other types of crashes at the site. For example, if there are two rear-end, one right-angle, and six left-turn collisions at an intersection during a given year, the left-turn collisions could be defined as a cluster or grouping, with abnormal occurrence at the site. However, it is very difficult to assign discrete values that can be used to identify crash patterns. This is because crash frequencies, which are the basis for determining patterns, differ considerably from site to site. It is sometimes useful to use exposure data, such as traffic volumes, to define patterns of crash rates. Care must be taken, however, to use correct exposure data. For example, if total intersection volume is used to determine left-turn crash rates at different sites, these rates are not directly comparable because the percentages of left-turn vehicles at these sites may be significantly different. Because of these difficulties, it is desirable to use good engineering judgment when this approach is being used.

Methods of Summarizing the Crash Data

A summary of crashes can be used to identify safety problems that may exist at a particular site. It can also be used to identify the crash pattern at a site from which possible causes may be identified, leading to the identification of possible remedial actions (countermeasures). There are five different ways in which a crash at a site can be summarized:

- Type
- Severity
- Contributing Circumstances
- Environmental Conditions
- Time Periods

Summary by Type: This method of summarizing crashes involves the identification of the pattern of crashes at a site, based on the specific types of crashes. The types of crashes commonly used are:

- Rear-End
- Right-Angle
- Left-Turn
- Fixed Object
- Sideswipes
- Pedestrian Related
- Run-off Road
- Head-on
- Parked Vehicle
- Bicycle Related

Summary by Severity: This method involves listing each crash occurring at a site under one of three severity classes: fatal (F), personal injury (PI), and property damage only (PDO). Fatal crashes are those that result in at least one death. Crashes that result in injuries, but no deaths, are classified as personal injury. Crashes that result in neither death nor injuries but involve damage to property are classified as property damage only. This method of summarizing crashes is commonly used to make comparisons at different locations by assigning a weighted scale to each crash based on its severity. Several weighting scales have been used, but a typical one is given as:

Fatality = 12

Personal injury = 3

Property damage only = 1

For example, if one fatal crash, three personal injury crashes, and five property damage crashes occurred during a year at a particular site, the severity number of the site is obtained as follows. The disadvantage in using the severity number is the large difference between the severity scales for fatal and property damage crashes. This may overemphasize the seriousness of crashes resulting in fatalities over those resulting in property damage. For example, a site with only one fatal crash will be considered much more dangerous than a site with nine property damage crashes. This effect can be reduced by using a lower weighting, for example, 8 for fatal crashes, especially at locations where fatal crashes are very rare in comparison with other crashes.

Summary by Contributing Circumstances: In this method, each crash occurring at a site is listed under one of three contributing factors: (1) human factors, (2) environmental factors, and (3) vehicle-related factors. The necessary information is usually obtained from accident reports.

Summary by Environmental Conditions: This method categorizes crashes based on the environmental conditions that existed at the time of the crashes. Two main categories of environmental conditions are (1) lighting condition (i.e., daylight, dusk, dawn, or dark) and (2) roadway surface condition (i.e., dry, wet, snowy/icy). This method of summarizing crashes facilitates the identification of possible causes of crashes and safety deficiencies that may exist at a particular location. The expected value method may be used to ascertain whether crash rates under a particular environmental condition are significantly greater at one site than at other similar sites.

Summary by Time Period: This method categorizes all crashes under different time periods to identify whether crash rates are significantly higher during any specific time periods. Three different time periods can be used: (1) hour, (2) day, and (3) month. This method of summarizing data also facilitates the use of the expected value method to identify time periods during which crash occurrences take place.

Identifying and Prioritizing Hazardous Locations and Elements

Hazardous locations are sites where crash frequencies, calculated on the basis of the same exposure data, are higher than the expected value for other similar locations or conditions. Several methods have been used to identify and prioritize hazardous locations. Any of the crash rates or summaries described earlier may be used to identify hazardous locations. A common method of analysis involves the determination of crash rates based on the same exposure data for the study site with apparent high rates and several other sites with similar traffic and geometric characteristics. An appropriate statistical test, such as the expected value analysis is then performed to determine whether the apparent high crash rate at the study site is statistically significant. If the statistical test shows that the apparent high crash rate is significantly higher, an abnormal rate of crashes at the test location is likely and that site is to be considered a hazardous location. All hazardous locations are then prioritized with that having the highest crash rate assigned the highest priority.

A technique that is used to identify possible hazardous locations is known as the critical CRF method. Since traffic crashes are random occurrences and can be considered as “rare events,” it is not possible to identify hazardous locations simply on the basis of the number of crashes. Rather, the critical rate method incorporates the traffic volume to determine if the crash rate at a particular location is significantly higher than the average for the type of facility. Statistics are typically maintained by facility type, which is determined by factors such as traffic volume, traffic control, number of lanes, land-use density, and functional classification. The crash ratio of actual crash occurrence for the segment being studied with respect to the critical rate is determined. Locations with crash ratios greater than 1 are considered hazardous. All hazardous locations can then be prioritized by assigning the location with the highest crash ratio the highest priority, that with the next highest crash ratio the next highest priority, and so on.

An alternative method is that proposed by the Federal Highway Administration which uses an index that indicates the Potential for Safety Improvement (PSI) at a location. The PSI can be determined for fatal, injury, and property damage only crashes separately and a combined index (PSI index) for the location determined by using a weighting factor for different crash types. The PSI index also should be found for different types of roads.

Determining Possible Causes of Crashes

Having identified the hazardous locations and the crash pattern, the next stage in the data analysis is to determine possible causes. The types of crashes identified are matched with a list of possible causes from which several probable causes are identified. Table 1 shows a list of probable causes for different types of crashes. The environmental conditions existing at the time may also help in identifying possible causes.

Conducting Engineering Studies

After a particular location has been identified as hazardous, a detailed engineering study is performed to identify the safety problem. Once the safety problem is identified, suitable safety-related countermeasures can be developed.

The first task in this sub process is an in-depth study of the crash data obtained at the hazardous site. The results of the analysis will indicate the type or types of crashes that predominate or that have abnormal frequency rates. Possible causes can then be identified from Table 1. However, the list of possible causes obtained at this stage is preliminary, and

Pattern	*Probable Cause*
Left-turn head-on collisions	• Large volume of left turns • Restricted sight distance • Too short amber phase • Absence of special left-turning phase • Excessive speed on approaches
Right-angle collisions at signalized intersections	• Restricted sight distance • Excessive speed on approaches • Poor visibility of signal • Inadequate signal timing • Inadequate roadway lighting • Inadequate advance intersection warning signs • Large total intersection volume
Right-angle collisions at unsignalized intersections	• Restricted sight distance • Large total intersection volume • Excessive speed on approaches • Inadequate roadway lighting • Inadequate advance intersection warning signals • Inadequate traffic control devices
Rear-end collisions at unsignalized intersections	• Driver not aware of intersection • Slippery surface • Large number of turning vehicles • Inadequate roadway lighting • Excessive speed on approach • Lack of adequate gaps • Crossing pedestrians
Rear-end collisions at signalized intersections	• Slippery surface • Large number of turning vehicles • Poor visibility of signals • Inadequate signal timing • Unwarranted signals • Inadequate roadway lighting
Pedestrian-vehicle collisions	• Restricted sight distance • Inadequate protection for pedestrians • School crossing area • Inadequate signals • Inadequate phasing signal

Table 1 Probable Causes for Different Types of Crashes

personal knowledge of the site, field conditions, and police accident reports should all be used to improve this list.

