SAFETY AND HIGHWAY INVESTMENT

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PREFACE

One of the principal reasons governmental agencies invest in better highways is to improve safety. Safer roads reduce the likelihood of personal injuries, property damage, and even loss of life due to accidents. To determine whether safety and other benefits would be great enough to at least equal the costs of a highway investment, state departments of transportation often conduct benefit-cost analyses.

How safety improvements should be taken into account in highway benefit-cost analyses has never been completely clear. A major part of the uncertainty pertains to placing a dollar value on reductions in the risk of fatalities and personal injuries. No uniformly accepted dollar values exist, nor is consensus likely. For safety improvements to be given proper weight, however, we must estimate the values of preventing fatalities and injuries.

Similarly, it is difficult to estimate the probable reduction in accident rates (risk) that would result if a particular highway improvement were undertaken. Many road characteristics affect accident rates, and these characteristics interact with each other. They also interact with other factors such as driver performance, vehicle condition, and meteorological conditions, as well as changes in flow speed and traffic volume that result from the highway improvement itself.

This monograph examines issues related to the valuation of accident cost saving and the estimation of accident rate reductions likely to be associated with highway investments.

The research team has benefited greatly from its collaboration with a five-member project advisory committee. This committee helped to focus the issues to be addressed, and its members shared their insights throughout the research process.

ACKNOWLEDGMENTS

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CHAPTER 1

SAFETY BENEFITS OF HIGHWAY INVESTMENTS: AN OVERVIEW

In fiscal year 1992, the Iowa Department of Transportation (Iowa DOT) spent $320.9 million on improvements to maintain and upgrade Iowa's primary highways (Iowa Department of Transportation 1991, p. iii). The amounts by which these investments reduce transportation costs are the "benefits" (transportation cost saving). Benefits result from reductions in:

- travel time,
- vehicle operating costs (fuel and wear and tear),
- air pollution and other environmental costs, and
- accident risks.

A state DOT must place values on these benefits if it is to determine whether a project's benefits exceed its costs. To make a comparison possible, benefits must be measured in the same units as costs, namely dollars. An investment decision can be made, of course, without the guidance of benefit-cost analysis. However, even if the DOT does not explicitly compare a project's benefits and costs, it cannot avoid making an implicit judgment about their relative magnitudes. For example, in deciding to undertake a project costing $1 million, the DOT is making a judgment that the project will save, in today's terms, at least $1 million in transportation costs by reducing travel time, accidents, vehicle operating costs, and environmental costs. Figure 1–1 shows the main categories of benefits and how they fit into the process of evaluating projects.

The need to valuate the accident reduction benefits of highway investments is now widely recognized. There is less agreement, however, on *how* to valuate such benefits, and once defined how best to estimate them. To date, the value assigned to accident reduction in benefit-cost analyses has varied widely. Estimates of the value of reducing the risk of fatalities by one per year range from $1.0 to $3.6 million, as reported in a recent study by the Urban Institute (Miller et al. 1991, p. 78). Viscusi (1993) reported a range for labor market studies from $600,000 to $16.2 million. Partly, these divergent values reflect different estimation methodologies and different points in time (i.e., the effects of inflation are not controlled for), but it is clear that the value of reducing fatal accident risk varies quite widely.[1]

Placing a dollar value on lives saved and injuries prevented may seem callous. Individuals and governments, however, frequently place a value on the risk of fatality or injury. Individuals drive faster to save time, or they travel by private auto rather than by rail or air because auto travel is less expensive, even though it is also more risky. Similarly, governments do not exploit all opportunities to increase safety, whether in transportation, health, or other areas. Safety is not

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[1] Using the values for fatal accidents, personal injuries, and property damage currently being used in Iowa, the Governor's Traffic Safety Bureau estimated that in 1991 the cost of traffic accidents in the state was $828 million (Laski 1993).

Decrease in risk of fatal, personal injury, or property damage accident

Value of preventing one fatal, personal injury, or property damage accident

Value of decrease in accident risk (dollars)

Value of reduction in travel time (dollars)

Decrease in vehicle operating costs (dollars)

Decrease in environmental costs (dollars)

Benefits of project (dollars)

Costs of project (dollars)

Is the present value of benefits greater than the present value of costs?

Figure 1–1. Role of accident cost saving in highway investment analysis

maximized by either individual or government decision makers because increasing safety pulls resources from other uses that also contribute to the well-being of individuals. Thus, while it is unpleasant to think of human life and injury in monetary terms, that is precisely what must be done if safety improvements are to be taken into account in the economic evaluation of highway investments. Whenever decisions about such investments are made, safety impacts are necessarily valued in monetary terms, either implicitly or explicitly.

The two primary purposes of this research were to 1) develop a practical method for estimating the reduction in accident risk if a roadway is improved and 2) shed light on the appropriate value to be assigned to a reduction in accidents. Chapter 2 considers in detail the question of how to valuate the safety benefits of highway investments. We stress that a highway project that makes travel safer does not prevent accidents for *identifiable* individuals. Instead, it decreases the accident risk faced by highway users as a group. The safety benefit of a project is the dollar value assigned to this decrease in accident risk:

safety benefit =
(dollar value of risk reduction)x(risk reduction attributable to the project).

To estimate the safety benefit of a project, we therefore need estimates of 1) how the project affects the rate and type of accidents and 2) the value to be assigned to a reduction in accidents. In developing these estimates, we draw upon the extensive theoretical and empirical literature on how to valuate resource allocations that save lives and/or reduce injuries. The same issues and problems also arise in evaluating safety benefits of regulations such as speed limits and required safety features on automobiles.

While there is still debate about how to define and measure the value of decreases in accident risk, the emerging consensus is that "willingness to pay" is the appropriate concept of value. Under this concept, the safety benefit of a

project is the amount persons who use the highway segment would be willing to pay to bring about the decrease in accident risk that is expected to occur as a result of the project.

Information on how state DOTs currently evaluate safety benefits was obtained by a survey, the results of which are described in Chapter 3. These results show that state DOTs vary in the values they assign to decreases in accident risks. Most still use a value that is less than the value that the Federal Highway Administration (FHWA) requires be used in evaluating safety benefits of federally funded projects.

The other piece of information needed to estimate the safety benefits of a project—how the project affects the rate and type of accidents—can be obtained from data on accidents and road characteristics. We used detailed data bases developed by the Iowa DOT to analyze the relationships between road characteristics, accident rates, and accident costs; the results are presented in Chapter 4. The predictive models we developed enable accident rates and costs of an illustrative two-lane road to be compared with those likely if a specific upgrade were made. We also tested the sensitivity of accident cost saving per million vehicle miles of travel to the dollar values assigned to reductions in fatal, personal injury, and property damage accidents.

Chapter 5 summarizes our research findings. We also offer three recommendations to improve the ability of state DOTs to take accident cost saving into account when evaluating potential highway investments.

CHAPTER 2

VALUATING SAFETY BENEFITS

A project that increases the safety of travel on a road segment does not prevent accidents for identifiable individuals. Instead, it reduces the risk of fatality, injury, and property damage faced by the people who use the segment. When the state undertakes a project, it therefore buys a reduction in risk for that population. *The safety benefit of a project is the dollar value assigned to the decrease in accident risk attributable to the project.* To valuate safety benefits, it is therefore necessary to determine a risk-dollar trade-off.

In this chapter, we discuss alternative approaches to valuating changes in accident risk—to determining a trade-off between dollars and risk of accidents that involve injury and death. We also summarize estimates of the value of risk reduction. These estimates vary widely, but even the lower values are large enough to be of significance in highway planning.

VALUE DEFINED AS "WILLINGNESS TO PAY"

How should the value of safety benefits be defined? Debate on this question, while continuing, appears to be converging on "willingness to pay" as the appropriate concept of value.[2] According to this concept, the safety benefit of a project is the amount persons who use the highway segment would be willing to pay to bring about the decrease in accident risk that is expected to occur as a result of the project.[3] For example, in the case of accidents that involve only property damage, the amount that highway users would be willing to pay to reduce the risk of such accidents is the expected saving in costs of repairing and replacing damaged property and settling damage claims.[4] As a second example, a project may reduce the expected number of fatalities on a road segment by one per year. The safety benefit of this project is the amount that the population in question would be willing to pay to reduce the expected number of fatalities by one per year on that segment.

This amount is commonly referred to as the value of a life, but such terminology is somewhat misleading in that it is not the amount that individuals in the population place on their individual lives. Neither is it the amount that the

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[2] "Although the value-of-life literature is now roughly two decades old, the essential approach became well established in the 1970s. The appropriate measure of the value of life from the standpoint of government policy is society's willingness to pay for the risk reduction...." (Viscusi 1993, p. 1942). See also National Safety Council (1993), Jones-Lee (1989), and U.S. OMB (1991).

[3] The literature on willingness to pay distinguishes between private and altruistic motives for paying. The latter are broadly defined to include many motives for being concerned about others. Also, the compensation required to endure a risk should, in principle, be distinguished from willingness to pay to avoid the risk. The two concepts differ in the income level that underlies the value assigned to risk reduction. Compensation required places individuals at an income level that is equal to or greater than the income level that is assumed for willingness to pay. For small changes in risk, applying the two concepts leads to similar estimates of the value of reducing risk.

[4] The costs of settling damage claims are not restricted to monetary costs; they can include the time and annoyance involved in dealing with the financial and repair consequences of an accident that involves only property damage.

population would pay to save the life of a specific person. It is only the amount that the population would pay to reduce by one the number of persons killed annually in highway accidents on a given road segment.

Schelling (1968) highlighted this fundamental distinction between the death of a known individual and a statistical death. He described the awe we feel when confronted with a risk or immediate danger to a known individual, "[b]ut most of this awesomeness disappears when we deal with statistical deaths, with small increments in a mortality rate in a large population" (p. 142).

Why is willingness to pay an appropriate concept of value? The resources to be used in the highway project could be used for other purposes. The cost of the project is best thought of in terms of the most valuable alternative use of the resources committed to the project. Highway users' willingness to pay for a project measures the value of these same resources when they are used in the project. Therefore, if willingness to pay is less than cost, the resources used in the highway project have greater value to the population in another use. Undertaking the highway project rather than the higher-value use must therefore make someone worse off. In contrast, if willingness to pay exceeds the cost of the project, then there is the possibility of making someone better off by shifting resources to the highway project from other uses. Using willingness to pay as the concept of value is necessary to answer the basic question faced when we decide whether to undertake a highway project (or any other public investment): Are the payoffs to the investment sufficiently great that people gain on net from the diversion of resources from other uses to the highway investment?

Estimating willingness to pay

One method for estimating willingness to pay is to observe market trade-offs between risks and other goods. In this case, we estimate willingness to pay for risk reduction the same way that we estimate the value of other goods produced with scarce resources—by the amount that people are observed to pay for them. Because some people would be willing to pay more for a good than the asking price, the amount that people pay for the good is a lower-limit estimate of the value that they place on it.

Similarly, a lower-limit estimate of the value of the reduction in risk brought about by a highway investment is the amount that individuals have in fact paid in other circumstances to achieve an equivalent reduction in risk of fatality or injury. To estimate a population's willingness to pay to reduce the risk of fatalities from highway accidents, we therefore need information on the amounts that individuals have in fact paid to reduce the number of fatalities per period (year) associated with other activities. As an example, suppose we observe that five million people pay $100 each for a safety enhancement on the new cars they buy. Suppose also that the buyers expect this enhancement to reduce their chances of a fatal injury by one in 5,000 over the period that they will be using the cars. As a group, the buyers expect their $500 million investment to save 1,000 lives. Collectively, the buyers have thus demonstrated that they are willing to pay $500,000 per life saved.

Surveys are an alternative to market-based estimates of risk-dollar trade-offs. Surveys attempt to infer trade-offs from responses to hypothetical situations that involve different risks. For example, interviewees might be asked to state the wage differential that they would require to accept a relatively dangerous job. Viscusi (1993, pp. 1937–1942) explained the advantages of surveys and summarized the results of studies that used surveys.

Alternatives to willingness to pay

There is little controversy about how to valuate safety benefits in the case of accidents that involve only property damage. The amount highway users would be willing to pay to reduce the risk of such accidents is the expected saving in costs of repairing and replacing damaged property and settling damage claims.

There is controversy, however, over whether meaningful information can be obtained about individuals' willingness to pay to decrease the risk of accidents that involve injury or loss of life. For such accidents, values must be placed on avoiding pain and suffering and, ultimately, loss of life, as well as property damage. While the same principles apply in the valuation of changes in risk of injury and fatality, implementation of the principles is difficult. In particular, it is often argued that the validity of this approach is limited because of the assumption that people make rational decisions regarding safety.

This has led some to advocate and use other approaches to valuate safety benefits. The two more commonly used alternatives measure benefits in terms of costs avoided when the frequencies (risks) of fatalities and injuries are reduced. The direct-cost approach limits benefits to the amount of direct costs avoided. It measures the value of the safety benefits of a project by the reduction in accident-related outlays such as medical care and legal services. Direct costs are a component of willingness to pay; that is, willingness to pay to avoid accidents increases by the amount of any decrease in direct costs that is expected to result from a project. We should stress, however, that willingness to pay consists of more than direct costs.

