A Comprehensive Analysis Framework for 4E Safety Investment Decisions

DRAFT FINAL REPORT

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Cambridge Systematics, Inc.
555 12th Street, Suite 1600
Oakland, CA 94607

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Executive Summary

INTRODUCTION

The study aims to advance road safety practice towards greater use of cost-effectiveness analysis so that the maximum safety improvement can be achieved for every dollar of investment. Cost-effectiveness analysis currently is used to some extent within the sub-disciplines of safety, but is rarely used to compare investments across the 4 Es of safety (education, engineering, enforcement, and emergency response).

This report provides several resources to assist practitioners in moving towards greater use of cost-effectiveness analysis across the 4 Es of safety in strategic planning and other applications. These resources include:

- A **conceptual framework** for better integrating 4 E strategy cost-effectiveness comparisons into safety investment decision-making processes (Chapter 2);
- **Two methods** (a quantitative method and a sketch method) for conducting cost-effectiveness comparisons across the 4 Es of safety (Chapters 3 and 4); and example applications (Appendices C, D, and E); and
- A conclusion discussing potential applications of the framework and future research needs (Chapter 5).

CONCEPTUAL FRAMEWORK

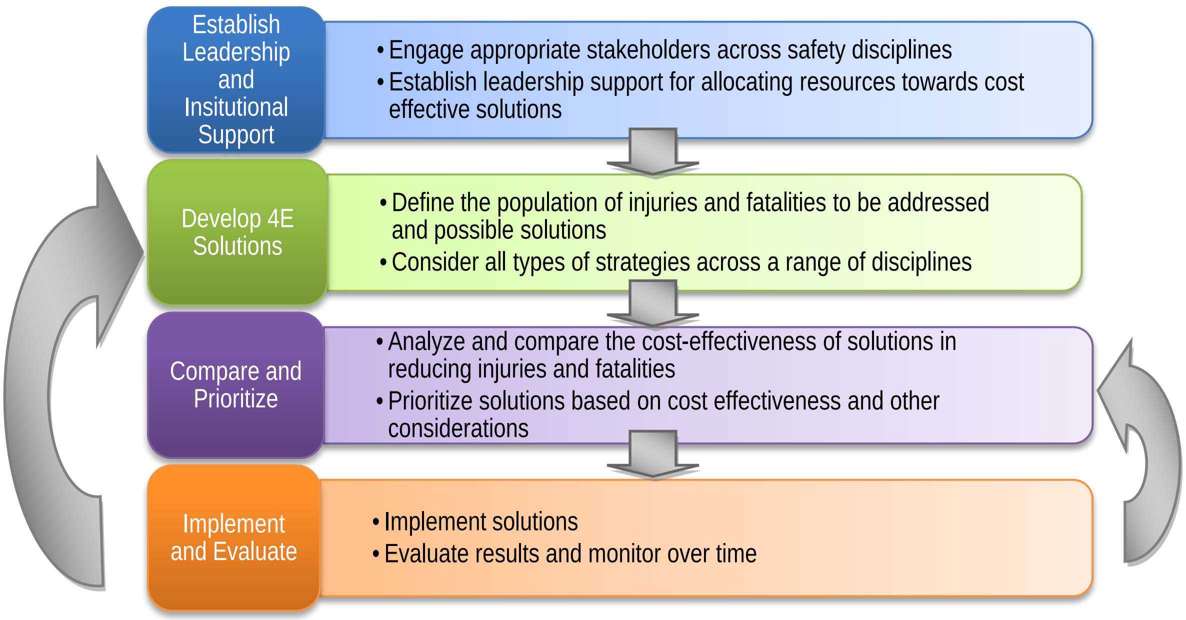
A multidisciplinary approach to safety planning is well-established in the safety field. Federal transportation legislation (MAP-21) allows the Highway Safety Improvement Program (HSIP) funds to be used on 4E safety countermeasures that are consistent with the State's to Strategic Highway Safety Plans (SHSP) and the Federal Highway Administration (FHWA) Office of Safety references the 4 E approach in its mission statement.[1]

Although the 4 E approach to safety is accepted as a best practice, some safety practitioners struggle to operationalize it, particularly as it relates to safety investment decisions. Beyond information sharing, attending summits, and occasional coordination on projects, some safety professionals are uncertain of how the 4 E approach should inform resource allocation decisions. The

[1] The FHWA Office of Safety's mission is to reduce highway fatalities by making our roads safer through a data-driven, systematic approach and addressing all "4 Es" of safety: engineering, education, enforcement, and emergency medical services.

conceptual framework provided here fills that gap by focusing specifically on integrating a 4 E approach into investment decision-making. It describes the importance of engaging leadership support for a cost-effective approach; developing a range of strategies from across different disciplines; comparing their cost-effectiveness; and evaluating results. Application of these steps will help support prioritization of more cost-effective safety solutions. Figure ES.1 lists the framework steps at a summary level.

Figure ES.1 Conceptual Framework for 4 E Safety Investment Decisions



COST-EFFECTIVENESS ANALYSIS METHODS

Executing Step 3 of the conceptual framework requires analysis of the cost-effectiveness of different types of safety countermeasures. This report provides a quantitative and a sketch-level method for making these comparisons.

The quantitative method is appropriate when detailed, quantitative results are desired and sufficient basis exists to make quantitative assumptions for all variables in the analysis, including crash modification factors, duration of effectiveness, geographic extent of effectiveness, costs, and so forth. The sketch-level method is appropriate when quantitative information is not complete, insufficient basis exists upon which to make quantitative assumptions, or when detailed results are not necessary. Both methods result in safety strategies grouped by their relative cost-effectiveness, and this information can be used as one factor among others in ranking countermeasures for implementation. Chapters 3 and 4 describe the methods in more detail. Appendices C, D, and E provide example analysis results from the application of the cost-effectiveness

analysis methods to safety projects in San Francisco, North Carolina, and another example state.[2]

Conclusions and Next Steps

This report provides a conceptual framework and analysis methods to assist practitioners in better integrating cost-effectiveness analysis into safety investment decisions. If successfully applied, these resources will help advance the state of the practice towards a comprehensive, data-driven approach that maximizes the injuries and fatalities reduced for every public dollar invested.

This report also has brought to light several areas for future study, including the need for better and more reliable information on the effectiveness of a broad range of safety countermeasures, especially those from emergency response, education, and enforcement; the need for more consistent definitions of safety effectiveness across resource documents; the need for uniform cost and useful life assumptions for different types of countermeasures; and the need for better quality crash data.

Additionally, further consideration should be given to how to improve the flexibility of safety funding sources. While MAP-21 has lifted its 10 percent flex funding cap on non-infrastructure projects, other Federal programs limit emphasis on the most cost-effective solutions, as many of them channel funding to specific solutions if not specific programs and projects. This forces focus on projects that conform to funding requirements rather than those that would deliver the most benefit for the least cost.

[2] The state wished not to be named in the final report.

1.0 Introduction

In an environment of resource constraints, public agencies strive to focus resources on the most cost-effective investments. Within the road safety field, this means giving preference to strategies that deliver the greatest injury and fatality reduction for the least cost; however, cost-effectiveness analysis is not systematically used to compare safety countermeasures, particularly when it comes to comparing countermeasures across the 4 Es of safety (education, engineering, enforcement, emergency response). For example, State Strategic Highway Safety Plans do not typically compare the cost-effectiveness of candidate safety strategies across disciplines. However, the Federal legislation MAP-21 highlights the need for this type of comparison. Under this legislation, 4Es countermeasures are eligible for HSIP funds if they are consistent with the state's SHSP, address a data driven need, and reduce fatalities and serious injuries. .

The 4 Es of Safety and Beyond

This report focuses on methods for comparing strategies across the 4 Es of safety (education, engineering, enforcement, emergency response) to identify the most cost-effective approaches for addressing safety issues. In the future, additional strategies can also be considered beyond the 4 Es such as vehicle technology improvements or exposure reduction (e.g., vehicle miles of travel), that also could prove cost-effective.

This report seeks to advance the state of road safety practice towards greater use of cost-effectiveness analysis in safety project prioritization and strategic planning involving the 4 Es of safety. To that end, it provides:

- A **conceptual framework** for better integrating 4 E strategy cost-effectiveness comparisons into safety investment decision-making processes (Chapter 2);
- **Two methods** (a quantitative method and a sketch method) for conducting cost-effectiveness comparisons across the 4 Es of safety (Chapters 3 and 4); and
- A conclusion discussing potential applications of the framework and future research needs (Chapter 5).

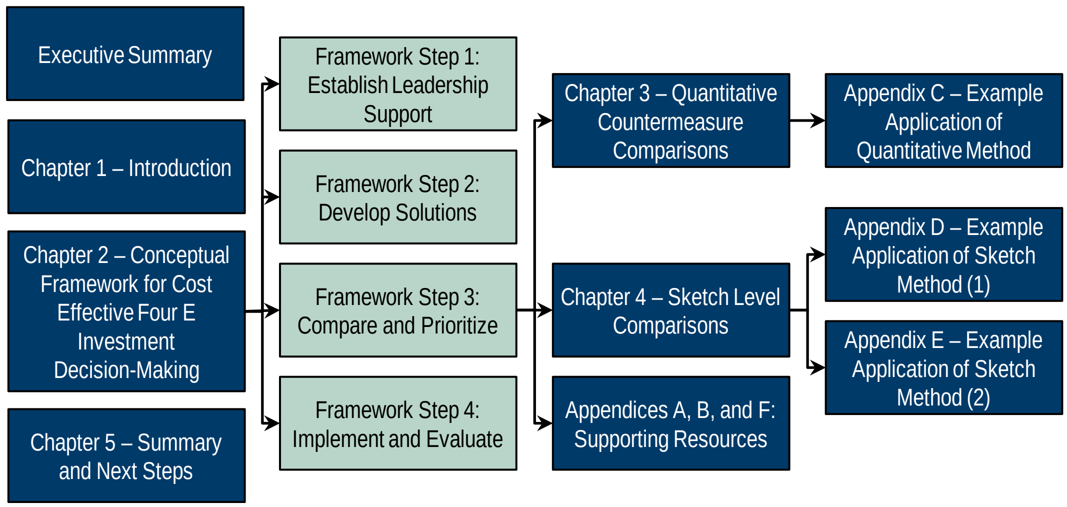
It also contains:

- Supporting tools and resources (Appendices A and B) for safety countermeasure analysis and project prioritization;
- An example application of the quantitative cost-effectiveness comparison method (Appendix C); and
- Two example applications of the sketch cost-effectiveness comparison method (Appendices D and E).

- Supporting marketing materials summarizing the research, including example articles and PowerPoint webinar presentations (Appendix F, attached separately).

Figure 1.1 provides a graphic overview of the relationship between the report Chapters and appendices. Report Chapters are shown in dark blue, key content within Chapter 2 is shown in light blue.