The next task is to conduct a field review of the study site. This review involves an inspection of the physical condition and an observation of traffic operations at the site. The information obtained from this field review is then used to confirm the existence of physical deficiencies, based on the pattern of crashes, and to refine the list of possible causes. The refined list is used to determine what data will be required to identify the safety deficiencies at the study site. Table 2 gives a partial list of data needs for different possible causes of crashes. A complete list is given in the Department of Transportation publication cited. After identifying the data needs, existing records then will be reviewed to determine whether the required data are available. Care must be taken to ensure that any existing data are current and are related to the time for which the study is being conducted. In cases where the necessary data are available, it will not be necessary to carry out specific engineering studies. When appropriate data are not available, the engineering studies identified from Table 2 will then be conducted.

The results of these studies are used to determine traffic characteristics of the study site from which specific safety deficiencies at the study site are determined. For example, a sight-distance study at an intersection may reveal inadequate sight distance at that intersection, which results in an abnormal rate of left-turn head-on collisions. Similarly, a volume study, which includes turning movements at an intersection with no separate left-turn phase, may indicate a high volume of left-turn vehicles, which suggests that a deficiency is the absence of a special left-turn phase. Having identified the safety deficiencies at the study site, the next task is to develop alternative countermeasures to alleviate the identified safety deficiencies. A partial list of general countermeasures for different types of possible causes is shown in Table 3.

Possible Causes	*Data Needs*	*Procedures to Be Performed*
	Left-Turn Head-On Collisions	
Large volume of left turns	• Volume data • Vehicle conflicts • Roadway inventory • Signal timing and phasing • Travel time and delay data	• Volume Study • Traffic Conflict Study • Roadway Inventory Study • Capacity Study • Travel Time and Delay Study
Restricted sight distance	• Roadway inventory • Sight-distance characteristics • Speed characteristics	• Roadway Inventory Study • Sight-Distance Study • Spot Speed Study
Too short amber phase	• Speed characteristics • Volume data • Roadway inventory • Signal timing and phasing	• Spot Speed Study • Volume Study • Roadway Inventory Study • Capacity Study
Absence of special left-turning phase	• Volume data • Roadway inventory • Signal timing and phasing • Delay data	• Volume Study • Roadway Inventory Study • Capacity Study • Travel Time and Delay Study
Excessive speed on approaches	• Speed characteristics	• Spot Speed Study

	Rear-End Collisions at Unsignalized Intersections	
Driver not aware of intersection	• Roadway inventory • Sight-distance characteristics • Speed characteristics	• Roadway Inventory Study • Sight-Distance Study • Spot Speed Study
Slippery surface	• Pavement skid resistance characteristics • Conflicts resulting from slippery surface	• Skid Resistance Study • Weather-Related Study • Traffic Conflict Study
Large number of turning vehicles	• Volume data • Roadway inventory • Conflict data	• Volume Study • Roadway Inventory Study • Traffic Conflict Study
Inadequate roadway lighting	• Roadway inventory • Volume data • Data on existing lighting	• Roadway Inventory Study • Volume Study • Highway Lighting Study
Excessive speed on approaches	• Speed characteristics	• Spot Speed Study
Lack of adequate gaps	• Roadway inventory • Volume data • Gap data	• Roadway Inventory Study • Volume Study • Gap Study
Crossing pedestrians	• Pedestrian volumes • Pedestrian/vehicle conflicts • Signal inventory	• Volume Study • Pedestrian Study • Roadway Inventory Study
	Rear-End Collisions at Signalized Intersections	
Slippery surfaces	• Pavement skid resistance characteristics • Conflicts resulting from slippery surface	• Skid Resistance Study • Weather Related Study • Traffic Conflict Study
Large number of turning vehicles	• Volume data • Roadway inventory • Conflict data • Travel time and delay data	• Volume Study • Roadway Inventory Study • Traffic-Conflict Study • Delay Study
Poor visibility of signals	• Roadway inventory • Signal review • Traffic conflicts	• Roadway Inventory Study • Traffic-Control Device Study • Traffic Conflict Study

Table 2 Data Needs for Different Possible Causes of Crashes

Probable Cause	*General Countermeasure*
	Left-Turn Head-On Collisions
Large volume of left turns	• Create one-way street • Widen road • Provide left-turn signal phases • Prohibit left turns • Reroute left-turn traffic • Channelize intersection • Install stop signs (see MUTCD)* • Revise signal sequence • Provide turning guidelines (if there is a dual left-turn lane) • Provide traffic signal if warranted by MUTCD*
Restricted sight distance	• Retime signals • Remove obstacles • Provide adequate channelization • Provide special phase for left-turning traffic • Provide left-turn slots • Install warning signs • Reduce speed limit on approaches
Too short amber phase	• Increase amber phase • Provide all-red phase
Absence of special left-turning phase	• Provide special phase for left-turning traffic
Excessive speed on approaches	• Reduce speed limit on approaches

Rear-End Collisions at Unsignalized Intersections	
Driver not aware of intersection	• Install/improve warning signs
Slippery surface	• Overlay pavement • Provide adequate drainage • Groove pavement • Reduce speed limit on approaches • Provide "slippery when wet" signs
Large number of turning vehicles	• Create left- or right-turn lanes • Prohibit turns • Increase curb radii
Inadequate roadway lighting	• Improve roadway lighting
Excessive speed on approach	• Reduce speed limit on approaches
Lack of adequate gaps	• Provide traffic signal if warranted (see MUTCD)* • Provide stop signs
Crossing pedestrians	• Install/improve signing or marking of pedestrian crosswalks

Rear-End Collision at Signalized Intersections	
Slippery surface	• Overlay pavement • Provide adequate drainage • Groove pavement • Reduce speed limit on approaches • Provide "slippery when wet" signs
Large number of turning vehicles	• Create left- or right-turn lanes • Prohibit turns • Increase curb radii • Provide special phase for left-turning traffic
Poor visibility of signals	• Install/improve advance warning devices • Install overhead signals • Install 12-in. signal lenses (see MUTCD)* • Install visors • Install back plates • Relocate signals • Add additional signal heads • Remove obstacles • Reduce speed limit on approaches

Rear-End Collision at Signalized Intersections	
Inadequate signal timing	• Adjust amber phase • Provide progression through a set of signalized intersections • Add all-red clearance
Unwarranted signals	• Remove signals (see MUTCD)*
Inadequate roadway lighting	• Improve roadway lighting

Table 3 General Countermeasures for Different Safety Deficiencies

The selection of countermeasures should be made carefully by the traffic engineer based on his or her personal knowledge of the effectiveness of each countermeasure considered in reducing the rate at similar sites for the specific types of crashes being studied. Note that countermeasures that are very successful in achieving significant major benefits in one part of the country may not be that successful in another locality due to the complexity of the interrelationship that exists among the traffic variables.

Crash Reduction Capabilities of Countermeasures

Crash reduction capabilities are used to estimate the expected reduction that will occur during a given period as a result of implementing a proposed countermeasure. Crash reduction capabilities usually are expressed as crash reduction factors (CRFs)or crash modification factors (CMFs). A CRF gives an estimate of the percent reduction in the number of crashes due to the implementation of a countermeasure, while a CMF is given as (1-CRF). Some states have developed their own CRFs, while others have adopted those developed by other states. The problem about adopting other states' factors is that roadway, traffic, weather, and driver characteristics may be significantly different from one state to the other. Factors developed by states usually are based on the evaluation of data obtained from safety projects and can be obtained from state agencies involved in crash analysis. In using the CRF to determine the reduction in crashes due to the implementation of a specific countermeasure, the following equation is used:

$$\text{Crashes prevented} = N \times CR \frac{(ADT \text{ after improvement})}{(ADT \text{ before improvement})}$$

Where

N = expected number of crashes if countermeasure is not implemented and if the traffic volume remains the same.

