CHAPTER 6

Evaluation of Safety Impacts

I am prepared for the worst, but hope for the best.
—Benjamin Disraeli (1804–1881)

INTRODUCTION

Transportation projects generally have a direct or indirect safety component that reduces the rate or severity of crashes. As such, safety enhancement is considered a key aspect of user benefits associated with physical or policy changes in a transportation system. In the period 1992–2002, approximately 40,000 to 45,000 fatalities per year were experienced on the U.S. transportation system. Of this, 90 to 95% was highway-related (USDOT, 2004). As seen in Figure 6.1, for every 100,000 residents in 2002, highways had a fatality rate of approximately 15 deaths, while railroads had 0.33. In the figure, the fatality statistics for air transportation include air carrier service, commuter service, air taxi service, and general aviation; for the highway mode, fatalities include all types of highway motor vehicles, bicycles, and pedestrians. Railroad fatalities include deaths from railroad highway–rail grade-crossing incidents. For transit fatality statistics, the modes considered include: motor bus, heavy rail, light rail, commuter rail, trolley bus, aerial tramway, automated guideway transit, cablecar, ferry boat, and monorail. Waterborne fatalities include those due to vessel- or non-vessel-related incidents on commercial and recreational vessels. Pipeline facilities include hazardous liquid and gas pipelines.

For people under 65 years of age, the Center for Disease Control has ranked transportation accidents as the third-leading cause of death in the United States (after cancer and heart disease) each year from 1991 to 2000 (USDHHS, 2003). During those years, an annual average of nearly 36,000 people under 65 lost their lives due to transportation accidents. A far larger number of people are injured than killed; an estimated 3.0 million people suffered some type of injury involving passenger and freight transportation in 2002, and a majority of these injuries (98%) resulted from highway crashes (USDOT, 2004).

The economic cost of transportation crashes, which is borne by individuals, insurance companies, and government, consists of loss of market productivity, property damage, loss of household productivity and workplace costs. Intangible costs include pain and suffering, and loss of life. The costs of crashes can be very high. For instance, motor vehicle crashes in the United States cost an estimated $230 billion in 2000, representing approximately $820 per person or 2% of the gross domestic product (USDOT, 2004).

Within the highway mode, safety problems are most pernicious at roads in rural areas and at roads that have only one lane in each direction. Most of these roads were designed and built many decades ago using standards that have become outdated. As such, they are generally characterized by operational and safety deficiencies arising from inadequate road geometry, driver information deficiencies, lack of passing opportunities, and traffic conflicts due to driveways. Transportation projects typically include interventions to upgrade these and other facilities to acceptable standards.

In this chapter we present a procedural framework that can be used by analysts to assess the safety impacts of transportation investments. Much of the discussion focuses on the highway mode, because compared to all other modes, highway safety continues to be the major transportation safety problem. Nevertheless, the general concepts discussed here are applicable to other modes of transportation. We first present the basic taxonomy associated with transportation safety, briefly discuss the factors that affect crashes, identify possible safety projects, and present evidence of the agency costs and effectiveness (user benefits) of various project types. Then the procedural framework for safety evaluation is presented. This essentially comprises the product of two elements: change in *crash frequency* after the proposed transportation intervention, and unit *crash monetary costs*. Crash frequency or its reduction can be estimated using crash relationships (rates, equations), developed from national data or preferably, recent local data. We also identify existing software packages that may be used or customized for safety evaluation of highway projects and list some current resources for safety evaluation.

Transportation Decision Making: Principles of Project Evaluation and Programming. Kumares C. Sinha and Samuel Labi

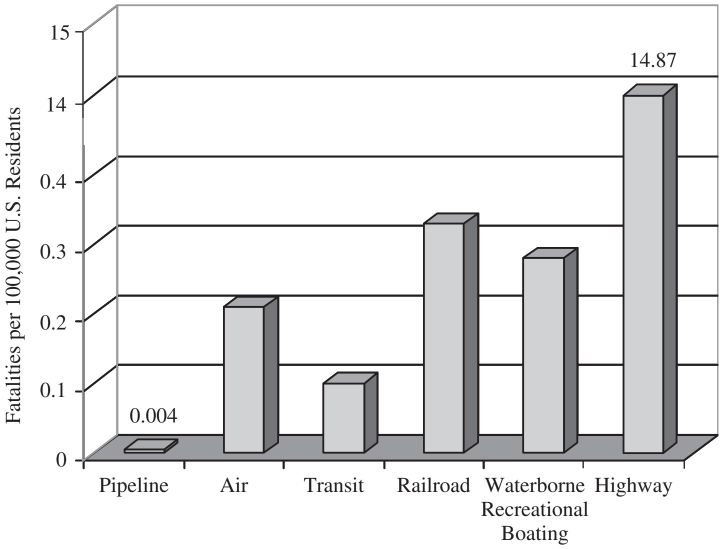

Figure 6.1 Transportation fatality distribution by mode 2002. (From USDOT, 2004.)

6.1 BASIC DEFINITIONS AND FACTORS OF TRANSPORTATION SAFETY

6.1.1 Definition of a Crash

The most basic unit for measuring transportation safety is a crash. A *crash* can be defined as a collision involving at least one moving transportation vehicle (car, truck, plane, boat, railcar, etc.) and another vehicle or object. Transportation crashes are typically caused by factors such as driver, pilot, or operator error, mechanical failure, and poor design of the guideway, roadway, waterway, or runway. A crash can also involve noncollision off the transportation path, such as a vehicle rollover.

6.1.2 Transportation Crashes Classified by Severity

On the basis of severity, transportation crashes are broadly classified into three categories:

1. A *fatal crash* is one where the highest casualty level is a fatality.
2. An *injury crash* is one where the highest casualty level is a nonfatal injury.
3. A *property-damage-only crash* is one that involves a loss of all or part of the transporting vehicle and/or property, but no injury or fatality.

Transportation crashes can also be scaled on the basis of the extent of injury. For example, for highway crashes, two commonly used injury scales are the abbreviated injury scale (AIS) and the KABCO injury scale.

(*a*) *Abbreviated Injury Scale for Crash Severity* Introduced in 1969 by the Association for the Advancement of Automotive Medicine, the AIS is an anatomical scoring system and ranks injuries on a scale that represents the “threat to life” associated with an injury (Table 6.1). The AIS score of the most life-threatening injury [i.e., the maximum AIS or (MAIS)] is often used to describe the type and extent of injury sustained by one or more persons involved in the crash.

(*b*) *KABCO Injury Scale* Established by the American National Standards Institute, the KABCO injury scale (Table 6.2) is designed for police coding of crash details at a crash scene. The coding does not require medical expertise—the police officer at the crash scene assesses the sustained injuries and assigns a code depending on the level of severity. The KABCO system has faced some criticism because it does not always classify injuries classification in a consistent manner (e.g., the code assigns equal severity to a broken arm and a severed spinal cord). Therefore, in a bid to reduce the variability in reporting, the National Highway Traffic Safety Administration (NHTSA) uses both AIS and KABCO scales to describe transportation injuries.

6.1.3 Categories of Factors Affecting Transportation Crashes

Figure 6.2 shows the categories of factors that affect the frequency and severity of transportation crashes. This is followed by a brief discussion of each factor category.

Table 6.1 Abbreviated Injury Scale

Code	Severity	Description
AIS 6	Fatal	Loss of life due to decapitation, torso transaction, massively crushed chest, etc.
AIS 5	Critical	Spinal chord injury, excessive second- or third-degree burns, cerebral concussion (unconscious more than 24 hours)
AIS 4	Severe	Partial spinal cord severance, spleen rupture, leg crush, chest wall perforation, cerebral concussion (unconscious less than 24 hours)
AIS 3	Serious	Major nerve laceration; multiple rib fracture, abdominal organ contusion; hand, foot, or arm crush/amputation
AIS 2	Moderate	Major abrasion or laceration of skin, cerebral concussion finger or toe crush/amputation, close pelvic fracture
AIS 1	Minor	Superficial abrasion or laceration of skin, digit sprain, first-degree burn, head trauma with headache or dizziness
AIS 0	Uninjured	No injury

Source: Blincoe et al. (2002).

Table 6.2 KABCO Scale for Crash Severity

Code	Severity	Injury Description
K	Fatal	Any injury that results in death within 30 days of crash occurrence
A	Incapacitating	Any injury other than a fatal injury which prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred (e.g., severe lacerations, broken limbs, damaged skull)
B	Injury evident	Any injury other than a fatal injury or an incapacitating injury that is evident to observers at the scene of the crash in which the injury occurred (e.g., abrasions, bruises, minor cuts)
C	Injury possible	Any injury reported that is not a fatal, incapacitating, or nonincapacitating evident injury (e.g., pain, nausea, hysteria)
O	Property damage only	Property damage to property that reduces the monetary value of that property

Source: NSC (2001).

(a) Environmental Factors Environmental conditions such as poor visibility, high winds, rain and snow storms, ice on a roadway or runway or on airplane wings, animals that cross vehicle paths, and birds that get sucked into plane engines are significant factors of transportation crashes.

(b) Engineering Factors Unfavorable roadway or guideway geometry (e.g., dimensions, alignment, sight distances) and topography (e.g., steep grades, mountain passes) are often associated with frequent crashes. Also, the poor condition of roadway or runway pavement surfaces (surface defects, low skid resistance, and so on) and of the guideway (deteriorated, deformed, or cracked guideway elements) can lead to crashes. Furthermore, for surface transportation, the absence of crash barriers at high embankments and other hazardous sites contribute to crash occurrence. The operational or usage characteristics of the transportation facility also influence the crash experience. For example, crash rates may be expressed as a function of the congestion level of the transportation facility (AASHTO, 2003). The analysis of safety impacts of transportation investments proceeds on the premise that such investments, besides their primary objective of facility preservation or capacity expansion, also enhance user

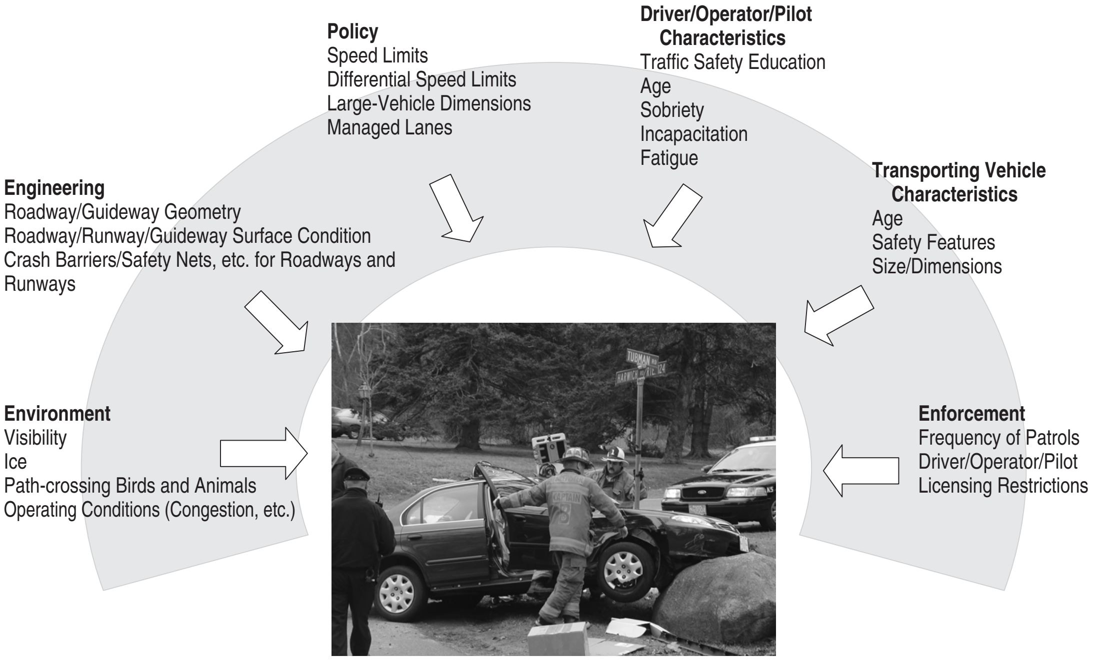

Figure 6.2 Factors affecting transportation crash occurrence and severity. (Photo courtesy of Peter Gene, Creative Commons Attribution-ShareAlike 2.0.)