Figure 1.1 Structure of Report – Overview



Report Audience

- This research is intended to be applied in the following contexts: **Strategic Planning.** Engineers and planners involved in preparing strategic safety planning documents (e.g., Strategic Highway Safety Plan, regional highway safety plan) could use the framework and methods to develop their approach and to prioritize safety strategies as part of these documents.
- **Prioritization of Applications for Grant Funding.** Highway Safety Office staff could use the sketch-method presented in Chapter 3 in prioritizing grant applications for funding. Highway Safety Engineers could use the method to compare applications for behavioral safety strategies under the Highway Safety Improvement Program (HSIP) Flex Funding with applications for traditional engineering investments, to identify which are more likely to produce beneficial results.
- **Corridor Planning.** Local engineers, planners, and behavioral safety specialists, such as those involved in road safety audits or corridor planning studies, could use the quantitative methods to compare the cost-effectiveness of approaches to addressing safety issues along a specific corridor.
- **Research and Policy.** Federal funding agencies and state safety management teams could use the framework and its applications to establish safety funding policies and to direct additional research in safety planning. In

particular, the summary information presented in Chapter 5 is intended for policy-makers at the state and Federal levels. It introduces them to the changes necessary to allow implementation of cost-effective approaches to safety planning.

Appendices - Content

Six Appendices provide supporting material for this report:

Appendix A – Supporting Tools and Resources - summarizes resources available to help with prioritization of different types of safety countermeasures, including technical software tools, research reports, and others.

Appendix B – Countermeasure Duration of Effectiveness – summarizes available research on the duration of effectiveness of engineering and behavioral safety countermeasures. Duration of effectiveness is a key assumption in completing cost-effectiveness analysis of safety countermeasures.

Appendix C - Quantitative Methods Case Study – contains a detailed quantitative comparison of the benefits and costs of four safety countermeasures applied in San Francisco, California, including pedestrian median extensions, automated enforcement, child pedestrian safety training, and driving under the influence checkpoints. The analysis illustrates the numerous assumptions that must be made in preparing a quantitative benefit cost analysis, and demonstrates the need for sensitivity analysis to test how results vary with different inputs.

Appendix D - Sketch Method Case Study (1) – details the application of the sketch method for prioritizing countermeasures to 31 example behavioral and engineering safety projects in North Carolina. It demonstrates the assumptions and steps necessary to complete the comparison, and shows how the results allow selection of the most cost effective engineering and behavioral safety project types.

Appendix E - Sketch Method Case Study (2) – details the application of the sketch method to a second example state.

Appendix F - Marketing Materials - provides two example articles and two PowerPoint presentations summarizing the research results, and a longer white paper on the issue of funding flexibility in highway safety.

2.0 Conceptual Framework for Cost-Effective 4 E Investment Decision-Making

2.1 INTRODUCTION

This Chapter presents a conceptual framework for how public agencies could modify their investment decision-making processes to integrate consideration of the cost-effectiveness of a wide range of safety strategies.

Why is Conceptual Framework Needed?

The field of safety planning has a well-established multidisciplinary approach. Highway Safety Improvement Program under the Federal transportation legislation (MAP-21) can fund 4 E safety countermeasures that are consistent with the state's Strategic Highway Safety Plans (SHSP). In its mission statement, the Federal Highway Administration (FHWA) Office of Safety references the 4 E approach.[3]

While the safety field accepts the 4 E approach as a best practice, some safety practitioners struggle to operationalize the approach in making safety investment decisions. Although safety practitioners share information, attend summits, and occasionally coordinate projects, they often do not know how to apply the 4E approach to resource allocation decisions. This Chapter provides a conceptual framework focusing specifically on integrating a 4 E approach into investment decision-making

How is this Framework Different?

Several safety planning frameworks already have been proposed or described in documents, such as NCHRP 501 – Integrated Safety Management Processes; the FHWA's Champions' Guide to Saving Lives; and NCHRP 8-36(57) – Institutional Needs in Safety Planning. These frameworks focus primarily on how to achieve better coordination and collaboration across the safety disciplines.

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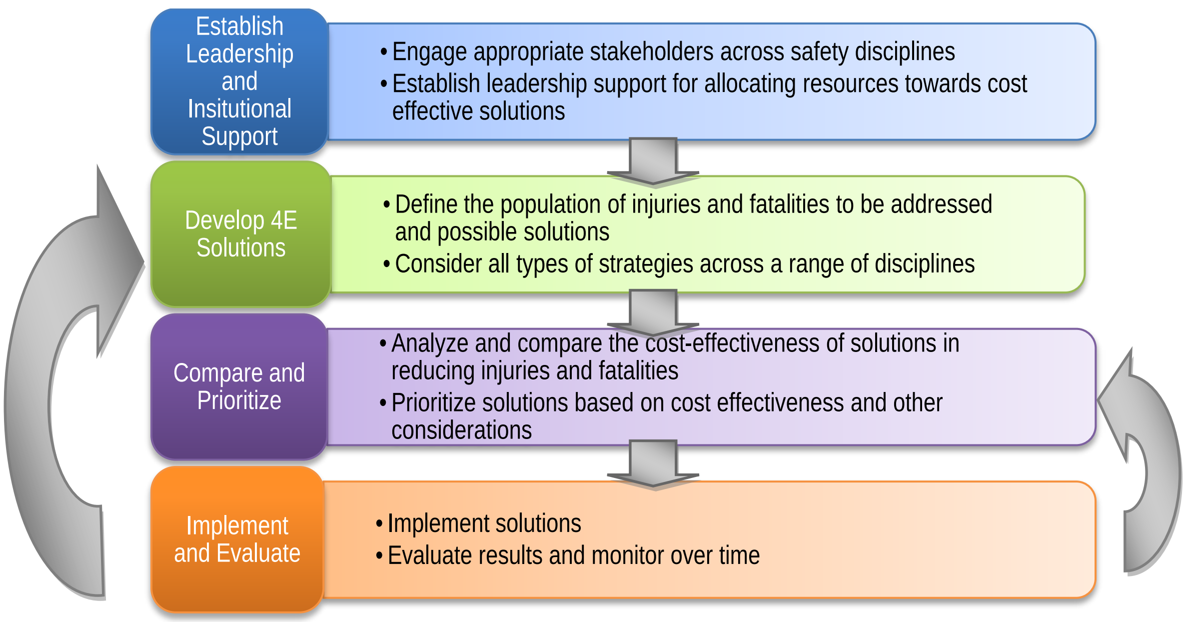
[3] The FHWA Office of Safety's mission is to reduce highway fatalities by making our roads safer through a data-driven, systematic approach and addressing all "4 Es" of safety: engineering, education, enforcement, and emergency medical services.

The steps proposed in this framework are similar to those proposed elsewhere, but focus explicitly on comparing the cost-effectiveness across multiple Es of safety. The intent here is not to create "yet another" safety framework, but to assist practitioners in understanding how they can integrate 4 E tradeoff analysis into existing safety programming processes.

2.2 Proposed Framework

Figure 2.1 lists the framework steps at a summary level.

Figure 2.1 Conceptual Framework for Cost-Effective 4 E Investment Decision-Making



The following sections discuss each of the framework steps in more detail, including possible challenges and actions towards implementing each step.

2.3 Framework Step 1: Establish Leadership and Institutional Support

The first step in the framework is to establish the group of individuals or leaders who will guide the process and who are committed to promoting cost-effective solutions to safety problems. Leadership also is responsible for identifying goals and performance measures to keep everyone focused on reducing injuries and fatalities.

Establish Leadership

The leadership group will focus on implementing cost-effective solutions to address roadway injuries and fatalities in a particular geographic area. This could be an entire state (e.g., the strategic highway safety planning process), a region (such as a metropolitan planning organization), or a local area (e.g., a city, county, or corridor). Leadership support is critical, because shifting resources towards more cost-effective solutions is often politically controversial.

Three organizational models for establishing this type of leadership include:

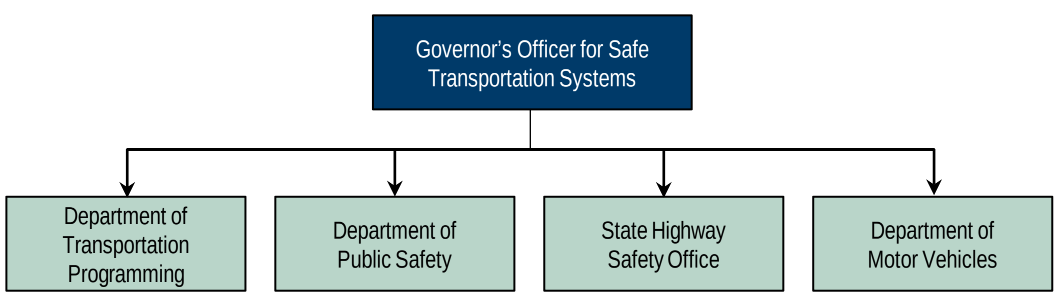
1. Structure a process under an existing organization;
2. Create a new organization to oversee the development and implementation of the process; or
3. Establish a partnership among multiple existing organizations to develop and implement the process.

This framework proposes establishing a partnership among multiple existing organizations with an executive team empowered to make safety investment decisions. The executive team could be empowered legislatively, by governor appointment, or through a memorandum of agreement among the organizations. Its members serve as champions for road safety and work to ensure that the most cost-effective safety solutions are adopted.

A possible organizational structure for this leadership team is shown in Figure 2.2. In this example, the organization is appointed by and answers to the Governor. The executive team members are likely to vary from state to state as a function of critical issues, institutional structures, and organizational features. A first activity of framework development is to facilitate a process for establishing the leadership team.

The leadership team's ability to influence safety investment decisions will depend on whether it controls safety funding sources. For example, the team could be given the power to allocate funding from several existing sources, or a new source could be created. This may require fundamental institutional changes to allow sharing funds across public agencies.