CR = crash reduction factor for a specific countermeasure (some states use the term AR for accident reduction).

ADT = average daily traffic.

Example 3:

The CRF for a specific type of countermeasure is 30 percent; the ADT before improvement is 7850 (average over three-year period), and the ADT after improvement is 9000. Over the three-year period before the improvement period, the number of specific types of crashes occurring per year are 12, 14, and 13. Use the following method to determine the expected reduction in number of crashes occurring after the implementation of the countermeasure.

Solution:

Average number of crashes/year = 13

Crashes prevented = (13 x 0.30 x 9000)/7850 = 4.47 say 4 crashes.

It is sometimes also necessary to consider multiple countermeasures at a particular site. In such cases, the overall CRF is obtained from the individual CRFs by using the Equation below, which was proposed by Roy Jorgensen and Associates:

$$CR = CR_1 + (1 - CR_1)CR_2 + (1 - CR_1)(1 - CR_2)CR_3 + \dots + (1 - CR_1)\dots(1 - CR_{m-1})CR_m$$

Where

CR = overall crash reduction factor for multiple mutually exclusive improvements at a single site.

CR_i = crash reduction factor for a specific countermeasure i.

m = number of countermeasures at the site.

In using the Equation above to compare various combinations of countermeasures, it is first necessary to list all of the individual countermeasures in order of importance. The countermeasure with the highest reduction factor will be listed first, and its reduction factor will be designated CR_1; the countermeasure with the second highest reduction factor will be listed second, with its reduction factor designated CR_2; and so on.

Example 4:

At a single location, three countermeasures with CRs of 40%, 28%, and 20% are proposed. Determine the overall CRF if all countermeasures are used.

Solution:

$CR_1 = 0.40$

$CR_2 = 0.28$

$CR_3 = 0.20$

$CR = 0.4 + (1 - 0.4) \times 0.28 + (1 - 0.4) \times (1 - 0.28) \times 0.2 = 0.66$

Establishing Project Priorities

The purpose of this task is to determine the economic feasibility of each set of countermeasures and to determine the best alternative among feasible mutually exclusive countermeasures. Benefits are determined on the basis of expected number of crashes that will be prevented if a specific proposal is implemented, and costs are the capital and continuing costs for constructing and operating the proposed countermeasure.

Implementation and Evaluation

Implementation and evaluation are the next two main steps in the HSIP. Implementation involves scheduling selected projects and implementing the highway safety improvements selected. The evaluation component involves determination of the effect of the highway safety improvement. This involves the collection of data for a period after the implementation of the improvement to determine whether anticipated benefits are actually accrued. This task is important, since the information obtained will provide valuable data for other similar projects.

Section 3 — Effectiveness of Safety Design Features

The document, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, published by the Transportation Research Board (TRB) consists of several guides, each of which gives a set of objectives and strategies to improve safety at specific locations. Table 4 gives some of these objectives and strategies for a few locations.

Crash Types	
Objectives	*Strategies*
Collisions with Trees in Hazardous Locations	
Prevent trees from growing in hazardous locations	Develop, revise, and implement guidelines to prevent placing trees in hazardous locations (T) Develop mowing and vegetation control guidelines (P)
Eliminate hazardous condition and/ or reduce severity of the crash	Remove trees in hazardous locations (P) Shield motorists from striking trees (P) Modify roadside clear zone in vicinity of trees (P) Delineate trees in hazardous locations (E)
Head-On Collisions	
Keep vehicles from encroaching into opposite lanes	Install centerline rumble strips for two-lane roads (T) Install profiled thermo-plastic strips for centerlines (T) Provide wider cross-sections for two-lane roads (T) Provide center two-way, left-turn lanes for four- and two- lane roads (T) Reallocate total two-lane roadway width (lane and shoulder) to include a narrow buffer median

Head-On Collisions	
Minimize the likelihood of crashing into an oncoming vehicle	Use alternating passing lanes or four-lane sections at key locations (T) Install median barriers for narrow-width medians on multilane roads (T)

Unsignalized Intersection Collisions

Improve management of access near unsignalized intersections	Implement driveway closures/ relocations (T) Implement driveway turn restrictions (Y)
Reduce frequency and severity of inter-section conflicts through geometric design	Provide left-turn lanes at intersections (T) Provide offset left-turn lanes at intersections (T) Provide right- and left-turn acceleration lanes at divided highway intersections (T) Restrict or eliminate turning maneuvers by signing or channelization or closing median openings
Improve sight distance at signalized intersections	Clear site triangles on stop- or yield intersections (T) Clear site triangles in the median of divided highways (T) Change horizontal and/or vertical align-ment of approaches to provide more sight distance (T)

Collisions on Horizontal Curves

Reduces likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	Provide advance warning of unexpected changes in horizontal curves (T) Enhance delineation along the curve Install shoulder and centerline rumble strips (T) Provide skid-resistant pavement surfaces (T) Improve or restore superelevation (P) Widen roadway (T) Modify horizontal alignment
Minimize adverse consequences of leaving roadway at the horizontal curve	Design safer slopes and ditches to prevent rollovers (P) Remove/relocate objects in hazardous locations

Collisions on Horizontal Curves

	Delineate roadside objects (E) Improve design and application of barrier and attenuation systems (T)

Collisions Involving Pedestrians	
Reduce pedestrian exposure to vehicular traffic	Provide sidewalks/walkways and curb ramps Install or upgrade traffic and pedestrian refuge islands and raised medians Install or upgrade traffic and pedestrian signals
Improve sight distance and/or visibility between motor vehicles and pedestrians	Provide crosswalk enhancements Signals to alert motorists that pedestrians are crossing Eliminate screening by physical objects
Reduce vehicle speeds	Implement road narrowing measures Install traffic calming road sections Install traffic calming intersections
Collisions at Signalized Intersections	
Reduce frequency and severity of intersection conflicts through traffic control and operational improvements	Employ multi-phase signal operation (P,T) Optimize clearance intervals (P) Employ signal coordination (P) Employ emergency vehicle preemption (P)
Reduce frequency and severity of intersection conflicts through geometric improvements	Provide/improve left-turn and right-turn channelization (P) Improve geometry of pedestrian and bicycle facilities (P,T) Revise geometry of complex intersections (P, T)
Improve sight distance at signalized intersections	Clear sight triangles (T) Redesign intersection approaches (P)

Table 4 Objectives and Strategies for Different Crash Types

Summary of Research Results on Safety Effectiveness of Highway Design Features

The FHWA has also published a series of reports that summarize the results of research dealing with safety effectiveness of highway design features. These reports provide useful information about the relationship between crashes and highway geometrics. These results generally support the strategies given in Table 4 for reducing crashes at specific locations. Among the features to be considered in this course are:

- Access Control

- Alignment
- Cross Sections
- Intersections
- Pedestrians and Bicyclists

Research results that spanned a 30-year period were examined, and in some instances, studies dating before 1973 were found to be the most definitive available. Design features are discussed in the following sections based on the information from these FHWA reports.

