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Benefit-Cost Analysis for Intersection Decision Support

Report #5 in the Series: Developing Intersection Decision Support Solutions

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16. Abstract (Limit: 200 words)

The Intersection Decision Support (IDS) system is designed to assist drivers on stop-controlled low-volume rural roads choosing gaps when confronted with busy multiple lane divided-highways, without affecting traffic on the high-volume road. The hope is, that by providing better gap guidance, fewer crashes (and fatalities) will occur. This research develops a framework for analyzing such a new, and presently under-specified technology, and illustrates that framework by comparing that with more conventional engineering approaches, as well as a “do-nothing” base case. The results show that the IDS System may be an effective tool to reduce crash rates at various intersections. More research is needed to address reliability and stability issues, and in determining how cost-effective of a solution the IDS System is compared to other “traditional” alternatives.

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Report #5 in the Series: Developing Intersection Decision Support Solutions

Final Report

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Executive Summary

The Intersection Decision Support (IDS) system is designed to assist drivers on stop-controlled low-volume rural roads choosing gaps when confronted with busy multiple lane divided-highways, without affecting traffic on the high-volume road. The hope is that by providing better gap guidance, fewer crashes (and fatalities) will occur. This research develops a framework for analyzing such a new and presently under-specified technology, and illustrates that framework by comparing that with more conventional engineering approaches, as well as a “do-nothing” base case.

Investments in roadway safety programs are often expensive, and may not always produce the intended results. Many alternatives exist, and it is desirable for the sponsoring agency to determine the best use of funds. Increasingly, agencies are conducting benefit-cost analyses to aid in their decision making. The main idea is to define a base-line scenario (often the “do-nothing” alternative), identify alternative solutions, develop measures of effectiveness, and determine the benefits and costs associated with each alternative. A comparison of benefit-cost ratios can identify the best alternative. However, simple reporting of benefit-cost ratios fails to capture the potential for variability in the costs and benefits incurred by a project. A more useful tool for decision makers would be to provide them with a range of probable outcomes for the benefits and costs of a project.

The results show that the IDS System may reduce crash rates at various intersections. More research is needed to address reliability and stability issues, and in determining how cost-effective of a solution the IDS System is compared to other “traditional” alternatives.

An analysis of the various safety countermeasures alternatives at US 52 and CSAH 9 in Goodhue County, Minnesota provided insight into the best use of funds for intersection safety improvements. In general, all of the alternatives had benefit-cost ratios greater than 1.0 on average, (meaning it is cost-effective to make the investment).

Two alternatives were compared, a best of breed engineering approach, in this case a Directional Median Opening, and the IDS. The Directional Median Opening Alternative will always cost more than the IDS alternative. If it works as intended, the IDS alternative will generally provide greater benefits, however there is an approximately 16 percent chance the DMO alternative will perform as well or better.

It is important to note several issues that may impact the results of the analysis. First, the cost of the directional median opening varies depending on site-specific circumstances, and requires there be existing adequate median space to construct U-turns that allow large vehicles to maneuver (otherwise the mainline lanes may need to be moved at considerable additional costs, and reduction in benefit-cost ratio). Second, it is possible that the crash reduction benefits in the IDS alternative may have been overestimated or underestimated. The crash reduction benefits were determined from driving simulator data, and the model has not been verified. Third, it is also possible these benefits would be reduced (or negative) due to a number of potential failure and reliability issues, driver interpretation issues, and attention issues as identified in Chapter 9.

It is recommended that additional research be carried out to resolve these issues.

1. Introduction

The Intersection Decision Support (IDS) system is designed to assist drivers on stop-controlled low-volume rural roads choosing gaps when confronted with busy multiple lane divided-highways, without affecting traffic on the high-volume road. The hope is that by providing better gap guidance, fewer crashes (and fatalities) will occur. There are a number of technologies being tested, including sensing technologies and a driver-infrastructure interface. This research develops a framework for analyzing such a new, and presently under-specified technology, and illustrates that framework by comparing that with more conventional engineering approaches, as well as a "do-nothing" base case.

Understanding driver behavior in traffic is a crucial element in developing safety improvement programs. A first step in this direction may involve learning how drivers interact with other drivers within the context of the overall driving environment. Of particular interest is how drivers select gaps when crossing and/or entering a traffic stream. Simulation methods are developed to estimate crash rates. These models can be applied to scenarios such as the installation of a safety countermeasure to estimate the change in driver behavior, conflict frequency, and crash frequency. The simulation is used to predict the effectiveness of the Intersection Decision Support System in terms of the impact it has on the conflict/crash frequency. It is expected the system will change not only the number of crashes, but the types of crashes and their severity as well. Data from these simulation runs will then be used to determine the potential benefits from the implementation of the IDS project.

Investments in roadway safety programs are often expensive, and may not always produce the intended results. Many alternatives exist, and it is desirable for the sponsoring agency to determine the best use of funds. Increasingly, agencies are conducting benefit-cost analyses to aid in their decision making. The main idea is to define a base-line scenario (often the "do-nothing" alternative), identify alternative solutions, develop measures of effectiveness, and determine the benefits and costs associated with each alternative. A comparison of benefit-cost ratios can identify the best alternative. However, simple reporting of benefit-cost ratios fails to capture the potential for variability in the costs and benefits incurred by a project. A more useful tool for decision makers would be to provide them with a range of probable outcomes for the benefits and costs of a project.

The benefit-cost analysis for the IDS project follows this approach and is the purpose of this research. Chapter 2 gives a brief history and theory of benefit-cost analysis. Chapter 3 presents the framework and methodology employed in the analysis. Chapter 4 identifies the relevant countermeasures. Estimates of the lifespans of the various technologies are presented in Chapter 5. Chapter 6 details the costs associated with each of the alternatives, and Chapter 7 describes the methodology used in determining delay costs. The methodology used in calculating crash-reduction benefits of the countermeasures is presented in Chapter 8. Chapter 9 discusses and presents the results of the sensitivity analysis performed on the benefits and costs of each alternative. Chapter 10 presents a discussion of the results, followed by recommendations and conclusions.

2. A Brief History and Theory of Benefit-cost Analysis

Early Beginnings

When Benjamin Franklin was confronted with difficult decisions, he often recorded the pros and cons on two separate columns and attempted to assign weights to them. While not mathematically precise, this “moral or prudential algebra,” as he put it, allowed for careful consideration of each “cost” and “benefit” as well as the determination of a course of action that provided the greatest benefit (Gramlich, 1990). While Franklin was certainly a proponent of this technique, he was not the first. Western European governments, in particular, had been employing similar methods for the construction of waterway and shipyard improvements.

Ekelund and Hebert (1999) credit the French as pioneers in the development of benefit-cost analyses for government projects. The first formal benefit-cost analysis in France occurred in 1708. Abbe de Saint-Pierre attempted to measure and compare the incremental benefit of road improvements (utility gained through reduced transport costs and increased trade), with the additional construction and maintenance costs. Over the next century, French economists and engineers applied their analysis efforts to canals (Ekelund and Hebert, 1999). During this time, the Ecole Polytechnique had established itself as France’s premier educational institution, and in 1837 sought to create a new course in “social arithmetic”: “…the execution of public works will in many cases tend to be handled by a system of concessions and private enterprise. Therefore our engineers must henceforth be able to evaluate the utility or inconvenience, whether local or general, or each enterprise; consequently they must have true and precise knowledge of the elements of such investments.” (Ekelund and Hebert, 1999, p. 47). The school also wanted to ensure their students were aware of the effects of currencies, loans, insurance, amortization and how they affected the probable benefits and costs to enterprises.

In the 1840s French engineer and economist Jules Dupuit (1844, tr. 1952) published an article “On Measurement of the Utility of Public Works,” where he posited that benefits to society from public projects were not the revenues taken in by the government (Aruna, 1980). Rather, the benefits were the difference between the public’s willingness to pay and the actual payments the public made (which he theorized would be smaller). This “relative utility” concept was what Alfred Marshall would later rename with the more familiar term, “consumer surplus” (Ekelund and Hebert, 1999).

Vilfredo Pareto (1906) developed what became known as Pareto improvement and Pareto efficiency (optimal) criteria. Simply put, a policy is a Pareto improvement if it provides a benefit to at least one person without making anyone else worse off (Boardman, 1996). A policy is Pareto efficient (optimal) if no one else can be made better off without making someone else worse off. British economists Kaldor and Hicks (Hicks, 1941; Kaldor, 1939) expanded on this idea, stating that a project should proceed if the losers could be compensated in some way. It is important to note that the Kaldor-Hicks criteria states it is sufficient if the winners could potentially compensate the project losers. It does not *require* that they be compensated (Zerbe, 1994).

Benefit-cost Analysis in the United States

Much of the early development of benefit-cost analysis in the United States is rooted in water related infrastructure projects. The US Flood Control Act of 1936 was the first instance of a systematic effort to incorporate benefit-cost analysis to public decision-making. The act stated that the federal government should engage in flood control activities if “the benefits to whomsoever they may accrue [be] in excess of the estimated costs,” but did not provide guidance on how to define benefits and costs (Aruna, 1980, Persky, 2001). Early Tennessee Valley Authority (TVA) projects also employed basic forms of benefit-cost analysis (US Army Corp of Engineers, 1988). Due to the lack of clarity in measuring benefits and costs, many of the various public agencies developed a wide variety of criteria. Not long after, attempts were made to set uniform standards.

The U.S. Army Corp of Engineers “Green Book” was created in 1950 to align practice with theory. Government economists used the Kaldor-Hicks criteria as their theoretical foundation for the restructuring of economic analysis. This report was amended and expanded in 1958 under the title of “The Proposed Practices for Economic Analysis of River Basin Projects” (Persky, 2001).

The Bureau of the Budget adopted similar criteria with 1952’s Circular A-47 - “Reports and Budget Estimates Relating to Federal Programs and Projects for Conservation, Development, or Use of Water and Related Land Resources”.

Modern Benefit-Cost Analysis

During the 1960s and 1970s the more modern forms of benefit-cost analysis were developed. Most analyses required evaluation of:

1. The present value of the benefits and costs of the proposed project at the time they occurred
2. The present value of the benefits and costs of alternatives occurring at various points in time (opportunity costs)
3. Determination of risky outcomes (sensitivity analysis)
4. The value of benefits and costs to people with different incomes (distribution effects/equity issues) (Layard and Glaister, 1994)

The Planning Programming Budgeting System (PPBS) - 1965

The Planning Programming Budgeting System (PPBS) developed by the Johnson administration in 1965 was created as a means of identifying and sorting priorities. This grew out of a system Robert McNamara created for the Department of Defense a few years earlier (Gramlich, 1981). The PPBS featured five main elements:

1. A careful specification of basic program objectives in each major area of governmental activity.
2. An attempt to analyze the outputs of each governmental program.
3. An attempt to measure the costs of the program, not for one year but over the next several years (“several” was not explicitly defined).
4. An attempt to compare alternative activities.
5. An attempt to establish common analytic techniques throughout the government.

Office of Management and Budget (OMB) – 1977

Throughout the next few decades, the federal government continued to demand improved benefit-cost analysis with the aim of encouraging transparency and accountability. Approximately 12 years after the adoption of the PPBS system, the Bureau of the Budget was renamed the Office of Management and Budget (OMB). The OMB formally adopted a system that attempts to incorporate benefit-cost logic into budgetary decisions. This came from the Zero-Based Budgeting system set up by Jimmy Carter when he was governor of Georgia (Gramlich, 1981).

Recent Developments

Executive Order 12292, issued by President Reagan in 1981, required a regulatory impact analysis (RIA) for every major governmental regulatory initiative over $100 million. The RIA is basically a benefit-cost analysis that identifies how various groups are affected by the policy and attempts to address issues of equity (Boardman, 1996).

According to Robert Dorfman, (Dorfman, 1997) most modern-day benefit-cost analyses suffer from several deficiencies. The first is their attempt “to measure the social value of all the consequences of a governmental policy or undertaking by a sum of dollars and cents”. Specifically, Dorfman mentions the inherent difficultly in assigning monetary values to human life, the worth of endangered species, clean air, and noise pollution. The second shortcoming is that many benefit-cost analyses exclude information most useful to decision makers: the distribution of benefits and costs among various segments of the population. Government officials require this sort of information and are often forced to rely on other sources that provide it, namely, self-seeking interest groups. Finally, benefit-cost reports are often written as though the estimates are precise, and the readers are not informed of the range and/or likelihood of error present.

The Clinton Administration sought proposals to address this problem in revising Federal benefit-cost analyses. The proposal required numerical estimates of benefits and costs to be made in the most appropriate unit of measurement, and “specify the ranges of predictions and shall explain the margins of error involved in the quantification methods and in the estimates used” (Dorfman, 1997). Executive Order 12898 formally established the concept of Environmental Justice with regards to the development of new laws and policies, stating they must consider the “fair treatment for people of all races, cultures, and incomes.” The order requires each federal agency to identify and address “disproportionately high and adverse human health or environmental effects of its programs, policies and activities on minority and low-income populations” (Environmental Protection Agency, 1994).

Probabilistic Benefit-Cost Analysis

In recent years there has been a push for the integration of sensitivity analyses of possible outcomes of public investment projects with open discussions of the merits of assumptions used. This "risk analysis" process has been suggested by Lewis and Flyvbjerg in the spirit of encouraging more transparency and public involvement in decision making (Gomez-Ibanez, *et al.*, 1999; Lewis and Flyvbjerg, 2003). This research attempts to incorporate their recommendations in the benefit-cost analysis of each of the relevant alternatives, because a sensitivity (or risk) analysis allows for a more accurate reflection of reality. The methodology adopted here resembles one prescribed by the Treasury Board of Canada, as it is one of the few recent and published guidelines put forth, and because Canada's issues and projects are likely to be more similar to those facing the United States than European nations (TBC Benefit-Cost Analysis Guide, 1998).

The Treasury Board of Canada's Benefit-Cost Analysis Guide recognizes that implementation of a project has a probable range of benefits and costs. It posits that the "effective sensitivity" of an outcome to a particular variable is determined by four factors:

- the *responsiveness* of the Net Present Value (NPV) to changes in the variable;
- the magnitude of the variable's *range of plausible values*;
- the *volatility* of the value of the variable (that is, the probability that the value of the variable will move within that range of plausible values); and
- the degree to which the range or volatility of the values of the variable can be *controlled*.

It is helpful to think of the range of probable outcomes in a graphical sense, as depicted in Figure 2.1 (probability versus NPV) and Figure 2.2 (cumulative probability distribution versus NPV).

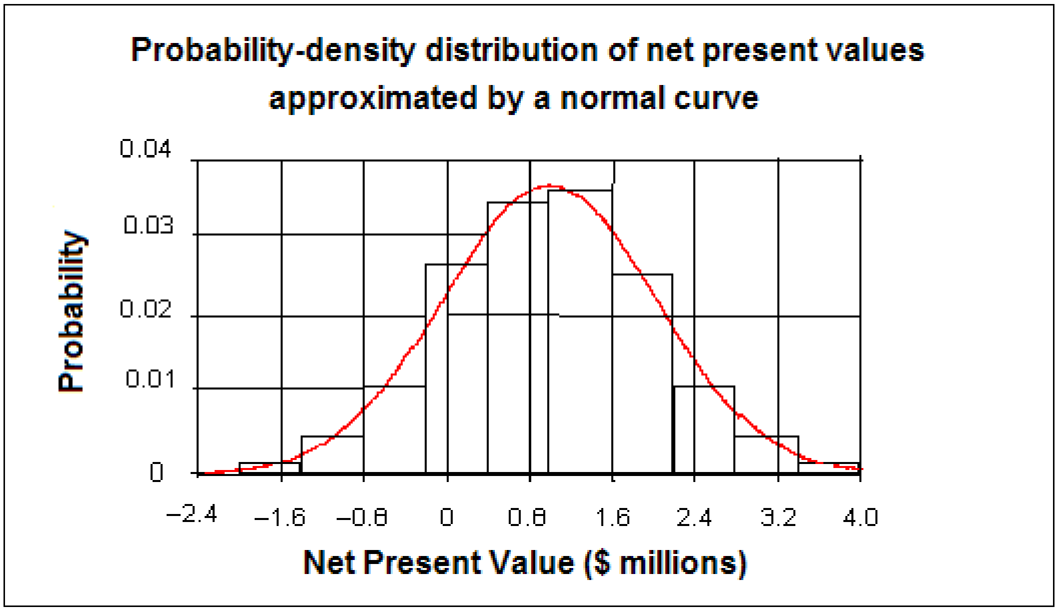

Figure 2.1
Source: Treasury Board of Canada, Benefit-Cost Analysis Guide, 1998

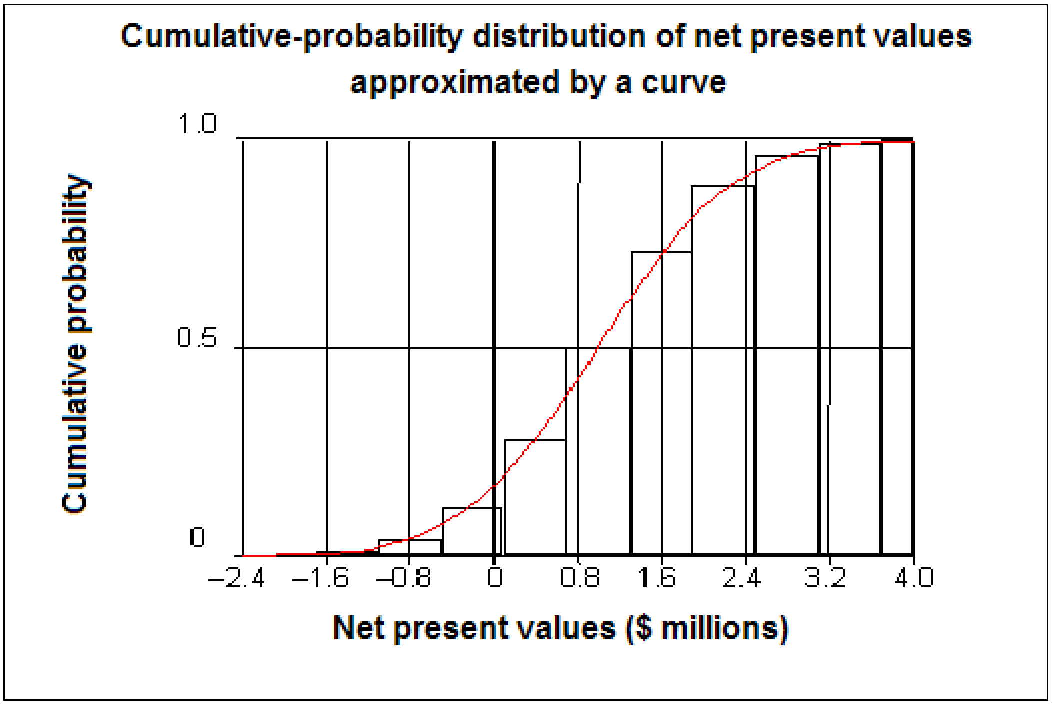

Figure 2.2
Source: Treasury Board of Canada, Benefit-Cost Analysis Guide, 1998

Once these probability curves are generated, a comparison of different alternatives can also be performed by plotting each one on the same set of ordinates. Consider for example, a comparison between alternative A and B (Figure 2.3).