Figure 2.2 Organizational Structure



Actions to Establish Leadership:

- **Emphasize the Strategic Highway Safety Plan.** The Strategic Highway Safety Plan (SHSP) serves as a tool for multidisciplinary safety policy, program, and project development. The law assigns development and implementation of the SHSP to the DOT. In most but not all cases, the DOT serves as the lead agency.
- **Identify Transportation Safety as a Priority by High-Level Leaders.** Leaders require agencies to work together to create a unified, implementable plan for addressing all areas of safety. This occurred in Washington State, for example, when the Governor required a unified safety plan from the major safety-related state agencies, e.g., the Department of Transportation, the Washington Highway Safety Commission, the State Patrol, and the licensing agency. Leadership from the agencies collaboratively report to the Governor quarterly; in other words, they present a single report rather than four separate reports. These sessions are highly interactive and televised. Washington State has been successful in realigning agency priorities to focus on proven solutions to the highest-priority problems – see the case study below.
- **Maximize Funding Flexibility**. A cost-effective approach to safety investment relies on having access to flexible funding sources. Some safety funding programs permit a flexible approach (e.g., the Highway Safety Improvement Program flex provision) but many others have rigid requirements that limit focus on the most cost-effective solutions. Agencies could address this problem by: 1) taking advantage of existing opportunities for flexibility; 2) creating new sources of funding with fewer constraints, e.g., Minnesota's Central Safety Fund; and 3) advocating for greater Federal funding flexibility.
- **Pilot Applications**. This framework is developed for a state or regional investment programming process; however, the framework also could be applied on a smaller scale. Example applications include:
  - Establish a multidisciplinary project management team to study and evaluate a specific project **such as a safety corridor study or a specific** crash trend (e.g., run-off-road crashes);
  - Establish a multidisciplinary project management team to develop, implement, evaluate, and monitor a regional safety action plan; or
  - Identify and set aside funding from each participating agency for multidisciplinary safety planning and investment.

Minnesota's Central Safety Fund

In creating the state Comprehensive Highway Safety Plan (a precursor to the SHSP), safety stakeholders in Minnesota identified the need for a flexible source of funding to support implementation of 4 E countermeasures identified in the plan, and particularly to address safety needs on local roads. The State Department of Public Safety (Office of Traffic Safety) and the Minnesota Department of Transportation agreed to contribute jointly to a Central Safety Fund to meet this need. To date, the CSF has been used to fund three programs, including cable median guardrail construction, the Minnesota Speed Management Program, and safety needs on county highways.

Source: NCHRP 17-18 (016): Creating a Traffic Safety Culture – A Case Study of Four Successful States, Draft Minnesota Case Study, 2007.

Identify Goals and Supporting Performance Measures

A major responsibility of the leadership team is to articulate an overall goal for safety. This shared vision of safety becomes the cornerstone for safety planning and decision-making across all disciplines. It galvanizes leadership and commits them to enhanced transportation safety.

A shared goal also is critical for supporting focus on cost-effective safety planning. Agreement on the goal leads to agreement that the most cost-effective solutions should be prioritized, since cost-effective approaches will allow goals to be achieved more quickly. To support a multidisciplinary approach, the goal should be expressed in terms of fatality and injury reduction, rather than crash-reduction. Many safety strategies, such as emergency response strategies, aim to reduce injuries and fatalities resulting from crashes, rather than the crashes themselves.

Once the goal is defined, individual performance measures can be adopted to help track progress towards achievement of the goal, hold leadership accountable to the program, and guide day-to-day program management.

Washington State – Leadership Support for Resource Realignment

Washington State provides an example in which agency leadership committed to re-aligning resources to focus on proven solutions to top priority problems. The Traffic Safety Commission (TSC) identified speeding and impaired driving as the most significant problem areas. To reflect the new priorities, the agency created a speeding program area and removed old program areas. The TSC then instituted a policy of funding only projects that provide proven solutions to the top priority areas. The DOT supported the top priority areas by identifying corridors with the highest number of speeding and impaired driving crashes, and implementing low-cost, high benefit countermeasures along those corridors.

2.4 Framework Step 2: Identify 4 E Strategies to Address Safety Issues

In this step of the framework, the crash data are evaluated to define major crash trends and descriptive statistics in the geographic area of interest. The data evaluation characterizes crashes using descriptive statistics such as number, type, and severity of crashes by various demographic, environmental, and roadway characteristics. The evaluation also summarizes various aggregate level trends such urban or rural crashes, crashes categorized by driver demographics, pedestrian and bicycle safety, etc. Similar to an SHSP analysis, the results are used to characterize crash conditions in the community, identify the most critical issues, and inform goal development. The analysis results are presented and discussed in a comprehensive manner considering all disciplines to support subsequent multidisciplinary solutions.

This section does not provide specific instructions for how to conduct safety crash data analysis and countermeasure identification, because these techniques are well-documented elsewhere. Rather, it highlights ideas for ensuring multiple types of 4 E safety strategies are considered as part of the analysis. Several ideas are discussed below.

Take a Multidisciplinary Approach

The Haddon Matrix (Table 2.1) is a multidisciplinary framework for identifying contributing crash factors and potential countermeasures. On a crash by crash basis, information from crash reports is evaluated and categorized according to the timeline of the event (e.g., pre-crash, during the crash, post-crash) and the contributing crash factors associated with the human, vehicle, and environment. Subsequently, potential countermeasures are identified according to the situation under consideration.

As part of applying this framework, practitioners could collect crash data in the geographic area of interest and fill in the cells in a Haddon matrix. This would help stimulate ideas for how to solve the problem from a variety of perspectives. Table 2.1 shows an example Haddon Matrix focusing on factors associated with vehicle rollover crashes in the United States. The factors suggest a range of possible solutions, including the:

- **Human Factors –** younger driver programs focused on driving impaired, belt use, vehicle handling skills;
- **Vehicle Factors –** improve SUV stability; reduce ejection potential; and
- **Environmental Factors –** reduce speed limits and roadside hazards.

Although post-crash factors were not analyzed in the study, possible contributing factors could include lack of passenger first aid skills, vehicle propensity to catch fire, and congestion blocking emergency access. These

factors could be addressed through training, vehicle design, and expanded incident response teams.

Table 2.1 Example Haddon Matrix – Factors Associated with Rollover Crashes

	Human Factors	Vehicle Factors	Environmental Factors
Before Crash	Less experienced younger driver more likely to rollover	Sport Utility Vehicle prone to rollover	High speed limit associated with rollover
During Crash	Alcohol impaired driver more likely to rollover	Drivers ejected from vehicle more likely to be injured	Many drivers hit an embankment before rolling over
After Crash	*[Not analyzed, but could include first-aid skill of vehicle passengers]*	*[Not analyzed, but could include risk of post-crash vehicle fire]*	*[Not considered, but could include roadway congestion blocking emergency access]*

Source: Based on the National Highway Safety Administration Report "An Analysis of Motor Vehicle Rollover Crashes and Injury Outcome," 2007.

Crash data quality is a notable challenge in defining the safety problem from a multidisciplinary perspective. Data timeliness, accuracy, completeness, uniformity, integration, and accessibility are considerations for how easily a jurisdiction can acquire the data needed to conduct analysis. For example, lack of linkages between crash data records and emergency response medical records makes diagnosis of after-crash factors more difficult. In the early stages of implementing this type of framework, it is necessary to work with the best available data and to concurrently develop a plan to collect and/or share more and better data as the program evolves.

Use Appropriate Software Tools and Reference Documents

Many tools and reference documents can assist in multidisciplinary crash data analysis and solution identification. Table 2.2 lists some commonly used software programs and resources and their applicability to the 4 Es. The NCHRP 500 Series, which suggests a broad range of countermeasures from across the 4 Es to address over 20 different types of safety issues, is a good resource for ensuring a multidisciplinary approach for identifying potential treatments. Other tools tend to focus predominantly on either behavioral or engineering measures.

Beyond the tools listed in Table 2.2, other approaches could include system-based screening concepts underdevelopment at FHWA and in practice in a small number of states, including Minnesota and Missouri; and benchmarking

concepts used in Europe.[4] System-based screening concepts involve proactive assessment of the characteristics of the road network to identify areas likely to yield higher numbers of injuries and fatalities in the future. The approach is typically engineering-focused but could be expanded to include consideration of behavioral safety issues as part of the systemic screening process.

Table 2.2 Tools and Resources for Safety Analysis and/or Countermeasure Identification

	Description	Applicability
Software Tool		
SafetyAnalyst	Software tool for analyzing contributing crash factors and identifying site-specific countermeasures	Engineering
Interactive Highway Safety Design Model	Software tool for geometric-based safety performance analysis.	Engineering
Vision Zero Suite (formerly Levels of Service of Safety)	Software tool for identifying sites with promise for safety improvement, contributing crash factors, and site-specific countermeasures.	Engineering Enforcement Education
Resource		
Highway Safety Manual	Includes chapter on crash data analysis, problem diagnosis, and countermeasure identification.	Primarily engineering
NCHRP 500 Series	Guidebooks containing a toolbox of different strategies for addressing a broad range of safety problems.	Engineering Enforcement Education EMS
NCHRP Report 622	Guidebook listing behavioral countermeasures and their effectiveness	Enforcement Education
Countermeasures that Work	Guidebook listing behavioral countermeasures and their effectiveness	Enforcement Education

Refer to the Road Network

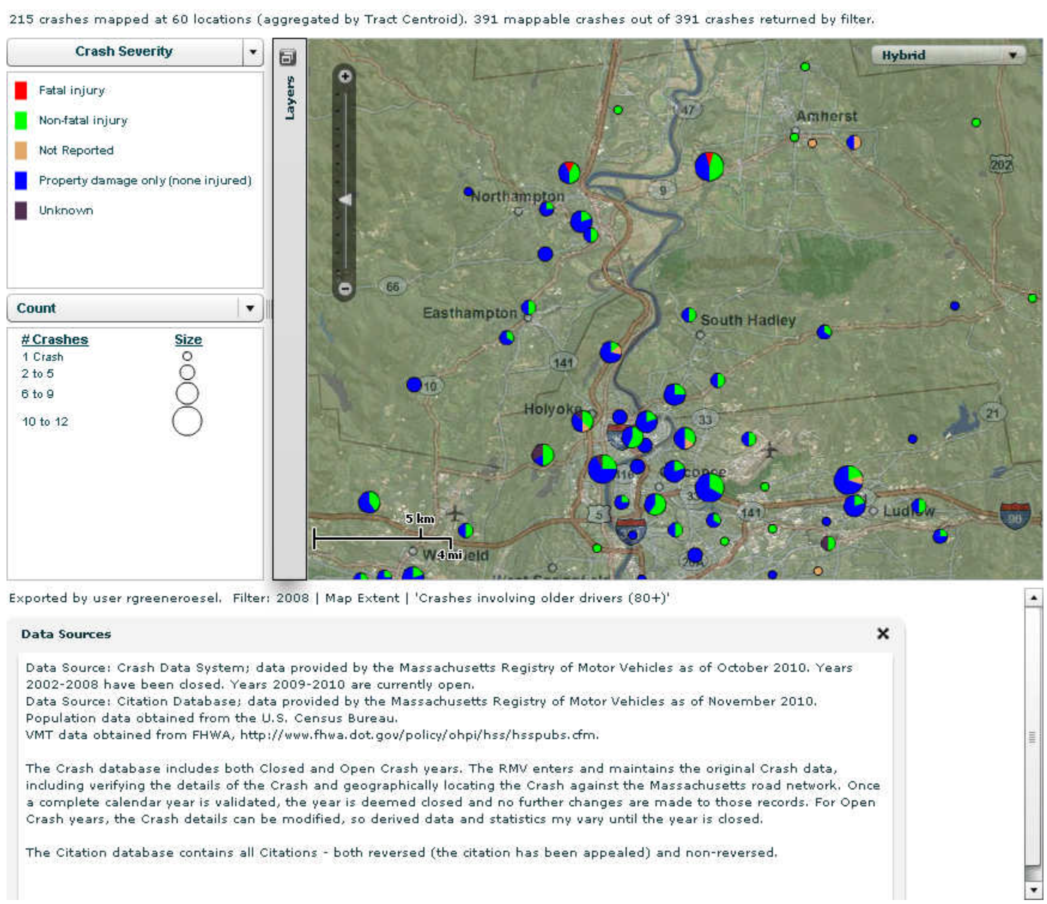
The State Highway Safety Office most often evaluates data and considers safety issues on a statewide or county by county basis. Engineers seek sites with potential for safety improvement or system-based safety solutions. The Motor Carrier Safety Assistance Program considers issues and identifies solutions by evaluating crash data by vehicle type (i.e., truck crash data).