The human-capital approach includes both direct costs and the economic value of lost production, with the latter typically measured by lost earnings and the imputed value of lost household production.[5] The human-capital approach first estimates the years of productive life lost as a result of a fatal accident and the years of functioning lost due to nonfatal injuries.[6] Then, based on the expected earnings (or household production) of persons who would have been involved in accidents, a dollar value is placed on the loss of years and functioning.[7] Even

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[5]This is the terminology employed in the recent Urban Institute study (Miller et al. 1991), which used the term "comprehensive" for the willingness-to-pay approach.

[6]For an extremely detailed analysis of the impacts of differing types of injuries on medical and rehabilitative costs, and on forgone years of earning, see Chapter 6: Motor Vehicle Injuries, of Hartunian, Smart, and Thompson (1981).

[7]The taxes that would have been paid by persons killed or injured in an accident are not included as an additional component of human-capital costs. These taxes represent a use of the income that is lost, which is already counted.

implicitly equating one's value to earnings is troublesome to those who do not possess great earning power (e.g., homemakers, elderly, disabled). It also is the case that estimating the impact of diminished earning ability for those suffering serious but nonfatal injuries is fraught with conceptual and practical difficulties. The National Highway Traffic Safety Administration (NHTSA) used a variant of this approach in its published estimates of accident cost.

The direct-cost and human-capital approaches to valuating risk reduction typically result in lower estimates of that value than the willingness-to-pay approach. This is because the willingness-to-pay approach assigns values to such intangibles as pain and grief, while the others do not.

ESTIMATES OF VALUE OF REDUCED RISK

Viscusi (1993) described, compared, and critiqued various methods of estimating the value of risk reduction and summarized the results of a number of studies that apply these methods. A recent report prepared for the FHWA by the Urban Institute (Miller et al. 1991) also summarized the results of numerous studies of the value of risk reduction. In these studies, researchers have inferred willingness to pay for risk reduction from the additional compensation that workers require to accept relatively risky jobs, from consumers' purchases and use of devices (seat belts and smoke detectors) that reduce risk of injury and fatality, and from surveys that ask, directly or indirectly, what individuals are willing to pay to assume specific risks. In the studies reviewed by Miller et al., the estimated value of reducing the risk of a fatality by one per year varied from $1.0 to $3.6 million, stated in 1988 dollars (p. 78).[8] Although estimates varied, even the lowest implies a significant payoff to reducing accident risks. Further, they are not greatly out of line with the values currently used by state DOTs, which are summarized in Chapter 3.

Figure 2–1 presents estimates of safety benefits drawn from the Urban Institute study. This study defined comprehensive costs of an accident as direct costs plus the value of lost wages and household services plus a value for pain and suffering. Comprehensive cost is treated as a measure of willingness to pay because individuals would presumably pay at least as much to avoid an accident as they expect the accident to cost them. The comprehensive cost of a fatality was estimated to be $2,392,742 (at 1988 price levels). Of this total, about 73 percent is due to pain and suffering alone. This estimate was arrived at by computing the mean value of risk reduction and subtracting direct costs, including losses in wages and household income. The resulting value of pain and suffering is $1.74 million per fatality prevented.

Figure 2–2 shows the comprehensive cost of A, B, and C severity injuries combined. Based on police reports, "A" level injuries are incapacitating, "B" level are evident injuries, and "C" level are possible injuries (see Miller [1991],

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[8]A much more detailed review of these studies is available elsewhere (Miller 1990). See also Jones-Lee (1989).
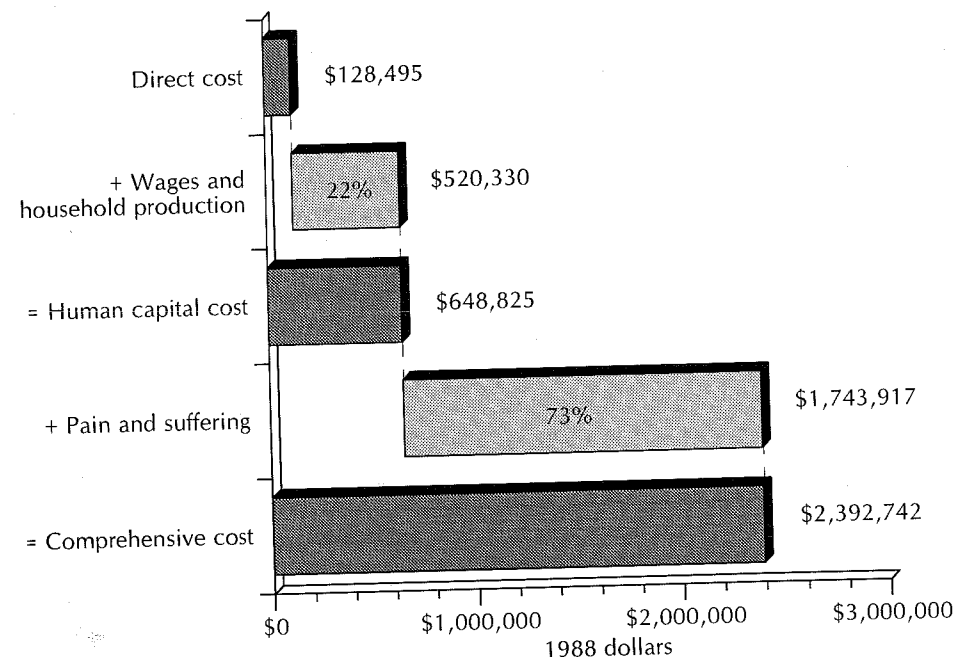
Figure 2–1. Per fatality cost estimates from Urban Institute study

- Direct cost: $128,495
- + Wages and household production: 22% — $520,330
- = Human capital cost: $648,825
- + Pain and suffering: 73% — $1,743,917
- = Comprehensive cost: $2,392,742

1988 dollars
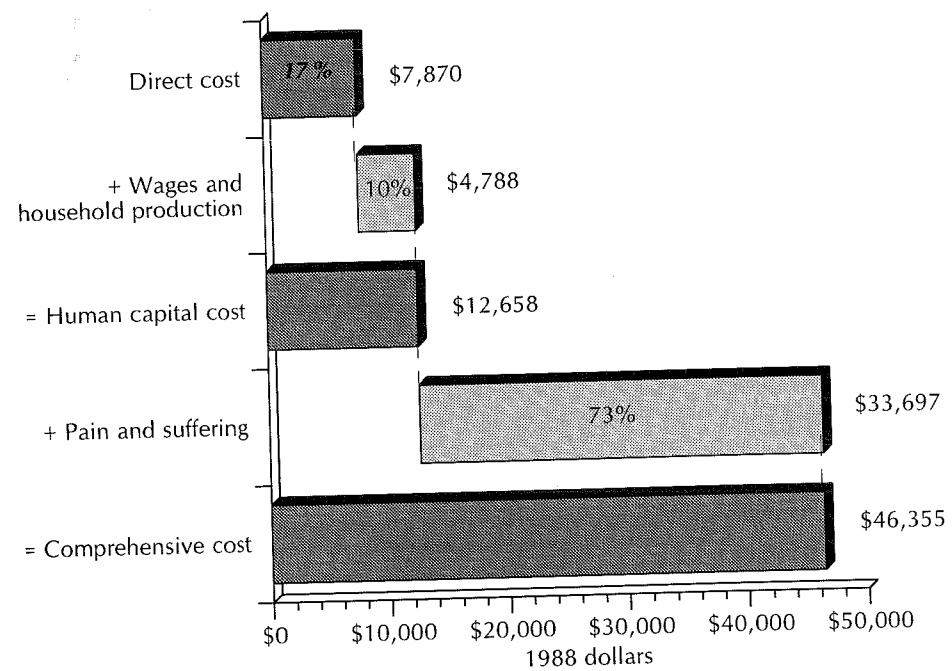
Figure 2–2. Per injury cost estimates from Urban Institute study

- Direct cost: 17% — $7,870
- + Wages and household production: 10% — $4,788
- = Human capital cost: $12,658
- + Pain and suffering: 73% — $33,697
- = Comprehensive cost: $46,355

1988 dollars

Valuating Safety Benefits

pp. 6–8). Table 2–1 presents more detailed breakdowns of these estimates, both per person and per crash, for fatalities, different severities of injury, property damage, and estimated unreported accidents.

The National Safety Council (NSC) annually estimates the cost of motor-vehicle accidents. Figure 2–3 shows how the NSC estimates have changed over the past two decades for fatalities, injuries, and property damage only accidents (PDOs). The NSC noted that these values should not be used in cost-benefit analysis of traffic safety improvements, as they do not incorporate any value for people's willingness to pay for longer life. In essence, these estimates are of human-capital costs. The NSC began using new estimating procedures in 1992, so the values before that year are not directly comparable.

The costs estimated by the NSC increased significantly through the 1970s and 1980s. After 1989, NSC's annual adjustments increased in real terms (net of inflation). The change in estimating procedures in 1992 raised the estimates further. For example, the cost of a fatality in 1991 was $450,000. In 1992, this human-capital-based estimate was revised to $880,000. The NSC also estimated a willingness-to-pay value for a fatality in 1992 of $3 million.

Figure 2–4 brings together a number of estimates of the cost of, or value of preventing, a fatality on highways. These figures have all been recalculated to 1992 dollars using the implicit price deflator for the U.S. gross domestic product. NHTSA's 1983 study used a human-capital approach. FHWA issued a memorandum in 1988 based on willingness to pay, with a value of $1.5 million per fatality (equal to $1.86 million in 1992 dollars). The Urban Institute report for FHWA in 1991 also used willingness to pay and its estimate was higher again. As is clear from Figure 2–4, more recent studies have estimated relatively high fatality costs, primarily because they have adopted the willingness-to-pay approach in lieu of the human-capital approach more prevalent in earlier studies.

Table 2–1. Estimates of comprehensive cost by police-reported severity

Severity	Per person (1988$)	Per crash (1988$)
Fatal	2,393,742	2,722,548
Incapacitating injury	169,506	228,568
Evident injury	33,227	48,333
Possible injury	17,029	25,228
Property damage	1,734	4,489
Accident unreported to police	1,601	4,144

SOURCE: Miller et al., 1991, p. 39.
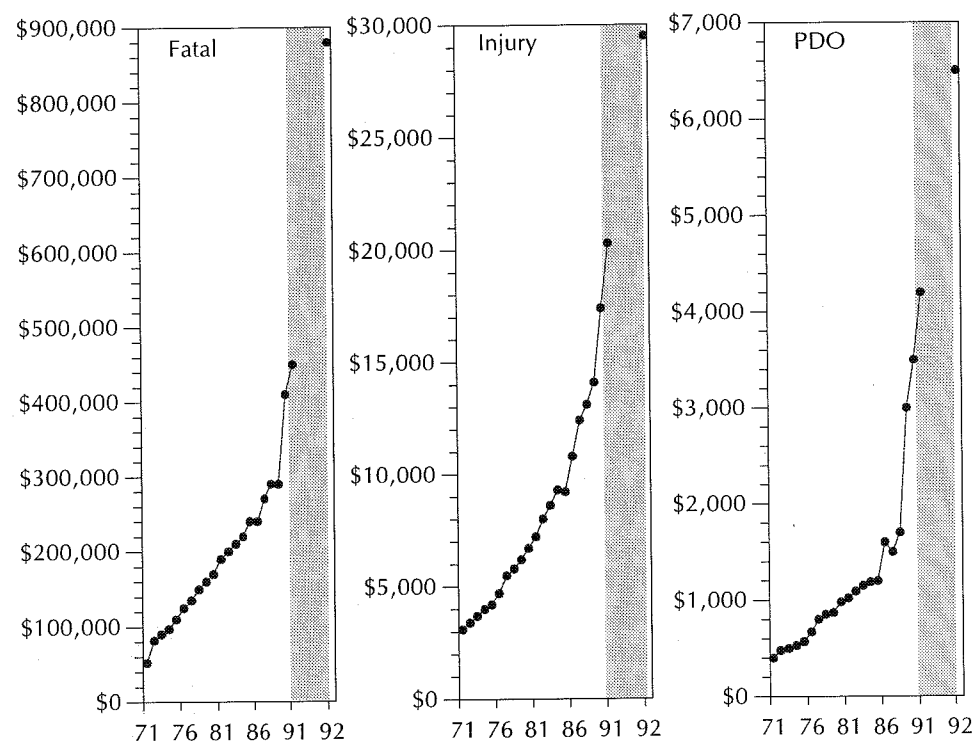
Figure 2–3. National Safety Council values for the cost of motor-vehicle accidents, 1971–1992*

*Because new cost estimating procedures were adopted in 1992, the cost estimates shown for 1992 are not comparable to those published in the past. Costs include wage and productivity losses, medical expenses, administrative expenses, motor vehicle damage, and employer costs. Dollar values in this figure have not been adjusted for inflation.
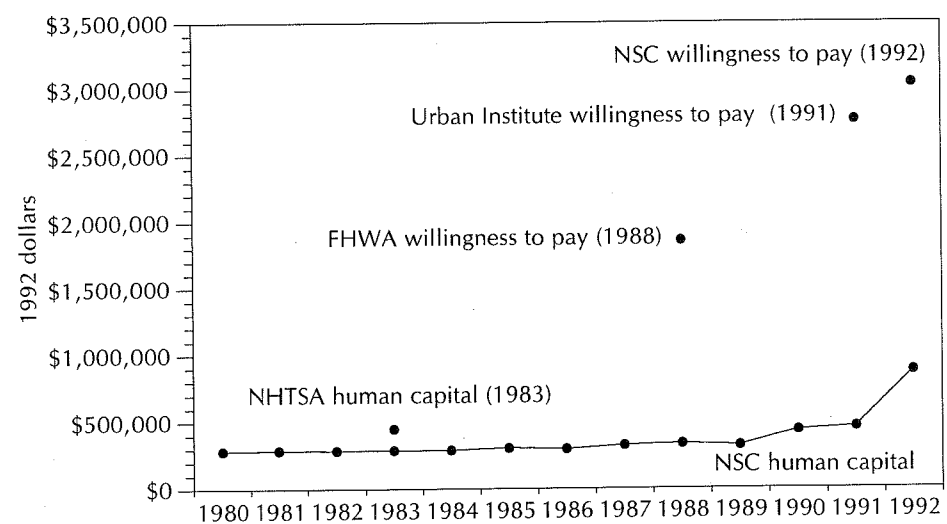
Figure 2–4. Values of fatalities from various studies, 1980–1992 (1992 dollars)

Why estimates vary

Estimates of the value of reducing the risk of fatality and injury vary for a number of reasons. First, individuals' incomes vary. Normally, the amount of risk reduction that people are willing to pay for will increase as income increases.