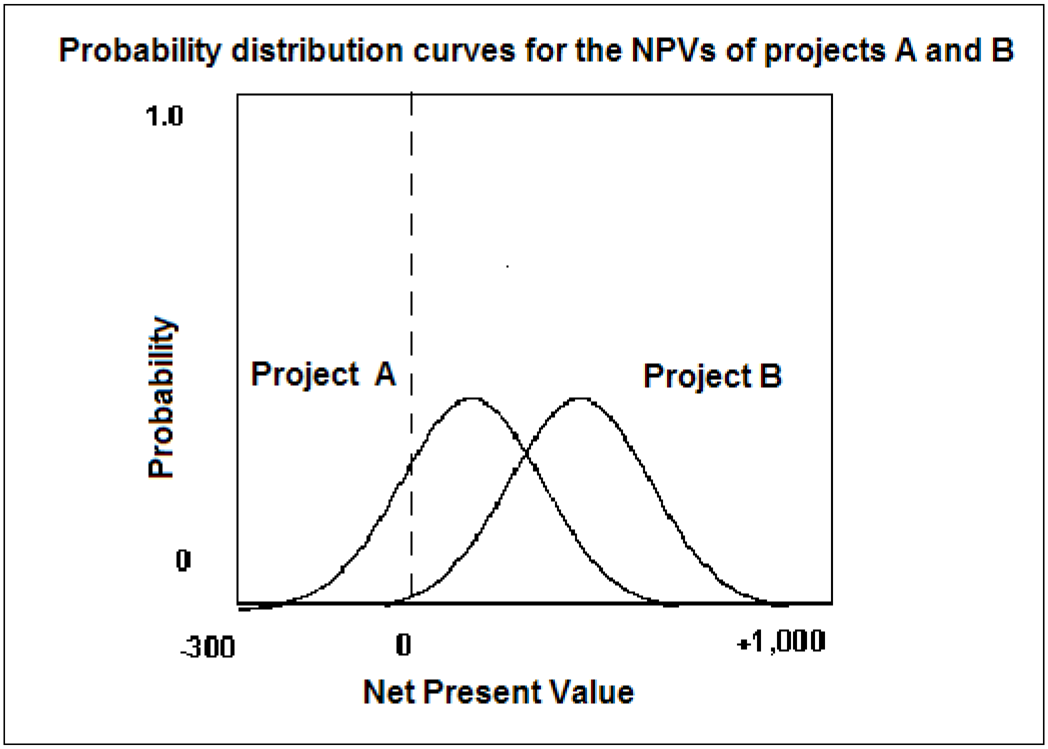

Figure 2.3
Source: Treasury Board of Canada, Benefit-Cost Analysis Guide, 1998

In this case, the probability that any specified positive outcome will be exceeded is always higher for project B than it is for project A. The decision maker should, therefore, always prefer project B over project A. In other cases, an alternative may have a much broader or narrower range of NPVs compared to other alternatives (Figure 2.4).

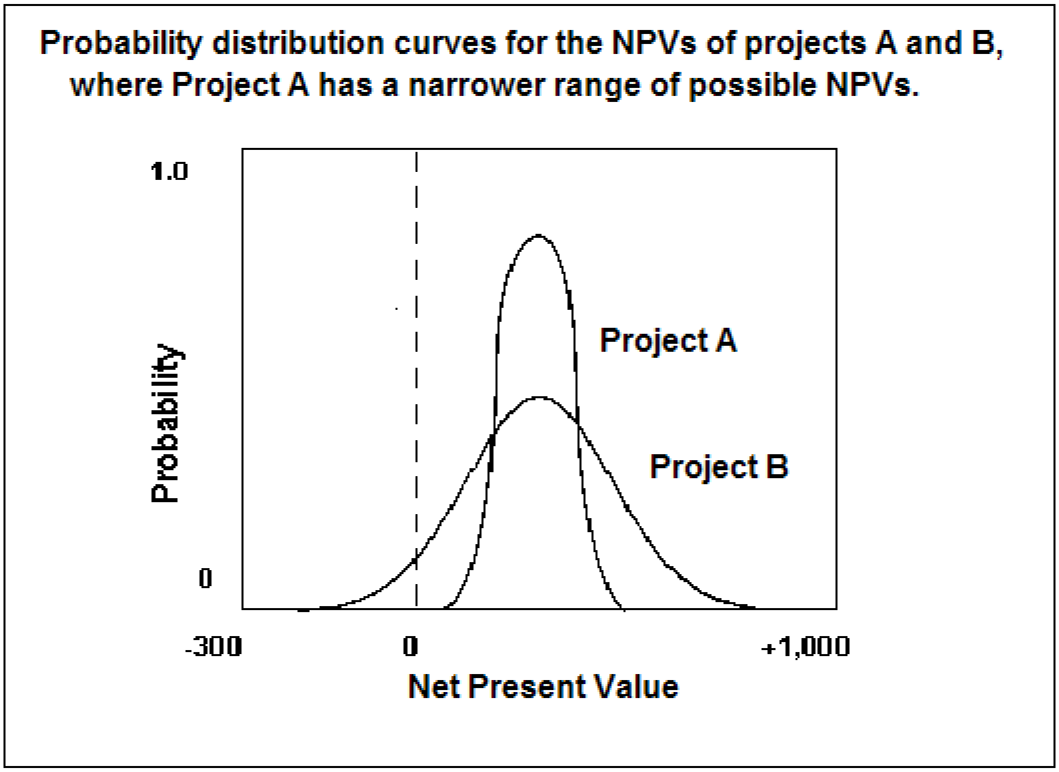

Figure 2.4
Source: Treasury Board of Canada, Benefit-Cost Analysis Guide, 1998

Some decision-makers might be attracted by the possibility of a higher return (despite the possibility of greater loss) and therefore might choose project B. Risk-averse decision-makers will be attracted by the possibility of lower loss and will therefore be inclined to choose project A.

This study determines the range of possible outcomes for each of the countermeasures mentioned in Chapter 4. This requires an estimation of the most probable costs and benefits associated with each alternative. The ranges can then be expressed in terms of their Net Present Values or benefit/cost ratios. These values can be compared to determine which alternative or alternatives should be preferred.

3. Benefit-Cost Analysis Framework

When considering whether or not to make large capital expenditures on potentially risky projects, public and private agencies need tools to assist them in their decision making. A benefit-cost analysis puts the expected benefits and costs of a project into quantifiable terms (generally dollars), and identifies the groups to which those benefits and costs are realized. In this project, the IDS countermeasure is compared to a number of alternatives. In order to adequately compare these dissimilar countermeasure strategies, a benefit-cost framework must be developed. The benefit-cost analysis methodology begins with the framework developed for Caltrans/PATH MOU 357: Benefit-Cost Analysis of Key Intelligent Transportation Systems (ITS) Applications (Levinson *et al.* 1999; Gillen *et al.* 1999a, 1999b; Kang and Gillen 1999).

First, a baseline, or "do-nothing" scenario must be identified. In this project, the baseline scenario is the current safety countermeasures at the unsignalized intersection (US 52 and CSAH 9 in Goodhue County). This scenario is compared to two other major alternatives: the traditional engineering countermeasures (or some combination thereof), and the countermeasure developed in the IDS project. The analysis period is 20 years.

For each of these scenarios, their impacts on various sub-markets or entities (the road agency, road users, society-at-large) are identified. The costs and benefits to each of the groups are determined, and discounted to the present (Net Present Value). The benefit/cost ratios for each of the alternatives are compared, including their probable ranges, allowing for the identification of the "best" alternative (the highest benefit-cost ratio). Because the value of some costs and benefits are unknown or difficult to quantify, the benefit-cost analysis is carried out under the auspices of a sensitivity analysis. This permits the testing of the robustness of the benefit-cost ratios to large variations in the benefit and cost values for each alternative. See Figure 3.1 for an illustration of the framework.

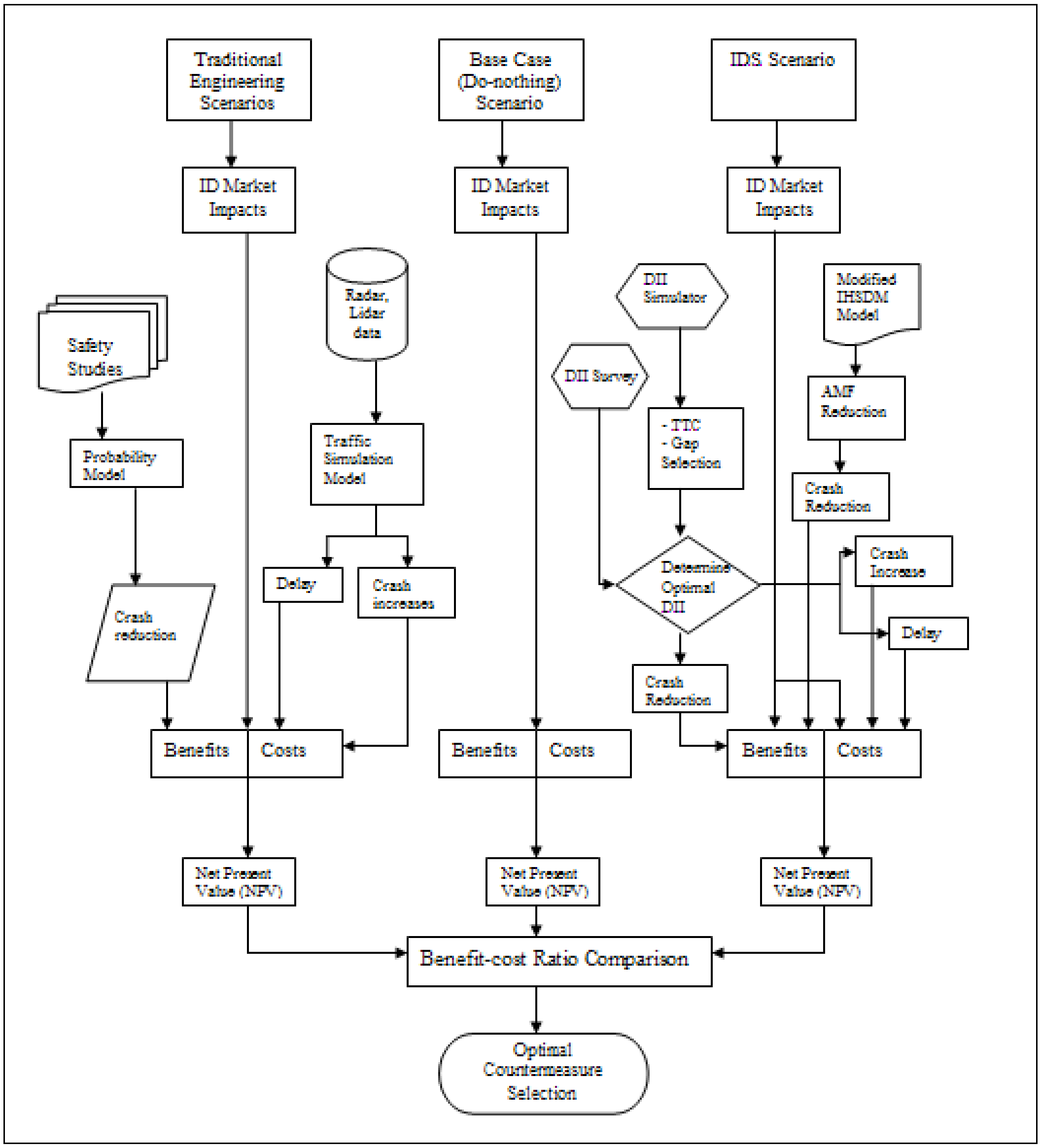

Figure 3.1: Benefit-Cost Analysis for IDS Project

Source: Author

Benefit Classification

The benefits of the IDS and alternative countermeasures may be a reduction in the crash rate, as well as reductions in the severity of crashes. Other benefits may come in the form of time savings for drivers and reduced vehicle emissions. The benefits to various groups (the road agency or service provider, roadway users on both major and minor intersection approaches, and society) are shown in Table 3.1.

Table 3.1: Benefits to Service Providers, Users & Society/Community from IDS

Benefits	**Service Provider**	**Roadway Users**	**Society/ Community**
Cost Savings			
Operating and Maintaining Costs	*		
Fuel Consumption		(*)	
Vehicle Operation		(*)	
Safety Improvement			
Fatality and Injury		*	*
Property Damage		*	*
Mobility			
Reduction in Travel Time Delay		(*)	
Reduction in Travel Time Variability		(*)	
Improvement in Customer Satisfaction		(*)	
Environmental Improvement			
Vehicle Emissions			(*)
Efficiency			
Increases in Highway Throughput	(*)		
Others			
Enhanced Facility	(*)		
Other Induced Effects			

Note: * means there is a benefit to this party; (*) means the benefit is uncertain or a cost

Source: Author

The costs of implementing safety countermeasures to the road agency or service provider may include capital costs, operating and maintenance costs, and other costs. The cost to users in the baseline and traditional alternative scenarios is not applicable if the costs in congestion and accidents are not considered. This framework considers the reduction in congestion (delay) and accidents as benefits of the two improvement alternatives. The users' cost of the IDS alternative scenario includes delay costs for non-incident conditions, considering the conservative nature of the warning system, and the potential for malfunctions. Other costs may also include an increase in crashes, whether in absolute terms or from an increase in certain crash types and/or severities (Table 3.2).

Table 3.2: Cost to Service Provider, Roadway Users and Community/Society

Costs		**Service Provider**	**Roadway Users**	**Society/ Community**
Costs of Baseline	Operating and Maintenance Costs	*		
	Others			
Cost of Traditional Alternative	Capital costs	*		
	Operating and Maintenance Costs	*		
	Others			(*)
Cost of IDS Alternative	Capital Costs	*		
	Operating and Maintenance Costs	*		
	Others			(*)

Note: * means there is a benefit to this party; (*) means the benefit is uncertain or a cost

Source: Author

If, as expected with most of the countermeasures, their implementation leads to a reduction in crashes, the component of costs due to an increase in crashes is considered to be zero.

The impact of many of the traditional countermeasures on traffic is unknown. It is expected some of the alternatives may decrease total delay, while others, such as the indirect-left turn strategies, will likely increase delay compared to the baseline since drivers making through and left turn maneuvers will have longer distances to travel. For the purposes of this study, one potential benefit of a safety countermeasure is a reduction in delay. If the result of a countermeasure is an increase in delay, the value of the “benefit” will be negative (or a cost). While the decision whether something is a cost or negative benefit will not affect the net present value, it will affect the benefit/cost ratio. In this study, increased delay is considered a cost, and a reduction in delay is considered a negative cost rather than a benefit for each alternative.

Many of the benefits and costs mentioned above are subject to various degrees of uncertainty. A particular countermeasure may lead to a substantial or marginal improvement in roadway safety, or somewhere in between. Equipment may wear out or malfunction; exactly when this occurs is not known. In an effort to capture these elements in the analysis, an attempt is made to determine the probabilities of various outcomes (benefits and costs).

4. Identification of Alternative Countermeasures

With a benefit-cost analysis framework in place, the next step is to identify possible alternative solutions to the problem. This Chapter identifies a number of countermeasures that have been employed by various agencies to improve safety at highway intersections. It is important to note that the IDS system was proposed to address one of the main causes of right angle crashes: gap selection (i.e., drivers misjudging safe gaps in traffic). Many of the countermeasures proposed below do not directly address gap selection issues or right angle crashes. However, each has the potential to reduce certain types of crashes and thus represent viable uses of funds earmarked for roadway safety improvements. After a review of potential alternatives, the alternatives considered in this analysis are identified.

Highway Safety Countermeasures

Individual highway accidents are irregular, unpredictable events, yet some locations are more likely to have them than others. Public officials (often at the request of their constituents) have employed a variety of countermeasures to improve highway safety. Many agencies have established criteria for identifying hazardous roads and intersections. Mn/DOT calculates the expected crash rates for various types of facilities and compares those to the actual crash rates. The threshold or “critical crash rate” is defined as a crash rate that is statistically significantly higher than the expected rate (Preston and Storm, 2004). Other agencies have set guidelines requiring there to be a certain number of crashes (fatal or otherwise) that occur at a particular road segment or intersection over a specified period of time before it can be classified as hazardous and eligible for improvements (Maze, 2004).

For highway planners, a vast array of safety countermeasures is available. Most countermeasures fall into one of two categories: traffic engineering countermeasures, and highway engineering countermeasures. Traffic engineering countermeasures are concerned with the types of traffic control devices such as signs, signals, posted speed limits, advanced warning signs, and lighting. Highway engineering countermeasures generally involve changing the geometry of the intersection and/or roadway.

Traffic Engineering Countermeasures

The types of traffic control available at rural intersections include no-control, stop control, yield control and signal control. A study by Hauer (1988) revealed that yield control intersections had a crash rate 40 percent lower than a no-control intersection. Hanna *et al.* (1988) showed that stop control and signal control intersections reduced the frequency of right-angle crashes, but led to an increase in rear-end collisions. However, in the case of a high-volume, high-speed road (a rural expressway) intersecting a low-speed, low-volume road, signals may cause a substantial amount of delay on the mainline. In addition, such a solution is costly to implement.
A turn prohibition is another possible solution. Lau and May (1989) found a significant reduction in crashes when left turns were prohibited. This approach may be of limited use since an analysis of the traffic volumes and turning movements at the intersection of interest may reveal such a restriction to be impractical. Elimination of left-turns may be possible through

channelization, median U-turns, and other geometric alterations, which are considered later in this Chapter.