Access Control

The effects of geometrics on traffic crashes have produced a variety of findings which are not always definitive because often more than one factor may have caused the crash to occur. Furthermore, it is difficult to conduct studies in a controlled environment, and often researchers must rely on data collected by others under a variety of circumstances. Despite these difficulties, research findings over an extended period have confirmed a strong relationship between access control and safety. Access control is defined as some combination of at-grade intersections, business and private driveways, and median crossovers. For any given highway, access control can range from full control (such as an interstate highway) to no access control (common on most urban highways). The reason why access control improves safety is because there are fewer unexpected events caused by vehicles entering and leaving the traffic stream at slower speeds, resulting in less interference with through traffic. The effect of control of access is illustrated in Table 5, which shows that the total crash rate per million vehicle-miles is almost three times as great on roads in urban areas with no access control than on fully controlled highways. This finding underscores the safety value of the interstate system compared with other parallel roads where access is either partial or non-existing.

	Crash Rates per Million Vehicle-Miles			
	Urban		*Rural*	
Access Control	*Total*	*Fatal*	*Total*	*Fatal*
Full	1.86	0.02	1.51	0.03
Partial	4.96	0.05	2.11	0.06
None	5.26	0.04	3.32	0.09

Table 5 Effect of Access Control on Crash Rates

Similarly, the increase in roadside development, which creates an increased number of at-grade intersections and businesses with direct access to the highway, will also significantly increase crashes. Table 6 shows how crash rates increase on a two-lane rural highway when the number of access points increases. For example, when the number of intersections per mile increases from 2 to 20, the crash rate per 100 million vehicle-miles increases by more than 600percent.

Intersections per Mile	*Businesses per Mile*	*Crash Rate**
0.2	1	126
2.0	10	270
20.0	100	1718

Table 6 Effect of Access Points on Crash Rates on Two-Lane Rural Highways

There are several mechanisms for reducing crashes due to access, all of which require the elimination of access points from through traffic. Examples include:

- removal of the access point by closing median openings
- Frontage road access for business driveways
- Special turning lanes to separate through vehicles from those vehicles using the access point
- Proper signing and pavement markings to warn motorists of changing conditions along the roadway

Alignment

The geometric design of highways, involves three elements:

- Vertical Alignment
- Horizontal Alignment
- Cross Section

The design speed is the determining factor in the selection of the alignment needed for the motorist to have sufficient sight distance to safely stop or reduce speed as required by changing traffic and environmental conditions. A safe design ensures that traffic can flow at a uniform speed while traveling on a roadway that changes in a horizontal or vertical direction.

The design of the vertical alignment (which includes tangent grades and sag or crest vertical curves) is influenced by consideration of terrain, cost, and safety. Generally, crash rates for downgrades are higher than for upgrades. One study reported that only 34.6 percent of crashes occurred on level grade, whereas 65.4 percent occurred on a grade or at the location where grades change.

The design of the horizontal alignment (which consists of level tangents connected by circular curves) is influenced by design speed and superelevation of the curve itself. Crash rates for horizontal curves are higher than on tangent sections, with rates ranging between 1.5 and 4 times greater than on straight sections. Several factors appear to influence the safety performance of horizontal curves, including:

- Traffic volume and mix
- Geometric features of the curve
- Cross section
- Roadside hazards
- Stopping sight distance
- Vertical alignment superimposed on horizontal alignment
- Distance between curves and between curves and the nearest intersection or bridge
- Pavement friction
- Traffic-control devices.

The improvement of horizontal curve design involves three steps. first, problem sites must be identified based on crash history and roadway conditions. Second, improvements should be evaluated and implemented. Third, before-and-after studies of crash performance should be conducted to assess the effectiveness of the changes.

Cross Sections

One of the most important roadway features affecting safety is the highway cross section. As illustrated in Figure 5, a rural two-lane highway cross section includes travel lanes, shoulders, side slopes, clear zones, and ditches. The road may be constructed on an embankment (fill) section or depressed below the natural grade (cut). Cross-section elements (including through and passing lanes, medians, and left-turn lanes) may be added when a two-lane road is inadequate, possibly improving both traffic operations and safety. Safety improvements in the highway cross section are usually focused on two-lane roads, with the exception of clear zone treatments and median design for multilane highways.

In general, wider lanes and/or shoulders will result in fewer crashes. A 1987 study by the FHWA measured the effects of lane width, shoulder width, and shoulder type on highway crash experience, based on data for approximately 5000 miles of two-lane highway. Table 7 lists the percentage reduction in crash types related to lane widening.

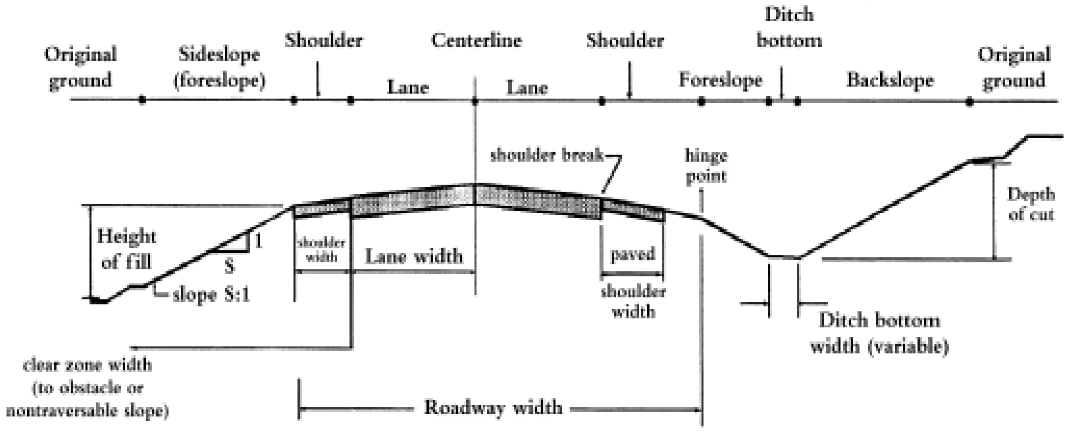


Figure 5 Cross Section Elements for Rural Two-Lane Highway

Amount of Lane Widening (ft)	*Crash Reduction (percent)*
1	12
2	23
3	32
4	40

Table 7 Effect of Lane Widening for Related Crash Types on Two-Lane Rural Roads

Related crashes include run-off-road, head-on, and sideswipe occurrences. Not all crash types are "related" to geometric roadway elements. For example, if a lane is widened by 2 ft (from 9 ft to 11 ft), a 23 percent reduction in related crashes can be expected. Table 8 provides similar results for shoulders. For example, if an unpaved shoulder is widened by 6 ft (from 2 ft to 8 ft), and the shoulder is paved, then a 40 percent reduction in related crash types can be expected, assuming that other features such as clear zone and side slopes are unaltered. If both pavement and shoulder-width improvements are made simultaneously, the percentage reductions are not additive. Rather, the contribution of each is computed assuming that the other has taken effect. Crash factors for various combinations of pavement and shoulder-width are shown in Table 9, and factors that convert total number of crashes to number of related crashes (RC) are shown in Table 10.

The physical condition along the roadside is also a factor that affects the safety of two-lane highways, since crashes can occur as a result of a vehicle running off the road. A motorist is

less likely to experience injury or death under these circumstances if the area adjacent to the pavement is clear of obstructions and has a relatively flat side slope.