Second, individual preferences vary. Some people enjoy taking risks while others are risk averse. Also, the amount that people are willing to pay to reduce the risk of fatality may depend on how the fatality occurs. Avoiding two equally probable risks to life may be valued quite differently because one is "dreaded" more than the other (see Savage [1992]).Psychologists have found that people especially fear multiple fatality accidents, and Savage found that commercial airplane accidents and stomach cancer (slow, painful death) are dreaded more than fatal automobile accidents, which actually are more likely to occur. He concluded that automobile accidents have a comparatively low dread level because people tend to feel more in control of the hazardous situation. A related finding is that unknown risks are especially troubling. People are uncomfortable not being able to observe a hazard, not knowing how risky it is, or not having a good sense of what its consequences might be. Yet, evidence suggests that people do not appear to exhibit a greater willingness to pay to avoid risks about which less is known (Slovic, Fischhoff, and Lichtenstein 1985).

Third, individuals' estimates of risks vary. Consequently, researchers who estimate what people are willing to pay to reduce risk of fatality may have different judgments about the risks involved than those who make the decisions. One reason for such differences is that projects often have other outputs than safety, and separating what is paid for safety from what is paid for other outputs is difficult. More important, individuals may over- or under-estimate risks or they may not appraise risks rationally. If so, the risk-dollar trade-off that they see themselves as making may not be the trade-off that they are in fact making.

Which estimates are relevant?

Different estimates of willingness to pay such as those reported in Miller et al. (1991) are not equally appropriate for valuing risk reduction achieved by highway investments. Most of these estimates are based on workers' choices among occupations that entail different risks. As such, they are less than ideal for evaluating risk reduction attributable to highway investment. This is because the wage differential paid to a worker in a relatively risky occupation measures compensation required to endure risk rather than willingness to pay to avoid risk. Ideally, estimates should be derived from decisions made by people who are similar in income and preferences to those who will be using the highways.[9] It may also be appropriate to use estimates with degrees of dread similar to those of highway accidents.

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[9]One might question whether values assigned to risk reduction should depend on the income of the beneficiaries of the reduction. Should risk reduction be undertaken for the poor only if they are themselves willing to pay for it?

While these constraints point to some estimates as being more appropriate than others, they leave a rather wide range of defensible estimates. Consequently, there will always be some room for differing judgments about the value to be assigned to the safety benefits of highway investment. This ambiguity does not mean that any value is reasonable; nor does it mean that the value of safety benefits should be ignored. There is ample evidence that individuals *do* pay to reduce risk in a variety of situations, and they pay significant amounts. The safety benefits of highway investments can be significant even when valued at the lower-limit estimates of the amounts that people are willing to pay to reduce risk of injury and fatality. More specifically, the smallest implicit value of a life estimated by the highway-related studies reviewed by Viscusi (1993) is $600,000, and the majority of estimates fall between $3 and $7 million.

Value of risk reduction implicit in public investments

As individuals make decisions involving risk, they trade risk for other goods and thus implicitly place a value on risk reduction. The estimates of willingness to pay summarized above are derived from the trade-offs that people have actually made in their market decisions. Similarly, many public agencies make decisions that affect accident risks and, in doing so, implicitly place values on preventing fatalities and injuries.

This implicit value of life and limb, reflected in the amount that government spends to reduce risks of fatality and injury, varies from agency to agency. Within agencies, it also varies from decision to decision. Decisions are thus made as if the value of saving a life or preventing an injury varies from situation to situation. When the amount spent to achieve a given decrease in risk varies in this manner, resources devoted to reducing risk are allocated inefficiently. The risks of fatality and injury from all sources could be reduced by shifting expenditures from areas for which implicit values of risk reduction are relatively high to those for which such values are relatively low. For example, if spending on air safety currently implies a higher value of life than spending on highway safety, then shifting spending from air safety to highway safety would save lives in total without an additional dollar outlay. Spending more to prevent fatalities in air travel than in highway travel makes sense only if the lives of those who would die in air accidents are worth more than the lives of those who would die on the highways. This is a difficult judgment to justify.

Following this reasoning, the U.S. Office of Management and Budget (OMB) has urged federal agencies to work toward more common values for reductions in health and safety risks. OMB observed that implicit values for the prevention of premature deaths range from about $100,000 for certain automobile safety features to more than $5 trillion for treating wood-preserving chemicals as hazardous chemicals (U.S. Office of Management and Budget 1991, p. 10).

A related point is that the amount of safety-enhancing investment that a DOT or other agency can justify depends on what it assumes people are willing to pay to reduce risk of fatality and injury. Agencies that assume high willingness to pay will be able to justify more investment than agencies that assume low

willingness to pay. Agencies that assign relatively low values to saving a life or preventing an injury may thereby place themselves at a disadvantage in competition for funds.

Public spending to reduce risks may reflect perceptions of risks as well as value placed on risk reduction. If agencies respond to public demands, they may overinvest in reducing accidents in some areas because the public has an incorrect perception of the risk of accidents. For example, the public may overestimate the risk of fatalities from air travel and underestimate risk from highway travel because the latter is more common and individuals feel more in control.

USING ESTIMATES TO CALCULATE SAFETY BENEFITS

The safety benefit of a project is: (dollar value of risk reduction) x (risk reduction attributable to the project). For any highway segment, this relationship can be expressed by the following formula:

(1) $B = p(\Delta r)V$

where B is the dollar value of the risk reduction, p is the amount that people are willing to pay to reduce the expected number of accidents by one per million vehicle miles traveled, Δr is the expected reduction in accident risk if a project that improves the segment is undertaken, and V is annual traffic on the segment in millions of vehicle miles per year.

A numerical example

Suppose that a project would increase the number of lanes from two to four and in doing so would reduce the expected number of accidents by 0.5 per million vehicle miles traveled (e.g., from three to 2.5 accidents per million VMT). For this project, then, Δr is 0.5. If the traffic volume is three million vehicle miles traveled per year and p = $100,000, the estimated benefits of the project are:

(2) $B = \$100,000(0.5)(3) = \$150,000$ per year.

Must safety benefits be valued?

A state DOT can, of course, decide whether to proceed with a project without explicitly placing a dollar value on its safety benefits. While such a policy may appear to sidestep the difficult problems of valuating safety benefits, it still does not allow the DOT to escape making an implicit judgment about their value. Typically, highway investment feasibility analysis involves comparing the added costs (construction and additional operating and maintenance) with the relevant benefits or cost saving (time, vehicle operating, and accident). If accident cost saving is to be given proper consideration, it is imperative that the saving be expressed as a dollar value. Reflecting this need, most state DOTs now use explicit values for lives saved and injuries avoided.

Although safety benefits are necessarily valuated, explicitly or implicitly, in deciding whether to undertake a project, a project's cost-effectiveness can be

determined without valuating safety benefits. A project is cost-effective if it is the least-cost means of achieving a given reduction in accident risk. Cost-effectiveness analysis thus attempts to answer the question: Which among a set of projects is the least-cost means of achieving a given reduction in accident risk? Benefit-cost analysis, in contrast, addresses the more difficult question: Is the reduction in accident risk, in combination with other types of cost saving, worth the project's cost?

CHAPTER 3

CURRENT STATE PRACTICES IN VALUATING ACCIDENT COSTS

The most challenging aspect of taking accident cost saving into account when evaluating potential highway investments is establishing a dollar value for lives saved, injuries prevented, and property damage averted. In this chapter we present the results of a survey of all 50 states regarding their practices in valuating accident cost saving. Our survey also addressed the issue of how the states take accident cost saving into account in economic feasibility analyses of highway upgrades.

SURVEY OF STATE DOTS

Several studies have examined the methods and values states use to evaluate highway improvements, including those related to safety (McFarland 1988). A study in the 1970s as part of updating the AASHTO "Red Book" (American Association of State Highway and Transportation Officials 1978) surveyed states to determine what sorts of economic analysis they perform (Roddin and Anderson 1975).[10] That survey identified a wide range in dollar values assigned to fatalities prevented; the highest value was over 16 times as great as the lowest.

We sent all state departments of transportation a survey early in 1993, addressed to the highest official responsible for safety. After a second mailing to initial nonrespondents and a few telephone follow-up calls, we obtained data from all 50 states, for a response rate of 100 percent. A copy of the questionnaire is included as an Appendix.

Use of dollar values in safety analysis

The first section of the survey asked whether states assign dollar values to decreases in rates (risks) of traffic fatalities, personal injuries, and property damage. Forty-five states indicated that they use specific dollar values. The five states that indicated they do not use specific dollar values most commonly assign priorities to sites with comparatively high accident rates.

Figure 3–1 presents the dollar values assigned to the three types of accidents by the states that provided us with data on these values. Regarding fatalities, the states tend to fall into three groups. One, containing 18 states, clusters around $500,000. A second group with 14 states uses values of approximately $1.5 million per fatality. Eight other states use values in the range of two to three million dollars. Differences in these values largely reflect the varying sources that states use for these values (discussed in Chapter 2). Among the 42 states for which values can be determined, both the mean and median values for preventing a fatality are approximately $1.2 million.

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[10]The AASHTO "Red Book" is a guide to applying economic analysis to transportation investment issues.
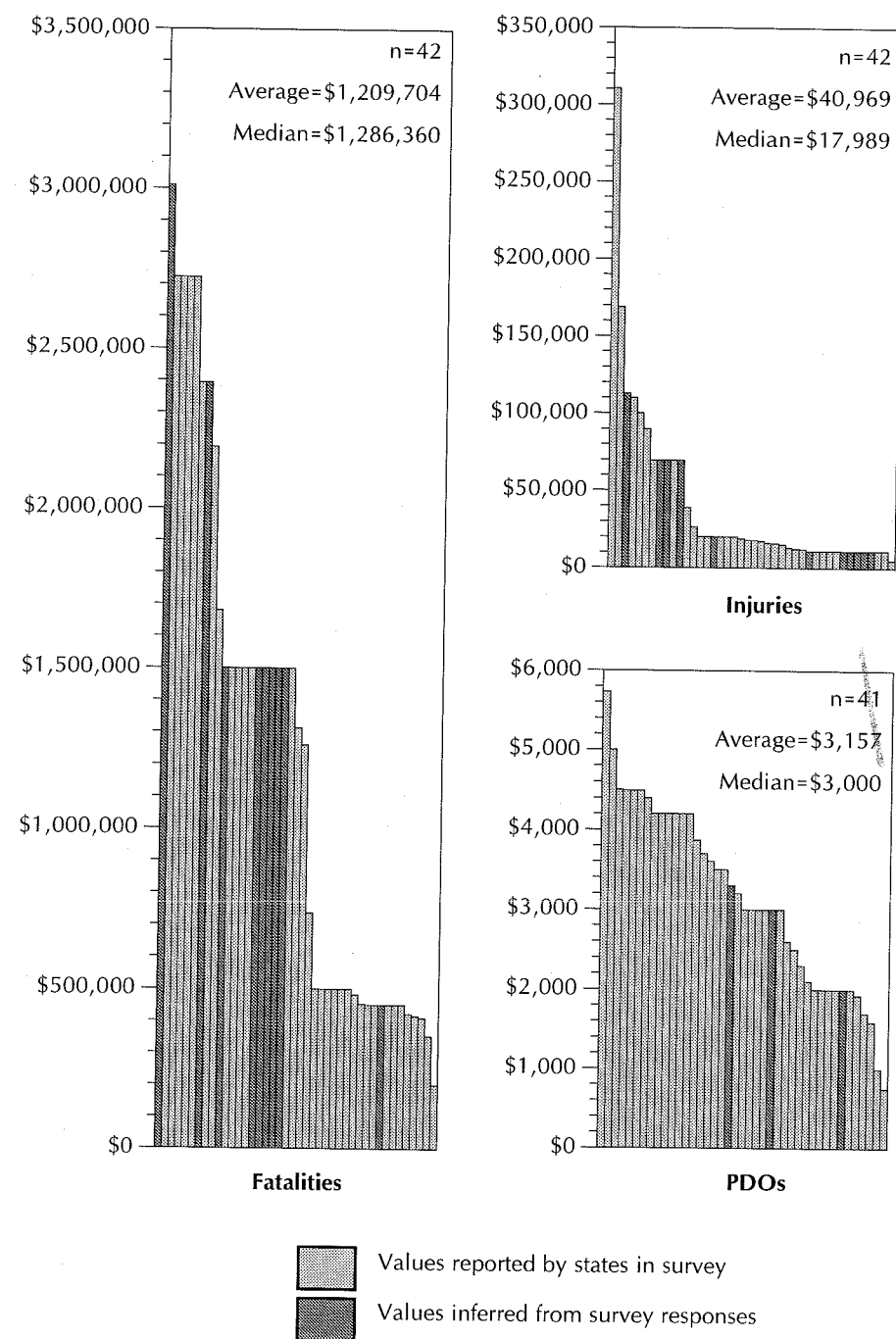
Figure 3–1. Distribution of accident cost values among the states, by accident severity, 1993

Chart 1 (Fatalities):
n=42
Average=$1,209,704
Median=$1,286,360

Chart 2 (Injuries):
n=42
Average=$40,969
Median=$17,989

Chart 3 (PDOs):
n=41
Average=$3,157
Median=$3,000

Legend:
Values reported by states in survey
Values inferred from survey responses

The distribution of values the states assign to reducing personal injuries largely hovers around $10,000 to $20,000 (the overall median value is $17,989). Twenty-nine states fall in this range. The other states use higher values, the largest being $310,000.