Another solution that may be employed involves changing the posted speed limit. Reducing the speed of approaching vehicles allows for an increase in reaction times for drivers facing conflicts. This in turn may lead to fewer crashes and/or a reduction in the severity of crashes. Similar to traffic signals, reducing the speed limit may cause significant delay for the high-speed, high-volume road. Both effects are unlikely however, since several studies have revealed that reductions in posted speed limits often have no significant impact on overall average speeds. It is also important to note that while there is a considerable amount of research linking vehicle speeds to crash frequency and severity; little has been found linking posted speed limits to intersection safety.

Many agencies have placed advanced warning signs ahead of hazardous intersections in attempts to reduce crashes. Caution signs with messages such as “Watch for Cross Traffic”, “Crossing Traffic”, “Fast Vehicles Approaching”, “Dangerous Intersection Ahead”, and “Signal Ahead” are some examples. Some of these signs are accompanied by flashing yellow beacons. A study by Pant and Huang (1992) concluded that “Signal Ahead” signs had no impacts on crash rates, while “Prepare to Stop When Flashing Signs” increased crash rates by 15 percent. Recent studies in Kansas and Minnesota revealed that installing more and larger “Stop Ahead” or “Cross-Traffic Does Not Stop” signs led to marginal reductions in crash rates (Stokes *et al.*, 2000, Preston and Storm, 2004).

Proper lighting can be used as a tool to improve intersection safety at night. Judging the speed and position of vehicles during nighttime is more difficult than in daytime. The placement of light poles near intersections may help to alleviate this problem, especially if the lighted areas extend well back from the intersection. Bauer and Harwood (1996) found that proper lighting may reduce the fatal and injury crash rate by 21 percent. Mn/DOT found illumination to be a very cost effective strategy, potentially reducing nighttime crashes by 50 percent (Preston and Albrecht, 2001).

Recent technological advances have focused on the use of Intelligent Transportation Systems (ITS) solutions such as Cooperative Intersection Collision Avoidance Systems (CICAS) and Intersection Decision Support (IDS) systems. For the IDS system in Minnesota, results from the HumanFIRST driver simulation may indicate whether an increase or decrease occurs in the crash rate associated with a particular type of guidance. The driver behavior model developed for this project by Xi Zou and David Levinson (the dynamic graphical model) estimated if the IDS system increased or reduced the frequency of conflicts. This model, which relates driver behavior (conflicts) to crash frequency, can in turn be used to predict the change in the crash rate. A statistical model predicted that the IDS system would reduce accidents to 22 to 52 percent of what would be considered “typical” for an intersection with these characteristics (Davis *et al*., 2006).

Highway Engineering Countermeasures

In addition to the various traffic engineering countermeasures, there are a number of highway engineering countermeasures available to enhance safety. Most of these applications involve altering the geometry of the intersection area, ranging from relatively low-cost measures such as road markings and rumble strips to more costly reconfigurations including the installation of turning lanes, channelization, approach realignments and grade-separated interchanges. A study by Maze, *et al.*, (2004) Preston and Albrecht (2001), and other studies mention a considerable number of possible strategies, several of which are detailed below.

Sight Distance

One important area of safety improvements lies in the realm of sight distances. It is crucial for drivers to have a safe sight distance that allows them to clearly identify and react to potential hazards and conflicts. Sight distances may be impeded by the existence of buildings, signs, vegetation, hills and curves. Vegetation and signs can often be removed or relocated, whereas applying such strategies to buildings and hills may prove to be expensive. The minimization or elimination of vertical and horizontal curves can increase sight distances, but often at a substantial cost to the road agency. A study by Mitchell (1972) showed removing intersection sight obstructions may reduce accidents at intersections by 67 percent, and Hanna, *et al.* (1976) found that intersections with “poor” sight distances had crash rates 18 percent higher than those with “good” sight distances. Preston and Albrecht (2001) predicts measures to improve sight distances may decrease head on, right angle, left- and right-turn intersection crashes by 20 percent. These numbers are largely based off of NCHRP 162 (Laughland, *et al*, 1975) and NCHRP 500 (Neuman, *et al*, 2003).

Channelization

Channelization is a broad term applied to strategies that may include a combination of right and left turn lanes, pavement markings, median dividers, signs and signals. The general purpose of channelization is to reduce the number of conflict points, the conflict frequency and/or severity. Studies by David and Norman (1976) and Hauer (1988) indicate channelization may improve safety.

Right turn lanes are relatively inexpensive and easy to construct in rural areas. On major arterials they provide a safety benefit by removing decelerating vehicles from the mainline before making their turning maneuver. Intuitively, this should lead to a decrease in rear-end and right collisions. Vogt (1999) and Bauer and Harwood’s (1996) investigations indicate decreases in total accidents and a reduction in fatal and injury accidents with the addition of right turn lanes. Later work by Harwood, *et al*. (2002) summarized a number of related studies and suggested the placement of right turn lanes for minor intersection approaches led to a 5 percent decrease in crash rates for rural intersections. They suggested a 10 percent reduction could be realized if the right turn lanes were only added to the major approaches.

Left turn lanes have been employed in a variety of intersection types. Their effectiveness in improving safety is somewhat mixed. McCoy, *et al.* (1985), found no significant difference in rear-end and left-turn accident rates between intersections with and without left-turn lanes at unsignalized intersections on rural 2-lane highways. Further work by McCoy and Malone (1989) found an increase in right angle accidents at unsignalized intersections. Bauer and Harwood (1996) also found increases in total multi-vehicle accidents and fatal and injury accidents at intersections where left-turn lanes were installed, but cautioned their results may be influenced by other variables. Gluck *et al.* (1999) presented a summary of several studies that showed reductions ranging from 18 to 77 percent. Work by Parker *et al.* (1983) revealed left turn lanes installed on 2-lane highways may reduce the potential of passing related accidents. Foody and Richardson (1973) found left turn lanes reduced crash rates by 38 percent for signalized intersections and 76 percent for unsignalized intersections. Modeling studies by Vogt (1999) predicted a 38 percent reduction in crashes at 4-leg STOP controlled intersections, while Maze (1994) showed a 35 percent reduction when left turn lanes with protected/permitted phases were implemented. In a more recent study, Harwood *et al.* (2000) developed accident modification factors (AMFs) for 2-lane highways. Based on the findings of the expert panel, they estimated a 33 to 42 percent reduction in the AMF from the installation of left turn lanes along the major approaches.

Pavement markings and raised medians are also believed to be successful in improving intersection safety. They attempt to reduce conflicts by guiding/delineating vehicles along appropriate paths. A number of studies have shown that raised medians tend to be more effective in reducing crash rates at intersections than those with painted medians. Washington *et al.* (1991) found that crash rates were 40 percent lower for the intersection approaches with raised medians versus approaches with flat medians. A California study (California Dept. of Public Works, 1967) revealed that left-turn lanes with raised medians had lower crash rates than those with only painted medians. Hauer (1988) reported that painted channelization at unsignalized intersections for rural areas reduced crash rates by 50 percent, while raised medians reduced crash rates by 60 percent.

In the case of divided highways, adding yield signs or stop bars along the minor approach may lead to safer conditions. These configurations encourage drivers attempting left-turn or thru movements to make their maneuvers in two stages. The first stage involves crossing the mainline on the near side, and the second stage allows drivers to stop and/or pause and select a safe gap on the far side. It is believed that this strategy may lead to a reduction in right angle crashes; however the median must be wide enough to accommodate storage of the vehicle used in the road agency’s design standard (Maze, 2004). Generally, medians have to be of a certain minimum width to allow the placement of stop signs or stop bars, especially if they wish to accommodate large trucks, buses, and farm equipment.

Related strategies include providing dashed markings (extended left edgelines) for the major approaches and double yellow lines for the minor approach in the median. The double yellow lines in the median help to better define the storage area for vehicles, and encourage drivers to make two-stage maneuvers. The Iowa Department of Transportation tested these applications in several intersections and found that they have led to a reduction of crashes in the median. Right angle crashes were also reduced when combined with stop bars/yield signs (Maze, 2004). In-lane rumble strips installed before the intersection represent another strategy that is believed to be effective at reducing "ran stop sign" right angle crashes.

A number of countermeasures improve existing road features such as providing longer turn lanes and wider medians, lanes, and shoulders. Adding longer turn lanes increases the capacity of the road and can reduce rear-end and side-swipe crashes (Maze, 2004). Wider medians can accommodate larger vehicles, allowing them to move through the intersection in two steps. Harwood *et al.* (1995) indicated that increasing median widths were correlated with decreasing crash rates.

Alternative Countermeasures

There are additional geometric reconfigurations that can be implemented to eliminate conflicts at intersections, most of which are relatively new and do not fall into the category of traditional approaches. Median left-turn acceleration lanes, offset right-turn and left-turn lanes, offset T-intersections and indirect left turns have been adopted by many state transportation agencies to various degrees.

Median left-turn acceleration lanes allow left-turning vehicles to accelerate and merge into traffic, making it easier for drivers to find acceptable gaps (Figure 4.1).

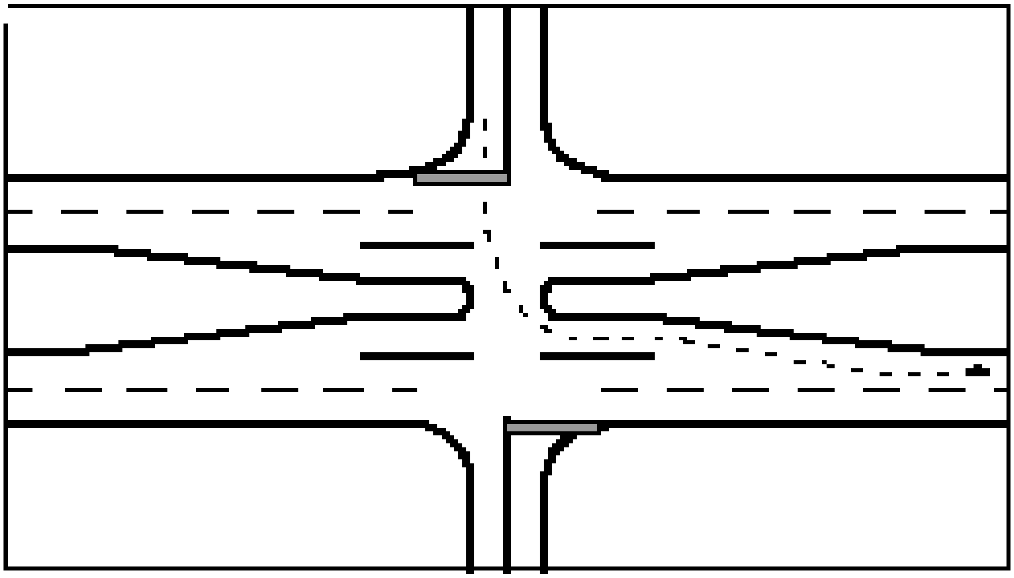

Figure 4.1: Median left-turn acceleration lane
Source: Maze, 2004

The acceleration lane eliminates the need for median storage and prevents larger vehicles like trucks from stopping in the median and blocking thru lanes. The Institute of Transportation Engineers (ITE) concluded that left-turn acceleration lanes appear to reduce crashes and conflicts while increasing the efficiency of left-turn movements (ITE, 1986). A Mn/DOT study (Janson,

2002) of 10 median acceleration lanes revealed that the percentage of vehicles that waited in the median decreased from 74 percent to 4 percent. In addition, rear-end collisions were found to have dropped 40 percent after the lanes were constructed. Rear-end crash rates were found to be 75 percent lower compared to similar intersections without median acceleration lanes.

Offset right- and left-turning lanes can be used to reduce the blocking of sightlines by turning vehicles. Vehicles in the left turn lanes can block the view of vehicles in the opposing direction that are also attempting to make left turns (Figure 4.2). Similarly, vehicles making right turns from the major approaches block the view of vehicles at the stop bar of the minor approaches.

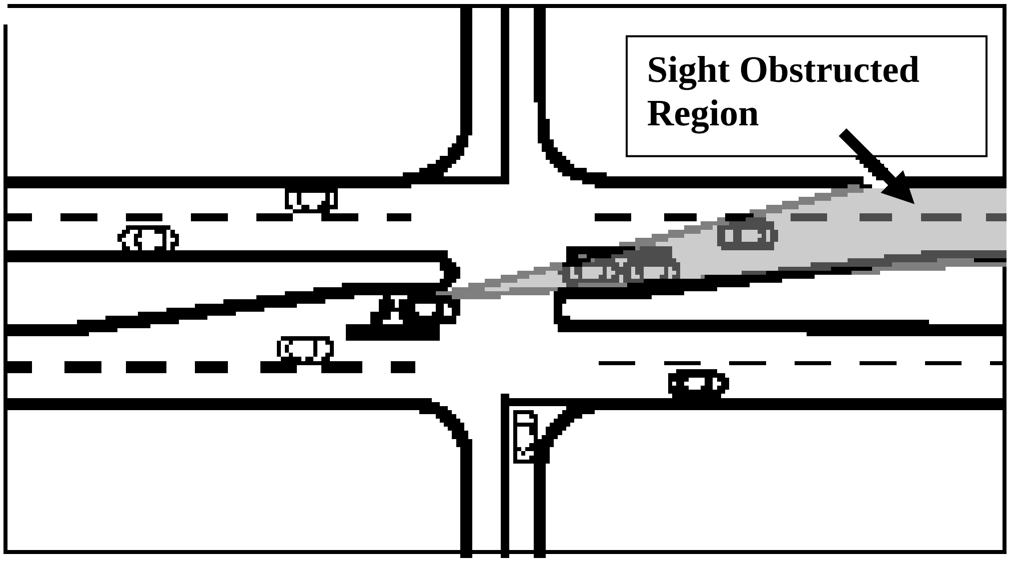

Figure 4.2: Obstructed Sight distance due to opposing left-turning vehicles
Source: Maze, 2004

Off-setting the turning lanes so that left turning vehicles from both directions face each other head-on improves sight distances and visibility, increasing the chances for drivers to select safe gaps, while also improving intersection efficiency (Figure 4.3 and Figure 4.4).

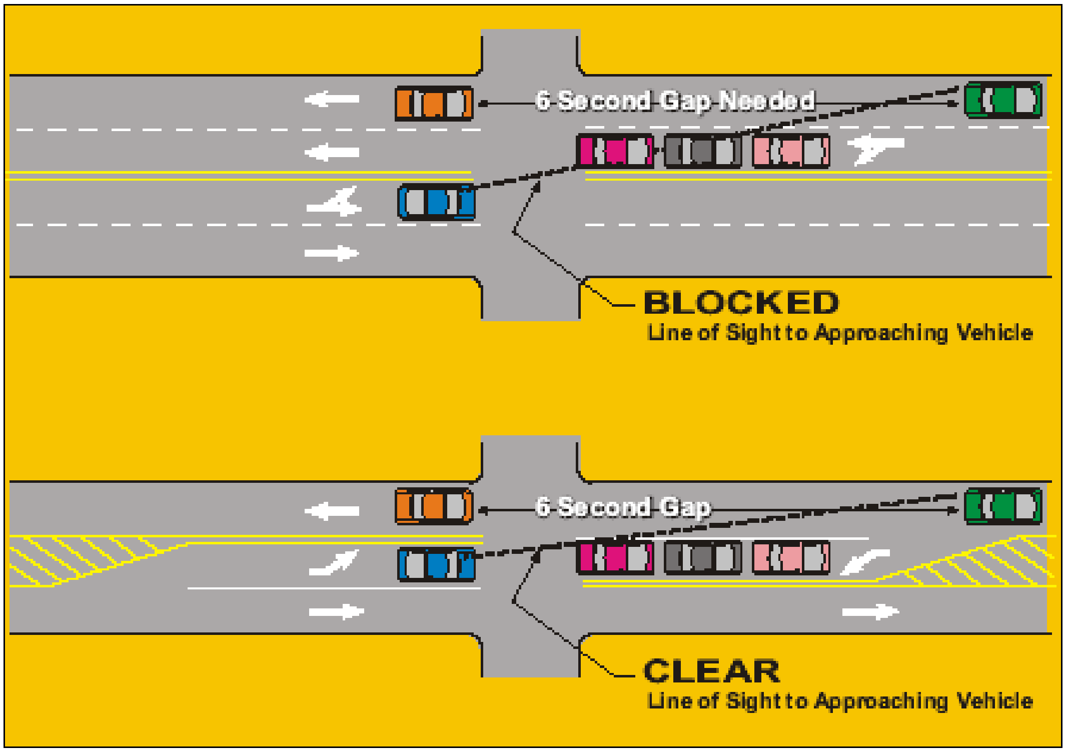

Figure 4.3: Effects of off-set left-turn design on sight distance
Source: Minnesota Traffic Safety Fundamentals Handbook (Preston and Albrecht, 2004)

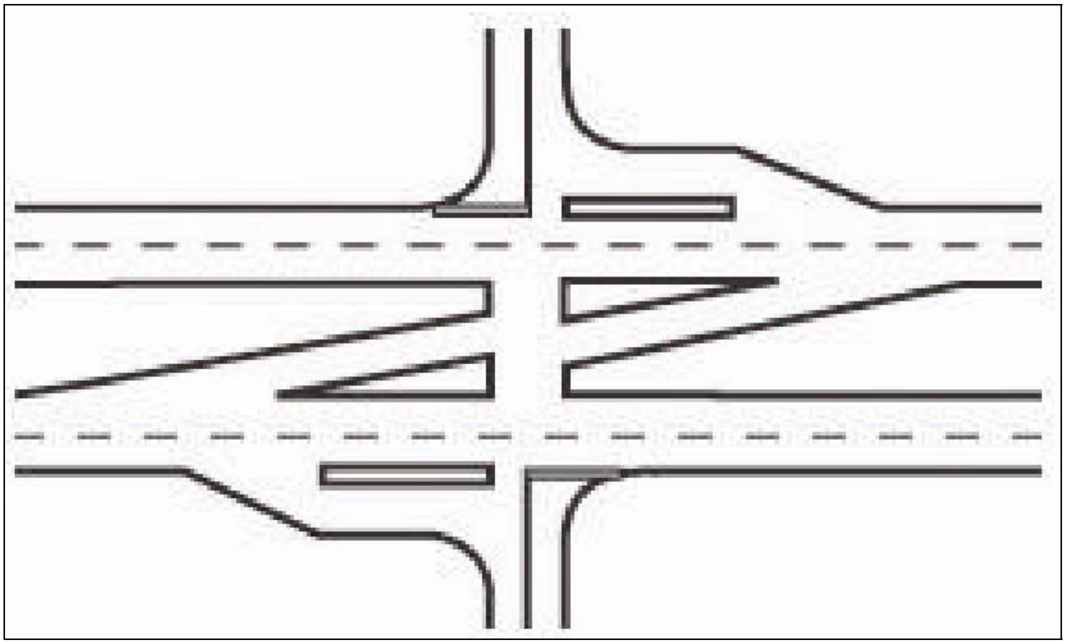

Figure 4.4: Intersection with offset right and left turn lanes
Source: Maze, 2004

Other strategies in intersection safety improvements revolve around the theme of reducing the number of conflict points. Intersections with three legs (a “T” intersection) have fewer conflict points, and generally, fewer crashes, than four-legged intersections. Hanna *et al.* (1976) found that right angle 3-legged intersection had 40 percent fewer crashes than conventional 4-legged intersections. Bauer and Harwood (1996) reported crash rates for 4-legged intersections were nearly twice the amount of 3-legged intersections for both urban and rural areas. With this in mind, conversion of a traditional 4-legged intersect into two offset T-intersections could provide a safety benefit to both of the minor approach legs (Figure 4.5).