	Crash Reduction (percent)	
Shoulder Widening per Side (ft)	*Paved*	*Unpaved*
2	16	13
4	29	25
6	40	35
8	49	43

Table 8 Effect of Shoulder Widening for Related Crash Types on Two-Lane Rural Roads

Amount of Lane Widening (in feet)	Existing Shoulder Condition (before period): Shoulder width	Surface type	Percent Related Crashes Reduced — Shoulder Condition (after period): 2-ft Shoulder P	2-ft Shoulder U	4-ft Shoulder P	4-ft Shoulder U	6-ft Shoulder P	6-ft Shoulder U	8-ft Shoulder P	8-ft Shoulder U
	0	N/A	43	41	52	49	59	56	65	62
	2	Paved	32	—	43	—	52	—	59	—
	2	Unpaved	34	33	44	41	53	49	60	56
	4	Paved	—	—	32	—	43	—	52	—
3	4	Unpaved	—	—	36	32	46	41	54	49
	6	Paved	—	—	—	—	32	—	43	—
	6	Unpaved	—	—	—	—	37	32	47	41
	8	Paved	—	—	—	—	—	—	32	—
	8	Unpaved	—	—	—	—	—	—	39	32
	0	N/A	35	33	45	42	53	50	61	56
	2	Paved	23	—	35	—	45	—	53	—
	2	Unpaved	25	23	37	33	46	42	55	50
	4	Paved	—	—	23	—	35	—	45	—
2	4	Unpaved	—	—	27	23	38	33	48	42
	6	Paved	—	—	—	—	23	—	35	—
	6	Unpaved	—	—	—	—	29	23	40	33
	8	Paved	—	—	—	—	—	—	23	—
	8	Unpaved	—	—	—	—	—	—	31	23
	0	N/A	26	24	37	34	47	43	55	50
	2	Paved	12	—	26	—	37	—	47	—
	2	Unpaved	14	12	28	24	39	34	48	43
	4	Paved	—	—	12	—	26	—	37	—
1	4	Unpaved	—	—	17	12	30	24	41	34
	6	Paved	—	—	—	—	12	—	26	—
	6	Unpaved	—	—	—	—	19	12	31	24
	8	Paved	—	—	—	—	—	—	12	—
	8	Unpaved	—	—	—	—	—	—	21	12

Table 9 Effect of Lane and Shoulder Widening for Related Crashes on Two-Lane Rural Roads

ADT (vpd)	Terrain Adjustment Factors: Flat	Rolling	Mountainous
500	.58	.66	.77
1,000	.51	.63	.75
2,000	.45	.57	.72
4,000	.38	.48	.61
7,000	.33	.40	.50
10,000	.30	.33	.40

Table 10 Ratio of Cross-Section Related Crashes to Total Crashes on Two-Lane Rural Roads

The distance available for a motorist to recover and either stop or return safely to the paved surface is referred to as the "roadside recovery distance" (also called the "clear zone" distance) and is a factor in crash reduction. Roadside recovery distance is measured from the edge of pavement to the nearest rigid obstacle, steep slope, non-traversable ditch, cliff, or body of water. Recovery distances are determined by averaging the clear zone distances measured at 3 to 5 locations for each mile. Table 11 shows the percent reduction in related crashes as a function of recovery distance. For example, if roadside recovery is increased by 8 ft, from 7 to 15 ft, a 21 percent reduction in related crash types can be expected.

Amount of Increased Roadside Recovery Distance (ft)	*Reduction in Related Crash Types (percent)*
5	13
8	21
10	25
12	29
15	35
20	44

Table 11 Effect of Roadside Recovery Distance for Related Crashes

Among the means to increase the roadside recovery distance are:

- Relocating utility poles.
- Removing trees.
- Fattening side slopes to a maximum 4:1 ratio.
- Removing other obstacles, such as bridge abutments, fences, mailboxes, and guardrails.

When highway signs or obstacles such as mailboxes cannot be relocated, they should be mounted so as to break away when struck by a moving vehicle, thus minimizing crash severity. When two-lane roads become more heavily traveled, particularly in suburban, commercial, and recreational areas, crash rates tend to increase. The reasons were discussed earlier and include lack of passing opportunities, increased numbers of access points, mixed traffic (including trucks and cars), and local and through destinations. Without the opportunity to create a multilane facility, there are several alternative operational and safety treatments possible. These are:

- Passing lanes.
- Short four-lane sections.

- Use of paved shoulders.
- Turnout lanes for slower moving traffic, especially on up-grades.
- Two-way left-turn lanes.

These options (illustrated in Figure 6) were evaluated for 138 treated sites, and crash data were compared with standard two-lane sections.

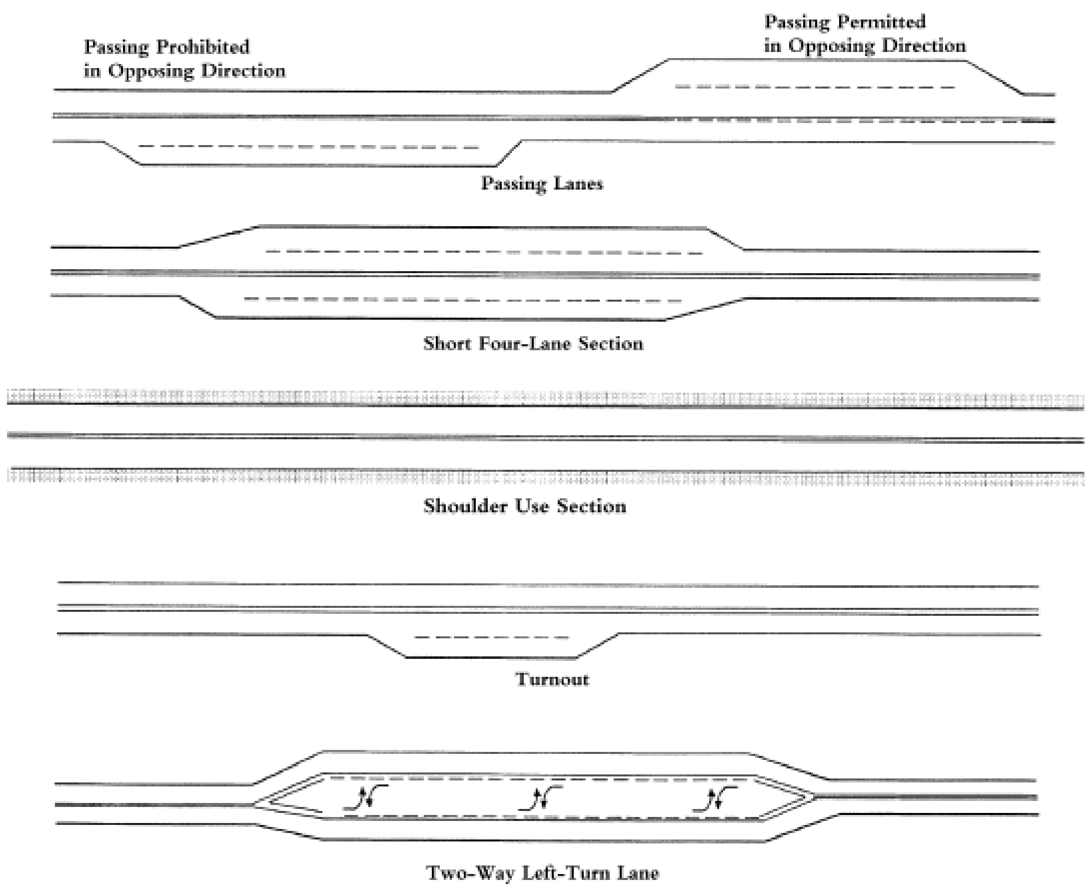


Figure 6 Operational and Safety Improvements for Two-Lane Highways

The results (shown in Table 12 for total and for fatal and injury crashes) are valid for high-volume conditions. For the option "use of paved shoulders," no effect was noted, whereas for the other options, reduction in fatal and injury crashes ranged from 30 to 85 percent. Since these results are site-specific, the operational treatment selected may not always be appropriate, and specific site studies are required.

