Arizona Local Government Safety Project Analysis Model

FINAL REPORT 504

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in cooperation with
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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

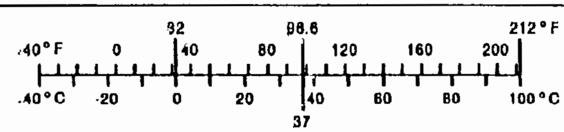
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

Due to the time and expense required for the preliminary data collection and site assessment, some local governments lack the resources for an in-depth analysis of highway safety needs in their jurisdiction. This is significant because these jurisdictions may not determine candidate projects for safety program funding, and high-incident locations statewide may go without remedy despite the availability of federal aid for local safety improvements.

The focus of this research has been primarily on development of site identification and implementation strategies for local safety projects. This research is intended to provide local governments with an efficient and justifiable means of assigning priority to potential projects in a local safety program. While some analysis has been devoted to the multiple variables that affect the outcome of a safety measure, the primary aim of that analysis was the synthesis of data such as traffic volumes, average speed, type and design of roadway, and special circumstances, in order to develop appropriate parameters for implementation strategies. This process was automated through the development of a database model intended to facilitate site identification and safety project selection by local jurisdictions and planning organizations.

By providing an automated method for identifying local safety hazards, prioritizing these locations, and evaluating the potential benefits of treatments designed to remedy these locations, the Arizona LGSP affords local jurisdictions more time for in-depth research of specific sites and a rationale for decision-making that is impartial and justifiable. It is expected that the Arizona LGSP model will help local governments address their highway safety needs on a more timely basis, and ensure that more attention is directed at the most hazardous locations, thereby improving the overall safety of the roadway system in Arizona.

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Summary of Key Findings

Due to the time and expense required for the preliminary data collection and site assessment, some local governments lack the resources for an in-depth analysis of highway safety needs in their jurisdiction. This is significant because these jurisdictions may not determine candidate projects for safety program funding, and high-incident locations statewide may go without remedy despite the availability of federal aid for local safety improvements.

The focus of this research has been primarily on development of site identification and implementation strategies for local safety projects. This research is intended to provide local governments with an efficient and justifiable means of assigning priority to potential projects in a local safety program. While some analysis has been devoted to the multiple variables that affect the outcome of a safety measure, the primary aim of that analysis was the synthesis of data such as traffic volumes, average speed, type and design of roadway, and special circumstances, in order to develop appropriate parameters for implementation strategies. This process was automated through the development of a database model intended to facilitate site identification and safety project selection by local jurisdictions and planning organizations.

Included in the results of this research are a survey of methods and theoretical issues in safety project site selection and evaluation; the application of these data to the development of a safety project implementation tool – the Arizona Local Government Safety Project Implementation Model; and the identification of parameters useful for the safety programming process. These results are divided into the following sections of the report:

- <u>Safety Project Evaluation</u>: provides background information on the evaluation of potential safety improvements, including a discussion of the multiple steps in the project selection and implementation process, and a review of existing literature related to the procedures involved
- <u>Arizona Local Government Safety Project (LGSP) Implementation Model</u>: contains a discussion of the database model developed to aid local governments in the highway safety programming process. Included in this section are a discussion of the structure and components of the model, rationale for design decisions and parameters for data collection and sorting, Arizona-specific estimators built into the model, and a summary of the model's capabilities and limitations (i.e. what can and can not be achieved)
- <u>Central Arizona Association of Governments (CAAG) Sample Study</u>: case study includes background highway safety information on CAAG region jurisdictions, the results of a preliminary site identification process using the Arizona LGSP model, the parameters used to identify these sites, and a sample project assessment obtained with the LGSP model for a hypothetical safety improvement

The appendices to this report provide supplementary data that should prove useful for evaluation of traffic safety treatments by local governments. Appendices A and B provide instructions for using the Arizona LGSP Model. Appendix C is a detailed glossary of safety-related terminology. Appendix D replicates Arizona-specific estimates of effectiveness for a variety of safety treatments, and Appendix E includes effectiveness estimates for a greater variety of projects assembled from previous research.

The LGSP Model is available for use by local jurisdictions in Arizona, and may be obtained from the Arizona Department of Transportation. Data files included with the preliminary version are the following:

- **AzLGSP.mde**: the database model, Microsoft Access 97 format
- **CRASHDATA-TEMP.mdb**: an automated template for converting Arizona crash records into the format used by the Arizona LGSP model
- **CRASHDATA95-99.mdb**: Arizona crash file database for calendar 1995 to 1999
- **CRASHDATA96-00.mdb:** Arizona crash file database for calendar 1996 to 2000 (partial-year data)

Documentation and user instructions for the AzLGSP and CRASHDATA templates are contained in this report.

By providing an automated method for identifying local safety hazards, prioritizing these locations, and evaluating the potential benefits of treatments designed to remedy these locations, the Arizona LGSP affords local jurisdictions more time for in-depth research of specific sites and a rationale for decision-making that is impartial and justifiable. It is expected that the Arizona LGSP model will help local governments address their highway safety needs on a more timely basis, and ensure that more attention is directed at the most hazardous locations, thereby improving the overall safety of the roadway system in Arizona.

I. Introduction

A significant number of local governments in Arizona do not determine candidate projects for safety program funding on and off the federal aid system. Due to the time and expense required for the preliminary data collection and site assessment, some local governments lack the resources for an in-depth analysis of highway safety needs in their jurisdiction. This is particularly significant because high-incident locations statewide may go without mitigation or correction despite the availability of federal aid for these projects.

The FHWA Surface Transportation Program provides a 10 percent set-aside for highway safety improvements, the majority of which (85.9 percent in fiscal 1999) are designated for hazard elimination. Of this amount, the Arizona Department of Transportation currently sets aside up to 25 percent of all safety category funds for "first-come, first-served" local government safety projects. Recipient jurisdictions are allocated 94.3 percent of project costs in HES funds, with a 5.7 percent match required of locally sponsored projects. In fiscal 1999, nearly $2.4 million was available for local government safety projects (Henry, 2000).[1]

The FHWA requires a detailed analysis to assess and determine the most critical candidate safety projects on the public road network. This assessment is made, in part, by using traffic accident records collected by the Traffic Records Department of the Arizona Department of Transportation, with supplementary information provided by local governments. Guidelines for the assessment require using data collected for a period of at least 3 years, with a 5-year time frame recommended. A benefit-to-cost ratio (BCR) of at least 1.0 is required to establish project eligibility.

This research is intended to provide local governments with an efficient and justifiable means of assigning priority to projects for a local safety program. Safety projects can be part of an existing program or recommendations based on identification of high-incidence locations. The method used to rank projects will entail a benefit/cost analysis of each safety project, subject to user-defined expectations of project effectiveness, as well as limitations on expected outcome based on the results of previous studies.

The study of highway safety data has been characterized in terms of two categories. The first, *analysis*, refers to the use of data to address problems and questions from the standpoint of evaluation and research and development. In contrast, *implementation* is concerned with the use of data to develop warrant criteria and to select projects based on these criteria (Mak, *et al.*, 1988). The focus of this research has been primarily on development of implementation strategies for local safety projects. While some analysis has been devoted to the multiple variables that affect the outcome of a safety measure, the primary aim of that analysis was the synthesis of data such as traffic volumes, average

[1] Note that federal funding is limited to a maximum of $350,000 for each project.

speed, type and design of roadway, and special circumstances, in order to develop appropriate parameters for implementation strategies.

It should be noted that few analyses or implementation strategies can be completed solely through the use of automation or centralized research. Identification and mitigation of safety hazards in local jurisdictions is subject to the unique characteristics of each local area and each particular countermeasure program, and there is no one who can understand and interpret the results of local-level analyses better than the individuals who are working in the local area on a daily basis (Brown, 1997). This research provides a tool for simplifying the process, but the key responsibility for translating this information into appropriate countermeasures rests with local officials and traffic engineers.

This report is divided into three primary sections. The first, Safety Project Evaluation, provides background information on the safety project evaluation process. This includes discussion of the multiple steps in the project selection and implementation process, and a review of existing literature related to the variables involved. These steps include the identification of hazardous locations for which mitigation is warranted, the conversion of crash[2] data to corresponding economic costs, the selection of specific project alternatives from a variety of treatments, and the estimation of net benefits associated with project implementation. When applicable, data have been adjusted to reflect local conditions.

The second section, contains a discussion of the Arizona Local Government Safety Project Model developed to facilitate site identification and safety project selection by local jurisdictions and planning organizations. Included in this section are a discussion of the structure and components of the model, rationale for design decisions and parameters for data collection and sorting, Arizona-specific estimators built into the model, and a summary of the model's capabilities and limitations (i.e. what can and can not be achieved). This section does not contain specific instructions for the end user. A brief instruction manual and update procedures are included in Appendix A of this report.

A sample study for the Central Arizona Association of Governments (CAAG) is provided in the third section of the report. The CAAG case study includes background information on the numerous jurisdictions in the CAAG region, historical summaries of motor vehicle travel and crash data, as well as hazardous sites for several jurisdictions identified with the Arizona Local Government Safety Project Model. The parameters used to identify these sites, as well as sample project assessments and expected benefits are also included.

The various appendices to this report provide supplementary data that should prove useful for evaluation of traffic safety treatments by users of the Arizona LGSP Model and non-users alike. As stated above, Appendices A and B provide instructions for using the Arizona LGSP Model. Appendix C is a detailed glossary of safety-related terminology, including roadway, safety, construction and economic terms. Appendix D replicates Arizona-specific estimates of effectiveness for a variety of safety treatments, and

[2] Various studies use the terms "crash" and "accident" to refer to the same event. This report uses the term "crash" in most cases, but both terms are considered interchangeable for the scope of this analysis.

Appendix E includes effectiveness estimates for a greater variety of projects assembled from previous research.

II. Safety Project Evaluation

A number of variables and related analyses are generally involved in the selection and evaluation of traffic safety measures. These include the selection of one or more sites requiring mediation, a related analysis of crash severity and other details for each site chosen, the selection of safety treatment alternatives to mitigate future crashes, cost/benefit analyses of safety projects under review, and post-treatment evaluation(s) of project effectiveness. The determination of candidate sites and safety treatments is normally a dynamic process, wherein sites or treatments warranted in early stages of analysis may be modified or replaced with alternatives in later stages. Often the process is governed by specific rules or guidelines that an organization may have for assigning relative value to sites and treatments.

This section will examine the above steps in greater detail. Where applicable, summaries of previous research and theoretical problems have been included. A description of the procedures applicable to selection of local government safety projects in Arizona is included in each section.

Identification of High-Risk / High-Incidence Locations

One of the primary applications of accident analysis is the identification of problem (e.g. hazardous, unsafe, abnormal) locations. A common practice in many jurisdictions is the identification and attempted improvement of high-risk crash sites. This is often done in two steps; the first of which is a review of the crash history for all sites, and the second examines a subset identified as dangerous in order to develop potential countermeasures. A multiple-step selection method is generally used because of the great amount of data that must be reviewed, making an evaluation of projects for all crash locations impractical (Hauer, *et al.*, 1984).

Table 1: Survey of Selection Methods for Hazardous Locations

Selection Method	Selection Criteria
Crash frequency	Crash counts at location
Crash rate	Crash counts ÷ traffic measurement[1.] at location
Frequency rate	Combination of frequency and rate
Rate quality control	Crash rate tested for statistical significance
Crash severity	Severe crashes and/or cost estimates at location
Hazard inventory	Site features with high potential[2.] of crash frequency or severity
Crash subset	Statistically high incidence of particular subcategory[3.] of crashes

Source: Zegeer, 1982

Notes: (1) Traffic measurement count such as average daily traffic (ADT) or vehicle miles of travel (VMT). (2) Site characteristics with high potential include poor sight distance, fixed roadside objects, improper superelevation, narrow bridges, inadequate guardrails, etc. (3) For example, method might focus on sites with abnormally high incidence of left-turn or run-off-road crashes.

Commonly used identification methods are the frequency, accident rate, frequency rate, rate quality control, and accident severity methods, described in Table 1. In addition to identifying and reviewing locations that have high accident experience (i.e. high accident numbers, rates and/or severity), it is important to identify and correct locations with a high accident potential. Hauer and Persaud (1984) characterize the selection of hazardous sites as a "sieve," in which the truly deviant (i.e. hazardous) locations are identified and normal sites are allowed to pass through."

A high-crash or hazardous location is usually defined as a location that experiences abnormal frequencies, rates or severity of accidents. However, such high crash experience may not necessarily mean that the location is truly hazardous (Zegeer, 1982). Depending on the unit of measurement, high crash experience may be caused by any of the following variables, unrelated to the hazard of the site:

- Random occurrence: simple year-to-year variation at a site
- High traffic volume: often leads to high crash frequency measures, but may not have high rate and/or severity
- Low traffic volume: can cause relatively high crash rate (crashes per VMT) at a site with infrequent traffic
- Specific crash circumstances independent of location: can influence severity (e.g. seat belts not used, age of occupants, etc.)

A hazardous location is one that presents a risk to the driver in terms of high probability of accident occurrence or high accident severity. This risk may not be reflected in past accident records. Locations may have a high potential for crashes and yet lack a history of abnormal crash experience. For example, sites with rigid fixed objects near the roadway have a potential for severe run-off-road crashes. A hazardous roadway features inventory can provide information on these potential accident problems. Many other factors can be influential in the comparison of potential risks at various crash sites. For example, a study of urban arterials in Phoenix, AZ and Omaha, NE (Bonneson, *et al.*, 1997) found that, in addition to average daily traffic demand, such variables as driveway density, land use patterns and unsignalized public street approach density were significantly correlated with accident frequency.[3]

Few analyses advocate the sole use of crash frequency as an indicator of hazard. This is due to the fact that traffic volumes will usually play a direct role in the incidence of crashes. A variety of statistical techniques have been developed for more advanced analysis of potential hazard at crash sites (Hauer, 1980; Hauer, *et al.*, 1984; Higle, *et al.*, 1988; Zegeer *et al.*, 1988). However, it is recognized that jurisdictions will vary in the amount of time and resources available for crash location analysis. Some analysts use

[3] Bonneson et al found that a positive, statistically significant relationship could be observed between driveway density, approach volume and crash frequency. Crashes were also observed to be more frequent in predominantly business- or office-use areas, and less frequent in residential and industrial areas.

crash frequency as a preliminary filter, from which additional refinements may then be made (e.g. frequency – rate methods).[4] In situations for which the use of a frequency measure is necessitated by external constraints, consideration should be paid to the crash details (e.g. types of crashes observed, roadside features, harmful events, etc.) for each location, which may at least help identify the measures most likely to be effective for that situation (Turner, *et al.*, 1988). The utility of crash details is directly related to available data collected from the crash site.

Data Collection

The criteria for selecting a method or methods to identify problem locations include the types of data available and the level of sophistication desired (Zegeer, 1982). The collection of crash data is a time-consuming and expensive endeavor that often necessitates making a trade-off between the level of detail desired and the amount of time and effort required to capture that level of detail (Turner, *et al.*, 1994). Differences in available resources (both labor and capital) among jurisdictions, thresholds for crash reporting, and the prioritization of competing interests (e.g. police coverage of multiple calls) will have an impact on the quality and quantity of crash data collected.

Crash data may be collected by a variety of agencies in a jurisdiction. In order to use data from multiple agencies and/or jurisdictions for establishing policy or the warrant of safety improvements, it is important that uniform standards exist. Such standards would include reporting thresholds, crash report content, and the definitions of data elements (Zegeer, *et al.*, 1998). If reporting thresholds are inconsistent, or the quality of reporting varies with the severity of the crash, data collected may not serve as a representative sample of the entire crash population. Although there is an incentive to raise reporting thresholds and/or minimize data elements collected in order to reduce the administrative costs associated with crashes, such practices will also have the effect of reducing the reliability and scope of crash data from which safety inferences may be made. A study of reporting thresholds in multiple states by Zegeer *et al.* (1998) found that use of a tow-away reporting threshold would eliminate nearly half of the available crash data (48.3 percent), while an injury-only reporting threshold would only capture 33.7 percent of data currently collected.

Perhaps the most important criterion for site identification is the location reference methodology used by the jurisdiction(s). A location reference system is defined as "the procedures that relate all locations to each other and includes techniques for storing, maintaining and retrieving location information." Highway location reference method is defined as "a way to identify a specific location with respect to a known point." Three elements common to all location reference methods are identified as (1) identification of a known point, (2) a measurement from the known point, and (3) a direction of measurement (Zegeer, 1982). Arizona uses sign-oriented location reference methods,

[4] Note that such a technique does not eliminate bias in the sample of crash sites, as the subset will still be limited to high-frequency locations without regard for severity, traffic volume or statistical validity. For further discussion of this difficulty, see "Problems of Measurement in Prioritizing Locations."

with the known reference point usually identified by milepost (state highways) or cross street (local roads).

The selection of an appropriate segment length or area of measurement is another important factor in accurate identification of crash locations. Crash location errors of 50 to 200 feet make a difference, especially when the relationship of the crash to the surroundings may be changed dramatically by a small change in distance. For instance, when a pedestrian is struck by a vehicle, it is relevant whether a crash occurred in a crosswalk, near a crosswalk, or out of sight of a crosswalk (Miller, 1997).

The distinction between "spot" and "section" improvements is dependent upon the segment length. Spot (or point) treatments generally refer to improvements on segments shorter than 0.3 mile. Zegeer (1982) recommends that spots should have consistent characteristics (e.g. geometrics, volume and class of highway) and be no smaller than the minimum unit of measurement for reporting crash locations. Spot lengths should also be chosen with regard for the degree of error expected in crash location reporting, with longer lengths or radii chosen when reporting accuracy is low. This will allow a greater number of relevant crashes to be included at a particular site.

Problems of Measurement in Prioritizing Locations

A great deal of research has been conducted to assess the most effective means of choosing and prioritizing spot locations for traffic safety programs. Hauer (*et al.*, 1988) defines the safety of a given highway location as the number of crashes expected to occur at that site per unit of time. A distinction is made between expected crashes (the long-term average under unchanging conditions) and crashes actually occurring at a particular location. Because all crashes are not reported, Hauer stresses that a functional relationship between reported crashes and highway safety should not be made without an estimate of the proportion of crashes that are reported (Hauer, *et al.*, 1988).

Various studies have concluded that unreported crashes make up a sizable portion of the motor vehicle crash population (Blincoe *et al.*, 1992; USDOT, 1994). Generally, crashes of low severity are reported less often than more severe crashes. Research has also indicated that reporting varies by legal thresholds and regional propensity (Hauer, *et al.*, 1988; Persaud, 1988). Estimates of reporting for fatal crashes tend to exhibit the least variance, with virtually all incidents reported. In contrast, reporting estimates for property-damage crashes (i.e. no injuries) vary considerably, from 62 percent to 46 percent depending on the research method and time period measured (USDOT, 1994; Hauer, *et al.*, 1988; Smith, 1966; Greenblatt, *et al.*, 1981).

The count of reported accidents does not reflect the number of accidents expected to occur at a location unless the probability of a crash being reported is also considered (Hauer, *et al.*, 1988). By nature, unreported crashes are difficult to measure and are not generally available for any specific jurisdiction. However, the US Department of

Transportation has published national estimates of unreported crashes as shown in Table 2.

Table 2: Estimated Underreporting of Crashes

Crash Severity[1.]	**Unreported**
Property damage only	48.0%
Minor injury	23.7%
Moderate injury	16.5%
Serious injury	6.8%
Severe injury	0.7%
Critical injury	0.0%
Fatality	0.0%

Source: Office of Regulatory Analysis, Plans and Policy, 1994

Notes: 1. Crash severity conforms to the Abbreviated Injury Scale discussed in "Severity Measures and Crash Cost Conversion."

Despite the established occurrence of underreporting of crashes, most jurisdictions permit site improvements to be warranted on the basis of crash history (Persaud, 1988). The problem of identifying hazardous sites on the basis of historical data (i.e. identification of a site as hazardous if its recent crash history exceeds some specified level) is that, because of random variation inherent in accident phenomena, historical crash data do not always reflect long-term site characteristics accurately (Higle, *et al.*, 1988).

Considerable attention has been paid to errors in statistical inference resulting from regression-to-the-mean sampling bias. "Regression to the mean" refers to a phenomenon in which the average measure of a variable for any particular sample of observances will, over time, tend to reflect the average of that variable for the entire population. Thus, untreated locations for which a high crash rate was observed over a given period would, on average, record *fewer* crashes in the following period, regardless of whether safety improvements were implemented. The opposite would be expected of low-incidence locations. Although commonly dismissed as having minimal impact on site selection and project effectiveness (see below), regression-to-the-mean has been shown to be both statistically significant and of considerable magnitude in year-over-year comparisons (Persaud, *et al.*, 1984; Hauer, 1980).

Regression to the mean deals with ensuring that all sites are included in the site selection process, not just sites with high crash frequencies or severity. Traditional analyses have tended to focus on sites with disproportionately high crash frequencies or severity, and have thus relied on biased samples for the estimation of crash incidence and project effectiveness. This bias may be avoided by comparing sites according to similar characteristics, regardless of relative magnitude of crashes observed (Turner, *et al.*, 1994). Sample selection criteria for comparison sites are particularly important, as research has shown that regression to the mean differs among sites of different traffic volumes, with low-volume sites tending to regress more than high-volume sites (Morris, op. cit. in

Higle, *et al.*, 1988). Alternatively, statistical methods have been developed to refine the "sieve" for hazardous site selection (Hauer, 1980; Hauer, *et al.*, 1984; Hauer, 1996).

Severity Measures and Crash Cost Conversion

The severity of a motor vehicle crash is an important element in the selection of crash mitigation strategies. The term severity refers to the injuries sustained by all affected persons in a crash. Crash data are usually aggregated by the most severe injury sustained by any person in a crash. In a general sense, the more severe the crashes observed in a specific location, the greater the priority assigned to that location. This observation does not preclude the selection of sites for safety improvement projects based on incidence (i.e. frequency of all crashes), but rather provides a means of prioritizing locations with otherwise similar characteristics. However, the importance of crash severity measurements must be examined with regard to the significant potential for error inherent in these measures.

A number of potential problems arise in attempts to measure crash severity: the potential for bias or subjectivity in classifying an injury at the scene, multiple means of classification, and statistical aberration. The first problem refers to the on-scene recording of data, almost always performed by responding police officers (Brown, 1997). Although it is often assumed that responding officers will be able to correctly classify an injury based on on-scene observation, such procedures are necessarily subjective to some extent. For example, the ability of a police officer to correctly identify internal injuries is curtailed by the lack of x-ray and other laboratory devices, which creates potential for under-reporting of severity. Similarly, superficial surface wounds may bleed profusely, leading to an incorrect injury classification of greater severity than warranted.

The second problem is one of multiple methods or standards for reporting the same data. Two indices have been developed to measure the severity of injuries sustained in motor vehicle crashes. The Abbreviated Injury Scale (AIS), developed by the American Association of Automotive Medicine, subdivides crash severity into property damage, fatalities, and five classes of injury (USDOT, 1994). These subclasses of injury are defined as follows:

AIS 1 Minor injury
AIS 2 Moderate injury
AIS 3 Serious injury
AIS 4 Severe injury
AIS 5 Critical injury

Because injured persons frequently sustain more than one injury, crash victims are classified according to the highest (most severe) injury sustained. This classification is known as the maximum injury severity (MAIS). The US Department of Transportation uses the MAIS designation to estimate the economic cost of injuries sustained in motor vehicle crashes (USDOT, 1994).

Most states categorize injuries by a method adopted by the American National Standards Institute (ANSI). This method is commonly referred to as “KABCO.” Under this system, injuries are generally classified as follows:

K	Killed (fatality)
A	Incapacitating injury
B	Non-incapacitating injury
C	Possible injury
0	No injury
U	Unknown if injured
ISU	Injured but severity unknown

The KABCO method of classification has the advantage of simplifying data collected at the scene of the crash. While the gradations of injury in the Abbreviated Injury Scale are not fully replicated by the KABCO method, the relatively straightforward nature of the KABCO classifications creates less of an administrative problem. For example, as previously discussed, the recording of severity measures at the scene of a crash is subject to some degree of subjective interpretation. Difficulties also arise in applying category definitions at a single point in time, as a severely injured person may later die (Turner, *et al.*, 1994). However, the distinction between an “incapacitating” injury and a “non-incapacitating” injury (KABCO) is subject to somewhat less interpretive variation than the distinction between a “severe” injury (MAIS 4) and a “serious” injury (MAIS 3). This does not imply that the KABCO severity index is a superior measure of crash severity, but rather that the decision by most jurisdictions to use the KABCO index is largely a function of simplicity.

In order to assess crash and safety performance data from multiple jurisdictions, it is necessary to have a means of comparing crashes classified according to different severity indices. Previous research using the National Accident Sampling System on crashes occurring between 1982 and 1986 has provided a means of translating MAIS crash severity designators to KABCO classifications (USDOT, 1994). Due to statistical variation in crash data, and to the specificity of the MAIS severity measures, a particular KABCO measure will be distributed across several MAIS classes. These distributions are shown in Table 3 for non-alcohol related crashes.

Table 3: Proportional Distribution of Injuries by Classification Method

Severity (MAIS)	Severity (KABCO)						
	K	A	B	C	0	U	ISU
Fatal	0.9604	0.0054	0.0003	0.0001	--	--	0.0038
5	--	0.0175	0.0007	0.0002	--	0.0005	0.0013
4	0.0022	0.0289	0.0027	0.0006	0.0000	0.0002	0.0171
3	0.0014	0.1662	0.0301	0.0151	0.0003	0.0078	0.0433
2	0.0068	0.2777	0.1248	0.0676	0.0021	0.0162	0.1565
1	0.0165	0.4892	0.7921	0.7172	0.0742	0.1599	0.7031
PDO	0.0128	0.0151	0.0494	0.1992	0.9234	0.8155	0.0749
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Source: MAIS vs. KABCO Translator, 1982-1986 NASS, from *Estimating Crash Costs in State or Local Jurisdictions*, NHTSA, USDOT, 1994)

A third problem that arises in the estimation of crash severity is statistical aberration. As in the case of statistical variation in incidence for a given location, so too might a few years exhibit crashes of greater or lesser severity than is ordinarily the case. The occurrence of abnormal severity in a given year does not pose a serious problem if a large amount of data are collected, as the influence of statistical outliers will tend to be mitigated by a greater number of measurements. However, when such data are used to prioritize potential safety treatment sites from a limited sample of local crashes, the influence of one or more outliers could lead to a sub-optimal allocation of resources. Given the potential variance in crash severity classification discussed above, the problem of statistical aberration could be the result of normal distributive properties or an artificial variance caused by a “moving target” in the interpretation of severity.

In addition, the tendency to group crashes according to the most severe injury sustained does not necessarily reflect the average magnitude of injuries attributed to that crash. As a hypothetical example, assume a three-vehicle crash in which one adult not wearing a restraint was severely injured but five adults wearing restraints sustained only minor injuries. Although the most frequently occurring injuries were minor, the crash would be assigned a MAIS or KABCO classification based on the single most severe observation. Just as random variation may influence short-term historical trends in frequency and severity, so may the aggregation of crash records by severity assign unwarranted importance to random fluctuations in severity.

Finally, all data sets are subject to errors in transcription and coding. This is particularly the case in databases such as that used by the Arizona Department of Transportation, in which injury severity is recorded twice; once for each affected person and again for the aggregate measure of severity for the crash. During the course of this research, several apparent errors were discovered in the Arizona crash records, with details for crashes indicating injuries of minimal severity (non-incapacitating) while the aggregated record indicated a fatal crash. Such disparities, while not common, can cause significant errors in estimates of severity and associated crash costs at a given location, which in turn may influence the (mis)direction of scarce resources to that site.

Estimating the Cost of Crashes

A substantial body of research has been devoted to the estimation of monetary costs associated with traffic crashes. In order to perform an economic analysis of crash incidence and the associated benefits of various mitigation treatments, it is necessary to estimate the financial impact of crashes of varying magnitude. However, efforts to assign costs to crashes have historically been subject to considerable differences of opinion (Turner, *et al.*, 1994). Several methods exist for estimating the economic costs associated with motor vehicle crashes. Various organizations have adopted different methods for estimating costs, and have conducted analyses using different cost values.

Both direct and indirect costs are typically included in estimating costs of motor vehicle crashes. Direct costs include all immediate losses to the parties involved in the crash, such as damage to personal property, ambulance and medical expenses, value of work time lost, and legal fees or obligations. Some definitions also include the loss of future earnings due to severe injury or fatality in the direct cost estimate (Turner, *et al.*, 1994). Direct costs are calculated through exhaustive documentation of costs associated with each component; such as the collection of crash-related hospital records.

Indirect costs are generally considered to be those incurred due to, but not immediately during, the crash incident. These "external" costs may include the social loss of production and consumption by the injured person, losses to the family or community of the injured person, and the costs of crash investigation and insurance administration (Turner, *et al.*, 1994). Inclusion of indirect variables has been the focus of debate, with several methods estimating these costs according to different assumptions. In addition, some studies (see below) include provisions for "intangible" costs related to lost quality of life resulting from pain and suffering. These costs, too, have been the subject of debate.

The cost of a fatality has been an issue of particular importance in assessing the differences between procedures for estimating crash costs. The National Safety Council (NSC) used a methodology prior to 1994 in which the cost of a fatality to others was incorporated , but the value of the person's life to himself or herself was not (Turner, *et al.*, 1994). The National Highway Traffic Safety Administration (NHTSA) used a different method, in which consumption was not subtracted from estimates of future production for persons killed in a crash. In recent years, both agencies have acknowledged the value of an alternate method, the willingness-to-pay approach (Turner, *et al.*, 1994; Blincoe, 1996).

The *human capital* method of estimating crash costs focuses on productivity losses. Human capital cost encompasses direct and indirect costs to individuals and to society as a whole from decreases in the general health status of those injured in motor vehicle crashes (Blincoe, 1996). This method is based on relative productivity measures such as wages, and therefore places lower value on children and the elderly, values injured women less than men, and excludes estimates of pain, suffering and lost quality of life (Miller *et al.*, 1998). Despite these shortcomings, the human capital method is often used in studies because of the difficulty of assigning values to qualitative variables such as pain and suffering.

The *willingness-to-pay* (WTP) method uses a market approach to estimate the cost of injury. This method attempts to estimate the amount a motorist would be willing to pay to avoid the injury. Not surprisingly, the WTP method generates the highest estimates of crash costs. Miller *et al.* (1998) found that willingness to pay values tend to be more than twice as high as human capital estimates. However, the value that an individual places upon his or her life is the impetus for decision making, and is thus the most rational for evaluating courses of action. The US Department of Transportation has adopted this approach for benefit-cost analyses of crash mitigation strategies (Turner, *et al.*, 1994), but many jurisdictions continue to use alternate economic measures.

The following categories are typically included in estimates of the human capital cost of crashes (Blincoe, 1996):

- Medical Costs: The cost of all medical treatment associated with motor vehicle injuries other than that given during ambulance transport. Includes emergency room and inpatient costs, follow-up visits, physical therapy, rehabilitation, prescriptions, prosthetic devices, and home modifications.
- Emergency Services: The cost of ambulance or helicopter EMS transport and care, as well as police and fire department response costs.
- Vocational Rehabilitation: The cost of job or career retraining needed due to disability caused by motor vehicle injuries.
- Market Productivity: The present discounted value of lost wages and fringe benefits over the remaining life span of the victims.
- Household Productivity: The present value of lost productive household activity, valued at the market price to hire someone else to accomplish these tasks.
- Insurance Administration: The administrative costs associated with processing insurance claims resulting from motor vehicle accidents.
- Workplace Cost: The cost of workplace disruption due to the loss or absence of an employee. Includes the cost of retraining new employees, overtime needed to accomplish work of injured employee, and administrative costs of processing personal changes.
- Legal/Court Costs: The legal fees and court costs associated with civil litigation resulting from traffic crashes.
- Premature Funeral Cost: The present discounted value of paying for a funeral in the present instead of at the end of the victim's normal expected life span.

- Travel Delay: The value of travel time delay for persons who are not involved in traffic crashes, but who are delayed in traffic congestion caused by these crashes.
- Property Damage: The value of vehicles, cargo, and roadways damaged in traffic crashes.

Estimates using the willingness-to-pay method also include the cost of lost "quality of life" in estimating crash costs. Quality of life costs assign a quantitative measure to the pain and suffering experienced by the injured and their families; for fatalities, these costs amount to the willingness-to-pay estimate for avoidance; for nonfatal injuries, estimates are based on "quality-adjusted life years lost. Willingness to pay estimates often rely on such data as wages for risky occupations and purchases of products for improvements in safety to assign values to these "intangible" categories. Miller *et al.* (1998) note that lost productivity should be excluded from these costs to avoid double-counting. A comparison of the human capital and WTP approaches to estimating the cost of injuries is shown in Table 4.

Table 4: MAIS Injury Cost Estimates by Method, 1994

Severity	Estimated Cost per Injury, 1994	
	Human Capital[1.]	Willingness to Pay[2.]
MAIS 1	$ 7,243	$ 10,840
MAIS 2	$ 34,723	$ 133,700
MAIS 3	$ 103,985	$ 472,290
MAIS 4	$ 230,042	$ 1,193,860
MAIS 5	$ 705,754	$ 2,509,310
Fatal	$ 831,919	$ 2,854,500

Source: Blincoe, 1996.

Notes: (1) Includes economic costs of crashes with no provision for "intangibles" such as lost quality of life. (2) Includes all expenses in item 1, plus valuation of intangible costs.

Revisions to crash cost categories are typically made according to annual inflationary changes in the Consumer Price Index (CPI) and wage or earnings indices such as the Employer Cost Index. State-specific analyses may adjust costs according to average personal income or related factors (NHTSA, 1994). Studies that estimate the total economic impact of crashes frequently make use of a crash cost multiplier to correct for underreporting of crashes to police (Miller, *et al.*, 1998 and Blincoe, 1996). A recent study by Miller *et al.* (1998) used an average multiplier of 1.088, varying by Abbreviated Injury Scale ranking.

Crash cost estimates for Arizona are prepared annually for the *Arizona Motor Vehicle Crash Facts* report (ADOT Traffic Records Section). These estimates follow the human capital method of valuation, and omit the "quality of life" estimate. All figures are converted to the KABCO injury categories used for crash reporting in Arizona. From 1997 to 1999, little change was recorded in cost estimates for most classes of injury. The largest relative change was observed for the "possible injury" category, in which estimated costs rose by 20.8 percent from 1997 to 1999. The cost estimates for incapacitating and non-incapacitating injuries rose by 7.0 percent and 6.3 percent respectively, while the estimated loss associated with a fatal crash declined slightly over the same period. Arizona human capital cost estimates for KABCO injury classes are shown in Table 5.

Table 5: Estimated Cost of Arizona Crashes by Severity, 1997 to 1999

Severity	Estimated Cost		
	1997	1998	1999
Fatality	$980,000	$980,000	$970,000
Incapacitating injury	$42,800	$44,000	$45,800
Non-incapacitating injury	$14,400	$14,800	$15,300
Possible injury	$7,200	$8,400	$8,700
PDO	$6,400	$6,400	$6,400

Source: *Arizona Motor Vehicle Crash Facts*. Motor Vehicle Crash Statistics Unit, Traffic Records Section, Arizona Department of Transportation, 1998-2000.

Estimates of crash costs in Arizona are further aggregated for the purpose of conducting benefit-cost analyses for safety treatments. The Traffic Group of the Arizona Department of Transportation publishes guidelines that must be followed to determine safety project eligibility for certain funding programs. The benefit-cost analysis required as part of the project evaluation process assigns a total cost estimate to each *crash*, based on the most severe injury, rather than on a per-injury basis (Henry, 2001). For example, a fatal crash would be assigned a flat cost of $2.6 million under the benefit-cost analysis guidelines, regardless of whether the incident was a single-vehicle, single-occupant rollover or a three-vehicle crash with multiple injuries. These values are shown in Table 6, alongside the most recent per-injury estimates for Arizona.

Table 6: Arizona Crash Cost Estimates by Aggregation Method

Severity	Estimated Cost	
	Per Injury[1.]	Per Crash[2.]
Fatality	$970,000	$2,600,000
Incapacitating injury	$45,800	$180,000
Non-incapacitating injury	$15,300	$36,000
Possible injury	$8,700	$19,000
PDO	$6,400	$2,000

Sources: (1) *Arizona Motor Vehicle Crash Facts*. Motor Vehicle Crash Statistics Unit, Traffic Records Section, Arizona Department of Transportation, 2000.
(2) "HES Eligibility: Benefit-Cost Analysis." *Traffic Engineering Policies, Guidelines and Procedures*. Arizona Department of Transportation. January, 2000.

A clear shortcoming in reliability exists for the per-crash method of aggregation. This methodology might be expected to skew overall costs (and hence relative benefits of crash reduction) to areas with lower vehicle occupancy and fewer overall injuries.

Nonetheless, these aggregated figures are used for the estimation of safety treatment effectiveness required for some funding programs. Interestingly, the per-crash estimates appear similar to the per-injury estimates obtained by the willingness-to-pay method.

Blincoe cautions against the use of human capital costs for calculating benefit-cost ratios, due to the omission of intangible costs that nevertheless play a role in the expected allocation of resources that might be chosen by an individual (1996). However, despite the non-comprehensive nature of human capital cost estimates, Blincoe goes on to suggest that these values are appropriate for "calculating the economic cost savings from reducing a given number of injuries or crashes [and] for demonstrating the economic magnitude of the crash problem in a state." In light of these qualifications, it appears that, insofar as the benefit-cost analysis compares only the economic cost of a safety treatment with the economic benefits (crash savings) of the treatment, the analysis would be justifiable.