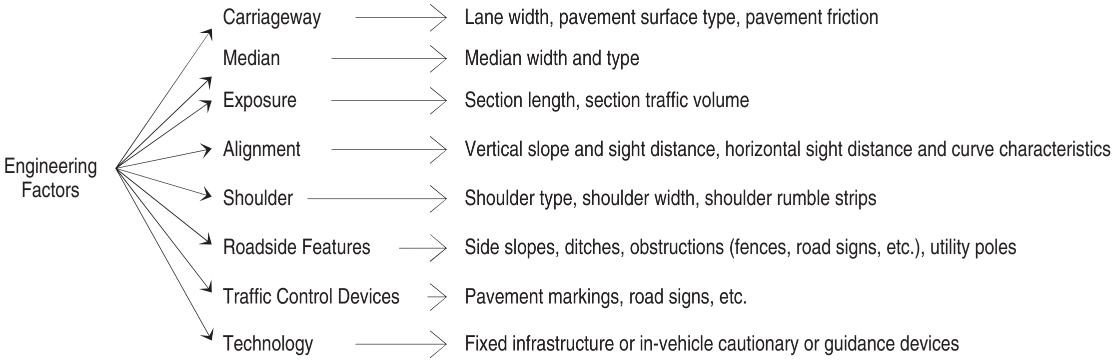

Figure 6.3 Engineering factors of highway transportation crashes.

safety. Interventions typically result in improved physical characteristics and dimensions and enhanced operational performance of the transportation facility, and the safety benefits of interventions are more visible particularly where the preintervention features are below established standards. The engineering factors that affect highway traffic safety are shown in Figure 6.3.

The safety impacts of changes in engineering factors are typically expressed in terms of crash reduction factors or accident modification factors. A *crash reduction factor* indicates the extent by which crashes are reduced in response to a specific intervention or improvement that enhances the safety-related engineering features of the facility. For example, if the crash reduction factor of shoulder widening is 10%, a road section that currently has narrow shoulders and experiences 50 crashes per year can be expected to have a reduction of 5 crashes per year after shoulder widening. An *accident modification factor* for a certain safety condition (e.g., addition of shoulders) is a factor that is multiplied with the number of crashes predicted for a base situation (e.g., absence of shoulders) to obtain the number of crashes that can be expected for the alternative situation (presence of shoulders). For highway transportation, improvements include enhancements to the carriageway, shoulder, median, alignment, roadside hazard elimination, and traffic control devices. Also technological devices may be embedded in the facility or placed in vehicles to serve as warning devices in case of hazardous situations. In many cases, the extent of crash reduction is not fixed but varies, depending on the extent of the improvement and the defect severity (e.g., widening a narrow lane by 2 ft may yield a higher crash reduction than widening the same lane by 1 ft; also, widening a narrow lane by 1 ft may yield a higher crash reduction than widening a wide lane by the same margin). Typically, crash reduction functions are discussed from the perspective of engineering improvements, but the concept could be extended to improvements in other crash factors, such as policy, enforcement, vehicle, and operator characteristics.

From the perspective of transportation systems evaluation, engineering factors are considered particularly pertinent because (a) enhancements in such factors can help reduce the crash contributions of the other crash factors (for example, enhanced facility condition or alignment renders the overall transportation operating environment more forgiving of operator error or limitations, vehicle inadequacies, and poor environmental conditions) and (b) engineering factors, to a greater extent compared to other crash factors, are within the direct control of transportation agencies.

(c) Policy Factors Recent years have seen increased attention to national policies such as sobriety laws for airline pilots, truck and transit operators, a 10-hour driving limit for truck drivers, seat belt use, and helmet use (for motorcycles). The most visible, yet probably most contentious policy factor in highway safety is that of speed limits. Policies that result in changed speed limits or establishment of speed differentials by vehicle class may lead to changes in crash rates and severities, depending on highway functional class, crash severity type, existing speeds, and other factors. Other policy factors that may influence safety include the managed lanes concept, which reduces the size heterogeneity of traffic—a traffic stream that is comprised of vehicles of uniform size may be safer than one that consists of vehicles of different sizes.

(d) Driver Characteristics Crashes are also influenced by characteristics of drivers, operators, and pilots of transportation vehicles, such as age and gender (Islam and Mannering, 2006), experience, and alcohol or drugs. Kweon and Kockleman (2003) showed that in road transportation, for example, young and middle-aged men are slightly more likely to have a crash than their female counterparts, but the opposite is true for older age groups. Also, younger and older drivers tend to have relatively high crash rates per vehicle-mile. Furthermore, professional drivers (operators of trucks, buses, taxis, etc.) generally have low "per mile" crash rates but relatively high "per vehicle-year" crash rates because of their relatively large amounts of travel. Intoxicated drivers tend to have crash rates (crashes per vehicle-mile) that far exceed those of sober drivers; approximately one-third of all traffic fatalities involve at least one intoxicated driver.

(e) Vehicle or Mode Characteristics Vehicle design features affect crash frequency and severity. Differences in size, weight, and shape of vehicles in a traffic stream can increase the likelihood of collisions. Also, occupants in passenger cars are twice as likely to have fatalities as those in larger and heavier vehicles. Newer vehicles tend to have design features and safety equipment that provide greater crash protection than that of older models, thus reducing crash severity, if not frequency. Recent research suggests that some drivers in vehicles with more safety features tend to drive more aggressively thus offsetting the intended benefits of safety features (Winston et al., 2006). Buses and other transit vehicles tend to have low crash rates per mile and have low injury rates for their occupants. Sport utility vehicles and large vans tend to have a high rate of rollover crashes, and motorcyclists, bicyclists, and pedestrians tend to have greater injuries when involved in a crash.

(f) Enforcement Factors The frequency of patrols and the establishment of effective driver education and licensing restrictions generally help to improve safety. Also, the higher severity of penalties for traffic infractions generally tends to encourage operator responsibility and thus can increase traffic safety.

6.2 PROCEDURE FOR SAFETY IMPACT EVALUATION

For purposes of evaluating the safety impacts of transportation projects (by comparing the "with" and "without improvement" scenarios), this chapter focuses on the engineering factors. The overall framework (Figure 6.4) revolves around three tasks:

1. Estimating the extent to which relevant engineering factors (or aggregated combination thereof) would be changed (such as lane-width increase)
2. Ascertaining the impact of each unit change of the engineering factor on crash reduction
3. From the results of tasks 1 and 2, computing the overall change in crashes expected due to the given intervention

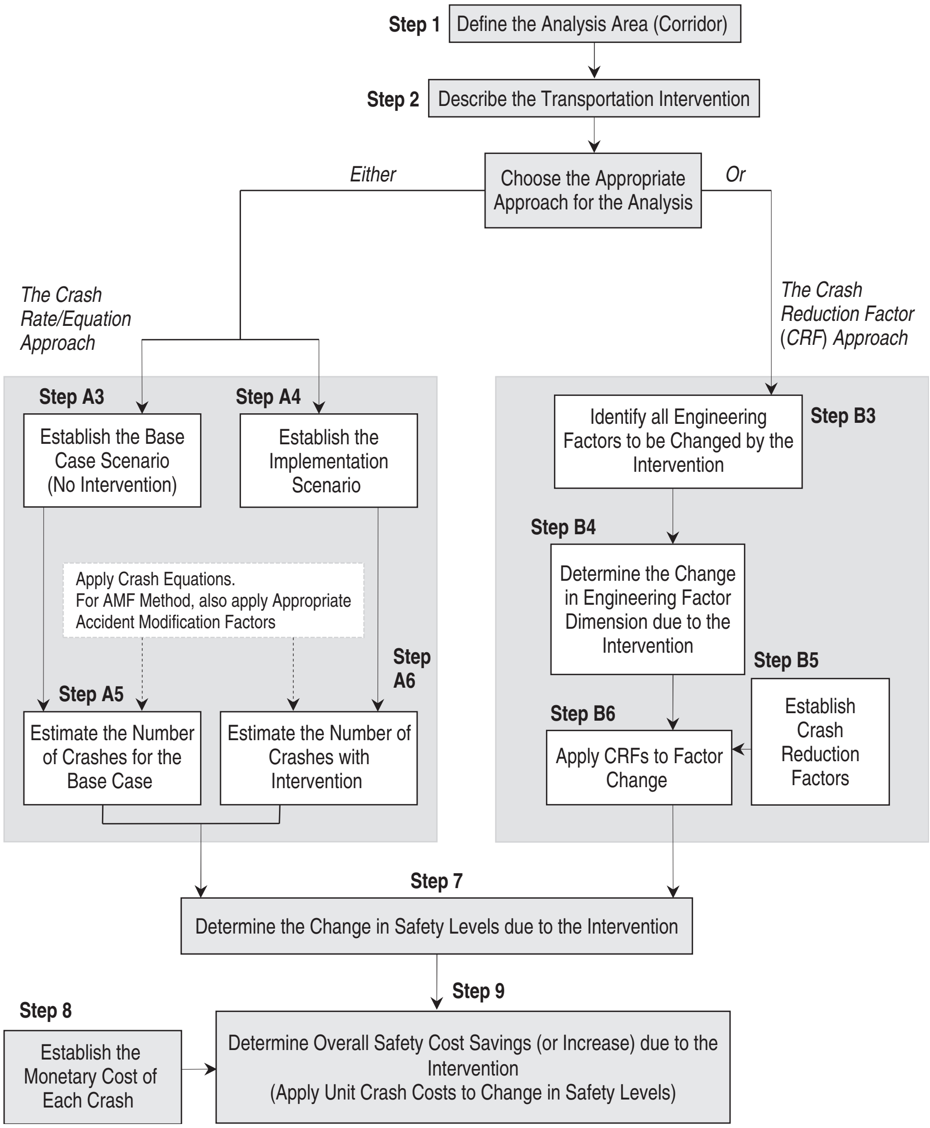

Figure 6.4 Framework for estimating safety impacts of transportation interventions.