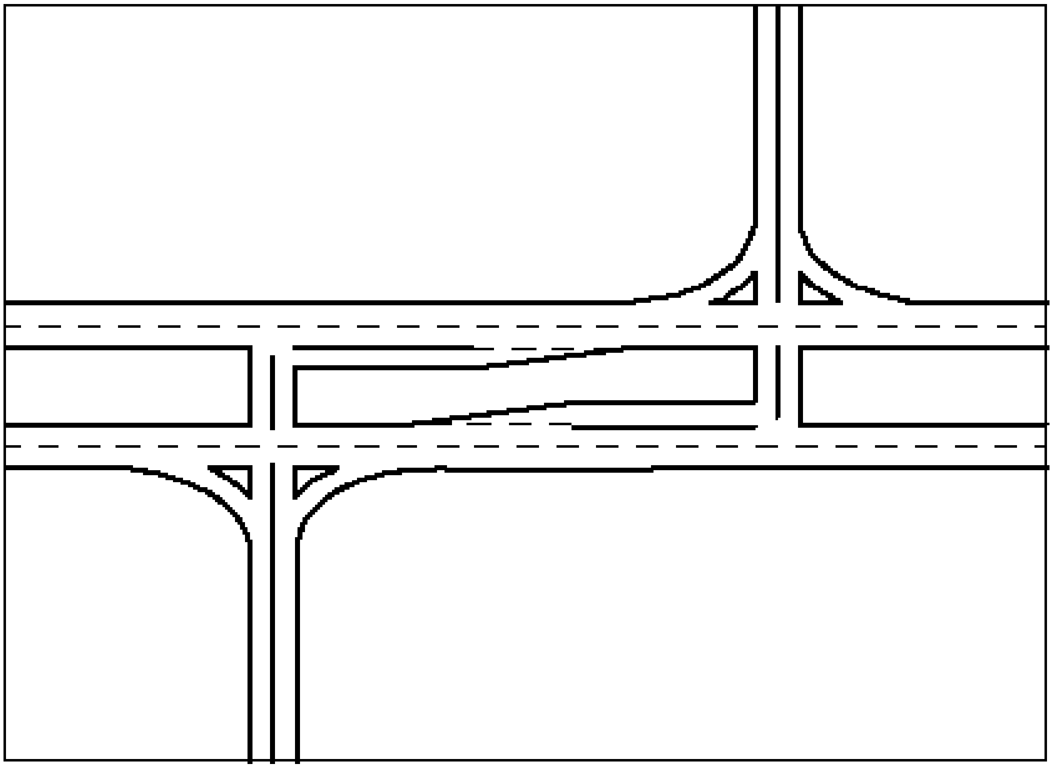

Figure 4.5: Offset T-Intersection
Source: Maze, 2004

Bared and Kaisar (2000) employed intersection safety models to estimate the reduction in crash rates resulting from the conversion of a 4-legged intersection into two offset T-intersections. The crash reduction rates were generally greater for lower volume intersections, and ranged from 40 to 60 percent.

Indirect left turns reduce the number of conflict points by prohibiting left-turns from the mainline and directing the movements through median U-turns, jug handles, and loops (Figures 4.6, 4.7 and 4.8).

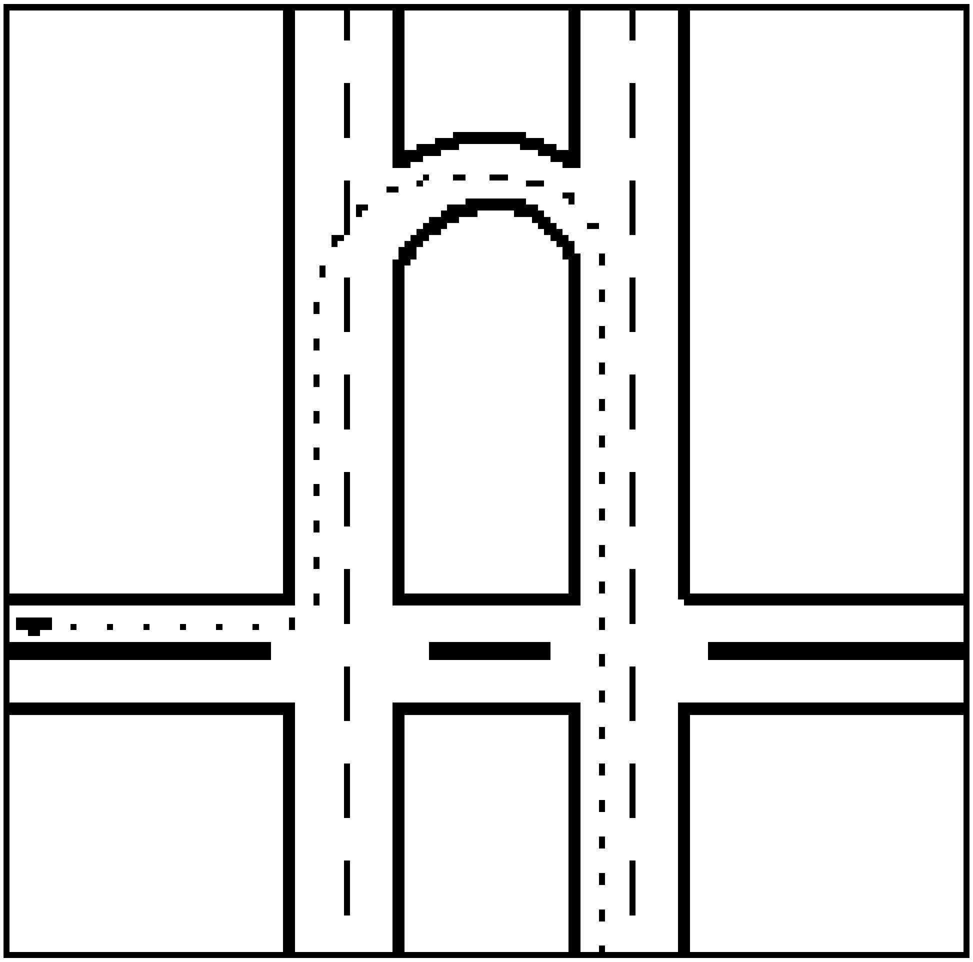

Figure 4.6: Indirect left-turn Median U-Turn
Source: Maze, 2004

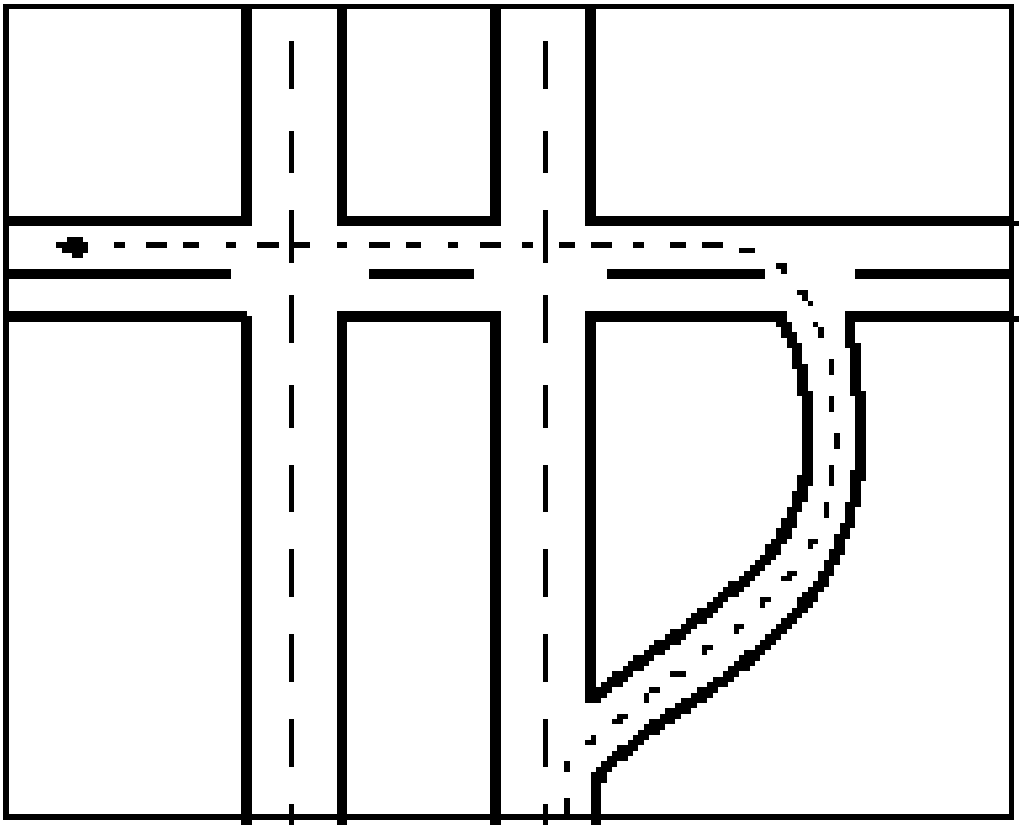

Figure 4.7: Indirect left-turn jug handle
Source: Maze, 2004

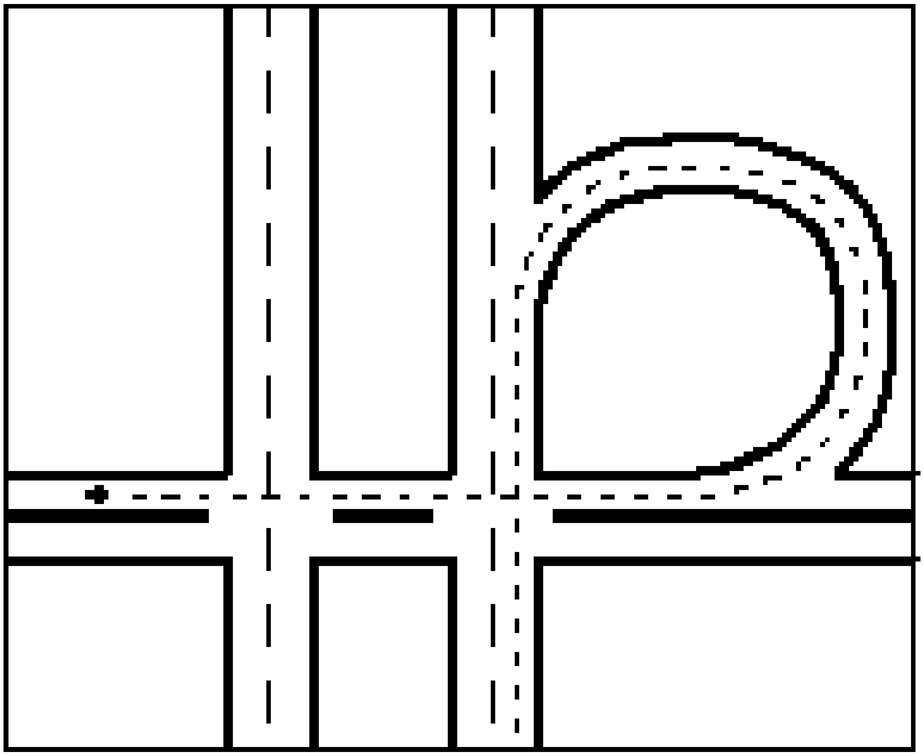

Figure 4.8: Indirect left-turn loop
Source: Maze, 2004

These countermeasures can cause delay for left turning vehicles in terms of increased travel and waiting times, however a study by Gluck *et al.* (1999) implied that delay may actually be reduced for roadways with higher speeds and volumes.

Zhou (Zhou *et al.*, 2001) proposed a directional median opening (Figure 4.9). This type of opening allows traffic from the mainline to make left turns at the intersection, while preventing traffic from the minor street from making through movements. Traffic from the minor approaches must turn right and use the indirect left turn U-turn to make left-turns and through movements. A recent study by Potts, Harwood, et al (2004) found that the crash rates experienced at 12 median openings in rural arterial corridors were an average of 0.20 crashes per median opening per year. Two studies in the state of Florida (FDOT, 1996 and Lu, *et al.*, 2000), showed decreases of 22 percent and 18 percent in accident rates, respectively, when left turns were replaced by a right-turn, U-turn combination. A recent study by H. Levinson, *et al.*, (2005) also showed a 20 percent decrease in accident rates.

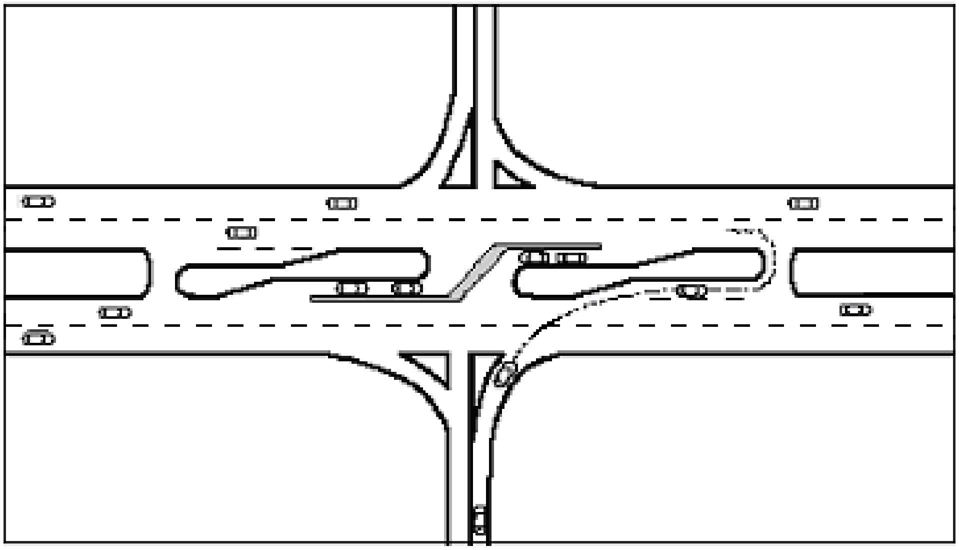

Figure 4.9: Directional Median Opening
Source: Author, adapted from Zhou (2001)

Finally, intersections can also be converted into grade separated interchanges. This approach eliminates the intersection conflict points on the mainline, often in exchange for merge zones. Capacity of the roadway is usually increased as well. In many areas, this may prove to be infeasible due to right-of-way acquisition difficulties, geographic limitations, and construction costs.

<u>Discussion</u>

There are many variations and combinations of the countermeasures mentioned above that could be implemented into a roadway safety improvement program. For the purposes of this study the two geometric alternatives that have the greatest potential to reduce the incidence of right angle crashes include:

- Re-grading the roadway to correct deficiencies in sight distances (as proposed by Mn/DOT District 6)
- Directional Median Openings

These alternatives will be compared to the baseline scenario and the IDS alternative. The estimated costs and benefits of each of these alternatives are outlined in Chapters 6, 7 and 8.

5. Lifespan of Countermeasure Components

Each of the traffic engineering safety methods described in Chapter 4 has a certain lifespan associated with them. Signs and pavement markings fade, electric lights burn out, and cameras, sensors, and wires need replacing. In this Chapter the lifespan of the countermeasures and their related components are determined, beginning with the IDS system and its components, followed by the alternatives.

Estimates of the lifespan of the various countermeasure system components and technologies were determined from a variety of sources, including the USDOT (2005) ITS Benefits and Costs Database - *Equipment Costs for Roadside Detection (RS-D)*, the FHWA (1996) *National ITS Architecture Cost Analysis*, and when possible, from the manufacturers of the equipment themselves. The values given are assumed to be the most probable values, unless otherwise noted. The lifespan estimates are utilized to determine the costs of future outlays for the replacement of equipment during the 20 year analysis period. It is assumed the salvage value of all the system components has a value of zero after 20 years.

Lifespan of IDS System Components

The IDS system requires a computer system, communication system, sensors, display devices, traffic signs, and power distribution center (the controller cabinet). The computer system requires an industrial quality PC and has an expected lifespan of 10 years. The communication system lifespan varies depending on whether wireless or hard-wired technology is used. Hard wiring is expected to last 20 years, while the wireless system has a lifespan of 10 years. Lifespans of the sensor systems are shown below (Table 5.1).

Table 5.1: Lifespan of Sensor System Components

Component	**Lifespan**
Radar	10 years
Lidar	10 years

Source: USDOT (2005) Equipment Costs for Roadside Detection (RS-D)

The lifespan of the display system depends upon which system is used. The pole system requires lights and poles, the variable message signs system require poles and LED panel displays, and the beacon system requires flashing beacons (Table 5.2).

Table 5.2: Lifespan of Display System Components

Component	**Lifespan**
Light System	
Poles	20 years
Lights	50,000 hours
Variable Message Sign System	
LED Panel Display	50,000 hours
Hazard Beacon System	
LED Flashing Beacons	50,000 hours

Source: USDOT (2005) Equipment Costs for Roadside Detection (RS-D)

The traffic signs (stop signs and additional signage) are expected to last 20 years. The lifespan of the power distribution center (controller cabinet) depends on the type selected and is expected to last 20 years as well.

Lifespan of Alternative Countermeasures and System Components

It is assumed that the lifespan of any of the alternatives involving geometric redesign of the intersection would be equal to the lifespan of the pavement in the IDS and baseline scenarios. In other words, if the pavement is expected to last 20 years in the baseline scenario, it should also last 20 years in any of the proposed alternatives. Thus, the additional pavement required for the directional median opening is expected to last 20 years, as are the Jersey barriers (or other barriers). Likewise, the raised medians are expected to last at least 20 years before requiring reconstruction or replacement. Many of the countermeasures involve posting of additional signs. It is assumed these signs will last for 20 years. Pavement markings such as stop/yield bars, left and right turn lane markings, and median lane markings are expected to last 6 years before repainting is needed, although the actual lifespan depends on wear and tear due to traffic volumes and weather related phenomena.