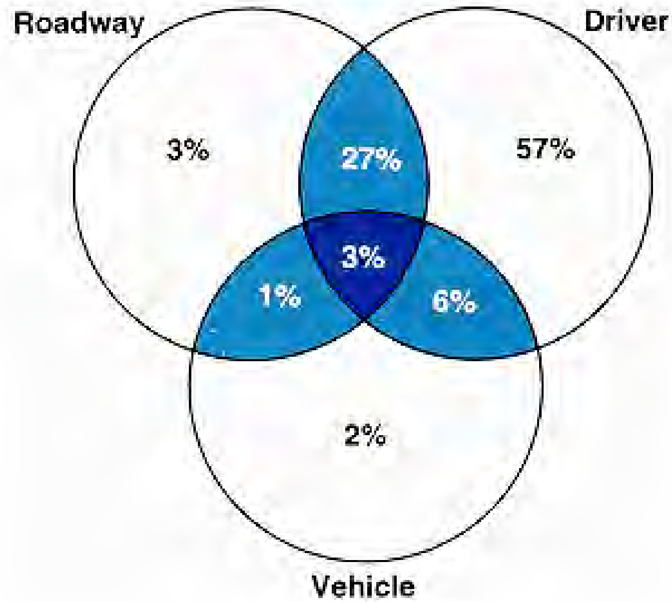
Selecting Traffic Safety Treatment(s)

The selection of traffic safety projects for potential implementation is a function of a number of inputs, from the obvious consideration of site characteristics and measures of hazard, to the directly related concerns of project cost and specific crash subcategories, to indirect factors such as political influence, and jurisdictional preference.

Most agencies perform field analysis, engineering studies and review crash specifics for a site to aid in identifying relevant treatments. Crash details commonly examined include type (e.g. left-turn), severity, contributing circumstances, environmental conditions and time of day (Zegeer, 1982). These details are often useful for "weeding out" treatment alternatives; that is, identifying specific conditions that warrant specific safety measures. For example, Turner (*et al.*, 1988) suggests investigation of sites with observed wet weather crashes in excess of twice the national average, postulating that these sites would be more likely to have smooth pavement with limited skid resistance. Such sites might be candidates for very specific safety projects such as skid treatment overlays or pavement grooving.

It should be noted that highway safety treatments are not limited to geometric improvements. Although roadway design elements play an important role in overall roadway safety experience, design elements do not comprise the most influential factor for most crashes. As indicated in Figure 15, crashes are dependent upon a complex set of interactions related to drivers, to vehicles, to the roadway, and to the natural environment (weather, ambient light conditions) over which design engineers have little control. This interaction complicates the task of sorting out the safety effect attributable to a specific geometric feature.

Figure 1: Causes of Crashes in the United States



Source: Lum and Reagan, 1995.

Major factors affecting highway safety are the environment (e.g. roadway and roadside), the drivers and the vehicles. As shown in Figure 15, crashes directly attributable to the roadway environment make up less than half of total crash incidence. Human factors (i.e. driver performance) are the primary determinant of safety, being the sole cause of over 55 percent of crashes, and at least partially responsible for more than 90 percent of crashes (Vogt, at al., 1998). However, while driver behavior and/or error makes up the most influential determinant of crash probability (Lum and Reagan, 1995), environmental factors present the best opportunity for mitigation – being the most controllable elements of the highway system.

Unusual situations can violate driver "expectancy," or the readiness of drivers to act in predictable and successful ways (Chatfield, 1987). When driving conditions change suddenly, requiring drivers to make sudden changes to their expectations, the results can sometimes contribute to the occurrence of a crash. Changing conditions might include a patch of slippery pavement, sudden reduction in the number of lanes, introduction of previously unseen vehicles or pedestrians, an unusually sharp curve in a series of moderate curves; in short, any occurrence that drivers are not used to encountering. The expectancy concept serves to explain the importance of roadway consistency in the safety equation. High risk (i.e. hazard) often reflects problems with roadway consistency – either violations of driver expectations, or unforgiving features, or both (Chatfield, 1987).

Roadway design elements are also the most constant variable in the assortment of factors related to driving experience – treatment of a site location will, in most cases, provide a more lasting and uniform condition than attempts to influence driver behavior. The selection of appropriate safety measures should reflect consideration of the treatment(s) most likely to be influential in a given circumstance. While driver behavior and vehicle conditions are important factors in overall highway safety, options for assessment and treatment of these variables are more limited than for engineering and design improvements to the roadway environment.

Hazard Elimination and Safety (HES) Program Funding

Another important consideration in the selection of highway safety improvements is the budgetary constraint imposed on the safety program. Many smaller entities are limited in the amount of resources that can be devoted to highway safety projects. However, there are a number of programs that provide grants or matching funds to local governments for warranted highway safety improvement. Substantial funds are available under the FHWA Hazard Elimination and Safety Program, designed to fund spot improvements to public roadways.

The HES Program has the overall objective of reducing the number and severity of crashes and decreasing the potential for crashes on public roadways. The Traffic Safety Program under TEA-21 is intended to improve crash locations with the highest crash frequency and/or severity within each jurisdiction. The Traffic Safety Program is also intended to ameliorate the worst roadway conditions and improve locations where previously implemented corrective measures have failed to produce adequate results. HES eligible safety improvement projects are spot improvements generated for those locations where roadway reconstruction or safety appurtenances such as lighting, traffic signals, or signing appear to be the most cost-effective means of reducing the crash experience (ADOT, 2000).

The funding for the HES Program is authorized under Section 924 of the Highway Safety Improvement Program of Title 23 of U.S.C. 105(f), 152, 315, and 402; Section 203 of the Highway Safety Act of 1973, as amended; 49 CFR 1.48(b). HES funds are administered by the Arizona Department of Transportation, and safety project proposals are reviewed by the ADOT Local Government Section prior to approval. Federal funding for HES-eligible projects amounts to a 94.3 percent share of project costs, with matching funds of 5.7 percent required of the local jurisdiction. HES-funded safety projects must be included as approved projects in the Metropolitan Planning Organization (MPO) and Council of Governments (COG) Transportation Improvement Plan (TIP). HES funds are limited to $350,000 per project (Murthy, 2000).

In order for a proposed safety treatment to be eligible for HES funding, ADOT guidelines require that the local jurisdiction demonstrate that:

- the location exhibits the worst type of situation and degree of severity;
- when applicable, other less extensive measures have been tried and have not reduced crash frequency and/or severity;

- the traffic crash frequency and/or severity at the location is significantly above average for similar situations within the same jurisdiction;
- the safety project would provide significant benefits to the majority of travelers on the roadway;
- the safety improvement(s) is/are economically feasible

Nearly all types of surface transportation improvements on public roadways, including pedestrian and bicycle facilities, may be approved for funding provided that the sole purpose of the improvements is to eliminate traffic hazards or to substantially improve safety (ADOT, 1999). Improvements primarily intended to improve such characteristics as capacity or drainage will not be funded; nor will improvements to non-public roadways. Additional guidelines for HES program eligibility are available from the ADOT Local Government Section at: http://www.dot.state.az.us/roads/localgov/hes.doc

The HES funding program is a potentially significant source of revenues for safety improvements in local jurisdictions. However, some jurisdictions have indicated that the amount of expenditure required to complete preliminary studies and submit an application creates a significant reduction in the expected benefits of the program. This is often the case for smaller jurisdictions, despite the larger benefit (relative to the jurisdictional budget) such entities would receive. A primary focus of this research has been the development of a model that reduces the amount of preliminary data collection and analysis required for submission of an HES program application. As such, the focus herein is upon spot-location safety improvements that are eligible for HES funding. When available, research on other types of programs (e.g. enforcement, system-wide improvements) has been included.

Selected Safety Project Types

Selection of appropriate safety projects requires that the researcher determine the probable cause(s) of crashes at the treatment location. Probable cause may be discerned from an analysis of relevant crash details, operational measures and physical site characteristics (Zegeer, 1982). In some cases, a number of alternative safety treatments may be proposed to address a particular site.

The selection of safety measures to address a particular hazard is often a matter of making a trade-off between desirable features and associated costs of implementation. It is frequently the case that costs of implementation are not limited to the monetary costs associated with implementing a project. For example, the addition of shoulders to a two-lane highway would likely increase the safety of the roadway. However, if additional right-of-way is not purchased, the shoulders would have added at the expense of either reduced lane width (re-marking of existing surface), narrower or steeper roadside recovery areas, or use of guardrails, all of which have a detrimental effect on roadside safety (Mak, 1995).

Previous research has stated that in general, "relationships between safety and highway features are not well understood quantitatively, and the linkage between these relationships and highway design standards has been neither straightforward nor explicit" (TRB, 1987). This observation does not imply a lack of study on the subject. A large body of inquiry exists for the measurement of safety effects for various types of treatment. However, in some cases, the applicability of results has been adversely affected by factors such as small sample size, incomplete data, failure to account for mitigating variables, location-specific characteristics, and random variation.

Factors that influence motor vehicle crashes can generally be divided into two classes: those that affect the operation of the vehicle, and those that affect the severity of the incident. In the former category, vehicle operation would include any variables that influence driver *behavior* and *control* of the vehicle, such as perception of hazard, roadway grade and surface condition, and vehicle defects. The latter category includes characteristics of the operating environment that influence the *consequences* of loss of control. These might include the presence of other vehicles, fixed objects near the roadway, and inadequate recovery zones.

Highway crashes are complex phenomena, and the above simplification is not intended to dismiss the importance of multiple causal factors. Nor should it be construed that the two classes of variables are mutually exclusive. For example, vehicle speed can play a role in both the ability of the driver to control the vehicle, and the severity of consequences if control is lost. At higher speeds, more time is required to stop a vehicle and more distance is traveled before corrective maneuvers can be accomplished. Less time is available for drivers to react to the loss of control of their own vehicle, or to avoid vehicles or objects that are in their path. The fact that a vehicle was exceeding the speed limit does not necessarily mean that this was the cause of the crash, but there probably would have been a better chance of avoiding the crash had the driver or drivers been traveling at slower speeds (Blincoe, 1996). Despite the interrelationships of multiple variables, virtually all potential causal factors, and the highway safety treatments intended to mitigate those factors, can be grouped in terms of one or both of these categories. The extent to which a safety project impacts one variable may have an unintended influence on another variable, even within the same category.

Various safety treatment alternatives are discussed in the following sections. These alternatives have been grouped according to broad project classes used by the Arizona Department of Transportation. The following sections are intended as a survey of various projects, and are not comprehensive. Because the safety treatment chosen will often depend on unique characteristics of the project site, specific project recommendations have not been made. However, when applicable, results of prior studies and potential interactions between safety improvements are included in the discussion.

Roadway Improvements

Maintaining the consistency of the roadway environment plays an important role in traffic safety. By decreasing the frequency and magnitude of changes to the operating environment, a consistent roadway design minimizes the likelihood of "critical driving maneuvers" – the need for drivers to make abrupt changes in speed or direction of travel (Lamm, *et al.*, 1995). AASHTO Policy on the Geometric Design of Highways and Streets (1984) recommends that (1) consistent alignment should always be sought; (2) sharp curves should not be introduced; and (3) sudden changes from areas of flat curvature to areas of sharp curvature should be avoided.

Chatfield (1987) identifies a number of roadway design features that can contribute to driver loss of control. These include abrupt reductions in design speed, unexpected combinations of sharp curvature and steep grade, and reduction of lane width or number of lanes without adequate warning. The common characteristic in all of these examples is the suddenness of the change, requiring that drivers adjust rapidly to unexpected circumstances, which may in turn increase the chance of a crash occurring (Lamm, *et al.*, 1995).

Of the various geometric factors that affect the safety of rural roadways, the horizontal curve has been observed to be one of the strongest indicators of safety (Council, 1998). Research that evaluated the impact of design parameters in New York state demonstrated that the most successful parameter in explaining variability in operating speeds and accident rates was the degree of curve (Lamm, et al, 1995). As the degree of curve (i.e. its "sharpness") and/or central angle increases, crash rates tend to increase. Curves have crash rates that range from 1.5 to 4 times higher than similar tangents (Council, 1998). The transition of the curve plays an important role in curve safety, providing the means for directing vehicles into the curve on a safe path, and allowing for necessary changes in superelevation while minimizing side frictional force.

A clear consensus has not been reached on the use of spiral curvature transitions. Zegeer *et al.* (1990) recommended the use of spiral transitions, noting a slight decrease in crash rates. In contrast, a study by Tom (1995) in the *ITE Journal* found that spiral transitions had no effect or a negative effect, and should therefore not be used. Research by Council (1998) suggests that the use of spirals is subject to interaction with other design elements (e.g. design speed, terrain), and should not be simply recommended or discouraged for all roadways. Despite conflicting assessments of transition techniques, virtually all studies indicate that road sections with extreme geometric features (e.g. grade, curvature) are more likely to be associated with severe crashes due to loss of control. A survey of New Mexico and Georgia crash sites found that fatal rollover crashes were far more common on such segments (Zador, *et al.*, 1987).

In addition to maintaining a consistent operating environment to ensure that vehicles stay under control (and thus within the roadway), various roadway improvements are also intended to provide more space for travel and "occasional" maneuvers. Examples of the latter include turns, merging and emergency stops. Additional lanes, lane and shoulder width and shoulder surface all play a role in managing the hazards associated with these maneuvers.

Crash rates tend to increase with decreases in lane and shoulder width. Crash types found to be related to lane and shoulder width, shoulder type, and roadside condition include run-off-road, head-on, and opposite- and same-direction sideswipe crashes. A predictive model by Zegeer and Council (1995) found that lane and/or shoulder widening reduced crash rates for these types of crashes on two-lane rural roads.[5] Lane widening of 1 ft was expected to reduce related crashes by 12 percent. Lane widening projects of 2 ft, 3 ft and 4 ft were expected to reduce related crashes by 23 percent, 32 percent and 40 percent respectively.

It is important to note that some combinations of design elements may yield benefits, even if one element might normally be considered a hazard. Despite documentation of a relationship between the use of wider lanes and reduction in crash rates, a study by Harwood (1995) found that narrower lanes, when used *in conjunction* with improvements designed to relieve congestion or address specific types of crashes (e.g. narrowing lanes to include a two-way left-turn lane), could provide benefits that offset perceived costs associated with narrow lanes. Projects involving narrower lanes were found to *reduce* accident rates when the project was made to implement a strategy known to reduce accidents, such as installation of a center TWO-WAY-LEFT-TURN-LANE or removal of curb parking.

A study of various median treatments in Phoenix, AZ and Omaha, NE concluded that a statistically significant difference in crash rates existed depending on the type of roadway median. However, the influence of other variables such as roadside parking was found to play an important role in measures of overall hazard. Undivided cross sections were shown to have higher crash frequency than TWO-WAY-LEFT-TURN-LANE or raised-curb median sections when parallel parking was allowed; but when no parking was allowed, less difference was observed between median treatments. In general, raised-curb medians did tend to yield the lowest crash frequency (Bonneson, *et al.*, 1997).

Improvements in roadway alignment, transitions and number of lanes are among the most capital intensive safety improvements, and may be difficult to fund for smaller jurisdictions. ADOT Traffic Engineering guidelines recognize that features such as shoulder width, vertical and horizontal curvature, and superelevation may be uneconomical to bring up to current standards (ADOT, 2000). However, other roadway design elements can play a significant role in crash frequency and/or severity as well. Just as abrupt changes to horizontal alignment, lane width or grade can create a “shock” to driver expectations, so too can such variables as slippery pavement and inadequate drainage on travel lanes. Mitigation of these hazards might include such treatments as

[5] Specific features of the sample rural two-lane roads used in the predictive model were lane widths of 8 to 12 feet, shoulder width of 0 to 12 feet, and traffic volumes (ADT) of 100 to 10,000.

skid-resistant overlays and drainage channels. For example, skid treatments are estimated to reduce Arizona crashes related to wet pavement by up to 39 percent (ADOT, 2000).

Some improvements to roadway consistency could have the unintended consequence of increasing driver confidence and operating speed. While many roadway improvements will facilitate safe travel at higher operating speeds (e.g. lane width or curvature improvements), the extent to which these improvements affect driver behavior is not clear. However, excessive speed, either in terms of posted speed limits or current roadway conditions, is a contributing factor in almost one-third of all fatal crashes on rural roadways. According to the National Sheriffs' Association, a driver traveling 20 mph above the speed limit has a crash potential 11 times greater than a driver traveling at the posted speed (NSA, 1992).

Roadside Improvements

Run-off-road (ROR) crashes usually occur when the driver loses control of the vehicle because the speed was too high for the course of the roadway, the cross-sectional characteristics, the grade or the surface condition of the pavement (Lamm, et al, 1999). These crashes are most common on curved sections of rural highways (Pfundt, 1969), and are not necessarily limited to a single vehicle, at times occurring in tandem with or as a result of collisions with other vehicles. While roadway conditions often play a causal role in these types of crashes, roadside features tend to have the greatest influence on ROR severity.

Collisions with roadside objects are normally severe, frequently resulting in fatalities and serious injuries (Turner, *et al.*, 1988). The severity of crashes involving roadside objects has made roadside improvement a focal point of safety research. Roadside objects include such entities as trees, poles, drainage devices, mailboxes, bridge supports and safety barriers. The closer these objects are to the roadway, the more hazardous the location becomes. Ditches and roadside embankments with steep slopes also create a potential hazard, by reducing the chance for safe recovery and/or increasing the likelihood of a rollover.

Providing a roadside relatively free of these obstacles will allow run-off-road vehicles to recover without having a serious crash (Zegeer and Council, 1995). Roadside improvements that can increase the chance of recovery include removal or relocation of rigid obstacles and using sideslopes of 4:1 pitch or flatter. Studies agree that slopes of 2:1 are dangerous and slopes of 10:1 are safe, but beyond these measures, controversy still exists (Cirillo, *et al.*, 1986). Use of flatter sideslopes has been found not only to reduce overall crash rates, but also to reduce incidence of rollover crashes, thereby lessening average crash severity.

For non-rollover fixed-object crashes, the obstacles associated with the highest percentage of injury occurrence were, in order, bridge or overpass entrances, trees, field approaches (i.e. ditches created by driveways), culverts, embankments, and wooden utility poles. Obstacles with the lowest crash severity included small sign posts, fences and guardrails (Perchonok, et al, 1978). Numerous roadside safety devices have been developed since the 1960s to improve the safety of the roadside. These include crash cushions, breakaway luminaire and sign supports, better-performing barriers, end treatment and transition designs to contain and redirect vehicles, and safety treatments for drainage structures.

Highway medians present a special case, in that while the choice of median treatment may be considered a roadway design element, the characteristics of the median itself are more closely related to roadside conditions. Elements of median design that may influence crash frequency or severity include median width, median slope, median type (raised, depressed), and the presence or absence of a median barrier. Wide medians reduce the likelihood of a head-on collision. Median slope and design can affect the incidence of rollover and other single vehicle (fixed object) crashes, as well as head-on collisions. As in the case of guardrails, installation of median barriers typically increases overall crash frequency, but reduces crash severity. Wider medians are generally considered better, and flat slopes are recommended, particularly for narrower medians (Zegeer and Council, 1995).

The following priorities are recommended by AASHTO for treatment of roadside obstacles: (1) eliminate the hazard; (2) relocate the hazard; (3) use breakaway devices to reduce the hazard; or (4) use a cost-effective traffic barrier to reduce crash severity (Chatfield, 1987). In cases where fixed objects must be placed close to the roadway, such as sign supports and lighting, breakaway designs can be used to minimize the hazard associated with these devices. A "breakaway" structure is designed to yield to impact force above a certain threshold, thereby controlling the counter force sustained by the vehicle striking the breakaway support.

In situations where fixed obstacles can not be removed, relocated or redesigned (e.g. bridge piers), crash cushions and impact attenuators are commonly used to shield vehicles from these hazards. However, Mak (1995) points out that crash cushions and traffic barriers are hazards themselves, and as such should only be employed when the severity of impacting the crash cushion would be less than the severity of impacting the original hazard.

<u>Intersections, Signals, Signage and Lighting</u>

As a practical matter for this discussion, physical improvements to roadway intersections have been aggregated with related improvements to traffic signals and other control devices. This has been done out of recognition that roadway intersections are a primary location for treatments intended to control the flow of vehicles moving in several directions. Although various treatments may be enacted at non-intersection sites (e.g. hazard warning signs), this grouping has been undertaken to reflect the most common situations.

Crashes at intersections represent a significant proportion of total traffic accidents, particularly relative to the amount of time drivers spend at these locations. A variety of factors influence the relative hazard of an intersection. These include the prevailing speeds and/or differential speeds on intersecting roadways, the type(s) of controls in each direction, the amount of entering traffic, the distribution of vehicles, the design of directional markings, and sight-distance characteristics of the location. Lee and Berg (1998) found that intersection hazard increased with higher prevailing speeds, higher ADT, and higher proportions of heavy vehicles.

The effects of traffic control devices, installed to provide protection for roadway crossing maneuvers, are perhaps the least understood and most contentious element of highway safety. The installation of traffic signals as a crash mitigation tactic has historically been met with ambivalence in the literature. Cross-sectional studies, in which signalized sites are compared to non-signalized sites, tend to show that signalized sites have a higher accident rate (Persaud, 1988). However, traffic signals have also been shown to decrease the relative severity of crashes occurring (Cirillo, *et al.*, 1986). In addition, Persaud (1988) suggests that, in many cases, studies that observed a higher crash rate for signalized locations were static analyses that did not correct for the possibility that a high pre-existing crash rate may have already existed before installation and may have been the reason for installing signals. Thus the overall benefit or harm remains subject to interpretation of the factor(s) considered.

Although past studies have failed to show a consensus on the effects of traffic signals, accident reduction factors for signal installation have been specified in such authoritative sources as the ITE *Transportation and Traffic Engineering Handbook* (Homburger, *et al.*, 1982). The ITE handbook estimates a reduction in the total number of crashes of 18 percent, and higher rates of reduction in injury crashes (32 percent) and fatal crashes (49 percent). But research by Persaud (1988) suggests that most traffic engineers are cautious in using the ITE figures, believing that signal installation is likely to increase rear-end accidents and reduce right-angle accidents, thereby making the overall safety impact dependent on the relative distribution of these types of accidents.

In addition to deciding whether a site should receive signal treatment, there is also the matter of selecting a particular type of signal. The type of signalization and the design of signals used at a site location can have an effect on the number of crashes observed. In a comparison various designs of electronic signals, Sayed *et al.* (1998) determined that use of larger traffic signal heads could significantly reduce crash incidence at signalized intersections. Treatment sites for the signals with larger displays experienced an average adjusted reduction of 33 percent for all crashes and 21 percent for fatal and injury crashes.

Stop-controlled intersections permit somewhat more subjectivity in driver assessments of right-of-way. However, studies indicate that stop controls generally have a positive impact on the safety of a treated location. In a study of the safety effects of conversion to all-way stop controls in several major metropolitan areas, a consistent reduction in most types of crashes was observed (Lovell *et al.*, 1986). However, the overall reduction varied with the type of crash. Larger reductions were observed for right-angle and pedestrian-related crashes (72 percent and 39 percent respectively), whereas incidence of left-turn crashes was reduced by 20 percent and rear-end crashes fell by only 13 percent.

Another study by Persaud (1986) examined the conversion of intersections with stop controls on one street and uncontrolled traffic on the intersecting street to all-way stop controls. After adjusting for possible changes due to statistical aberration, a significant reduction in the total number of crashes was also observed. Perhaps more important from a design perspective, this result was not affected by the total traffic volume or variance in approach volume at the sites examined.

Turn-related crashes are a common occurrence at traffic intersections. More specific controls are generally used to direct and separate traffic flow in these situations. Turn-specific signals and signal phasing, turn lanes and traffic lane channelization are generally considered effective strategies for remedying sites with high incidence of turn-related crashes. In a study of left-turn signal phasing in Arizona (Upchurch, 1991), sites with exclusive left-turn signals were found to have the lowest rate of crashes. Leading exclusive turn signals (i.e. green arrow permitting turn maneuvers only, followed by a red arrow prohibiting turns across regular traffic flow) were found to be safer than lagging exclusive signals in most locations.

The installation of turn lanes has been shown to be related to lower incidence of crashes in most locations. The safety impact of turn lanes can be affected by the type of roadway, number of lanes and volume of traffic. Zegeer and Council (1995) found that two-way-left-turn lanes (TWLTL) were more effective in suburban than rural settings, though in both cases significant reductions in crashes were observed. This differential (see Appendix E) may be the result of higher prevailing speeds on rural roads, and lower traffic volumes conducive to passing maneuvers.

Little controversy is observed in evaluation of pavement edge markings. Several studies have shown that these treatments provide a statistically significant reduction in crashes at intersections where edge markings are used (Cirillo, *et al.*, 1986). However, while a reduction in the number of crashes was consistently observed, considerable variance in the magnitude of the reduction existed. A study in Ohio (1960) observed a 19 percent reduction in crashes at intersections using edgeline markings relative to control intersections. A study in Kansas (1961) found a considerably larger reduction of 46 percent. Arizona research has indicated that a 30 percent reduction in crashes may be attainable with pavement edgeline markings.

Remarking existing pavement poses a challenge in that it is difficult to remove the old pavement markings completely. Overlay of new markings on older, partially visible markings in different locations can cause driver confusion. Because of these problems, some agencies implement almost all remarking projects in conjunction with pavement resurfacing (Harwood, 1995).

Visibility concerns are of primary importance in evaluating sight-distance improvements and lighting treatments. Lee and Berg (1998) have noted that the most hazardous movements at stop-controlled intersections are merging and crossing maneuvers, which are in turn heavily influenced by sight distance. Longer sight distances were found to be the most cost effective measures for improving safety at these locations. In a study of causes of motor vehicle crashes, the driver error “improper lookout” was found to be a causal factor in nearly 25 percent of crashes in the US, exceeding even the incidence of “excessive speed” as a causal factor (Lamm, *et al.*, 1999). These crashes typically occurred when drivers changed lanes, passed or pulled out from an alley, street or driveway without looking carefully enough for oncoming traffic. Half of the drivers looked, but failed to see, oncoming traffic, often due to view obstruction. This level of influence indicates the importance of sight distance improvements in ensuring that drivers make proper decisions.

Sight distance improvements may be enacted in tandem with the movement or elimination of roadside obstacles (e.g. removing trees that block driver sight-line for cross-traffic thoroughfares) or such improvements as re-designed parking schemes or pedestrian facilities that move potential sight-distance impediments further from the driver’s field of vision. Arizona estimates (see Appendix D) indicate a particularly high reduction in angle and improper turn crashes as a result of sight-distance improvements.

Lighting conditions and visibility can play an important role in proper maneuvering. A study of causal factors in Texas crashes found that single-vehicle crashes, particularly those involving median barriers and rollovers, were over-represented during evening and night hours on curved sections of roadway (Mak, *et al.*, 1986). However, installation of lighting must take into account the effect of transitional light conditions on driver vision. An important consideration for lighting design and night visibility is the degree of light-dark contrast between installations.

Some light is needed in all directions from an installation. Properly designed systems with symmetrical luminaires use overlapping beams to eliminate the presence of spots with low or zero contrast (Jung, *et al.*, 1987). In poor contrast scenarios, objects in the driving path (e.g. rocks) may not be visible at certain points or for short periods of time while a vehicle is in motion. In a before-and-after treatment of crash rates on the a California bridge, Janoff (1988) found that replacing lineal lighting systems (i.e. rail-type flourescent fixtures) with conventional pole-mounted overhead lighting reduced night-time crashes by 32 percent.

Whereas lighting systems and sight-distance improvements serve to improve the transmission of immediate conditions to drivers, roadway signs are intended to forecast future conditions. Information signs serve two basic functions: to alert drivers to the characteristics of the next portion of roadway, and to inform drivers of the potential consequences of disregarding traffic laws. Although both types have the primary aim of influencing driver behavior, an important distinction exists between these two functions. The first type of sign attempts to influence driver behavior through the identification of *physical* conditions and potential hazards, while the latter often addresses *material* consequences. As an example, there is a different message imparted by the standard speed limit sign and a sign identifying a “speed enforcement zone.” The former describes a legal threshold, determined to be physically prudent for the geographical and functional characteristics of the roadway, beyond which the driver might expect to be at some risk of physical harm. In contrast, the latter suggests that drivers who exceed the legal threshold, regardless of competence, will be subject to material penalty.

The difference in these two approaches is illustrated by two studies evaluating the impact of different types of signs on driver behavior. In the first, the effects of advisory speed signs were evaluated in conjunction with curve signs to determine whether an incremental influence could be attributed to the inclusion of such warnings on curved stretches of roadway. However, advisory speed signs were not found to be more effective in causing drivers to reduce their speeds through curves than curve signs alone (Zwahlen, 1987).

In contrast, a Canadian study evaluated the practice of posting roadside signs that provided feedback on the prevailing speeds on a section of roadway. The signs reported that a portion of drivers were exceeding the posted speed, even in the presence of law enforcement, thus suggesting that speeds were being actively monitored. Periodic changes in the information displayed served to reinforce this perception among regular travelers. The researchers observed a 40 percent reduction in post-treatment speeds with no change in enforcement effort (Maroney, at al., 1987).

Regardless of whether signs are intended to provide information about the physical characteristics of the roadway, or to induce compliance with traffic laws, signage serves as a primary source of information about future operating conditions. By alerting drivers to potential hazards, it is intended that a behavioral adjustment corresponding to the future conditions will be enacted. Such warnings are usually associated with a specific characteristic, and are likely to vary in effectiveness depending on visual impact of the sign treatment, distance from the hazard and driver perception of the risk associated with the hazard. However, research has suggested that some drivers may be deficient in properly interpreting traffic signs (Ogden, *et al.*, 1990; Hummer, *et al.*, 1990). Clearly, the degree to which a sign is properly interpreted will influence its effectiveness as a safety improvement strategy.

<u>Pedestrian Facilities, Railway Crossings and Other Structural Improvements</u>

A number of physical improvements have been omitted from the preceding discussion. Several of these, pedestrian facilities, railroad-highway crossings, and structural (bridge) improvements are included in this section. These types of safety treatments are distinct from the preceding categories in that they attempt to remedy a relatively small subset of traffic safety hazards. However, in all three cases, the potential severity of these hazards warrants considerable attention.

Pedestrian-related crashes tend to pose a one-sided risk of injury. However, these injuries tend to be quite severe. While the occupants of an automobile that strikes a pedestrian are unlikely to be harmed, the relative weight and momentum of the motor vehicle virtually ensures that the pedestrian will be injured. Of the 1,635 pedestrian-related crashes in Arizona in 1999, 148 (9.1 percent) resulted in a pedestrian fatality and 1,571 (96.1 percent) resulted in a pedestrian injury (ADOT, 2000). The odds of an injury or fatality in pedestrian-related crashes make the separation of pedestrians from moving vehicles an important design element.

While signal and channelization improvements have been shown to reduce the likelihood of pedestrian-related crashes (ADOT, 2000), several more specific strategies exist for ensuring that pedestrian-vehicle conflicts are minimized. Sidewalks are the most common of these treatments, providing a pedestrian-oriented thoroughfare separate from the traffic way. Pedestrian overpasses provide a means for pedestrians to cross a roadway without encountering cross traffic. These facilities have generally shown a large reduction in the incidence of pedestrian-related crashes. However, these benefits must be weighed in relation to the overall effects on the roadway environment.

Pedestrian structures can reduce the amount of roadway or recovery space available, which in some cases may have a detrimental impact on the total frequency of crashes (of all types). For example, ADOT estimates of the safety effects of sidewalk installation provide for a reduction in pedestrian-related crashes of up to nearly 90 percent. However, sidewalks are also estimated to increase the total number of crashes in some instances, though by a much smaller amount. The installation of pedestrian-oriented safety measures should consider the incidence of pedestrian-related crashes and the volume of pedestrian traffic, and compare the potential benefits of reducing these specific risks with the general likelihood of encroachment on the existing traffic way.

Crashes at railroad-highway crossings are relatively rare events. However, just as the mass and momentum differential makes pedestrians likely to be severely injured when struck by an automobile, so is an automobile likely to be severely damaged upon impact by a train. In the most ideal situation, automobile and train traffic should be separated by realignment or construction of over- or underpasses to eliminate the chance for conflict. However, these remedies are expensive, and unlikely to be implemented in many circumstances, particularly in rural areas with lower traffic volumes.

A number of treatments have been developed to alert drivers to the potential hazards of rail crossings, and/or to physically separate automobiles from approaching trains. Simple warning signs and pavement markings have been augmented by the use of flashing lights, warning bells and gates to prevent vehicles from crossing the train path. A combination of treatments is generally assumed to be the most effective remedy. Joint installation of flashing lights to warn drivers and gates to prevent automobile entry in the train path appear to have the most significant reduction in train-related crashes (ADOT, 2000). However, any treatment that provides advance notice of the existence of the crossing provides an improvement over unmarked or insufficiently marked crossings. While some treatments will be more effective than others, virtually no detrimental effects have been observed for rail-highway crossing improvements in general.

Excluding other capital-intensive roadway improvements such as realignment and new lane construction (see roadway improvements), major structural improvements generally focus on the construction or redesign of bridge structures. A number of geometrical design elements of bridges have been found to affect the bridge-related crash rate on rural highways. Among the most influential of these elements were the width of the bridge and the relationship between bridge width and width of the approaching roadway.

Previous research suggests that bridges should be considerably wider than the approaching roadway to ensure that errant vehicles do not miss the entry and impact the side of the bridge structure. While these incidents are relatively rare, severity measures indicate that impacts with bridge piers and abutments are among the most severe of fixed-object crashes (FHWA, 1991; Turner, 1994). A study by Turner (1984) found that bridges should be at least 6 feet wider than the approaching roadway. Using the assumptions of the Turner study, Zegeer and Council (1995) modeled the impact of bridge width and bridge shoulder width on crash rates. Their findings indicated that a 42 percent "minimum" reduction in crashes could be achieved when bridge shoulder width was increased from 0 feet to 3 feet on each side.

Due to the physical nature of bridge structures, an important concern is ensuring that vehicles remain on the bridge. Sufficient bridge railings and edge barriers can minimize the likelihood of this type of run-off-road crash. However, in constraining the lateral movement of vehicles on the bridge structure, the clear delineation of lane boundaries becomes even more significant. Because vehicles on bridges have few options in terms of directional travel, keeping vehicles in their respective lanes and out of the path of oncoming traffic should be considered a treatment priority as well.

Traffic Enforcement and Other Safety Programs

Crash rates are dependent not only on highway variables, but also on drivers, vehicles, and traffic reporting and enforcement practices (Vogt, *et al.*, 1998). Some serious safety problems (e.g. drunk driving) have no direct relationship to the characteristics of the roadway environment. Programs intended to modify driver behavior have the potential to play a significant role in overall highway safety. The most common technique intended to influence driver behavior is the enforcement of traffic laws. But other possibilities exist for influencing driver compliance with behavioral safety measures. These may include educational and public information programs external to the immediate driving environment.

The traditional method of driver control is the imposition of safety rules and the use of police enforcement to obtain compliance. The presence of enforcement usually results in an immediate reduction in offenses. For example, there is general agreement in the highway safety community that an increased level of enforcement is the single most effective countermeasure to reduce the number of alcohol- and other drug-related crashes (Mallory, 1984). Similarly, law enforcement administrators have found that the active enforcement of speed limits not only reduced the crash problem, but non-use of safety belts as well (NSA, 1992). However, increased enforcement must create the perception of taking a significant risk in order to influence driver behavior. If drivers are not aware of increased risk (e.g. a greater number of DUI arrests), enforcement will have a minimal impact on safety.

Despite some residual compliance after a reduction in the enforcement level, the major drawback to enforcement is its temporal effect on driver behavior. In and of itself, enforcement does not appear to substantially reduce hazardous behavior over the long term (Maroney, *et al.*, 1987). Studies have shown that a vigorous speed enforcement program not accompanied by public information and education is short lived. The most effective program is one that raises and maintains the public perception that speeders will be detected, apprehended and sanctioned (NSA, 1992).

Another problem with many enforcement efforts is a focus on specific violations rather than overall safety. The International Association of Chiefs of Police has stated that, "too frequently, when enforcement does take place, it consists of issuing a batch of citations at a location where motorists may be exceeding the speed limit but accidents are minimal, instead of targeting a location where unsafe actions are contributing to crashes" (IACP, 1999). The IACP *Highway Safety Desk Book* for law enforcement agencies recommends that more enforcement efforts be concentrated in "high-visibility activities," such as monitoring solid lines, stop signs and school bus stops; sitting in locations where neighbors complain about careless drivers; and frequently checking vehicles with defective lighting equipment while patrolling an area characterized by licensed drinking establishments.

The use of citation and arrest records is frequently used as a baseline for estimation of enforcement effectiveness. However, the number of arrests is usually a reflection of the level of enforcement, and does not provide an adequate indication of driver attitudes (Mallory, 1984). A more accurate indicator of success would be the measurement of crashes or prevailing speeds at a location before and after enforcement efforts. Such an approach requires that hazardous locations be identified and targeted prior to the enforcement effort.

A database provides an objective guide to designing an effective enforcement program, by indicating where a problem actually lies, not where somebody thinks it lies. Among the police traffic safety programs shaped by conclusions drawn from statistical databases, the Selective Traffic Enforcement Program (STEP) probably has the widest recognition. This program addresses the kinds of traffic violations that are major causes of collisions, and concentrates enforcement at those locations where most of these violations and resulting collisions occur, at the times of day and days of the week when their incidence is the highest. STEP attempts to maximize the productive use of officer time to achieve a meaningful reduction in fatalities, injuries and property damage (IACP, 1999).

Pairing enforcement efforts with measures to increase public awareness will provide greater incentives to modify unsafe behavior. A variety of public information programs have focused attention on such items as restraint usage, excessive speed, and particularly the safety impacts of alcohol consumption. A study of driving under the influence (DUI) cases in Pennsylvania found that a combination of extra enforcement grants and a media publicity campaign led to a reduction in crashes attributable to DUI (Mallory, 1984). However, the reduction could not be attributed to a single variable, and was likely the result of interaction between changes in perception due to the media campaign and reinforcement of those perceptions through visible enforcement.