The alternative to the use of crash reduction factors is one that involves an implicit or explicit combination of factors (such as road class) where existing crash rates or equations are used to determine the safety levels (number of crashes) for the "with improvement" and "without improvement" states of the facility. The steps of the framework for evaluating the safety impacts of transportation improvements are presented next.

Step 1: Define the Analysis Area Typically, only a specific transportation facility (e.g., road section or intersection) is analyzed. At the network level, the safety impacts of a systemwide transportation policy or other intervention can be evaluated by dividing the network into individual facility (or families of facilities) and carrying out the analysis for each facility.

Step 2: Describe the Intervention

(a) *Transportation Intervention* A transportation intervention or improvement may expand the capacity of the transportation system; improve the operational performance of the system; preserve the fixed assets by improving, for instance, roadway, runway, or guideway condition; upgrade the transportation facility to a higher class; preserve rolling stock (to improve the condition of mobile assets, thus lessening the likelihood of mechanical failure); or a policy-related intervention.

(b) *Approach for the Evaluation* There are two alternative approaches to determining the safety impacts of an intervention: *crash rate/crash equation approach*, and the *crash reduction factor approach*.

The choice of approach is dictated by the type of data and models that are available. Where only crash rates or crash equations are available, using the crash rate/crash equation approach (see the left-hand shaded box in Figure 6.4) may be preferable. Where detailed crash reduction factors for each engineering factor are available, the crash reduction factor approach can be used (see the right-hand shaded box in Figure 6.4).

Steps 3 to 6: Estimate the Crash Frequency Steps 3 to 6 involve estimation of the number of crashes with and without the improvement. There are a number of ways of doing this (see step 2): Using crash rates, crash equations with and without accident modification factors, or crash reduction factors (Figure 6.5). For the crash rates, the constant a is the crash rate for each category of facility. For the crash equations, the variable VMT is a measure of exposure in terms of traffic volume (AADT) and section length, and the vector $\mathbf{X}_i$ refers to various engineering features, such as the width of a lane, shoulder, or median; shoulder type; horizontal and vertical curve characteristics; and left-turn provisions. Most engineering features have an associated factor for crash reduction or accident modification (Appendix A6).

(a) *Crash Rate–Crash Equation Approach* Details of this approach are as follows:

1. Establish the function that gives the expected safety levels of each family of facilities. This may be in the form of *average crash rate values* (crashes per VMT, crashes per mile, or crashes per AADT) (examples provided in Table 6.3), or *regression equations that estimate crash frequencies or rates* as functions of the operating and physical characteristics of the facility (examples provided in Table 6.4).
2. Determine the values of the independent variables (representing the state of each engineering factor) as they pertain to the facility in question. If the crash rate method is being used, this step involves determination of the exposure or usage. For example, Figure 6.5 shows the determination of the number of crashes if VMT is used as a measure of exposure. If a regression equation is being used, determine the values of each variable in the regression equation, such as section VMT, lane width, shoulder type, and so on. This is done for both the base case (without the improvement) and the intervention case (with the improvement).
3. Substitute the given levels of the independent variables or exposure into the crash equation or crash rates to determine the total safety levels (number of crashes). This is done for both the without-improvement and with-improvement situations. For the existing without-improvement situation, the actual number of crashes, if known, may be used instead of estimating it from the table or the equation. Due to data aggregation, the crash rate approach may yield less precise estimates of safety impacts than the crash equation approach.

Example 6.1 A 6-mile urban "minor arterial" highway section is to receive major upgrading that will improve the design standards to the freeway and expressway category. Assume that crash reduction factors for the individual treatments associated with the upgrade are unknown, and crash prediction equations for both facility types are not available. Estimate the number of crashes with and without the upgrade. Assume traffic volumes of 7520 and 7800 vehicles per day (vpd) before and after the upgrade, respectively.

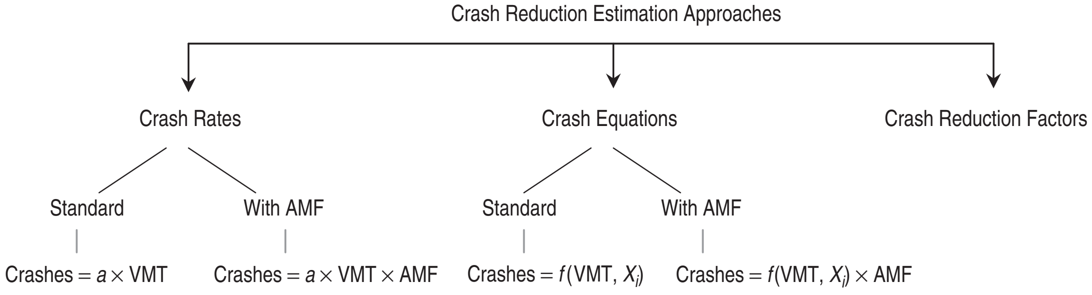

Figure 6.5 Approaches for estimating reduction of crash frequency (for steps 3 to 6).

Table 6.3 Motor Vehicle Traffic Fatality and Injury Rates by Functional Class

		Number of Crashes (per 100 million VMT)	
Area Class	Functional Class	Fatal	Non-Fatal
Rural	Interstate	1.05	25.08
	Other principal arterial	1.96	50.87
	Minor arterial	2.33	70.52
	Major collector	2.51	86.79
	Minor collector	3.16	106.02
	Local	3.52	147.79
Urban	Interstate	0.56	46.56
	Other freeway & expressway	0.75	68.60
	Other principal arterial	1.30	124.69
	Minor arterial	1.08	126.89
	Collector	1.00	104.95
	Local	1.33	194.40

Source: FHWA (1998).

Table 6.4 Selected Crash Estimation Functions

Facility	Equation
Urban freeways (AASHTO, 2003)	$\%\Delta C = 100\left[\dfrac{3.0234\,(V_1/C_1) - 1.11978\,(V_1/C_1)^2}{3.0234\,(V_0/C_0) - 1.11978\,(V_0/C_0)^2} - 1\right]$ $\%\Delta C$ = percentage change in crash rate (crashes per VMT) V_0, C_0 = volume and capacity of highway without improvement (pcphpl) V_1, C_1 = volume and capacity of highway with improvement (pcphpl)
Urban, four-leg signalized intersections (Bauer and Harwood, 2000)	Total crashes $Y = e^{-3.428}(X_1)^{0.224}(X_2)^{0.503}\exp(0.063X_{19} + 0.622X_{20} - 0.2X_{21} - 0.310X_5 - 0.13X_{22} - 0.053X_{16} - 0.115X_{11} - 0.225X_3 - 0.13X_{17})$ Fatal + injury crashes $Y = e^{-5.745}(X_1)^{0.215}(X_2)^{0.574}\exp(-0.051X_{19} + 0.4X_{20} - 0.240X_{21} - 0.290X_5 - 0.155X_{22} - 0.163X_3 - 0.151X_{17} + 0.005X_4)$ Y = expected number of total multiple-vehicle accidents in a three-year period X_1 and X_2 = average daily traffic (veh/day) on minor and major road, respectively X_{19} = pretimed signal timing design X_{20} = fully actuated signal timing design X_{21} = 1 if multiphase (>2) signal timing, 0 otherwise X_5 = 1 if no access control on major road; 0 otherwise X_{22} = number of lanes on minor road X_3 = 1 if major road has ≤ 3 through lanes in both directions of travel combined; 0 otherwise X_{17} = 1 if major road has 4 or 5 through lanes in both directions of travel combined; 0 otherwise X_4 = design speed on major road (mph)

Table 6.4 (*continued*)

Facility	Equation
Urban, four-leg intersections with stop control on the minor road (Bauer and Harwood, 2000)	Total crashes $Y = e^{-4.664}(X_1)^{0.281}(X_2)^{0.620}\exp(-0.941X_{15} - 0.097X_{16} + 0.401X_3 + 0.120X_{17}$ $-0.437X_5 - 0.384X_{11} - 0.160X_8 - 0.153X_6 - 0.229X_7)$ Fatal + injury crashes $Y = e^{-4.693}(X_1)^{0.206}(X_2)^{0.584}\exp(-0.747X_{15} - 0.081X_{16} - 0.382X_5 + 0.282X_3$ $+0.049X_{17} - 0.020X_{14} - 0.3X_{11} - 0.079X_6 - 0.401X_7)$ Y = expected number of total multiple-vehicle accidents in a three-year period X_1 and X_2 = average daily traffic (veh/day) on minor and major road, respectively $X_{15} = 1$ if left turns are prohibited; 0 otherwise X_{16} = average lane width on major road (ft) $X_3 = 1$ if major road has ≤ 3 through lanes in both directions of travel combined; 0 otherwise $X_{17} = 1$ if major road has 4 or 5 through lanes in both directions of travel combined; 0 otherwise $X_5 = 1$ if no access control on major road; 0 otherwise $X_{11} = 1$ if there is no free right-turn lane; 0 otherwise $X_8 = 1$ if the intersection has no lighting; 0 otherwise $X_6 = 1$ if minor arterial; 0 otherwise $X_7 = 1$ if major collector; 0 otherwise X_{14} = outside shoulder width on major road (ft)
Urban, three-leg intersections with stop control (Bauer and Harwood, 2000)	Total crashes $Y = e^{-5.557}(X_1)^{0.245}(X_2)^{0.683}\exp(-0.559X_{11} - 0.402X_{15} + 0.019X_{12} + 0.210X_{13}$ $-0.006X_4 - 0.147X_{18} - 0.037X_{16})$ Fatal + injury crashes $Y = e^{-6.618}(X_1)^{0.238}(X_2)^{0.696}\exp(-0.581X_{11} - 0.393X_{15} - 0.057X_{12} + 0.209X_{13}$ $-0.182X_{18} - 0.048X_{16} + 0.094X_{18})$ Y = expected number of total multiple-vehicle accidents in a three-year period X_1 and X_2 = average daily traffic (veh/day) on minor and major road, respectively $X_{11} = 1$ if there is no free right-turn lane; 0 otherwise $X_{15} = 1$ if left turns are prohibited; 0 otherwise $X_{12} = 1$ if there is no left-turn lane; 0 otherwise $X_{13} = 1$ if there is a curbed left-turn lane; 0 otherwise X_{18} = presence of median of major road; 0 otherwise X_{16} = average lane width on major road $X_8 = 1$ if the intersection has no lighting; 0 otherwise
Highway segments (Forkenbrock and Foster, 1997)	$Y = e^{0.517 \times 0.972^{\mathrm{PSR}} \times 1.068^{\mathrm{TOPCURVE}} \times 1.179^{\mathrm{PASSRES}} \times 1.214^{\mathrm{ADTLANE}} \times 0.974^{\mathrm{RIGHTSH}} \times 0.933^{\mathrm{LANES}} \times 1.051^{\mathrm{TOPGRAD}}}$ Y = Crash rate in millions of VMT PSR = present serviceability rating of the pavement surface ranging from 0 (failed) to 5 (excellent) TOPCURV = the severity of the worst horizontal curve ranging from 0 (no curve) to 12 (sharpest curve)