Property damage only accident cost estimates range from less than $1,000 to almost $6,000. The median and mean values are very similar (approximately $3,100), reflecting a rather even distribution over this range.

States use these values in various ways. As Table 3–1 shows, 34 of the 45 states providing cost data use these estimates in benefit-cost analyses of highway upgrades or improvements. This is a surprisingly high number, but we are unable to assess the rigor of these analyses.[11] It is significant, though, that accident cost data are taken into account in economic analyses of potential highway investments in numerous states.

Table 3–1. Use of accident cost estimates

Purpose	Number
Benefit-cost evaluation of highway upgrades or improvements	34 of 45 (76 percent)
Analysis of particular safety-related upgrades or improvements	31 of 45 (69 percent)
Evaluation of design exceptions	10 of 45 (22 percent)

NOTE: Six states noted other purposes.

The expected accident cost saving is considered for safety-related improvements in 31 states (multiple responses were allowed, so there is overlap in the categories in Table 3–1). Ten states consider accident costs when determining whether to pursue design exceptions on their road system.

Overall, 23 states use specific dollar values for both benefit-cost evaluations and analyses of particular safety improvements. Eight states use dollar values for all three purposes, and 15 additional states use them for both benefit-cost evaluation and analyses of specific safety-related upgrades.

Sources of dollar values

Along with the extent to which states assign dollar values to accidents prevented and the magnitudes of these values, we asked for the basis of the dollar values used. Table 3–2 displays the sources on which the respective states based accident cost values. The two most commonly used sources are National Safety Council estimates, which are published annually, and the 1988 FHWA memorandum ($1.7 million per fatal accident, $14,000 per accident involving personal injury, and $3,000 per PDO).

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[11]In 1975, Roddin and Anderson found that 25 of the 35 responding states used economic analysis when evaluating possible new construction.

Table 3–2. Sources of values for accident costs

Source	Number (of 45)
National Safety Council estimates	13
FHWA memorandum on "Motor Vehicle Accident Costs" T 7570.1 (June 30, 1988)	13
FHWA 1991 report "The Costs Of Highway Crashes" FHWA-RD-91-055	7
Research by your agency	2 *
NHTSA 1983 Report "The Economic Cost to Society of Motor Vehicle Accidents" DOT HS 806 342	2
FHWA 1984 report "Alternative Approaches to Accident Cost Concepts" FHWA/RD-83/079	2
AASHTO 1977 publication "A Manual on User Benefits Analysis of Highway and Bus-Transit Improvements"	2
State insurance claims for injury costs and PDOs	1
Rollins and MacFarland, "Costs of Motor Vehicle Accidents," Transportation Research Record 1086 (1986)	1
Kragh, Miller and Reinert (1986), "Accident Costs for Highway Safety Decisionmaking" Public Roads, Vol. 50, No. 1, pp. 15–20.	1
Other	1

*Two additional states noted "research by your agency" as well as one of the named sources.

Seven states now use the relatively high values recommended in the 1991 study for FHWA by the Urban Institute ($2,722,548 per fatal accident, $69,592 per accident involving personal injury, and $4,489 per PDO). These values are recommended by FHWA for use in economic feasibility analysis of proposed federally funded highway improvements. Table 3–2 also indicates that a variety of other sources are used by the remaining 12 states that place a dollar value on accident cost saving.

Methods of assessing accident cost saving

FHWA's Technical Advisory on Motor Vehicle Accident Costs, issued in 1988, recommended that "States should use a combined fatal-plus-injury cost (also property damage only [PDO] if available)" (Federal Highway Administration 1988, p. 2). In essence, this combined approach weights the costs of different types of accidents with their probability of occurring, instead of separating the costs. Hence the cost per fatal-plus-injury accident would be

$$\left[\frac{(\text{fatalities})\text{x}(\text{fatality cost}) + (\text{injuries})\text{x}(\text{injury cost})}{(\text{fatal accidents} + \text{injury accidents})} \right]$$

For example, instead of a cost of $1,500,000 per fatality and $11,000 per injury, this weighted approach would produce a cost per fatal-plus-injury accident of about $35,000, given typical relative frequencies of fatal and injury accidents (Bailey 1988). The advantage of such an approach is that it is often easier to predict the reduction in the number of major accidents, and hence the likelihood of reducing fatalities and/or injuries, rather than predicting separately the decrease in the number of fatalities and the decrease in the number of injuries.

To determine how many states were using this weighted approach to accident costs, we asked the following question:

> We are aware of two alternative ways to reflect the distribution of fatalities, injuries, and property damage when estimating accident cost saving for significant rural highway upgrades. Which of the two following descriptions best reflects your agency's approach using the appropriate dollar figures for value per fatality, injury, and PDO?
>
> - First, we estimate the likely reductions in fatalities, injuries, and PDOs independently. Second, we multiply each times the appropriate dollar value and sum them.
>
> - First, we estimate the likely total reduction in the number of accidents. Second, we apply the distribution of fatalities, injuries, and PDOs among all accidents using the appropriate dollar values to calculate a weighted cost saving per accident. Finally, we multiply this per accident figure times the number of accidents likely to be reduced by the upgrade.

Forty-five states answered this question. Seventeen (38 percent) indicated that they estimate reductions independently and 12 (27 percent) reported that they estimate the total reduction in accidents and use a weighted cost saving. The remaining 16 (36 percent) stated that they use an approach other than the two described. Four of these other approaches are modifications of the weighted cost approach and two are modifications of the independent cost approach. The other ten states either had no set policy, or they use engineering judgment or other analytical approaches based on severity indexes.

Estimating accident reductions

As normally applied, safety analysis requires the accident rate experienced on a particular road or location be estimated before a modification can be made to the road. Similarly, a projection or forecast must be made of the accident rate after the modification. A number of guides can aid highway engineers in estimating accident rates when they evaluate safety improvements. For example, Zegeer et al. (1990) demonstrated how to evaluate improvements on curves for rural two-lane highways. At a more local level, Dare (1990) illustrated how to identify high-accident sites and evaluate safety improvements for city engineers.

We asked the states what method they use to estimate current accident experience and the expected rate after an improvement. Multiple responses were

allowed. Most of the states (43 of 50) indicated that they use the actual accident rates specific to the road in question as a measure of the accident experience before the improvement. Some states responded that they use accident frequency or a modified form of accident rate as their measure. Of these 43 states, 35 use a three-year period to calculate such rates. Four states use a two-year period, and two states use data for five years. Two states did not indicate what time period they use.

Seven states indicated that they measure existing accident experience using the average accident rate for all roads of the same functional classification as the road before the improvement. Such rates are often broken down by factors such as urban and rural location, number of lanes, and median type.

States must also estimate accident rates expected after a proposed improvement. The approach followed by most states (34) is to apply accident reduction factors to each element of the project, such as lane widening or paving of shoulders. Respondents reported a wide range of sources for these accident reduction factors. Most states simply reported using their own data, data from "other states," or data from FHWA. Seven states indicated they use a series of factors developed at the University of Kentucky (Creasey and Agent 1985) to project the expected accident rate. In contrast to the 34 states that use accident factors, a much smaller number (seven) use average accident rates for all roads of the same classification as the road will have after the improvement.

Figure 3–2 depicts possible approaches for contrasting accident rates before and after road improvements. There are three basic methods for estimating accident rates before a road improvement: 1) calculate the actual accident experience, 2) use average rates for roads of the existing classification, and 3) use the results of a predictive model. There also are three methods for estimating the change in
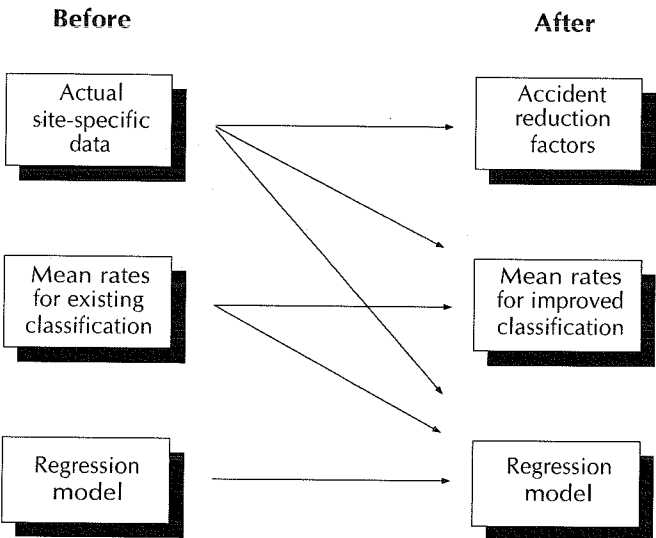
Figure 3–2. Approaches to estimating accident rates before and after road improvements

accident rates following an improvement: 1) apply accident reduction factors (related to specific physical changes), 2) use average rates for roads of the improved classification, and 3) use the results of a predictive model. The predictive models we have developed are presented in Chapter 4.

SUMMARY OF SURVEY RESULTS

Our survey of the 50 state departments of transportation has enabled us to examine how accident cost saving is currently being considered when potential highway improvements are evaluated. There is a wide divergence in the dollar values assigned to the three types of accidents: fatal, personal injury, and property damage only. Partly this is because the several widely used references for cost levels vary substantially, as we discuss in Chapter 2. The most commonly used sources of accident cost estimates are those of the National Safety Council and the 1988 FHWA memorandum. For the 42 states providing cost figures, median values for the three types of accident costs are: $1,286,360 for fatal accidents, $17,989 for personal injury accidents, and $3,000 for property damage accidents.

The mechanics of taking accident costs into account also vary among the states. About equal numbers of states estimate the three types of accident costs independently as use variations of a weighting system that combines fatal and personal injury accidents into a single value. The latter approach recognizes that the rate of serious accidents is easier to address analytically than are specific rates for fatalities versus personal injuries.

Most states use the actual accident rates experienced on a road segment prior to an improvement as the baseline condition. The most common practice for estimating the expected change in accident rates that would result from an improvement is to apply accident reduction factors. These factors are the products of studies that estimate the probable change in accident rates if specific physical improvements are made. Use of predictive models, such as those presented in Chapter 4, is as yet quite limited.

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HIGHWAY CHARACTERISTICS AND ACCIDENT RATES:

EVIDENCE FROM IOWA DATA

The central objective of this research is to examine how estimates of accident cost saving can best be incorporated into highway investment decisions. In this chapter we explore how specific types of improvements to highways can reduce accident rates and the costs of these accidents to society. As we concluded in Chapter 3, there is no widely agreed upon dollar amount that represents the value to society of preventing various types of accidents. In the calculations of this chapter, we therefore apply a range of accident cost values, including those now used in the state of Iowa.

The highway improvements considered in our analysis are the product of a rather lengthy selection process. Using three years of data, we experimented with a wide range of physical attributes of road segments before settling on seven that could be changed through capital investments. It was important that these attributes vary among the road segments analyzed, to discern their relationship with accident rates and concomitant accident costs.

ESTIMATING THE MODEL

We conducted two parallel regression analyses to assess the effects of several physical characteristics of primary road segments on accident rates and costs. In these analyses we used as explanatory variables seven characteristics for the 17,767 road segments comprising the rural non-interstate primary road system, 7,444 miles of roadway. Rural segments are defined as those not within incorporated municipalities. The seven explanatory variables are listed in Table 4–1; also in the table are the dependent variables used in the two analyses.

Functional form of the estimated equations

We applied a semi-logarithmic regression because this mode of analysis is well suited to the characteristics of these data. Because 31.6 percent of the road segments experienced no accidents over the three-year period, a standard linear regression model would have been inappropriate. By transforming the dependent variable to a natural log, we were able to achieve several objectives:

- a nonlinear relationship between the dependent and independent variables could be accommodated;

- negative accident rates, which are impossible, were ruled out;

- outlying values of the dependent variable (so-called "spikes" or high accident rates often due to accidents on relatively low average daily traffic [ADT] roads) were brought in closer within the distribution; and

- the analysis is comparable to other safety-related analyses that also have used this functional form (cf. Zegeer and Deacon 1987).