In recent years, there has been a heightened awareness of the problems caused by drunk driving. Alcohol-related crashes made up 6 percent of all crashes in Arizona in 1999, but accounted for 26 percent of fatalities (ADOT, 2000). Various groups, from NHTSA to Mothers Against Drunk Driving (MADD) and state and local agencies, have promoted the enactment of laws and launched public awareness campaigns to help combat this problem. Legal measures such as administrative license revocation/suspension have been enacted in numerous states. The effect of all this has been a marked decrease in the portion of fatalities that result from alcohol-involved crashes (Blincoe, 1996). Roadside sobriety checkpoints have provided the most effective documented results of any of the DWI enforcement strategies. Checkpoints raise the public's level of perception concerning DWI and become a valuable deterrent if used in conjunction with a strong media campaign (NSA, 1992).

Even in the event that safety improvement campaigns are limited to the physical attributes of the roadway, participation of police officers and drivers can play a significant role in identifying potential hazards. Cooperation between traffic engineers and law enforcement officers can result in a greater exchange of information about current roadway conditions. Similarly, providing a mechanism for the collection and evaluation of citizen feedback may lead to a more rapid reporting of such items as obscured or nonfunctioning traffic control devices and dangerous highway conditions.

Effectiveness of Traffic Safety Treatments

Analyses of effectiveness for various safety improvements are concerned with measurable reductions in crash-related variables (e.g. occurrence and/or severity). Effectiveness studies generally follow two different techniques: the before-and-after analysis and the cross-sectional study. The former refers to the practice of comparing specific location(s) for a period before and after installation of safety improvement(s). For example, the researcher might compare crash incidence on a section of highway for several years prior to installation of guardrails to the period following installation in an attempt to determine whether the guardrails reduced the frequency of crashes at the site.

In contrast, the cross-sectional analysis compares sites that are similar to each other, with the exception of the type of treatment (or lack thereof) at each site, over a period of time.

The cross-sectional analysis attempts to determine whether various treatments produce different results at sites with otherwise similar characteristics. For example, the researcher might compare similar intersections with different signing or signals, in an attempt to verify whether one treatment (e.g. four-way stop signs) is more effective than another (four-way signalization).

As noted by Persaud (1988), the cross-sectional analysis does not adequately determine cause and effect. The cross-sectional analysis assumes that crash rates for treated sites was the same prior to treatment; an assumption which may be incorrect. In other words, differences in safety at various sites may have preceded the safety treatment and/or been the reason for a treatment at a particular location. In ignoring the possible differential in pre-treatment safety measures among locations, the cross-sectional analysis is likely to underestimate the potential benefits of a safety project.

The before-and-after analysis is subject to the opposite problem: the tendency to overestimate safety treatment effectiveness. Because sites are often chosen for safety treatments because of a high incidence of crashes in an earlier period, the expected benefit of a treatment may be overstated, as the incidence returns to the mean in the post-treatment period.[6] In a survey of highway segments in Ontario, Hauer (1980) found a statistically significant decrease in crashes on segments with observed crashes in the prior year. Before-and-after studies that do not consider this phenomenon will overestimate the reduction in crashes attributable to a site improvement. Contrary to common practice, Persaud (1988) notes that this risk of overestimation would not be present if sites were chosen without regard for recorded crashes.

In short, caution should be used in interpreting the crash reduction benefits of various design alternatives. An accurate comparison of crash frequency before and after a safety treatment, will separate the changes that are due to random fluctuation from the changes that might be due to the project installation (Persaud, 1988).[7]

Crash incidence and severity can vary widely according to traffic and site-specific characteristics, and not all safety treatments may be viable or appropriate for a particular location. For example, Zegeer and Council (1995) found that the use of two-way left-turn lanes, ordinarily associated with a reduction in crash rates, could cause added problems on rural highways with passing zones. Similarly, in assessing the effectiveness of roadside treatments, Turner and Hall (1994) found that the projected severity of crashes along a section of highway is highly sensitive to the assumed severity of impacts, both

[6] For further discussion of regression to the mean, refer to subsection "Problems of Measurement in Prioritizing Locations."

[7] Much research has been devoted to the development of statistical methods for reducing bias in before-and-after comparisons. Most research suggests that the empirical Bayesian methodology produces superior results (Hauer, 1980; Persaud, et al., 1984; Higle, *et al.*, 1988; Hauer, 1992; Hauer, 1996; Harwood, 2000), though classical (Pendleton, op cit) and nonparametric (Hauer, 1984) techniques have also been proposed for various circumstances. The applicability of a particular method is, to some extent dependent upon sample characteristics, and thus the selection of a particular methodology to evaluate past site improvements is left to the discretion of the researcher.

with the existing objects along the roadside and the conditions that would exist if these objects were removed, relocated, redesigned or shielded.

Although many sources provide estimates of effectiveness for various treatments, most of these are also accompanied by a disclaimer (e.g. roadway specificity in Appendix E tables), noting that crash occurrence and severity are dependent on a variety of factors. Most will agree that a single set of accident reduction factors is meaningless, because the safety impact is likely to depend on a complex web of factors (Persaud, 1988). Estimates of effectiveness are subject to the specificity of the safety treatment. As discussed by Brown (1997), "… comparing severity of pedestrian accidents shows almost ten times the percentage of fatal accidents as in the general population of accidents." Thus it follows that, in a location with a high relative frequency of pedestrian-related crashes, a project treatment that specifically targets pedestrian safety would be expected to provide greater incremental benefits[8] than less-focused alternatives. However, such a prediction must be weighed according to the overall frequency of pedestrian-related crashes, and the likelihood that the treatment will mitigate the problem.

Severity indices[9] used to compare various hazards tend to vary dramatically, even for the same type of hazard (Turner *et al.*, 1994). The AASHTO *Roadside Design Guide* (1989) highlights some of the problems associated with assigning specific measures of danger or severity to a particular hazard, noting that (1) impact severity can differ for the same object depending on how it is struck (i.e. side impact, corners, frontal); (2) predominant speeds on a roadway will influence impact severity; and (3) type of vehicle and other external factors (e.g. restraint usage) will affect impact severity.

Mak (1995) cautions that the effectiveness of a safety treatment should not be considered as a constant value. Improvements to existing technology and/or design standards, restraint usage by motor vehicle occupants, and changes to the mix of vehicles on the roadways are expected to have an impact on safety treatment performance in the longer term. Although there has been a great deal of research on the safety effects of geometric design elements, much of this research has focused on specific issues in isolation, and has neglected to consider the effect on safety of the interactions between geometric features (Harwood, 2000). Safety impact estimates typically rely on the judgments of individual analysts about the available safety research rather than on uniform procedures.

Despite the interpretive quality of most attempts to quantify the effectiveness of highway safety improvements, a substantial body of research has documented the effects of site-specific improvements. Researchers have recognized that the results of well-designed before-and-after evaluations provide better measures of safety effectiveness than

[8] Incremental benefits in this case refers to the expected reduction in severity converted to economic costs. The cost differential between high-severity and low-severity crashes is of such magnitude that small reductions in the former will generate larger benefits (i.e. lower crash costs) than large reductions in the latter.

[9] Severity indices are scaled values for describing the expected outcome of collisions with a fixed object. Values measure relative hazard, and are comparable within an index, but not between indices.

regression relationships, which do not necessarily represent cause-and-effect relationships (Harwood, *et al.*, 2000). However, these techniques require an investment of time and effort on the part of planners and engineers that may not be feasible for many jurisdictions. In a survey of state transportation agencies, Turner and Hall (1994) found that, despite having little confidence in roadside severity indices published in the AASHTO *Roadside Design Guide*, few states were willing to devote the resources necessary to develop alternative index measures.

The various tables in Appendices D and E of this report provide effectiveness estimates for multiple treatments. However, many of these figures attempt to quantify project effectiveness for a wide range of circumstances and should therefore be approached with caution. Some estimates were also made prior to the development of more sophisticated techniques for before-and-after comparisons.[10] Should the development of location or jurisdiction-specific crash reduction factors be outside the scope of project analysis, it is suggested that the figures presented in Appendices D and E be viewed as an *obtainable* or *potential* measure of effectiveness for a given improvement, but not necessarily the appropriate measure for a particular situation.

For example, Arizona guidelines estimate that a 56 percent reduction in crashes may be achieved by a lane widening improvement. However, this guideline applies to *all* crashes, regardless of type, observed at a site location. Potential reductions for a specific type of crash are different. The potential reduction in run-off-road crashes is 49 percent. In a situation where a few run-off-road crashes were the only incidents observed, there would appear to be little justification for using the higher estimate. The Arizona Department of Transportation evaluates local transportation projects on site-specific basis, and the rationale for applying a particular estimate of project effectiveness is left to the traffic engineer or analyst making the project proposal (Murthy, 2000).

Benefit/Cost Analysis:

The objective in identifying hazards is to find those that can be removed or mitigated most cost-effectively (Chatfield, 1987). Cost-effectiveness procedures provide a means for comparison of alternative safety treatments in terms of reduced crash costs associated with each safety improvement (i.e. project benefits) and the implementation costs associated with that project. Most cost-effectiveness procedures are based on the concept of benefit-cost analysis (Mak, 1995). The basic assumption of this type of analysis is that the expected benefits associated with a particular safety project should exceed the cost of project implementation. Depending on the methodology, benefits can be measured in terms of reductions in crash frequency, crash severity, or a combination of both. Project implementation costs generally include initial installation, as well as normal maintenance and repair over the life cycle of the project.

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[10] The empirical Bayesian technique of before-and-after comparisons is widely regarded as the most appropriate means of evaluating safety improvement effectiveness. Refer to Hauer, Higle and Persaud references for quantitative analytical techniques appropriate for this type of analysis.

Just as in the case of other depreciable assets, the effective "life" of a project varies depending on the type of treatment and the environmental factors to which the treatment will be subject. The Arizona Department of Transportation Traffic and Engineering Section has published guidelines for estimating the effective life of various improvements (2000). These project life cycle estimates for major classes of improvements are shown in Table 7.

Table 7: Life Cycle Estimates for Various Safety Improvements

Project Description	Project Life Cycle
Intersection Projects[1.]	10 years
Cross Section Projects	
Pavement/shoulder widening, new lanes, slope clearing	20 years
Skid treatment, grooving or overlay	10 years
Combination of pavement widening and skid treatment	15 years
Structures	
Construction of minor structure, widening major structure	20 years
Construction of bridge or other major structure	30 years
Alignment Projects, vertical and/or horizontal adjustments	20 years
Railroad Crossing Projects	
Lighting, signals, gates and/or signage	10 years
Grade separation and/or relocation	30 years
Roadside Appurtenances	
Markings and delineators	2 years
Traffic signs	6 years
Guardrails, fencing, impact attenuators, breakaway supports	10 years
Lighting, median barriers	15 years
Drainage structures	20 years

Notes: 1. Includes signals, channelization and other improvements *except* structures
Source: ADOT Traffic Engineering HES Guidelines, January 2000.

Calculation of an expected benefit/cost ratio (BCR) for a given safety improvement project requires a series of steps for estimating both the benefit of the project in terms of crash reduction and the cost of the project over its effective life. A general rule of thumb is that the more capital-intensive the project, the longer its effective life span. Whereas pavement markings will wear away to the point of being illegible after a few years, a pavement widening project or new bridge will have an effective life of twenty or thirty years.

One method of assessing safety projects by benefit-cost ratios entails a simple comparison of projected crash cost savings and implementation costs over the project life cycle. Such analyses are often made when project feasibility depends on a specific benefit-cost threshold. For example, the HES eligibility guidelines used by the Arizona Department of Transportation require a simple benefit-cost ratio of 1.0 to be eligible for funding. In other words, the expected benefits of a safety treatment in terms of crash cost reduction must be equal to or greater than the projected cost of implementing and maintaining that treatment for the project to be warranted. Using this method, several project alternatives for a site can be compared simply by their benefit-cost ratios, with the highest ratio implying the superior treatment for that location.[11]

An alternate means of performing the benefit-cost analysis uses an incremental method to compare changes in benefits to changes in costs from one project to the next. The formula for comparing these incremental benefits and incremental costs is summarized by Mak (1995) as follows:

$$BC_{2-1} = (B_2 - B_1) / (C_2 - C_1)$$

where B refers to the annualized benefits of a project alternative, C refers to the annualized costs of a project alternative, and subscripts indicate specific alternatives to be evaluated. It should be noted that the incremental methodology allows for the selection of a project with a lower benefit-cost ratio, provided that the added benefits of project #2 (lower ratio) relative to project #1 exceed the cost differential between the two projects.

For example, assume two safety improvement projects, SP_1 and SP_2. SP_1 has a total cost estimate of $2,000 and an estimated benefit of $5,000. SP_2 has an estimated cost of $4,000 and an estimated crash reduction benefit of $8,000. All other factors being equal, under the simple benefit-cost analysis, SP_1 would be chosen, as its benefit-cost ratio of 2.5 exceeds that of SP_2 ($BCR_2 = 2.0$). However, an incremental benefit-cost assessment would warrant selection of SP_2, because the net increase in benefits from choosing SP_2 ($3,000) exceeds the added cost of choosing SP_2 ($2,000).

Either or both methods may be chosen, depending on the preferences of the decision making entities. However, regardless of the method used, all benefit-cost analyses require two forecasts that are problematic in that limited data must be used to estimate benefits prior to project implementation. In order to assess any safety treatment before the fact, it is necessary to determine (1) an estimate of future crashes at a given site, and (2) the degree to which the safety treatment(s) will reduce these future crashes. Estimates of the cost of crashes assume that the investigating researcher can determine the total number of crashes, including severity and type, for the period of analysis. However, such estimates are subject to changes in data collection and reporting (Zegeer, *et al.*, 1998), and are susceptible to random fluctuations over shorter periods of analysis.

The calculation of crash benefits (i.e. savings) requires the use of accident reduction factors, which are the percentage reductions in related crash types to be expected from the implementation of a specific highway improvement (Zegeer, 1982). The use of accident reduction factors (ARF) poses a problem in that benefits must be assumed prior to implementation. This creates an unavoidable disconnect between the implementation of a project and the actual measure of its effectiveness, as the former must precede the latter.

[11] All other things being equal, this assumption holds. However, in many cases the selection of a particular treatment will be influenced by external factors, including political and funding decisions, past experience with a project type, public opposition to certain types of project (e.g. roadway widening), and so forth.

It is therefore assumed that benefit-cost analyses undertaken to determine whether a safety treatment is warranted will be subject to considerable speculation. This is a necessary byproduct of estimating crash frequency and associated costs before these events occur. To some extent, the accuracy of these estimates may be improved by use of an appropriate methodology. However, it is assumed that no method will eliminate all variation between expected and future outcomes of a safety treatment. Multiple analyses of the same treatment may be instrumental in determining an "effectiveness threshold" at which the expected benefits of a project would exceed its costs. In cases where the effectiveness threshold is low, the project is more likely to be warranted regardless of variation in future benefits.

As discussed in the preceding section, crash/accident reduction factors for various treatments are included in Appendices D and E of this report. These figures are intended as guidelines for forward estimation of project benefits, and should not be interpreted as universal measures of effectiveness. It is recommended that post-treatment studies for completed projects evaluate the degree to which crashes and/or crash rates were reduced, relative to the expected improvement set forth as a crash reduction factor. Conducting these comparative analyses will aid in the development and applicability of crash reduction factors used for future projections.

III. Local Government Safety Project Model

The Arizona Local Government Safety Project Model (LGSP) was designed as a tool to assist local government in allocating resources among traffic safety alternatives. The LGSP model is intended to simplify the decision-making process, allowing the user to specify various criteria for site selection, identify problem locations, and evaluate multiple safety treatments for one or more hazardous sites. However, the model does not make specific safety project recommendations, as it is assumed that there is no one who can understand and interpret the results of local problem identification information better than the individuals who are working in the local area on a daily basis (Brown, 1997). The model can not consider previous treatments at a given site, nor can it capture location-specific variables that may impact project selection, design or feasibility.

The traffic safety model provides a means of evaluating various local jurisdiction safety projects in terms of benefits versus costs. Methodologies exist for the translation of crash-related injuries and fatalities, as well as associated property damage, into "crash costs." By selecting the probability of crash reduction according to traffic and incident frequency on a given location, the benefits of a particular safety project can be estimated in terms of a reduction in crash-related costs. This benefit can then be compared to the cost of implementation, yielding a benefit/cost ratio for each safety project under consideration.

It is assumed that local governments are faced with allocating scarce resources, and will therefore be best served by choosing safety projects with the highest benefit "yield" for each dollar invested. The model provides more options than a simple prioritization based on the number of crashes at a given location. In addition to the ranking of sites by crash frequency, the LGSP model allows for several frequency/severity-based prioritization methods. The choice of method used will depend on the focus of the individual researcher.

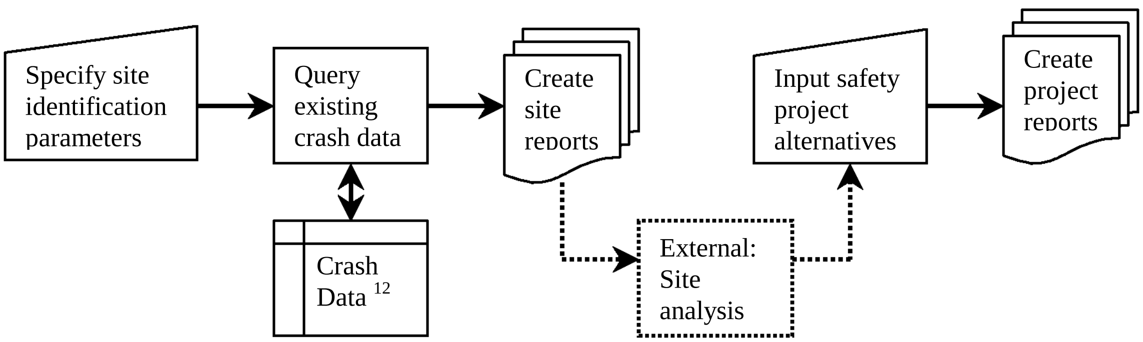
A high "relative risk" (e.g. average severity) may ordain a higher ranking for a location with fewer observed crashes. Similarly, an inexpensive project that does not have the greatest overall benefit may nonetheless provide the most incremental benefit and be ranked accordingly. It should be noted that the crash cost data will provide a means of prioritizing according to severity, as crashes with higher rates of fatality or serious injury are also much more expensive in terms of government and private costs. As an example, a "deadly curve" on a rural route with low relative risk might still be assigned a higher expected benefit if a large proportion of the (infrequent) crashes at that location resulted in fatalities.

LGSP Model Overview and Assumptions

The Arizona Local Government Safety Project Implementation Model is basically divided into two parts. The first selects a subset of hazardous locations from one or more jurisdictions based on user-defined parameters. These locations are prioritized according to one of several measures of hazard or severity, and multiple reports are generated to summarize crash incidence, roadway and driver characteristics, and estimated costs associated with each location. The second component of the LGSP model prompts the user for possible safety treatments for one or more locations, calculates the expected benefits for each project, and returns a benefit-cost analysis that follows HES eligibility guidelines.

The LPSG model stores crash location data until another update is run. Although the data stored takes up a substantial amount of hard disk space, storage facilitates the update process, providing faster access to jurisdiction-specific crash subsets and allowing the user to test alternate safety treatment scenarios without rerunning the model. The two-step procedure takes the following form:

Figure 2: Local Government Safety Project Model Process



After the user specifies site selection parameters, a series of queries are run on the database[12] to extract, sort and aggregate jurisdictional crash records. From this procedure, a series of reports are generated. These reports identify the highest-priority site locations, summarize such information as the frequency, severity and cost of crashes at each location, provide specific details of roadway type, condition and relationships; vehicle actions, speeds and harmful events; and external factors such as weather. The LGSP model generates a report listing comparable sites for a specific location, allowing the user to perform statistical analyses of relative risk and regression-to-the-mean if needed. These data are also useful for before-and-after comparisons of treated and untreated locations. From various report outputs, it is expected that local traffic engineers will be able to identify target sites for mitigation.

Prior to input of safety project alternatives, it is assumed that each potential site will be subjected to greater study, identifying relevant information not provided by the LGSP model. These might include traffic counts, engineering studies, and prior site treatment history. Traffic counts are recommended to “normalize” crash frequency by the volume

[12] The crash data files are contained in a separate database distributed on CD. Each database file is limited to five calendar years of data. Instructions for creating new crash data files in the proper format are included in Appendix B of this report.

of traffic at various locations. Crash rates (frequency / traffic volume) are often considered more reliable indicators of relative risk at a location than are simple measures of frequency. Probabilistically, an intersection with one crash for every thousand entering vehicles is relatively more hazardous than an intersection with one crash for every ten thousand entering vehicles, even if more crashes are observed at the latter intersection.[13]

Site engineering studies and surveys of prior treatments are necessary for determining feasibility of improvements at a treatment location. This information provides an invaluable resource for determining what can and can not be accomplished, and what has been tried in the past. On-site analysis provides the most reliable assessment of influential factors at a project location, and should identify far more site characteristics than an automated review of crash data. Although some degree of inference regarding potential safety improvements can often be made from the LGSP outputs, these reports are not intended to supplant a rigorous on-site evaluation.

Once the target sites have been evaluated, it is expected that one or more improvement projects will be identified as appropriate for the site conditions. At this point, projects can be entered in the LGSP model and evaluated in terms of a benefit-cost analysis. Each project alternative is assigned expected levels of effectiveness for reducing crashes at the site location. Effectiveness measures (crash reduction factors) can be assigned by the user, or default values generated by the model can be used when available. The effectiveness measures are combined with crash frequency measures to yield an overall reduction in crashes of varying severity at each location. This reduction is then multiplied by the cost associated with a crash of that severity to yield an annual benefit.

Annual project benefits are compared with the annualized costs of implementing the safety improvement to yield a benefit-cost ratio. Projects are assumed to be worthwhile if they can "pay their way." In other words, in order to be considered economically sound, a safety improvement must generate an annual reduction in crash costs that exceeds the annual expenditures required to implement the project. This does not imply that projects with a benefit-cost ratio of less than one (i.e. benefits less than costs) are not "good" in the sense that some reduction in crashes will be expected to occur, but rather that more efficient means of allocating safety improvement resources are likely to exist.

[13] It should be noted that the use of crash rates and corresponding treatment of exposure is subject to a significant methodological criticism. Most of the research methods developed for rate-based estimation techniques, including the generally accepted approach developed by Hauer (1988), implicitly assume a linear relationship between exposure and crashes. In other words, an increase of one unit of exposure is assumed to have a constant effect on the number of crashes observed. Research by Mahalel (1986) illustrates an alternate possibility: that relative risk is subject to a declining rate of increase with each added unit of exposure. In such a situation, calculations based on a constant-rate risk assumption could lead to erroneous conclusions about the relative risk differential between two sites. For further discussion of the limitations of exposure-to-crash rate relationships, refer to "A Note on Accident Risk," *Transportation Research Record 1068*.

LGSP User Requirements

The LGSP model requires that the user make a number of decisions before generating a list of sites for improvement. In addition to identifying the jurisdiction(s) of analysis, the user must specify the methods by which the model should include or exclude crash records, how those records should be grouped, and how crash sites should be prioritized. It is expected that different jurisdictions will have different priorities when making these decisions, so the model has not been designed with a single set of allocation parameters. The items that must be specified by the LGSP user prior to site identification are listed in Table 8 below.

Crash data can be restricted to any month/year combination contained in the linked crash data file. HES eligibility guidelines require that data from a period of at least three years be included in the site analysis. All annualized data outputs are converted to whole-year values. Using partial year data will not affect the annualized outputs, as the base period will be set to the sum of whole year and partial year values. For example, the period from January 1995 to September 1999 would be converted to a 4.75-year term, and annual frequencies/rates would reflect totals divided by 4.75.

Alcohol- and drug-related crashes can be included or excluded from the analysis depending on user preferences. Depending on the purpose of the analysis, exclusion of these crashes may be warranted. This input requires a yes/no (include/exclude) response.

The LGSP model sorts locations by cross street references. Each location is assigned an identification number that corresponds to the junction of cross streets. These locations can be sub-grouped in several ways. The user must decide whether to examine only the crashes occurring on a single route at that junction, or to include crashes on both cross streets. In the latter case, crash records can be further limited to those documented as directly related to the junction and/or intersection. These restrictions are intended as a means of narrowing down the possible causes of crashes at a particular location, which should be useful for identifying safety treatment alternatives.

In addition to the multiple means of sub-grouping crash locations, the LGSP model also requires that the user specify a distance from the point of reference within which crash records will be returned. Crashes identified as occurring further from the reference point than the specified aggregation distance will be excluded from the analysis.

Finally, the user must select a means of prioritizing crash locations. The simplest option is to select the total number of crashes observed. Options for ranking locations by total number of fatalities or total number of persons harmed (fatalities plus injuries) are also provided. These options serve to weed out sites with high frequencies of minor crashes. Finally, locations can be assessed in terms of total costs associated with the crashes observed. This measure returns similar results similar to the "total persons harmed" option, but further refines the results by considering the relative severity of each incident.

Table 8: User Input Specifications for the Arizona LGSP Model

User Inputs	Description
Jurisdiction	• County level or City/Town level • County level can include sublevels (i.e. cities and towns)
Period of Analysis	• Five year periods are recommended as standard • Other periods can be evaluated, subject to data availability
Alcohol Involvement	• Alcohol and drug-related crashes may be excluded from the analysis if the researcher desires
Location Reference	• Locations can be aggregated according to four methods: 1. *Route-specific* identifies locations on the same route, within specified distance of a cross street junction 2. *Junction-specific* identifies all locations, on either route, within specified distance of the junction of the two routes 3. *Junction-specific (junction)* returns a subset of option 2 limited to crashes classified as junction and/or intersection-related 4. Junction-specific (intersection) returns a subset of option 2 limited to crashes classified as intersection-related
Distance (Radius)	• Various distances may be specified for the Location Reference method, from 0 feet (exact location match), to one mile (5,280 feet). An unlimited distance option is also available.
Weighting Method	• Several methods may be used to rank sites for prioritization: 5. Prioritized according to number of crashes recorded, 6. Number of fatal crashes observed, 7. Number of fatal and injury crashes observed, or 8. Severity of crashes in terms of overall cost estimates

LGSP Calculation Procedures

Average distance from the reference point location is calculated for all crash sites using the distance reported for each crash record. Because distance is reported in positive and negative values depending on the direction from the reference point, the LGSP model converts all distances to absolute (positive) values prior to calculating averages. This is done to eliminate the offsetting effects of negative and positive values, returning the average distance from the reference point regardless of direction.

Total number of crash records (i.e. incidents), number of vehicles and persons involved, and the most severe injury in each crash are aggregated for all crash locations falling within the specified radius. In addition to the most severe injury observed, separate counts are made of the total number of persons killed or injured at the crash location. These figures are used to sort records in the format most useful to the user. Measures of total incidence are relatively straightforward, as are counts of total fatalities. If the list is sorted by the total number of persons harmed (fatalities and injuries), counts of injuries are normalized using an ordinal scale (one to five, "5" being fatal) of the most severe injury observed. Finally, the results can be sorted according to the estimated cost associated with crashes at each location.

The LGSP model uses a single set of cost values that are assigned on a per-crash basis, depending on the most severe injury observed for a given crash. While this method has the benefit of simplifying cost calculations, differences in number of vehicles involved and vehicle occupancy among crashes are not reflected in these figures. The use of aggregated "maximum severity" costs is recognized as a detriment to the reliability of crash cost estimates in general. However, the LGSP model is intended to follow specific eligibility guidelines for the HES funding program, and thus incorporates the method of cost estimation required for this process.

Crash cost estimates use a static, current year value for all periods. This is done to reflect the discount-rate adjustments used in estimating safety project costs. All projected amounts are thus returned in present value format. Although crash costs are likely to fluctuate with changes in prices and earnings, the historical amounts are kept constant to standardize results in terms of the most recent cost estimates. Because the historical figures are used only as a relative measure of severity, and not as a predictor of future cost estimates, the model results are not adversely affected by the use of a constant value cost estimate.

LGSP Project Evaluation

Several of the safety project evaluation measures are exogenous in the sense that they are neither specified by the user nor calculated independently by the LGSP model. Such variables as project life cycle estimates (see Table 7) and the capital recovery factors used to annualize lump-sum project costs according to an appropriate discount rate (shown in Table 9), have been taken directly from the ADOT HES Eligibility Guidelines, and are not flexible. However, these calculations remain dependent upon user-defined parameters such as total project cost, annualized project maintenance costs, and interest rates used for the capital recovery factors.

Table 9: Capital Recovery Factors

Project Life	Interest Rate				
	8%	**10%**	**12%**	**14%**	**16%**
2 yr.	0.5608	0.5762	0.5917	0.6073	0.6230
4 yr.	0.3019	0.3155	0.3292	0.3432	0.3574
6 yr.	0.2163	0.2296	0.2432	0.2572	0.2714
8 yr.	0.1740	0.1874	0.2013	0.2156	0.2302
10 yr.	0.1490	0.1627	0.1770	0.1917	0.2069
15 yr.	0.1168	0.1315	0.1468	0.1628	0.1794
20 yr.	0.1019	0.1175	0.1339	0.1510	0.1687
25 yr.	0.0937	0.1102	0.1275	0.1455	0.1640
30 yr.	0.0888	0.1061	0.1241	0.1428	0.1619

Source: ADOT Traffic And Engineering, HES Guidelines, 2000

Estimates of safety treatment effectiveness are provided in a limited scope by the LGSP model. If project effectiveness estimates are left blank in the preliminary assessment, the LGSP model will assign default values when available. Arizona-specific estimates of effectiveness for several project types have been built into the model. Additionally, FHWA estimates of effectiveness have been used where Arizona-specific figures were not available. The default effectiveness values returned by the LGSP model have been set at 50 percent of the “obtainable” (i.e. maximum) crash reduction factor indicated for a particular project type. For example, installation of a new guardrail has an Arizona-specific base crash reduction factor of 47 percent for fatal crashes, 12 percent for injury crashes, and 21 percent for property damage crashes. The Arizona LGSP model would therefore assign a new guardrail project default crash reduction factors of 23.5 percent, 6 percent and 10.5 percent for these respective categories. It should be noted that the 50 percent reduction is arbitrary, based on the assumption that roughly half of the observed effectiveness of a treatment might be attributable to regression-to-the-mean fluctuation.

The base figures for Arizona-specific estimates and FHWA estimates are contained in Appendices D and E respectively. Additional estimates for a variety of treatments from various studies are also included in Appendix E. However, the figures provided with the LGSP model are not comprehensive; nor should they be considered anything more than a rough guideline for treatment estimates. The effectiveness of a treatment at a given site will likely depend on far more information than is produced by the crash records database. The final responsibility for deciding the appropriate estimate of safety treatment effectiveness is left to the local engineers or officials preparing the project analysis.

Limitations of the Arizona LGSP Implementation Model

A number of design elements of the Arizona Local Government Safety Project Implementation Model have been influenced by the availability (or lack) of data and the need for simplicity of design. Several limitations provide room for improvement as data become available. The principal limitations of the Arizona LGSP model are discussed below.

Crash Site Identification and Indexing

A principal limitation of the Arizona LGSP Model is its site identification methodology. Local sites in Arizona are not generally identified by milepost, but instead by cross street, and this method has therefore been used in the to index crash sites in local jurisdictions. The junction of two routes provides the reference point for location of a particular crash. Crashes are then placed by determining on which of the two routes the crash occurred and the distance from the junction reference point. This method poses several difficulties, of which the most important is the lack of uniform geographical coordinates (i.e. GPS references) for site positioning.

Lack of geographical coordinates creates greater room for error, as local streets may be renamed, misspelled or assigned different suffixes in traffic crash reports. Such errors in data collection may lead the model to split crashes among locations that should be aggregated. The model relies on a unique numerical identifier for each location, but this identifier is based on conversion of route and route suffix names to numerical values, and as such can not eliminate these potential errors. As data become available, the "Location Identifier" for each site can and should be replaced with geographical coordinates.

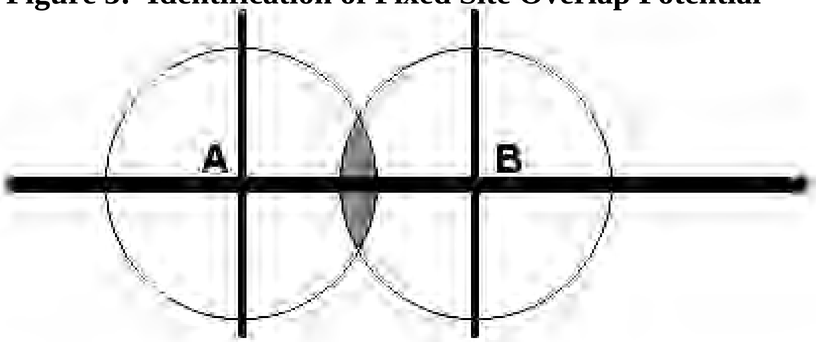
A related problem is the means of aggregating crashes by reference point. The use of floating segments, in which incremental numerical adjustments (e.g. MP 0.0 – 0.3, 0.1 – 0.4, etc.) are used to identify overlapping crash sites, is generally considered superior for site identification (Zegeer, 1982). Unfortunately, the floating segment length is not feasible for the location analysis performed by the LGSP model. Because the LGSP model does not contain geographical coding for each cross street location, no comparable identification method could be developed. The LGSP model is therefore limited to the fixed-segment means of site identification, whereby segments within a given radius of a *predetermined* point are analyzed as a location. In many cases, this limitation will have little effect on crash location. However, should the radius of analysis exceed the distance between two sites, overlap will occur. This problem is demonstrated in Figure 3.

The aggregation distance[14] in from each site (A, B) in Figure 3 exceeds the distance between sites A and B. Crashes occurring in the gray shaded area in the diagram will have been assigned to one site or another by the reporting officer, but could be aggregated at *either* location based on the aggregation distance chosen. While it is assumed that the

[14] Aggregation distance refers to the radius from a specific reference point location within which crashes will be coded as occurring at that location.

reporting officer identified the most relevant reference point for each crash, there is no way to verify this assumption. Furthermore, the reduction of the aggregation distance will not eliminate the problem, because a smaller radius would cause sites in the gray area to be excluded from the analysis altogether.

Figure 3: Identification of Fixed Site Overlap Potential



Estimating Effectiveness

A substantial body of research has targeted the influence of regression-to-the-mean (RTM) on measures of crash incidence and treatment effectiveness. A more thorough discussion of the phenomenon has been included in the analysis of hazardous location identification in a preceding section. Although sophisticated techniques have been developed for estimating future crash rates at a given site based on sample characteristics (see Hauer *et al.*, 1984; Hauer, *et al.*, 1988; and Higle, *et al.*, 1988), this section uses a simpler method for calculating future incidence. A simpler notation is needed because the traffic data required for crash rate calculations in more complex methodologies are not always readily available for local jurisdictions.

The following notation has been developed by Hauer (Persaud, 1986) for estimation of future crashes at a specific site, based on crashes observed at that site and other similar locations:

$$T(x) = x + [(\underline{x} / s^2)*(\underline{x} - x)]$$

T(x) refers to the number of crashes expected to occur at site X, assuming no improvements are made to site X. The variables x and $\underline{x}$ represent the average number of crashes observed at site X and other similar sites respectively over the same historical period; and s^2 is the variance of sample $\underline{X}$.

The Arizona LGSP generates a report of sites similar to the one selected for comparative analysis, and calculates the statistics shown in the above equation for the entire sample. The option of converting crash frequencies to crash rates is also provided, and summary statistics can be calculated for crash rates as well. However, the model does not contain traffic data, and collection of traffic counts for comparable sites is required of the user prior to performing the rate-based analysis. The LGSP model only allows subset analysis (i.e. the study of only a few related sites) for crash *rates*, while frequency analyses are limited to the entire sample. The user will have sample sites and statistics from which to correct for regression-to-the-mean in post-treatment analyses, but the calculation of RTM-adjusted treatment benefits can not be done in the current version of the model.

Summary of Capabilities and Limitations

The Arizona Local Government Safety Project Model is a tool that can be used to facilitate the selection of hazardous roadway locations in local jurisdictions, to prioritize those locations by rational means, and to aid in the evaluation of potential spot treatments of safety hazards. However, the model is not intended to automate the entire decision-making process, and can not substitute for the analysis and judgment of a traffic engineer. The Arizona LGSP Model can accomplish the following tasks:

- Analyze multiple jurisdictions
- Limit crash records returned based on user-defined parameters
- Aggregate crash records based on distance from a specific location
- Provide total and annualized crash details, including:
  - Frequency/incidence
  - Units involved
  - Severity (highest observed for each record)
  - Severity (injuries for each person involved)
  - Estimated costs associated with crashes
  - Summary statistics for incidence measures
- Summarize crash details and limit details to a specific subset
- Provide a list of sites comparable to the chosen site of analysis
- Accept and analyze *user input* of traffic volumes at multiple sites
- Analyze multiple safety projects at a location
- Rank order project alternatives by cost effectiveness
- Format project details to supplement HES eligibility applications

The Arizona LGSP Model does not do the following:

- Provide traffic data for a given site, though user inputs for these data can be analyzed
- Know the site history (i.e. which treatment alternatives have been evaluated or implemented in previous years)
- Automatically update crash cost estimates, though these can be modified by the user from the STARTUP page
- Automatically update the crash records file, though instructions for performing this action using an automated format are included in Appendix B

The Arizona LGSP Model should prove to be a useful tool, particularly for jurisdictions with limited research budgets or capabilities. However, use of the model is *not mandatory*, and is subject to the preference of each jurisdiction.