(*continued overleaf*)

Table 6.4 (*continued*)

Facility	Equation
	PASSRES = dummy variable representing the presence/absence of passing restrictions (1/0, respectively) ADTLANE = hourly traffic volume in thousands per lane RIGHTSH = right shoulder width (ft) LANES = dummy variable representing the number of lanes (1 for 4 lanes, 0 for 2 lanes) TOPGRAD = measure of the average vertical grade ranging from 0 (no grade) to 12 (severe grade)
Rural FLSC (four-leg stop-controlled) intersections at rural two-lane highways (Bauer and Harwood, 2000)	Total crashes $Y = e^{-10.025}(X_1)^{0.532}(X_2)^{0.758}\exp(0.321X_3 + 0.009X_4 + 0.2X_5 + 0.181X_6 + 0.173X_7 + 0.122X_8 + 0.053X_9 - 0.159X_{10} + 0.157X_{11})$ Fatal + injury crashes $Y = e^{-10.294}(X_1)^{0.546}(X_2)^{0.680}\exp(0.385X_3 + 0.013X_4 + 0.183X_9 - 0.234X_{10} + 0.261X_6 + 0.170X_7 + 0.219X_8)$ Y = expected number of total multiple-vehicle accidents in a three-year period X_1 and X_2 = average daily traffic (veh/day) on minor and major road, respectively $X_3 = 1$ if major road has ≤ 3 through lanes in both directions of travel combined; 0 otherwise X_4 = design speed on major road (mph) $X_5 = 1$ if no access control on major road; 0 otherwise $X_6 = 1$ if minor arterial; 0 otherwise $X_7 = 1$ if major collector; 0 otherwise $X_8 = 1$ if the intersection has no lighting; 0 otherwise $X_9 = 1$ if surrounding terrain is flat; 0 otherwise $X_{10} = 1$ if surrounding terrain is mountainous; 0 otherwise $X_{11} = 1$ if there is no free right-turn lane; 0 otherwise
Rural TLSC (three-leg stop-controlled) intersections at rural two-lane highways (Bauer and Harwood, 2000)	Total crashes $Y = e^{-9.178}(X_1)^{0.383}(X_2)^{0.830}\exp(0.213X_{12} + 0.124X_{13} + 0.225X_5 + 0.145X_6 + 0.211X_7 - 0.017X_{14} - 0.045X_9 + 0.095X_{10})$ Fatal + injury crashes $Y = e^{-9.141}(X_1)^{0.384}(X_2)^{0.781}\exp(-0.03X_{14} + 0.169X_8 + 0.180X_{12} + 0.062X_{13} + 0.164X_6 + 0.192X_7 - 0.219X_{11})$ Y = expected number of total multiple-vehicle accidents in a three-year period X_1 and X_2 = average daily traffic (veh/day) on minor and major road, respectively $X_{12} = 1$ if there is no left-turn lane; 0 otherwise $X_{13} = 1$ if there is a curbed left-turn lane; 0 otherwise $X_5 = 1$ if no access control on major road; 0 otherwise $X_6 = 1$ if minor arterial; 0 otherwise $X_7 = 1$ if major collector; 0 otherwise X_{14} = outside shoulder width on major road (ft) $X_9 = 1$ if surrounding terrain is flat; 0 otherwise $X_{10} = 1$ if surrounding terrain is mountainous; 0 otherwise $X_8 = 1$ if the intersection has no lighting; 0 otherwise $X_{11} = 1$ if there is no free right-turn lane; 0 otherwise.

SOLUTION As no safety information is available for the highway section or the local region, national crash rates associated with highway classes can be used. From Table 6.3, the average crash rates for the initial highway class (urban minor arterial) as well as for the class to which it will be upgraded (other freeway and expressway), an approximation of expected crashes for each scenario can be determined as follows:

Without improvement:

$$\begin{aligned}&\text{For urban minor arterials, rate of fatal crashes}\\&\quad= 1.08 \text{ per } 10^8 \text{ VMT}\\&\text{Annual VMT} = (7520)(6)(365) = 16{,}468{,}800\\&\text{Number of fatal crashes expected per annum}\\&\quad= (1.08)(10^{-8})(16{,}468{,}800) = 0.18\end{aligned}$$

With improvement:

$$\begin{aligned}&\text{For urban freeways and expressways, rate of fatal crashes}\\&\quad= 0.75 \text{ per } 10^8 \text{ VMT}\\&\text{Annual VMT} = (7800)(6)(365) = 17{,}082{,}000\\&\text{Number of fatal crashes expected per annum}\\&\quad= (0.75)(10^{-8})(17{,}082{,}000) = 0.13\end{aligned}$$

Example 6.2 The monthly PDO crash frequency prediction equation for rural principal arterials in a certain state is

$$\begin{aligned}\text{PDO crashes} = {} & 0.8921 + 0.7097\ln(\text{LENG})\\& + 0.2409\ln(\text{AADT}) - 0.1128\text{LW}\\& - 0.0676\text{SW} - 0.0624\text{PSI}\\& - 0.0553\text{ARAD} + 0.0646\text{AGRAD}\end{aligned}$$

where ln(L ENG) = the natural logarithm of section length (miles), ln(AADT) = the natural logarithm of section traffic volume, LW = the lane width (feet), SW = shoulder width (ft), PSI = present serviceability index (a measure of pavement condition), ARAD = average radius (tens of ft) of all horizontal curves, and AGRAD = average grade of vertical curves (%).

Table EX6.2 shows the improvement of specific road factors after a major rehabilitation of a major rural principal arterial.

Table E6.2 Change in Road Factors

	Without Improvement	With Improvement
Lane width (ft)	8	10
Shoulder width (ft)	2	4
Pavement condition (PSI)	3	4
Horizontal alignment (average curve radius, ft)	500	600

Assume that all other roadway factors are not changed significantly by the improvement (section length = 20 miles, traffic volume = 75,254 vpd, average vertical grade = 1.3%). Estimate the expected number of crashes with and without the improvement.

SOLUTION Without the improvement, the number of property-damage crashes is

$$\begin{aligned}&0.8921 + (0.7097 \times \ln 20) + (0.2409 \times \ln 75{,}254)\\&\quad - (0.1128 \times 8) - (0.0676 \times 2) - (0.0624 \times 3)\\&\quad - (0.0553 \times 500/10) + (0.0646 \times 1.3) = 1.65\end{aligned}$$

With the improvement, the number of property-damage crashes is

$$\begin{aligned}&0.8921 + [0.7097 \times \ln 20) + (0.2409 \times \ln 75{,}254)\\&\quad - (0.1128 \times 10) - (0.0676 \times 4) - (0.0624 \times 4)\\&\quad - (0.0553 \times 600/10) + (0.0646 \times 1.3) = 0.67\end{aligned}$$

Example 6.3 In a bid to reduce congestion, it is proposed to add a lane to an existing urban freeway that currently has a volume–capacity (v/c) ratio of 1.15. It is expected that after the capacity expansion, the v/c ratio would fall to 0.75. Determine the percentage change in crash rate.

SOLUTION

$$\frac{V_0}{C_0} = \text{volume–capacity ratio without improvement} = 1.15$$

$$\frac{V_1}{C_1} = \text{volume–capacity ratio with improvement} = 0.75$$

Using the equation in Table 6.4, the reduction in crash rate is given by

$$\begin{aligned}\%\Delta C &= (100)\left[\frac{(3.0234)(0.75) - (1.11978)(0.75)^2}{(3.0234)(1.15) - (1.11978)(1.15)^2} - 1\right]\\&= 17.95\%\end{aligned}$$

(b) *The Accident Modification Factor Approach* In this approach, the established crash rates or equations, such as those shown in Tables 6.3 and 6.4, are multiplied by a factor [the accident modification factor (AMF)] that represents the safety improvement to yield a new frequency of crashes. AMFs are the incremental effects of safety of specific elements of traffic control and highway design. The AMF for a nominal or base element is 1.00. A set of elements associated with a higher crash experience than the nominal condition has an AMF exceeding 1.00, and another set that has a lower crash experience than the nominal has an AMF of less than 1.00.

For a transportation improvement under evaluation, AMF is given by the ratio of the AMF of the with-intervention scenario to the AMF without intervention. Thus, for a project that has an AMF of 90%, one can expect crashes to be reduced by 10%.

The use of crash rates with AMF is relatively straightforward—the accident modification factor represents all the safety impacts associated with improvement related to the various engineering features. If the AMF applies only to certain crash types or patterns (also referred to as *related crashes*), certain adjustments are necessary to obtain the AMF on all crashes (Harwood et al., 2003). Example 6.4 shows how AMF values could be used to adjust the number of crashes predicted on the basis of crash rates. The general procedure is similar to that for crashes predicted using crash equations. A caution: The specific road feature whose AMF factor is being used must not be present as an independent variable in the crash prediction model—doing so would mean double-counting its effects. NCHRP's *Research Results Digest 229* (Harkey et al., 2004) provides a comprehensive list of AMFs for various traffic engineering and ITS improvements (some of these are presented in Table A6.3.).

Example 6.4 A rural 6-mile-long minor arterial road segment has a traffic volume of 10,000 per day. As part of a corridor improvement project, the existing shoulder width is widened from 2 ft to 6 ft. Estimate the number of fatal crashes with and without improvement. Use the crash rates in Table 6.3 and the accident modification factors in Appendix Table A6.4. Assume that the VMT remains the same.

SOLUTION From Table 6.3, the fatal crash rate for rural minor arterials = 2.33 per 100 million VMT.