Multilane Design Alternative	Type of Area	Percent Reduction in Crashes	
		Total	F + I only
Passing lanes	Rural	25	30
Short four-lane section	Rural	35	40
Turnout lanes	Rural	30	40
Two-way, left-turn lane	Suburban	35	35
Two-way, left-turn lane	Rural	70–85	70–85
Shoulder use section	Rural	no known significant effect	

Table 12 Effect of Auxiliary Lanes on Crash Reduction on High-Volume, Two-Lane Highways

Example 5:

Records indicate that there have been a total of 53 crashes per year over a three-year period along a two-lane rural roadway section with 10-ft lanes and 2-ft unpaved shoulders. The highway is located in a mountainous area where average daily traffic is 4000 veh/day. Determine the crash prevention that can be expected:

(a) if only the lanes are widened to 12 ft.

(b) if only the shoulders are paved and widened to 6 ft.

(c) if both measures are implemented together.

Solution:

Compute the number of cross-section related crashes prevented (CP) using factors in Table 10.

RC = 53 x 0.61 = 32 related crashes/yr.

(a) Crash prevented (CP) due to lane widening alone. From Table 7, the reduction is 23%.

CP = 32 x 0.23 = 7 crashes prevented/yr.

(b) Crash prevented due to shoulder widening and paving alone. From Table 8, the reduction is 29%.

CP = 32 x 0.29 = 9 crashes prevented/yr.

(c) Crash prevention due to both lane and shoulder widening. From Table 9, the reduction is 46%.

CP = 32 x 0.46 = 15 crashes prevented/yr.

Intersections

Intersections represent the site of most urban motor vehicle crashes in the United States. The number of crashes at intersections has increased by 14 percent over a 20-year period. This result is not surprising, since intersections are the confluence of many vehicle and pedestrian paths that may conflict with each other. An encouraging trend, however, is the reduction in severity of intersection crashes, such that fatal crashes have reduced by 11 percent over the same 20-year period, to 28 percent of the total.

The reduction in fatalities is the result of improvements in intersection design, use of passenger restraints, separation of vehicles from pedestrians, enhanced visibility, and improvements in traffic control devices.

In urban areas with high-traffic volumes, intersections must accommodate a high volume of turning movements that traverse a large surface area. In this situation, channelization is an effective means to improve safety. Right-turn-only lanes have become recognized as a simple means to separate through traffic from slow-turning traffic. For left-turning traffic, however, several options are available, including left-turn storage lanes and raised dividers to guide traffic through the intersection area. Types of lane dividers used for intersection channelization are raised reflectors, painted lines, barriers, and medians.

Crash rates also are affected by the sight distance available to motorists as they approach an intersection. Stopping sight distance is affected by the horizontal and vertical alignment. Vertical curve lengths and horizontal curve radii should be selected to conform with the design speeds; when this is not feasible, advisory speed limit signs should be posted. The ability to see traffic that approaches from across the street is dependent on obtaining a clear diagonal line of sight. When blocked by foliage, buildings, or other obstructions, the sight line may be insufficient to permit a vehicle from stopping in time to avoid colliding with side street traffic. Figure 7 illustrates how the sight distance is improved when trees are removed near an intersection, and Table 13 indicates the expected reduction in the number of crashes per year as a function of the ADT and the increased sight radius. The following example illustrates in general terms the effect of the sight distance on safety. However, in the design of an intersection, in order to account for an adequate sight distance, the approach velocity must be taken into account.

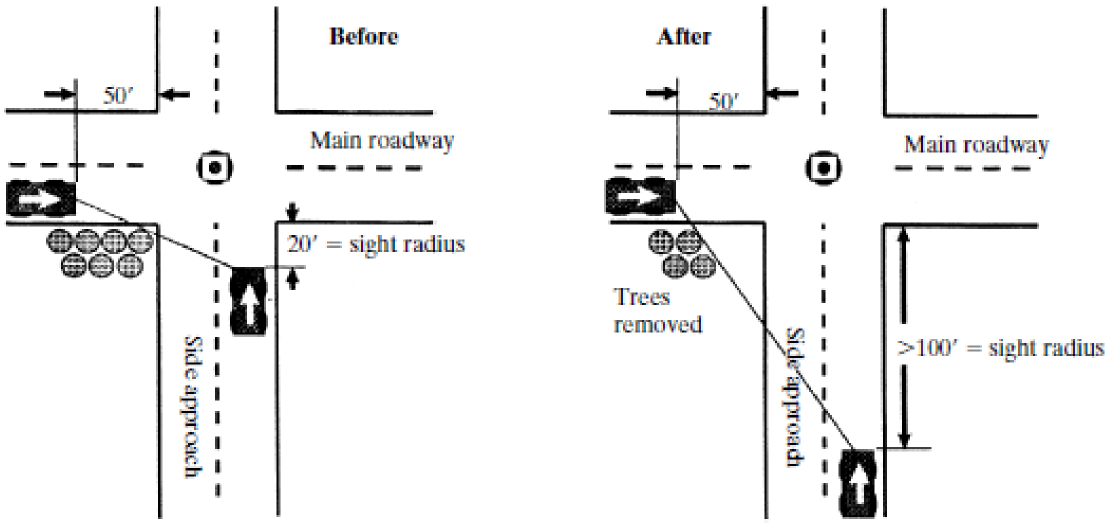


Figure 7 Increased Sight Radius by Removal of Obstacles

	Increased Sight Radius[1]		
ADT[2]	*20–49 ft*	*50–99 ft*	*>100 ft*
<5000	0.18	0.20	0.30
5000–10000	1.00	1.3	1.40
10000–15000	0.87	2.26	3.46
>15000	5.25	7.41	11.26

[1] *At 50 ft from intersection, increasing obstruction on approaching leg from initial < 20 ft from intersection.*

[2] *Average daily Traffic*

Table 13 Crash Reduction, Per Year, Due to Increased Intersection Sight Distance

Example 6:

A motorist is 50 ft from an intersection and sees a vehicle approaching from the right when it is 20 ft from the intersection. After removal of the foliage that has been blocking the sight line, it is now possible to see the same vehicle when it is 75 ft from the intersection. Average daily traffic volumes on the main roadway are 12,000veh/day. Prior to removal of the obstructing foliage, the average number of crashes per year was 8.6. Determine the expected number of crashes per year after the foliage has been removed based on the research data provided in Table 13.

Solution:

From Table 13, the crash reduction (CR) is 2.26 crashes/year. The average number of crashes/year = 8.60 - 2.26 = 6.34crashes/year.

Pedestrian Facilities

The safety of pedestrians is of great concern to traffic and highway engineers. Efforts to reduce pedestrian and bicycle crashes involve education, enforcement, and engineering measures, as is the case for motor vehicle crashes. In addition, characteristics of pedestrian crashes indicate that factors related to occurrence include age, sex, alcohol use, time of day, urban or rural area type, and intersection or midblock crossing location.