[4] Wegman, F., J. Commandeur, E. Doveh, V. Eksler, V. Gitelman, S. Hakkert, D. Lynam, and S. Oppe, SUNflowerNext: Towards a composite road safety performance index. Deliverable D6.16 of the EU FP6 project SafetyNet, 2008.

These different methods and geographic scales for summarizing crash data may create barriers to multidisciplinary data analysis. This could be addressed through identification of a common geography for analysis (e.g., a county), and through examination of all crashes within that geography in terms of location on the roadway network. Geographic Information Systems (GIS) software provides a useful mechanism for exploring all types of injuries and fatalities occurring on the network. It allows safety stakeholders representing all 4 Es to look at the same data sets when identifying the most appropriate solutions.

Figure 2.3 shows an example of a crash data visualization tool useful to a broad community of safety stakeholders, including engineers, law enforcement, and behavioral safety specialists. The tool displays crash data aggregated for a selected geographic area and allows the user to filter data several ways, including type of driver (e.g., older driver, young driver), type of roadway (e.g., urban arterials, two-lane rural road), crash type (e.g., head-on collision), citation (e.g., DUI), road user type (motorcyclist, pedestrian, injury severity (e.g., percent PDO, injury, fatality), etc.

Figure 2.3 Crash Visualization Tool Screenshot – Older Driver Crashes



Note: MassTRAC developed by Massachusetts Executive Office of Public Safety and Security (EOPSS).

2.5 FRAMEWORK STEP 3: COMPARE AND PRIORITIZE STRATEGIES

The next framework step is to compare safety strategies and prioritize according to their cost-effectiveness and other considerations. An overview of the process is provided here; Chapters 3 and 4 provide more detailed methods on how to perform a cost-effectiveness analysis.

Considerations in Safety Project Prioritization

A number of questions may be considered as part of safety project prioritization, such as:

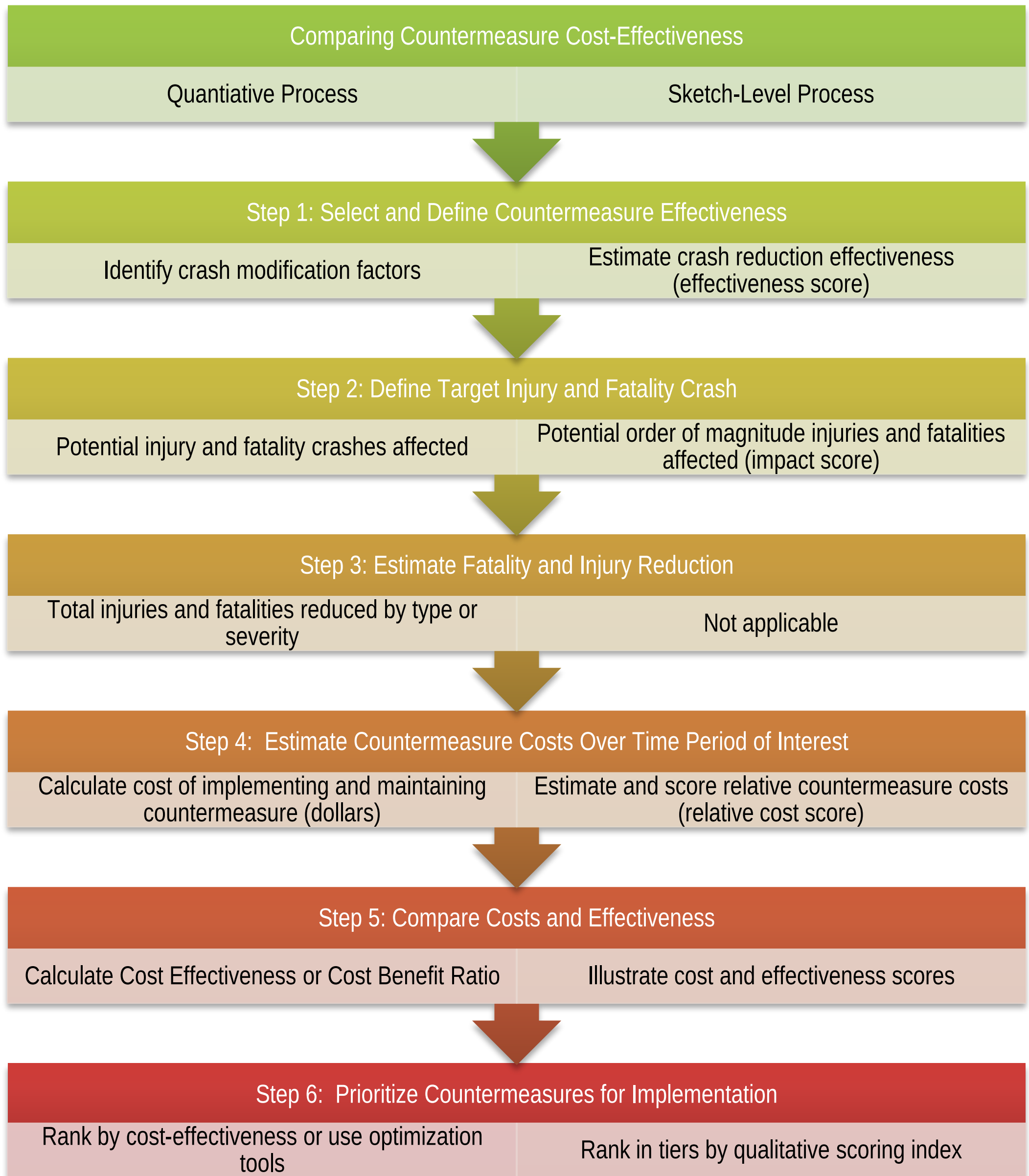
- **Legal Feasibility** – Would the strategy require a law change or other regulatory change?
- **Political Support** – Is the strategy supported by stakeholder agencies, interest groups and politicians?
- **Technical Capacity** – Does the implementing agency have the experience and personnel to implement the strategy?
- **Cobenefits** – Does the strategy help achieve multiple agency goals beyond safety (e.g., mobility improvement)?
- **Cost –** Is the strategy affordable given budget constraints?
- **Benefit-Cost –** Do the overall economic benefits of this project outweigh the economic costs to the agency and the public?
- **Cost-Effectiveness** – How many injuries and fatalities would this strategy reduce per dollar of project cost relative to other types of safety strategies?

All these considerations can enter into the selection of safety strategies, and all are important. Because the purpose of this research effort is to investigate cost-effective approaches to safety investment decision-making, the material presented in this step focuses on comparing the cost-effectiveness and/or benefit-cost of safety countermeasures. Other factors should be taken into consideration as appropriate.

Proposed Methods for Cost-Effectiveness Analysis

Two methods for comparing the cost-effectiveness of safety countermeasures are proposed: a sketch-level method and a quantitative method. Figure 2.4 provides an overview of the steps involved in the two methods.

Figure 2.4 Overview of Methods for Safety Cost-Effectiveness Comparisons



The quantitative method is appropriate when detailed, quantitative results are desired and sufficient basis exists to make quantitative assumptions for all variables in the analysis, including crash modification factors, duration of effectiveness, geographic extent of effectiveness, costs, and so forth.

The sketch-level method is appropriate when quantitative information is unavailable or when detailed results are not required. Table 2.3 compares the two methods. Both methods result in safety strategies grouped by relative cost-

effectiveness, and this information can be used as one factor among others in ranking countermeasures for implementation.

Table 2.3 Method Comparison

	Quantitative Method	Sketch-Method
Information needs	Quantitative effectiveness information (e.g., Crash Modification Factors) for all countermeasures Geographic extent and duration of countermeasure impacts Project costs (initial and ongoing) for all countermeasures	Quantitative or qualitative effectiveness information (e.g., CMF, star quality rating) Information on type of crashes to be addressed by the project Project cost information Duration of countermeasure effectiveness
Process	Calculate cost-effectiveness	Score projects based on relative cost-effectiveness
Results	Cost-effectiveness ratio for each project	Graphical illustration of relative project cost-effectiveness
Best for	Evaluating a small number of projects in-depth	Evaluating a large number of projects at a high level
Possible contexts	Corridor study, focused policy analysis, prioritization of projects where quantitative information is available for all projects.	Prioritizing projects as part of a strategic planning process or a project prioritization process where quantitative information on project effectiveness is limited (e.g. prioritization of behavioral safety projects).

The sketch and quantitative methods can also be used together at different stages of the safety planning process. The sketch-level method could be used during the initial, strategic planning stage to identify the most promising project concepts that should be considered further. This could be followed by a more detailed quantitative analysis of specific, fully-defined candidate projects to determine which have the highest benefits relative to costs.

Prioritizing Among Indirect Safety Strategies

The sketch and quantitative methods described above apply to countermeasures expected to directly improve safety. Many valuable safety strategies, however, cannot be directly linked to injury and fatality reduction, such as:

- Traffic data system improvements (better database connectivity, systems for automatic digital submittal, crash data processing, etc.);
- Staff training and development (publication of guidebooks on safety topics, development of training courses for safety practitioners, etc.);
- Research activities to better understand specific safety problems or to test solutions; or

- Administrative process improvements in efficiency and effectiveness with which existing safety-related administrative processes are carried out, such as investments in courtroom staff capacity or equipment, the efficiency of driver licensing or testing, etc.

Any of these activities could ultimately impact crash frequency or severity, but the linkage is expected to be indirect, potentially nonlinear, and difficult to quantify. Nevertheless, since these types of activities often consume a significant share of discretionary resources spent on safety, particularly at the state level, they should not escape scrutiny. Two important questions may be addressed. First, the funding agency may evaluate the appropriate share of the discretionary budget to spend on such activities. Second, these activities may be evaluated to ensure they have the intended impact.