Without improvement:

$$\text{Expected number of fatal crashes} = \frac{(2.33)(10{,}000)(365)(6)}{100 \times 10^6} 0.57 = 0.51$$

$$\text{Accident modification factor for 2-ft shoulders} = (1.30)$$

$$\text{Modified expected number of fatal crashes} = (0.51)(1.30) = 0.66$$

With improvement:

$$\text{Expected number of fatal crashes} = \text{same as above} = 0.51$$

$$\text{Accident modification factor for 6-ft shoulders} = 1.00$$

$$\text{Modified expected number of fatal crashes} = (0.51)(1.00) = 0.51$$

(c) *Crash Reduction Factor Approach*

(c1) Identify all engineering factors that are likely to be changed by the intervention. For example, highway improvements may add lanes, increase lane width, improve pavement surface friction, remove road side obstacles, and so on.

(c2) Establish the extent to which each relevant engineering factor (identified in step c1) will be changed by the intervention.

(c3, c4) Obtain the crash reduction factors for improvements in individual crash factors. The crash reduction factor (CRF) for each improvement is a measure of the efficacy of that improvement in reducing crashes associated with deficient levels of the corresponding engineering factor. It is calculated simply as the percentage decrease in the number of crashes:

$$\text{CRF} = \frac{C_{\text{WO}} - C_{\text{W}}}{C_{\text{WO}}} \times 100 = \left(1 - \frac{C_{\text{W}}}{C_{\text{WO}}}\right) \times 100$$

where C_{WO} is the number of crashes *without* the improvement and C_{W} is the number of crashes *with* the improvement.

Alternatively, C_{WO} and C_{W} can be defined as follows: C_{WO} is the average number of crashes at all sites that *lack* the improved feature at a given time and C_{W} is the average number of crashes at all otherwise similar sites that *have* the improved feature at the same time. C_{WO} and C_{W} are given or are estimated from crash prediction models.

For example, a CRF of 0.2 for shoulder paving means that if an unpaved shoulder were to be paved, a 20% reduction in crashes is expected. Obviously, most crash reduction factors are only average values, because the efficacy of the improvement would depend on the extent of the treatment (widening an 8-ft lane to 10 ft and widening a 8-ft lane to 12 ft will have different crash reduction effects) as well as the existing severity of the factor deficiency (widening a 8-ft lane to 10 ft will yield a crash reduction that is different from that of widening a 10-ft lane to 12 ft).

Many highway agencies have established a set of crash reduction factors for each safety countermeasure and extent thereof. When local or national data on crash reduction factors are not available, the analyst can collect field data or use an existing relevant data set to develop crash prediction equations from which crash reduction factors can be established using the procedures described in Section 6.3.

Example 6.5 An intersection improvement project in a certain city is proposed. It involves the provision of left-turn lanes at the signalized intersection between two major urban arterials. Also, the signal timing was redesigned to include a dedicated green phase for left turns. Currently, there are 6 fatal or injury crashes per year at the intersection over a three-year period. What reduction in fatal or injury crashes can be expected due to the project? Assume that the effects of such improvements on safety are mutually exclusive and complementary.

SOLUTION If C_{W} and C_{WO} are the number of crashes at similar sites that are with improvement and without improvement, respectively, at a given time, the crash reduction can be given by

$$\mathrm{CRF} = \frac{C_{\mathrm{WO}} - C_{\mathrm{W}}}{C_{\mathrm{WO}}} \times 100$$

From Table A6.1, the appropriate CRF is 0.53.

$$\Rightarrow C_{\mathrm{WO}} - C_{\mathrm{W}} = \frac{\mathrm{CRF} \times C_{\mathrm{WO}}}{100} = \frac{(53)(6)}{100} = 3$$

Estimated number of crashes saved due to improvement = 3 crashes per year.

Example 6.6 As part of a major corridor expansion project to facilitate international freight and passenger travel, a stretch of an existing multilane urban minor arterial highway is to have a median installed (full restriction of access between opposing lanes) and full control of access from local roads. Also, the pavement is to be resurfaced to improve its skid resistance. Determine the safety impacts of the corridor improvement project in terms of total crashes. Without the improvement, the total number of all crashes over a three-year period is 23.

SOLUTION From Table A6.1, the crash reduction factors are as follows:

$$\text{Median installation}: 25\% \rightarrow 6 \text{ crashes saved}$$

$$\text{Resurfacing(to improve surface friction)}: 10\% \rightarrow 2 \text{ crashes saved}$$

$$\text{Total reduction in total crashes} = 6 + 2 = 8$$

$$\text{Number of crashes after improvements} = 23 - 8 = 15$$

Therefore, there are 23 and 15 crashes without and with improvement, respectively, over a three year period.

Final Comments on Steps 3 to 6: In these steps, the analyst estimates the expected number of crashes using one of many alternative approaches. Although a few aspects deal with predictions of frequencies of specific crash types (Table 6.4), the discussion is generally for total crashes. In cases where separate models for different crash severities are unavailable and where the analyst needs to segregate all predicted crashes by severity type (for purposes of costing or reporting), approximate distributions from past crash histories may be used. Such distributions are expected to vary from region to region and also across transportation facilities that differ by class, location, and so on. For highway facilities, a rough guide for the distribution of total crashes, for planning purposes, is as follows (Labi, 2006): fatal crashes, 0.5 to 1%; injury crashes, 20 to 30%; PDO crashes, 70 to 80%.

Step 7: Determine the Safety Benefits Crash cost is one of the several categories of user costs that decrease with improved facility or safer roadway. When demand is elastic, there will be an increase in demand due to the shift in the supply curve, reflecting improved safety, that is, reduced safety cost of transportation (Figure 6.6). Therefore, in case of elastic demand, the safety benefits of a transportation intervention can be calculated as follows: safety savings $= (0.5)(U_1 - U_2)(V_1 + V_2)$, where U_1 and U_2 are the unit safety rates or "costs" (number of crashes per million VMT per year, for example) without and with the improvement, and V_1 and V_2 are the travel demand values (millions of VMT) without and with the improvement, respectively. When demand is inelastic, user safety benefit occurring from an improved transportation system is taken as the product of the reduction in the unit safety cost of travel and the (quantity) of travel demand (millions of VMT per year).

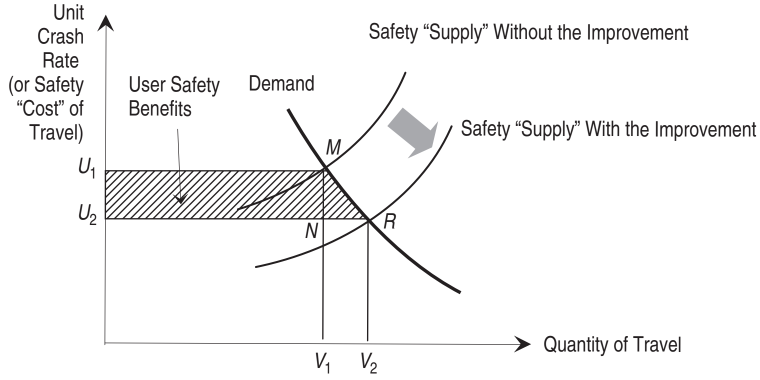

Figure 6.6 User benefits of increased safety due to a transportation intervention.

Step 8: Establish the Unit Monetary Crash Cost When safety benefits are expressed in terms of the number of reduced crashes per VMT, the corresponding monetary cost savings is determined as the product of the *crash reduction per VMT* and the *unit monetary crash cost* to yield the dollars saved per VMT. The unit monetary cost of crashes is a function of (1) market or economic costs, which include property damage, insurance and legal costs, medical costs, and lost productivity, and (2) nonmarket costs, the emotional and social costs of casualties resulting from road crashes (Lindberg and Borlänge, 1999; Miller et al., 2000). To estimate the cost of a road crash. Blincoe et al. (2002) examined the economic cost of motor vehicle crashes to society using the human capital approach by discounting to present value the victim's income that is foregone due to the victim's premature death or injury. Loehman et al. (2000) applied the willingness-to-pay (WTP) approach to estimate the value of pain, grief, suffering, and uncompensated lost time resulting from crash-related injuries. Lindberg and Borlänge (1999) used the concept of marginal external costs to estimate the cost of road crashes. The marginal external costs are the incremental costs of a crash borne by society at large, including family and friends, and can also include costs borne by the victims of the crash. Using the WTP approach, Lindberg and Borlänge (1999) concluded that the nonmarket cost component was the dominant component and overshadows all other cost components of road crashes: the nonmarket costs account for 90% for fatal, 80% for severe injury, and 60% for light injury crash costs.

The two commonly used sources for the dollar value estimates are the annual publication of the National Safety Council Estimates and the 1988 FHWA memorandum. Also, the cost of road crashes can be based on a weighted injury scale by using indices to the level of severity of the road crash. The unit costs of each crash severity type are available for injury scales such as the KABCO rating scale (NSC, 2001) and the abbreviated injury scale (Blincoe et al., 2002). Table 6.5 shows the unit crash cost values for KABCO crash coding scheme, updated using consumer price indices from the U.S. Department of Labor (USDL, 2006).

Step 9: Determine the Overall Safety Cost Savings Due to the Intervention Given the expected number of crashes reduced due to the improvement (from step 7) and the unit cost per crash (from step 8), the analyst can calculate the dollar value of the overall crash cost savings.

Example 6.7 The injury crash rate with and without the improvement project at a rural two-lane highway is 2.87 and 3.5 per million VMT, respectively. Determine the user safety benefits in monetary terms due to the reduction in injury crashes. Assume an average vehicle occupancy rate of 1.00. The annual VMT is 1.5 and 1.8 millions for the without- and with-improvement scenarios, respectively.

Table 6.5 Unit Crash Costs on the Basis of the KABCO Injury Scale

Code	Severity	Unit Cost (2005 dollars)
K	Fatal	3,654,299
A	Incapacitating	181,276
B	Injury Evident	46,643
C	Injury Possible	22,201
O	Property Damage Only	2,116

Source: Updated from NSC (2001).

SOLUTION

$$\text{Crash rate without improvement} = 3.5 \text{ per million VMT}$$

$$\text{Crash rate with improvement} = 2.87 \text{ per million VMT}$$

$$\begin{aligned}\text{Safety savings} &= 0.5(U_1 - U_2)(VMT_1 + VMT_2)\\ &= (0.5)(3.5 - 2.87)(1.5 + 1.8) = 1.04\end{aligned}$$

From Table 6.5,

$$\text{Average cost of incapacitating injury crash} = \$181{,}276$$

$$\begin{aligned}\text{Injury crash cost savings} &= (1.04)(\$181{,}276)\\ &= \$188{,}527\end{aligned}$$

due to the improvement project in the first year.

6.3 METHODS FOR ESTIMATING CRASH REDUCTION FACTORS

In the methodology presented in Section 6.2, a critical part of the CRF approach for crash reduction prediction is the establishment of crash reduction factors. Many state highway agencies have established crash reduction factors and functions associated with various improvements or interventions using their local data. These may be used by the analyst. However, in cases where crash reduction factors or crash prediction functions for other jurisdictions may not be applicable to a specific evaluation problem, the analyst should develop CRF values using local data. Generally, two types of studies can be used to develop crash reduction functions or factors: *before-and-after studies* and *cross-sectional (with-and-without) studies*.