IV. Local Safety Case Study: Central Arizona (CAAG) Region

In order to evaluate the merits of the Arizona Local Safety Project Implementation Model, a case study was prepared using data specific to a local region of analysis. The region chosen for this case study was the transportation planning area for the Central Arizona Association of Governments. This area includes multiple jurisdictions in Gila and Pinal counties. A brief overview of crash history in the CAAG region over the most recent three-year period reported (calendar 1997 to 1999) is followed by specific results for CAAG region locations obtained with the Arizona LGSP model.

CAAG Region Crash History Overview

This section contains a summary of crash statistics published annually by the Motor Vehicle Crash Statistics Unit of the Arizona Department of Transportation. Published data include detailed statewide analyses, as well as crash frequencies for local jurisdictions. For this analysis, county-level crash frequencies have been combined with estimates of motor vehicle travel to develop crash rates for CAAG region counties. These rates are compared with county and state rates to determine the relative highway safety of the CAAG region.. Crash rates expressed in terms of vehicle miles of travel are presented for CAAG region counties in Table 10.

Table 10: Arizona Crash Rates by Vehicle Miles of Travel, 1997 to 1999

Locale	Crashes / 100 million VMT			Fatalities / 100 million VMT		
	1997	1998	1999	1997	1998	1999
Gila County	169.2	178.6	176.6	4.3	3.0	3.6
Pinal County	128.6	127.4	129.3	2.9	3.5	3.7
County Average	160.4	159.5	159.0	2.7	2.7	2.6
County Median	138.1	140.5	142.8	2.6	2.6	2.4
State Total	262.5	264.5	267.5	2.2	2.2	2.2

Sources: *Arizona Motor Vehicle Crash Facts*, Motor Vehicle Crash Statistics Unit, Arizona Department of Transportation, 1998-2000; *Motor Vehicle Travel Estimates by County*, Transportation Planning Division, Arizona Department of Transportation, 2000.

Both Gila County and Pinal County had crash rates below the rate of crashes statewide. However, the state totals are heavily influenced by figures for major metropolitan areas in Maricopa and Pima Counties. Crashes in these two counties made up nearly 82 percent of crashes statewide. However, despite the relatively low incidence of crashes in the CAAG region, crashes tended to be more dangerous in Gila and Pinal Counties relative to crashes statewide. Fatality rates declined in Gila County over the three-year period, but were still over 50 percent greater than fatality rates statewide. Fatality rates in Pinal County increased each year by an average of 13 percent, and exceeded the statewide fatality rate by more than 50 percent in 1998 and 1999.

On a county-level basis, Gila County had an above-average crash rate per 100 million VMT for all three years, exceeding the average crash rate for Arizona counties by 5 percent in 1997 and 11 – 12 percent in 1998 and 1999. Crash rates were more pronounced relative to the median crash rate for Arizona counties, indicating that crash rates in Gila County exceed those of more than half the counties in Arizona. Fatality rates in Gila County were also high relative to other Arizona counties, exceeding the average and median county fatality rates for all years measured.

Pinal County had a crash rate lower than the average and median crash rates in Arizona counties for all years shown in Table 10. However, fatality rates were higher in Pinal County relative to other counties, particularly in more recent years. For the three year period, estimated economic losses due to traffic crashes averaged 5.5¢ per mile of travel in Gila County and 4.7¢ per mile in Pinal County. In comparison, Arizona counties had an average crash-related economic loss of 4.4¢ per mile and a median loss of 4.2¢ per mile.

Countywide crash rates do not reflect the distribution of crashes within a county. Crash frequency and severity can vary substantially among local jurisdictions. Reported crashes for 1997 to 1999 are summarized for CAAG region counties (Gila and Pinal) by jurisdiction in Table 11. In both Gila and Pinal Counties, the majority of crashes were observed on rural roads, outside of incorporated areas. These locations also had the largest number of fatalities observed during this period. Excluding rural roads, crash frequency tended to have a direct relationship to population by jurisdiction. However, observed fatalities did not exhibit such a direct relationship, possibly due to relative differences in density, prevailing speeds and vehicle occupancy.

Excluding Indian reservations, for which complete data were not available, reported crashes in Gila County increased by an average of 2.7 percent annually over the three-year period. Crashes in Globe increased by an average annual rate of 9.7 percent, while crash frequency in Payson averaged a 21.5 percent annual increase. Miami had the largest relative change in crash frequency, averaging a 45 percent increase on an annual basis. Reported crashes on rural roads decreased slightly, but made up the majority of fatalities in most periods. The San Carlos Indian Reservation had a particularly high number of fatalities relative to the number of crashes reported in 1998 and 1999. However, it is not clear whether this disparity represents an actual hazard or incomplete reporting.

Overall, the frequency of reported crashes in Pinal County remained constant from 1997 to 1999. Reported crashes decreased on an annualized basis in Casa Grande and Mammoth, and on rural roads. Year-over-year increases were reported in Apache Junction and Eloy, while considerable variance in crash frequency was observed in Superior and Coolidge. Crash data recorded for the Gila River Reservation were incomplete, but a high proportion of fatalities relative to total crashes was reported, just as for reservations in Gila County. The majority of fatalities were observed on rural roads in Pinal County, though high relative frequencies were observed in Apache Junction in 1998 and Eloy in 1999.

Table 11: Reported Crashes and Fatalities, Gila and Pinal Counties, 1997 to 1999

Jurisdiction	1997		1998		1999	
	Crashes	Persons Killed	Crashes	Persons Killed	Crashes	Persons Killed
Gila County						
Globe	162	3	180	1	195	0
Hayden	3	0	3	0	4	0
Miami	18	0	38	0	30	0
Payson	116	0	183	0	156	0
Winkelman	0	0	4	0	1	0
Ft. Apache Reserv.	n/a	n/a	25	1	30	2
San Carlos Reserv.	n/a	n/a	19	5	46	11
State Rural Roads	612	17	537	8	556	10
Other Rural roads	120	6	149	4	145	1
Subtotal Gila County	1,031	26	1,138	19	1,163	24
Pinal County						
Apache Junction	388	3	405	9	413	1
Casa Grande	594	3	594	2	580	5
Coolidge	73	0	63	0	89	0
Eloy	86	2	123	2	138	7
Florence	60	1	66	1	61	1
Gila River Reserv.	n/a	n/a	226	7	224	11
Kearny	3	0	6	0	2	0
Mammoth	12	1	11	0	9	0
Superior	25	0	46	0	20	0
State Rural Roads	1,053	31	889	44	1,022	44
Other Rural roads	587	24	556	18	572	20
Subtotal Pinal County	2,881	65	2,985	83	3,130	89
Total	3,912	91	4,123	102	4,293	113

Source: *Arizona Motor Vehicle Crash Facts*, Motor Vehicle Crash Statistics Unit, Arizona Department of Transportation, 1998-2000.

Of the crashes shown in Table 11, a portion were likely observed at repeat locations. While some crashes are outside the reporting of local jurisdictions, and thus not captured by the Arizona Local Government Safety Project Model, it is likely that several local jurisdictions will have sites at which an unusually high frequency and/or severity of crashes were observed. A test run of the Arizona LGSP model was run for CAAG region jurisdictions in an attempt to identify these sites. The preliminary results for the CAAG region are contained in the following section.

Site Identification: CAAG Region

Separate iterations of the LGSP model were run for Gila and Pinal Counties. Both county-level analyses included all sub-level jurisdictions. Crash data were not restricted by alcohol involvement, but were limited to calendar years 1995 to 1999. Although some data for calendar year 2000 were available, this data set remained incomplete at the time of this analysis.

Crash sites were aggregated according to the Junction methodology for all routes intersecting a reference point. The preliminary run of the model used an aggregation radius of 100 feet. Results were sorted according to the total number of crashes observed at each location. Run time for the Gila County update was 5 minutes, while the Pinal County update required 13 minutes.[15]

Results for each county are shown in Tables 12 and 13, sorted according to number of crashes and sub-level jurisdiction. Initial Priority List results were further restricted according to the estimated cost associated with crashes at each location. Gila County locations shown in Table 12 were limited to sites with total estimated costs of $250,000 or more, and Pinal County sites were included only if costs were $500,000 or greater. These restrictions were imposed to refine the lists by approximated crash severity at each location.[16]

As shown in the tables, the total incidence reporting method tends to return results for larger communities, which is likely due to the higher traffic levels observed in areas of greater population. The lower frequency of crashes at Gila County sites relative to Pinal County sites supports this assumption.

Among jurisdictions with more than one crash location (Globe, Apache Junction and Casa Grande), crashes tended to be more costly on a per-incident basis in Globe. Excluding fatal crashes, Globe had the highest average cost/crash and cost/injury measures as well.

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[15] Run time figures were obtained using a machine with a 700MHz Pentium III processor and 128Mb RAM. Results will vary depending on processor speed, available memory and disk access speed.

[16] More complicated versions of this screen can be done by selecting the "Total Fatalities and Injuries" or "Weighted by Severity: Cost" options in the LGSP model INPUTS form.

Table 12: CAAG Case Study, Gila County Priority Locations, 1995 to 1999

Jurisdiction[1.]	Route Identifiers [2.]:		Avg Dist (feet) [3.]	Severity Measures:				
	Primary	**Secondary**		**Crashes**	**Vehicles**	**Fatalities**	**Injuries**	**Cost[4.] $000**
Globe	Willow St.	Broad St.	1.5	40	77	0	29	$1,259
	Ash St.	3rd St.	7.3	26	51	0	18	$866
	Sycamore St.	Hill St.	17.5	26	50	0	3	$264
	Cedar St.	Broad St.	13.2	19	35	0	11	$352
	Ash St.	7th St.	37.8	15	28	0	12	$505
	High St.	Ash St.	6.4	14	25	0	9	$486
	Broad St.	Blake St.	25.4	12	29	0	19	$482
	South St.	Ash St.	15.0	11	22	0	10	$336
	East St.	Ash St.	12.5	11	22	0	10	$302
	Murphy St.	Broad St.	21.7	10	18	0	6	$444
	Mesquite St.	Broad St.	20.9	9	13	2	4	$2,718
	Oak St.	Broad St.	12.6	9	18	0	4	$264
	Willow St.	Oak St.	4.5	8	11	0	6	$372
Payson	Longhorn Rd.	Colcord Rd.	29.8	11	24	0	5	$251

Notes: (1.) Jurisdiction refers to most specific level of government relevant to crash location. In this case, only crashes from Globe met the criteria for inclusion. (2.) Route identifiers only serve to locate a specific reference point, and do not indicate route on which the crash occurred (see crash details for this information). (3.) Average distance from reference point of all crashes recorded at a particular location. (4.) Costs calculated using estimates from ADOT Traffic and Engineering (2000), adapted from FHWA (1994). Results in this table have been limited to locations with total cost estimates greater than $250,000.

Table 13: CAAG Case Study, Pinal County Priority Locations, 1995 to 1999

Jurisdiction[1.]	Route Identifiers [2.]:		Avg Dist (feet) [3.]	Severity Measures:				
	Primary	Secondary		Crashes	Vehicles	Fatalities	Injuries	Cost[4.] $000
Apache Junction	Ironwood Dr.	Apache Trail	18.8	117	245	1	71	$4,522
	Delaware Dr.	Apache Trail	9.8	76	148	1	57	$4,744
	Winchester Rd.	Old West Hwy.	3.7	57	111	0	41	$1,353
	Old West Hwy.	Idaho Rd.	17.4	48	96	0	16	$775
	Phelps Dr.	Apache Trail	12.5	46	96	0	19	$822
	Ocotillo Dr.	Apache Trail	12.0	36	70	0	15	$827
	Palo Verde Dr.	Apache Trail	16.6	32	59	0	11	$658
	Ironwood Dr.	Baseline Ave.	2.0	31	65	0	29	$1,029
Casa Grande	Trekell Rd.	Florence Blvd.	20.3	115	240	0	53	$1,615
	Florence Blvd.	Colorado St.	32.0	106	214	0	61	$1,800
	Pueblo Dr.	Florence Blvd.	25.2	81	170	0	51	$1,190
	Pinal Ave.	Cottonwood La.	15.7	67	132	0	25	$966
	Trekell Rd.	Cottonwood La.	10.7	60	124	0	28	$664
	Peart Rd.	Florence Blvd.	10.8	55	110	0	33	$815
	Florence Blvd.	Cameron Ave.	16.8	53	111	0	27	$692
	Trekell Rd.	McMurray Blvd.	3.5	49	101	0	38	$676
	Pinal Ave.	Florence Blvd.	4.6	46	90	0	27	$551
	Florence Blvd.	Amarillo St.	22.5	43	91	0	20	$672
	Florence St.	2nd St.	13.4	35	65	0	13	$503
Coolidge	Coolidge Ave.	Arizona Blvd.	17.1	32	70	0	29	$794

Notes: (1.) Jurisdiction refers to most specific level of government relevant to crash location. (2.) Route identifiers only serve to locate a specific reference point, and do not indicate route on which the crash occurred (see crash details for this information). (3.) Average distance from reference point of all crashes recorded at a particular location. (4.) Costs calculated using estimates from ADOT Traffic and Engineering (2000), adapted from FHWA (1994); limited to locations with total cost estimates greater than $1,000,000.

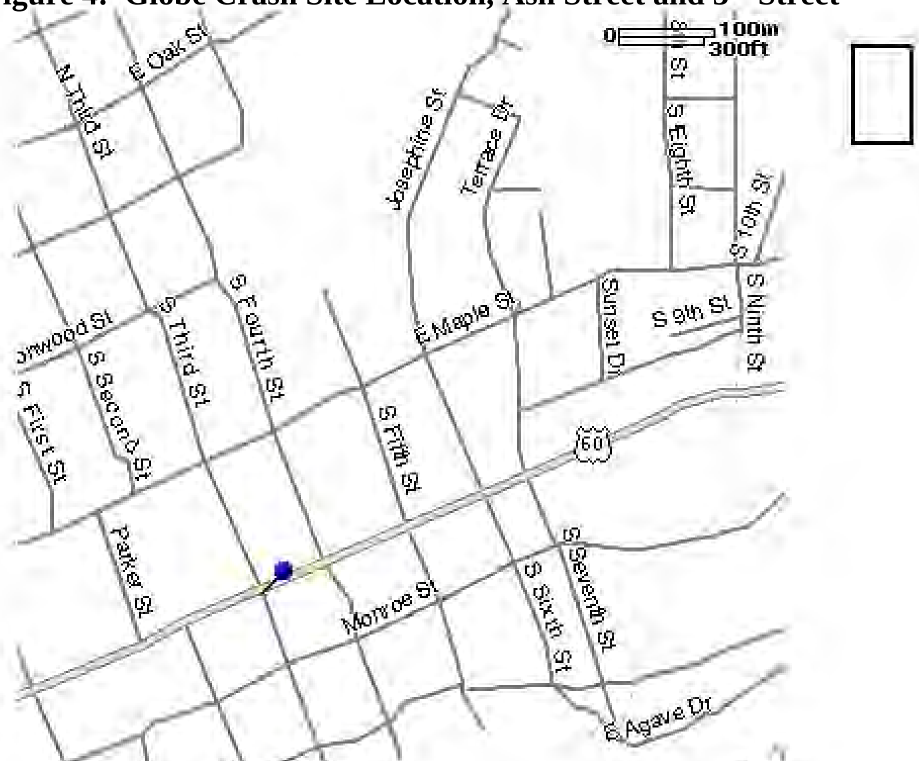
Sample Crash Site Analysis

As a sample of available data, a site location in Globe was arbitrarily chosen for additional analysis. The Ash Street and 3rd Street location was selected from priority list locations in Globe. From 1995 to 1999, a total of 26 crashes involving 51 vehicles were recorded within a 100-foot radius of this location. Eighteen persons were injured, but no fatalities were recorded. Crashes meeting the aggregation criteria were distributed among the years of analysis as follows: 4 crashes in 1995, 2 in 1996, 5 in 1997, 5 in 1998, and 10 in 1999. [17]

Crashes reported at Ash Street and 3rd Street averaged 0.7 persons harmed per incident and 0.4 persons harmed per vehicle (unit) involved. The average estimated cost per incident was $33,300; the average cost per injury was $48,100. Excluding fatal crashes in Globe, the estimated costs per crash and per injury at Ash and 3rd Streets are slightly higher than the jurisdiction average.

Note that Ash Street is the local designation for US highway 60. A map of the immediate vicinity is shown in Figure 4.

Figure 4: Globe Crash Site Location, Ash Street and 3rd Street



Source: Mapquest, 2001

[17] Crash records sorted by year are available from the Priority Locations Record List

A summary of crash location details for the Ash Street and 3rd Street site in Globe returned the following information:

- Results were location specific, averaging 7.3 feet from the reference point with a maximum distance of 46 feet
- Virtually all crashes, 25 of 26, occurred on Ash Street, and over 77 percent were intersection-related
- Ninety-six percent of crashes occurred between two motor vehicles; one single-vehicle, fixed-object crash was recorded
- Eleven crashes were rear-end collisions, 11 were angle collisions, and 2 were sideswipe collisions
- Average vehicle speeds (15 mph) were below the average posted speeds (29 mph), but above the average safe speed (2.5 mph) recorded by the reporting officers; this indicates that failure to stop or yield may have been a factor in several crashes
- Of the 51 vehicles involved, 33 were going straight ahead, 9 were turning (left, right, or U-turns), 7 were stopped in the traffic way, and 2 were passing or changing lanes
- Most vehicles were in motion, but the 7 stopped vehicles were either waiting for a traffic signal change (43%) or waiting for other vehicles to clear the traffic way (57%)
- Twenty-nine violations were recorded, of which 14 were evenly split between "inattention" and "disregarded traffic signal" categories, 5 were "failure to yield," and 9 were related to speeding or following too closely
- In all cases but one, traffic signals were functional
- Driver vision was obscured by parked vehicles in two cases

The Comparison Sites report generates a list of sixteen junctions comparable to the Ash Street and 3rd Street location. These locations have an average annual crash incidence of 2.14, with a standard deviation of 2. The annual crash incidence at the Ash Street and 3rd Street location exceeds the average for comparable locations by roughly 1.5 standard deviations. However, as these figures do not include traffic volumes, assessments of relative risk should be considered with caution.

The number of rear-end crashes, inattention and failure to obey traffic signals suggests that a portion drivers were not properly assessing the intersection controls at this location. This could indicate that changes or improvements to traffic signals, signs, or pavement markings would be effective at the Ash and 3rd Street location. Although virtually all control devices were functional, one treatment hypothesis might be that the controls are not optimal for the traffic flow at this location.

Driver speed was determined to exceed safe speeds in many cases. Because Ash Street is a US highway, it is plausible that this location receives a large amount of non-local through traffic. Another hypothesis could be that many highway users passing through this location are not aware of the amount of cross-street traffic, and assume that driving conditions will more closely reflect highway conditions than local street conditions. In such a case, early placement of traffic warning or speed reduction signs might convey the information needed to reduce crashes. Speed enforcement zones some distance from the location might also create a “buffer” of lower speeds as drivers react to the enforcement zone.

A sample safety improvement project for this location was entered to demonstrate the project evaluation criteria in the LGSP model. It should be noted that traffic or site engineering analyses were not done for this location. The treatment selected reflects a hypothetical scenario, and should not be interpreted as a safety project recommendation.

The hypothetical safety improvement scenario assumed that a significant cause of crashes at Ash and 3rd Streets was due to signal design. A recent study (Sayed *et al.*, 1998) determined that use of larger traffic signal heads could significantly reduce crash incidence at signalized intersections. For the sake of this hypothesis, it was assumed that the Ash and 3rd Street location was fitted with older, smaller traffic signal heads, and that the recurring incidence of driver disregard for signals suggested that the Sayed findings might be applicable in this situation.

The sample safety project evaluation is shown on the following page. The project selected was an upgrade of signals at the Ash and 3rd Street location. Upgrade cost was estimated at $70,000, annualized over a 10-year capital recovery period at an interest rate of 8 percent.

Crash reduction factors were left as the default values generated by the LGSP model (i.e. 50 percent of attainable reductions). Injury and PDO crashes were thus estimated to be reduced by 11 percent, which yielded an annual crash reduction benefit of $14,256. This benefit exceeded annual project implementation costs of $10,430, giving the signal upgrade treatment a benefit-cost ratio of 1.37.

Hypothetical Safety Project Evaluation Report

PROJECT NUMBER	**Test 1**	**Date**	**4/3/01**	**Alternative**	**1**
Primary Route	ASH			ST	
Secondary Route	3RD			ST	
Project On Route	Ash	**From MP**	0	**To MP**	0

Safety Project Details

Project Class	INTERSECTIONS & INTERCHANGES		
Project Category	Revamped signals		
Project Description	Signal upgrade, test project 1		
Benefit/Cost Ratio	**1.3668**	**Annual Benefit:**	**$14,256**
BCR In Range?	**YES**	**Annual Cost:**	**$10,430**

Safety Project Benefits

Crash Type	Annual Incidence	Reduction Factor	Annual Reduction	Severity Cost	Annual Benefit
Fatal	0.0000	20.0%	0.0000	$2,600,000	$0
Incap. Injury	0.6000	11.0%	0.0660	$180,000	$11,880
Non-incap. Injury	0.0000	11.0%	0.0000	$36,000	$0
Possible Injury	0.8000	11.0%	0.0880	$19,000	$1,672
Property Dmg. Only	3.2000	11.0%	0.3520	$2,000	$704
			Total Annual Benefit:		**$14,256**

Safety Project Costs

Assumptions:		**Total Construction Cost**	$70,000
Capital Recovery Factor	0.149	**Annual Construction Cost**	$10,430
Interest Rate	8.0%	**Annual Maint. Cost**	$0
Project Life (Years)	10	**Annual Project Cost**	**$10,430**

V. Conclusions and Recommendations

This research is intended to address the challenges faced by local governments in identifying treatment sites for safety program funding. Traffic safety programming is a multiple-step process, in which data must be collected and analyzed to determine where problems are occurring, what types of problems are occurring, and what treatments might have the potential to remedy these problems. Once potential treatments have been identified, additional decisions must be made regarding available funds and the relative benefit to be obtained from each potential safety improvement. Because this is a time-consuming process, many local governments in Arizona do not regularly determine candidate projects for safety program funding, even though federal aid may be available for these projects.

This report addresses these concerns in a number of ways. First, background information has been collected and summarized for many of the facets involved in the identification of hazardous locations, the selection of treatment strategies, and the evaluation of potential projects. Using this information as a base from which to start, an automated model was then designed to facilitate the site selection and project evaluation portions of the local safety programming process. The Arizona Local Government Safety Project Implementation Model was designed as a tool for aiding local governments in this process by automating the following procedures:

- Identification of hazardous locations in a jurisdiction;
- Prioritization of those sites by user-defined parameters;
- Aggregation of details for crashes at each site, including estimated economic costs of crashes observed;
- Statistical summaries of crash rates and variance for each site, with the option to evaluate data adjusted for user-input traffic volumes;
- Identification of comparable locations in a jurisdiction for before-after treatment comparisons;
- Input and formatting of potential safety projects for further analysis;
- Evaluation of safety project alternatives to determine benefit-cost ratios
- Reporting of data in user-friendly formats, following project submittal guidelines

The Arizona LGSP model provides an effective and rational means of selecting and prioritizing hazardous local sites, and evaluating safety treatment strategies. The model's project evaluation routine allows multiple projects to be analyzed at once, with minimal run time, providing opportunities to revise site selection and project characteristics throughout the programming process. It is important to note that the Arizona LGSP model is intended as a *tool*, not as a replacement for the expertise of a traffic engineer. By automating the collection and preliminary analysis of crash records, the LGSP model affords local traffic engineers more time to evaluate hazardous locations and select appropriate safety improvements.

Several improvements could be made to the Arizona LGSP model as the required data become available. Note that most of these options were considered for the preliminary design, but were rejected due to constraints in available data or policy requirements. The following revisions could improve the functioning or utility of future versions of the LGSP model:

- Coordination of traffic data with crash locations as Arizona HPMS coverage increases;
- Inclusion of geographical coding or spatial reference data to identify sites visually and to augment the fixed-point method of site identification;
- Change from costs per crash to costs per injury to allow for the variance in vehicle and occupant involvement by location;
- Conversion of crash data to smaller CD files (county level) to speed model updates

Implementation of the first two items would allow the model to provide additional data that many jurisdictions might find useful. However, at the time of development, these data sets remained incomplete. Estimated costs per injury were removed from the first version of the Arizona LGSP to comply with reporting requirements for HES program funding eligibility. The last item may be easily accomplished by local governments as crash data files are updated. Using smaller data files would reduce the amount of time required for Arizona LGSP updates, making adjustments easier to perform.

Use of the Arizona LGSP model is voluntary, and is not required of any jurisdictions applying for safety program funding in Arizona. However, users of the LGSP model should find that it significantly reduces the amount of time required for preliminary data collection and analysis. In addition, the model contains reference values for project assessment variables such as economic costs of crashes according to severity, capital recovery factors for annualizing safety project expenditures, project life cycles by type, and estimated reduction in crashes that may be obtained for a variety of safety improvements. Finally, the model generates a variety of location, crash and project reports that should prove useful for safety program funding applications.

It should be noted that few analyses or implementation strategies can be completed solely through the use of automation or centralized research. This research provides a useful tool for simplifying the process, but the key responsibility for translating this information into appropriate countermeasures rests with local officials and traffic engineers.

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Appendix A: Arizona Local Safety Project Model User Instructions

The Arizona Local Government Safety Project Implementation Model (LGSP model) was created in MS Access 97. The model consists of a self-contained query and reporting database, and a supplemental database of crash records on CDROM. Running the model requires the following hardware and software:

- Microsoft Office 97: Access, Word and Excel programs
    - MS Access must be loaded with the "Linked Table Manager" add-in
- CDROM drive or network access
- Approximately 32Mb RAM and 100Mb hard disk space

The model is computation-intensive, and will require a significant amount of time to run on machines with slower processors. On processors slower than 500MHz, it is particularly important that additional programs be closed while the update is being run. The amount of time required for a complete update of the model will vary with the power of the machine used, the speed of CDROM or network data transfer, and the size of the jurisdiction(s) being analyzed. It is recommended that smaller units of analysis (e.g. a single city rather than an entire county) be examined separately whenever possible.

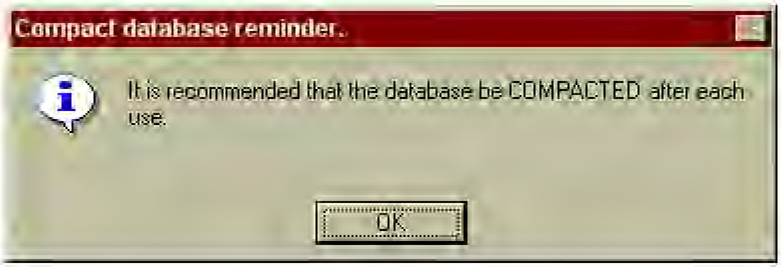
A discussion of the assumptions and procedures of the LGSP model can be found in Section III. of this report. This appendix contains instructions for using the LGSP model, illustrations of available outputs, and suggestions for speeding up the analyses. The first section of this appendix provides an illustrated, step-by-step account of user inputs, data screens and model capabilities. The second section discusses the framework of the LGSP classification procedure, and relationships between the various database elements. A discussion of procedures for creating and formatting new crash data files in contained in Appendix B.

Arizona LGSP Model Step-by-Step Procedures

When opened, the LGSP model first displays two messages for the user. The first message box is a reminder that the CD containing crash records must be loaded for the model to function properly. Previously generated reports may be viewed without the CD, but no new analyses can be completed without the crash data files.[18] Users that have stored crash data on a network drive may ignore this warning.

[18] Refer to Appendix B for instructions on creating a new crash data file in the proper format.

The next message that appears is a reminder to *compact* the database periodically. Because many of the LGSP queries rewrite data tables, the file will grow each time it is run. Compacting the database will condense empty spaces (deleted tables), reducing the size of the file and improving performance. To compact the database, let the STARTUP screen (see below) load, and then select **Tools** > **Database Utilities** > **Compact Database** from the menubar.



NOTE: The first time the model is opened, the crash data tables will need to be updated before use. To update all linked tables, use the Linked Table Manager located in **Tools > Add-Ins > Linked Table Manager. This will open the dialog box shown on the next page. To refresh the linked data, press the "Select All" button, and then select a new file name and/or location for the linked tables.

Example: The figures on the next page illustrate the linked table update for CDROM drive E:\. After opening the Linked Table Manager dialog and selecting all tables, drive E:\ is opened in the New Location dialog box (update step 2). The "CRASHDATA.mdb" file is selected, and then the "Open" button pressed. Because all linked files are located in the CRASHDATA file, the remaining tables will automatically be refreshed.

This process must also be completed if a new crash data file is to be analyzed. For example, if the user wishes to replace "CRASHDATA95-99.mdb" (i.e. the calendar 1995 to 1999 data file) with a new file "CRASHDATA96-00.mdb," the tables must be refreshed with the new file name. This requirement can be avoided if all crash data files are given the same name. However, such a practice makes the files difficult to organize.

Figure 5: Crash Data Linked Table Update, Step 1

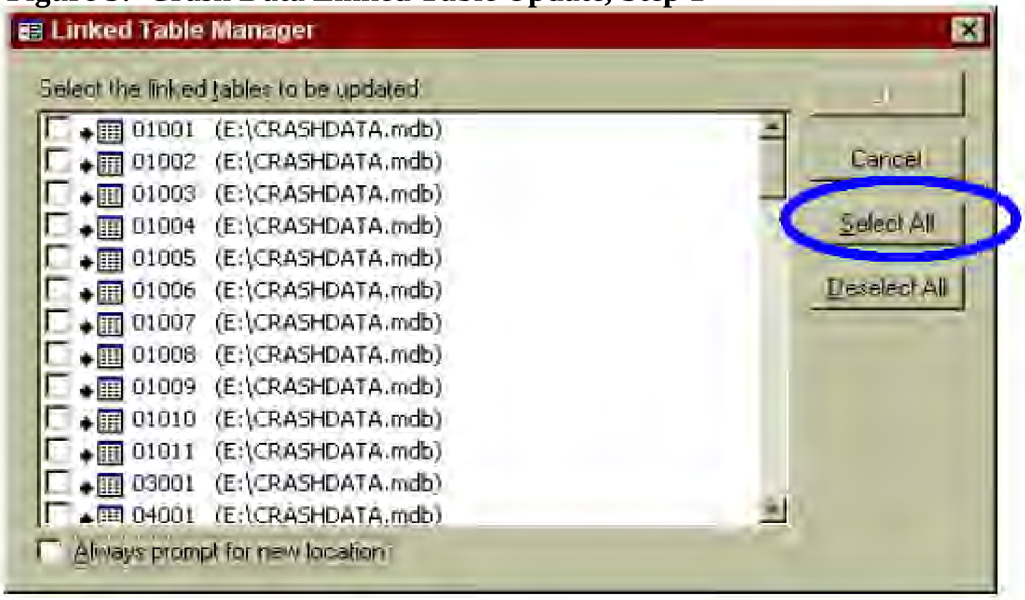
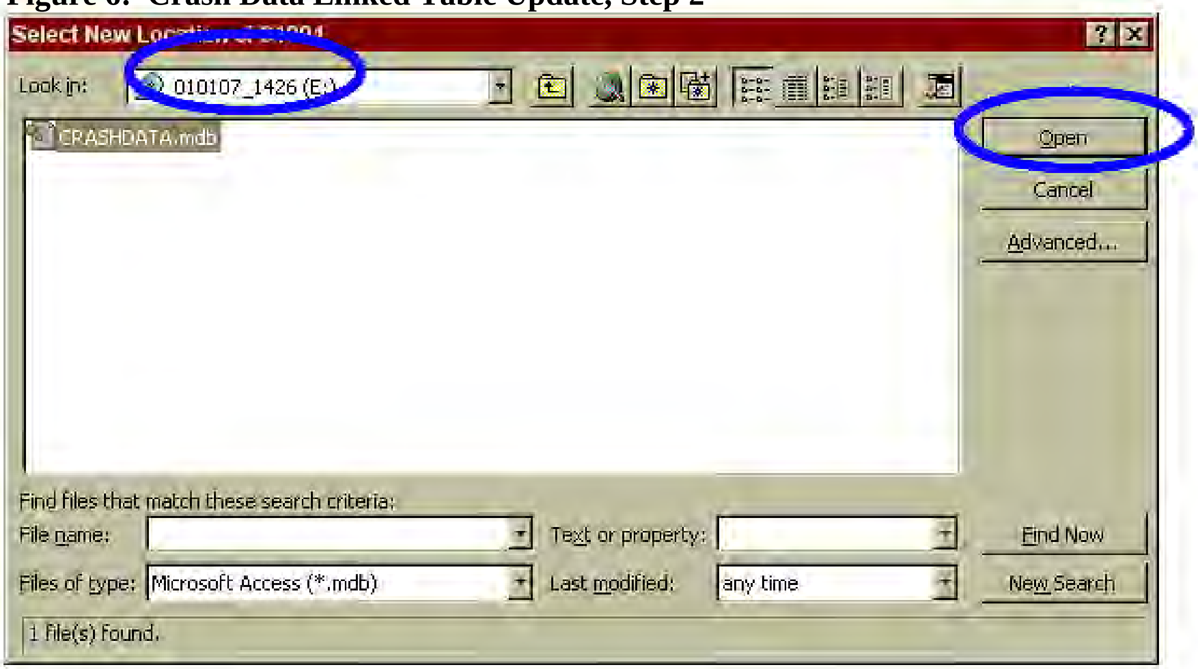


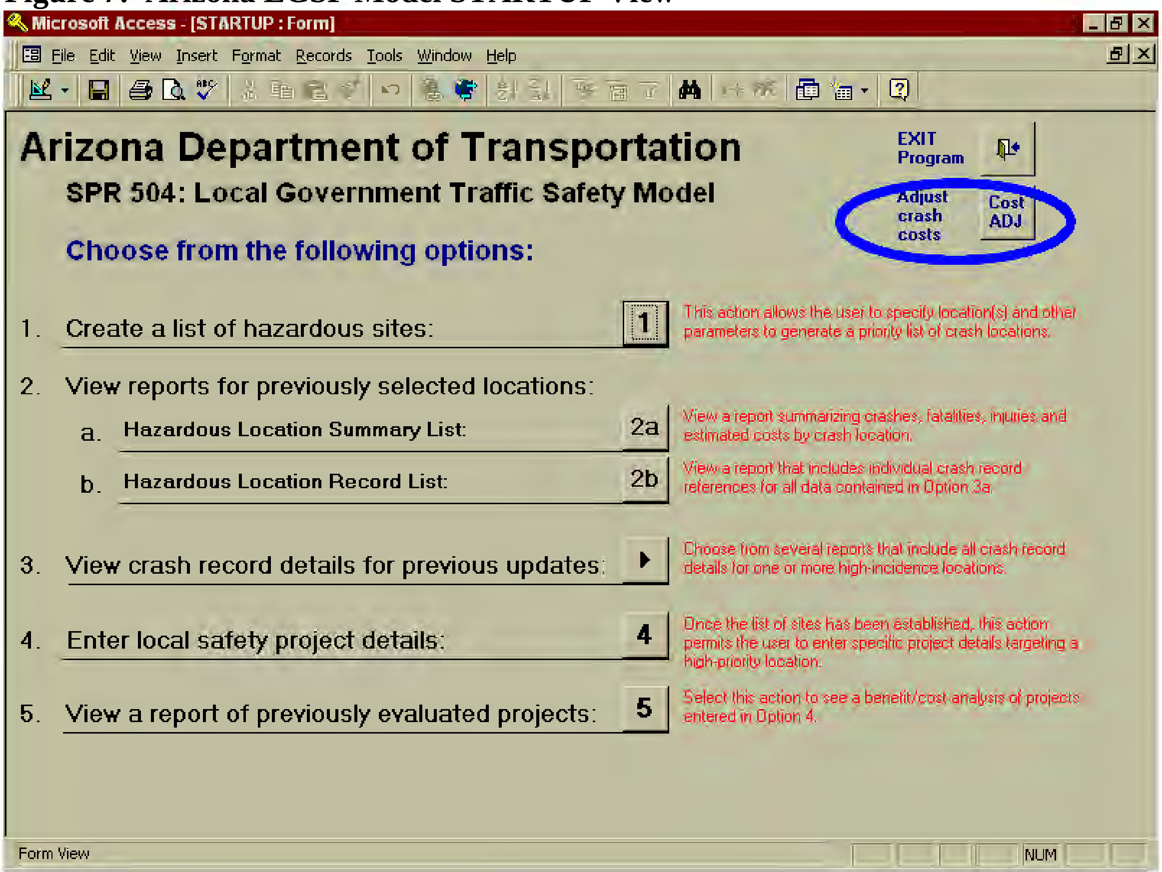
Figure 6: Crash Data Linked Table Update, Step 2



STARTUP Form

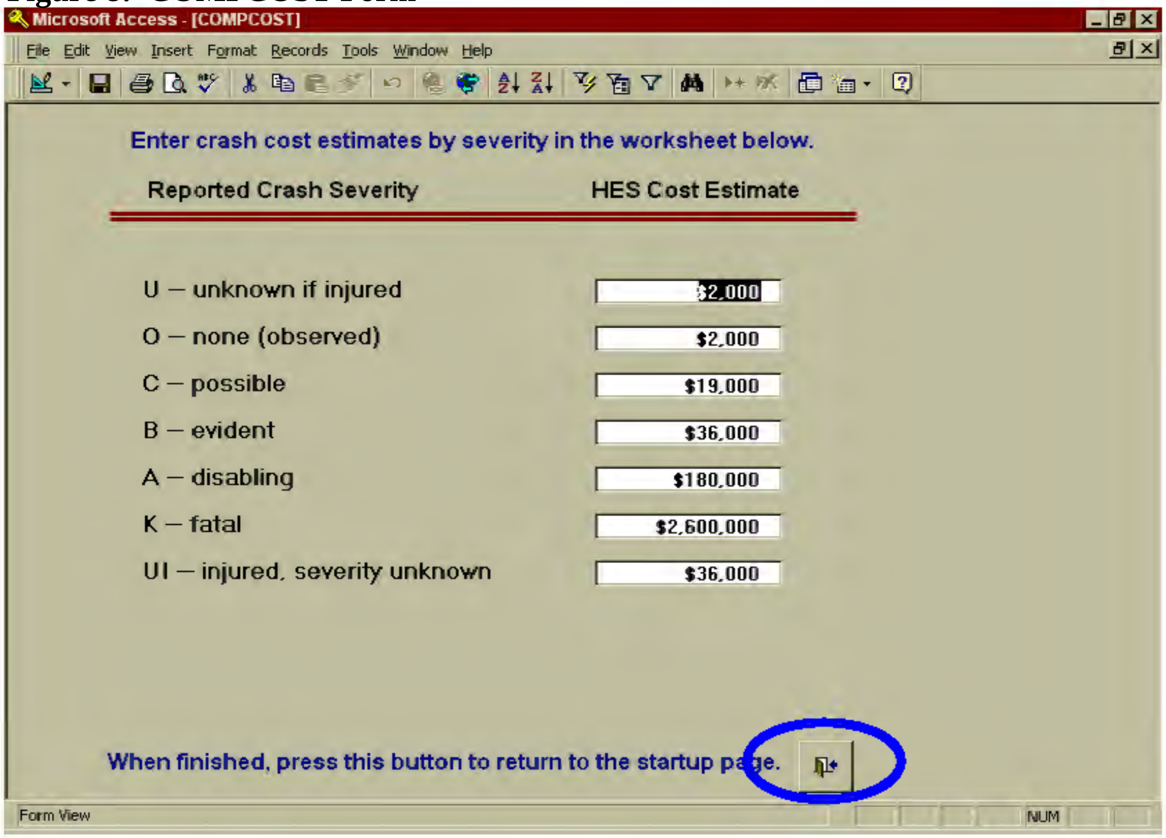
Once the database has been opened, and compacted or refreshed as necessary, the STARTUP view form will appear (Figure 7). This form provides an outline of the available procedures in the LGSP model, and will reappear at the end of each option procedure chosen. The LGSP model should be accessed using the buttons shown on each screen whenever possible. For example, the "EXIT Program" button will close the database from the STARTUP screen, and other forms contain an "EXIT to Start" button that will return the user to the STARTUP screen.