2.6 Framework Step 4: Implement and Evaluate

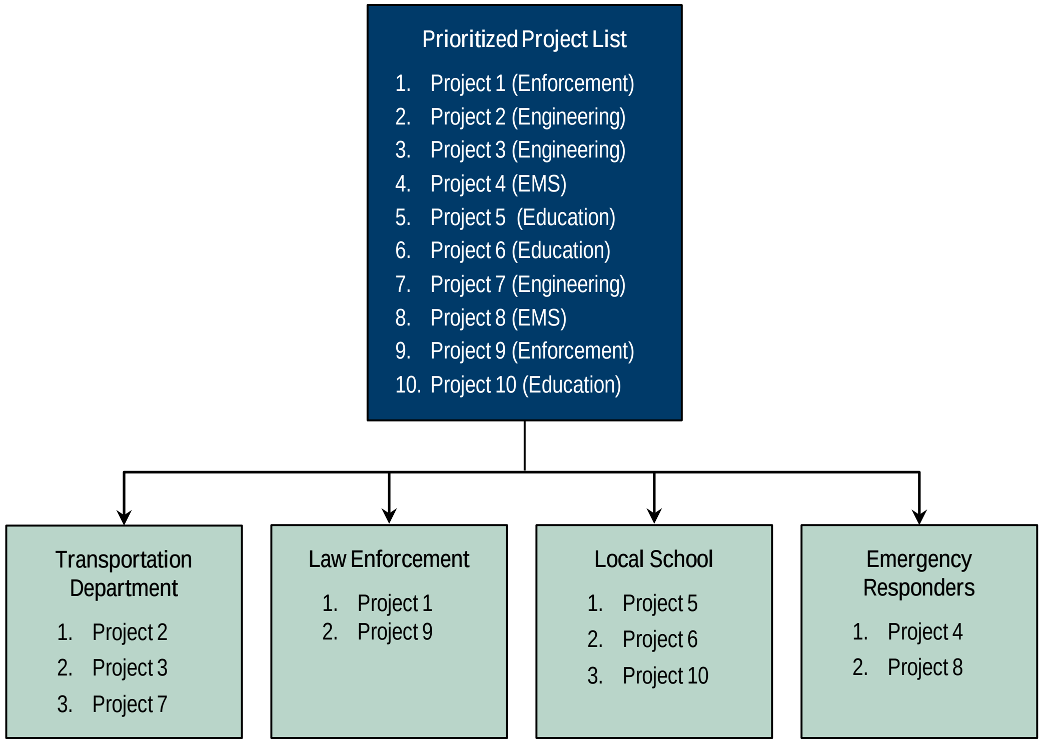
The final framework step is to implement the selected strategies and evaluate results.

Implementation

The previous step ranks strategies for implementation taking into account cost-effectiveness and implements in priority order. In practice, institutional silos and funding constraints may not allow following priority order of cost-effectiveness. Nevertheless, each implementing agency can focus on the most cost-effective strategies within their purview. Figure 2.5 illustrates the process. Strict priority order is not followed because the most cost-effective project is implemented at the same time as the second, fourth, and fifth most cost-effective projects, but each agency prioritizes the most cost-effective approaches they can implement.

Another approach for implementation mentioned above would involve safety practitioners gathering (for example, as part of a Strategic Highway Safety Planning exercise) candidate safety strategies, and prioritizing them into tiers using the sketch level method described in Chapter 4. Each agency could then use the quantitative method to prioritize amongst the top-tier strategies it is capable of implementing.

Figure 2.5 Process for Implementing a Prioritized Project List Across Several Agencies



Monitoring and Evaluation

A final component of implementation is monitoring and evaluation to verify the investment package is contributing to achievement of the injury and fatality reduction goal. Monitoring could occur quarterly, or annually in the case of countermeasures with longer implementation timeframes, such as infrastructure projects. Example evaluations could include: compare base year performance measure targets to current five-year rolling average; or for each performance measure compare the current year five-year rolling average to the near-term and long-term goals to identify overall progress. These assessments reveal impacts of the investment program and the need for modification.

Evaluation of the impacts of individual projects, in addition to the investment package as a whole, is also important. This is particularly true for experimental pilot projects. The Highway Safety Manual provides four methods for evaluating project-specific safety impacts:

- Before and after evaluation that uses SPFs – the Empirical Bayes Method;
- Before and after evaluation that uses a comparison-group method;
- Before and after evaluation that evaluates shifts in collision crash type proportions; and

- Observational cross-sectional study.

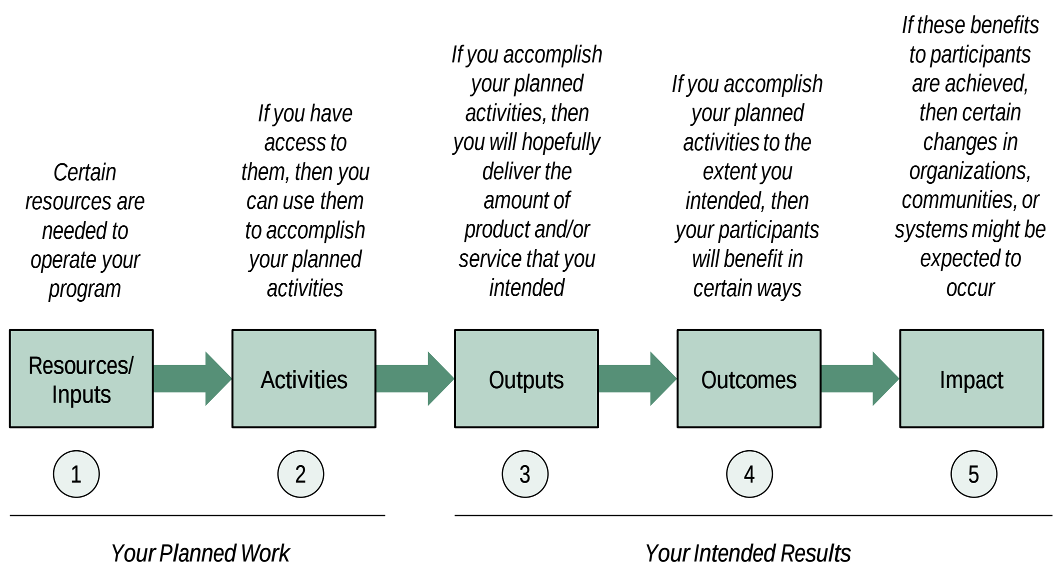
The evaluations demonstrate whether projects are resulting in measurable injury and fatality reduction benefits and therefore should be given higher priority in the future.

Evaluating Projects with Indirect Effects

Certain types of projects cannot be evaluated using the standard methods described in the HSM because they are not expected to directly impact serious injuries and fatalities. These include indirect and administrative activities such as trainings, crash data systems improvements, guidebook development, etc. These types of activities may improve safety in the long term, but the effects are too difficult to measure. Nevertheless, given that they can consume significant funding, they should not escape scrutiny.

A logic model is a useful tool for evaluating these indirect and administrative activities. Logic models specify the causal chain of effects expected to ultimately result in the desired impact (e.g., injury and fatality reduction). Figure 2.6 from a Kellogg Foundation guide illustrates the components of a logic model.

Figure 2.6 Components of a Logic Model

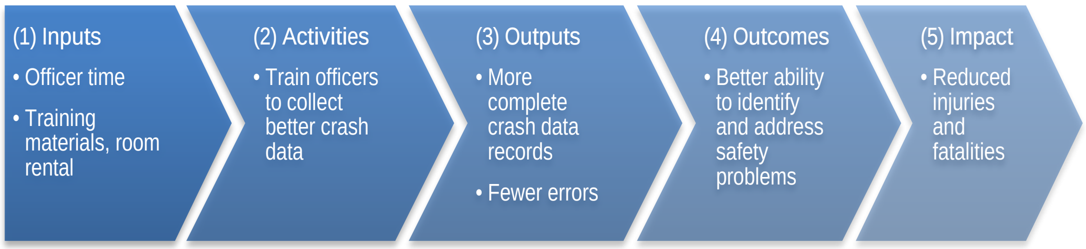


Source: Kellogg Foundation Logic Model Development Guide, 2004.

Having specified the logic model, the agency can evaluate, over time, one or more links along the chain, as a means of ensuring activities have the intended effect. Figure 2.7 illustrates a sample logic model for a program to train law enforcement officers in crash data collection techniques. The agency could evaluate whether activities under Step 2 (training officers to collect better crash data), is resulting in expected outcomes in Step 3 (more complete and accurate crash data records), even if it is not possible to quantify the ultimate long-term

impact on injuries and fatalities. Evaluation of steps 3 and 4 could also provide direct feedback to future decisions regarding inputs and activities in steps 1 and 2.

Figure 2.7 Sample Logic Model for Law Enforcement Training



The purpose of this discussion is to illustrate the importance of carefully identifying the expected outputs, outcomes, and impact of all funded activities. This justifies investment in the program and may help reveal weak linkages or areas that need further evaluation.

3.0 Quantitative Countermeasure Comparisons

Chapter 3 discusses methods for calculating a quantitative cost-effectiveness ratio (number of crashes or crash severity reduced per dollar invested) and/or a benefit-cost ratio (monetized value of crash reductions divided by cost of achieving such reductions) for safety countermeasures so they can be compared and ranked for prioritization. This analysis can only be completed if quantitative inputs for all parameters can be developed and justified. If such measures are not available, the sketch-level method discussed in Chapter 4 may be used.

Benefit-cost and cost-effectiveness analysis is routinely used to compare safety countermeasures, and methods are well-developed. For example, a survey of safety engineers at state departments of transportation indicated the vast majority use benefit-cost analysis to determine safety countermeasure selection.[5] The Highway Safety Manual (HSM) contains a chapter on economic appraisal of safety investment decisions and covers both benefit-cost and cost-effectiveness analysis procedures.

This section is based on techniques presented in the HSM but goes into greater detail regarding how cost-effectiveness calculations should be performed for a range of different types of countermeasures across the 4 Es of safety. Some of the challenges specific to comparing different types of 4 E investments include:

- Defining the useful life of the countermeasure;
- Defining and quantifying the target number of crashes that will be addressed;
- Considering spillover/halo effects of countermeasures; and
- Accounting for the costs of different types of countermeasures.

As discussed in the introduction, the basic steps to conducting a cost-effectiveness analysis are:

1. Define the effectiveness of each countermeasure in reducing injuries and fatalities;
2. Define the target crashes to be affected by the countermeasure(s) of interest;
3. Assess magnitude of crash frequency and fatality/injury reduction;

[5] Transportation Research Board, NCHRP Synthesis 295 – Statistical Methods in Highway Safety Analysis, 2001. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_295.pdf.

4. Assess the costs of achieving reductions over the time period of interest;
5. Assess cost-effectiveness; and
6. Rank or package countermeasures for implementation.