Table 4–1. Variables used in regression models of accident rates and costs

Dependent variables

- Natural log of *number of accidents* per million vehicle miles traveled.
- Natural log of *accident costs* per million vehicle miles traveled.

Independent variables

- PSR: present serviceability rating, ranging from 0 (poor) to 5 (excellent), is a measure of the general surface quality of a road segment.
- TOPCURV: the number of degrees of arc subtended by a 100-foot length for the sharpest curve on the segment (see AASHTO 1990, p. 151). Scaling of the variable is as follows: 0 = no curve, 1 = 0.1 to 1.4 degrees, 2 = 1.5–2.4 degrees, 3 = 2.5– 3.4 degrees, 4 = 3.5–4.4 degrees, 5 = 4.5–5.4 degrees, 6 = 5.5–6.9 degrees, 7 = 7.0–8.4 degrees, 8 = 8.5–10.9 degrees, 9 = 11.0–13.9 degrees, 10 = 14.0–19.4 degrees, 11 = 19.5–27.9 degrees, and 12 = 28.0 degrees or more.
- PASSRES: a dummy variable coded 1 if a passing restriction exists anywhere on the road segment and 0 if no passing restriction exists.
- ADTLANE: average daily traffic in thousands per lane.
- RIGHTSH: width of the right shoulder in feet.
- LANES: a dummy variable coded 1 if the road segment has 4 traffic lanes and coded 0 if it has 2 lanes.
- TOPGRAD: the change in elevation, as a percentage of the horizontal distance traversed for the greatest slope in the segment. Scaling of the variable is as follows: 0 = no grade, 1 = 1.0–1.9 percent, 2 = 2.0–2.9 percent, 3 = 3.0–3.9 percent, 4 = 4.0–4.9 percent, 5 = 5.0–5.9 percent, 6 = 6.0–6.9 percent, 7 = 7.0– 7.9 percent, 8 = 8.0–8.9 percent, 9 = 9.0–9.9 percent, 10 = 10.0–11.9 percent, 11 = 12.0–14.9 percent, and 12 = 15.0 percent or more.

Because the natural log of zero is undefined, a small number had to be added to the dependent variable (accident rate or cost) in the case of segments having zero accidents. There has been a useful dialog in the literature about the appropriate value to add to zero values prior to transforming the dependent variable to a natural logarithm (Dixon, Muler, and Seligson 1993). We chose to add the lowest nonzero accident rate or accident cost, as appropriate, in the data file to the segments with zero accidents. These values were 0.109 accidents per million VMT for the rate estimation and $252 per million VMT for estimation of the cost equation.

The distortion brought about by adding these minimal values is inconsequential. One way to think about this issue is that there probably is not a major difference between low accident rate roads and those having no accidents. Stated differently, it is quite likely that eventually segments with zero accidents will experience one or more accidents. If during the three-year period they have not had an accident, it may simply be due to the fact that not enough VMT occurred on them. In short, adding the minimum accident rate or cost per million VMT enables the log transformation to be made without distorting the data in a meaningful way.

Subfile of road segments examined

The Iowa DOT's primary road base file includes the 31,555 road segments that are part of the state's primary road system. Our analysis focused on the 17,767 segments that constitute the non-interstate, rural primary road system.[12] We excluded interstate segments because they are very different from other rural four-lane segments both in design and accident rates. More important, the design features of interstate segments do not vary much, so the physical characteristics of these segments cannot be expected to effectively explain accident rate differences among interstate highway segments.

We also excluded municipal segments because a municipal street with four lanes that is part of the primary road system generally will have quite different traffic characteristics and physical attributes than rural four-lane segments. (The same is true of two-lane segments.) It is unlikely that analyzing municipal primary road segments would produce useful insights as to which attributes of municipal streets in general are correlated with accident rates or costs.

Finally, we included only two-lane and four-lane road segments. The Iowa DOT base file also contains about 2,600 segments with zero (a code for freeway ramps), one, three, and five lanes. These typically are segments with turn lanes or other special features.

In the Iowa DOT base file, intersections are assigned to the connecting segment that has the highest functional classification. Thus, it was impractical to attempt to segregate road segments with intersections because not all segments joined at an intersection would be treated similarly. Furthermore, removing the 24 percent of all accidents that occurred at intersections would instill a downward bias on accident rates. It is also quite likely that attributes of the road segments leading to intersections play important roles in relative accident rates at intersections. For these reasons, intersections were not treated explicitly in this analysis.

For each of the 17,767 road segments we analyzed, the Iowa DOT base file was merged with the DOT's Accident Location and Analysis System (ALAS), which is maintained by the Office of Transportation Safety. Originally developed in the 1970s (Goolsby and Yu 1975), ALAS is a detailed data file on conditions present at road accidents, vehicles involved, and persons injured or killed.[13] Combined, these two data files enabled us to correlate fatal, personal injury, and property damage only (PDO) accidents with physical characteristics of the segment on which these accidents occurred. Our analysis included all accidents on the relevant road segments for 1989, 1990, and 1991, a total of 21,224 accidents (see Table 4–2).

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[12] The road segments analyzed have a mean length of 0.419 miles and range in length from 0.01 to 1.78 miles.

[13] We should stress that reporting requirements for accidents vary greatly from state to state. In Iowa, both police and citizens report accidents, and the threshold for damage is $500 per accident (O'Day 1993, p. 25).

Table 4–2. Types of accidents by number of lanes*

Number of lanes	Accident type			Total
	Fatal	Personal injury	PDO	
2	369	5,491	13,552	19,412
	(1.9)	(28.3)	(69.8)	(100.0)
4	18	476	1,318	1,812
	(1.0)	(26.3)	(72.7)	(100.0)
Total	387	5,967	14,870	21,224
	(1.8)	(28.1)	(70.1)	(100.0)

*The figures in this table are three-year totals for 1989, 1990, and 1991 on two- and four-lane rural primary non-interstate segments in Iowa. Values in parentheses are row percentages. Two-lane roads account for 96.0 percent of the system mileage and 89.2 percent of the vehicle miles traveled on the road segments represented in this table.

Table 4–3. Statistical description of variables used in regression models of accident rates and costs

Variable	Mean	Standard deviation	Range
Dependent variables (per million VMT)			
Accident rate	1.864	6.278	0 to 240.327
Accident cost			
$650,000			
32,500	$43,024	$325,942	0 to $20,901,666
2,300			
Independent variables (units defined in Table 4–1)			
PSR	3.113	0.672	0 to 5
TOPCURV	0.289	1.306	0 to 12
PASSRES	0.742	0.438	0 to 1
ADTLANE	1.103	0.711	.005 to 5.15
RIGHTSH	7.832	2.558	0 to 14.0
LANES	0.074	0.262	0 to 1
TOPGRAD	1.045	1.658	0 to 10*

*While the scale of TOPGRAD ranges from 0 to 12, no data values exist for categories 11 and 12.

Characteristics of the data set

Table 4–3 provides a description of the variables used in our analysis. Several characteristics of the data should be highlighted. The average accident rate per million VMT is quite low (1.86), but it has a wide range, from zero to 240. Values for accident cost are based on those currently used in Iowa: $500,000 per

fatality, $16,500 per personal injury, and $2,300 per property damage incident.[14] On the state's rural roads, a fatal accident averages 1.17 fatalities, 1.10 personal injuries, and $10,000 in property damage. Also, on rural roads a personal injury accident involves 1.53 personal injuries and $4,900 in property damage, on average. The average property damage only (PDO) accident involves $2,300 in damage. Composite average costs for the three types of accidents, using the aforementioned dollar values, are $650,000 per fatal accident, $32,500 per personal injury accident, and $2,300 per PDO accident. These figures apply to rural roads; somewhat different composite values result for municipal streets.

As one would expect, accident costs per million VMT also vary rather widely among the 17,767 road segments. They are greatly affected by the dollar costs assigned to all three types of accidents, not just fatal accidents. By far the largest portion of accidents involve property damage only (70.1 percent); personal injury accidents account for 28.1 percent and fatal accidents 1.8 percent of the total.

Turning to the independent (predictor) variables, the mean present serviceability rating (PSR) value of 3.1 on a zero-to-five scale reflects an average condition of road segments that is good but not excellent.[15] Very few of the road segments have curves, only 6.8 percent.[16] On the other hand, 74.2 percent of the road segments have passing restrictions.[17] Virtually all of these restrictions are found on two-lane road segments. The average daily traffic per lane is 1,103 vehicles, which is quite low. The range, however, is wide: from five to 5,150 vehicles per lane daily.[18] Right shoulder widths have a mean of 7.8 feet and a standard deviation of slightly over 2.5 feet. Table 4–3 also shows that 7.4 percent of the road segments have four lanes; the other 92.6 percent have two lanes. Finally, 61.6 percent of the segments are flat and 17.9 percent have grades of three percent or more.[19]

All independent variables were weighted by VMT before we included them in either the accident rate or accident cost models. The effect of weighting by VMT

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[14]Actually, $1,000 is the default value when an estimate of the cost of the damage is not provided by the investigating officer. Using a combination of reported values and the default value, the Iowa DOT calculated the average property damage to be $2,300 on rural roads for 1992.

[15]A present serviceability rating (PSR) is a numerical value ranging from zero to five, reflecting poor pavement conditions at the lower end of the scale and very good conditions at the higher end. While they are to some degree subjective, PSRs provide a general sense of comparative conditions among highway segments. The Iowa DOT derives PSRs for each of its pavement management sections, of which there were 1,610 in 1991. These sections vary in length and are typically five to ten miles long. Thus, each pavement management section includes a number of road segments.

[16]It is important to stress that the effect of a given degree curve is conditioned by the road's side friction (texture) and superelevation (bank) angle.

[17]Passing restrictions are necessary for a number of reasons, including elevation changes, curves, intersections, merges, and roadside activities (e.g., schools). They may be in effect for only a very small portion of a particular road segment.

[18]Segments with very low ADT include those leading to state parks and institutions. They represent a very small portion of road segments: four percent have less than 300 ADT.

[19]Generally speaking, a grade of less than three percent has only a slight effect on passenger car speeds in uncongested areas (AASHTO 1990, p. 227). It also poses little difficulty in terms of horizontal visual range.

is to place greater emphasis on road segments with higher VMT levels. Our rationale is that the relationship between road segment attributes and accident rates is likely to be better defined on comparatively well traveled roads. On low volume roads, an accident may create a "spike," that is a relatively high number of accidents per million VMT. Less emphasis is placed on these cases. Although most road segments are not dramatically affected by this weighting procedure, very low VMT segments are affected most.

ACCIDENT RATE MODEL

We fitted a semi-log regression equation (dependent variable transformed to a natural log) to the data just described and took anti-logs of the result. The latter step restored the dependent variable to its original form, thus allowing accident rates to be predicted. Our equation is

$$\frac{\text{accidents}}{\text{million VMT}} = 0.517(0.972^{PSR})(1.068^{TOPCURV})(1.179^{PASSRES})(1.214^{ADTLANE})$$

$$(0.974^{RIGHTSH})(0.933^{LANES})(1.051^{TOPGRAD})$$

where

PSR = present serviceability rating of the segment,

TOPCURV = degrees of the sharpest curve on the segment,

PASSRES = whether a passing restriction exists on the segment,

ADTLANE = average daily traffic per lane,

RIGHTSH = width of the right shoulder,

LANES = whether the segment has two or four lanes, and

TOPGRAD = percent slope of the steepest grade on the segment.

In an equation of this type, a coefficient greater than one implies that as the magnitude of the particular independent variable increases, the accident rate per million vehicle miles also increases. Coefficients less than one mean that as the independent variable increases, the accident rate falls. The relationship between values of the independent variable and accident rates is exponential, meaning that doubling any given variable amounts to squaring the coefficient.

The equation tells us that as PSR increases, accident rates fall. All else equal, improving a road segment from a level of three to four would reduce the accident rate by 2.8 percent (equal to $1 - 0.972$). Reducing the sharpness of the greatest curve by two steps (among the 13 levels) would lower the accident rate by 12.3 percent (equal to $1 - 1/1.068^2$), and removing all passing restrictions on the road segment would decrease accident rates by 15.2 percent (equal to $1 - 1/1.179$).

Increasing ADT per lane on a road segment from 2,000 to 4,000 vehicles per day, as an example, would raise the accident rate by 47.4 percent (equal to 1.214^2), while widening the right shoulder from eight to ten feet would

reduce accidents per million VMT by 5.1 percent (equal to $1 - 0.974^2$). If no other changes were made, upgrading a two-lane road to four lanes would reduce accidents by 6.7 percent (equal to $1 - 0.933$). Finally, reducing the steepest grade by two steps (among the 13 levels) would result in a drop of 9.5 percent (equal to $1 - 1/1.051^2$) in the accident rate. We should stress that the cost-effectiveness of these percentage changes may vary considerably because of differing costs of the relevant improvements.

All coefficients are statistically significant at the 0.001 level except PSR and LANES, which are significant at the 0.100 level. The number of lanes is moderately correlated with right shoulder width and is correlated negatively with passing restrictions. These two attributes tend to vary between two- and four-lane highways and explain much of the same effects as number of lanes.