6.3.1 Before-and-After Studies

A vital requirement in before-and-after studies is the recognition that some other extenuating factors besides the safety intervention may be partly responsible for the safety improvement and hence the crash frequency, or number of crashes per year, n_B, in the before period B without improvement may not be the same as the crash frequency, n_{A*}, in the after period A without improvement. Such extenuating factors may include random trends in crash occurrence or changes in other engineering factors, such as pavement friction factor, slopes, and VMT. In such a scenario, the crash frequency n_{B} for the before period B cannot be used as a reference in estimation of the crash reduction factor. Hence, the crash frequency n_{B} for the without-intervention scenario is adjusted for the change in annual exposure (VMT, AADT, etc.), and the crash reduction factor is calculated as follows:

$$\text{CRF} = \left(1 - \frac{n_{\text{A}}}{n_{\text{A}*}}\right) \times 100 \qquad \text{where} \quad n_{\text{A}*} = \frac{E_{\text{A}}}{E_{\text{B}}} n_{\text{B}}$$

where n_{A} is the crash frequency with the improvement, and E_{A} and E_{B} represent the exposure (VMT, AADT, etc.) in the after and before periods, that is, with and without the improvement, respectively.

Example 6.8 At a certain site, 30 crashes were reported over three years before a lane-widening project. The number of crashes reduced to 22 when observations were made over three years after the improvement project. The AADT on the 4.5-mile section changed from 12,260 before the improvement to 13,430 after the improvement. Calculate the crash reduction factor. Assume that all the other engineering factors remain constant over time.

SOLUTION The crash frequencies before and after the improvement project are $n_{\text{B}} = 30/3 = 10$ crashes per year and $n_{\text{A}} = 22/3 = 7.333$ crashes per year. Since the AADT changed when the number of crashes was observed after the improvement, the crash frequency in the before period is adjusted for the change in exposure as follows:

$$n_{\text{A}*} = \frac{(10)(13{,}430)(4.5)}{(12{,}260)(4.5)} = 10.954$$

Therefore, the CRF can be calculated as

$$\text{CRF} = 100\left(1 - \frac{7.333}{10.954}\right) = 33.05\%$$

Conventional before-and-after studies use crash frequency data from several years before and after an intervention, from single or several control sites (where no improvement has been made), to estimate the CRF. The crash reduction factor at the control site is determined to estimate the change in the number of crashes due to factors other than those in the improvement project, such as random trends in crash occurrence or changes in VMT or any other engineering factors affecting safety (Figure 6.3). Detailed steps for computing crash reduction factors using the control site method are available in standard texts (Hauer, 1997).

Shortcomings of the Before-and-After Approach: Before-and-after studies, which involve a one-to-one match of improved sites with control sites, can suffer from the *regression-to-the-mean* (RTM) phenomenon (Hauer, 1997). RTM simply means that if a location has been selected for implementing a transportation improvement or intervention based on a short-span crash history, it is likely that in the ensuing years, crash experience would decrease (i.e., would regress to the long-term average crash rate) even if no interventions are made. As such, a decrease of crash experience (or part thereof) could mistakenly be attributed to the intervention thus overestimating the effectiveness of the intervention.

To adjust observed crash data to account for the RTM effect, the *empirical Bayesian* (EB) *procedure* can be used (Hauer, 1997; Harwood, et al., 2000). The EB method is applicable where there are data on historical crash frequency and estimated crash frequency. EB adjusts the predicted number of crashes by assigning weights to the crash frequencies predicted and observed (C_P and C_O, respectively) and utilizes these parameters to determine the number of crashes that can be expected (C_E). The weight is calculated on a parameter that is designed to account for overdispersion. The formula used to estimate the expected number of crashes is as follows:

$$C_E = w_P C_P + w_O C_O$$

where w_P, the weight for predicted crashes, $= 1/(1 + kC_P)$; w_O, the weight for observed crashes, $= 1 - w_P = kC_P/(1 + kC_P)$; and k is the overdispersion parameter. Suggested k values are as follows (AASHTO, 2003): 0.31 for roadway segments, 0.54 for three-leg stop-controlled intersections, 0.24 for four-leg stop-controlled intersections, and 0.11 for four-leg signalized intersections.

Example 6.9 For a certain roadway segment, six crashes, over a three year period, are observed after a roadway geometry improvement project. It was predicted that the section will have five crashes. Using the EB procedure, find the number of crashes expected for the segment after the improvement project. Assume no changes in engineering factors over time other than those due to the improvement project.

SOLUTION For roadway segments, the overdispersion factor, $k = 0.31$. Therefore,

weight of crashes predicted, w_P

$$= \frac{1}{1 + kC_P} = \frac{1}{1 + (0.31)(5)} = 0.392$$

weight of crashes observed, $w_O = (1 - w_P) = 0.608$

number of crashes expected, C_E

$$= (0.392)(5) + (0.608)(6) = 5.608$$

For a safety improvement effectiveness evaluation at a road section (a function of the difference in before and after crash values), the EB value should preferably be used. If the number of crashes predicted (five) is used, the effect of the improvement would be underestimated. Also, using the number of crashes observed (six) would lead to overestimation of effectiveness.

6.3.2 Cross-Sectional Studies

Cross-sectional analyses may involve a straightforward comparison of crashes at sections with and without the crash factor under investigation. Such analyses may also involve an approach where models are developed using data from several sections during a given time period, which differ by the crash factor under investigation. This approach was used by Tarko et al. (2000) to estimate crash reduction factors from given crash equations. Considering that the expected number of crashes with and without an improvement are $n_{\mathrm{W}} = f(X_{\mathrm{W}})$ and $n_{\mathrm{WO}} = f(X_{\mathrm{WO}})$, respectively, where X is a vector of crash factors, the general formulation was stated as follows:

$$\mathrm{CRF} = \left[1 - \frac{f(X_{\mathrm{W}})}{f(X_{\mathrm{WO}})}\right] \times 100$$

Depending on the functional form for $f(X)$, the crash reduction function may take one of several forms. In the Tarko et al. (2000) study, the functional form was exponential:

$$f(X) = kYQ^{\gamma}e^{\beta X}$$

where k is a constant, Y and Q are exposure variables representing the temporal span of data and indicate the section length and traffic volume, respectively, and β is the slope parameter associated with the variable X. It is often assumed that crash reductions of roadway factor improvements are independent of each other, but some research studies have established composite crash reduction factors for specific combinations of multiple crash factors.

Example 6.10 Tarko et al. (2000) developed the following crash prediction model for signalized intersections:

$$C = e^k Y Q^{\gamma} e^{\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n}$$

where C is the number of crashes over a period of Y years; Q is the traffic volume entering the intersection (AADT); $X_1, X_2, \ldots, X_n$ are independent variables representing various roadway factors; k, γ, and β are constants. (a) Derive an expression for the crash reduction function for any roadway factor X_{j}. (b) Using cross-sectional data collected for several signalized intersections in a certain city, a crash prediction equation was developed based on the functional form above (after the natural logarithm is taken for both sides). Derive the crash prediction equation if the estimated values of the parameter coefficients are

Table E6.10

Variable Code	Variable Description	Coefficient
Constant	Constant term	−6.3771
ln Y	Natural log of the number of years	1.0000
ln Q	Natural log of traffic volume	0.7821
X_1	Number of lanes, including turning lanes	0.0673
X_2	Separation between directions by adding median with divisional islands on approaches	−0.5499
X_3	Number of raised separation at the intersection	0.4627
X_4	Average width of the separation	−0.0257

given in Table E6.10. (c) Using the results above, develop the crash reduction function for each roadway factor.

SOLUTION

(a) Let X_j^B and X_j^A be the values of the roadway factor before and after the improvement. Then the crash reduction function with respect to this roadway factor can be derived as follows:

$$\begin{aligned}\text{CRF} &= 1 - \frac{e^k Y Q^{\beta} e^{\alpha_1 X_1 + \alpha_2 X_2 + \cdots + \alpha_j X_j^A + \cdots + \alpha_n X_n}}{e^k Y Q^{\beta} e^{\alpha_1 X_1 + \alpha_2 X_2 + \cdots + \alpha_j X_j^B + \cdots + \alpha_n X_n}} \\ &= 1 - \frac{e^{\alpha_j X_j^A}}{e^{\alpha_j X_j^B}} \\ &= 1 - e^{\alpha_j (X_j^A - X_j^B)}\end{aligned}$$

(b) Taking the natural logarithm on both sides of the functional form

$$\begin{aligned}C &= e^k Y Q^{\beta} e^{\alpha_1 X_1 + \alpha_2 X_2 + \cdots + \alpha_j X_j + \cdots + \alpha_n X_n} \\ \ln C &= k + \ln Y + \beta \ln Q + \alpha_1 X_1 + \alpha_2 X_2 + \cdots \\ &\quad + \alpha_j X_j + \cdots + \alpha_n X_n\end{aligned}$$

Substituting the value of the coefficients yields

$$\begin{aligned}\ln C = {} & -6.3771 + \ln Y + 0.7821 \ln Q + 0.0673 X_1 \\ & - 0.5499 X_2 + 0.4627 X_3 - 0.0257 X_4\end{aligned}$$

(c) Using the results from (a) and (b), the crash reduction functions with respect to each of the roadway factors above is given as

$$\begin{aligned}\text{CRF}(X_1) &= 1 - e^{0.0673(X_1^A - X_1^B)} \\ \text{CRF}(X_2) &= 1 - e^{-0.5499(X_2^A - X_2^B)} \\ \text{CRF}(X_3) &= 1 - e^{0.4627(X_3^A - X_3^B)} \\ \text{CRF}(X_4) &= 1 - e^{-0.0257(X_4^A - X_4^B)}\end{aligned}$$

6.3.3 Comparison of the Before-and-After and Cross-Sectional Methods

The key difference between the before-and-after and cross-sectional studies is that the former uses data pertaining changes in safety over time, whereas the latter uses data on the differences in safety between locations at a given point in time. The main advantage of the before-and-after approach is that it is more conformable to the concept of controlled experimentation. Its main shortcoming is the great amount of effort or resources needed to ensure a proper experimental design and execution of such studies, particularly over the desired range of levels of each roadway factor. The main advantage of cross-sectional models is that they make use of data that is often readily available at highway agencies and are much less expensive in terms of time and effort compared to before-and-after studies. The main disadvantage of the cross-sectional approach is that it requires an extensive amount of data to ensure proper specification and is often subject to estimation problems related to data quality. However, with ongoing automation of roadway inventory data at highway agencies, the effect of specification-related problems is increasingly being mitigated, and the number and range of crash factors that can be included in cross-sectional models is being broadened. A combination of before-and-after analysis and a cross-sectional analysis using negative binomial regression was proposed by Poch and Mannering (1996).