For example, it is known that fatality rates increase sharply for pedestrians over 70 years of age, and that the highest crash rates occur for males 15 to 19 years old. The peak crash periods occur in the afternoon and evening hours, and over 85 percent of all non-fatal crashes occur in urban areas. Approximately 65 percent of all pedestrian crashes occur at locations other than intersections, and many of these involve younger children who dart out into the street. The various types of pedestrian crashes and percentage occurrence are listed in Table 14. Note that dart-out at locations account for over one-third of the 14 crash types listed. The most common types of pedestrian crashes are illustrated in Figure 8.

The principal geometric design elements that are used to improve pedestrian safety are:

- Sidewalks
- Overpasses or tunnels
- Raised islands
- Auto-free shopping streets
- Neighborhood traffic control to limit speeding and through traffic
- Curb cuts that assist wheelchair users and pedestrians with baby carriages
- Shoulders that are paved and widened

Other traffic control measures that may assist pedestrians include crosswalks, traffic signs and signals, parking regulations, and lighting. Sidewalks and pedestrian paths can significantly improve safety in areas where the volumes of automobile and pedestrian traffic are high. The sidewalk provides a safe and separated lane intended for the exclusive use of pedestrians. However, they should not be used by higher-speed non-motorized vehicles, such

DART-OUT (FIRST HALF) (24%)
Midblock (not at intersection)
Pedestrian sudden appearance and short time exposure (driver does not have time to react)
Pedestrian crossed less than halfway

DART-OUT (SECOND HALF) (10%)
Same as above, except pedestrian gets at least halfway across before being struck

MIDBLOCK DASH (8%)
Midblock (not at intersection)
Pedestrian is running but *not* sudden appearance or short time exposure as above

INTERSECTION DASH (13%)
Intersection
Same as dart-out (short time exposure or running) except it occurs at an intersection

VEHICLE TURN-MERGE WITH ATTENTION CONFLICT (4%)
Vehicle is turning or merging into traffic
Driver is attending to traffic in one direction and hits pedestrian from a different direction

TURNING VEHICLE (5%)
Vehicle is turning or merging into traffic
Driver attention is *not* documented
Pedestrian is *not* running

MULTIPLE THREAT (3%)
Pedestrian is hit as he steps into the next traffic lane by a vehicle moving in the same direction as vehicle(s) that stopped for the pedestrian, because driver's vision of pedestrian obstructed by the stopped vehicle(s)

BUS STOP–RELATED (2%)
Pedestrian steps out from in front of bus at a bus stop and is struck by vehicle moving in same direction as bus while passing bus

VENDOR–ICE CREAM TRUCK (2%)
Pedestrian struck while going to or from a vendor in a vehicle on the street

DISABLED VEHICLE–RELATED (1%)
Pedestrian struck while working on or next to a disabled vehicle

RESULT OF VEHICLE-VEHICLE CRASH (3%)
Pedestrian hit by vehicle(s) as a result of a vehicle-vehicle collision

TRAPPED (1%)
Pedestrian hit when traffic light turned red (for pedestrian) and vehicles started moving

WALKING ALONG ROADWAY (1%)
Pedestrian struck while walking along the edge of the highway or on the shoulder

OTHER (23%)
Unusual circumstances, not countermeasure corrective

Table 14 Pedestrian Crash Types and Frequency

as bicycles. Guidelines for the minimum width and location of sidewalks are illustrated in Figure 9 based on classification of roadway and residential density. For example, for residential areas with 1 to 4 dwelling units per acre, sidewalks are preferred on both sides of the local street. In commercial and industrial areas, sidewalks are required on both sides of the street. Sidewalks are often carried on grade-separated structures, such as overpasses or subways, when crossings involve freeways or expressways that carry high-speed and high-

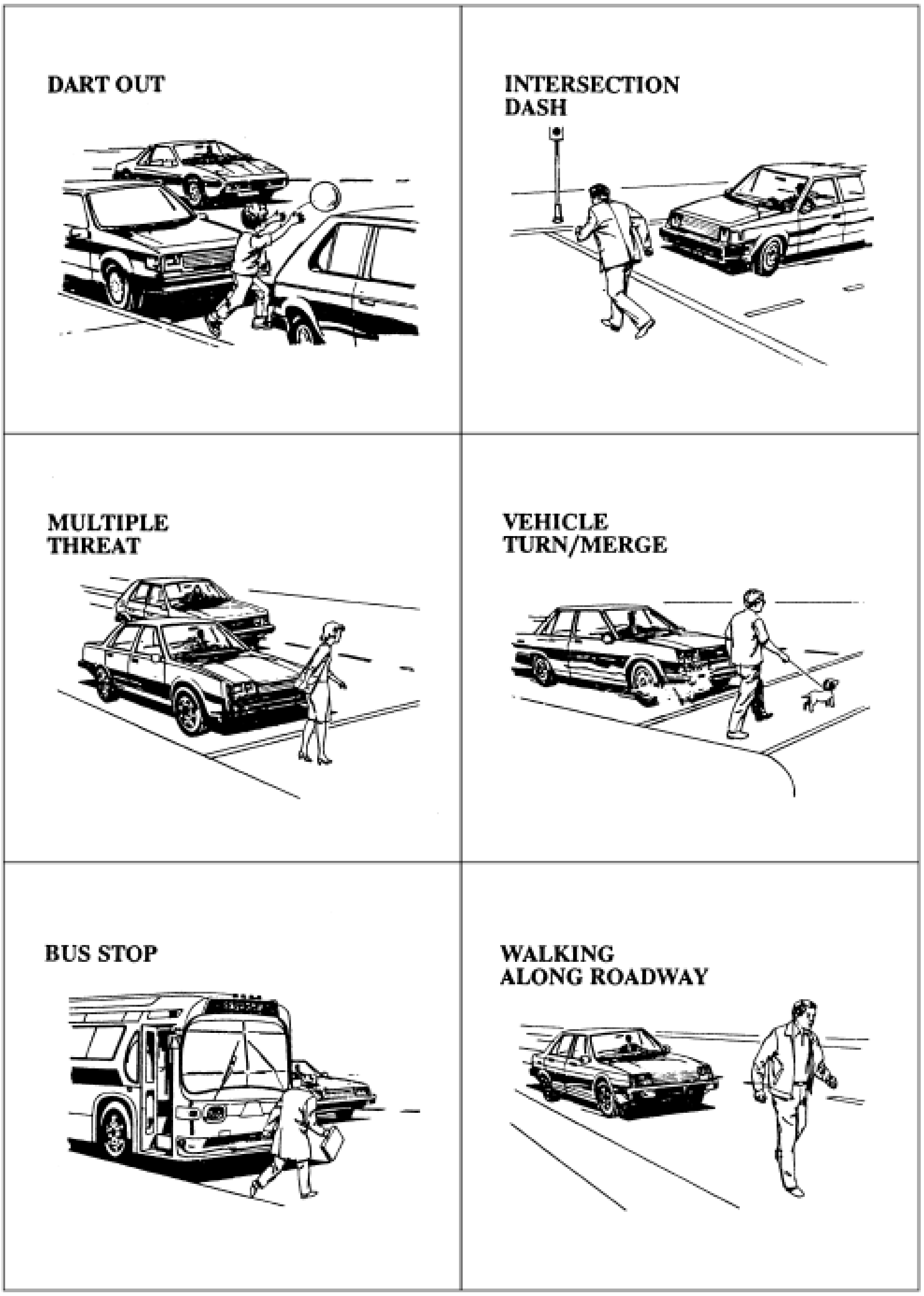


Figure 8 Common Types of Pedestrian Crashes

volume traffic. They are most effective when pedestrian demand is high, for example, as a connector between a residential area and destinations such as schools, hospitals, and shopping areas. Pedestrians will use these facilities if they are convenient and do not require circuitry of travel, but they will select the alternative unsafe path if they are required to walk significantly farther on the overcrossing or through the tunnel. Traffic safety in residential

Proposed Minimum Sidewalk Widths

Central Business Districts - Conduct level of service analysis according to method in 1985 Highway Capacity Manual.