Figure 7: Arizona LGSP Model STARTUP View



In addition to the five STARTUP options in the numerical outline, the user can also adjust the cost estimates for crashes of varying severity used in the benefit-cost analyses. Because this procedure should be done prior to running a new update, it is shown prior to the update procedures. To access the crash costs page, press the "Cost ADJ" button circled on the STARTUP form shown above. The COMPCOST form, shown in Figure 8 will be opened. This form allows the user to adjust the average estimated *total* cost of a crash depending on the maximum severity observed. The format follows the HES eligibility guidelines used by the Arizona Department of Transportation. These figures are posted on the Internet, and are also available from ADOT Traffic and Engineering.

Figure 8: COMPCOST Form



After adjusting crash costs as necessary, the "Exit" button (circled in Figure 8) will return the user to the STARTUP page. From the STARTUP outline, the following choices can be made:

1. Run the entire update and prioritization procedure to select potentially hazardous sites. This option also allows the results of a previous update to be re-sorted by new parameters. Pressing **Button 1** will open the **INPUTS** form.
2. Buttons 2a and 2b open summary reports for the most recent run of the model. **Button 2a** opens the **PRIORITY LIST** report, which summarizes the top twenty-five hazard locations, sorted by the parameters selected in the previous update. **Button 2b** opens the **RECORD LIST** report for the locations summarized in the PRIORITY LIST. The RECORD LIST contains individual summaries for each crash record at a high-priority location.
3. Button 3 is linked to multiple options for viewing and/or exporting crash record details. Pressing **Button 3** opens the **LOC_DTL** form, in which additional options are presented.
4. **Button 4** opens the **Safety Project Details** form, used to input safety project ideas once sites and potential treatments have been identified.

5. **Button 5** opens the **Project Evaluation Report** containing an analysis of effectiveness and benefits versus costs for project entered in option 4.

<u>Option 1: INPUTS Form</u>

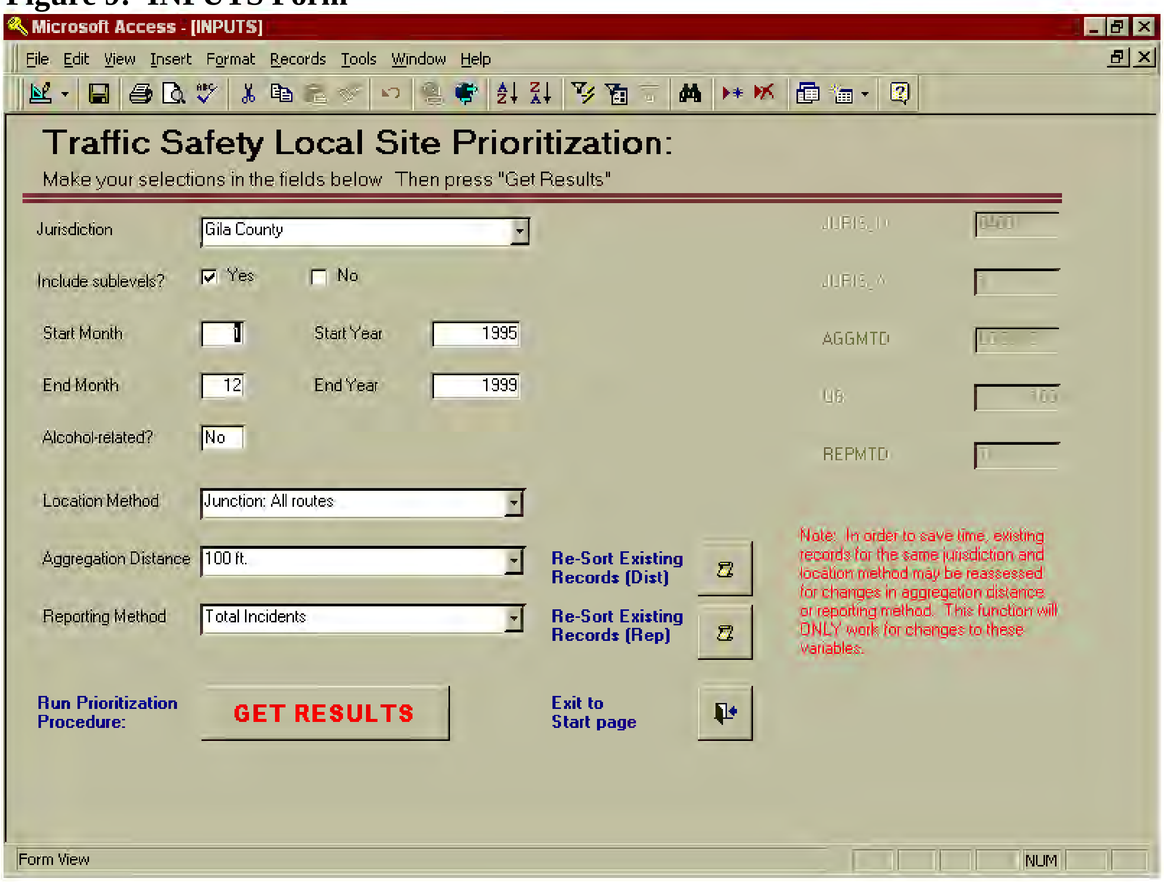
Pressing Button 1 on the STARTUP page opens the INPUTS form, which allows the user to specify criteria for selection of hazardous roadway sites. Each option is linked to a reference table, and the option selected is copied to the INPUTS table.

a. To create a list of high-priority (i.e. hazardous) sites, the user must specify a jurisdiction of analysis. This can be a county or city/town. In checkbox below the **Jurisdiction** menu, the user can specify whether to include cities and towns in the county-level analysis. For example, to include all jurisdictions in Gila County, the **Include sublevels** option would be set to "Yes."

b. Start and end dates must be entered in numerical format. In most cases, no more than five years of data will fit on a crash data CDROM. However, if the program is run over a network, there is no limitation on the number of years of data that could be included on a server-based crash data file.

c. To exclude **alcohol-related** crashes, type "No" in the appropriate box. To include all crashes, type "Yes." The default value for this option is "No."

Figure 9: INPUTS Form

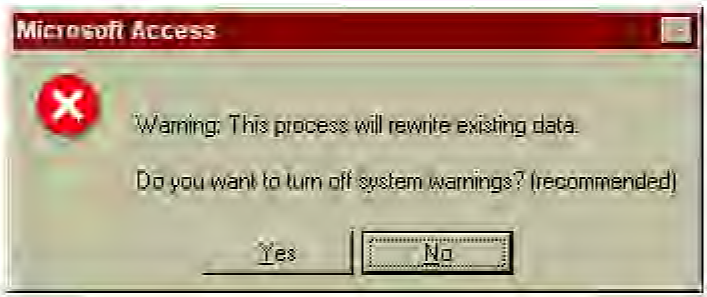


d. The **Location Method** menu provides four options for identifying a crash site, all of which rely on cross streets to identify the reference point. The "Route" method limits a site to crashes occurring on one route at a junction, whereas the "Junction" method aggregates all crashes at a junction regardless of route. The Junction method can be further refined by selecting "Junction-related" (all junction crashes classified as related to the junction and/or intersection) or "Intersection-related" (only the junction crashes specifically related to the intersection).

e. After specifying the site identification method, the **aggregation distance** must be selected. Aggregation distance refers to the radius from the cross street reference within which crashes will be included at that site. For example, selecting "500 feet" will include all crashes referencing a particular junction that occurred *no more than* 500 feet from that junction.

f. Finally, the user must specify the criterion used to prioritize hazardous locations. Again, four options are provided. The "Total Incidence" **reporting method** prioritizes sites by the number of crashes observed in the period of analysis. Similarly, the "Total Fatalities" and "Total Fatalities + Injuries" options rely on crash counts, but are filtered by ordinal measures of severity. The "Weighted by Severity" option is similar to the "Total Fatalities + Injuries" option, except that the relative differential of severity in terms of crash costs is also considered.

Once the user inputs have been specified, the **GET RESULTS** button will run the prioritization procedure (the TRAFSAF macro). This process can take anywhere from 10 minutes to several hours, depending on the jurisdiction(s) selected an the speed of the computer used. When the TRAFSAF macro begins, the following message will be displayed:



Because the macro rewrites existing tables, the program will ordinarily verify that the previous information should be deleted. These verification messages will appear every few minutes while the model is running, and will stop the update until the user responds. By selecting the "YES" button, the delete warnings will be temporarily disabled while the TRAFSAF macro runs. This option speeds up the site identification procedure and allows the user to avoid constant monitoring of the update process. A notification message will still appear approximately halfway through the update to document progress thus far.

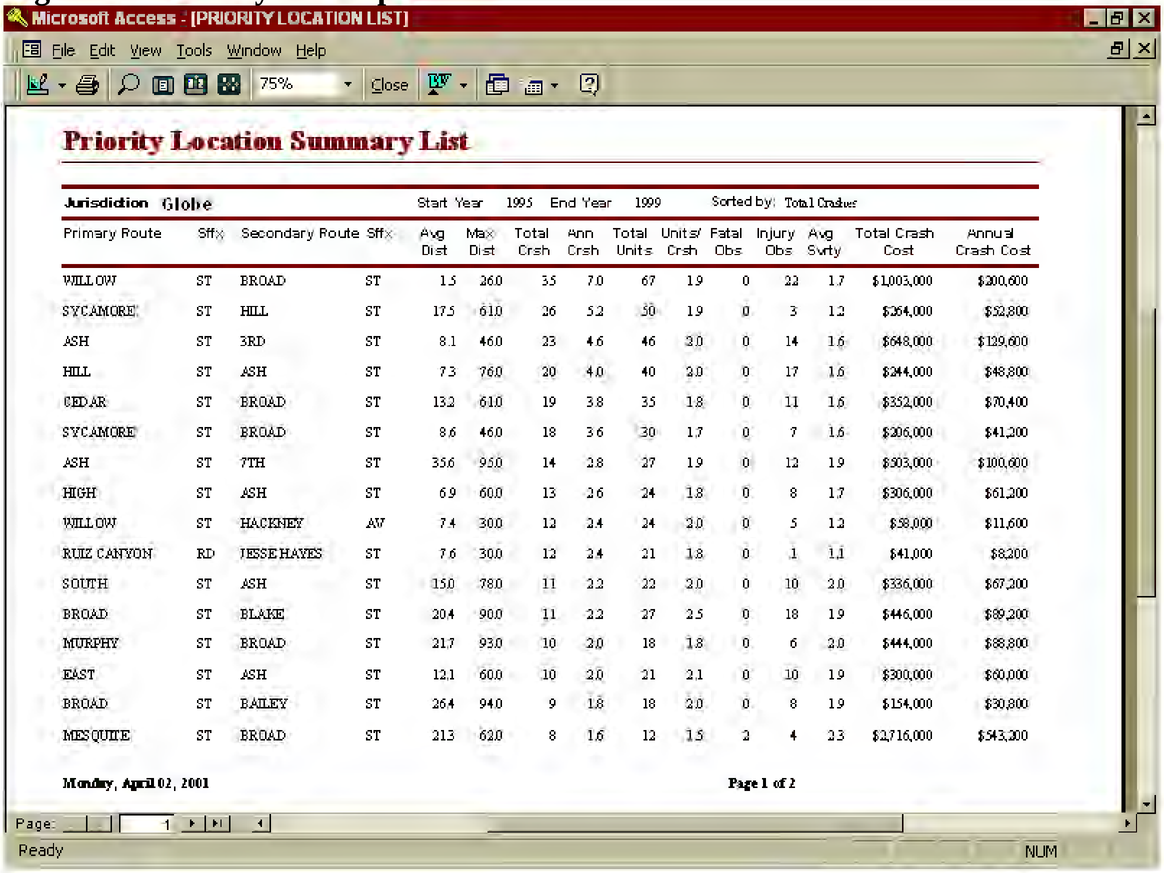
If the "YES" button is selected, the database windows will minimize and the LGSP model will appear inactive for some length of time. Again, it is recommended that no other programs be run until the PRIORITY LIST report appears at the end of the update.

After the initial run of the TRAFSAF macro, jurisdiction locations can be re-queried for new aggregation distances or reporting methods *without running the entire procedure* again. The macro action buttons next to the Aggregation Distance and Reporting Method menus can be used to re-sort locations. The time savings from using this method is greater than 50 percent. However, no other changes should be made prior to running these procedures. For example, changing the Location Method will cause the program to return invalid and/or incomplete data. These options are intended to facilitate the examination of existing data for a variety of scenarios, and should only be used after a full update procedure has been completed.

Option 2: Viewing Priority Location Reports

When the TRAFSAF macro has finished running, the **PRIORITY LIST** report will be displayed. If an update has already been completed, the PRIORITY LIST report can also be accessed by pressing **Button 2a** on the STARTUP menu. As shown in Figure 10, the PRIORITY LIST summarizes the results of the local site prioritization procedure, returning the twenty-five most hazardous locations as defined in the user inputs section. Locations are ranked by jurisdiction in descending order of importance as specified in the "Reporting Method" option. Crash incidence and severity measures are included for each location.

Figure 10: Priority List Report



Priority Location Summary List

Jurisdiction Globe   Start Year 1995   End Year 1999   Sorted by: Total Crashes

Primary Route	Sffx	Secondary Route	Sffx	Avg Dist	Max Dist	Total Crsh	Ann Crsh	Total Units	Units/ Crsh	Fatal Obs	Injury Obs	Avg Svrty	Total Crash Cost	Annual Crash Cost
WILLOW	ST	BROAD	ST	1.5	26.0	35	7.0	67	1.9	0	22	1.7	$1,003,000	$200,600
SYCAMORE	ST	HILL	ST	17.5	61.0	26	5.2	50	1.9	0	3	1.2	$264,000	$52,800
ASH	ST	3RD	ST	8.1	46.0	23	4.6	46	2.0	0	14	1.6	$648,000	$129,600
HILL	ST	ASH	ST	7.3	76.0	20	4.0	40	2.0	0	17	1.6	$244,000	$48,800
CEDAR	ST	BROAD	ST	13.2	61.0	19	3.8	35	1.8	0	11	1.6	$352,000	$70,400
SYCAMORE	ST	BROAD	ST	8.6	46.0	18	3.6	30	1.7	0	7	1.6	$206,000	$41,200
ASH	ST	7TH	ST	35.6	95.0	14	2.8	27	1.9	0	12	1.9	$503,000	$100,600
HIGH	ST	ASH	ST	6.9	60.0	13	2.6	24	1.8	0	8	1.7	$306,000	$61,200
WILLOW	ST	HACKNEY	AV	7.4	30.0	12	2.4	24	2.0	0	5	1.2	$58,000	$11,600
RUIZ CANYON	RD	JESSE HAYES	ST	7.6	30.0	12	2.4	21	1.8	0	1	1.1	$41,000	$8,200
SOUTH	ST	ASH	ST	15.0	78.0	11	2.2	22	2.0	0	10	2.0	$336,000	$67,200
BROAD	ST	BLAKE	ST	20.4	90.0	11	2.2	27	2.5	0	18	1.9	$446,000	$89,200
MURPHY	ST	BROAD	ST	21.7	93.0	10	2.0	18	1.8	0	6	2.0	$444,000	$88,800
EAST	ST	ASH	ST	12.1	60.0	10	2.0	21	2.1	0	10	1.9	$300,000	$60,000
BROAD	ST	BAILEY	ST	26.4	94.0	9	1.8	18	2.0	0	8	1.9	$154,000	$30,800
MESQUITE	ST	BROAD	ST	21.3	62.0	8	1.6	12	1.5	2	4	2.3	$2,716,000	$543,200

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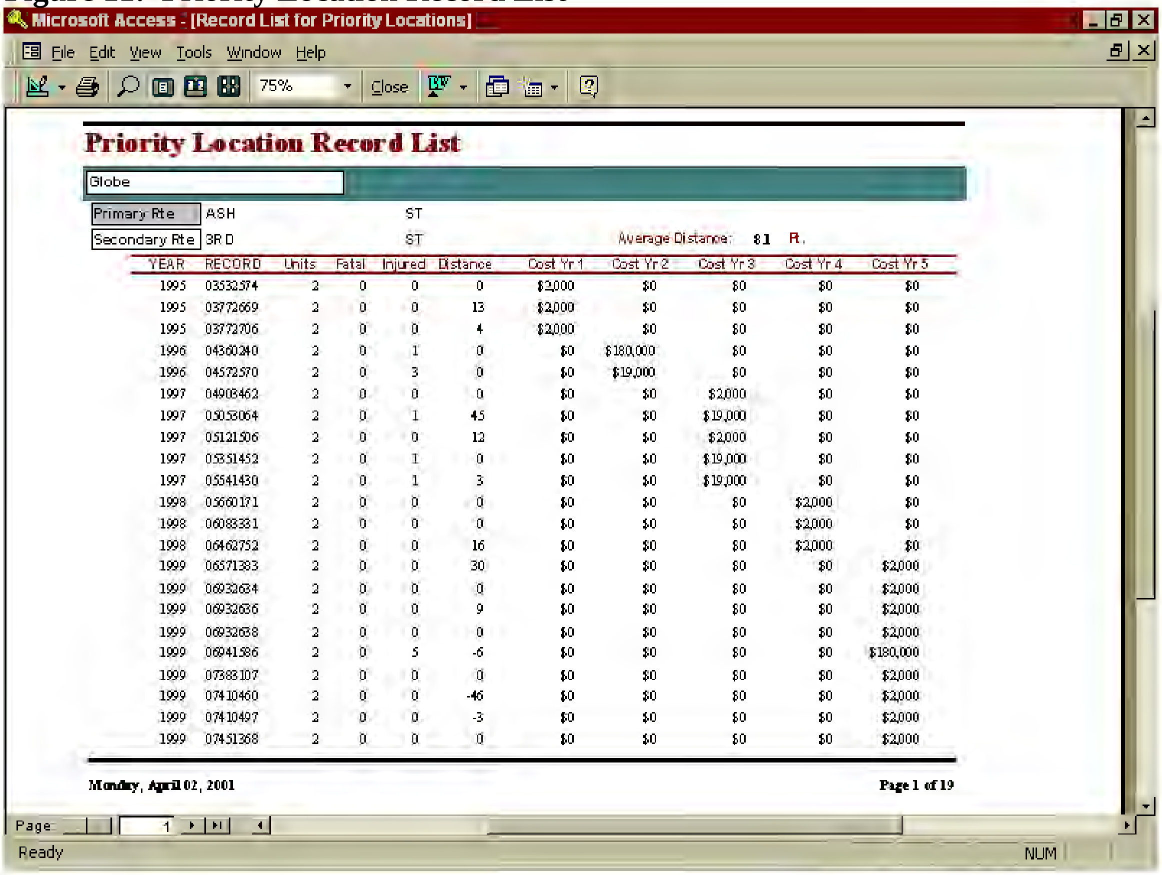
The PRIORITY LIST report can be printed or closed from the preview screen, but can not be modified. Closing the report returns the user to the STARTUP menu. If greater detail is required for the location summary, **Option 2b** can be run to open the **Priority Location Record List**. This report contains the same site location references as the Priority List, but each individual crash record is represented along with costs for each crash sorted by year of analysis.

The Priority Location Record List is also useful for gathering any additional data that may be required. Because crashes are indexed according to record number, a list of records provides a simple means of identifying items of interest. However, the record list report does not provide substantially different information than the Priority List report, and is intended only as a supplemental reference to be used as needed. Because the record list report can be quite long (e.g. records for Gila County locations shown in Figure 11 take up 19 pages), it is recommended that printing be done from the file menu (File > Print) and then specific page numbers selected for printing.

Figure 11: Priority Location Record List



Priority Location Record List

Globe

Primary Rte: ASH ST

Secondary Rte: 3RD ST

Average Distance: 81 ft.

YEAR	RECORD	Units	Fatal	Injured	Distance	Cost Yr 1	Cost Yr 2	Cost Yr 3	Cost Yr 4	Cost Yr 5
1995	03532574	2	0	0	0	$2,000	$0	$0	$0	$0
1995	03772669	2	0	0	13	$2,000	$0	$0	$0	$0
1995	03772706	2	0	0	4	$2,000	$0	$0	$0	$0
1996	04360240	2	0	1	0	$0	$180,000	$0	$0	$0
1996	04572570	2	0	3	0	$0	$19,000	$0	$0	$0
1997	04903462	2	0	0	0	$0	$0	$2,000	$0	$0
1997	05053064	2	0	1	45	$0	$0	$19,000	$0	$0
1997	05121506	2	0	0	12	$0	$0	$2,000	$0	$0
1997	05351452	2	0	1	0	$0	$0	$19,000	$0	$0
1997	05541430	2	0	1	3	$0	$0	$19,000	$0	$0
1998	05660171	2	0	0	0	$0	$0	$0	$2,000	$0
1998	06083331	2	0	0	0	$0	$0	$0	$2,000	$0
1998	06462752	2	0	0	16	$0	$0	$0	$2,000	$0
1999	06571383	2	0	0	30	$0	$0	$0	$0	$2,000
1999	06932634	2	0	0	0	$0	$0	$0	$0	$2,000
1999	06932636	2	0	0	9	$0	$0	$0	$0	$2,000
1999	06932638	2	0	0	0	$0	$0	$0	$0	$2,000
1999	06941586	2	0	5	-6	$0	$0	$0	$0	$180,000
1999	07383107	2	0	0	0	$0	$0	$0	$0	$2,000
1999	07410460	2	0	0	-46	$0	$0	$0	$0	$2,000
1999	07410497	2	0	0	-3	$0	$0	$0	$0	$2,000
1999	07451368	2	0	0	0	$0	$0	$0	$0	$2,000

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As in the case of the Priority List report, closing the Priority Location Record List will return the user to the STARTUP menu. In the case of a complete update, the next step would be the examination of individual crash details for one or more locations.

Option 3: Viewing Crash Record Details

Pressing **Button 3** (marked with an arrow) on the STARTUP menu takes the model user to the **Record Details** form shown in Figure 12. Several viewing options are available for individual crash records. The most complete data are available by selecting the "Details for each crash" option for all Priority List locations (a.i.), all locations where fatal crashes occurred (a.ii.), or a specific location chosen from the Priority List (a.iii.). These options will create one-page reports for each crash record, listing recorded details on roadway, driver, incident and vehicle characteristics. A sample report is shown in Figure 13 on the following page.

Figure 12: Crash Record Details Selection Form

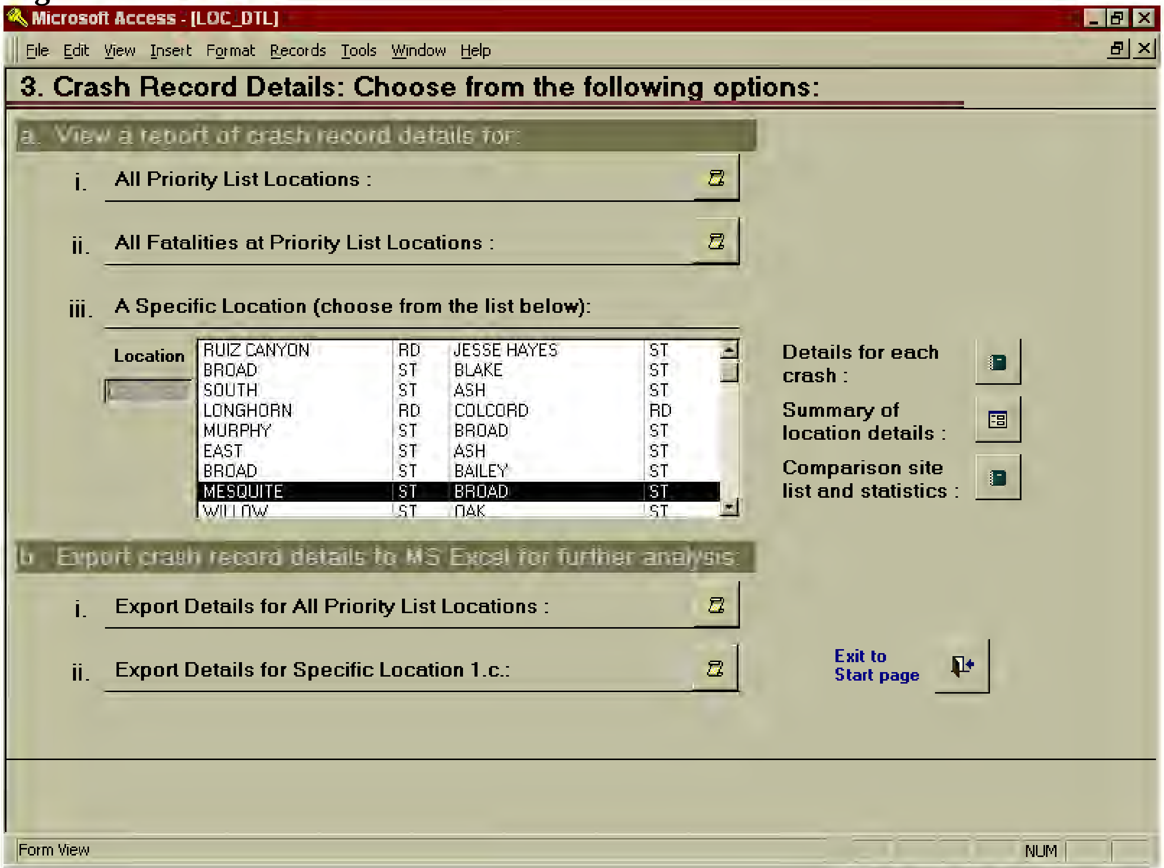
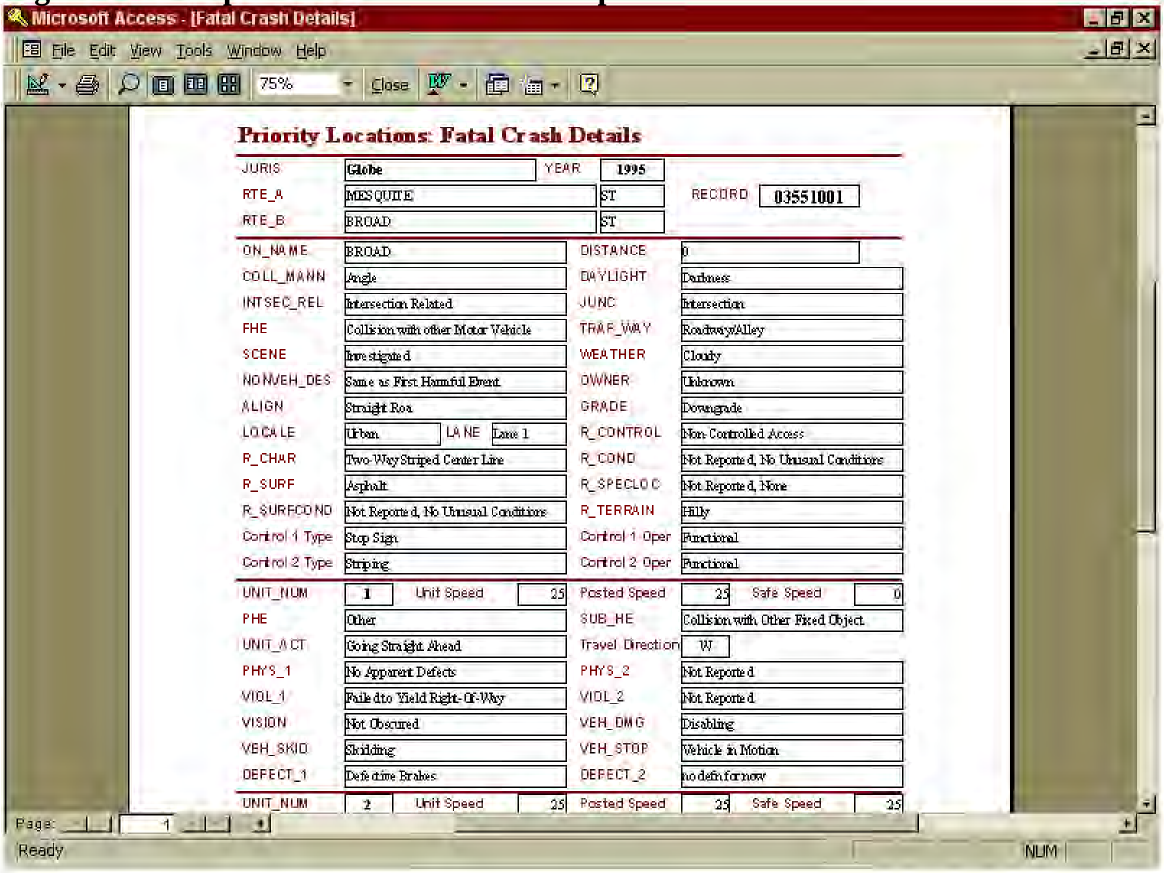


Figure 13: Sample Crash Record Detail Report



Due to the number of crashes at many sites, the detail reports can be tedious to examine, particularly in the case of option a.i. "All Priority List locations." Items b.i. and b.ii. are intended to facilitate the use of the information contained in the detail reports. Selecting either of these buttons will automatically export crash details to an Excel spreadsheet. The export options have been pre-formatted to simplify analysis (e.g. record subtotaling by route, harmful event(s), etc.), and will automatically write to the following location:

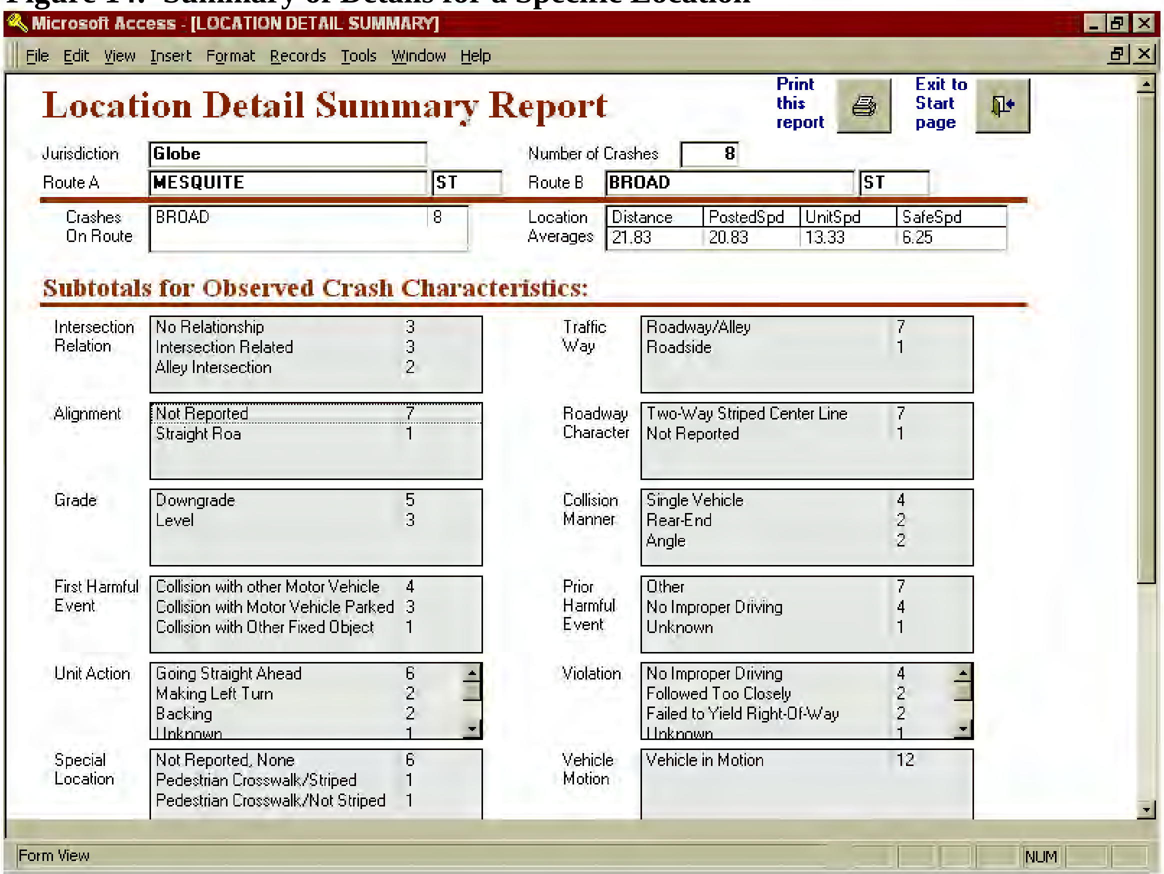
C:\ADOT\SPR504\SFTYPROJ.XLS

Note that the data transfer takes less than two minutes, but the spreadsheet will not automatically open. The following dialog box will appear as a reminder of the export file location when one of the b. options is chosen.

In addition to the crash details export capability, the LGSP model can also produce a summary of many crash details for a single location. This option can be accessed by pressing the "**Summary of Location Details**" button after choosing a location in option iii. The summary report form will be generated after a run-time of approximately two minutes.

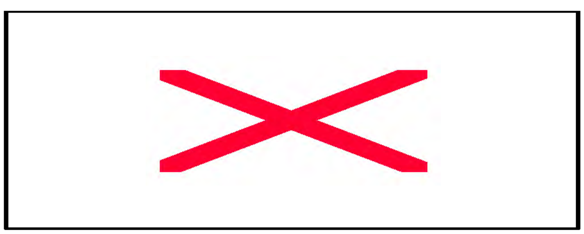
As shown in Figure 14, the Location Detail Summary Report subtotals a number of crash details for the chosen location, and return such information as crash counts per route, average distances from the reference junction, average vehicle speeds and posted speed limits. This form can be printed in a one-page layout by selecting the print option at the top of the screen. It should be noted that counts for different variables will not always match the number of crashes. This occurs because some variables are recorded for each vehicle (e.g. unit action and violation), while others pertain to the site (e.g. traffic way and grade).

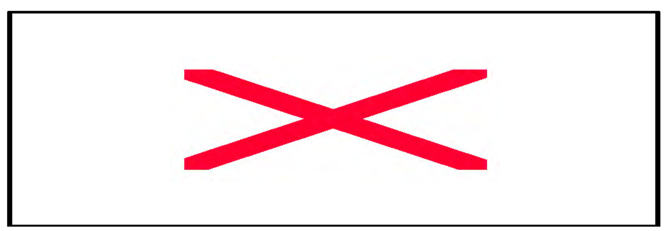
Figure 14: Summary of Details for a Specific Location



The final option available for crash location detail reporting is the **Comparison Site List**, also located in section iii. The Comparison Site List report returns a summary of additional sites in a jurisdiction that have similar characteristics to the site location being analyzed. This report is intended to facilitate before-and-after comparisons between treated and untreated locations, and to provide basic statistics for estimating regression-to-the-mean potential at a given site (refer to Section 3: "Estimating Effectiveness" for a sample equation). The Comparative Site List identifies other locations in the jurisdiction that match the following criteria from the reference location: junction and intersection relationships, traffic way and roadway characterisitics, any special locations (e.g. pedestrian crosswalks), traffic control devices, and maximum posted speed. Depending on the characteristics of the reference location, the number of sites returned can range from none to several hundred. The Comparative Site List generates summary statistics (average annual crash incidence and standard deviation) for *all* sites in the report. Analysis of any location subsets is left to the user of the model.