6.3.4 Elasticity of Crash Frequency

Crash reduction efficacy of safety-related transportation projects can be expressed in terms of the marginal effects (such as elasticities) on crash frequency of unit changes in levels of each engineering variable. However, this is applicable only if the change is small.

$$E_{x_j} = \frac{\partial f}{f} \frac{x_j}{\partial x_j}$$

where E is the elasticity of crash frequency with respect to the jth independent variable, x_j is the magnitude of the variable X_j under consideration, and f is the crash prediction function.

Table 6.6 Common Functional Forms and Elasticity Functions

	Functional Form of the Crash Prediction Equation, $f(X)$	Elasticity Function $[X_j/f(X)](\partial f/\partial X_j)$	References
Linear	$\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$	$\dfrac{\beta_j X_j}{\beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n}$	
Product	$\beta_0 \times X_1^{\beta_1} X_2^{\beta_2} \cdots X_n^{\beta_n}$	β_j	Forkenbrock and Foster (1997); Tarko et al. (2000)
Exponential	$\beta_0 e^{\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_N}$	$\beta_j X_j$	Forkenbrock and Foster (1997)

Table 6.6 presents the elasticity functions corresponding to three common functional forms of crash prediction equations. In many cases, the elasticity function is not a constant but is a function of the value of the X_j variable. In the context of crash reduction, this implies that the effectiveness of a safety improvement often depends on the level of the existing engineering factor or deficiency.

6.4 SAFETY-RELATED LEGISLATION

Safety has long been a key consideration in transportation-related federal legislation such as transportation funding reauthorizations. Initial requirements set forth by the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) set the stage for the establishment of safety management systems in various states and therefore helped establish the databases and knowledge bases needed for systematic safety impact evaluation of transportation projects. The Transportation Equity Act for the 21st Century (TEA-21) of 1998 focused on five deployment goals designed to improve the efficiency, safety, reliability, service life, environmental protection, and sustainability of the nation's surface transportation system. In 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) was signed to reaffirm the national emphasis on transportation safety. SAFETEA-LU established a new core highway safety improvement program that is structured and funded to make significant progress in reducing highway fatalities. It created an agenda for increased highway safety by doubling the funds for safety infrastructure and by requiring results-driven strategic highway safety planning.

6.5 SOFTWARE PACKAGES FOR SAFETY IMPACT EVALUATION OF TRANSPORTATION INVESTMENTS

6.5.1 Interactive Highway Safety Design Model

IHSDM is a suite of software analysis and evaluation tools for assessing the safety impacts of geometric design decisions. For a given highway project, IHSDM checks existing or proposed designs against relevant design policy values and estimates the expected safety and operational performance of the design (FHWA, 2003). IHSDM therefore helps transportation planners to incorporate safety considerations in project selection. The overall IHSDM contains modules for safety evaluation tasks and concepts such as crash prediction, design consistency monitoring, driver–vehicle interaction, and intersection safety diagnostics. The current version of IHSDM focuses on rural two-lane highways, and future versions are expected to include other road classes.

6.5.2 Indiana's Safety Management System

Several safety management systems have been developed at the state level. In Indiana, the system has been automated to form a software package that consists of several evaluation modules for assessing project- or network-level safety impacts of transportation projects (Lamptey et al., 2006). By determining the safety impact of individual treatments associated with transportation projects, *SMSS-IN* helps planners in quantifying and monetizing the reductions in fatal, injury, and PDO crashes and produces outputs that can be used for economic efficiency analysis of transportation projects.

6.6 CONSIDERATIONS IN SAFETY IMPACT EVALUATION

The procedural evaluation framework presented in Section 6.2 can be used for assessing the safety impacts of transportation projects. This generally involves an estimation of crash frequencies with and without an intervention using crash rates, crash equations, or crash reduction factors. Choosing an appropriate method to estimate crash frequency depends on the availability of data. The crash rate method is the least data intensive but may provide the least reliable estimates of future crash frequency; the crash reduction factor method generally yields more reliable crash estimates but is data intensive and may be plagued with problems of overlapping (where the project involves multiple safety interventions). Furthermore, regardless of which estimation approach is chosen, the analyst will have to decide whether the given crash relationships (crash rates, equations, or reduction factors) are sufficiently representative of the given problem. In many cases, such relationships exist only at a more aggregate level (such as regional or national) or may be local but outdated. As such, recent local data may need to be collected to develop such relationships so that they can be used for crash prediction for specific projects.

Another issue is that of the influence of other crash factors. Prediction of future crashes on the basis of current relationships (rates, equations, or reduction factors) proceeds on the implicit assumption that the status of the other crash factors (such as enforcement levels, operator characteristics, education, and policy) will remain the same in the future. Crash occurrence is a complex interaction of the various crash factors; as such, it is not very certain how future changes in the nonengineering factors will affect the expected number of future crashes that were estimated on the basis of only the engineering factors. Elvik and Vaa (2004) cataloged over a hundred road safety measures associated with highway engineering, traffic control, vehicle design, public information, and police enforcement that have been tried and tested at locations all over the world and have provided some discussion of the interrelationships between factors.

The issue of equity arises in the context of safety impact evaluation of transportation projects. The analyst must ascertain whether a transportation intervention yields greater safety benefits to certain population groups while other groups get significantly lower (or even negative) safety benefits. For example, upgrading a local minor collector street to major arterial status may improve the safety of through traffic but may pose a hazard for residents (particularly children) of the area (Forkenbrock and Weisbrod, 2001).

There is also the issue of crash cost sources and responsibilities. The largest components of the total motor vehicle crash cost are market productivity (the cost of foregone paid labor due to death and disability) and property damage, each accounting for about 26% of the total costs. The loss of household productivity (the cost of foregone household labor) accounted for 9% of the total cost. Workplace cost (2% of the total cost) is the disruption due to the loss or absence of an employee such that it requires training a new employee, overtime to accomplish the work of the injured employee, and administrative costs to process personnel changes. Other costs are associated with insurance administration (7%), legal (5%), and emergency services (less than 1%). Ultimately, all citizens, whether or not they are involved in a crash, pay a part of motor vehicle crash costs through insurance premiums, taxes, out-of-pocket expenses, and so on. Data from 2000 indicate that approximately one-fourth of the total crash cost is paid directly by those involved, while society in general pays the rest. Insurance companies, which are funded by all insured drivers (whether or not they are involved in a crash) paid about 50% of the cost and the government paid 9% (NHTSA, 2002). These are the economic costs only and therefore do not include the intangible consequences of these events to individuals and families, such as pain and suffering and loss of life.

SUMMARY

In this chapter we presented a procedural framework for assessing the safety impacts of transportation projects. While the safety issue remains a key consideration in evaluation of projects for all transportation modes, in this chapter we focus on the highway mode because of the overwhelming dominance of the highway safety problem. The general evaluation framework, however, is applicable to projects associated with other transportation modes.

Even with highway transportation, it is only the engineering factors that typically are mostly affected by improvements to the system. The overall framework presented in this chapter may be applicable to impact evaluation of increased enforcement levels or regulatory initiatives, such as increased patrols, changed speed limits, stricter driver under influence (DUI) laws, and so on.

In the past, safety evaluation included primarily those projects that were directly safety related, such as guardrail installation, treatments of freeway gore areas, and so on. As such, safety considerations were not included for projects such as pavement preservation. In the case of federal 3R projects, for instance, safety engineers did not participate in the design of such projects. At a later time when it was necessary to accommodate safety-related improvements (such as reconstructing sharp curves, replacing or extending bridges with narrow decks) in 3R projects, safety evaluation of such projects was stymied. In recent years, it has been duly recognized that there are safety impacts associated with most projects and state agencies have subsequently reshaped their 3R design procedures. New practices for 3R projects include various safety-related tasks grouped in the following categories: safety-conscious design practices, design practices for key highway features, planning and programming 3R projects, safety research and training, and other design procedures and assumptions.

EXERCISES

6.1. For each mode of transportation, the factors that affect crashes may be categorized broadly as follows: system engineering features, environment (weather), operator characteristics (age, education, etc.), vehicle characteristics, policy, and so on. Against this background, explain why crashes are still by far highest for the highway mode of transportation compared to the other modes.

6.2. Mention some initiatives that have helped reduce the high rate of highway crashes over the past 20 years. Even at their current rates, highway crashes are unacceptably high. What can be done to further reduce the rate of highway crashes?

6.3. What is the difference between "safety impacts of transportation projects" and "impacts of transportation safety projects"? Give three examples of highway transportation projects for which safety impacts are typically evaluated in addition to other impact types. Also, give three examples of highway transportation safety projects.

6.4. Two-lane rural and urban roads experience unique operational difficulties and safety problems, such as the lack of passing opportunities due to oncoming traffic and/or poor sight distance. As part of a proposed major corridor improvement of a two-lane highway near Brunswick Town, it is intended to construct a passing lane at a certain crash-prone stretch of the highway. This would enable left-turners to seek refuge in an island as they wait for a gap to make the turn, and would also enable passing traffic to bypass the waiting left turners. Currently, all 70 crashes per year at that T-intersection are due to rear-ending of waiting left-turners. Of all crashes, 2 are fatal crashes, 20 are injury crashes, and the rest are PDO crashes. What will be the safety impact of the transportation project in terms of (a) crash frequency and (b) crash costs? Use Table A6.2 to obtain the appropriate crash reduction factor and Table 6.5 for the unit crash costs.

6.5. To reduce severe congestion and intolerable travel times for commuters using State Road 555, a two-lane highway connecting the City of Light to its fast-growing western suburbs, it is proposed to upgrade the highway to a four-lane facility. The project will also involve pavement resurfacing, shoulder widening, and passing opportunities. It is expected that there will be a 5% increase in traffic due to the project. Values of the roadway factors with and without the improvement project are given in Table EX6.5.

Table EX6.5 Values of Roadway Factors

	Without Improvement	With Improvement
Pavement condition (PSR)	Fair (2.5)	Very good (4.4)
Horizontal alignment (TOPCURV)	Good (4)	Good (4)
Passing restrictions (PASSRES)	2	0
Traffic volume per lane (ADTLANE)	2.5	Determine this value
Lane class	0	1
Road shoulder width (RIGHTSH)	2 ft	4 ft
Vertical alignment (TOPGRAD)	Good (4)	Good (4)

Using the crash prediction model developed by Forkenbrock and Foster (1997) in Table 6.4, determine the safety impact of the project in terms of crash reduction on the basis of:

- **(a)** The aggregate approach. Here, use the crash prediction equation to directly determine the number of crashes with and without the improvement project.
- **(b)** The disaggregate approach. Here, apply marginal effects analysis to derive the crash reduction function (for each affected roadway factor) from the crash prediction equation. Then using the data given, determine the reduction in crashes associated with each factor and sum them up to get the overall crash reduction.
- **(c)** Compare the results from (**a**) and (**b**). Comment on the relative ease of each approach. Under what circumstances is it more appropriate to use the disaggregate approach?