6. Infrastructure and Operating Costs of Countermeasures

Implementing any of the countermeasures mentioned in the previous Chapters requires capital costs (equipment, labor), operation (power) and maintenance costs, and imposes other costs, such as user delay. Estimates of equipment costs and operation and maintenance costs came primarily from the *National ITS Architecture Cost Analysis* (FHWA, 1996) the ITS Units Costs Database (2005), and when possible, from the manufacturers themselves. Estimates of construction and maintenance costs of the alternatives involving geometric redesign (including signage and lighting) were obtained from various sources, including Mn/DOT district cost estimates, the Minnesota Comprehensive Highway Safety Plan (Preston and Storm, 2004) and others. Delay costs are determined by applying HumanFIRST driving simulator data (Creaser, 2005) into a queuing delay model (Daganzo, 1998) which is detailed in Chapter 7.

Costs of IDS System Components

The costs of each of the components for the IDS system are shown in Table 6.1. It is important to note that the final display system (hazard warning) has not been set, so the costs of the various components in each of the proposed designs are included. However, results from the HumanFIRST driving simulator study (Creaser, 2005) seem to indicate that the most favored interface is the countdown display/Icon LED panels, and thus is selected in the benefit/cost analysis. Other technologies would impose different costs.

Table 6.1: Costs of IDS System

Component	Initial Capital Cost	Operating/Maintenance Costs
Computer		
System/Controller	$11,000 - $17,500	$200 - $500/year
Wireless communications	$500 - $1,000	$500 - $1,000/year
Hard-wired communications	$500 - $1,000	$50 - $150/year
Sensor System		
Radar	$3,300 - $6,000 for 2 units	$200 - $400/year
Lidar	$3,300 - $6,000 for 2 units	$200 - $400/year
Display System		
Poles	$2,000 - $12,000 for 2 units	$0/year
Light Poles LED	$2,500 - $5,500 for 2 units	$400 - $800/year
Variable Message LED Panels	$20,000 - $30,000 for 2 units	$2,400 - $3,000/year
Speed display LED Panels	$5,000 - $8,000 for 2 units	$2,400 - $3,000/year
Countdown display/Icon LED Panels	$5,000 - $8,000 for 2 units	$2,400 - $3,000/year
2 LED Beacons	$5,000 - $8,000 for 2 units	$400 - $800/year
Traffic Signs		
Stop signs	$150 - $260 for 1 unit	$20 - $100/year
Other signs	$150 - $260 for 1 unit	$20 - $100/year

Sources: Author, Donath, USDOT: ITS Benefits and Costs Database (2005)

In order to carry out a detailed analysis of all the costs involved, the maintenance cost (annualized and over the total analysis period) and annual operating costs must be determined. Data for the operation and maintenance costs of the various components were determined from the ITS Benefits and Costs Database (2005). Most of the ranges were obtained from this database. Although in some cases more precise costs were known, these were also given a range to account for the possibility of year to year variations. It was assumed that the actual costs were uniformly distributed between the ranges listed above. In the cost calculations, a random value between upper and lower bounds of each of the components initial capital and operating costs was generated. It is important to note that this is a use of subjective probability (i.e. it is the author’s opinion that costs are uniformly distributed between the lower and upper bounds). Sample calculations are shown in tables 6.2, 6.3, 6.4, and 6.5.

Table 6.2: IDS Computer System Costs

	System/ Controller		**Wireless Comm**		**Hard-wired Comm**		**Installation**
	Initial Capital Cost	Oper/ Maint Cost/yr	Initial Capital Cost	Oper/ Maint Cost/yr	Initial Capital Cost	Oper/ Maint Cost/yr	
Cost Range							
Low	$11,000	$200	$500	$500	$500	$50	$21,760
High	$17,500	$500	$1,000	$1,000	$1,000	$150	$21,760
Sample Value	$14,380	$365	$679	$971	$686	$135	$21,760
Lifespan	10 yr		10 yr		20 yr		

Sources: Author, Donath, USDOT: ITS Benefits and Costs Database (2005)

The System/Controller and Wireless Communications are replaced after ten years, the operation/maintenance costs are annual costs. To convert future annual costs into a net present value, equation (1) is used.

$$NPV = A\frac{(1+i)^n - 1}{i(1+i)^n} \qquad (1)$$

Where A = annual cost
i = interest rate (3.6% or 0.036)
n = number of years in analysis period (20)

Thus the Net Present Value can be calculated by:

$$\$14{,}380 + \$14{,}380\,(1.036)^{-10} + \$365\frac{(1+0.036)^{20}-1}{0.036(1+0.036)^{20}} + \$679 + \$679(1.036)^{-10} +$$

$$\$971\frac{(1+0.036)^{20}-1}{0.036(1+0.036)^{20}} + \$686 + \$135\frac{(1+0.036)^{20}-1}{0.036(1+0.036)^{20}} + \$21{,}760 = \$68{,}803$$

Table 6.3: IDS Sensor System Costs

	Radar		Lidar	
Cost Range	Initial Capital Cost (for 2 units)	Oper/ Maint Cost/yr	Initial Capital Cost (for 2 units)	Oper/ Maint Cost/yr
Low	$3,300	$200	$3,300	$200
High	$6,000	$400	$6,000	$400
Sample Value	4193	352	3609	339
Lifespan	10 yr		10 yr	

Sources: Author, USDOT: ITS Benefits and Costs Database (2005)

The system requires a total of 12 radar and 4 lidar units, so the NPV is:

$$6(\$4{,}193 + \$4{,}193(1.036)^{-10}) + 6\left(\$352\ \frac{(1.036)^{20}-1}{0.036(1.036)^{20}}\right) + 2(\$3{,}609 +$$

$$\$3{,}609(1.036)^{-10}) + 2\left(\$339\frac{(1.036)^{20}-1}{0.036(1.036)^{20}}\right) = \$94{,}379$$

Table 6.4: IDS Display System Costs

	VMS LED Panels	
Cost Range	Initial Capital Cost (for 2 units)	Oper/ Maint Cost/yr
Low	$20,000	$2,400
High	$30,000	$3,000
Sample Value	$27,092	$2,591
Lifespan	50,000 hrs (5.7 years)	

Sources: Author, USDOT: ITS Benefits and Costs Database (2005)

$$\$27{,}092 + \$27{,}092\ (1.036)^{-5.7} + \$27{,}092\ (1.036)^{-11.4} + \$27{,}092\ (1.036)^{-17.1} +$$

$$\$2{,}591\frac{(1.036)^{20}-1}{0.036(1.036)^{20}} = \$118{,}631$$

Table 6.5: IDS Traffic Sign Costs

Cost Range	**Stop Signs**		**Other Signs**	
	Initial Capital Cost	Oper/ Maint Cost/yr	Initial Capital Cost	Oper/ Maint Cost/yr
Low	$150	$20	$150	$20
High	$260	$100	$260	$100
Sample Value	177	76	175	66
Lifespan	20 years			

Sources: Author, USDOT: ITS Benefits and Costs Database

$$2\left(\$177 + \$76\,\frac{(1.036)^{20} - 1}{0.036(1.036)^{20}} + \$175 + \$66 \times \frac{(1.036)^{20} - 1}{0.036(1.036)^{20}}\right) = \$4{,}702$$

The sum of all these Net Present Values is added to the delay costs, which is detailed in Chapter 7.

Alternative Countermeasures Costs

The costs of the alternative countermeasures are shown below (Table 6.6). The costs of many of the alternatives involving geometric redesign depend on the surrounding topography, land use, and agency overseeing the construction and maintenance of the proposed facilities.

Table 6.6: Costs of Alternative Countermeasures

Component	Cost	Operating/Maintenance Costs
Directional Median Opening		
Median Barriers	$20,000 - $100,000 / barrier	$500 - $1,000
U-Turn Lanes	$40,000 - $100,000 / lane	$2,840 - $5,680
Pavement Markings	$1.50 - $2.65 per linear foot	Replace 6 years
Stop signs	$150 - $260 for 1 unit	$20 - $100/year
Other warning signs	$150 - $260 for 1 unit	$20 - $100/year
Intersection Approach Re-grade	$900,000	Same as baseline

Sources: Author's estimates, USDOT: ITS Benefits and Costs Database (2005), Donath, M. (2005)

Note: *The cost of U-Turn installation may be higher depending on the geometric configuration of the roadway. In particular, if the median is narrow, the existing roadway may need to be moved out to allow a U-Turn with sufficient distance to store a large commercial vehicle.*

For the directional median opening, it was assumed anywhere from 1,000 to 2,000 feet (300 – 600 m) of additional pavement would be needed, depending on the length of the left turn lanes leading into the U-turns (some road agencies may choose the standard 300 feet (91.4 m), but possibly up to 1000 feet (300 m)). Since Mn/DOT estimates for rural lane maintenance is approximately $15,000 per mile ($9,000/km), this translates into annual extra lane maintenance costs ranging from $2,840 - $5,680. The Missouri DOT estimates directional median openings with downstream U-turn ramps cost between $100,000 - $250,000 to construct (MoDOT, 2006) while the Iowa DOT estimates range from $250,000 to $400,000 (Donath, 2005). A cost estimate of up to $400,000 for the direction median opening alternative is employed as part of the sensitivity analysis.

Sample calculations of implementing and maintaining a directional median opening (with 8 extra traffic signs) are shown below (Table 6.7, 6.8). The cost of the directional median opening varies depending on site-specific circumstances, and requires there be existing adequate median space to construct U-turns that allow large vehicles to maneuver.

Table 6.7: Directional Median Opening Component Costs

	Median Barriers		**U-turn Lanes**		**Other Signs**	
	Initial Capital Cost (for one barrier)	Oper/ Maint Cost/yr	Initial Capital Cost (per lane)	Oper/ Maint Cost/yr	Initial Capital Cost	Oper/ Maint Cost/yr
Cost Range						
Low	$20,000	$500	$40,000	$284	$150	$20
High	$100,000	$1,000	$100,000	$568	$260	$100
Sample Value	$33,777	$744	$56,210	$364	$163	$89
Lifespan	20 yr		20 yr		20 yr	

Sources: Author, Donath, M. (2005)

$$2\left(\$33{,}777 + \$56{,}210 + \$744\,\frac{(1.036)^{20}-1}{0.036(1.036)^{20}} + 364\,\frac{(1.036)^{20}-1}{0.036(1.036)^{20}}\right) + 8\left(\$163\right)$$

$$+\ 8\left(\$89 \times \frac{(1.036)^{20}-1}{0.036(1.036)^{20}}\right) = \$217{,}301$$

Table 6.8: Directional Median Opening Pavement Markings Cost

	Pavement Markings	
	Initial Capital Cost	Oper/ Maint Cost/yr
Cost Range	(per foot)	
Low	$1.50	$0
High	$2.65	$0
1000 ft needed		
Sample Value	$1.74	0
Lifespan	6 yr	

Sources: Author

$$\$1{,}740 + \$1{,}740(1.036)^{-6} + \$1{,}740(1.036)^{-12} + \$1{,}740(1.036)^{-18} = \$5{,}193$$

Increased Crash Costs from Alternative Countermeasures

Some of these countermeasures may lead to an increase in crashes and/or crash types and severities while possibly reducing others. These are assigned negative values for benefits, and are based on Mn/DOTs injury scale, detailed in chapter 8.

The IDS system is expected to reduce overall crash rates if the system is error-free and compliance is high. It is possible the IDS system may lead to an increase in certain crash types (e.g., property damage only), but actual percentage increases are difficult to determine. The increase of certain crash types is more readily estimated in the case of the directional median opening. While this alternative is expected to reduce the overall crash rate, the increase in right turn movements will lead to an increase in the right turn crash rate, as well as crash rates for the segment between the intersection and the U-turn. Information obtained from a crash analysis of US 52 and CSAH 9 revealed right-turn crashes accounted for 5 percent of the overall crash distribution. The crash rate was 0.33 crashes per 201,115 right turning vehicles per year (assuming 551 right turning vehicles on an average day).

Under the directional median opening alternative, an additional 140 vehicles per day would be making right-turn maneuvers. Simple linear interpolation results in a new right-turn crash estimate of 0.42, or a 25 percent increase. Since right-turn crashes account for 5 percent of all crashes at this intersection, the overall crash rate would increase by 1.25 percent. An analysis of the intersection crash diagram reveals that the right turn crashes resulted in property damage only. Therefore, we assume the installation of the directional median opening would result in a 1.25 percent increase in these types of crashes.

The directional median opening would also lead to an increase in mainline and U -turn crashes. It is important to note that the U-turn crash rate for this intersection is not known, since the existing data does not allow for disentangling of crashes according to the type of maneuver. However, it can be estimated as part of the crash rate for the segment. The segment crash rate includes crashes due to weaving, merging, diverging, acceleration, deceleration, and lane changes. Vehicles utilizing the U-turn ramps must make all of these maneuvers. These types of movements are accounted for in the segment crash rates.

The directional median opening will lead to an increase of 140 vehicles traveling southbound on US 52 between CSAH 9 and the southern U-turn opening and 140 vehicles traveling northbound on US 52 between CSAH 9 and the northern U-turn opening. The 280 additional vehicles on a roadway with an ADT of 17,500 represent a 1.6 percent increase in traffic for the segment between the two U-turn openings. Thus, the crash rate for the segment (for all types of crashes) is expected to increase by 1.6 percent. These additional crash costs will be offset somewhat by the decrease in right-angle crash rates that are detailed in the benefits chapter (chapter 8). Figure 6.1 shows the sites under a directional median opening scenario where crashes will increase or decrease. It is hoped that the increased crashes at right turns, on the mainline, and at the U-turn will be outweighed by reduced right-angle and median crashes.

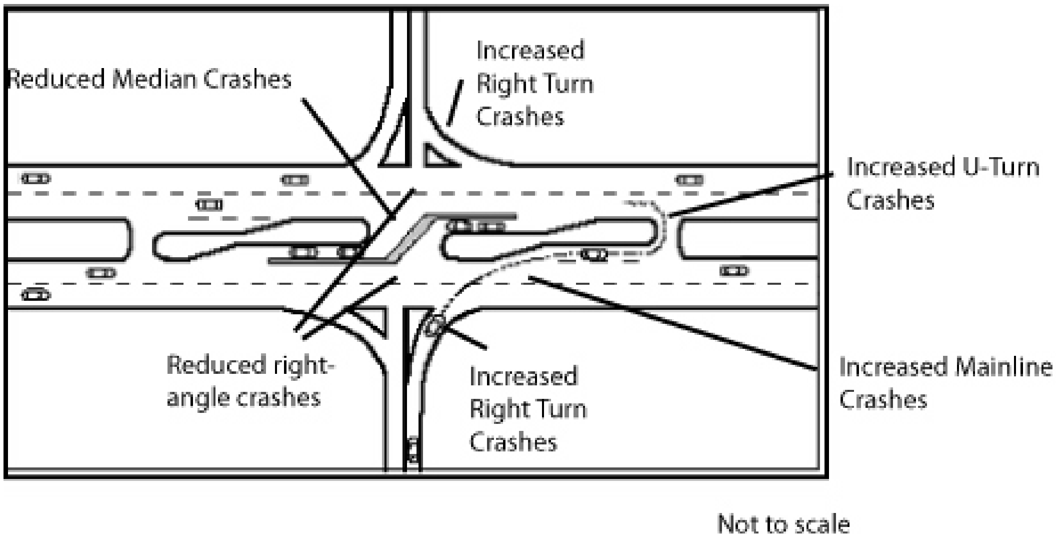

Figure 6.1: Directional Median Opening Crash Reduction and Increase Locations
Source: Author, figure adapted from Zhou (2001)

7. Delay Costs of Countermeasures

In many transportation projects, drivers are often subjected to certain amounts of delay during the construction/implementation phase and subsequent operational phases. In many benefit-cost analyses, all of the vehicles are assumed to experience the same amount of delay and have the same value of time, and are often based on average values. In reality, each individual vehicle driver in a particular study area has a different value of time and amount of delay that they experience. The methodology used to simulate this phenomenon for each of the alternatives is detailed below.

IDS Delay Time Variations

According to AASHTO/NCHRP recommendations (Creaser, *et al.,* 2005), "safe" gaps at this intersection are defined as 7.5 seconds on the nearside and 12.5 seconds on the far side. Simulation and real traffic data have shown some drivers choose to enter the intersection with smaller gaps. Thus, assuming drivers comply with the interface guidance, a portion of users will be subjected to increased delay. First, data for the base case is obtained from the driving simulator experiment and actual traffic data from the intersection. Results from the conditions tested in the driving simulator reveal that drivers in the baseline scenario spent an average of 54.5 seconds waiting at the intersection. In the Countdown display (Icon) scenario, this increases to 70.85 seconds, an increase of 30 percent. According to the actual intersection traffic count data, the mean waiting time was 15.6 seconds. Thus, if the Icon scenario were to increase waiting time by an average of 30 percent, the average delay for each vehicle would increase from 15.6 seconds to 20.28 seconds. Thus, the average delay cost per vehicle is 4.68 seconds (0.0013 hours).

The intersection count data also revealed that there was a wide variation in the arrival and departure rates, as well as waiting time. In an effort to model this, a spreadsheet queuing model developed by Daganzo was used (Daganzo, 1998). The model simulates queuing at an intersection (delay) where vehicles have Poisson arrival and departure rates. The two inputs required for the model, the average arrival rates and service times (vehicles per second), were determined from the actual intersection count data. In one typical 24 hour day, nearly 700 vehicles (691) came from the minor approaches and the average delay was 15.6 seconds. Thus the arrival rate for the baseline scenario was calculated as 0.0080 vehicles per second, and the service time was calculated as 0.0641 vehicles per second. The resulting output of the model showed the total delay for each day of operation ranged from approximately 11,000 to 14,000 seconds. Assuming the IDS scenario increases delay time by 30 percent, (an average delay of 20.28 seconds), the service time input into the model changes to 0.0493 vehicles/second. Thus, the total delay in the IDS scenario for a typical day ranges from approximately 15,000 to 18,000 seconds. This means the IDS System imposes an additional 1,000 to 7,000 seconds of delay daily.