Two different Comparison Site List reports can be generated. The only difference between them is that one report contains crash rate data using average daily traffic (ADT) counts entered by the user. When the Comparison Site List button is selected in details section iii., a message box will appear, asking whether the user would like to include traffic count data. If the "No" button is pressed, no further action is required. A summary list of related crash locations is generated (see Figure 16: Comparative Sites Report A – No Traffic Data). If the "Yes" button is pressed, another message box will appear, this time asking whether traffic counts need to be added or modified. If traffic counts have already been entered, pressing "No" will open the Comparison Site List containing ADT counts, crash rates for each location and summary statistics for the crash rates measurements (see Figure 17: Comparative Sites Report B – Traffic Data). Note that crash rates are expressed in terms of annual crashes per 10,000 passing vehicles.



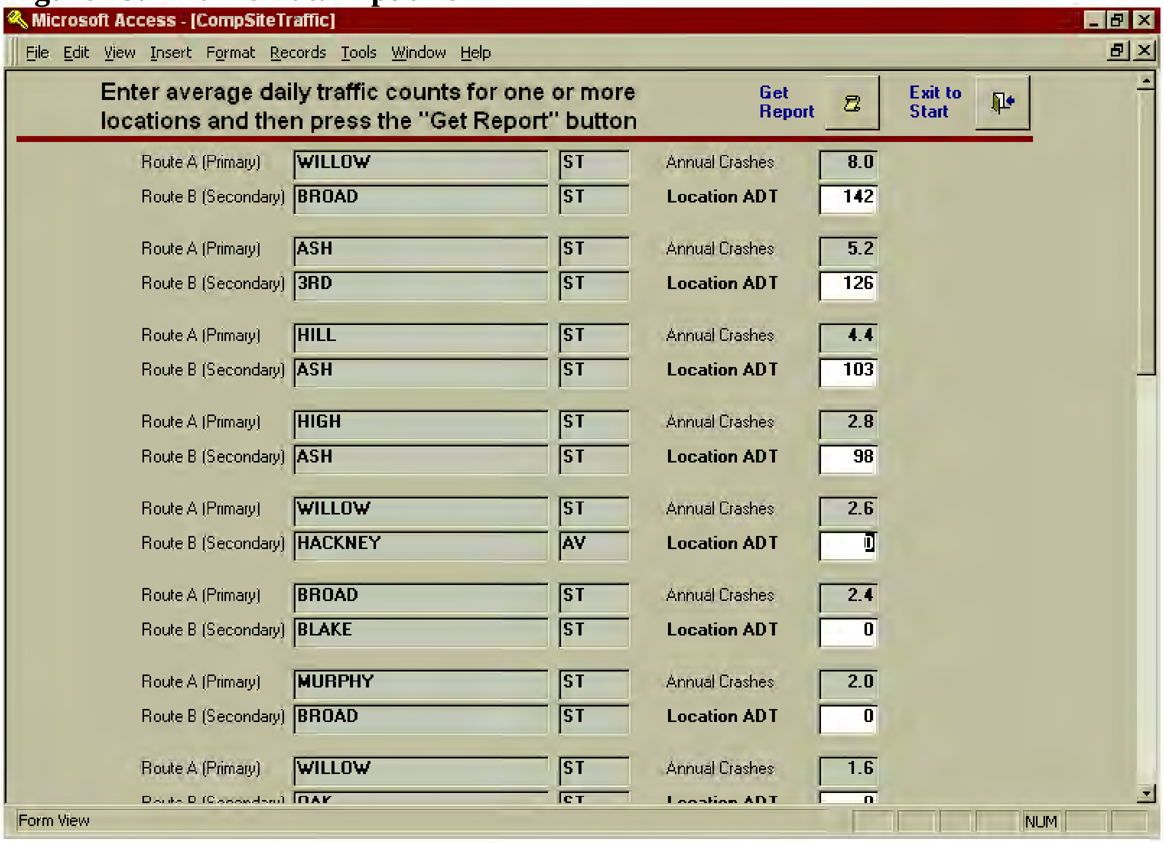


Pressing "Yes" on the second dialog box will open the Comparative Sites Traffic form shown in Figure 15 below. This form allows the model user to enter average daily traffic counts for any or all locations in the comparison site report. Average daily traffic counts can be based on any period, but must reflect *daily* figures. The LGSP calculates annual crash rates per 10,000 passing/entering vehicles using the following formula:

$$AnnualCrashRate = AnnualCrashes * ADT * 365 / 10,000$$

Note that it is not necessary to enter traffic counts for all sites. The LGSP model calculates crash rate statistics based only on the sites for which traffic counts have been entered. Leaving some sites blank will not affect the calculation of statistical outputs (comparison sites average and standard deviation). However, the more sites for which traffic counts are included, the more reliable the forecast.

Figure 15: Traffic Data Input Form



WARNING Crash data will only be stored for the location most recently selected in the Record Details Form. Changing the location and then choosing to enter traffic data will *delete* traffic data for the previous location. Printing or copying traffic data is strongly recommended prior to analyzing a new site. Once traffic counts have been entered, pressing the "Get Report" button in the Comparative Sites Traffic form will open the Comparison Site List that includes traffic-adjusted crash rates. Refer to the following page for illustrations of the two Comparison Site reports. Closing either Comparative Site List will return the user to the STARTUP menu.

To recount the traffic-related and non-traffic-related comparison options, select Option 3 from the STARTUP menu, then press the Comparison Site List button in Record Details Form section iii. At the first message box, press "No" to view the report that does not contain traffic data. Press "Yes" to continue to the second message box. At the second message box, press "No" to view the report containing previously entered traffic data. Press "Yes" to modify traffic data in the Traffic Data Input form.

Figure 16: Comparative Sites Report A – No Traffic Data

Microsoft Access - [COMP_REPORT]

Comparative Site Report

Selection Criteria: Jurisdiction, Junction, Intsec Relation, Traffic Way, Rdwy Characteristics, Special Location(s), Traffic Control(s), Speed

Jurisdiction: Globe — Sorted by: Total Crashes

Primary Route	Sffx	Secondary Route	Sffx	Crashes	Annual Crashes	Total Units	Units / Crash	Total Fatal	Total Injured
WILLOW	ST	BROAD	ST	40	8.0	77	1.9	0	29
ASH	ST	3RD	ST	26	5.2	51	2.0	0	18
HILL	ST	ASH	ST	22	4.4	43	2.0	0	17
HIGH	ST	ASH	ST	14	2.8	25	1.8	0	9
WILLOW	ST	HACKNEY	AV	13	2.6	27	2.1	0	7
BROAD	ST	BLAKE	ST	12	2.4	29	2.4	0	19
MURPHY	ST	BROAD	ST	10	2.0	18	1.8	0	6
SANTEE	ST	BROAD	ST	8	1.6	14	1.8	0	1
WILLOW	ST	OAK	ST	8	1.6	11	1.4	0	6
LANE	ST	BROAD	ST	7	1.4	14	2.0	0	5
WILLOW	ST	CEDAR	ST	5	1.0	9	1.8	0	3
WILLOW	ST	MESQUITE	ST	4	0.8	9	2.3	0	3
BROAD	ST	BERAUTTI	ST	4	0.8	9	2.3	0	5
WILLOW	ST	EUCLID	ST	3	0.6	4	1.3	0	0
WILLOW	ST	PINAL	ST	2	0.4	4	2.0	0	0
BROAD	ST	0060		2	0.4	3	1.5	0	1

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Figure 17: Comparative Sites Report B – Traffic Data

Microsoft Access - [COMP_REPORT]

Comparative Site Report

Selection Criteria: Jurisdiction, Junction, Intsec Relation, Traffic Way, Rdwy Characteristics, Special Location(s), Traffic Control(s), Speed

Jurisdiction: Globe — Sorted by: Total Crashes

Primary Route	Sffx	Secondary Route	Sffx	Crashes	Annual Crashes	Total Units	Units / Crash	Total Fatal	Total Injured	Loc ADT	Ann Crsh Rate
WILLOW	ST	BROAD	ST	40	8.0	77	1.9	0	29	85	2.5786
ASH	ST	3RD	ST	26	5.2	51	2.0	0	18	96	1.4840
HILL	ST	ASH	ST	22	4.4	43	2.0	0	17	73	1.6513
HIGH	ST	ASH	ST	14	2.8	25	1.8	0	9	66	1.1623
WILLOW	ST	HACKNEY	AV	13	2.6	27	2.1	0	7	22	3.2379
BROAD	ST	BLAKE	ST	12	2.4	29	2.4	0	19		0
MURPHY	ST	BROAD	ST	10	2.0	18	1.8	0	6		0
SANTEE	ST	BROAD	ST	8	1.6	14	1.8	0	1		0
WILLOW	ST	OAK	ST	8	1.6	11	1.4	0	6		0
LANE	ST	BROAD	ST	7	1.4	14	2.0	0	5		0
WILLOW	ST	CEDAR	ST	5	1.0	9	1.8	0	3		0
WILLOW	ST	MESQUITE	ST	4	0.8	9	2.3	0	3		0
BROAD	ST	BERAUTTI	ST	4	0.8	9	2.3	0	5		0
WILLOW	ST	EUCLID	ST	3	0.6	4	1.3	0	0		0
WILLOW	ST	PINAL	ST	2	0.4	4	2.0	0	0		0
BROAD	ST	0060		2	0.4	3	1.5	0	1		0

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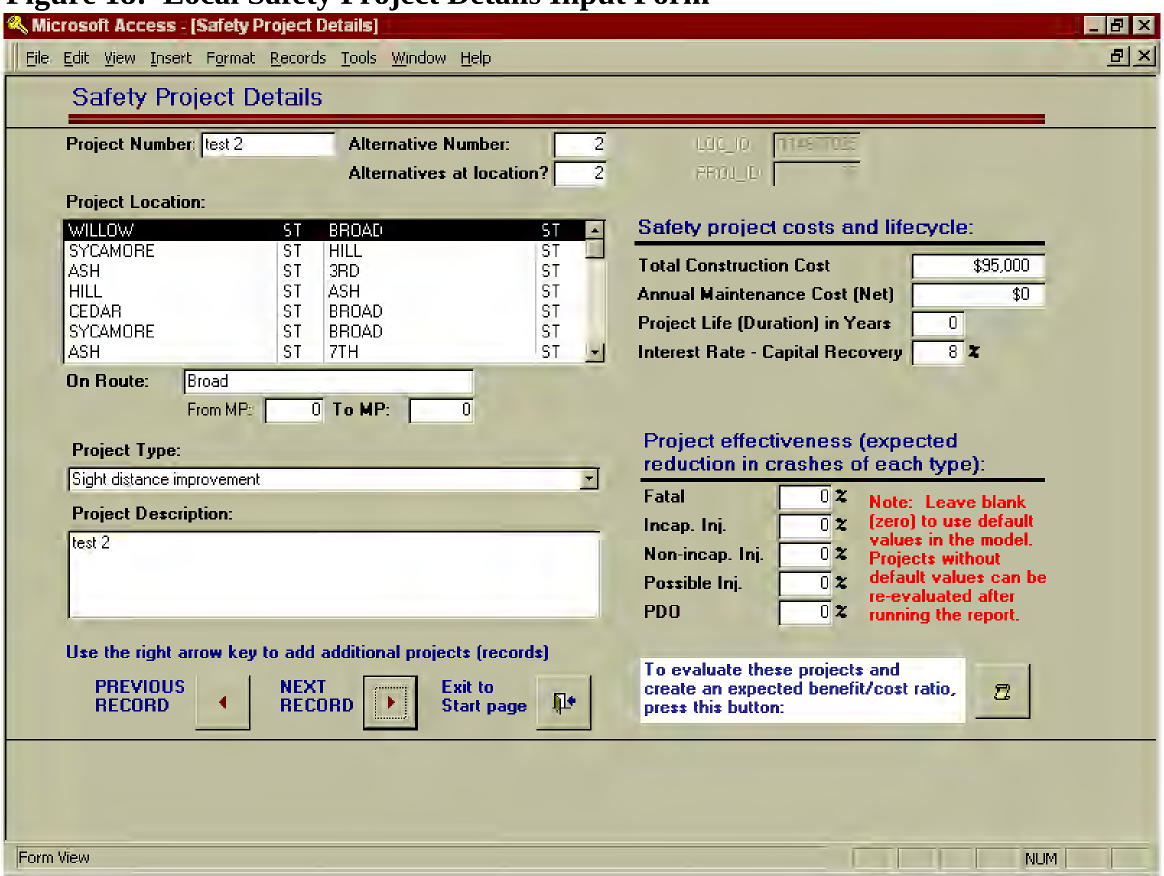
Option 4: Input Local Safety Project Details

In most cases, additional studies and site analyses will be required before proceeding to Option 4: Input of Potential Projects. The Priority List and various detail reports provide a means of identifying hazardous sites and enough additional information to form hypotheses about the appropriate site treatments. However, these details do not supplant the need for on-site evaluation(s) by local traffic engineers. Once a field evaluation has been performed for one or more hazardous sites identified in Options 1 – 3, it is assumed that several potential safety treatments will have been identified for these locations. Option 4 provides an input form for potential safety projects, which can then be evaluated in terms of expected effectiveness and associated benefits versus project costs.

Pressing **Button 4** on the STARTUP menu opens the **Safety Project Details** form. Any number of safety projects can be evaluated from this page. However, each project must be assigned a unique "Project Number" identifier prior to analysis. It is recommended that the "Alternatives" fields also be used to distinguish between multiple possibilities at the same location. A site location must be selected from the "Project Location" menu – omitting this step will cause the project data to be ignored.

Figure 18: Local Safety Project Details Input Form



The remaining inputs for a preliminary project assessment are listed below. Note that some fields are required inputs, while others may be left blank.

On Route: specify which route at the project location will receive the safety treatment

Project Type: select from the menu of 76 different project types organized by seven broad project classes; an "other safety improvements" category is also provided in the event that none of the available types are suitable; this field is used to assign default values for project life cycle and estimated effectiveness (*required*)

Project Description: enter a brief but specific description of the safety treatment; this field will help discern multiple treatments at the same site and is included in the Project Evaluation report (Step 5 below)

Total Construction Cost: enter the total estimated implementation cost of the project; do *not* annualize this figure – the model will perform this calculation (required)

Annual Maintenance Cost: enter the annual cost (if any) of operating or maintaining the treatment; only include costs that are not reflected in the "Total Construction Cost;" for example, include the annual cost of periodic repairs to crash cushions after construction

Project Life: enter the expected life span of the safety improvement in whole years; the model will assign default values based on the Project Type; this field is only required if defaults are not available for the Project Type selected

Interest Rate: enter the interest rate used to annualize costs by calculating capital recovery factors; as in all term-based financing, the higher the interest rate, the more expensive the project; the model currently uses a range from 8 percent to 16 percent per HES guidelines

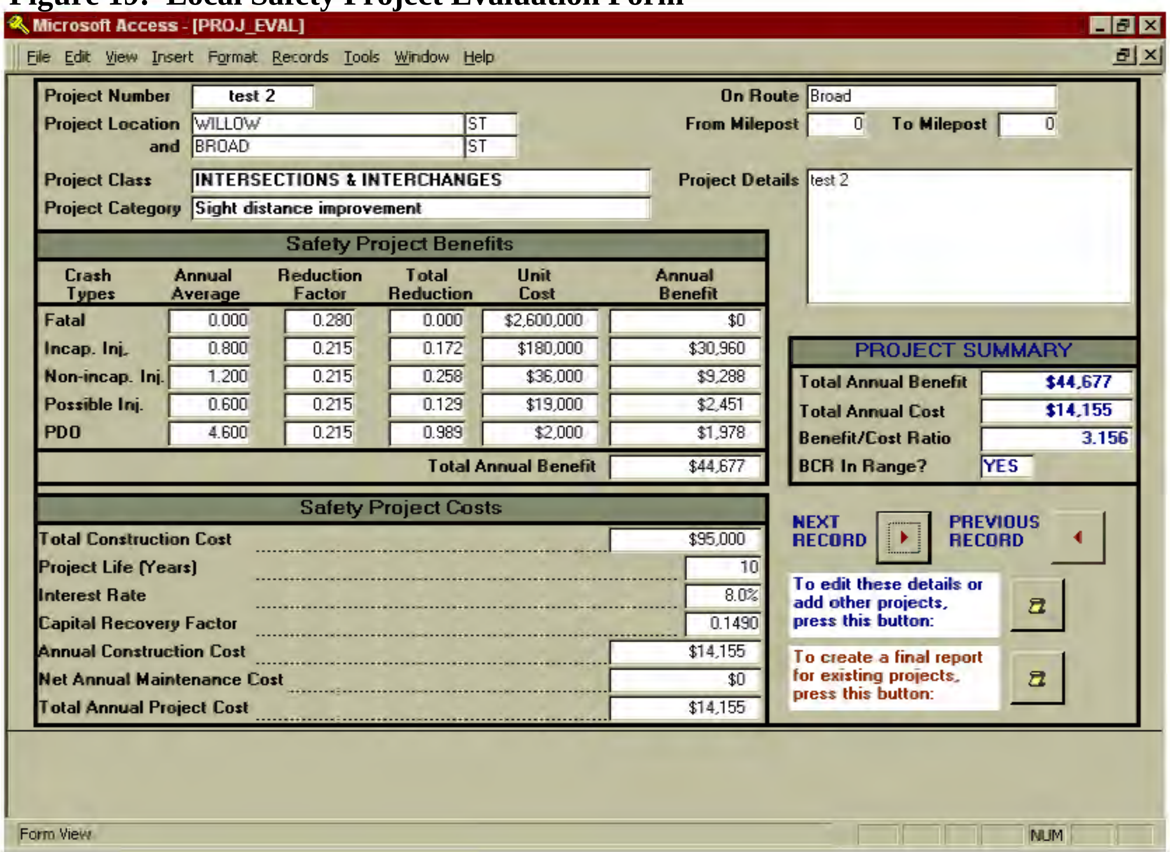
Project Effectiveness: enter expected crash/accident reduction factors for crashes of each severity class; this field is not required for the preliminary analysis – when available, the LGSP model will assign default values if these fields are left as "0"; note that the final estimate of effectiveness is the responsibility of the model user, but these figures can be adjusted in the next step

When entering multiple projects, use the "Next Record" and "Previous Record" arrow buttons to move from screen to screen. For example, after entering Project #1, press the "Next Record" button to view a blank screen in which Project #2 can then be entered. To edit Project #1, simply press the "Previous Record" button to back up one input screen. Once all projects have been entered, press the "Evaluate" button in the bottom right corner of the screen. This will activate a Project Evaluation macro, and after several minutes (generally less than three) the **Project Evaluation Form** will be displayed.

The Project Evaluation Form contains a preliminary benefit-cost analysis and associated estimates of effectiveness for each project entered in the Project Details form. Projects are displayed individually, and may be viewed by using the "Next Record" and "Previous Record" buttons. As shown in Figure 19, each project view contains a summary of project number, type, class, location and description.

Project benefits are annualized using historical crash rates, crash cost figures and effectiveness parameters. It should be noted that, regardless of estimated effectiveness, the benefits associated with a safety improvement will be constrained by average incidence rates for each type of crash. Annual benefits are calculated by multiplying the annual crash rate by the reduction factor to yield a "Total Annual Reduction," which is then multiplied by the estimated cost of each type (i.e. severity) of crash to yield the "Annual Benefit" estimate. Safety project costs are annualized in a similar manner. Depending on the interest rate and life cycle of the safety improvement, an appropriate capital recovery factor is assigned. The capital recovery factor is multiplied by the total construction cost to yield an annual construction/implementation cost. Annual maintenance costs are then added to the annualized construction costs to calculate the "Total Annual Project Cost." The "Total Annual Benefit" and "Total Annual Cost" figures are compared in the "Project Summary" section on the right side of the form. Dividing total annual benefits by total annual costs returns a project benefit-cost ratio. If this figure is greater than 1.0, the project is within the range required for HES funding eligibility. However, this does not imply that projects are automatically eligible for HES funds. A completed application must be submitted and approved prior to funding.

Figure 19: Local Safety Project Evaluation Form


Microsoft Access - [PROJ_EVAL]

File Edit View Insert Format Records Tools Window Help

Project Number: test 2
Project Location: WILLOW ST
and: BROAD ST
Project Class: INTERSECTIONS & INTERCHANGES
Project Category: Sight distance improvement
On Route: Broad
From Milepost: 0 To Milepost: 0
Project Details: test 2

Safety Project Benefits

Crash Types	Annual Average	Reduction Factor	Total Reduction	Unit Cost	Annual Benefit
Fatal	0.000	0.280	0.000	$2,600,000	$0
Incap. Inj.	0.800	0.215	0.172	$180,000	$30,960
Non-incap. Inj.	1.200	0.215	0.258	$36,000	$9,288
Possible Inj.	0.600	0.215	0.129	$19,000	$2,451
PDO	4.600	0.215	0.989	$2,000	$1,978
				Total Annual Benefit	$44,677

Safety Project Costs

Total Construction Cost	$95,000
Project Life (Years)	10
Interest Rate	8.0%
Capital Recovery Factor	0.1490
Annual Construction Cost	$14,155
Net Annual Maintenance Cost	$0
Total Annual Project Cost	$14,155

PROJECT SUMMARY

Total Annual Benefit	$44,677
Total Annual Cost	$14,155
Benefit/Cost Ratio	3.156
BCR In Range?	YES

NEXT RECORD PREVIOUS RECORD

To edit these details or add other projects, press this button:

To create a final report for existing projects, press this button:

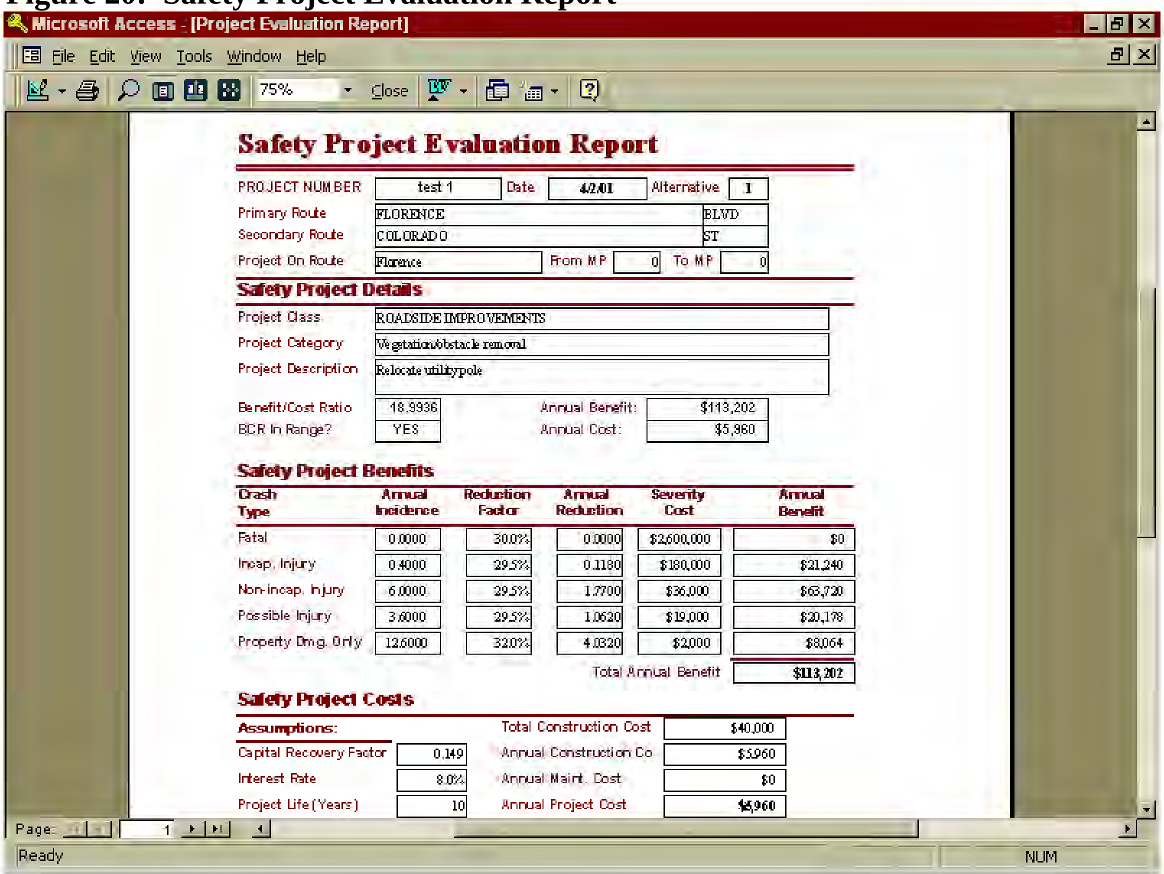
Form View NUM

Once the evaluation procedure has been run, the user has the option of editing existing projects and/or adding new projects or creating a final **Project Evaluation Report**. These options can be chosen via the buttons located in the bottom right corner of the Project Evaluation Form. If the "Edit/Add" button is selected, the user will be returned to the Safety Project Details form. If the "Report" button is chosen, the model creates the report shown in the following section (Option 5).

Option 5: Safety Project Evaluation Report

The Safety Project Evaluation report can be accessed through the previous step, or by selecting Option 5 from the STARTUP menu. This report contains the same data as the Project Evaluation form, formatted for printing. A Project Evaluation report should be accompanied by the Priority List, Location Details and/or the Detail Summary, as well as the Comparative Sites report. Additional data are required for HES applications. The LGSP model outputs can be used to support an application, but traffic, engineering and historical treatment analyses are also required for an HES program application.

Figure 20: Safety Project Evaluation Report


Microsoft Access - [Project Evaluation Report]

File Edit View Tools Window Help

75% Close

Safety Project Evaluation Report

PROJECT NUMBER: test 1 | Date: 4/2/01 | Alternative: 1

Primary Route: FLORENCE BLVD

Secondary Route: COLORADO ST

Project On Route: Florence | From MP: 0 | To MP: 0

Safety Project Details

Project Class: ROADSIDE IMPROVEMENTS

Project Category: Vegetation/obstacle removal

Project Description: Relocate utility pole

Benefit/Cost Ratio: 18.9936 | Annual Benefit: $113,202

BCR In Range?: YES | Annual Cost: $5,960

Safety Project Benefits

Crash Type	Annual Incidence	Reduction Factor	Annual Reduction	Severity Cost	Annual Benefit
Fatal	0.0000	30.0%	0.0000	$2,600,000	$0
Incap. Injury	0.4000	29.5%	0.1180	$180,000	$21,240
Non-incap. Injury	6.0000	29.5%	1.7700	$36,000	$63,720
Possible Injury	3.6000	29.5%	1.0620	$19,000	$20,178
Property Dmg. Only	12.6000	32.0%	4.0320	$2,000	$8,064
				Total Annual Benefit	$113,202

Safety Project Costs

Assumptions:			
		Total Construction Cost	$40,000
Capital Recovery Factor	0.149	Annual Construction Co	$5,960
Interest Rate	8.0%	Annual Maint. Cost	$0
Project Life (Years)	10	Annual Project Cost	$5,960

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Use of the LGSP model need not be confined to spot treatment analyses. However, the availability of funding for spot improvements makes it likely that these projects will be the primary focus for most LGSP users. In cases where treatments are limited in scope or area of influence, it is recommended that multiple iterations of the model be run using different aggregation distances. For example, while a guardrail installation may conceivably affect a large stretch of highway, the relocation of a utility pole has a much more concentrated impact area. Whereas an aggregation of crash data within a 500-foot radius may be appropriate for the guardrail evaluation, a radius of 100 feet or less may be more appropriate for the utility pole. These analyses can be reassessed from the inputs form (select Option 1) to save update time.

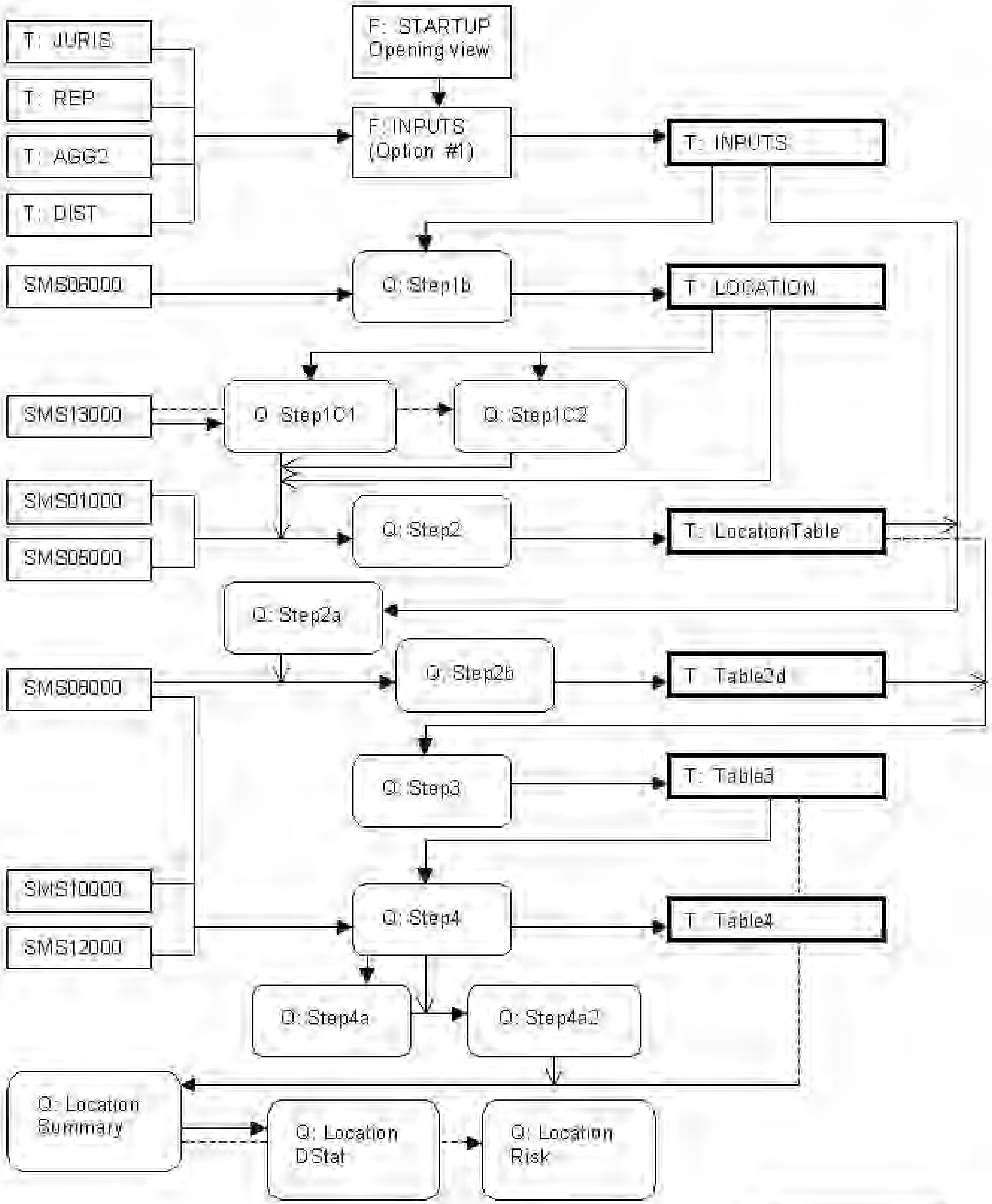
Arizona LGSP Model Site Identification Procedure

The LGSP model returns prioritized local crash sites and relevant details based on a number of user inputs. Data are grouped and manipulated according to a series of Access queries that run upon activation of the TRAFSAF macro. A flowchart delineating the order of macro procedures is provided on the following pages. Activation of the TRAFSAF macro from the INPUTS form will follow the steps shown in Table 14. For each step, the purpose of the procedure and the data elements involved are identified. Tables are indicated with a “T:” prefix, queries by the “Q:” prefix.

Table 14: Arizona LGSP Model TRAFSAF Classification Query

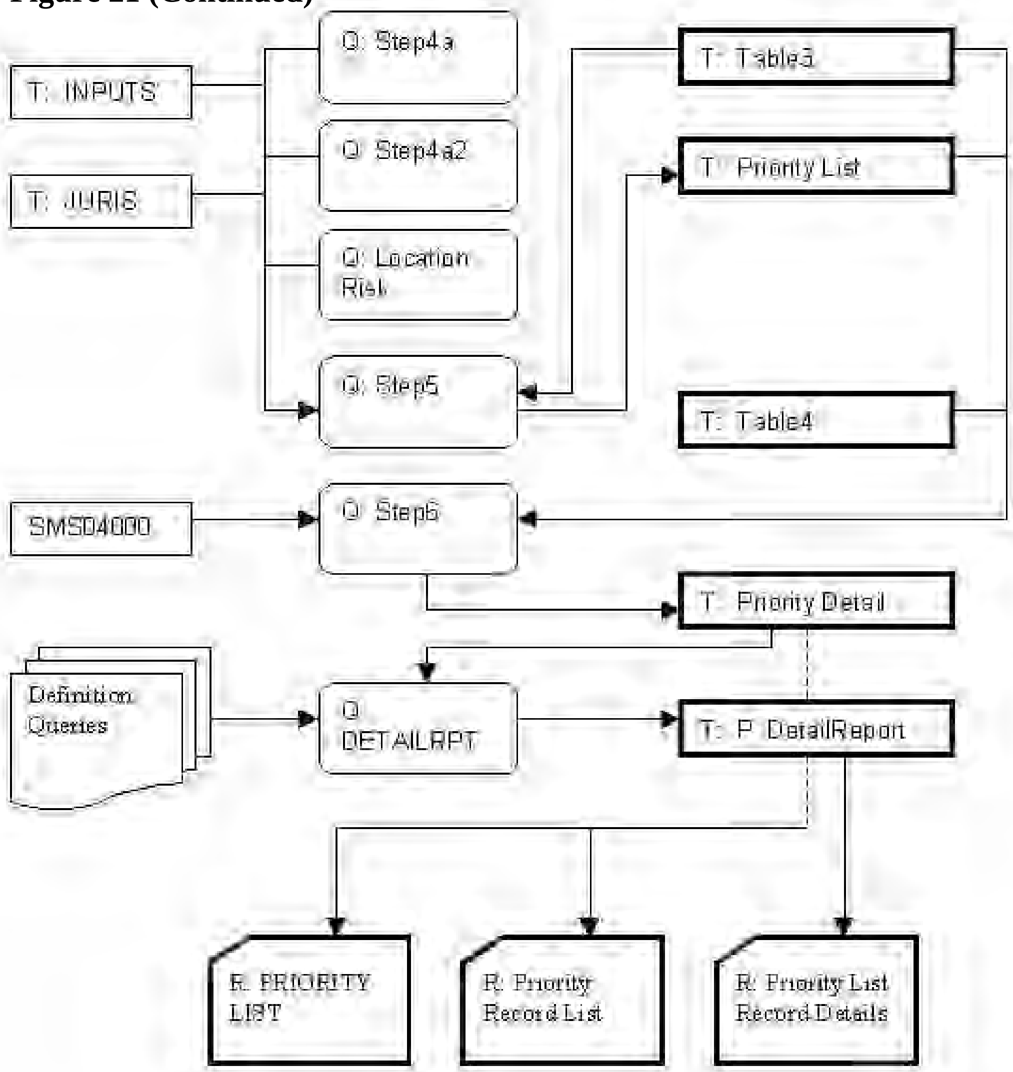
Query	Purpose	Elements	Type
Step1	Translate inputs to proper jurisdiction(s)	T: INPUTS; T:JURIS	Select
Step1b	Return all crashes identified in Step1 jurisdiction	Q: Step1; T:SMS06000	T: LOCATION
Step1c1	Assign unique identifier (On_Road)	T:LOCATION; T:SMS13000	Select
Step1c2	Assign unique identifier (At_Road)	T:LOCATION; T:SMS13000	Select
Step2	Return incident-level details for all crashes in T: LOCATION	T:LOCATION; T:SMS01000; T:SMS05000; Q:Step1c1; Q:Step1c2	T: LocationTable
Step2a	Filter locations by Reference Method and Aggregation Distance	T:LocationTable; T:INPUTS	Select
Step2b	Restrict Step2a results by Alcohol delimiter; summarize records	Q:Step2a; T:SMS08000	T: Table2d
Step3	Return incident-level results for filtered records for T:LocationTable, limited by month and year filter	T:LocationTable; T:Table2d; T:INPUTS	T: Table3
Step4	Return unit and person details for Table3 records, add crash cost estimates by maximum injury	T:Table3; T:SMS08000; T:SMS10000; T:SMS12000; T:COMPCOST	T: Table4
Step4a	Aggregate and annualize Table4	T:Table4; T:INPUTS	Select
Step4a2	Return Step4a maximum values	Q:Step4a	Select
Step5	Create a priority list of locations, sorted by user preference	T:Table3; T:Table4; T:INPUTS; T:JURIS; Q:Step4a; Q:Step4a2	T: PRIORITY LIST
Step6	Join and summarize all details for each incident in T:PRIORITYLIST	T:PRIORITYLIST; T:Table3; T:Table4; T:SMS04000	T:PRIORITY DETAIL
DETAIL RPT	Add descriptor fields to T: PRIORITY DETAIL	T:Priority Detail; T:LocationTable; Q:01000; Q:05000; Q:07000-1; Q:07000-2; Q:08000; Q:12000; Q:08000-1; Q:08000-2; Q:12000-1	T: P_DETAILRPT

Figure 21: Arizona LGSP "TRAFSAF" Macro Flowchart



Continued on next page

Figure 21 (Continued)



Appendix B: Updating Crash Data in the Local Safety Project Model

The Arizona Local Government Local Safety Project model references crash data collected by the Arizona Department of Transportation Traffic and Engineering section. These data are updated continuously, as local jurisdictions forward crash reports to ADOT for record keeping. In order for the LGSP model to be effective, it recommended that the crash data reference CD be updated at least annually. Crash data for the previous calendar year are normally complete in the summer of the following year, and are available as a series of text files on CD from Traffic and Engineering. This section contains instructions for converting the text files to the format recognized by the Arizona LGSP model.