These steps outline a cost-effectiveness analysis. This section also provides optional steps for monetizing project benefits to perform benefit-cost analysis. Cost-effectiveness analysis compares the costs of an investment with its effects (e.g., dollars per injury and fatality reduced), to identify projects with the greatest "bang for the buck." Benefit-cost analysis compares benefits expressed in monetary terms (e.g., by benefits of cost associated with reduced injuries and fatalities) with costs to implement the solutions. This allows the practitioner to determine whether a policy or investment is economically justified (e.g., the benefits are greater than the costs).

The following sections explore each step listed above in more detail, focusing on issues specific to comparing 4 E countermeasures. Appendix C presents an example quantitative analysis of engineering and behavioral safety countermeasures in San Francisco County, California.

3.1 Step 1 – Select and Define Countermeasure Effectiveness

Identify a Crash Modification Factor

In a quantitative cost-effectiveness analysis, the effectiveness of the treatment is typically expressed in terms of a crash modification factor (CMF). The CMF is a multiplicative factor used to calculate the expected change in crash frequency and/or severity associated with implementing a safety countermeasure investment. Examples include:

- Four-legged signalized intersection – the CMF for serious and minor injury crashes for converting a four-legged signalized intersection to a roundabout is 0.40 with a standard error of 0.14, indicating that one would expect to see a 46 percent to 74 percent reduction in serious and minor injury crashes.[6]
- Mandatory attendance at driver treatment programs has a CMF of 93, indicating it is expected to reduce all alcohol-related crashes by seven percent.[7]

[6] FHWA Crash Modification Factors Clearinghouse, based on research reported in NCHRP 572: Applying Roundabouts in the United States.

[7] NCHRP 622, Effectiveness of Behavioral Safety Countermeasures.

Three main sources of quantitative countermeasure effectiveness information include the FHWA Crash Modification Factors Clearinghouse (www.cmfclearinghouse.org); the Highway Safety Manual; and NCHRP 622, *Effectiveness of Behavioral Safety Countermeasures.* These are discussed in more detail below. No comprehensive source of quantitative information is available for emergency response countermeasure effectiveness; however some qualitative information is available (see Section 4.2).

Highway Safety Manual[8]

The Highway Safety Manual provides the best available research-based Crash Modification Factors (CMF) for over 200 engineering countermeasures. The CMF indicates the percentage change of a specific crash type expected after countermeasure installation. CMFs are adjusted to correct for regression-to-the-mean and traffic volume bias. Standard errors are adjusted to correct for weaknesses in the study design. The most reliable CMFs are listed in bold typeface (standard error of 0.1 or less). Less reliable CMFs are listed in italic typeface (standard error of between 0.2 and 0.3).

Crash Modification Factors Clearinghouse[9]

The Crash Modification Factors Clearinghouse, maintained by the Federal Highway Administration, is a database of over 1,000 engineering countermeasures, including the smaller set of high-quality CMFs listed in the HSM.

The quality of each CMF is rated from one to five stars, where five indicates the highest degree of reliability and accuracy and one indicates the lowest. The star rating is based on the judgment of expert reviewers who consider study design, sample size, standard error, potential bias, and data source to score each CMF according to its performance in each category.

Effectiveness of Behavioral Safety Countermeasures[10]

NCHRP 622, *Effectiveness of Behavioral Safety Countermeasures* provides a quantitative assessment of countermeasure effectiveness (e.g., 10 percent crash reduction) for a limited set of proven behavioral countermeasures. It also provides information on the target population, likely duration of the effect, monetary costs, and benefit-cost ratios where possible. Countermeasures rated Unknown/Uncertain/Unlikely are separated into the following categories: (+)

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[8] AASHTO – Highway Safety Manual. http://www.highwaysafetymanual.org.

[9] FHWA – Crash Modification Clearinghouse. http://www.cmfclearinghouse.org.

[10] NCHRP Report 622, Effectiveness of Behavioral Safety Countermeasures. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_622.pdf

some basis for thinking it might work; (0) unknown or no opinion; and (−) some basis for thinking the countermeasure will not work.

In some cases, a CMF is available but outdated, unreliable, or irrelevant. This can occur when conditions have changed substantially from when the CMF was developed (e.g., CMF for a cable median barrier is based on an outdated design), when the CMF was derived under conditions different than those anticipated in the project, or if the before-after study conducted to estimate the CMF is not reliable.

If no CMF is available, but qualitative effectiveness information is, the practitioner can apply the qualitative countermeasure comparison methods described in Chapter 4. If no reliable quantitative or qualitative information is available, the practitioner may consider the following courses of action:

- Set aside the proposed countermeasures and identify countermeasures for which some kind of effectiveness information (qualitative or quantitative) is available. This will help ensure investment of public dollars in the most effective possible safety measures, rather than investment in measures which may have little effect. Many safety agencies, including the FHWA, are emphasizing the value of focusing resources on countermeasures proven to be effective.[11]
- Recognize the project as a pilot study to gain information on the effectiveness of the proposed countermeasures.
- Use effectiveness information from similar countermeasures but recognize potential variability of results and the need for future evaluation.
- Prepare an estimate of effectiveness using judgment and awareness of the size of the target crash population (described in Section 3.2). This will provide an upper bound on the number of crashes that could potentially be reduced by the countermeasure. The practitioner could then make a range of assumptions regarding crash reduction and illustrate the results for policy-makers via a sensitivity analysis (described in Section 3.5). However, using judgment rather than empirical research may produce unreliable results.

[11] The most recent list of proven countermeasures, issued by FHWA in 2012, includes the following: safety edge; roundabouts; corridor access management; backplates with retroreflective borders; longitudinal rumble strips and stripes on 2-lane roads; enhanced delineation and friction for horizontal curves; medians and pedestrian crossing islands in urban and suburban areas; pedestrian hybrid beacon; and road diets.

Considerations

Crash Severity

Countermeasure effectiveness should take into account the degree to which the countermeasure reduces severe crashes. Focusing on fatal and severe injury crashes can have far greater economic and social benefits than reducing property damage only crashes, which contribute very little to overall monetary loss or nonmonetary pain, grief, and suffering.

Focusing on total crash reduction also ignores some important types of safety countermeasures that may positively affect crash severity yet may not reduce the number of crashes. For example, many emergency response countermeasures focus on keeping crash victims alive rather than reducing the occurrence of crashes.

Many, but not all, crash modification factors include information about the crash severity addressed by implementing the countermeasure. When this information is provided, it can be readily integrated into cost-effectiveness or benefit-cost analysis. For example, the CMF clearinghouse indicates that installing rigid barriers along embankments will reduce fatal crashes by 41 percent. In applying this countermeasure, only the number of fatal crashes in the period prior to installing the countermeasure would be reduced by 41 percent.

If no information is available regarding the effect of the countermeasure on different types of crashes, it becomes necessary to make assumptions using information about the current distribution of crashes by severity for the type of crash in question, typically by assuming all crash types are reduced by the same amount.

For example, the FHWA CMF clearinghouse indicates flattening a side slope to a specific angle (1V:3H to 1V:4H), will reduce all run-off-road crashes by 18 percent. If crash data indicate 20 percent of run-off-road crashes are fatal; 30 percent are severe-injury, and 50 percent are property damage only, then one would assume all crash severity levels for run-off-road crash types are reduced by 18 percent.

Considerations

Reduced Countermeasure Effectiveness Over Time

Some countermeasures lose effectiveness over time. For engineering countermeasures, this could occur because of driver adaptation and familiarity (e.g., warning signs drivers may notice at first but become used to), poor facility maintenance (e.g., infrequent striping) or other causes. For behavioral countermeasures, this could occur if a program has no lasting effects on behavior after the period in which the countermeasure is funded. For example, according to NCHRP 622, School Pedestrian Training Programs for children have limited effects unless the program is ongoing. On the other hand, other types of

behavioral countermeasures could have virtually permanent effects, such as the addition of a state requirement for six months of supervised driving prior to full licensure for teens. These changes are essentially permanent and very effective in reducing young driver crashes.

Unfortunately, much of the research on CMFs does not quantify the potential declining effectiveness of countermeasures. Again, in the absence of information on this effect, judgment informed by available research should be used to account for the effectiveness of the countermeasure over the lifetime of the projects.

Example – Suppose the CMF of a pavement resurfacing project on a 10-mile stretch of two-lane rural road is 0.40 for all crashes initially, and then loses 10 percent of its initial effectiveness for the life of the pavement, which is 10 years. The CMFs decline over the life of the project, yielding CMFs of 0.40, 0.36, 0.32, 0.28, etc.

Combining Safety Countermeasures

The Highway Safety Manual recommends combining the effects of multiple countermeasures by multiplying their CMF values. This assumes the countermeasures are independent. Currently, there is no definitive information about how many CMFs may be theoretically multiplied together; therefore the HSM provides guidance to consider whether the countermeasures being implemented are independent, and advises against multiplying more than three independent CMFs. Research is underway by the NCHRP to determine a method for combining the effects of multiple countermeasures.

3.2 STEP 2 – DEFINE TARGET POPULATION OF CRASHES

Countermeasures are aimed at reducing specific crash types and/or crash severities. Speeding enforcement for example will influence mostly speeding-related crashes, whereas guaranteed drive home programs target impaired driving crashes.

Quantifying the number of target crashes reduced by the countermeasure involves considering both the amount of time the countermeasure will be effective in addressing crashes and estimating the number of crashes per unit time addressed by the countermeasure.

Defining the Countermeasure's Useful Life

The lifespan of the countermeasure will influence its potential crash reduction benefits. According to the Highway Safety Manual, the useful life of a countermeasure corresponds to the number of years in which it is expected to have a noticeable and quantifiable effect on crash occurrence.

For engineering countermeasures, this may be equivalent to the number of years the countermeasure will be operative without needing to be completely replaced; however, it also could be affected by the availability of funding for ongoing maintenance and declining countermeasure effectiveness over time (as discussed previously).

For behavioral safety countermeasures, which do not typically involve major capital investments, the useful life of the countermeasure may be thought of as the time period during which the effect of the countermeasure is expected to persist. As discussed previously, the duration of effectiveness of some behavioral countermeasures is related in part to the amount of time the program is ongoing, which is related to the amount of funding available. However, certain behavioral safety measures have been shown to have impacts beyond the funded period of the program. Appendix B summarizes literature on the duration of impacts for certain types of countermeasures. To compare different types of countermeasures, the costs and benefits must be compared over the same time period.

Example – An intersection has chronic red-light running issues and the two alternative improvements are installing roundabout or increasing police enforcement. To compare the effectiveness of the two countermeasures, the cost and benefits of the two countermeasures are compared over the *same* life. Therefore, if the roundabout has a 20-year life span, the costs and benefits of increased police enforcement would be compared to the costs and benefits of the roundabout over a 20-year life.