An illustrative application of the model

Perhaps the most illuminating way to illustrate the practical use of the accident rate model is to apply it to a hypothetical highway upgrade. Table 4–4 depicts a case where a two-lane highway is a candidate for upgrading to four lanes. This two-lane segment carries 5,000 ADT, which is comparatively high.[20] It has a PSR of 3.0, which is slightly below average on rural non-interstate primary road segments, and following the upgrade it would have a PSR of 4.0. The sharpest curve on the road segment is 4.5 to 5.4 degrees and would be reduced (made more shallow) to 2.5 to 3.4 degrees. A passing restriction on the two-lane highway would no longer exist, and the ADT per lane would be halved (i.e., the overall traffic level on the road would be unchanged). Width of the right shoulder would increase from seven to ten feet. The slope would be reduced from 4.0 to 4.9 degrees to 2.0 to 2.9 degrees.

Table 4–4. Application of the cost model to a typical upgrade

	Base 2-lane	Improved 4-lane
PSR	3.0	4.0
TOPCURV	5	3
PASSRES	1	0
ADTLANE	2.5	1.25
RIGHTSH	7.0	10.0
LANES	0	1
TOPGRAD	4	2
Accident rate (per million VMT)	1.28	0.56

To estimate the change in accident rate that would result from this upgrade, the appropriate values are plugged into the regression model. Each coefficient is thus

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[20]While 5,000 ADT on a two-lane road is high (over three standard deviations above the mean) this level of traffic is a common point at which upgrading to four lanes is contemplated. Our example, then, is a two-lane road that arguably could be upgraded to four lanes.

raised to a power equal to the value being used for prediction. For example, the PSR coefficient of 0.972 is raised to the third power if the PSR value for the base case two-lane road is 3.0. The resulting values are then multiplied to produce an estimate of accident rate. Plugging the respective two-lane attributes into the model we obtain

$$1.28 = 0.517(0.972^{3.0})(1.068^{5.0})(1.179^{1.0})(1.214^{2.5})(0.974^{7.0})(0.933^{0.0})(1.051^{1.0}).$$

Because the model was estimated using road segments as the observational units, these are the units for which accident rates can be predicted. Typically, a length of road that is a candidate for upgrading will be comprised of numerous segments. Values for each of the seven independent variables should be determined for each affected road segment. Using a spreadsheet, estimates of the accident rate per million VMT can then be calculated for each road segment. Taking into account the length of each segment and its average daily traffic (ADT), an annual VMT figure for the segment can be estimated. These annual VMT figures should be used as segment-by-segment weights to calculate an overall accident rate per million VMT for the entire length of road. The procedure can be repeated using values for the independent variables corresponding to the upgraded road, segment by segment.

For the example in Table 4–4, the accident rate model estimates the accident rate prior to upgrading to be 1.28 accidents per million VMT. The accident rate following the upgrade would be reduced to 0.56 accidents per million VMT, a 56.3 percent drop.[21]

Issues of specification and other factors

Our accident rate model has limitations. Because not all factors influencing accident rates could be included in the model, it cannot predict perfectly the rate for a given road segment. It can, however, accurately estimate the effects of changes in road characteristics if omitted factors are not correlated with our independent (predictor) variables. Other factors that could influence accident rates were not incorporated into the model for one of two reasons:

- the data are not available in the primary road base or ALAS file, or

- an attribute is listed as present at an accident site, but no data exist as to its presence at other locations.

Regarding the latter point, consider a case where a vehicle struck a vertical obstruction at the side of a road. What would be the change in accident rates if all such obstructions were removed? Not knowing how prevalent these vertical obstructions are on all road segments, this question cannot be answered. If there are very few such obstructions and one of them was a factor in an accident, that is very different than if there are many of them and only one was struck by a

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[21]A greater improvement would be possible if the road were upgraded to a freeway (interstate standard). Interstate highways tend to have substantially lower accident rates than do expressways (non-interstate four-lane highways). Because interstate highways cost about twice as much as expressways, a sizable transportation cost saving is needed to justify this cost. This implies that traffic volumes far in excess of 5,000 ADT are required for a freeway to be contemplated.

vehicle. The variables included in the model have values on all road segments, regardless of whether accidents actually occurred on them. This is necessary to estimate the effects of changing particular attributes.

The independent variables included in the accident rate model explain slightly more than three percent of the variability in the natural log of accident rates. In addition to the physical road attributes included in our model, two other groups of factors may influence whether accidents occur:

- other road characteristics for which data are not available, and

- factors other than road characteristics, such as meteorological conditions, mechanical failure of vehicles, or human factors (e.g., judgment error, chemical influence, fatigue).[22]
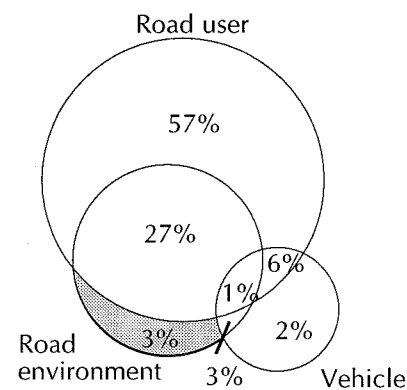
Figure 4–1. Interaction among factors contributing to vehicle accidents*

*Areas in this figure are not precisely equal to the proportions depicted. The shaded area represents road environment alone.

SOURCE: Rumar's (1985) summary of Treat (1980).

There is no doubt that these other factors are highly important. Rumar (1985) summarized the role of various precrash factors in traffic accidents and concluded that the road user is the key factor. Figure 4–1 depicts Rumar's summary of Treat (1980), who studied precrash factors in the United States. The graphic shows that an interaction exists among the road user, road environment, and vehicle. In Treat's study, the road user alone was the key influencing factor in 57 percent of all accidents, the road environment alone accounted for three

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[22]A good discussion of drivers' attributes and accident frequency appears in Evans (1991). Research needs regarding factors influencing accidents are discussed in a special report of the Transportation Research Board (1990). It is worth noting that the U.S. DOT estimates that 20 percent of all motor vehicle accidents involving fatalities or serious injuries involve alcohol (U.S. DOT Bureau of Transportation Statistics 1994, Table 6–8). National Highway Traffic Safety Administration (NHTSA) figures quoted in the *New York Times* indicate that in 1992, 45 percent of the drivers, passengers, or pedestrians involved in fatal accidents were found to have been drinking (Ayres 1994).

percent, and the vehicle for two percent. Interaction between the road user and the road environment was a key factor in 27 percent of the accidents studied.[23]

In summary, our objective is to use the best data available to enable safety improvements to be considered when assessing the economic feasibility of potential highway investments. We stress that other factors can and do influence whether an accident will occur on any particular road segment.

ACCIDENT COST MODEL

Using exactly the same independent or predictor variables as in the accident rate model just discussed, we estimated a semi-log regression model of accident costs. To construct a dependent variable, we assigned costs to each of the three types of accidents: fatal, personal injury, and property damage only (PDO). The ALAS (accident) file we incorporated in our analysis contains information on the number of each type of accident that occurred on each road segment during the three-year period that was analyzed.

Practically speaking, assigning different cost values to each of the three types of accidents amounts to weighting them. A segment that had a fatal accident thus has a high-cost value to be explained by the respective independent variables.

As discussed in Chapter 3, the states differ widely in terms of the cost levels assigned to the three types of accidents. Our preliminary analysis uses the current Iowa values of $650,000 per fatal accident, $32,500 per personal injury accident, and $2,300 per PDO accident (see pages 28–29).

Using these values, our equation is

$$\frac{\text{accident cost}}{\text{million VMT}} = 1{,}587.580(0.994^{PSR})(1.111^{TOPCURV})(1.442^{PASSRES})(1.741^{ADTLANE})$$
$$(0.952^{RIGHTSH})(0.936^{LANES})(1.085^{TOPGRAD})$$

where

PSR = present serviceability rating of the segment,

TOPCURV = degrees of the sharpest curve on the segment,

PASSRES = whether a passing restriction exists on the segment,

ADTLANE = average daily traffic per lane,

RIGHTSH = width of the right shoulder,

LANES = whether the segment has two or four lanes, and

TOPGRAD = percent slope of the steepest grade on the segment.

The same variables are statistically significant as with the accident rate equation except for PSR and LANES, whose significance levels fall below the

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[23] We should note that Hauer and Hakkert (1988) reviewed a number of studies and concluded that reporting of accidents varies quite considerably from place to place and is much less complete for less serious accidents.

0.100 level. The accident cost semi-log regression model explains about six percent of the variance in accident costs. The equation indicates that segments with higher PSR values (i.e., smoother surfaces) have slightly lower accident costs, all else equal. Raising the PSR value on a road segment by two (the scale is zero to five) would reduce accident costs by 1.2 percent. Holding everything else constant, reducing the sharpest curve on a road segment by two steps would lower accident costs per million VMT by 19.0 percent. Similarly, removing any passing restrictions on a segment would reduce these costs by 30.7 percent. Of particular importance is that increasing ADT per lane on a road segment from 2,000 to 4,000 would raise accident costs of that segment by 203.1 percent. Widening the right shoulder from eight to ten feet would reduce accident costs by 9.4 percent. Upgrading a two-lane road to four lanes would decrease accident costs by 6.4 percent if nothing else were changed. It is unlikely, however, that additional lanes would be added without making some of the other improvements alluded to in our model. Finally, reducing the steepest grade of a segment by two steps would lower accident costs by 15.1 percent.

In Figure 4–2, we show the effects of varying some of the independent variables. We held all values of the independent variables at the values of the base case two-lane highway. One variable at a time was assigned the value for the improved four-lane highway, and the impact on accident cost saving was then calculated.

Figure 4–2 shows that reducing the ADT per lane from 2,500 to 1,250 (which, all else equal, doubling the number of lanes would do if the ADT is 5,000) would lead to a saving of $7,474 per million VMT. Removing all passing restrictions on
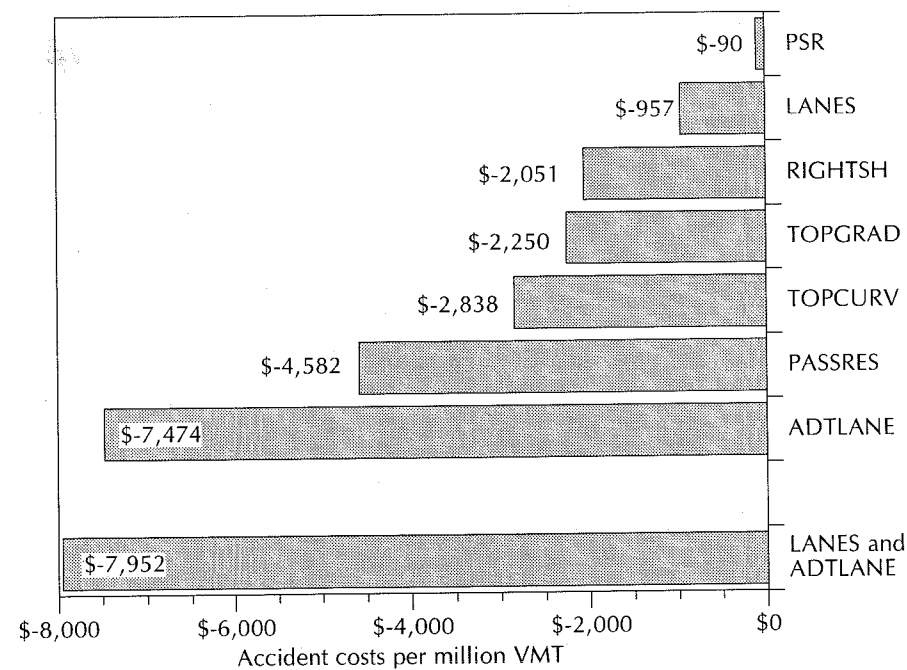

Figure 4–2. Effects on accident costs of varying individual characteristics

a segment would decrease accident costs by $4,582, reducing the degrees of the greatest curve by two steps would decrease costs by $2,838, and flattening the steepest slope by two steps would reduce costs by $2,250. Widening the right shoulder from seven to ten feet would reduce costs by $2,051, increasing PSR from three to four would decrease costs by $90, and upgrading from two lanes to four would reduce costs by $957 per million VMT. We should stress that because the equation is multiplicative, not additive, these individual effects cannot be added together to estimate the total cost saving. That is done by plugging the appropriate values into the equation and solving for the dependent variable.

One interesting aspect of these results is that most of the accident cost saving could be achieved without necessarily upgrading to four lanes. In cases where the ADT is not sufficiently high to require additional lanes, a "super-two" upgrade may be advisable. If this upgrade included wider shoulders, removal of passing restrictions by adding passing lanes where needed, reducing grades, reducing the sharpness of curves, and improving pavement smoothness (PSR), most of the accident cost saving would be achieved. Specifically, if all features of the example upgrade except additional lanes were made, using the current Iowa cost figures, the accident cost saving per million VMT would equal $8,830. If the same improvements were made in addition to upgrading to four lanes, the accident cost saving per million VMT would be $12,085, or $3,255 more. Thus, 73 percent of the safety benefits from a four-lane highway could be obtained with a super-two highway, if the ADT is 5,000.

The role of traffic volume

If the current accident cost values used by the Iowa DOT (defined earlier) are used to estimate the regression equation, the example upgrade in Table 4–4 produces a sizable cost saving. Specifically, the two-lane road depicted in this example would have an accident cost of $14,949 per million VMT. Upgrading this road segment to four lanes and making other changes would reduce this accident cost to $2,864 per million VMT.