Traffic and Engineering File Components

Crash data records are provided by ADOT Traffic and Engineering (602-712-8230) in two series of text files. The first series consists of encoded crash data contained in twelve files, shown in Table 15. The second series consists of smaller definition files used to interpret the codes in each of the data files. Data file specifications for each of the tables listed in Table 15 are shown in the pages that follow. Each "SMSxxxxx.txt" file must be converted to these specifications for use by the LGSP model. The following table format references provide a count of required fields for importing data, appropriate reference names for each field, and details of data type, encoding, and where applicable, the associated definition file that contains descriptions for each encoded item.

Table 15: SMS Crash Data Files, ADOT Traffic and Engineering

File Name	**Contents**	**Record Linked**	**Multiple Records**
SMS01000.txt	Incident summary (total units, injuries, FHE, etc.)	Yes	No
SMS03000. txt	Emergency service response	Yes	Yes
SMS04000. txt	Non-vehicle incident involvement	Yes	No
SMS05000. txt	Roadway characteristics	Yes	No
SMS06000. txt	Location details, road reference	Yes	No
SMS07000. txt	Traffic control devices	Yes	No
SMS08000. txt	Traffic unit (type, speed, harmful event) details	Yes	Yes
SMS09000. txt	Hazardous materials involvement	Yes	Yes
SMS10000. txt	Person details (injury, age, gender, etc.)	Yes	Yes
SMS12000. txt	Vehicle details (damage, defects, etc.)	Yes	Yes
SMS13000. txt	Road identification (number, jurisdiction, etc.)	No	--

****IMPORTANT**** It is not necessary to import these files individually. The following tables have been provided solely as a reference to aid in understanding the LSPG file layout. The Crash Data Update procedure (see next section) provides instructions for creating new

"CRASHDATA" files, and should be followed unless the format or layout of ADOT crash data files changes.

Table 16: Arizona LGSP Table Format, SMS01000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	RECORD	Text	10	Yes ND	No	--
2	ACC_DATE	Text	255	--	No	--
3	OFCR_NCIC	Text	255	--	No	--
4	OFCR_ID	Text	255	--	No	--
5	TOT_UN	Number	LI	--	No	--
6	TOT_INJ	Number	LI	--	No	--
7	TOT_FTL	Number	LI	--	No	--
8	JUNC	Number	LI	--	Yes	01007
9	INTSEC_REL	Number	LI	--	Yes	01006
10	NSC_REP	Number	LI	--	Yes	01008
11	FHE	Number	LI	--	Yes	01004
12	COLL_MNR	Text	255	--	Yes	01001
13	SCENE	Number	LI	--	Yes	01009
14	DAYLIGHT	Number	LI	--	Yes	01003
15	WEATHER	Number	LI	--	Yes	01011
16	EXT_NCIC	Text	255	--	No	--
17	TRAF_WAY	Number	LI	--	Yes	01010
18	DMG_SEV	Number	LI	--	Yes	01002
19	INJ_SEV	Number	LI	--	Yes	01005
20	HIT_RUN	Number	LI	--	No	--
21	HAZ	Number	LI	--	No	--
22	ROR	Number	LI	--	No	--
23	FILE_NUM	Text	255	--	No	--
24	RECV_DATE	Text	255	--	No	--

Notes: (1) Field name in Local Govt. Safety Model table design; (2) Refers to type of data stored in database, LGSP model uses text and numbers only; (3) Number of characters in text field, otherwise "long integer" numbers; (4) Indicates that field is indexed, "ND" equals no duplicates allowed in field; (5) If "yes," field is related to a definition table; (6) Definition tables provide descriptors for each coded variable and are provided on the CRASHDATA CD file.

Table 17: Arizona LGSP Table Format, SMS03000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	255	--	No	--
3	SVC_COD	Text	255	--	Yes	03001
4	CALL_TIME	Number	LI	--	No	--
5	ARR_TIME	Number	LI	--	No	--

Notes: See Table B__: SMS01000 for notes discussion.

Table 18: Arizona LGSP Table Format, SMS04000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	RECORD	Text	255	Yes ND	No	--
2	NONVEH_DESC	Number	LI	--	Yes	04001
3	NONVEH_OWNER	Number	LI	--	Yes	04002

Notes: See Table B__: SMS01000 for notes discussion.

Table 19: Arizona LGSP Table Format, SMS05000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	10	--	No	--
3	ROAD_CHAR	Text	5	--	Yes	05006
4	GRADE	Text	5	--	Yes	05003
5	SURF_COND	Text	5	--	Yes	05010
6	ROAD_SURF	Text	5	--	Yes	05008
7	SPEC_LOC	Text	5	--	Yes	05009
8	ROAD_COND	Text	5	--	Yes	05007
9	LANE	Text	5	--	Yes	05004
10	SECT_NUM	Text	5	--	No	--
11	CONTROL	Text	5	--	Yes	05002
12	LOCALE	Text	5	--	Yes	05005
13	ALIGNMT	Text	5	--	Yes	05001
14	TERRAIN	Text	5	--	Yes	05011

Notes: See Table B__: SMS01000 for notes discussion.

Table 20: Arizona LGSP Table Format, SMS06000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	8	--	No	--
3	JURIS1	Text	4	--	Yes	JURIS
4	ON_DIR_PREF	Text	2	--	No	--
5	ON_NAME	Text	20	--	No	--
6	ON_SFFX	Text	6	--	No	--
7	ON_DIR_SFFX	Text	2	--	No	--
8	JURIS2	Text	4	--	Yes	JURIS
9	AT_DIR_PREF	Text	2	--	No	--
10	AT_NAME	Text	20	--	No	--
11	AT_SFFX	Text	6	--	No	--
12	AT_DIR_SFFX	Text	2	--	No	--
13	MARKER	Text	6	--	No	--
14	DISTANCE	Number	LI	--	No	--

Notes: See Table B__: SMS01000 for notes discussion.

Table 21: Arizona LGSP Table Format, SMS07000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	10	--	No	--
3	CONTROL_TYPE	Number	LI	--	Yes	07001
4	OPER	Number	LI	--	Yes	07002

Notes: See Table B__: SMS01000 for notes discussion.

Table 22: Arizona LGSP Table Format, SMS08000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	10	--	No	--
3	UNIT_NUM	Number	LI	--	No	--
4	PHE	Number	LI	--	Y	08003
5	SHE	Number	LI	--	Y	08004
6	UNIT_TYPE	Number	LI	--	Y	08007
7	UNIT_ACTION	Number	LI	--	Y	08006
8	VISION	Number	LI	--	Yes	08009
9	FAMILIAR	Number	LI	--	Y	08001
10	PHYSICAL_1	Number	LI	--	Y	08002
11	PHYSICAL_2	Number	LI	--	Y	08002
12	VIOLATION_1	Number	LI	--	Y	08008
13	VIOLATION_2	Number	LI	--	Y	08008
14	TRAV_DIR	Text	5	--	No	--
15	CITATION	Text	10		No	--

Notes: See Table B__: SMS01000 for notes discussion.

Table 23: Arizona LGSP Table Format, SMS09000

Field	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	10	--	No	--
3	UNIT_NUM	Number	LI	--	No	
4	USDOT	Text	15	--	Y	
5	ICC	Text	10	--	Y	
6	VEH_TYPE	Text	5	--	Y	09001
7	AXLES	Number	LI	--	Y	
8	GW	Number	LI	--	Yes	
9	PLACARD	Text	5	--	Y	--
10	CLASSCD	Text	5	--	Y	--
11	HAZ_REL	Number	LI	--	Y	--

Notes: See Table B__: SMS01000 for notes discussion.

Table 24: Arizona LGSP Table Format, SMS10000

Fld	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	10	--	No	--
3	UNIT_NUM	Number	LI	--		--
4	PERSON_NUM	Number	LI	--		--
5	AGE	Number	LI	--		--
6	SEX	Text	2	--		--
7	ID_NUM	Text	25	--		--
8	BIRTHDATE	Text	25	--		--
9	PERSON_TYPE	Number	LI	--		10005
10	SEAT_NUM	Number	LI	--		10008
11	RESTRAINT_USED	Number	LI	--		10006
12	INJURY	Number	LI	--		10003
13	LICENSE_CLASS	Text	2	--		10004
14	DRIVER_STATE	Text	5	--		10009
15	ENDORSEMENT	Text	5			10002
16	RESTRIC_1	Text	2			10007
17	RESTRIC_2	Text	2			10007
18	AIRBAG	Number	LI			10001

Notes: See Table B__: SMS01000 for notes discussion.

Table 25: Arizona LGSP Table Format, SMS12000

Fld	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	RECORD	Text	10	--	No	--
3	UNIT_NUM	Number	LI	--	N	--
4	PLATE_NUM	Text	10	--	N	--
5	VEH_STATE	Text	5	--	Y	12008
6	OWNERCLASS	Number	LI	--	Y	12004
7	BODY_STYLE	Number	LI	--	Y	12001
8	POSTED_SPEED	Number	LI	--	N	--
9	EST_SPEED	Number	LI	--	N	--
10	SAFE_SPEED	Number	LI	--	N	--
11	DEFECT_1	Number	LI	--	Y	12003
12	DEFECT_2	Number	LI	--	Y	12003
13	SKID	Number	LI	--	Y	12005
14	COMM_CARR	Text	5	--	N	--
15	DAMAGE	Number	LI	--	Y	12002
16	STOPPED	Number	LI	--	Y	12006
17	TRAILER	Text	5	--	Y	12007

Notes: See Table B__: SMS01000 for notes discussion.

Table 26: Arizona LGSP Table Format, SMS13000

Fld	LGSP Name[1.]	Type[2.]	Size[3.]	Index[4.]	Coded[5.]	Defn Table[6.]
1	ID	AutoNum	LI	Yes ND	No	--
2	JURIS	Text	255	--	No	13001
3	DIR_PREF	Text	255	--	N	--
4	ROAD_NAME	Text	255	--	N	--
5	SFFX	Text	255	--	Y	--
6	DIR_SFFX	Text	255	--	Y	--
7	ROADWAY	Text	255	--	Y	--
8	QUALIFIER	Text	255	--	N	--
9	PLUS_DIR	Text	255	--	N	--
10	CHANGE_SRC	Text	255	--	N	--
11	ROAD_NUM	Text	255	--	Y	--
12	SPACE	Text	255	--	Y	--
13	CHG_DATE	Text	255	--	Y	--
14	RAMP_LEN	Number	LI	--	N	--
15	SPACE2	Text	255	--	Y	--
16	CHG_DATE2	Text	255	--	Y	--

Notes: See Table B__: SMS01000 for notes discussion.

Crash Data Table Update Procedure

Updates of crash data files collected by ADOT Traffic and Engineering should be completed at least once per year. Due to the lag times between data collection, reporting, and formatting, it is recommended that an annual update be performed in June/July for the previous year's records. Data are available on CDROM from Traffic and Engineering, and should be requested for a five-year period (e.g. Jan 1, 1996 to Dec 31, 2001).

****IMPORTANT**** It is not recommended that data be requested in any other increment than 5 years. The following automated update procedure is intended for use with five complete years of data, and will *not* append new data to an existing file.

A template for future data files is included with the CDROM data file that accompanies this report. The template can be accessed directly from the CDROM under the filename "CRASHDATA-temp.mdb" The following steps should be followed in order to update CRASHDATA-temp and rename the file with the appropriate year reference. Prior to the update, the researcher must have a copy of the LGSP model CDROM, and a copy of current period ADOT crash data on CDROM.

Step 1: Open the "MyComputer" or "Windows Explorer" folder and locate the file: **CRASHDATA-temp.mdb**

Step 2: Copy the **CRASHDATA-temp.mdb** file to the appropriate directory. Select the copied file, and then choose **File>Rename** from the toolbar. Rename the file as **CRASHDATAxx-yy.mdb** where **xx** is the first year of data to be imported, and **yy** is the last year.

Example: If importing data from 1996 to 2000, use CRASHDATA96-00.mdb

Step 3: If using drive letters D, E, F, or G for the CD-ROM data, simply open the renamed **CRASHDATAxx-yy.mdb** file and follow the instructions on the screen. If using any other drives, a manual import must be performed. For a manual import, open CRASHDATAxx-yy.mdb, select option # 2., and then follow the steps in the following section for each table to be imported.

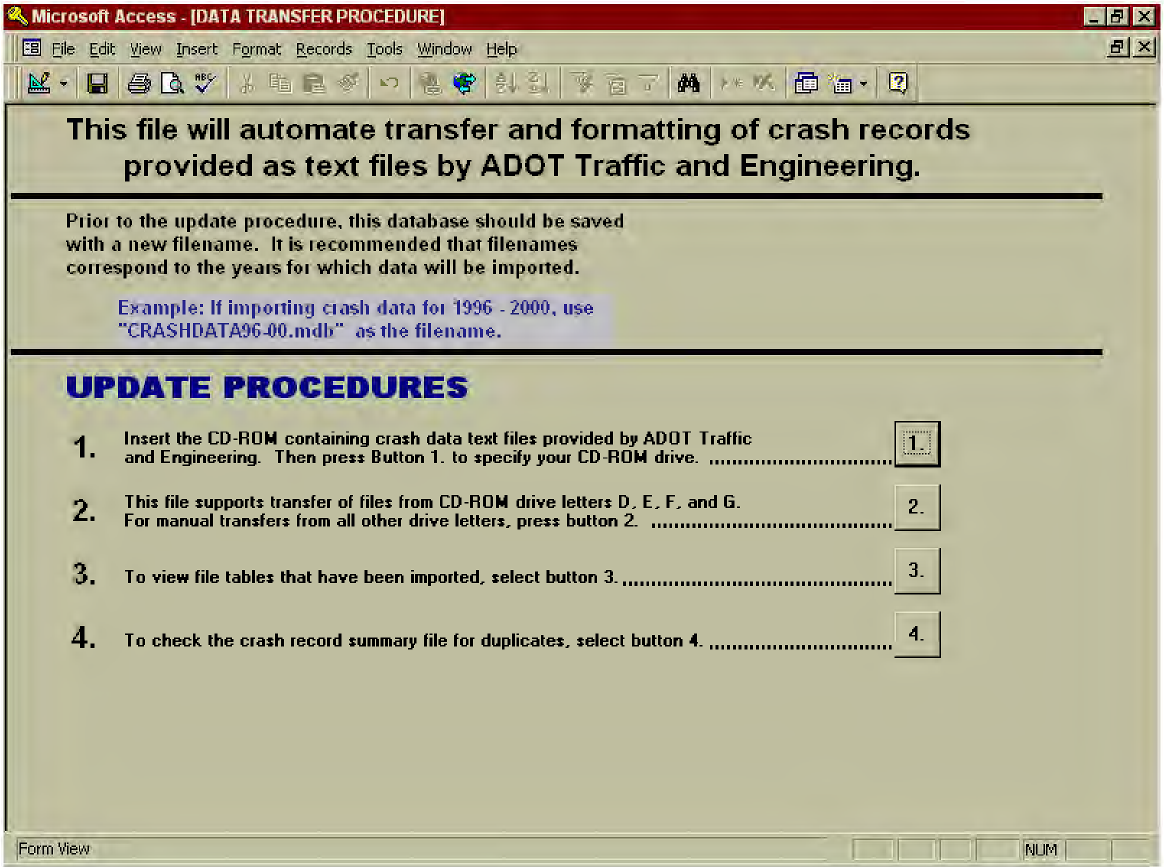
<u>Manual Import of Crash Data Files</u>

A manual (i.e. non-automated) import of the crash data will be necessary on two occasions:

1. The user's CD-ROM drive letter is not D:\, E:\, F:\, or G:\
2. The structural layout of the ADOT data files changes.

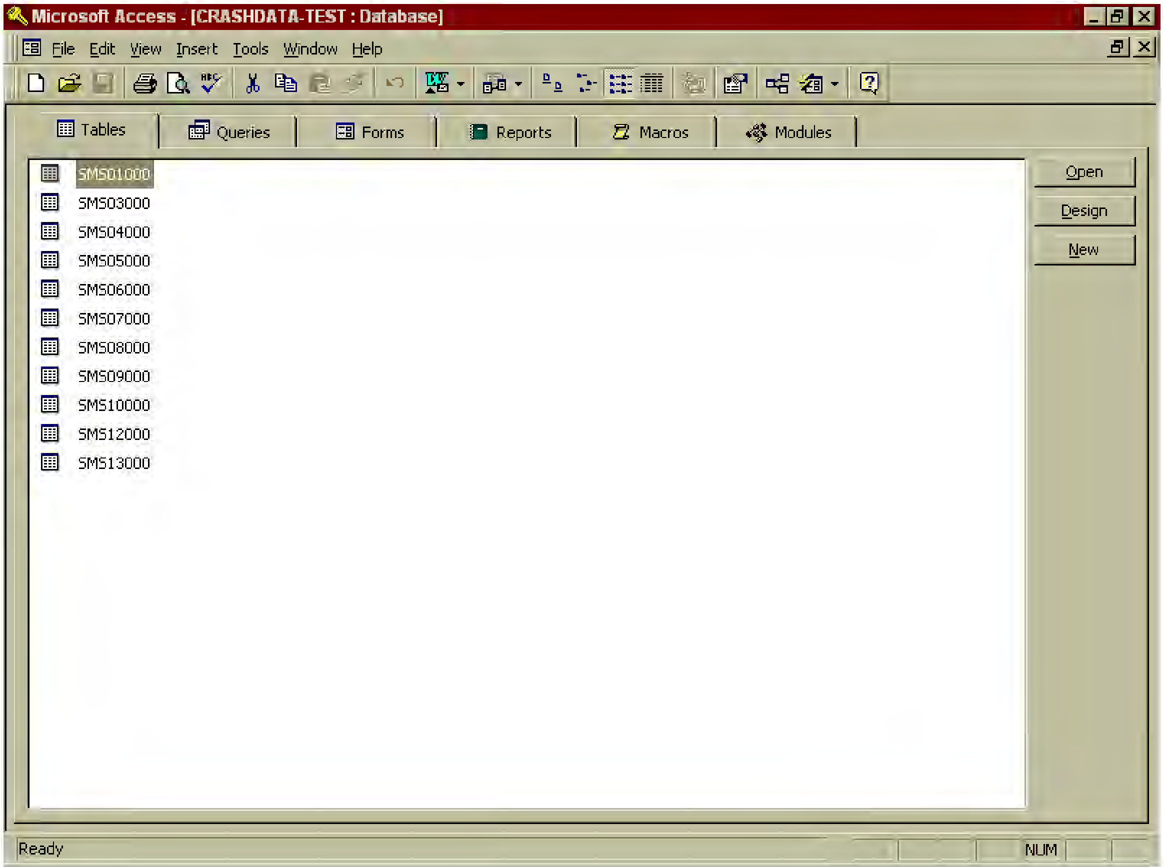
In the first case, predetermined specifications contained within the CRASHDATA-temp.mdb file can be used to simplify the import procedure. Instructions for this event are contained in this section. Should the layout of the files change, the procedure will depend on the new file layout. Importing data from a new file structure should follow the data formats outlined in Tables 16 to 26.

To import crash data manually, first follow steps 1 – 3 on the previous page. These instructions will use a hypothetical filename "**CRASHDATA-TEST.mdb**" for the copied and renamed file (step 2). When CRASHDATA-TEST.mdb is opened, the user will see the following screen:



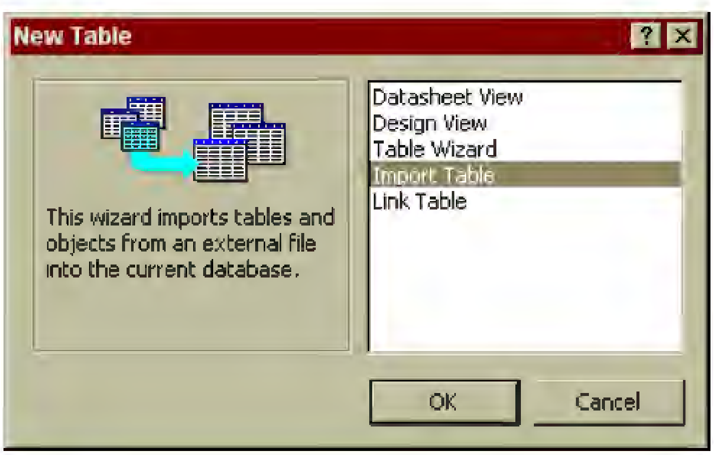
For the manual file import procedure, select option # 2.

Option 2 will run a macro that takes the user to the Tables window of the database (shown below). From this window, all import procedures can be performed.



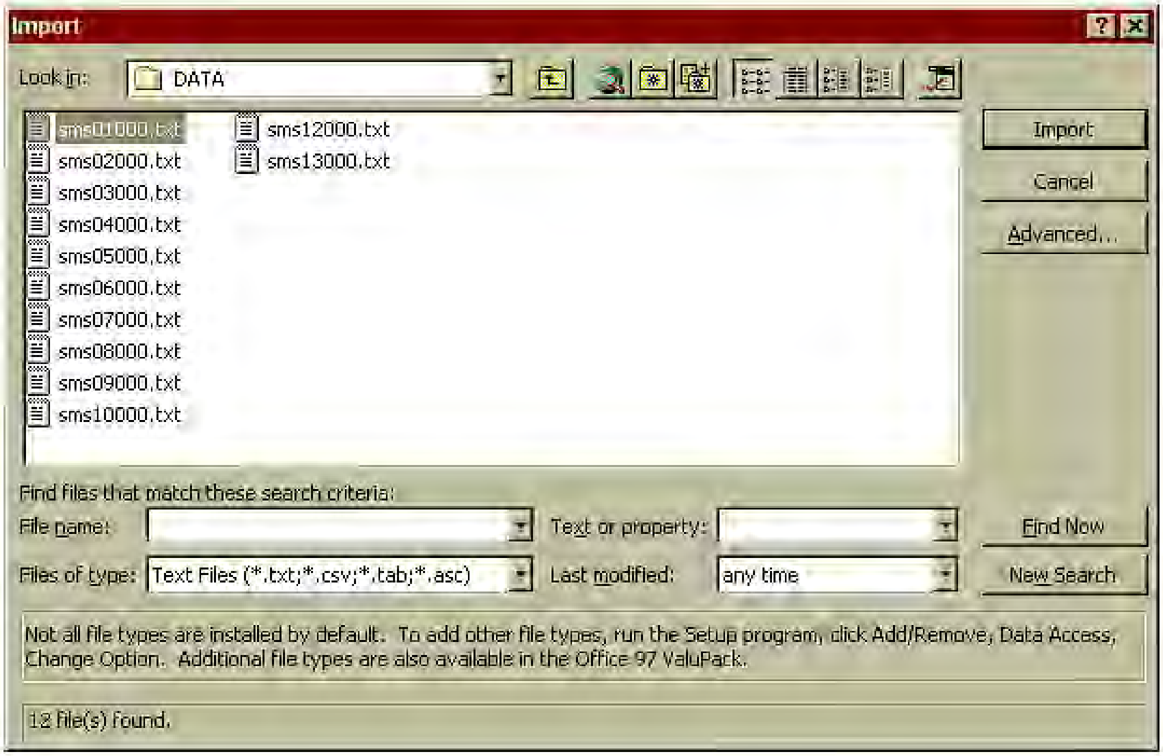
From the Tables window, select the "**New**" action button.

The "New" action button will open the New Table dialog box shown below. Select the "**Import Table**" option, and then press the "**OK**" button.



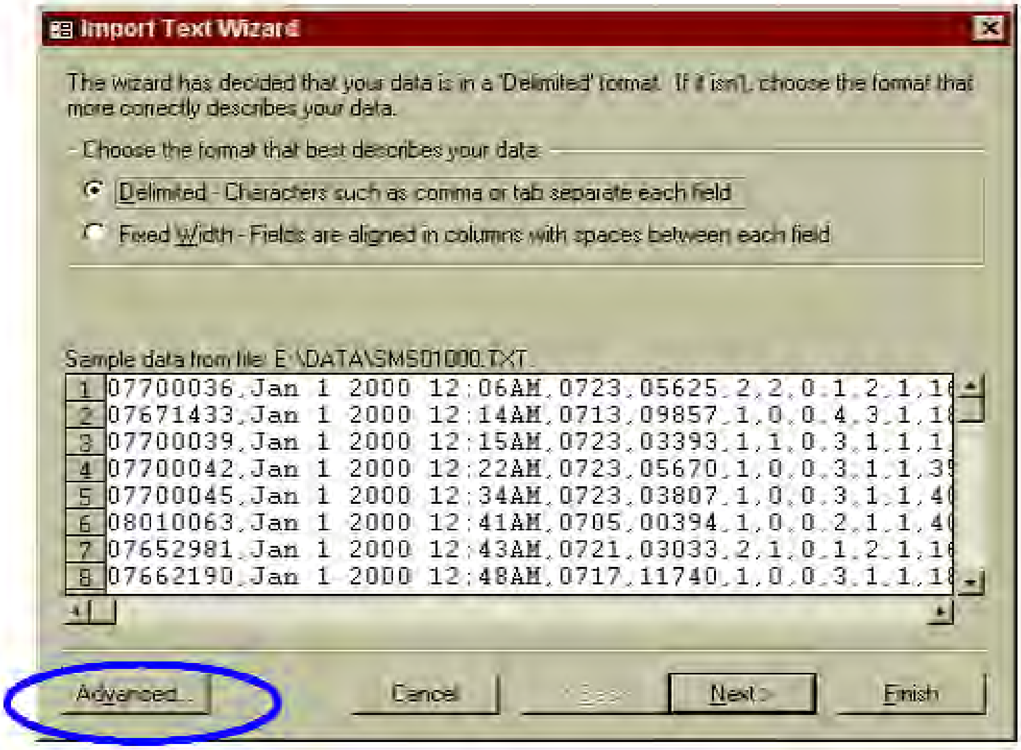
Pressing "OK" will open the Import File dialog box shown below. From this dialog box, the user must specify which file to import. This is done by selecting the text file from the ADOT crash files CD that corresponds to the table being updated. For this example, Table SMS01000 was chosen, so the appropriate text file would be "sms01000.txt." Note that:

1. the "**Look in**" menu must reflect the path to the data files. For example, for CD-ROM drive K, the path would be K:\DATA\sms01000.txt
2. the "**Files of type**" menu must be changed to "Text Files"

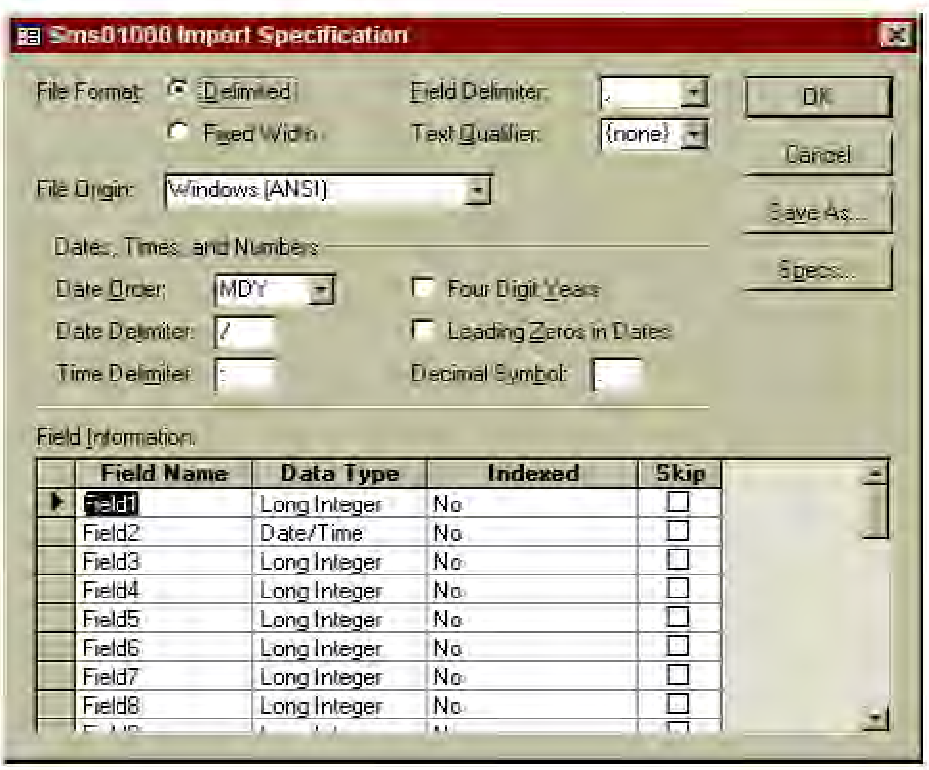


Select the text file to be imported (e.g. sms01000.txt) and press the "**Import**" button. This will open the Import Text Wizard shown on the following page.

****IMPORTANT**** Once the Import Text Wizard has been opened, a series of pre-formatted criteria can be used to delimit data and assign the appropriate categories. Unless the data file layout has changed, it is *not recommended* that these criteria be overridden. Follow the steps continuing under the Import Text Wizard graphic to use the pre-formatted specifications.

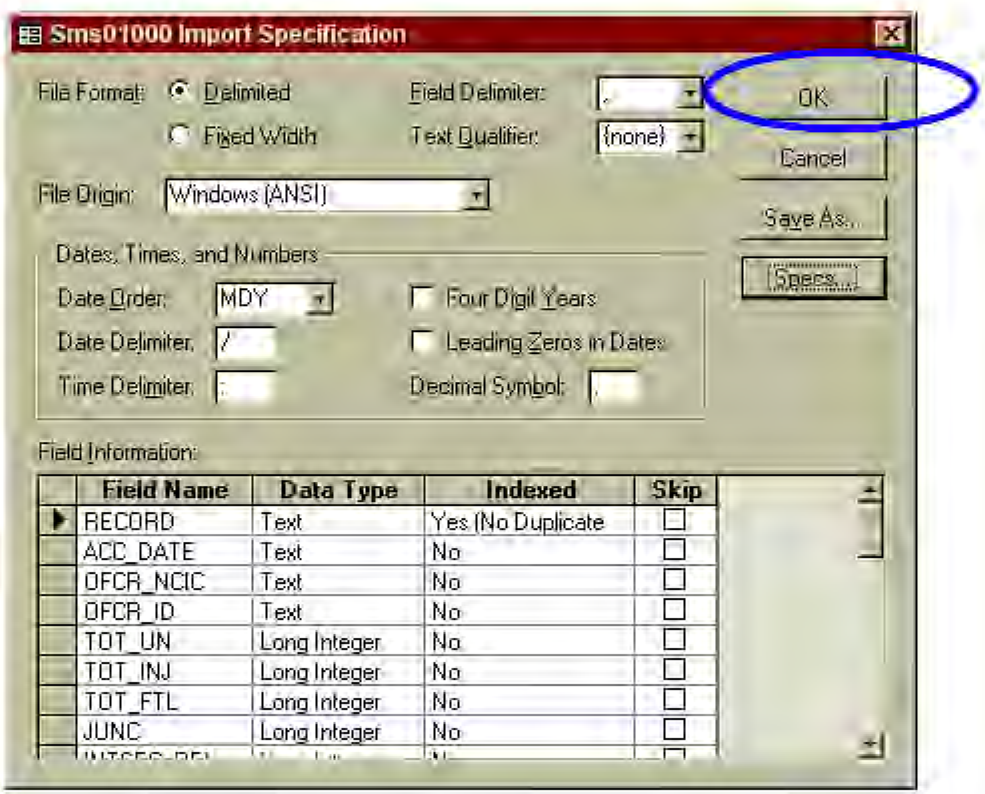


As discussed above, the file import should be performed using preset specifications. To access these options, press the "**Advanced**" button shown at the bottom left of the Import Text Wizard (circled above). This will open the Import Specification dialog box shown below. Do not make changes to any fields. Just select the "**Specs**" button.



Pressing the "**Specs**" button will open a list of Import/Export Specifications, as shown below. Select the **specifications option** that corresponds to the table being imported, then press "**Open**."

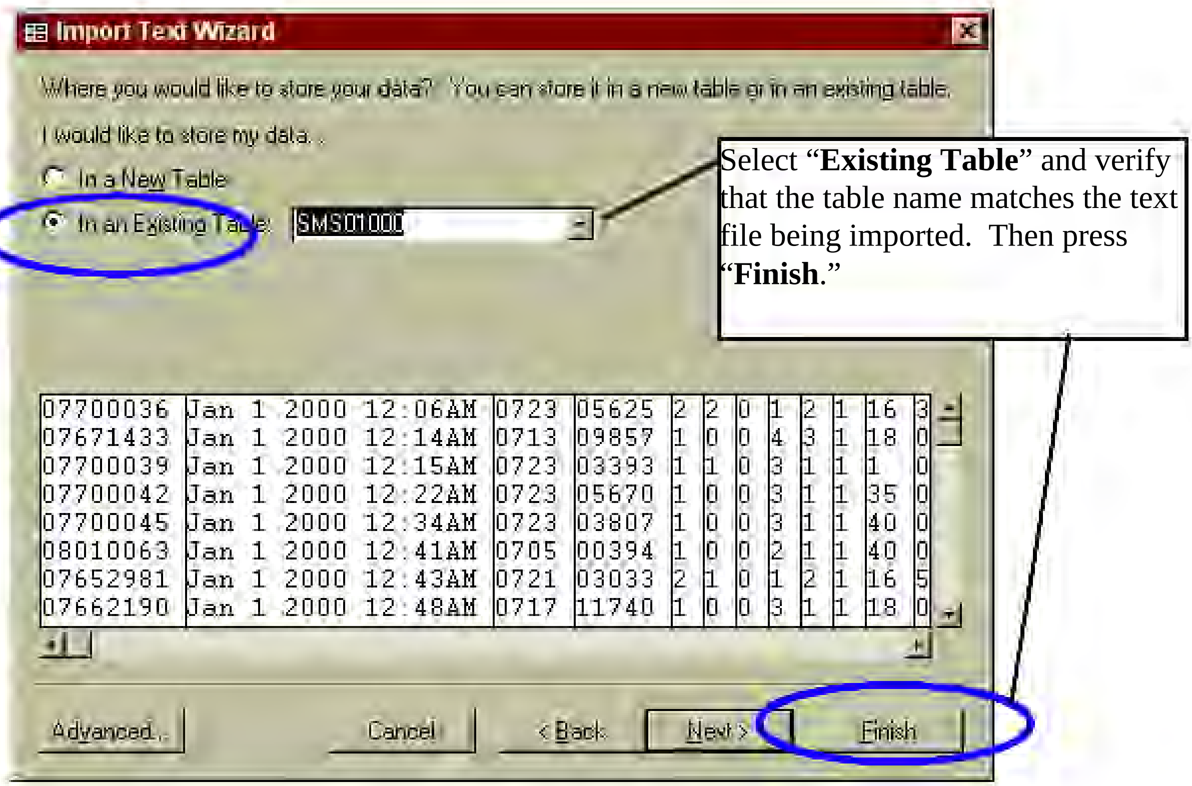
The **specification option** selected will automatically fill in the Field Name, Data Type, Indexed and Skip sections of the Field Information columns. Press "**OK**" when the field have been updated.



Although the fields have been named, formatted and sized for the imported data, this information will not be shown on the next Import Text Wizard dialog box. As long as the specifications have been properly set, this will not cause any problems with the data import. The next Import Text Wizard dialog box asks whether the incoming data should be placed in a new table or an existing table.

****IMPORTANT**** Be sure to select "**Existing Table**" as the location for incoming data, and verify that the correct table is highlighted in the **Existing Table Menu**.

When the appropriate existing table has been selected, press "**Finish**." There is no need to view additional options.



This completes the manual data import procedure *for the first table*. Repeat this process for *all* tables to be updated. When finished, it is suggested that the database be compacted, by selecting the following option from the main toolbar:

Tools > Database Utilities > Compact Database

Compacting the database will ensure that all files have been stored efficiently. When the procedure is complete, the database will reopen at the Startup Menu page. To view the imported tables, select option 3. To check the crash record summary table for duplicate records, select option 4. If import errors are indicated in the option 4 results, a new file will need to be created an the process repeated. In the event that errors are visible in option 3, contact ADOT Traffic and Engineering for file layout specifications.

Appendix C: Glossary of Safety Terms and Treatment Descriptions

The following terms appear frequently in highway safety literature. Definitions have been taken from a variety of sources, with emphasis on the glossary provided by Turner and Hall (1994) in *Severity Indices for Roadside Features*.