IDS Value of Time Variations

To determine the total delay costs over the 20 year analysis period, the delay time must be converted to a monetary value. Mn/DOT recommends a value of time of $10.21 per person per hour for automobile drivers and $18.93 per person per hour for truckers (Mn/DOT Benefit-Cost Analysis Guide, 2005). The USDOT recommends using a range of $7.40 - $25.40 per person per hour for cars (USDOT, February 2003). The Spring Load Restriction (SLR) Study (Smalkoski and Levinson, 2004) determined a value of $49.42 per hour for trucks, (with a standard deviation of $4.49).

Each of the vehicles on a “typical” day will have a different value of time. It is assumed trucks constitute 10 percent of the minor road traffic volume. A typical day of traffic has approximately 700 vehicles entering from the minor approach legs (691 vehicles on the day used for this study comprised of 622 passenger cars and 69 commercial vehicles). Thus, in the queuing model, 10% or 69 of the 691 vehicles were given different values of time that were assumed to vary around $49.42, with a normal distribution (i.e., 95% of the values lie within 2 standard deviations of the mean, from $40.45 to $58.39). The value of time for the remaining 622 cars was assumed to vary randomly (uniformly) between $7.40 and $25.40 per hour.

IDS Delay Cost Determination

Using the queuing model, each vehicle’s delay time was multiplied by its value of time to determine their delay cost. The delay costs in the baseline scenario were subtracted from the delay costs in the IDS scenario to determine the total additional delay costs experience by the road users. Since these costs represent a typical day, the delay costs were annualized over the 20 years analysis period and added to the other costs (IDS component installation and operation/maintenance costs). These delay costs are added to the system component costs detailed in tables 6.2 - 6.5. Results are shown in chapter 9.

Directional Median Opening Delay Cost Variations

It was assumed that cars making the right-turn, U-turn maneuver wait between 7.8 to 15.6 seconds upon arrival at the intersection, then average between 20-40 mph (32-64 km/h) along the 0.25 mile (0.4 km) distance between the intersection and the U-turn, wait an additional 7.8 to 15.6 seconds to enter the mainline, and then average between 20-40 mph (32-64 km/h) from the U-turn opening back to the intersection. This results in an extra 0.5 miles (0.8 km) of travel, and takes between 52.8 and 106.6 seconds. Similarly for trucks, the range of waiting times is assumed to be the same, but the travel speeds average between 15-30 mph (24-48 km/h), resulting in an extra 67.8 – 135.6 seconds. These travel times are added to the baseline delay times for each vehicle as calculated in the queuing model baseline scenario. It is important to note that since 140 out of 691 (20.3%) vehicles on a typical day have to travel further as a result of the directional median opening (those desiring to make left-turn and through maneuvers), the total delay for each day is multiplied by 20.3% to reflect the additional delay per vehicle. The resulting output of the model showed the total delay in the DMO scenario for a typical day ranges from approximately 23,000 to 24,600 seconds. This means the DMO alternative imposes an additional 9,000 to 13,600 seconds of delay each day.

Directional Median Opening Value of Time Variations

The methodology for determining the value of time for cars and commercial vehicles is similar to that used in the IDS scenario. Approximately 10% of the vehicles (69 of them) were given commercial vehicle values of time that were drawn from the normal distribution calculated in the SLR study, while the value of time for the 622 cars was assumed to vary randomly between $7.40 and $25.40 per hour. The sum of the car and commercial vehicle value of time was multiplied by 20.3% to reflect proportion of vehicles subjected to the additional delay.

Directional Median Opening Delay Cost Determination

The vehicle delays calculated using the queuing model, (and the additional travel time delays), are multiplied by their value of time to determine the total delay cost. The total delay cost was multiplied by 20.3 percent to reflect proportion of vehicles subjected to the additional delay. These costs were annualized over the 20 years analysis period and added to the other costs (directional median opening component installation and operation/maintenance costs). Results are shown in Chapter 9.

Intersection Re-grade Delay Cost Determination

It is important to note that the alternative involving re-grading the intersection approach (the southbound leg south of CSAH 9) is assumed to have no difference in delay versus the baseline scenario. It is possible that the improvement in sight distance brought about by the re-grade would decrease waiting time, but there is no data to support this. The re-grading of the approach might require the closure of the two lanes and diversion onto one of the northbound lanes or other route. This construction would create a certain amount of delay. To illustrate, if each automobile were delayed by one minute each day for 200 days, delay costs would exceed $500,000.

8. Crash-reduction Benefits of Countermeasures

The benefits of implementing the countermeasures are expected to come primarily in the form of reduced crash rates. These crashes must have monetary values associated with them in order to carry out a benefit-cost analysis. This is made possible through the use of the Abbreviated Injury Scale (AIS), the Federal DOTs guidelines for assigning monetary values to the AIS scale, and Mn/DOTs Benefit/Cost Analysis for Transportation Projects, 2005.

The AIS classifies crashes in terms of injuries to the body by region on a six point scale of risk to life. The maximum AIS (MAIS) is the highest single AIS code for an occupant with multiple injuries. A value of zero indicates a property damage only (PDO) crash, while a value of 5 indicates severe injuries. The National Highway Transportation Safety Administration (NHTSA, 2002) sets guidelines for associating monetary values with the MAIS values. The Federal DOT has also set a value of life for fatal crashes (Table 8.1).

Table 8.1: Costs of Crashes

	Year 2000 Dollars	September 2003 Dollars
PDO:	$2,256	$2,532
MAIS 0:	$1,748	$1,962
MAIS 1:	$13,383	$15,017
MAIS 2:	$140,766	$157,958
MAIS 3:	$280,007	$314,204
MAIS 4:	$651,957	$731,580
MAIS 5:	$2,141,462	$2,402,997
Fatal:	$3,000,000	$3,366,388

Sources: NHTSA (2002), USDOT (2003)

The Minnesota Department of Public Safety reports crashes using the following scale (Table 8.2).

Table 8.2: Damage Severity Classification in Police Traffic Accident Reports

0	Not Applicable	
1	None	
2	Light	(PDO, MAIS 1, MAIS 2)
3	Moderate	(MAIS 2, MAIS 3)
4	Severe	(MAIS 4, MAIS 5)
5	Fatal	(Fatal)
6	Unknown	

Source: Minnesota Department of Public Safety

Mn/DOT uses a simplified classification scheme, with three categories of injuries (Table 8.3). Mn/DOT uses this system in its crash diagrams, and thus it is adopted for use in the benefit/cost analysis. An analysis of the intersection in question, US 52 and CSAH 9, revealed the following crash statistics (Table 8.3). (See also Appendix A). These crashes were combined with the Mn/DOT Benefit-Cost Analysis guide to determine the annual crash rate and associated costs (Table 8.3).

Table 8.3: Annual Crash Rates and Costs for US 52 and CSAH 9

	Crashes 2000-2002	Cost (2005) Mn/DOT	Crashes per year	Cost per year
Fatal	0	$3,500,000	0.000	$ -
"A" Injury	1	$ 270,000	0.333	$ 90,000
"B" Injury	10	$ 59,000	3.333	$ 196,667
"C" Injury	4	$ 29,000	1.333	$ 38,667
PDO (N)	5	$ 4,300	1.667	$ 7,167

Sources: Mn/DOT Benefit-Cost Analysis for Transportation Projects, 2005, Preston et al. (2004), author

IDS Crash Reductions

The safety effects of the IDS system were estimated by using Time To Contact (TTC) data from the HumanFIRST Driving simulator study and applying it to a general Gaussian Model to determine the probability of a conflict occurring that results in a crash. The methodology is discussed below.

The HumanFIRST Driving simulator study (Creaser, 2005), tests how drivers reacted to various warning systems (including the base case) in a simulated version of the actual intersection. The use of a driving simulator is required to identify the benefits (costs) that result from application of IDS technology. While real-world data would provide far superior estimates of baseline conditions, until IDS is actually deployed, it cannot provide an estimate of the change that takes place due to the installation of IDS technology. In order to provide a fair basis of comparison, both the base and the scenario with IDS technology data need to come from the same source, in this case the driving simulator. It is important to note that the use of the driving simulator is only for the purposes of estimating the reduction in crashes associated with IDS, not the likelihood of a crash in the first place.

Accident reduction rates are based on an analysis of the Time To Contact (TTC) data from the HumanFIRST driving simulator study. In this study, TTC is defined as the actual amount of time between the nearest oncoming vehicle and the participant's vehicle when it first enters the intersection (See Appendix B for further details on TTC theory). Results from the driving simulator revealed that drivers in the baseline scenario accepted gaps averaging 2.735 seconds (i.e., an average TTC of 2.735 seconds). The IDS Icon scenario resulted in an average gap acceptance of 3.455 seconds. This change in gap acceptance (TTC) should lead to a reduction in conflicts, and thus crash frequency. A distribution of the TTC in the baseline and IDS Icon scenario (both from the driving simulator runs) is shown in Figure 8.1.

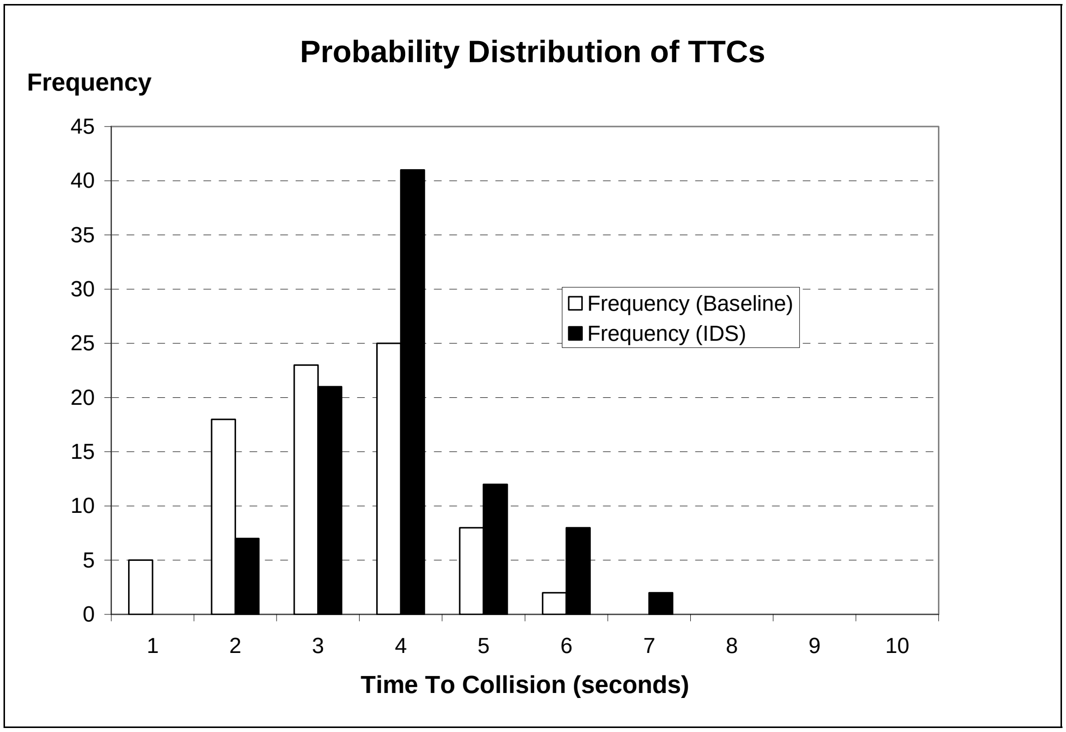

Figure 8.1

Sources: Creaser (2005), X. Zou, (2005)

In this study, a crash is defined as conflict with a 0 second time to collision, taking into account average vehicle size (so there is a time window from 0 to some negative number during which a crash could take place, clearly the first time to collision is the most relevant). Thus a small non-zero TTC represents a near-crash or a severe conflict. Using the means and the standard deviations from the distributions, the probability of a crash occurring is calculated by determining the tail probability from negative infinity to zero for both the baseline and IDS TTC distributions. Results are shown in Table 8.4.

Table 8.4: Probability of TTCs less than zero

	Baseline	IDS
Mean	2.735	3.455
Standard Deviation	1.113	1.068
Z	-2.458	-3.234
Prob (Z < 0)	0.00670	0.00057

Thus, the probability of a conflict resulting in a crash (a time to collision of 0 seconds) equals 0.67 percent in the baseline scenario, and 0.057 percent in the IDS scenario. According to this analysis, the IDS system is expected to reduce crashes on average by:

(1 - (0.057/0.6))*100 = **90.5%**

Although the IDS system may reduce crashes by 90.5 percent on average, it is more useful to determine the range of potential crash reduction percentages. One method of determining this range is to use variations in the mean and standard deviations from the TTC data. This is accomplished using the following methodology.

First, 82 normal random numbers are generated using the mean and standard deviation from the baseline condition (the sample size was 82). Next, the mean and standard deviation is calculated from this set of numbers, followed by a calculation of the probability (p1) of TTC < 0. The same methodology is applied to the IDS TTC data, except 92 normal random numbers are generated (the sample size was 92). Similarly, the probability (p2) of TTC < 0 is calculated. Finally, the percent reduction is calculated (1 – (p2/p1)). This process is repeated 1000 times to obtain a range of accident reduction percentages. The distribution of accident reduction percentages was centered near the 90.5 percent reduction calculated earlier (Figure 8.2).

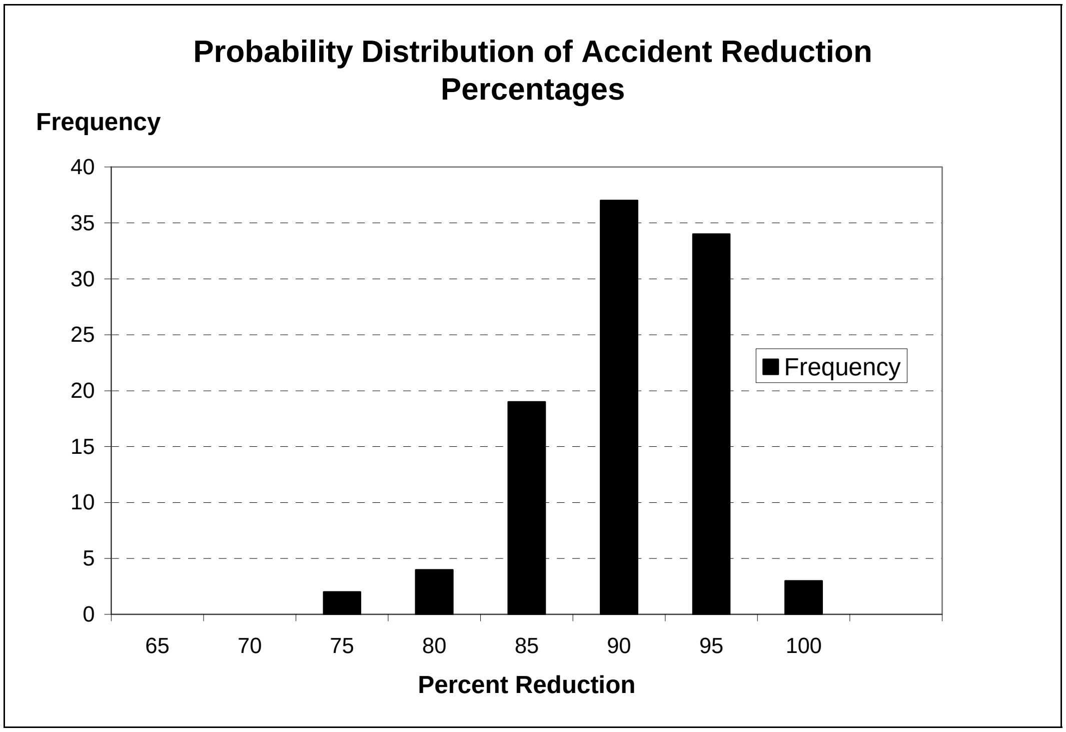

Figure 8.2

It is important to note that the estimates of the IDS accident reduction percentages are based on an unvalidated model that has not been subjected to peer review. The estimates are used only to illustrate how a benefit/cost analysis would be performed when more defensible estimates become available. Future research should be directed to refining these estimates. In particular, increased data sets (e.g. real traffic data rather than driving simulator data) might produce different results.

Alternative Countermeasure Crash Reductions

For the alternative countermeasures, crash rate reductions are based on studies described in chapter 4 for each of the countermeasures, as well as an analysis of the collision diagram for US 52 and CSAH 9.

Crash reductions for the directional median opening can be determined by analyzing the collision diagram for US 52 and CSAH 9 (Appendix A). Examination of the diagram reveals that the directional median opening could prevent 13 out of 20 crashes from occurring, or 65 percent (11 far side right-angle crashes in the northbound lanes, 2 far side right-angle crashes in the southbound lanes). A more detailed review indicates “A” injury crashes would be reduced 100 percent, “B” injury crashes by 90 percent, “C” injury crashes by 50 percent, and PDO crashes by 20 percent.

It is important to recall that in section 6, PDO crashes were expected to increase 1.25 percent because of the increase in right turn maneuvers, while the overall segment crash rate between the

U-turn lanes is expected to increase by 1.6 percent. Thus, the actual reduction in PDO crashes will be 18.75 percent, and the reduction in A, B and C level injury crash rates are 98.4 percent, 88.4 percent and 48.4 percent, respectively. Using these assumptions, the crash reduction benefits are calculated (Table 8.5).

Table 8.5: Crash Reduction Benefits from Directional Median Opening, as determined by the Collision Diagram (Appendix A)

	Crashes	Cost (2005)	Crashes	Cost per year	Crash Reductions	Benefits
	2000-2002	Mn/DOT	per year		From Collision Diagram	
Fatal	0	$ 3,500,000	0.000	$ -	NA	$ -
"A" Injury	1	$ 270,000	0.333	$ 90,000	98.4%	$ 1,247,337
"B" Injury	10	$ 59,000	3.333	$ 196,667	88.4%	$ 2,448,665
"C" Injury	4	$ 29,000	1.333	$ 38,667	48.4%	$ 263,590
PDO (N)	5	$ 4,300	1.667	$ 7,167	18.75%	$ 18,926
					Total NPV	$ 3,978,518

Recall in chapter 4 the three studies on directional median openings that reported accident reduction rates of 18 percent, 20 percent, and 22 percent (Lu, *et al*., 2000, H. Levinson, 2005, FDOT, 1996). Assuming the crash reduction percentage was an average of these values (20 percent) the total NPV would be $936,630 (Table 8.6).