The extent to which upgrading this example road segment to four lanes would produce a sizable accident cost saving is greatly affected by the average daily traffic (ADT) on the segment. As Figure 4–3 shows, the magnitude of cost saving per million VMT is substantially less when the ADT is lower. If the ADT is only 2,000, the accident cost would only be reduced from $6,507 per million VMT for the two-lane road to $1,889 for the four-lane facility.

Alternative accident cost values

In Chapter 3, we discussed the values to states of using accident costs in their evaluations. We also reviewed the sources of accident cost figures that are the basis for these values. We now show how varying the three accident cost parameters affects the cost saving for the example highway upgrade.

Table 4–5 presents the three accident cost combinations we have used. The highest value is that recommended by the Urban Institute in its 1991 study for FHWA. Next are the values advanced by the 1988 FHWA study discussed
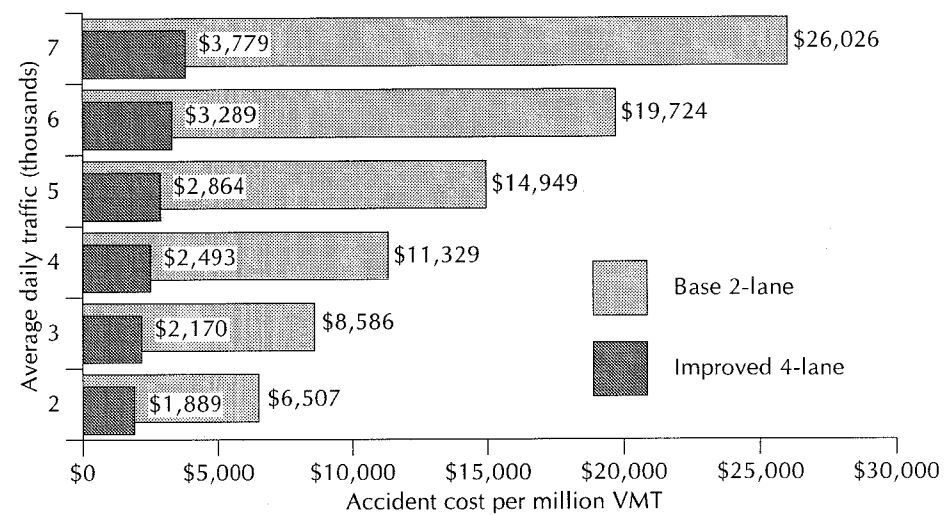
Figure 4–3. Effects of ADT on accident cost saving

Table 4–5. Some possible accident cost figures

Source	Cost per accident		
	Fatal	Personal injury	PDO
Urban Institute	$2,722,548	$69,592	$4,489
FHWA 1988	$1,700,000	$14,000	$3,000
Iowa current	$650,000	$32,500	$2,300

earlier. The last accident cost combination is the empirically derived values for rural Iowa primary non-interstate highways. These values are *per accident*, based on a value of $500,000 per fatality prevented, $16,500 per personal injury prevented, and $2,300 per PDO incident. As discussed on page 29, the $650,000 and $32,500 per accident values reflect the fact that in fatal accidents there tends to be more than one fatality, as well as personal injuries. In personal injury accidents, usually more than one person is injured.

We ran the accident cost model for each of the three cost value combinations to estimate three different equations. Using the example discussed earlier (see Table 4–4), we calculated the magnitude of accident cost saving in each case that would result from this particular highway upgrade.[24] Our results are presented in Table 4–6.

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[24]Miller et al. (1987) examined the effect of variable accident reporting thresholds, different discount rates and estimates for fatalities and injuries on safety project evaluation. They found that some safety projects would only be desirable with certain combinations of these factors.

Table 4–6. Cost model results using other accident cost figures

Accident cost figures	Costs per million VMT		
	Base 2-lane	Improved 4-lane	Reduction
$2,722,548 $69,592 $4,489	$33,862	$5,940	$27,922
$1,700,000 $14,000 $3,000	$12,323	$2,791	$9,532
$650,000 $32,500 $2,300	$14,949	$2,864	$12,085

Using the current Iowa values for the three types of accidents, the accident cost per million VMT of the base two-lane road is $14,949. By upgrading it to four lanes, improving the PSR from 3.0 to 4.0, lowering the sharpest curve by two steps, flattening the steepest grade by two steps, widening the right shoulder from seven to ten feet, eliminating all need for passing restrictions, and reducing the ADT per lane by half, the accident cost per million VMT is lowered to $2,864. This represents a saving of $12,085 per million VMT. Of course, as one increases the dollar values assigned to reductions in the three types of accidents, estimates of the accident cost saving brought about by the upgrade likewise increase. We should note that the accident cost saving when the Urban Institute figures are applied (the top grouping) are over twice as great as when the current Iowa values are used (the bottom grouping).

In Table 4–7 we convert these cost reductions per million VMT to a present value over the 20-year life of the highway upgrade. Using an ADT of 5,000 and a real discount rate of 7.0 percent (as mandated by the U.S. Office of Management and Budget [1992]), the table shows the present value of accident cost saving per one-mile length of highway upgraded. The current Iowa accident cost values in this example upgrade would bring about a saving with a present value of $250,009 per mile of road. As before, higher values of accident cost saving lead to correspondingly greater present value figures.[25]

How sensitive is the accident cost saving to the respective cost saving values assigned to fatal, injury, and property damage only accidents? Using the current Iowa values of $650,000 per fatal accident, $32,500 per injury accident, and $2,300 per property damage accident, we varied each of these three parameters, one at a time. Specifically, we reduced each cost value by 20 percent, and we also increased it by 20 percent. Figure 4–4 displays the results of this analysis. Largely because 70.1 percent of all accidents in our data file were PDO

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[25]Recall that these cost reductions are for a segment that has comparatively high traffic. There are few such segments in Iowa, and consequently few candidates for upgrading that would yield the returns reported in Table 4–7.

Table 4–7. Present values of alternative accident cost saving

Accident cost figures	Annual saving	Present value
$2,722,548		
$69,592	$50,959	$577,646
$4,489		
$1,700,000		
$14,000	$17,394	$197,176
$3,000		
$650,000		
$32,500	$22,055	$250,009
$2,300		

NOTE: Saving is per mile of highway length; assumptions are 5,000 ADT, 7.0 percent real discount rate, and 20-year project life.

accidents, values assigned to this parameter are important to the accident cost both before and after upgrading.[26] Another 28.1 percent of all accidents involve personal injuries; because this too is a substantial share of accidents and because the values assigned to these accidents are greater, cost values of personal injury accidents are also important in determining total accident costs for road segments.

Particularly noteworthy is the comparatively small role played by the dollar value assigned to fatal accidents. Varying the figure of $650,000 million by plus or minus 20 percent affects the total accident costs of road segments very little. This is largely because fatal accidents constitute only 1.8 percent of the total. It is worth noting that on four-lane highways, fatal accidents represent 1.0 percent of all accidents but about 1.9 percent of all accidents on two-lane highways.

Perhaps the most impressive message of Figure 4–4 is that the accident cost saving is quite robust. Changing any of the three parameters by 20 percent one way or the other does not greatly alter the accident cost saving that results for our example upgrade. In every case the improved highway has 18 to 21 percent of the accident costs of the unimproved highway. The dollar value of the accident cost saving per million VMT has a narrow range, from $10,652 to $13,527. This range occurs when the personal injury value is varied; it has the greatest effect on total accident cost.

Applying the accident cost model

The accident cost model can be applied in a manner similar to the accident rate model discussed earlier in the chapter. Plugging into the regression equation the seven base-case (prior to the upgrade) attribute values for each road segment,

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[26]According to the National Highway Traffic Safety Administration (1987), 36.9 percent of the total cost of accidents is due to property losses. This is the largest single category.
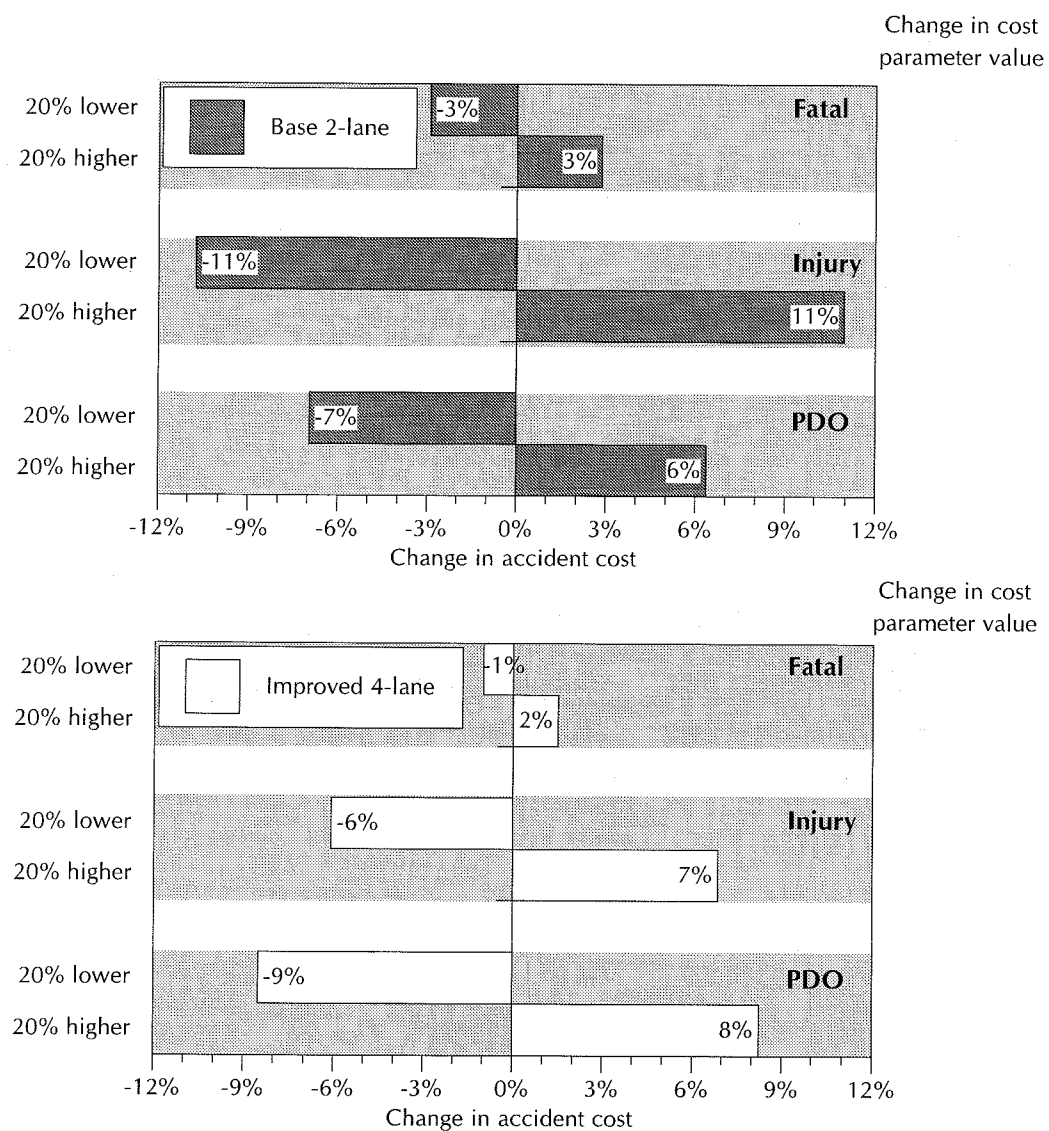
Figure 4–4. Effects on accident cost saving of varying cost parameters

expected accident costs per million VMT are computed for the respective segments. The resulting value for each segment is divided into the annual VMT for that segment (ADT times segment length times 365). This yields the segment's annual accident cost. The annual accident costs of all relevant segments are then summed. From this sum is subtracted the figure derived by similarly calculating the accident cost when the seven attribute values corresponding to the improved highway are used. The result is the expected annual accident cost saving due to upgrading the length of road. This value can be included in a benefit-cost analysis of the road upgrade.

CONCLUSIONS

We combined data from the Iowa DOT primary road base file and the DOT's Accident Location and Analysis System (ALAS) to facilitate a comprehensive analysis of accident rates and costs. Focusing on rural primary non-interstate highways (7,444 miles of roadway), we examined the effects of changing basic road characteristics. To do this, we estimated two separate semi-log regression models, using the same independent (predictor) variables in each.

The accident rate analysis reveals that the average daily traffic (ADT) per lane is the greatest determinant of accidents among the factors we were able to consider. Fewer accidents are likely when ADT per lane is lower; vehicles in proximity to each other have more accidents per million vehicle miles of travel (VMT). The analysis also shows that lower accident rates are likely on smoother, better maintained roads, as well as those with shallow curves, no need for any form of passing restriction, wide right shoulders, four lanes instead of two, and a grade that is not steep.

We stress that it was not possible to take into account all road characteristics that might possibly influence accident rates. Data on some of these characteristics do not exist: it is not feasible to measure the presence of certain characteristics when accidents have not occurred (i.e., effects on accident rates cannot be deduced). It also is the case that accident rates are influenced by numerous factors other than those pertaining to the roadway itself.