Abutment	the supporting structure at the end of a bridge
Accident	an unplanned event that usually results in damage or injury – see also Crash
Backslope	the sloping earth surface that lies between the bottom of a ditch and the natural grade of the adjacent land
Barrier	a device that limits the passage of a vehicle by retention or redirection
Breakaway	design feature of a support device (e.g. pole or sign) that allows the device to yield or separate upon impact
Bridge railing	longitudinal barrier intended to prevent a vehicle from going over the side of the bridge
Clear zone	the entire roadside border area that provides a recovery space for vehicles that have left the roadway; includes the entire clearance area (shoulders, slopes, etc.)
Clearance	lateral distance from the edge of the roadway to a roadside object or feature
Conflict	an event involving two or more road users, in which the action of one user requires the other user to make an evasive maneuver to avoid a collision
Controlled-Access Highway	Every highway, street, or roadway in respect to which owners or occupants of abutting lands and other persons have no legal right of access to or from the same except at such points only and in the manner as may be determined by the public authority having jurisdiction over such highway, street, or roadway.
Crash	an unplanned collision between motor vehicles, or between a motor vehicle and another object or person, that usually results in damage or injury
Crash cushion	device that prevents an errant vehicle from impacting a fixed hazard by gradually decelerating the vehicle or redirecting it away from the hazard
Design speed	the speed selected and used for correlation of the physical features of a highway that influence vehicle operation

Embankment	a negative roadside slope, typically in conjunction with a roadway constructed on a fill section
Encroachment	movement of a vehicle beyond the traveled roadway and toward the roadside
First harmful event	the initial damage-causing impact to occur in a crash
Front slope	the graded sloping earth surface between the outside edge of the shoulder and the inside edge of an adjacent ditch (in a cut section) or the toe of the slope (in a fill section)
Guardrail	barrier installed at the edge of the roadway or shoulder to limit vehicular passage beyond the edge of the roadway – see also Barrier
Hazard	any condition, feature or obstacle that could cause injury or damage to motor vehicles and/or vehicle occupants
HAZMAT	Hazardous materials, generally used in the context of hazardous materials regulatory enforcement.
Impact angle	measure of angle between the tangent to vehicle path subsequent to a collision and the tangent to path/face/axis of object struck
Impact attenuator	same as Crash cushion
Lane, travel	the portion of the highway intended for use by general traffic
Longitudinal barrier	barrier intended to prevent penetration and redirect an errant vehicle away from a roadside or median hazard (e.g. guardrail)
Median	the portion of a divided highway separating the traveled ways for traffic in opposite directions
Median barrier	a longitudinal barrier used to prevent vehicles from crossing the highway median
Most-harmful event	the impact in the sequence of harmful events for each involved vehicle in a crash that causes the greatest amount of injury and property damage – see also Primary harmful event
Nonrecoverable slope	a roadside slope that is considered traversible, but on which the errant vehicle will not be able to return to the roadway
Obstacle, rigid	a fixed object that obstructs normal travel, not intended to be in the path of a vehicle (e.g. bridge rail, tree, culvert, utility pole)
Offset	the distance between the traveled way and a roadside barrier or other obstacle
Operating speed	the highest speed at which reasonably prudent drivers can be expected to operate vehicles on a section of highway under low traffic density and good weather
PDO	a property-damage-only crash, with no personal injuries observed
Recoverable slope	a roadside slope on which a motorist may retain or regain control of a vehicle, generally flatter than 4:1

Recovery area	same as Clear zone
Regression to the mean	phenomenon in which sites that appear to be unusually hazardous during one time period will, on average, improve during a subsequent time period, even in the absence of a safety treatment
Ridedown acceleration	the deceleration that a vehicle experiences during a collision, occurring between initial impact and actual stopping of the vehicle
Roadside	the area between the outside shoulder edge and the right-of-way limits
Roadside barrier	a longitudinal barrier used to shield roadside obstacles or nontraversible terrain features
Roadside recovery distance	a relatively flat, unobstructed area adjacent to the travel lane (i.e. edgeline) that provides a reasonable chance for ROR recovery; therefore the distance from the outside edge of the travel lane to the nearest rigid obstacle, steep slope, ditch or other threat
Roadway	the portion of a highway, including shoulders, intended for vehicular use, exclusive of the sidewalk, berm or shoulder
ROR	run-off-road crash involving a single vehicle
Severity index	a means of categorizing crashes by the probability of property damage, personal injury and/or fatality; used for estimating relative effectiveness of alternate safety treatments
Shielding	introduction of a barrier or crash cushion between vehicles and an obstacle to reduce severity of impact
Shoulder	the portion of the highway immediately adjacent to, and outside of, the lanes; designed and intended to accommodate occasional use by vehicles, but not continuous or regular travel
Sideslope	also termed “foreslope,” an area adjacent to the roadway edge providing drainage for run-off and recovery space for off-road vehicles
Slope	relative steepness of terrain, generally expressed as the horizontal distance required for a unit change in elevation, categorized as positive (backslope) or negative (foreslope)
Traffic barrier	device used to prevent a vehicle from striking a more injurious roadside or median obstacle, or to prevent a vehicle from leaving the roadway
Transition	a section of barrier between two different barriers, or where a barrier is connected to a rigid object
Traveled way	the portion of the roadway used for the movement of vehicles, excluding the shoulders and auxiliary lanes
Traversable slope	a slope from which a motorist will be unlikely to steer back to the roadway but may be able to slow and stop safely; generally between 4:1 and 3:1
Warrants	the criteria by which the desirability or necessity of a safety treatment or improvement can be determined

Width, lane	distance from centerline of a two-lane road to the edgeline, or to the joint separating the lane from the shoulder
Width, roadway	the combination of lane, shoulder and median (if any) widths
Willingness to pay	a methodology used to estimate the costs of vehicle crashes based on the price a motorist would be willing to pay to avoid the risk of injury or death

Appendix D: Guidelines for Estimating Safety Project Effectiveness

This information is adapted from the HES eligibility section of *Traffic Engineering Policies, Guidelines and Procedures* (ADOT, 2000), as excerpted from *Accident Rate Reduction Levels Which May Be Attainable From Various Safety Improvements (Arizona Data) February 1991*. Not that the information contained herein should serve only as a baseline for estimation of project effectiveness. These figures do not imply uniform effectiveness measures for the project types shown below, and it should not be assumed that use of these measures is required for HES funding eligibility. Each project should be evaluated based on the specific roadway, crash and other relevant details for each site location.

The Arizona Local Government Safety Project Model uses the estimates in this section for estimating default values for project effectiveness *in the event that the model user does not specify these data*. The LGSP model assigns default project effectiveness values of 50 percent of the values shown in the following tables. Effectiveness values are scaled down by one half to acknowledge that the following data are obtainable estimates of crash reduction, not average or minimum values.

Crash reduction factors are grouped according to broad treatment category and project type subcategory. The following tables are organized according to seven broad categories of treatment:

1. Roadway improvements
2. Roadside improvements
3. Intersection and interchange improvements
4. Traffic control devices
5. Pedestrian facilities
6. Bridges and other structures
7. Railroad – highway crossings

Many treatments have different estimates of effectiveness depending on the type of crash observed. For example, lane additions are considered more effective at reducing run-off-road crashes than rear-end crashes. Similarly, crash reduction factors have been estimated for crashes of varying severity. For some combinations, negative values are observed, indicating that a particular project type has been associated with *increased* incidence of particular types of crash and/or crash severity.

The estimates of effectiveness for each project type embedded in the LGSP model reflect only the aggregate crash reduction factors for "all crashes" of "all types" (refer to the top left CRF for each treatment in the tables below). For locations where a specific type of crash (e.g. head-on) is observed in relative high frequency, use of the more specific estimates of treatment effectiveness should be considered. Again, these values serve only as guidelines, and the final estimate of effectiveness for a specific project is left to the user of the model.

Table 27: Arizona Estimated Crash Reduction Factors, Roadway Improvements

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
1-1	Lane addition	All	25%	39%	23%	23%	27%
		Rear-end	32%	67%	28%	28%	35%
		Run-off-road	44%	55%	44%	45%	44%
		Sideswipe/Same	30%	100%	36%	37%	28%
		Sideswipe/Opp & Head-on	53%	100%	39%	70%	59%
1-2	Lane widening	All	56%	58%	57%	57%	54%
		Run-off-road	49%	100%	35%	41%	54%
		Sideswipe/Same	52%	0%	43%	43%	54%
		Sideswipe/Opp & Head-on	70%	0%	100%	100%	25%
1-3	Shoulder widening	All	57%	48%	59%	58%	57%
		Run-off-road	60%	25%	57%	54%	65%
		Sideswipe/Same	41%	100%	75%	78%	28%
		Sideswipe/Opp & Head-on	75%	33%	80%	72%	83%
		Pedestrian	71%	86%	57%	71%	0%
1-4	TWLTL, continuous	All	30%	40%	20%	20%	35%
		Rear-end	36%	0%	38%	38%	34%
		Left-turn	33%	100%	0%	2%	48%
		Run-off-road	37%	100%	-3%	0%	49%
		Pedestrian	19%	0%	19%	18%	50%
		Sideswipe/Opp & Head-on	36%	0%	50%	50%	27%
1-5	Realignment	All	48%	33%	56%	55%	42%
		Run-off-road	66%	33%	71%	69%	62%
		Rear-end	37%	0%	42%	42%	34%
		Sideswipe/Opp & Head-on	85%	67%	89%	83%	87%
		Sideswipe/Same	54%	0%	57%	57%	53%
1-6	Shoulder grooving	All	18%	15%	18%	18%	17%
		Run-off-road	27%	12%	27%	26%	26%
1-7	Skid-resistant overlay	All	9%	2%	4%	4%	13%
		Rear-end	19%	25%	18%	18%	20%
		Run-off-road	13%	-16%	11%	10%	15%
		Wet pavement	39%	61%	25%	27%	43%
1-8	Truck escape ramp	All	18%	-75%	28%	20%	16%
		Defective brakes	-14%	-100%	0%	-100%	20%
		Rear-end	33%	0%	71%	71%	-100%
1-9	Brake check area	All	45%	100%	55%	58%	50%
		Defective brakes	100%	0%	100%	100%	0%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 28: Arizona Estimated Crash Reduction Factors, Roadside Improvements

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
2-1	Guardrail, new	All	19%	47%	12%	15%	21%
		Run-off-road	30%	56%	23%	26%	34%
2-2	Guardrail, upgraded and/or extended	All	15%	9%	13%	13%	16%
		Run-off-road	26%	10%	27%	25%	26%
2-3	Drainage structure extensions	All	36%	18%	34%	33%	38%
		Run-off-road	44%	27%	36%	36%	50%
2-4	Slope flattening	All	-4%	30%	-15%	-12%	2%
		Run-off-road	10%	30%	18%	19%	2%
2-5	Vegetation/obstacle removal	All	61%	0%	59%	58%	64%
		Run-off-road	77%	100%	76%	77%	76%
2-6	Median barrier, new/upgraded	All	36%	60%	26%	28%	39%
		Run-off-road	35%	50%	11%	13%	46%
		Sideswipe/Opp & Head-on	0%	0%	0%	0%	0%
2-7	Impact attenuators	All	41%	-100%	55%	50%	36%
		Run-off-road	45%	0%	30%	30%	58%
2-8	Object markers	All	16%	41%	17%	19%	14%
		Run-off-road	29%	60%	24%	29%	29%
2-9	Delineation	All	11%	8%	19%	18%	4%
		Run-off-road	34%	14%	43%	40%	24%
		Nighttime	25%	14%	41%	38%	10%
		Sideswipe/Opp & Head-on	67%	100%	25%	63%	71%
2-10	Animal fencing	All	-12%	0%	-17%	-15%	-9%
		Animal	66%	0%	91%	91%	61%
2-11	Animal reflectors	All	10%	0%	6%	6%	11%
		Nighttime animal	25%	0%	0%	0%	25%
2-12	Snow fencing	All	71%	0%	83%	83%	64%
		Snowy pavement	58%	0%	67%	67%	56%
2-13	Rockfall containment	All	14%	0%	0%	0%	25%
		Strike rocks	100%	0%	0%	0%	100%
2-14	Illumination	All	19%	0%	8%	8%	23%
		Nighttime	30%	100%	35%	42%	23%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 29: Arizona Estimated Crash Reduction Factors, Intersections and Interchanges

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
3-1	New signals	All	-17%	-14%	-20%	-20%	-15%
		Angle	42%	60%	39%	40%	45%
3-2	New signals and geometric revamp, channelization	All	21%	57%	28%	30%	13%
		Angle	68%	56%	73%	72%	63%
		Sideswipe/Same	53%	0%	100%	100%	42%
		Pedestrian	33%	100%	0%	33%	0%
3-3	Revamped signals	All	9%	0%	3%	3%	13%
		Angle	32%	100%	37%	37%	27%
		Left-turn	3%	0%	-44%	-44%	26%
		Pedestrian	57%	0%	50%	50%	100%
3-4	Revamped signals and geometric revamp, channelization	All	40%	50%	33%	34%	43%
		Rear-end	48%	100%	45%	45%	50%
		Left-turn	18%	50%	24%	25%	11%
		Angle	19%	0%	21%	20%	19%
		Improper turn	80%	0%	83%	83%	79%
		Sideswipe/Same	48%	0%	17%	17%	52%
		Pedestrian	-14%	100%	-60%	-33%	100%
3-5	Left-turn phasing	All	15%	33%	6%	6%	21%
		Left-turn	35%	50%	4%	6%	52%
3-6	Turn lanes	All	6%	100%	-1%	3%	9%
		Rear-end	-8%	100%	-40%	-31%	3%
		Angle	13%	100%	14%	17%	6%
		Left-turn	24%	100%	33%	38%	12%
		Sideswipe/Same	59%	0%	75%	75%	54%
		Improper turn	54%	0%	25%	25%	67%
3-7	Geometric revamp, channelization	All	43%	0%	71%	71%	20%
		Angle	17%	0%	58%	58%	-27%
		Run-off-road	67%	0%	80%	80%	50%
		Rear-end	60%	0%	100%	100%	33%
		Improper turn	10%	0%	100%	100%	100%
		Left-turn	67%	0%	50%	50%	100%
		Sideswipe/Same	67%	0%	100%	100%	50%
3-8	Illumination	All	-48%	0%	-14%	-14%	-73%
		Nighttime	18%	0%	29%	29%	8%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 29 (cont.): Arizona Estimated Crash Reduction Factors, Intersections and Interchanges

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
3-9	Sight distance improvement	All	7%	0%	6%	5%	8%
		Angle	21%	75%	3%	7%	31%
		Rear-end	10%	0%	17%	17%	4%
		Left-turn	13%	0%	21%	21%	3%
		Improper turn	30%	0%	30%	30%	29%
3-10	Channelization pavement markings	All	0%	100%	-4%	-2%	1%
		Left-turn	19%	0%	9%	9%	24%
		Angle	33%	100%	-50%	-36%	-31%
		Improper turn	17%	0%	60%	60%	-14%
		Pedestrian	80%	0%	100%	100%	-100%
		Sideswipe/Same	25%	0%	0%	0%	33%
3-11	Channelization signing	All	14%	-100%	-2%	-7%	27%
		Left-turn	36%	-100%	36%	27%	45%
		Angle	14%	0%	-50%	-50%	63%
		Sideswipe/Same	67%	0%	100%	100%	33%
		Improper turn	100%	0%	100%	100%	100%
3-12	Cross road/ side road signing	All	33%	100%	56%	59%	15%
		Rear-end	27%	0%	38%	38%	-75%
		Angle	29%	100%	25%	50%	20%
		Improper turn	64%	0%	86%	86%	43%
		Left-turn	86%	0%	75%	75%	100%
3-13	Stop signs	All	19%	0%	20%	20%	18%
		Angle	8%	0%	0%	0%	17%
		Rear-end	48%	0%	67%	67%	38%
		Left-turn	22%	0%	14%	14%	27%
3-14	Yield signs	All	-37%	0%	25%	25%	-89%
		Angle	43%	0%	33%	33%	50%
3-15	Signal removal	All	100%	0%	100%	100%	100%
		Rear-end	100%	0%	100%	100%	100%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 30: Arizona Estimated Crash Reduction Factors, Traffic Control Devices

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
4-1	Edgeline markings	All	30%	-100%	63%	52%	15%
		Run-off-road	30%	0%	60%	56%	10%
4-2	RPM's	All	11%	16%	11%	12%	11%
		Nighttime	16%	35%	10%	12%	18%
		Run-off-road	33%	23%	37%	37%	31%
		Sideswipe/Same	13%	100%	6%	7%	14%
		Sideswipe/Opp & Head-on	12%	40%	-15%	-4%	38%
4-3	Rumble strips	All	53%	83%	65%	73%	29%
		Run-off-road	54%	75%	56%	60%	38%
		Sideswipe/Opp & Head-on	80%	100%	100%	100%	67%
4-4	Signing (New), Curve	All	14%	55%	20%	24%	3%
		Run-off-road	17%	57%	24%	27%	1%
		Sideswipe/Opp & Head-on	29%	57%	47%	49%	3%
		Sideswipe/Same	75%	100%	100%	100%	71%
4-5	Signing (Upgraded), Curve	All	21%	6%	23%	22%	21%
		Run-off-road	21%	0%	25%	23%	18%
		Sideswipe/Opp & Head-on	26%	50%	11%	14%	34%
		Rear-end	48%	0%	38%	38%	76%
		Sideswipe/Same	100%	100%	100%	100%	100%
4-6	Signing, Icy pavement	All	-15%	67%	-24%	-13%	-17%
		Icy pavement	-22%	100%	-52%	-42%	-16%
4-7	Signing, Slippery when wet	All	7%	-81%	10%	6%	8%
		Wet pavement	31%	0%	29%	28%	33%
4-8	Signing, Narrow bridge	All	47%	0%	86%	86%	13%
		Run-off-road	50%	0%	100%	100%	0%
		Sideswipe/Opp & Head-on	20%	0%	100%	100%	-33%
4-9	Signing, Watch for rocks	All	13%	0%	13%	12%	14%
		Strike rocks	64%	0%	88%	88%	56%
4-10	Signing, Animal warning	All	10%	-15%	8%	6%	13%
		Strike animals	18%	83%	2%	12%	19%
4-11	Signing, Interstate	All	7%	8%	10%	10%	25%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.

Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 31: Arizona Estimated Crash Reduction Factors, Pedestrian Facilities

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
5-1	Sidewalks	All	-15%	100%	-70%	-58%	7%
		Hit pedestrian	89%	100%	88%	89%	0%
5-2	Pedestrian overpass	All	-33%	0%	0%	0%	-62%
		Hit pedestrian	67%	0%	50%	67%	0%
5-3	Pedestrian signing	All	4%	4%	8%	8%	1%
		Hit pedestrian	15%	22%	17%	17%	-33%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 32: Arizona Estimated Crash Reduction Factors, Bridge Structures

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
6-1	Bridge widening	All	36%	50%	38%	38%	32%
		Run-off-road	44%	50%	27%	29%	62%
		Sideswipe/Same	57%	0%	100%	100%	0%
6-2	Bridge replacement	All	62%	100%	36%	40%	70%
		Run-off-road	52%	100%	0%	17%	65%
		Rear-end	100%	0%	100%	100%	100%
		Sideswipe/Opp & Head-on	100%	0%	0%	0%	100%
		Sideswipe/Same	100%	0%	100%	100%	0%
6-3	New bridge	All	11%	0%	38%	36%	-15%
		Wet pavement	50%	0%	50%	50%	50%
6-4	Bridge barrier upgrade	All	25%	-100%	50%	41%	14%
		Run-off-road	42%	0%	46%	46%	40%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Table 33: Arizona Estimated Crash Reduction Factors, Railroad – Highway Crossings

Code	Project Type	Crash Type	Arizona Crash Reduction Factors /1.				
			All Crashes	Fatal Crashes	Injury Crashes	Fatal & Injury	PDO Crashes
7-1	Flashing lights, new	All	43%	0%	0%	0%	60%
		Hit train	0%	0%	0%	0%	0%
7-2	Flashing lights, upgraded	All	43%	0%	29%	29%	57%
		Hit train	38%	0%	0%	0%	60%
7-3	New gates and flashing lights to replace X-bucks	All	59%	90%	73%	76%	44%
		Hit train	96%	100%	95%	96%	95%
7-4	New gates to supplement flashing lights	All	62%	100%	71%	73%	53%
		Hit train	80%	100%	100%	100%	60%
7-5	Surface improvement	All	7%	-100%	0%	-22%	20%
		Hit train	20%	-100%	50%	-50%	67%
		Run-off-road	25%	0%	33%	33%	20%
7-6	Signing	All	100%	0%	100%	100%	100%
		Hit train	100%	0%	100%	100%	0%
		Run-off-road	100%	0%	100%	100%	100%
7-7	Pavement markings	All	48%	100%	43%	42%	51%
		Hit train	56%	100%	50%	43%	62%
		Rear-end	58%	0%	52%	52%	62%
		Run-off-road	22%	0%	8%	8%	30%

Source: *Traffic Engineering Policies, Guidelines and Procedures,* Arizona DOT, 2000.
Notes: (1) Negative values imply an increase in observed crashes of this type.

Appendix E: Survey of Previous Crash Reduction Factor Research

The following tables are intended to supplement the crash reduction factors (CRF) for various safety treatments found in Appendix C and embedded in the Arizona Local Traffic Safety Model. Note that many of the examples contained herein are based on previous studies of limited sample size or specific roadway characteristics. As such, much of this research should serve only as a guideline for estimating expected crash reduction factors for a specific treatment. The effectiveness of a particular treatment will be subject to a wide range of external factors (e.g. traffic volume and composition, visibility, grade, prevailing speed) that should be taken into account.

Also note that the combination of various treatments generally will not have a cumulative effect on crash reduction (Zegeer and Council, 1995). Crash reduction factors for multiple treatments at the same site should not simply be combined to yield an overall benefit. Some treatments will have only a marginal effect on crash reduction when combined with other treatments, and some combinations could conceivably offset each other. These examples are not intended to represent all types of roadway and treatments, and should therefore be treated with caution.

When applicable severity indices should only be compared within the context of a particular source. For example, to calculate the relative safety of a 3-strand cable barrier versus a retaining wall, the appropriate safety indices from Table 38 may be compared to each other, but not to another source index.

Table 34: FHWA Estimated Crash Reduction Factors, 1974-1994

Project Class	Project Type	Crash Reduction Factors /1.		
		Fatal Crashes	Injury Crashes	Fatal & Injury
Intersections & Signals	Turning lanes and traffic channelization	48%	26%	26%
	Sight distance improvements	N.S.	N.S.	N.S.
	Traffic signs	32%	15%	15%
	Pavement markings and delineators	15%	5%	6%
	Illumination	38%	14%	14%
	Traffic signals, upgraded	40%	22%	22%
	Traffic signals, new	N.S.	22%	23%
Structures	Bridge, widen or modify	49%	30%	31%
	Bridge, new	86%	69%	70%
	Replace or improve minor structure	36%	20%	21%
	Upgrade bridge rail	75%	29%	33%
Roadway	Construct median for traffic separation	71%	28%	30%
	Shoulder, widen or improve	21%	12%	12%
	Realign roadway	63%	41%	42%
	Skid treatment, overlay	18%	18%	18%
	Skid treatment, groove pavement	33%	15%	15%
Roadside	Utility poles, relocated or breakaway	32%	45%	44%
	Guardrail, upgraded	36%	8%	9%
	Median barrier, upgraded	N.S.	20%	22%
	Median barrier, new	64%	12%	15%
	Impact attenuators	N.S.	34%	34%
	Flatten side slopes	N.S.	27%	27%
	Remove obstacles	60%	23%	25%
Rail-Highway Crossing	Flashing lights, upgrade	85%	35%	44%
	Flashing lights, new	87%	79%	81%
	Flashing lights and gates, new	92%	85%	86%
	Gates, new	92%	74%	78%

Source: *Traffic Engineering Policies, Guidelines and Procedures*, Arizona DOT, 2000. Adapted from *The 1996 Annual Report on Highway Safety Improvement Programs*, FHWA-SA-96-040.

Notes: (1) Negative values imply an increase in observed crashes of this type; “NS” indicates no observed significance at 95% confidence level.

Table 35: Sample Crash Reduction Factors, Lane and Shoulder Widening

Add lane width	Condition before trtmnt		ACCIDENT REDUCTION (%) BY "AFTER" PERIOD SHOULDER CONDITION							
	Shldr width	**Srfce type**	**2' P shldr**	**2' U shldr**	**4' P shldr**	**4' U shldr**	**6' P shldr**	**6' U shldr**	**8' P shldr**	**8' U shldr**
3 ft	0 ft	N/a	43%	41%	52%	49%	59%	56%	65%	62%
	2 ft	P	32%	--	43%	--	52%	--	59%	--
	2 ft	U	34%	33%	44%	41%	53%	49%	60%	56%
	4 ft	P	--	--	32%	--	43%	--	52%	--
	4 ft	U	--	--	36%	32%	46%	41%	54%	49%
	6 ft	P	--	--	--	--	32%	--	43%	--
	6 ft	U	--	--	--	--	37%	32%	47%	41%
	8 ft	P	--	--	--	--	--	--	32%	--
	8 ft	U	--	--	--	--	--	--	39%	32%
2 ft	0 ft	N/a	35%	33%	45%	42%	53%	50%	61%	56%
	2 ft	P	23%	--	35%	--	45%	--	53%	--
	2 ft	U	25%	23%	37%	33%	46%	42%	55%	50%
	4 ft	P	--	--	23%	--	35%	--	45%	--
	4 ft	U	--	--	27%	23%	38%	33%	48%	42%
	6 ft	P	--	--	--	--	23%	--	35%	--
	6 ft	U	--	--	--	--	29%	23%	40%	33%
	8 ft	P	--	--	--	--	--	--	23%	--
	8 ft	U	--	--	--	--	--	--	31%	23%
1 ft	0 ft	N/a	26%	24%	37%	34%	47%	43%	55%	50%
	2 ft	P	12%	--	26%	--	37%	--	47%	--
	2 ft	U	14%	12%	28%	24%	39%	34%	48%	43%
	4 ft	P	--	--	12%	--	26%	--	37%	--
	4 ft	U	--	--	17%	12%	20%	24%	41%	34%
	6 ft	P	--	--	--	--	12%	--	26%	--
	6 ft	U	--	--	--	--	19%	12%	31%	24%
	8 ft	P	--	--	--	--	--	--	12%	--
	8 ft	U	--	--	--	--	--	--	21%	12%

Source: Zegeer and Council, 1995

Notes: (1) Reduction factors for two-lane rural roads. (2) Blanks indicate projects that would decrease shoulder width and/or change paved shoulder to unpaved. (3) "P" = paved, "U" = unpaved

Table 36: Sample Crash Reduction Factors, Sideslope Flattening

Sideslope Before Trtment	Sideslope After Treatment							
	4:1		5:1		6:1		7:1 or Flatter	
	Single Vehicle CRF	Total CRF	Single Vehicle CRF	Total CRF	Single Vehicle CRF	Total CRF	Single Vehicle CRF	Total CRF
2:1	10%	6%	15%	9%	21%	12%	27%	15%
3:1	8%	5%	14%	8%	19%	11%	26%	15%
4:1	0%	--	6%	3%	12%	7%	19%	11%
5:1	--	--	0%	--	6%	3%	14%	8%
6:1	--	--	--	--	0%	--	8%	5%

Source: Zegeer and Council, 1995

Notes: Reduction factors applicable for two-lane rural roads

Table 37: Sample Crash Reduction Factors, Bridge Shoulder Widening

Bridge Shoulder Width Before Treatment[1.]	Crash Reduction (%) by Bridge Shoulder Width After Treatment[1.]						
	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft
0 ft	23%	42%	57%	69%	78%	83%	85%
1 ft	--	25%	45%	60%	72%	78%	80%
2 ft	--	--	27%	47%	62%	71%	74%
3 ft	--	--	--	28%	48%	60%	64%
4 ft	--	--	--	--	28%	44%	50%

Source: Zegeer and Council, 1995

Notes: (1) Shoulder width refers to each side, total shoulder width equals single-side width multiplied by two. (2) Reduction factors applicable for bridges on two-lane rural roads. (3) Assumes constant travel lane width.

Table 38: Average Severity Indices for Roadside Barriers

Hazard	Surface	Design Speed			
		40 mph	50 mph	60 mph	70 mph
Longitudinal Barrier					
3-Strand cable	Face	2.2	2.5	2.8	3.1
W-beam (weak)	Face	2.4	2.7	3.2	3.5
Thrie beam (weak)	Face	2.4	2.7	3.0	3.3
Blocked-out W-beam (strong)	Face	2.6	3.1	3.6	4.3
Blocked-out Thrie beam (strong)	Face	2.6	3.1	3.6	4.3
Concrete safety shape	Face	2.3	2.7	3.4	4.3
Stone masonry wall	Face	2.6	3.1	3.8	4.5
Retaining wall / Vertical barrier	Face	2.6	3.1	3.8	4.5
Barrier Terminal					
3-Strand cable	Side	2.3	2.8	3.5	4.4
W-beam					
Anchored in backslope	Side	2.7	3.2	3.9	4.6
Breakaway cable terminal	Side	2.7	3.2	3.9	4.6
Turned-down	Side	2.9	3.4	4.1	4.8
Concrete safety shape					
80 ft. sloped end	Side	2.9	3.4	4.1	4.8
Obsolete / non-functional	Side	3.8	4.6	5.5	6.5
Crash Cushion					
Hi-Dro cell	Both	2.3	2.7	3.0	3.3
G-R-E-A-T system	Both	2.3	2.7	3.0	3.3
Hex-form sandwich	Both	2.3	2.7	3.0	3.3
Sand-filled plastic barrels	Both	2.3	2.7	3.0	3.3

Source: *Supplemental Information for Use with the ROADSIDE Computer Program*, FHWA, August 1991 (cit. in Turner, *et al.*, 1994)

Table 39: Average Severity Indices for Roadside Slopes

Hazard	Surface	Design Speed			
		40 mph	50 mph	60 mph	70 mph
Parallel Slopes					
Foreslope					
10:1	Face	0.4	0.7	1.0	1.3
6:1	Face	0.6	1.1	1.6	2.0
4:1	Face	1.2	1.7	2.4	3.0
3:1	Face	1.8	2.5	3.2	4.0
2:1	Face	2.6	3.5	4.4	5.5
Backslope					
4:1	Face	0.8	1.1	1.6	2.0
3:1	Face	1.2	1.7	2.4	2.9
2:1	Face	2.0	2.5	3.4	4.1
Vertical rock cut					
Smooth	Face	2.6	3.1	3.6	4.3
Rough	Face	3.0	3.7	4.5	5.3
Cross Slopes					
Embankment (uphill)					
10:1	Side	0.4	1.1	1.8	2.5
6:1	Side	1.2	1.7	2.6	3.1
4:1	Side	2.0	2.7	3.6	4.5
3:1	Side	2.2	3.1	4.0	4.9
2:1	Side	3.4	4.3	5.4	6.8
Vertical rock cut	Side	4.6	5.5	6.6	7.9
Ditch					
Foreslope Backslope					
3:1 3:1	Face	2.1	2.7	3.6	4.3
3:1 4:1	Face	1.5	2.2	3.0	3.5
3:1 6:1	Face	1.3	1.8	2.6	3.1
4:1 3:1	Face	1.5	2.2	3.0	3.5
4:1 4:1	Face	1.3	1.8	2.6	3.1
4:1 6:1	Face	1.1	1.5	2.1	2.6
6:1 3:1	Face	1.3	1.8	2.6	3.1
6:1 4:1	Face	1.1	1.5	2.1	2.6
6:1 6:1	Face	0.9	1.3	1.8	2.3

Source: *Supplemental Information for Use with the ROADSIDE Computer Program*, FHWA, August 1991 (cit. in Turner, *et al.*, 1994)

Table 40: Average Severity Indices for Roadside Objects

Hazard	**Surface**	**Design Speed**			
		40 mph	**50 mph**	**60 mph**	**70 mph**
Rigid Objects					
Tree					
Diameter < 4”	Both	1.5	1.9	2.3	2.7
Diameter < 4”	Both	3.8	4.6	5.5	6.5
Utility pole	Both	3.8	4.6	5.5	6.5
Bridge pier	Both	3.8	4.6	5.5	6.5
Rigid sign support					
Single / multiple	Both	3.4	4.2	5.3	6.3
Cantilever / overhead	Both	3.8	4.6	5.5	6.5
Breakaway sign support					
Fracture	Both	0.8	1.1	1.6	2.1
Mechanical / yielding	Both	1.0	1.3	1.8	2.3
Rigid base luminaire support	Both	3.8	4.6	5.5	6.5
Breakaway luminaire support	Both	2.2	2.5	2.8	3.1
Headwall, pedestal, foundation					
Height < 4”	Both	0.8	1.4	1.9	2.4
Height = 4” – 10”	Both	1.8	2.5	3.0	3.7
Height > 10”	Both	3.8	4.6	5.5	6.5
Edge drop-off					
Height < 4”	Face	0.7	1.0	1.3	1.6
Height = 4” – 10”	Face	1.3	1.8	2.3	2.8
Height > 10”	Face	1.9	2.6	3.3	4.0
Curb					
Mountable (< 6”)	Face	0.8	1.4	1.9	2.4
Non-mountable (6” – 10”)	Face	1.9	2.4	3.0	3.5
Barrier (> 10”)	Face	2.9	3.4	4.1	4.8
Fire hydrant	Both	2.1	2.6	3.1	3.6
Mail box	Both	1.7	2.2	2.7	3.4
Chainlink fence	Face	1.6	2.3	2.8	3.1

Source: *Supplemental Information for Use with the ROADSIDE Computer Program*, FHWA, August 1991 (cit. in Turner, *et al.*, 1994)

Table 41: Average Severity Indices for Drainage Structures

Hazard	Surface	Design Speed			
		40 mph	50 mph	60 mph	70 mph
Culvert Opening					
Cross culvert					
Pipe end diameter < 3ft.	Both	2.2	2.5	3.0	3.5
Pipe end diameter > 3ft.	Both	3.4	3.9	4.6	5.3
Sloped w/ bar grates	Both	*USE VALUES FOR PARALLEL SLOPE*			
Parallel culvert					
Pipe end diameter < 3ft.	Side	2.4	2.7	3.2	3.7
Pipe end diameter > 3ft.	Side	3.6	4.1	4.8	5.5
Sloped w/ bar grates	Side	*USE VALUES FOR CROSS SLOPE*			
Miscellaneous Drainage Items					
Raised inlet w/ grate	Both	*USE VARIABLE HEIGHT VALUES*			
Rip-rap					
Average diameter < 6”	Both	0.7	1.4	1.9	2.4
Average diameter = 6” – 10”	Both	1.8	2.3	2.8	3.3
Average diameter > 10”	Both	3.8	4.6	5.5	6.5
Permanent stream or pond					
Depth < 3 ft.	Both	3.0	3.6	4.2	5.0
Depth > 3 ft.	Both	5.5	6.2	6.9	7.8

Source: *Supplemental Information for Use with the ROADSIDE Computer Program*, FHWA, August 1991 (cit. in Turner, *et al.*, 1994)

Table 42: Sample Crash Reduction Factors, Multiple Lane Conversion

Multiple Lane Treatment	Type of Area	Crash Reduction (%) [1.]	
		Total Crashes	Fatal and Injury Crashes
Add passing lanes	Rural	25%	30%
Add short four-lane section	Rural	35%	40%
Add turnout lanes	Rural	30%	40%
Add two-way left-turn lane	Rural	35%	35%
Add two-way left-turn lane	Suburban	70 – 85%	70 – 85%
Add shoulder use section	Rural	NS [2.]	NS

Source: Zegeer and Council, 1995

Notes: (1) CRF applicable for two-lane roads in rural or suburban areas. (2) "NS" = not significant

Table 43: Sample Crash Reduction Factors, Urban Two Way Left-Turn Lane

Street Type Before Treatment	Street Type After Treatment	Area Type	Crash Reduction Factors	
			Expected CRF (%)	90% Conf. Interval
4-lane undivided	5-lane with TWLTL	Urban	44%	13 – 75%
4-lane divided (narrow median)	5-lane with TWLTL	Urban	53%	24 – 82%
6-lane divided (narrow median)	7-lane with TWLTL	Urban	24%	11 – 38%

Source: Harwood, 1995

Notes: (1) Crash reduction factors apply to urban arterial street treatments. (2) "TWLTL" refers to two-way left-turn lane. (3) Conversion study used *narrower* lanes to implement turn-lane strategy, and still found statistically significant reduction in crash rates

Table 44: Arizona Crash Rates for Various Left-Turn Signal Treatments

Left-Turn Signal	2 Opposing Lanes		3 Opposing Lanes	
	Rate[1.]	Count[2.]	Rate	Count
Permissive	2.62	162	3.83	25
Leading exclusive/permissive	2.71	62	4.54	52
Lagging exclusive/permissive	3.02	44	2.65	35
Leading exclusive	1.02	57	1.33	80
Lagging exclusive	2.09	4	0.55	2

Source: Upchurch, 1991

Notes: (1) Rate expressed in crashes per million left-turning vehicles. (2) Count refers to sample size.

Table 45: Survey of Traffic Signal Crash Reduction Factors

Reference[1.]	Study Period[2]	Location	No. of Signals	% Reduction by Accident Type[3.]				
				Total	Rear-end	Right angle	Injury	Left turn
Solomon, 1959	--	MI Rural	39	-23%	-200%	+51%	+20%	n/a
King, 1975	1-2 yr.	VA --	30	-24%	-181%	+34%	+18%	-16%
King, 1975	--	MI --	33	-8%	-84%	+45%	n/a	-236%
NY DOT, 1982	3-4 yr.	NY Rural	39	+7%	+21%	+13%	-11%	-13%
Hammer, 1970		CA Rural	170	+21%	-90%	+76%	+32%	+14%
Clyde, 1964		MI Urban	52	-34%	-98%	+45%	-11%	-66%
Short, 1982	3 yr	WI Urban	31	+2%	-37%	+34%	-6%	n/a
Vey, 1933		Var. Mixed	599	+20%	-37%	+56%	n/a	n/a
Cribbins, 1970	1 yr	NC Rural	19	-7%	-147%	+73%	-21%	-21%
Malo, 1967		MI Urban	20	+47%	+24%	+75%	n/a	n/a
SF, CA, 1974	1 yr	CA Urban	48	+53%	+72%	+80%	+50%	n/a
Leckie, 1971	1 yr	Ontario Rural	13	+8%	n/a	n/a	-27%	n/a
Schoene, 1968	2 yr	Illinois Rural	30	-16%	-221%	+48%	-26%	n/a
Smith, 1964	1 yr	CA Mixed	32	+39%	n/a	n/a	n/a	n/a

Source: Persaud, 1988.

Notes: (1) Refer to Persuad for specific citations. (2) Years indicate typical lengths for before and after periods, where given. (3) Negative values indicate an observed increase in crash frequency.