6.6. An existing rural two-lane county road has a lane width of 6 ft and unpaved shoulders of 1 ft width. It is proposed to upgrade the road to higher standards.

- **(a)** On the basis of safety impacts only, which of the following alternative schemes would have the greatest impact?
  - **(1)** Widen the lane to 8 ft and do nothing to the shoulder (technically, this means adding the shoulder to the lane and constructing new 2-ft-wide shoulders). Use Table A6.2(a).

   (2) Do nothing on the lane and widen shoulder width to 3 ft. Use Table A6.2(b).

   (3) Pave the shoulder and do nothing else. Use Table A6.1.

(b) What other decision parameter beside effectiveness (expected crash reduction) of each action would be needed to make a final decision?

6.7. An existing urban freeway currently has a volume–capacity ratio of 1.05. It is planned to add a lane to accommodate increasing traffic growth at this highway. It is expected that the volume–capacity ratio after the capacity expansion will be 0.82. Determine the safety impact of the improvement.

6.8. For a four-leg stop controlled intersection in a certain city, seven crashes were observed in a 3-year period. Also, it has been predicted that the section will have five injury crashes over the next three-year period. Using the EB procedure, find the expected number of injury crashes for the intersection over that period.

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Database for Crash Analysis

The Highway Safety Information System (HSIS) is a multistate database containing crash, roadway inventory, and traffic volume data. It is operated by the University of North Carolina Highway Safety Research Center (HSRC) and LENDIS Corporation under contract with the FHWA. Analysts can use this database to develop crash rates, crash equations, or crash reduction functions for subsequent use in predicting crashes for projects under investigation.

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APPENDIX A6: CRASH REDUCTION AND ACCIDENT MODIFICATION FACTORS

Table A6.1 Crash Reduction Factors: All Highways

Activity Category	Specific Activity	Crash Reduction Factor (%) All Crashes
Channelization	Channelize intersection	23
	Provide left-turn lane (with signal)	24
	Provide left-turn lane (without signal)	40
	Install two-way left turn in median	34
	Add mountable median	15
	Add nonmountable median	25
	Provide right-turn-lane	28
	Increase turn-lane length	28
	Horizontal alignment changes	50
Geometric improvements	Gentler horizontal curve	
	Change in horizontal curvature	
	20 to 10°	48
	15 to 5°	63
	10 to 5°	45
	Improve vertical curve	43
	Improve sight distance at intersection	31
	Superelevation	46
Median device installation	Install median barrier (general)	25
	Install raised median	23
	Add flush median	52
	Add flush median with refuge for left turns	44
Widening of lane/shoulder, shoulder paving	Widen lane	28
	Widen paved shoulder	29
	Widen unpaved shoulder	22
	Pave shoulder	17
	Stabilize shoulder	24
Lane additions	Add acceleration/deceleration lane	16
	Add lanes	23
	Add turning lane	17
Bridge improvements	Bridge replacement	46
	Bridge widening	48
	Bridge deck repair	14
	Bridge rail upgrade	20
Intersection improvements	Increase turning radii	13
	improve sight distance	33
Freeway improvements	Construct interchange	57
	Modify entrance/exit ramp	25
	Construct frontage road	35

(*continued overleaf*)

Table A6.1 (*continued*)

Activity Category	Specific Activity	Crash Reduction Factor (%) All Crashes
Traffic signal improvements	Install sign	27
	Change 2WSC to signal	28
	Change 2WSC to signal and add lane	36
	General upgrade of existing signal system	25
	Replace lenses with larger ones (12 in.)	12
	Improve signal phasing	25
	Improve signal timing	12
	Add exclusive left-turn phase (protected)	29
	Install/improve pedestrian signal	23
	Remove unwarranted signal	66
Guardrail improvements	Install guardrail	20
	Upgrade guardrail	10
	Install guardrail at bridge	24
	Install guardrail at outer lane in curve	63
	Install guardrail at culverts	27
Pavement improvements	General pavement treatment	25
	Groove pavement	19
	Resurface with skid-resistant material	10
	Resurfacing (general)	20
	Install rumble strips	30
	Groove shoulder	25
Roadside improvements	Relocate fixed objects	40
	Install impact attenuators	30
	Flatten side slope	25

Source: Harkey et al. (2004).

Table A6.2 Crash Reduction Factors: Rural Two-Lane Highways

(a) Factors for Lane Widening

Amount of Lane Widening (ft)	% Reduction in Crashes
1	12
2	23
3	32
4	40

Source: Zegeer et al. (1987).

(b) Factors for Shoulder Widening[a]

	% Reduction in Crashes	
Amount of Lane Widening (ft)	Paved	Unpaved
2	16	13
4	29	25
6	40	35
8	49	43

Source: Zegeer et al. (1987).

[a] Values are for run-off-road, head-on, opposite-direction sideswipe crashes.

(c) Factors for Increasing Roadside Recovery Distance[a]

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

Source: Zegeer et al. (1987).

[a] Values are for run-off-road, head-on, opposite-direction sideswipe crashes.

(d) Factors for Side-Slope Improvements

	Side Slope After Flattening							
	1:4		1:5		1:6		1:7 or Flatter	
Side Slope Before Flattening	Single Vehicle	Total	Single Vehicle	Total	Single Vehicle	Total	Single Vehicle	Total
1:2	10	6	15	9	21	12	27	15
1:3	8	5	14	8	19	11	26	15
1:4	0	—	6	3	12	7	19	11
1:5	—	—	0	—	6	3	14	8
1:6	—	—	—	—	0	—	8	5

Source: Zegeer et al. (1987).

(e) Factors for Bridge Shoulder Widening[a]

	Bridge Shoulder Width after Widening					
Bridge Shoulder Width on Each Side before Widening	2 ft	3 ft	4 ft	6 ft	7 ft	8 ft
0	23	42	57	78	83	85
1	—	25	45	72	78	80
2	—	—	27	62	71	74
3	—	—	—	48	60	64
4	—	—	—	44	44	50

Source: Turner (1984).

[a] Width of bridge lanes assumed constant.

(f) Factors for Providing Passing Opportunities

Countermeasure	% Reduction in Crashes: Total Crashes	% Reduction in Crashes: Fatal + Injury Crashes
Passing lanes	16	13
Short four-lane section	29	25
Turnout	40	35
Shoulder use section	49	43

Source: Harwood and Hoban (1987).

(g) Factors for Increased Roadside Recovery Distance at Curve Sections

Increase in Roadside Clear Recovery Distance (ft)	Percent Reduction in Total Curve Crashes
5	9
8	14
10	17
12	19
15	23
20	29

Source: Zegeer et al. (1991).

(h) Factors for Flattening Side Slopes on Curves

Initial Side Slope of Curve (Before Treatment)	Percent Reduction in Total Curve Crashes — Side Slope After Treatment: 1:4	1:5	1:6	1:7 or flatter
1:2	6	9	12	15
1:3	5	8	11	15
1:4	—	3	7	11
1:5	—	—	3	8
1:6	—	—	—	5

Source: Zegeer et al. (1991).

(i) Factors for Curve Widening

Total Amount of Lane or Shoulder Widening at Curve (ft)		% Reduction in Crashes		
Total	Per Side	Lane Widening	Paved-Shoulder Widening	Unpaved-Shoulder Widening
2	1	5	4	3
4	2	12	8	7
6	3	17	12	10
8	4	21	15	13
10	5	—	19	16
12	6	—	21	18
14	7	—	25	21
16	8	—	28	24
18	9	—	31	26
20	10	—	33	29

Source: Zegeer et al. (1991).

Table A6.3 Accident Modification Factors: All Highways

(a) General Improvements

		AMF	
Activity	Facility Type	All Crashes	Fatal + Injury Crashes
Add shoulder rumble strips (effect on single-vehicle run-off road crashes)	Urban and rural freeways	0.82	—
	Other highways	0.79	—
Install roundabout	Urban and rural freeways	0.87	—
	Other highways	0.93	—
	Urban single lane (prior control—stop sign)	0.28	0.12
	Rural single lane (prior control—stop sign)	0.42	0.18
	Urban Multilane (prior control—stop sign)	0.95	—
	Urban single/multilane (prior control—signal)	0.65	0.26
Install guardrails	All facilities	0.56 (all injury crashes)	0.56
Install traffic signal	Three-leg intersections		
	All crash patterns	—	0.86
	Right-angle crashes	—	0.66
	Rear-end crashes	—	1.50
	Four-leg Intersections		
	All crash patterns	—	0.77
	Right-angle crashes	—	0.33
	Rear-end crashes	—	1.38

(b) Exclusive Turning Lanes

		AMF for One Approach		AMF for Two Approaches	
Activity	Facility Type	All Crashes	Fatal + Injury Crashes	All Crashes	Fatal + Injury Crashes
Add exclusive left-turn lane	Four-leg rural stop-controlled intersection	0.72	0.65	0.52	0.42
	Three-leg rural stop-controlled intersection	0.56	0.45	—	—
	Four-leg rural signalized intersection	0.82	—	0.67	—
	Three-leg rural signalized intersection	0.85	—	—	—
	Four-leg urban stop-controlled intersection	0.73	0.71	0.53	0.50
	Three-leg urban stop-controlled intersection	0.67	—	—	—
	Four-leg urban signalized intersection	0.90	0.91	0.81	0.83
	Three-leg urban signalized intersection	0.93	—	—	—
Add exclusive right-turn lane	Four-leg rural stop-controlled intersection	0.86	0.77	0.74	0.59
	Four-leg urban signalized intersection	0.96	0.91	0.92	0.83

Source: Harkey et al. (2004).

Table A6.4 Accident Modification Factors: Rural Two-Lane Highways

(a) Factors for Providing Superelevation at Horizontal Curves

Existing Superelevation Deficiency	Accident Modification Factor
0.00	1.00
0.01	1.00
0.02	1.06
0.03	1.09
0.04	1.12

Source: Zegeer et al. (1991).

(b) Factors for Shoulder Widening

Shoulder Width (ft)	Accident Modification Factor[a]
0	1.50
2	1.30
4	1.15
6	1.00
8	0.87

Source: Harwood et al. (2000).

[a] For run-off-road, head-on, opposite-direction sideswipe crashes.

(c) Factors for Shoulder Surface Improvement[a]

	Shoulder Width (ft)							
Shoulder Type	0	1	2	3	4	6	8	10
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.00	1.01	1.01	1.02	1.02	1.03
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11	1.14

Source: Harwood et al. (2000).

[a] For run-off-road, head-on, opposite-direction sideswipe crashes.