Considerations

If candidate investments are not well-defined, it may be desirable to assume a similar level and time period of deployment and compare the resulting fatality and injury reduction benefits. The estimate of countermeasure costs would simply take into account the amount of funding necessary to keep the countermeasures operative over the desired time period.

Note the definition of the target population of crashes and the definition of the crash modification factor must match. For example, if a CMF is expressed in terms of reduction in child pedestrian crashes, the target population must be child pedestrian crashes. If a CMF is not available for the exact target population of interest, it may be necessary to redefine the population of target crashes to allow application of the CMF.

Calculate Number of Target Crashes per Unit of Time

Predicting target crashes involves estimating the future crashes that will occur in the absence of the countermeasure. This can be estimated: 1) using software tools such as those discussed in Appendix B, 2) for crashes on specific facilities, using procedures in the Highway Safety Manual; or 3) using analysis of historical crash data.

Regardless of the tool, the basic procedure is the same, which is to define the geographic area where crash incidence is likely to be affected by the countermeasure, and then predict future crashes occurring in that area in the absence of the countermeasure.

The geographic area could be a specific facility, a set of facilities, or an area such as a Census tract, traffic analysis zone, or government boundary (city, county, state). The selection of geographic area should be informed by knowledge of where the countermeasure is most likely to impact crashes. Engineering countermeasures are most likely to impact crashes on the facility where they are installed, perhaps with some spillover effects (see discussion below); behavioral countermeasures are likely to impact crashes on the facilities where populations affected by behavioral measures travel. For example:

- Educational programs in high schools in a given county might dominantly affect teen driver crashes within county boundaries but also could affect teen driver crashes in neighboring counties or states if teens frequently travel outside county boundaries.
- Installation of rumble strips on all arterials in a county would dominantly affect lane departure crashes on county arterials.

In defining the most appropriate geography, it is important to consider spillover effects (see Considerations section below).

Tools for Estimating Target Crashes

The *Highway Safety Manual (HSM)* provides tools for estimating existing and future crash frequency and severity as a function of traffic volume, roadway characteristics, and roadway length for segments. The guidebook provides these techniques for two-lane rural highways, rural multilane highways, urban and suburban arterials and in the very near future for freeways. Three key characteristics of this method include a safety performance function (SPF), a crash modification factor (CMF), and a calibration factor (C). Part C of the Highway Safety Manual provides an explanation of the theory and method to predict future crash frequency by type and severity. Note: the HSM principally addresses engineering countermeasures.

Some jurisdictions have developed and calibrated SPFs for local facilities. These can be used instead of calibrated SPFs in the HSM. Without the HSM or locally developed and calibrated SPFs, it will be necessary to estimate future crash frequency by type and/or severity as a function of *historic trends*, such as projecting the straight-line trend of the running five-year crash average into the future. Historic trends will be influenced in the future by potential changes in land use, traffic volume, or driver demographics in the area. Therefore, if past trends are used as a proxy for future conditions, sensitivity to future growth and changes should be a consideration in the estimate.

Considerations

When defining the geographic boundaries of the site, consider 'spillover' or 'halo' effects, which are effects of a safety investment that spillover to other transportation network locations. Spillover effects can be positive or negative. Some examples of projects that may have spillover effects include:

- Red light running cameras installed at intersections influence red light running at nearby noninstrumented intersections.
- Access control projects along a roadway median encourage more turning activity prior to and following the immediate project boundaries.
- Traffic calming measures divert traffic to alternate routes, resulting in increasing conflicts at other system locations.
- Enforcement of DUI in one jurisdiction affecting the behavior of travelers in another jurisdiction.

This illustrates the importance of careful consideration and thought in defining the geographical extent of project impacts. In most cases, the geographic influence of a safety project is larger than that defined by the physical limits of the safety investment on the transportation network.

3.3 Step 3 – Estimate Crash and/or Injury and Fatality Reduction

The overall countermeasure impact on crash frequency and the number of injury and fatal crashes is calculated by multiplying the countermeasure CMF by the estimated target population of crashes per time period and summing over all time periods (e.g., years) in the useful life of the project. As discussed previously, this should take into account:

- The expected (or assumed, based on funding availability) useful life of the countermeasure and expected changes in countermeasure effectiveness over time, if available or estimated using judgment;
- Expected changes in the target population of crashes over time, e.g., due to demographic change or change in projected traffic volumes; and
- Estimated effects of the treatment on crash frequency and/or injury and fatality crashes, if available.

Optional Step: Monetize Benefits

If desired, the practitioner can go a step further to translate estimates of crash frequency or injury and fatality reduction into monetized benefits. This involves multiplying the number of expected injuries and fatalities reduced by established monetary values for injuries and fatalities and discounting these benefits over the life of the project to a Net Present Value of benefits. Chapter 7 of the Highway

Safety Manual, *Economic Appraisal*, provides a methodology and examples for converting a multiyear cost stream into a net present value. Appendix A of Chapter 7 of the Highway Safety Manual discusses discount rates.. Discount rates are critical assumptions in determining cost and benefits; there are two sources for discount rates. FHWA provides guidance on selecting discount rates for safety projects in its Technical Advisory T 7570.2 on Motor Vehicle Accident Costs.[12] For net present value calculation, the White House Office of Management and Budget publishes an annual forecast of interest rates going out for the next 30 years.[13] The quantitative example in Appendix C uses a four percent discount rate based on the examples in the Highway Safety Manual.

Monetization of benefits can be desirable for two reasons:

- **It addresses the fact that some countermeasures may result in immediate injury and fatality benefits while others may not yield benefits for several years.** Because of increased uncertainty regarding any benefits that occur in the more distant future, it is preferable to have near-term rather than long-term benefits. Benefit monetization takes this into account by applying a discount rate to future benefit streams.
- **It allows calculation of a benefit-cost ratio.** Monetization of both benefits and costs and conversion to net present value allows calculation of a benefit-cost ratio. The b/c ratio indicates whether the investment is economically justified (e.g., monetized benefits exceed monetized costs), and also allows comparison between safety projects and other types of projects. In this case, it is appropriate to include any project benefits beyond safety (e.g., mobility, environment) so that the full impact of the project can be included in the cost benefit analysis.

Considerations

Some controversy exists surrounding the monetization of injury and fatality reduction benefits for the purpose of computing a cost benefit ratio. Critics argue[14]:

- It is unethical and inappropriate to place a monetary value on a human life; such valuations are arbitrary and highly variable in government guidance.

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[12] FHWA, T 7570.2 Technical Advisory on Motor Vehicle Accident Costs, 1994.

[13] White House Office of Management and Budget, Circulation A-94, 2011. http://www.whitehouse.gov/omb/circulars_a094/a94_appx-c

[14] Criticisms are discussed in: Elvik, R., *How would setting policy priorities according to cost–benefit analyses affect the provision of road safety?* Accident Analysis and Prevention, 35 (2003) 557–570, and Hauer, E *Computing what the public wants: Some issues in road safety cost–benefit analysis.* Accident Analysis and Prevention, 43 (2011) 151-164.

- Travel time savings are typically valued at a higher rate than injury and fatality savings, leading to a bias against road safety investments in cost benefit analysis.
- The results of benefit-cost analysis depend heavily on the selection of an appropriate discount rate. Discounting tends to unjustifiably diminish the value of lives saved in the future.
- It is inappropriate to require the monetized benefits of safety investments to exceed costs, since members of the public are not willing to pay for safety benefits. Safety benefits must be "marketed" to the public, which may require additional expenditure of public funds resulting in higher costs than benefits.
- It is unethical to reject proposals for improving safety because monetary benefits are believed to be smaller than monetary costs.

Others argue that these concerns regarding safety projects where costs are higher than benefits are not relevant, since such projects are not common. Many examples exist of safety investments for which monetized benefits exceed costs.[15] Practitioners should use discretion to determine whether monetizing benefits would be appropriate for the projects being evaluated.

3.4 Step 4 – Estimate Costs

Quantitative assessment of project costs requires defining the timeframe for cost accrual, assessment of cost streams over this time period, and discounting costs to their net present value.

Timeframe for Cost Accrual

The timeframe for cost accrual should be defined by the useful life of the countermeasure. Document all assumptions carefully, since they can heavily impact results. Further, it can be useful to consider varying assumptions (e.g., different costs, discount rates) in a follow-up sensitivity analysis to confirm final project selection.

Calculate Costs

Calculate the costs streams that occur over the specified timeframe and define the year they are likely to accrue. For engineering countermeasures, typical costs include:

- Up-front planning and environmental costs;

[15] Elvik, R., *How would setting policy priorities according to cost–benefit analyses affect the provision of road safety?* Accident Analysis and Prevention, 35 (2003) 557–570

- Up-front right-of-way, and capital construction costs (e.g., concrete, materials, construction labor); and
- Ongoing maintenance and operating costs.

Typically, the bulk of the cost occurs early in the useful life of the project due to up-front investments. At the end of their useful life, these investments also may have some salvage value that should be taken into account when assessing cost.

By contrast, the costs of behavioral countermeasures may involve less up-front capital costs but more ongoing labor costs to implement. NCHRP 622 defines several cost categories for behavioral safety countermeasures to consider, including:

- **Direct costs.** These include the direct costs of operating behavioral safety programs such as educational materials, equipment, and additional labor costs. NCHRP 622 gives examples of direct costs for several types of proven behavioral safety countermeasures.
- **Existing resources.** Some new programs and policies can be accommodated within existing agency resources, and thus appear to have minimal cost. In reality, these programs result in existing personnel spending less time executing other agency priorities. The full costs of any new program should be accounted for regardless of whether it will be funded through existing or new resources.
- **User costs.** Some policy changes result in additional expenses for individuals subject to them (e.g., parents who must purchase helmets for their children). Similarly, some policies are paid for with fines that come out of citizen's pockets. These may result in a net monetary benefit to the implementing agency, but, according to NCHRP 622, any such benefits should not be included in the benefit-cost analysis to avoid creating an incentive to raise agency revenues through fines and tickets.
- **Political capital.** Some policy changes require relatively little out-of-pocket agency cost but significant political capital.

Although it can be difficult to account for the cost of policy changes requiring political capital, one could begin by estimating the staff time to develop, justify, and lobby for the policy/legislative change by examining the cost of past policy changes for guidance. Once adopted there may be follow-on activities needed for educating other staff or the public at large about the change. Thus while the costs may not be specific capital outlay, they may be quite large in terms of new staff time or staff time diverted from other activities. Other policy changes may have relatively little direct implementation cost.

As much as possible, the calculation of costs should rely on the practitioner's knowledge of the specific countermeasures being considered rather than standard cost values for certain countermeasures. Costs for the same countermeasure can vary widely from place to place depending on staff salaries,

right-of-way, equipment, and other types of costs. Document all assumptions so they can be varied in sensitivity analysis (Section 3.5) if desired.

Convert Costs to Present Value

Project costs need to be converted to the present to obtain a net present worth of costs. This is the same procedure as used for converting benefits to a net present value (discussed previously).