Table 8.6: Crash Reduction Benefits from Directional Median Opening as determined by several recent studies

	Crashes 2000-2002	Cost (2005) Mn/DOT	Crashes per year	Cost per year	Crash Reductions	Benefits
Fatal	0	$ 3,500,000	0.000	$ -	NA	$ -
"A" Injury	1	$ 270,000	0.333	$ 90,000	20%	$ 253,524
"B" Injury	10	$ 59,000	3.333	$196,667	20%	$ 553,997
"C" Injury	4	$ 29,000	1.333	$ 38,667	20%	$ 108,921
PDO (N)	5	$ 4,300	1.667	$ 7,167	20%	$ 20,188
					Total NPV	$ 936,630

In order to provide decision makers with a useful range of probable outcomes, the crash reduction percentages are allowed to vary randomly between the values determined in the collision diagram analysis and the recent studies (20 percent to 98.4 percent). Thus the range of benefits from the directional median opening is expected to range between $936,630 and $3,978,518.

Crash reductions for the intersection re-grade improvement are assumed to reduce the overall crash rate by 20 percent (Preston and Albrecht 2001, Neuman *et al*. 2003). Thus, the NPV would be $936,630, the same as shown in Table 8.6.

9. Sensitivity Analysis and Benefit-Cost Analysis Results

The sensitivity analysis is designed to provide decision makers with a wider range of possible outcomes, as well as providing useful information as to the probability of a particular outcome occurring. The costs of most of the system components for the IDS and directional median opening alternatives are assumed to fall within specified ranges. The costs of these components may vary from year to year, resulting in some degree of uncertainty. Each individual vehicle driver in a particular study area has a different value of time and amount of delay that they experience. In addition, the crash reduction benefits may vary widely from year to year, since crashes themselves are infrequent events. The sensitivity analysis in this study employs ranges of each alternative's benefits and costs in a spreadsheet simulation in an attempt to capture this variability.

The construction, operation and maintenance costs of the various components for each alternative was determined by selecting a random value between each of the listed cost ranges, as detailed in Chapter 6. Delay costs were determined by the methodology outlined in Chapter 7. Crash reduction percentages (benefits) for each alternative were assumed to vary randomly between the percentages described in Chapter 8. It is important to note the assumption of benefits and costs as uniformly distributed between the lower and upper bounds is subjective. The actual ranges may have different distributions (e.g., normal). The assumption of uniform distributions between the benefit and costs ranges (except where noted) were used to capture the variability that may occur in real conditions.

The spreadsheet simulation generated different values each time it was run. The total costs in each iteration were annualized over the 20 year analysis period, converted into a Net Present Value, and compared to the total benefits (also converted into a Net Present Value), resulting in a benefit-cost ratio. The calculated Net Present Values and benefit-cost ratios may vary significantly from iteration to iteration, thus the simulation is repeated 100 times to produce a range of values to determine an average. Probability distributions of the Net Present Values of the costs, benefits, and benefit-cost ratios for the IDS alternative are shown in Figures 9.1 - 9.3. Probability distributions of the Net Present Values of the costs, benefits, and benefit-cost ratios for the Direction Median Opening alternative are shown in Figures 9.4 - 9.6.

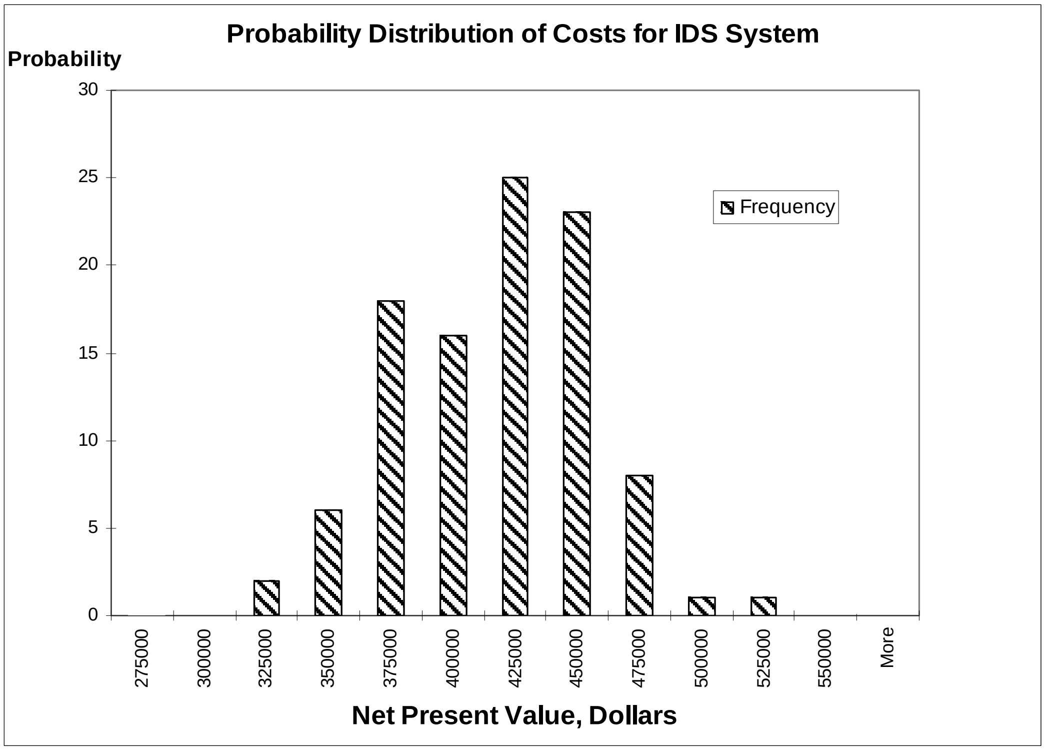
Probability Distribution of Costs for IDS System
Probability
30
25
20
15
10
5
0
▨ Frequency
275000
300000
325000
350000
375000
400000
425000
450000
475000
500000
525000
550000
More
Net Present Value, Dollars

Figure 9.1

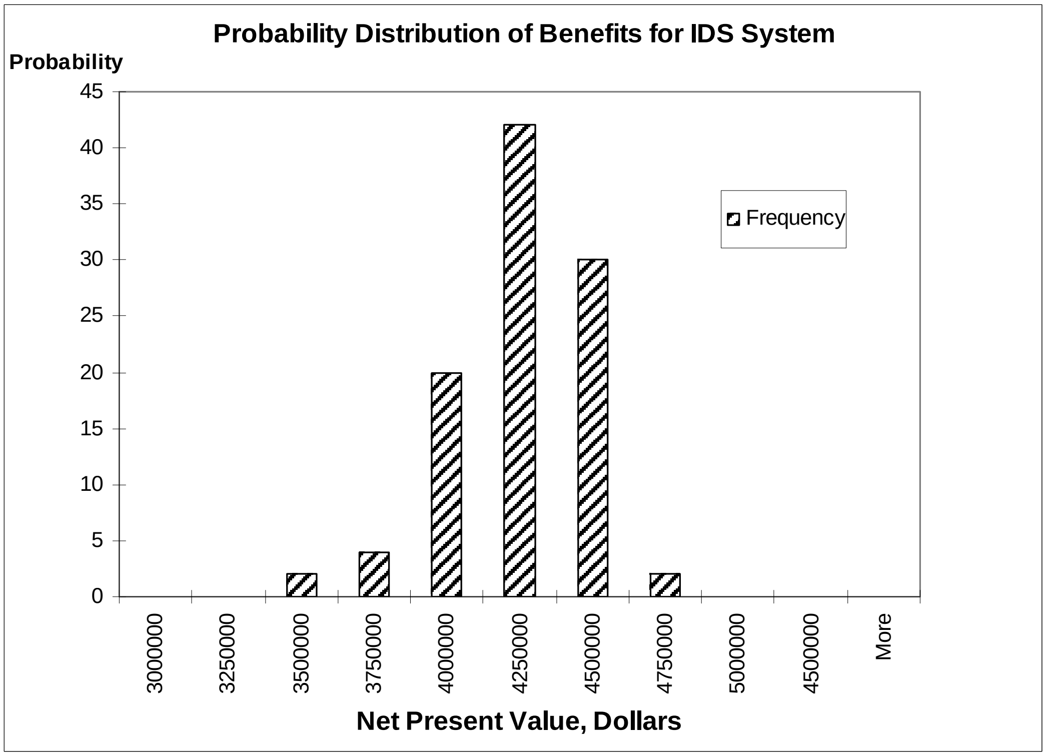

Figure 9.2

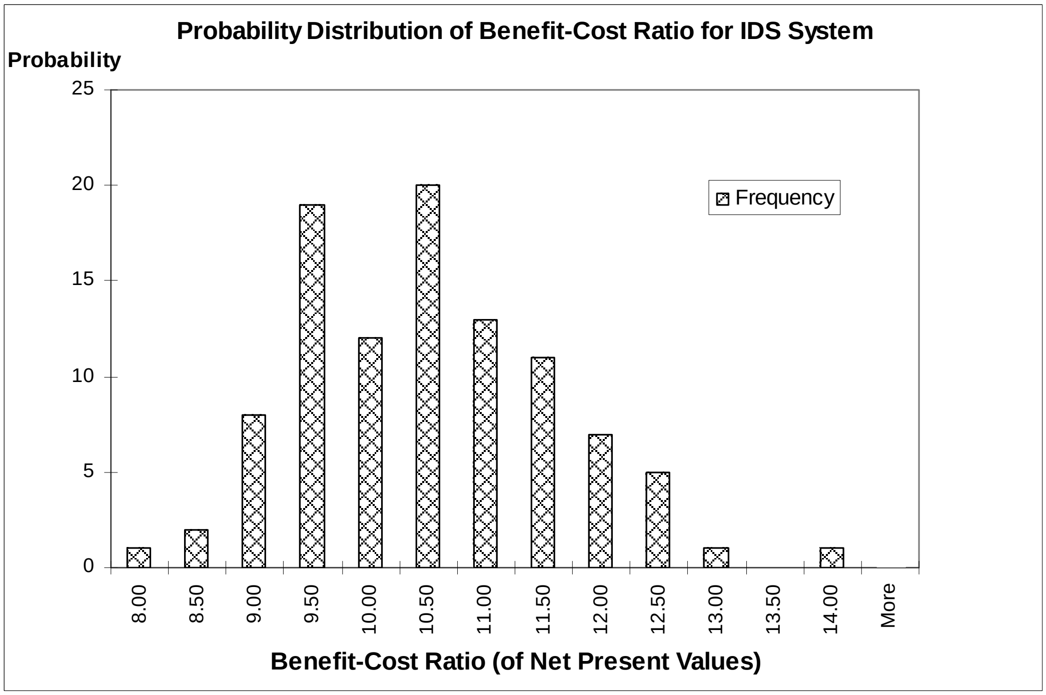

Figure 9.3

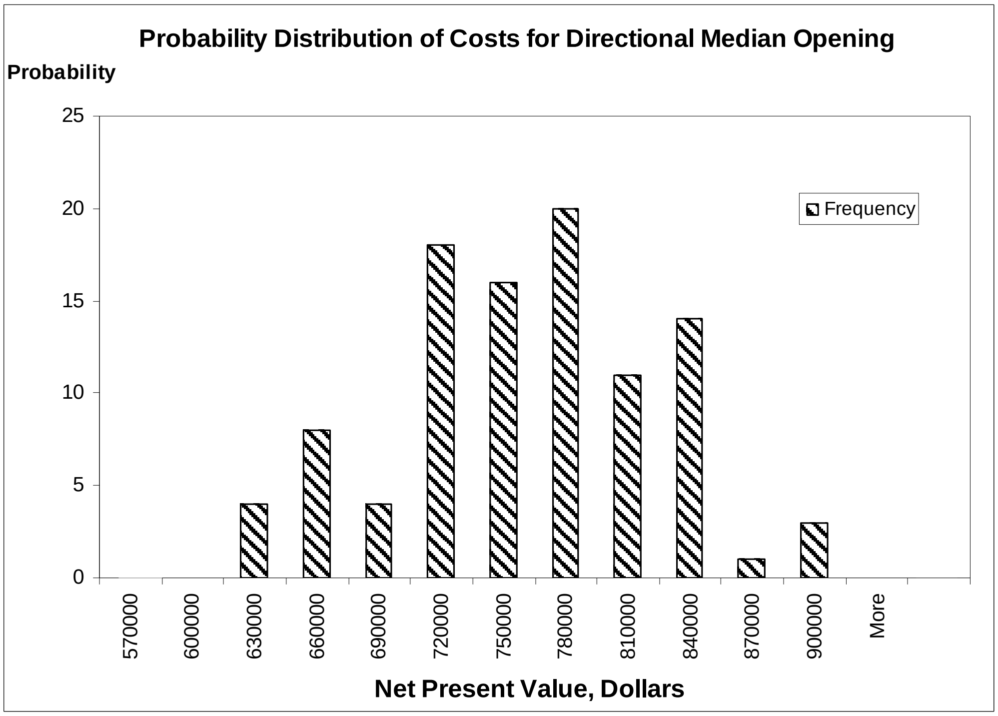

Figure 9.4

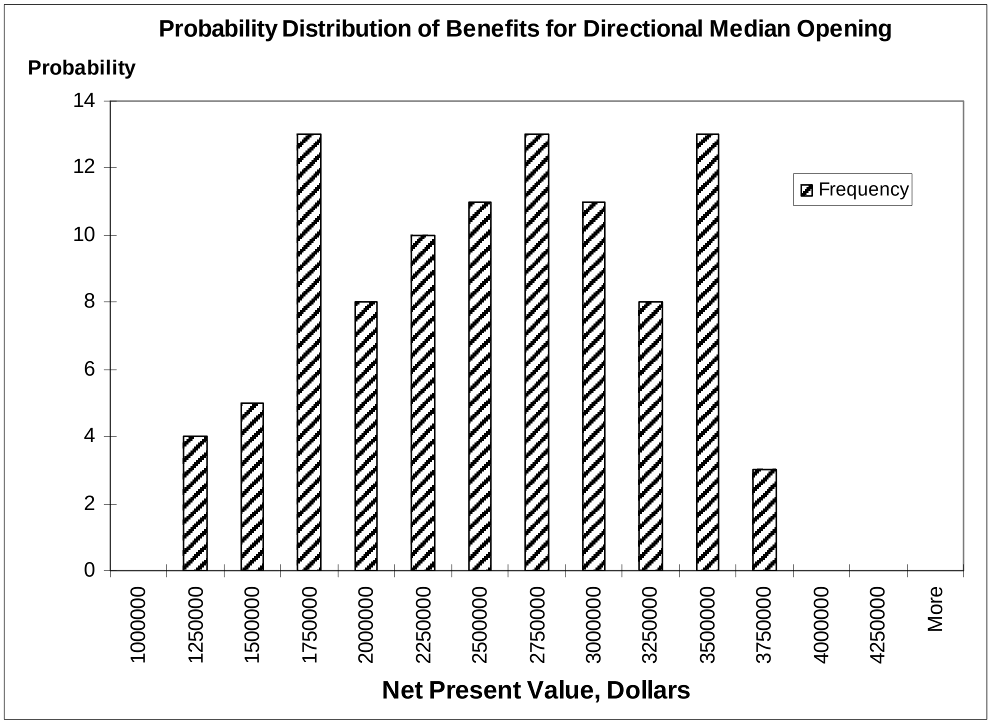

Figure 9.5

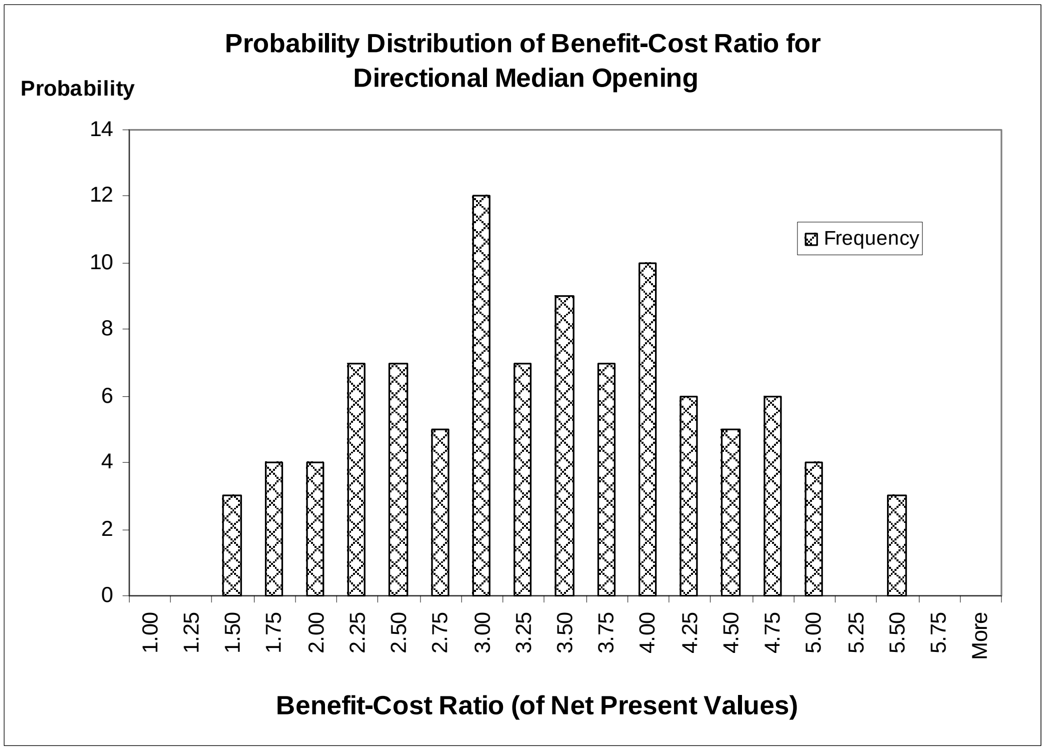

Figure 9.6

In order to present decision makers with more useful interpretation of the data, a side-by-side comparison of the Net Present Values of the costs and benefits for the IDS and DMO alternatives are shown in Figure 9.7 and Figure 9.8, respectively.