Commercial/industrial areas outside a central business district - Minimum 5 ft wide with 2 ft planting strip or 6 ft wide with no planting strip.

Residential areas outside a central business district:

Arterial and collector streets - Minimum 5 ft with minimum 2 ft planting strip.

Local Streets:

- Multi-family dwellings and single-family dwellings with densities greater than four dwelling units per acre - Minimum 5 ft with minimum 2 ft planting strip.
- Densities up to four dwelling units per acre - Minimum 4 ft with minimum 2 ft planting strip.

Land-Use/Roadway Functional Classification/Dwelling Unit	New Urban and Suburban Streets	Existing Urban and Suburban Streets
Commercial & Industrial (All Streets)	Both sides.	Both sides. Every effort should be made to add sidewalks where they do not exist and complete missing links.
Residential (Major Arterials)	Both sides.	
Residential (Collectors)	Both sides.	Multi-family - both sides. Single-family dwellings - prefer both sides required at least one side.
Residential (Local Streets) More than 4 Units Per Acre	Both sides.	Prefer both sides, required at least one side.
Residential (Local Streets) 1 to 4 Units Per Acre	Prefer both sides; required at least one side.	One side preferred, at least 4 ft shoulder on both sides required.
Residential (Local Streets) Less than 1 Unit Per Acre	One side preferred, shoulder both sides required.	At least 4 ft shoulder on both sides required.

Figure 9 Guidelines for Sidewalk Installation

neighborhoods is a major concern, especially in sub-urban areas where through traffic uses residential streets as a shortcut, thus bypassing congested arterials and expressways. Typically, citizens protest when they perceive that their neighborhoods are becoming more dangerous for children and others who are required to walk along the same roadways as moving traffic. Several geometric designs have been developed in the United States and in Europe to create more friendly pedestrian environments. Several options, some illustrated in Figure 10, are as follows:

- Create cul-de-sacs by closing streets at an intersection or at midblock.

- Reduce the roadway width at the intersection, or provide on-street parking at midblock (a narrower roadway tends to reduce speeds and improve pedestrian crossing).

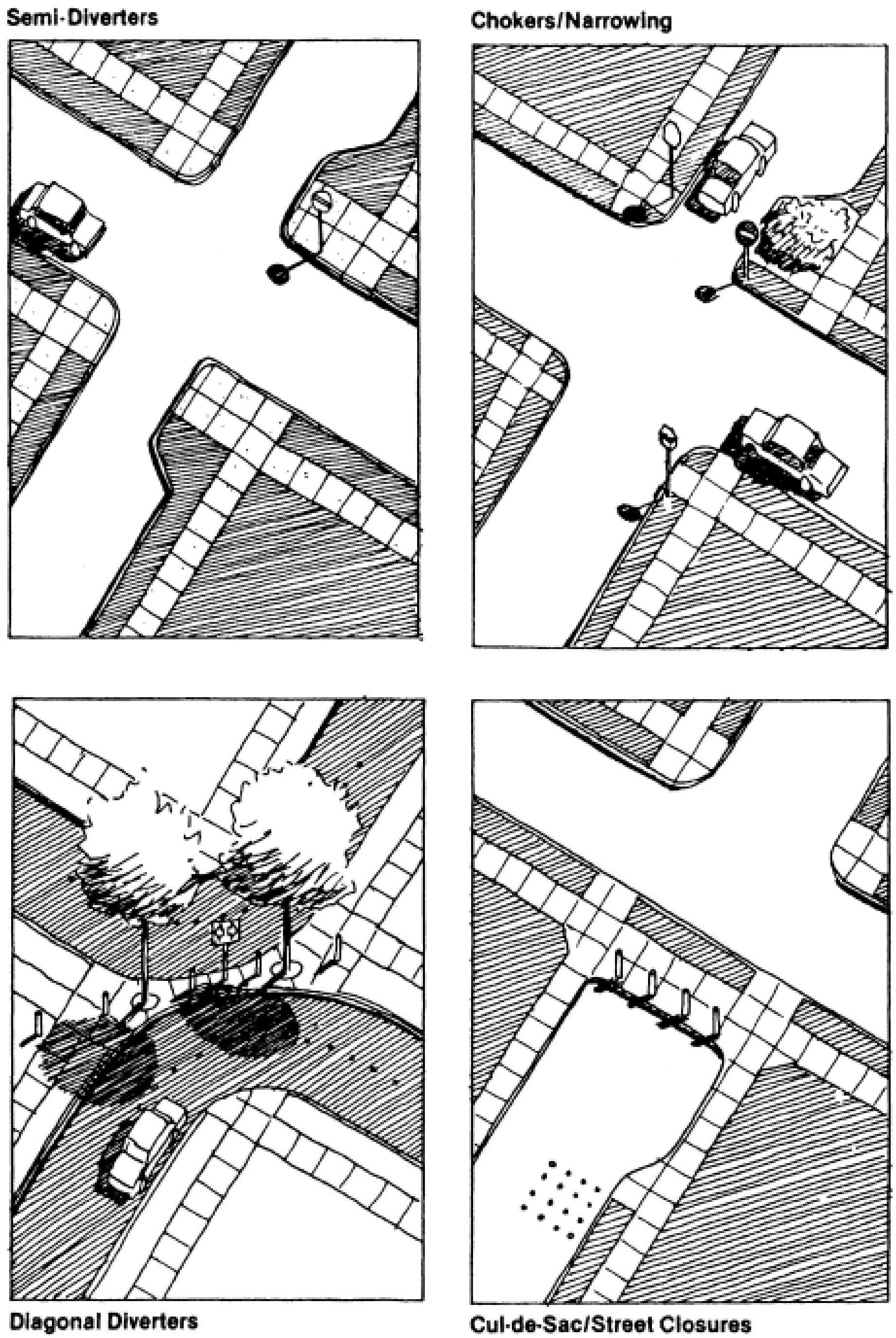


Figure 10 Neighborhood Traffic Control Measures

- Limit street access to one-way traffic, and narrow the intersections to improve pedestrian crossings; often four-way stop signs are used to further reduce traffic speeds.

- Install diagonal barriers at the intersection to divert the traffic and thus discourage through traffic with increased travel time and distance.
- Use mechanisms such as speed humps, photo radar, electronic speed reminders, direct police enforcement, and traffic circles to reduce speeds and eliminate through traffic; these types of traffic control measures for residential areas are used in some U.S. cities, but more extensive experience with these techniques is found in many cities in Europe.

- Use other roadway and geometric features that can assist both pedestrians and bicyclists, such as curb ramps, widened and paved shoulders along rural two-lane highways, stripes to signify separate bicycle lanes, and widened highway lanes in urban areas. Some of these options (such as roadway width reduction and speed humps) are traffic calming measures.

Section 4 — References

- Highway Safety Engineering Studies Procedural Guide, U.S. Department of Transportation, Washington, D.C.