Generally the same independent variables substantially affect accident costs per million VMT as is the case with rates. We estimated accident cost semi-log regression models using a variety of accident cost figures, including those now used by the Iowa DOT. Using an example highway upgrade, we calculated the present value of the accident cost saving over the 20-year life of the improvement. The cost saving ranged from $197,000 to $578,000, depending on the accident cost figures used. We also varied each of the three accident cost parameters—fatalities, personal injuries, and property damage—one at a time, to test the sensitivity of the predicted cost saving to the level of cost associated with each type of accident. The dollar figure assigned to personal injury accidents proved to be most crucial.

Our overall finding is that it is feasible to estimate the extent to which society will gain if investments are made that make highways safer. This analysis bears out the fact that policy decisions as to the dollar level assigned to the three types of accident cost saving are important for safety to be appropriately considered when highway investments are made.

CHAPTER 5

CONCLUSIONS AND POLICY RECOMMENDATIONS

The two primary purposes of this research have been to 1) develop a practical method for estimating the reduction in accident risk if a roadway is improved and 2) shed light on the appropriate value to be assigned to a reduction in accidents. In this concluding chapter we first recap our principal findings, and we then recommend how these findings can be implemented.

RESEARCH FINDINGS

In Chapter 2 we espouse the concept of willingness to pay as the appropriate way to place a value on safety benefits (reductions in accident costs). By far, the preponderance of recent studies on accident cost valuation embrace willingness to pay because of its conceptual clarity and logical appeal. If one can measure the willingness of highway users to pay for an upgrade, in part due to safety improvements, a rational decision can be made as to whether the upgrade would produce sufficient user benefits to outweigh the relevant costs.

Chapter 3 provides several estimates of willingness to pay for reductions in accident risk. We cite a recent Urban Institute study, which reviewed numerous previous estimates and recommended substantially higher values for reductions in fatal, personal injury, and property damage only accidents. A sizable part of that study's estimate of willingness to pay is related to pain and suffering. In fact, 73 percent of the estimated fatal and personal injury accident costs are related to pain and suffering. We also note that with willingness to pay becoming the dominant valuation approach, accident cost estimates have tended to increase.

In Chapter 3 we also report the results of a survey of state departments of transportation regarding the values of lives saved, injuries prevented, and property damage averted. These values have rather wide ranges because the sources upon which the values are based differ substantially. Iowa's current value for a fatality ($500,000) is comparatively low, as are its values for personal injuries ($16,500) and property damage ($2,300, the current reported PDO accident average value for rural roads).

Our survey results indicate that 34 states use accident cost data in benefit-cost studies of potential highway investments. Of these, 12 states combine fatalities and personal injuries to construct a weighted estimate of the costs associated with serious motor vehicle accidents. These per-accident costs are incorporated into benefit-cost analyses.

Results of our survey provide insights into how the states estimate differences in accident rates before and after a highway upgrade. Forty-two states use the actual rates on a highway for the "before" rates. Our concern with this approach is that other similar roads may have higher or lower rates simply due to the

random nature of accidents. By using data from a single road, the impact analysis may understate or overstate the safety of the road before it is upgraded.

In Chapter 4 we present a systematic approach for estimating changes in accident rates and attendant costs likely to result from upgrading rural primary non-interstate highways. We used semi-log regression to estimate the association between a series of road segment attributes and observed accident frequency. This analysis involved merging the Iowa DOT's primary road base file and its Accident Location and Analysis System (ALAS). Our data consists of 21,224 accidents on 17,767 road segments (averaging 0.419 miles in length). Of these road segments, 31.6 percent had no accidents for the three-year period of analysis (1989, 1990, and 1991).

Attributes affecting accident rates most are the number of curves on a road segment and average daily traffic (ADT) per lane. To demonstrate the practical utility of the accident rate model, we applied it to a hypothetical upgrade problem: a two-lane road with unusually high ADT (5,000). By upgrading the road to four lanes, improving its pavement quality, and widening the right shoulder, we predict the accident rate per million vehicle miles traveled (VMT) would drop from 1.28 to 0.56.

The accident rate model has distinct advantages over the common practice of using the actual accident rate on the road to be upgraded. Accidents tend to be comparatively rare events, and a stable relationship between road attributes and accident rate is unlikely to be derived from a single road segment, particularly one with moderate to low ADT. It is true, however, that there is a place for using actual accident rates, such as at specific sites with comparatively high traffic volumes and accident rates. These "hot spots" may not be typical of segments with many similar geometric attributes, and it would not be appropriate to apply a predictive model in such situations. Especially in system-level analysis, however, predictive models enable analysts to base estimates of accident cost saving on relatively stable relationships between road attributes and safety.

Our approach builds on the common practice of applying accident reduction factors to estimate the accident rate following the highway upgrade. The advantage of an accident rate model is that "before" and "after" upgrading estimates can be similarly derived and compared. The change in rates can then be taken into account when evaluating the economic efficiency of the upgrade investment.

Also in Chapter 4, we estimate an accident cost model using the same independent variables (i.e., the same road attributes). This model is similar to the accident rate model except that instead of using total accidents per road segment, we in effect weighted accidents on the basis of severity. To do this we used the current dollar values for fatal, personal injury, and property damage accidents for the state of Iowa.

In our example upgrade, the accident cost saving per million VMT would be $12,085 ($14,949 before and $2,864 after the upgrade). It is worth noting that

most of the accident cost saving (73 percent) would be attained at a much lower capital cost if a "super-two" highway were constructed instead of a four-lane non-interstate highway.[27]

In our hypothetical example, we varied the values assigned to fatal, personal injury, and property damage only accidents one at a time to determine the sensitivity of accident cost saving to each value. Interestingly, the value assigned to fatal accidents is not nearly as important in determining accident cost saving as that assigned to personal injury accidents. Primarily, this is because personal injury accidents represent 28.1 percent of all accidents, while fatal accidents are 1.8 percent of the total.

POLICY RECOMMENDATIONS

Our research leads us to suggest three changes in how reductions in accident costs are taken into account when assessing the benefits and costs of highway investments.

Increase the values of accident costs

Iowa's current accident cost values of $500,000 per fatality, $16,500 per personal injury, and $2,300 per accident involving property damage only are comparatively low. Our survey of state departments of transportation revealed that currently the average values are $1,202,623, $41,725, and $3,186, respectively.

How high should the Iowa values be? The FHWA values of $2.7 million per fatal accident and $69,592 per personal injury accident are dramatically higher than those currently used by Iowa and most other states. Thirteen states use the previous FHWA (1988) values of $1.7 million for fatal accidents and $14,000 for personal injury accidents.

We recommend that the Iowa DOT consider raising its accident cost values to a level closer to the national average, or about $1 million per fatality, $30,000 per personal injury, and $3,000 per property damage only accident. These values would essentially double the accident cost saving that would result from highway upgrades. They also would constitute a significant step toward reflecting contemporary thinking regarding society's willingness to pay for safer highways.

Enhance data resources

The Iowa DOT has two data bases that have been valuable to this research: the primary road base file and the Accident Location and Analysis System (ALAS). These files have enabled us to correlate road attributes with accident rates and

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[27]Super-two highways have only two lanes, but these lanes and the shoulders are comparatively wide. Other features of super-two highways are passing lanes where needed, bypasses around communities, flatter grades, and larger radius curves. Super-two highways, however, cost approximately 40 percent as much as four-lane highways and are a reasonable alternative to four-lane highways up to an ADT of five to six thousand.

costs. In some cases, however, attributes referenced in ALAS are not contained in the base file. One such example is vertical obstructions (fixed objects in the roadside environment). Thus, even though vertical obstructions may have played a role in a certain number of accidents according to ALAS, we were unable to evaluate the overall relationship between obstructions and observed accident rates because no data on the presence of obstructions were available in the base file.

If a greater number of safety-related attributes were included in the primary road base file, more comprehensive predictive models would be possible. With recent federal legislation increasingly emphasizing safety management systems, this seems to be a propitious time to further enhance already very good data bases.

Use predictive models to estimate costs

We have argued the merits of accident rate and accident cost models such as those developed in this study. Most importantly, these models enable sensible estimates of current accident costs and of the effects of highway improvements. Using such models, we are able to estimate changes in accident rates and accident costs per million VMT, per year, or during the life of an improvement. In this way, benefit-cost analyses of potential highway upgrades can take accident cost saving into account more systematically.

Accident cost models should be updated periodically, using three to five years of accident data. They must also be updated occasionally to reflect changes in highway design practices, motor vehicle technology, social mores, and travel patterns. Also, as decision makers contemplate changes in accident cost values, models can be estimated to evaluate the implications of these revisions.

Our overarching conclusion is that carefully developed accident cost values used in combination with accident rate and cost models can greatly improve the ability of a state DOT to consider safety when evaluating potential highway investments.

APPENDIX:

SURVEY OF ACCIDENT COST SAVING AND HIGHWAY INVESTMENT

ANALYSIS FOR RURAL PRIMARY HIGHWAYS

RESPONSES ARE SHOWN IN BOLD (N=50 REPLIES)

This survey is a key element in a U.S. DOT-sponsored study of accident cost saving and highway investment analysis. As used in this survey, an accident cost saving brought about by highway improvements refers to reductions in accident-related losses.

1. Does your agency for any purpose use specific dollar values for reductions in traffic fatalities, personal injuries, and accidents involving only property damage?

45 ❑ Yes   **5** ❑ No ➤

> If no, how do you take into account accident reductions in analyses that your agency carries out?
>
> **0** ❑ We look at the cost of the safety improvement per accident avoided
>
> **4** ❑ We prioritize based on accident hot-spots
>
> **1** ❑ Other (please specify) _____
>
> _____
>
> (Please skip to question 6.)

If yes, please indicate the dollar amounts that you use for the following:

Value per reduced:	Dollar amount	Which year does this value apply to?
Fatality	$ **see chapter 3**	
Injury*	$ **see chapter 3**	
Accident involving property damage only (PDO)	$ **see chapter 3**	

*Please use a separate sheet to show separate values if you break injuries into major injuries, minor injuries and so on.

2. For what purposes do you use these dollar amounts? (Check all that apply.)

   ❑ Benefit-cost evaluation of highway upgrades or improvements   **34 of 45**

   ❑ Analysis of particular safety-related upgrades or improvements   **31 of 45**

   ❑ Evaluation of design exceptions   **10 of 45**

   ❑ Other (please specify) **six replies**

3. Do you adjust your values for traffic fatalities, personal injuries, and PDOs annually to reflect inflation?　　**23** ❏ Yes　　❏ No **22**

   If yes, what price index or method do you use? _**20 replies, generally consumer prices or National Safety Council updates**_

4. Which of the following best describes the source of the dollar values you use?

   13 FHWA memorandum of June 30, 1988, on "Motor Vehicle Accident Costs"

   7 FHWA 1991 report "The Costs Of Highway Crashes" FHWA-RD-91-05

   13 National Safety Council estimates. If so, which year's estimate do you use?
   19 _____

   2 NHTSA 1983 Report "The Economic Cost to Society of Motor Vehicle Accidents"
   DOT HS 806 342

   2 FHWA 1984 report "Alternative Approaches to Accident Cost Concepts" FHWA/RD-83/079

   2 AASHTO 1977 publication "A Manual on User Benefits Analysis of Highway and Bus-Transit Improvements"

   4 Research by your agency

   11 Other (please specify) **see chapter 3 for detailed breakdown**

5. We are aware of two alternative ways to reflect the distribution of fatalities, injuries, and property damage when estimating accident cost saving for significant rural highway upgrades. Which of the two following descriptions best reflects your agency's approach using the appropriate dollar figures for value per fatality, injury, and PDO?

   17 First, we estimate the likely reductions in fatalities, injuries, and PDOs independently. Second, we multiply each times the appropriate dollar value and sum them.

   12 First, we estimate the likely *total* reduction in the number of accidents. Second, we apply the distribution of fatalities, injuries, and PDOs among all accidents using the appropriate dollar values to calculate a weighted cost saving per accident. Finally, we multiply this per accident figure times the number of accidents likely to be reduced by the upgrade.

   16 Neither (please elaborate) **see chapter 3**

6. In estimating likely reductions in accidents or fatalities, injuries, and property damage, one must compare accident experience on the road *before* and the expected experience *after* the improvement. **(More than one response allowed.)**

a) In order to estimate accident rates *before* the improvement, does your agency use:

43 actual accident rates specific to the road in question, for _____ years beforehand

7 average accident rates for all roads of the same classification as that of the road before the improvement

If so, please describe the scope of the data and the degree of classification used (e.g., state-level, all arterials, by rural/urban) _____

_____

11 other (please explain) _____

_____

b) In order to estimate accident rates *after* the improvement, does your agency:

7 use average accident rates for all roads of the same classification as that of the road after the improvement?

If so, please describe the scope of the data and the degree of classification used (e.g., state-level, all arterials, by rural/urban) _____

_____

34 apply accident reduction factors to each element of the project, such as lane widening or paving of shoulders?

If so, please describe the source of the reduction factors that you use (e.g., state-level data, for all major classifications, by rural/urban and volume level) _____-

14 other (please explain) _____

If we have any questions, whom should we contact at your agency?

Name: _____

Telephone number: _____

Fax number: _____

Many thanks for your assistance. Would you like us to send you a copy of the completed study?

❏ Yes   ❏ No

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