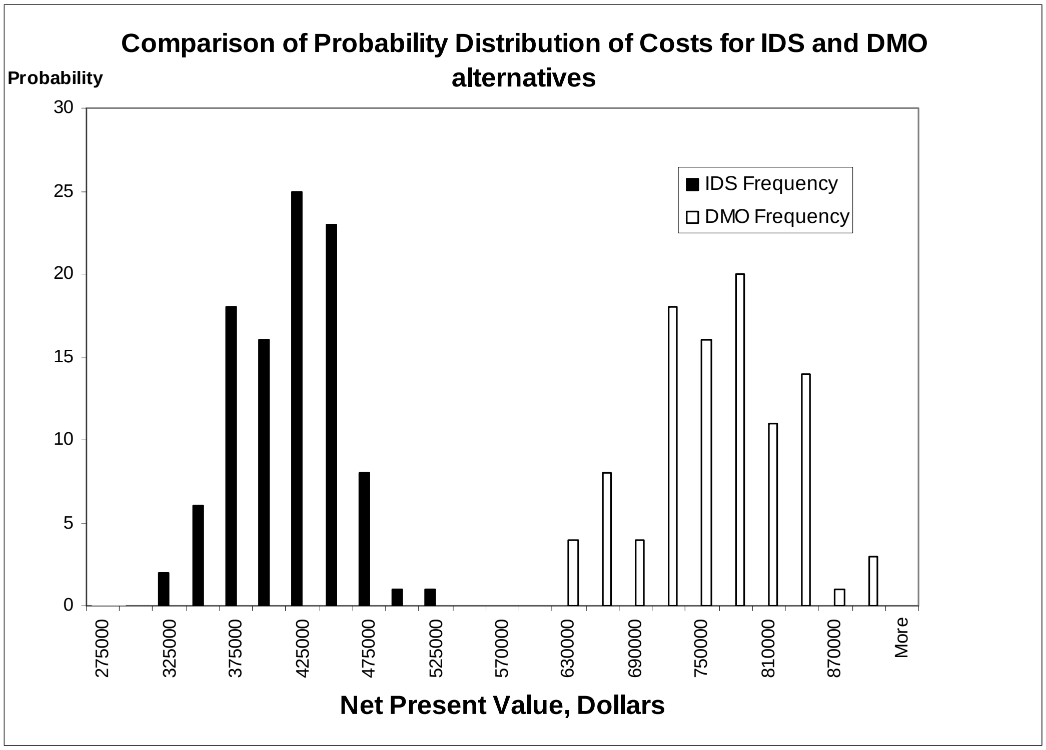

Figure 9.7

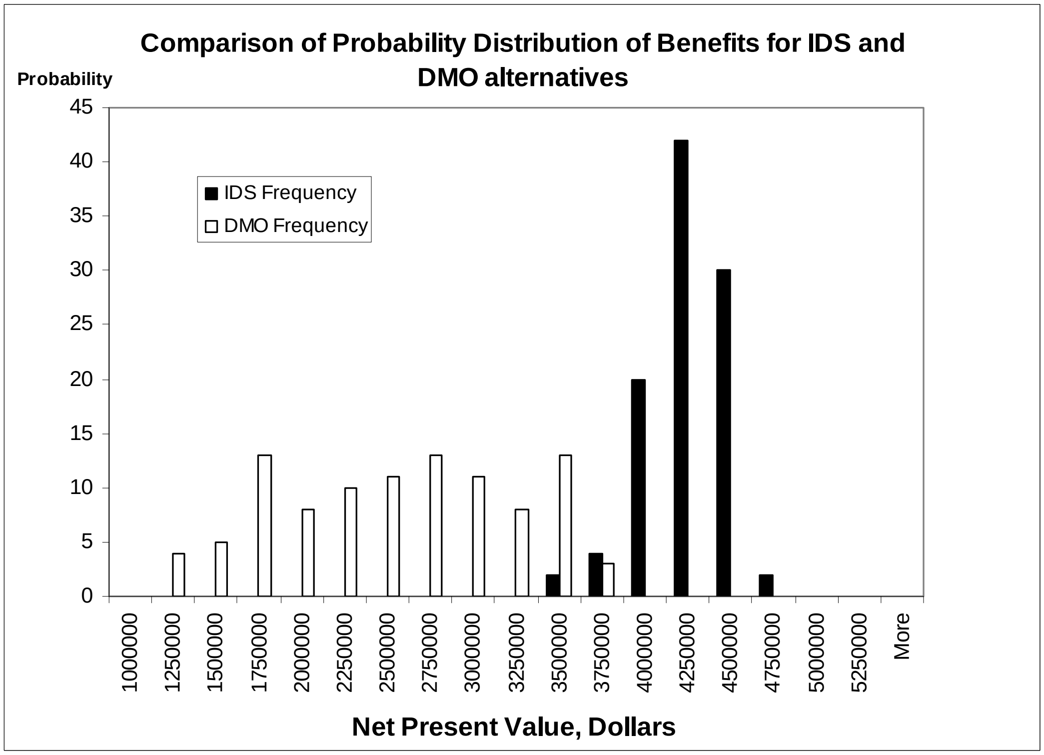

Figure 9.8

Similarly, a comparison of each alternative’s benefit-cost ratios is shown in Figure 9.9. A summary of the benefit-cost ratios is presented in Table 9.1.

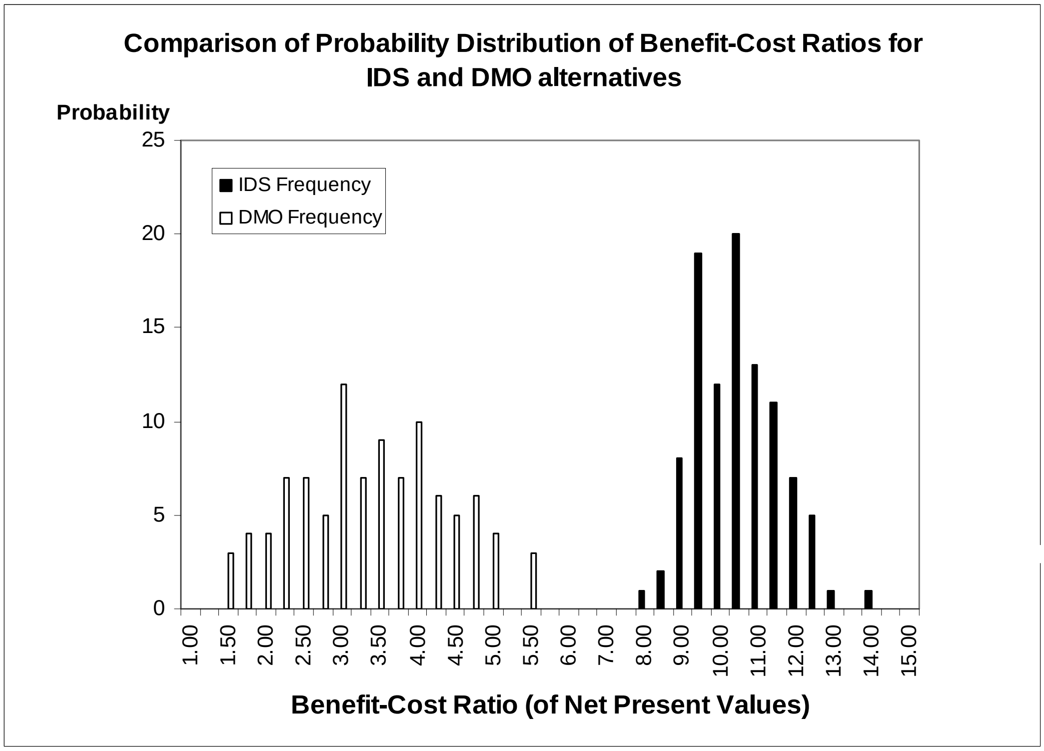

Figure 9.9

Table 9.1: Benefit-Cost Ratios for the IDS and DMO Alternatives

	B/C Ratio	95% Confidence Level	
		(Low)	(High)
IDS System	10.252	8.028	12.477
DMO Alternative	3.275	1.295	5.256

The 95% confidence intervals were determined assuming the 2 standard deviations rule.

The re-grade alternative was estimated to cost $900,000, while producing $936,630 in crash reduction benefits, for a benefit-cost ratio of 1.04.

Failure and Reliability Issues

There are several factors that may have an impact on the benefits and costs of the IDS system that need to be assessed qualitatively. The probability of any of the components failing needs to be determined, as does its effects on the system as a whole. Sensors can fail and the processor could freeze-up or make computational errors. There could also be communication errors between each of the sensors and the processor. The effects of one sensor failing may be different than the effects of a different one failing. System stability and reliability is not known at this point in the analysis. There exists the possibility that the system may not recognize or communicate failures to the processor and/or system monitors. Sensor detection errors are also a strong possibility. There may be gap errors, speed errors, and lane errors.

In addition, there are issues of what the warning system will display to drivers when it is not operational/fails. False positives (displaying a warning when there is no danger) create problems. The conservative nature of the system (designing it for drivers with the slowest reaction time and slowest accelerating vehicles) will cause many drivers to wait longer than necessary. This may lead to some drivers ignoring the sign, and perhaps losing respect for traffic signs in general.

The occurrence of these events may reduce the benefits and/or increase the costs of the IDS system. It is possible that such system failures could result in a negative benefit-cost ratio.

Interpretation Issues

One of the Driver Infrastructure Interfaces used in the IDS system featured a “countdown” display. The countdown here is the time until the next vehicle arrives, which may be misinterpreted since many countdown systems in the U.S. are time until red or “Don’t Walk” appears. While this misinterpretation may be a low frequency event, the consequences could be severe.

Simulation Issues

Much of the data on the crash reduction comes from a driving simulator. In this simulator the baseline crash rate during the nighttime period is unexpectedly high, casting doubt on the reliability of the data and suggesting more research is required before any IDS system is deployed.

Attention Issues

Providing additional signage, especially dynamic signs, may take drivers attention from the road itself, and lead to adverse consequences. There is evidence for this in ITS Institute funded research of Harder and Bloomfield (2003), which noted traffic slowdowns.

10. Recommendations and Conclusions

The results show that the IDS System may be an effective tool to reduce crash rates at various intersections. More research is needed to address reliability and stability issues, and in determining how cost-effective of a solution the IDS System is compared to other “traditional” alternatives.

An analysis of the various safety countermeasures alternatives at US 52 and CSAH 9 in Goodhue County, Minnesota provided insight into the best use of funds for intersection safety improvements. In general, all of the alternatives had benefit-cost ratios greater than 1.0 on average, (meaning it is cost-effective to make the investment).

Examination of Figure 9.7 indicates that the Directional Median Opening Alternative will always cost more than the IDS alternative. Figure 9.8 reveals that the IDS alternative will generally provide greater benefits, however there is an approximately 16 percent chance the DMO alternative will perform as well or better. Figure 9.9 shows that the distribution of benefit-cost ratios for the IDS alternative consists of higher values than the DMO alternative.

It is important to note several issues that may impact the results of the analysis. First, the cost of the directional median opening varies depending on site-specific circumstances, and requires there be existing adequate median space to construct U-turns that allow large vehicles to maneuver (otherwise the mainline lanes may need to be moved at considerable additional costs, and reduction in benefit-cost ratio). Second, it is possible that the crash reduction benefits in the IDS alternative may have been overestimated or underestimated. The crash reduction benefits were determined from driving simulator data, and the model has not been verified. Third, it is also possible these benefits would be reduced (or negative) due to failure and reliability issues mentioned in Chapter 9. It is recommended that additional research be carried out to resolve these issues.

Future research on this subject should employ a probabilistic benefit-cost analysis, as it is able to account for the variability in the potential benefits and costs of an investment. Probabilistic benefit-cost analyses allow for better-informed decision-making in transportation investments, and have the potential to reduce stakeholder risks and cost overruns. In addition, reporting the ranges of potential costs and benefits of transportation investments to the public may increase their confidence in government.

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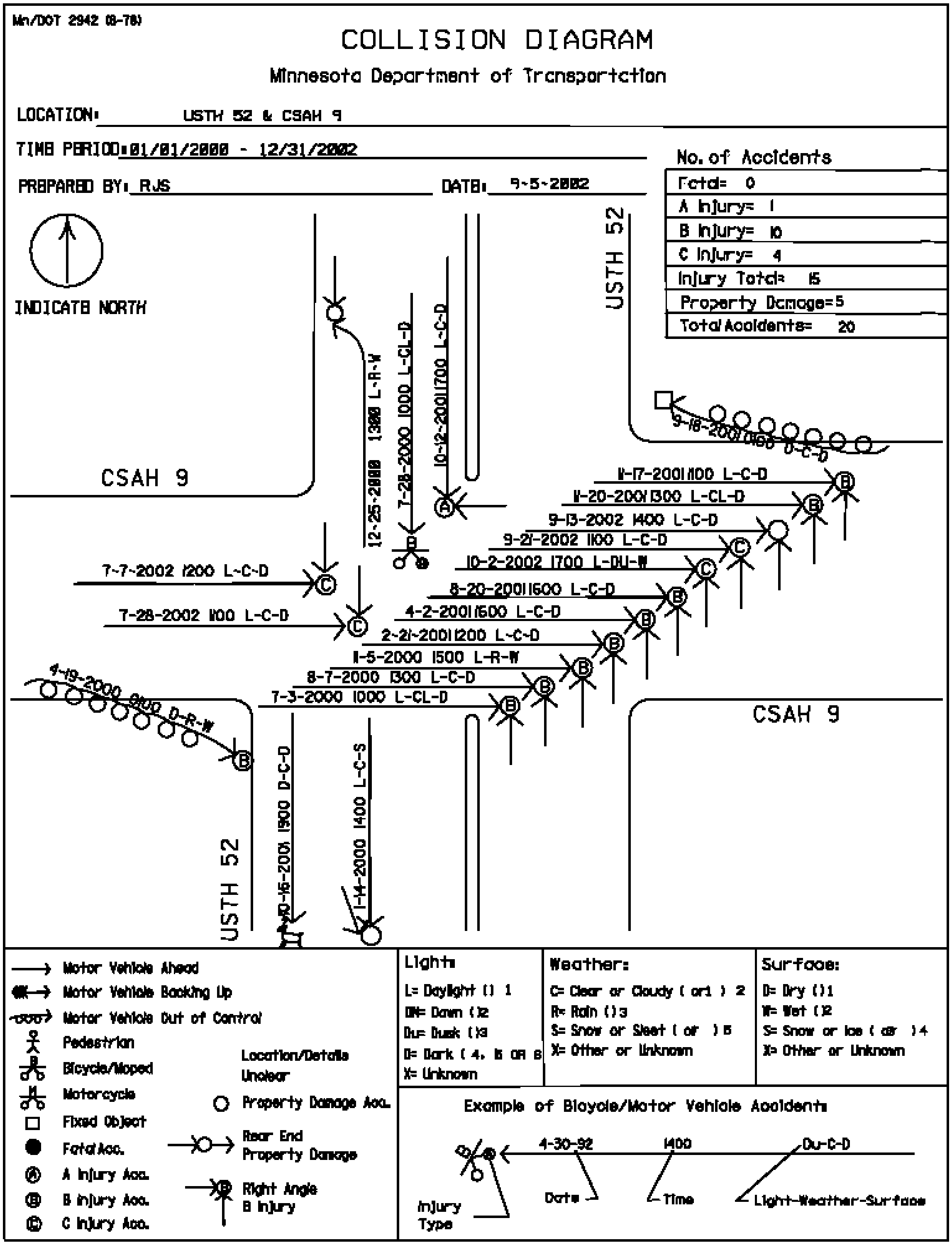
Appendix A

Appendix A: Collision Diagram of US 52 and CSAH 9, 2000 – 2002



Mn/DOT 2942 (8-78)

COLLISION DIAGRAM

Minnesota Department of Transportation

LOCATION: USTH 52 & CSAH 9

TIME PERIOD: 01/01/2000 - 12/31/2002

PREPARED BY: RJS DATE: 9-5-2002

No. of Accidents
Fatal= 0
A Injury= 1
B Injury= 10
C Injury= 4
Injury Total= 15
Property Damage= 5
Total Accidents= 20

Light:	Weather:	Surface:
L= Daylight () 1	C= Clear or Cloudy (or1) 2	D= Dry ()1
DN= Dawn ()2	R= Rain ()3	W= Wet ()2
Du= Dusk ()3	S= Snow or Sleet (or)5	S= Snow or Ice (or)4
D= Dark (4, 5 OR 6	X= Other or Unknown	X= Other or Unknown
X= Unknown		

Source: Preston *et al.* (2004)

Appendix B

Appendix B: Details on Time to Collision Calculations

The probability of a conflict occurring can be determined from the distribution of Time To Contact (TTC). TTC is defined as the actual amount of time between the oncoming vehicle and the participant's vehicle when it first enters the intersection. In the HumanFIRST Driving simulator, all drivers experienced some pre-designed conflicts that have TTCs with bounded values and took some maneuvers to avoid crashes.

The definition of traffic conflict is important in this analysis; however, the problem is that different studies have used different definitions of conflict. For instance, in traffic engineering, there is a Traffic Conflict Technique (TCT), which says: "Traffic conflicts are traffic events involving the interaction of two or more drivers where one or both drivers take evasive action to avoid a collision [Robertson et al. 1994, Parker and Zegeer 1988a,b]".

In TCT, human observers perceive potential collisions and drivers' maneuvers and subjectively determine the severity of conflict. The approach in this study improves on the TCT by using machine observers, e.g. using Time To Collision (TTC) from radar sensors (at the intersection) or computers (in the driving simulator).

However defining conflict is still difficult. The key point in the traditional definition is "take evasive action to avoid a collision". If a driver decelerated their car when approaching the intersection, one cannot be certain that they did it to avoid a collision they perceived. Perhaps they didn't perceive any conflict, or they wanted to make a right turn and thus had to decelerate. It is not possible to know whether the driver really intended to take an evasive action without any objective observation. The traditional definition doesn't deal with this issue but assumes that all drivers who decelerated were to take evasive actions.

In this analysis, it was assumed that all drivers crossing the intersection are involved in conflicts if there is a possible TTC. Thus, a conflict exists even when the TTC is very large and the probability of crash is very small.

Theoretically all major road vehicles have TTCs with minor road vehicles. But if the measured area is limited, some major road vehicles may not encounter any crossing vehicles. Therefore in some cases, there is no TTC but a driver's collision avoidance maneuvers are observed. For instance, a driver may decelerate/brake when they see a vehicle crossing the intersection even if there is no chance of a crash if they keep their current speed. In this case, the driver perceived conflict is not considered a conflict because a TTC cannot be calculated. Thus, not all drivers who undertook braking maneuvers were involved in conflicts. These drivers must be screened out of the analysis.

In the definition used in this study, a conflict is defined as potential crash (no matter how small the possibility is), not how drivers avoid crashes. It was observed that in some cases, drivers did not make any maneuvers in the face of a potential collision. These are still counted as conflicts, which contrast with the traditional TCT definition. This is because 'Do-nothing' is also an option for drivers in conflict, even though from the perspective of observers it is mistaken strategy and unsafe.