3.5 Step 5: Compare Costs and Effectiveness

Calculate Cost-Effectiveness

The final step in the quantitative analysis is to compare the estimated effects (or monetized benefits) of the countermeasure to its costs over the life of the project. This calculation can be conducted in the form of a:

- **Cost-effectiveness analysis** – total crash reduction (by type or severity) over the period of implementation divided by the net present value of the cost of implementing the countermeasure. The higher the ratio the more effective the countermeasure as compared to other alternatives; or
- **Benefit-cost analysis** – the net present dollar value of the benefits of the crash reductions over the life of the project divided by the cost of the countermeasure over the life of the countermeasure.

Sensitivity Analysis

The results of cost-effectiveness and benefit-cost analysis may be strongly influenced by assumptions made along the way. Consider conducting a sensitivity analysis in which major assumptions are varied to determine the range of impact on cost-effectiveness or benefit-cost ratios. Key assumptions to be varied include:

- Demographic changes (e.g., population growth, average daily traffic growth) impacting the size of the target population of crashes;
- Crash modification factors, to take into account standard error or other uncertainty;
- Effect of assumptions regarding combining countermeasures;
- Countermeasure effect on injury and fatal crashes;
- Changes in countermeasure effectiveness over time; and
- Price of materials (asphalt, concrete) and labor.

3.6 Step 6: Prioritize Countermeasures for Implementation

The quantitative accounting of project costs and benefits described above provides a foundation for project prioritization. Additional steps are required to identify which projects should be implemented first. The most cost-effective projects could be implemented first, but some of these may be unaffordable within the overall budget. Others may have relatively low ratios but very affordable costs, making them more attractive from a budgetary perspective. Agencies, in many cases, use discretion and judgment to prepare a final prioritized list taking into account total project costs, benefit cost ratios, or other related metrics such as the number of total crashes, fatalities, or injuries by project. Other factors mentioned previously must also be considered, including readiness for implementation and co-benefits.

Mathematical models can also be used to identify the optimal set of projects that together achieve the greatest benefit for the least cost and fit within the available budget. The HSM summarizes several different approaches including linear programming, integer programming, and dynamic programming. Most of these require the use of software. One demonstration of techniques for optimizing the allocation of a safety budget among different improvement types noted that, without software, the calculations and data requirements of the procedures could pose a problem for jurisdictions.[16]

Another challenge in identifying the optimal combination of projects is that combining projects can change safety outcomes. For example, mass media campaigns and enforcement are typically more effective when implemented together than separately. Additional research is needed to identify how implementing different types of projects together rather than separately affects injury and fatality reduction.

SafetyAnalyst is a comprehensive software that essentially completes Steps 1 through 6 for engineering solution concepts only. In summary, SafetyAnalyst conducts:

- **Network screening –** to identify sites with potential for safety improvement (this module also can be used to forecast an estimated crash frequency on facilities);
- **Diagnosis –** to identify potential crash contributing factors at a site;
- **Countermeasure selection –** to provide suggestions about possible countermeasures to address crash conditions at a site;

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[16] Persaud, B. and Kazakov, A, 1994. "A Procedure for Allocating a Safety Improvement Budget Among Treatment Types." *Accident Analysis and Prevention*, Vol. 26, No. 1, pp. 121-126,

- **Economic appraisal –** performs a benefit-cost analysis of a specific solution concept for a site;
- **Priority ranking –** provides a ranking of the mix of improvement projects that should be constructed; and
- **Evaluation –** the tools to conduct before/after safety effectiveness evaluations.

In the event only engineering solutions are under consideration, and the jurisdiction has a complete SafetyAnalyst data system, it is a useful tool for project ranking. However, additional steps and considerations are necessary beyond SafetyAnalyst to conduct a multidisciplinary approach to solutions development.

3.7 Example Results

Appendix C contains an example of this quantitative method applied to four safety countermeasures in San Francisco County, California.

4.0 Sketch-Level Comparisons

4.1 Introduction

Quantitative methods such as cost-effectiveness or benefit-cost analysis allow for detailed comparisons between countermeasures, but are not always possible due to lack of data or lack of time for in-depth analysis. Sketch-level, semi-qualitative comparisons may be an appropriate alternative in cases where:

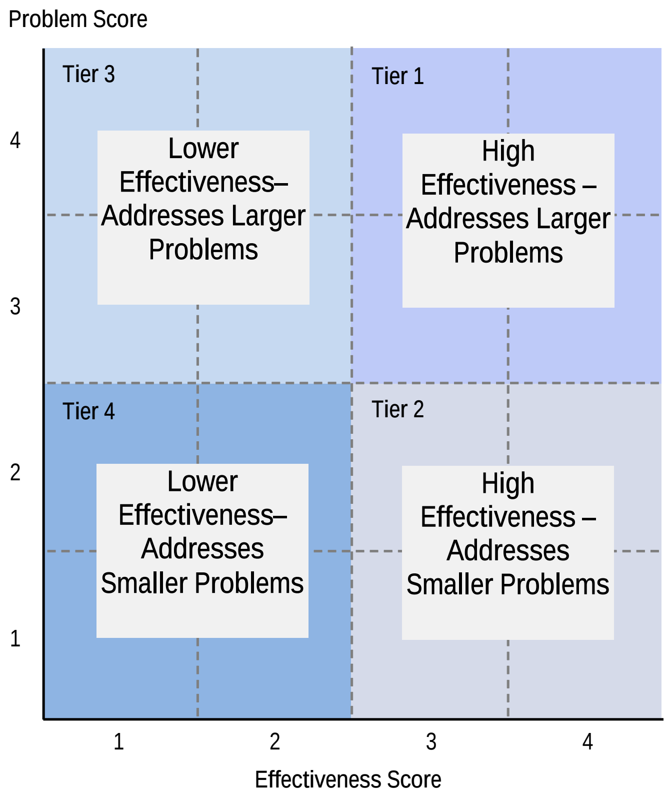
- Elements of candidate investment opportunities are not quantitatively known (e.g., crash modification factors are not known, costs and locations are not known), or no basis exists for making assumptions;
- Only qualitative information on countermeasure effectiveness is available; or
- A large number of projects must be analyzed, limiting the depth of analysis possible for each. For example, this may be the case in prioritizing grant funding applications.

This section describes a sketch-level method for ranking countermeasures by cost-effectiveness using a mix of qualitative and quantitative information. Conceptually this method involves:

- Calculating an **effectiveness score** indicating the relative effectiveness of the countermeasure;
- Calculating a **problem score** indicating the relative size of the target crash population potentially affected by the countermeasure; and
- Calculating a **cost score** indicating the annualized cost of the countermeasure relative to other measures.

These three scores can then be used to graphically illustrate relative countermeasure costs, effectiveness and potential impact, and then group countermeasures into tiers by relative priority as shown in Figure 4.1.

Figure 4.1 Tiers for Project Prioritization



- Countermeasures in the upper right-hand quadrant (Tier 1) are implemented first. They are the most effective and address the most significant problems. They may be implemented in order of relative cost.
- Countermeasures in the lower right-hand quadrant (Tier 2) are implemented second. They are the most effective but address smaller-scale problems.
- Countermeasures in the upper left-hand quadrant (Tier 3) are implemented third. They are less effective but address significant problems.
- Countermeasures in the lower right-hand quadrant (Tier 4) are implemented last or not at all. They are less effective and do not address significant problems.

These tiers are intended to separate the most promising projects from the least promising projects. They are not useful for precisely quantifying the specific benefits of individual projects. The quantitative method described in Section 3 should be used if more precise results are needed.

The following pages provide more detailed explanation of the process, using three simplified hypothetical projects:

1. Rumble strips (engineering);
2. Motorcyclist training programs (education); and
3. Driving under the influence checkpoints (enforcement).

Appendices D and E provide examples of this method applied to a set of behavioral and engineering projects in North Carolina and another example state.

Cautions in Applying the Sketch Method

- The method should be used to place projects into broad tiers (e.g., most cost-effective, least cost-effective), not to score individual projects. Practitioners must use discretion in determining how to rank projects based on the results. For example, top-tier projects could be fully funded, middle-tier projects could be partially funded, and low-tier projects could be considered for funding if additional funds become available.
- Application of this method may mean that quantitative information available for certain projects is not fully used. For example, in comparing a group of 20 behavioral and engineering projects, it may be possible to quantitatively estimate cost-effectiveness for some of the engineering measures but not the behavioral measures. To compare all the projects the same way, they must all be scored using the same scoring system even though some quantitative calculations are possible.
- The results of the scoring process are specific to the projects included in the process and can't be compared with the results of another set of projects, since the scores are based on relative comparisons among the measures.
- This sketch-level process uses a 1-4 scoring system for each project element. The practitioner is free to choose a different score range (e.g., 1.-3, 1-5) for each element. Clear criteria will need to be established and documented for assigning scores.
- The method is not capable of defining the optimal combination of projects to meet a budgetary constraint. This is only possible through application of the quantitative method discussed in Chapter 3 followed by the use of mathematical models or software (see section 3.6).

4.2 Step 1: Select an Effectiveness Score

The purpose of this step is to score the likely effectiveness of each project in reducing serious injuries and fatalities. The score is determined by matching the project to research on the effectiveness of different types of countermeasures.

Sources of Effectiveness Information

Countermeasures effectiveness is defined by drawing on the results of credible before-after research studies or by conducting original before-after studies. Section 3 presented several sources of quantitative effectiveness information, including the Highway Safety Manual, the FHWA Crash Modification Factors Clearinghouse, and NCHRP 622. Two additional sources containing primarily qualitative crash reduction information are discussed below (the AASHTO SHSP implementation guides and NHTSA's *Countermeasures that Work*).

AASHTO SHSP Implementation Guides

NCHRP 500, the AASHTO SHSP Implementation Guides, include a series of more than 20 reports summarizing effectiveness and other information for a wide range of 4 E countermeasures, including behavioral (e.g., education and enforcement), engineering, and emergency response. Countermeasures are classified as follows:

- **Proven (P) –** Strategies used in one or more locations for which properly designed evaluations have been conducted that show the strategies to be effective.
- **Tried (T) –** Strategies implemented in a number of locations, and may even be accepted as standards or standard approaches, but for which no valid evaluations exist.
- **Experimental (E) –** Strategies representing suggested ideas, with at least one agency considering them sufficiently promising to conduct an experiment in at least one location.

Countermeasures that Work

Countermeasures that Work is an annual report published by the Governor's Highway Safety Association. It provides qualitative cost and effectiveness information for a number of behavioral countermeasures. Effectiveness is measured according to a star rating:

- **Five Stars –** demonstrated to be effective by several high-quality evaluations with consistent results.
- **Four Stars –** demonstrated to be effective in certain situations.
- **Three Stars –** likely to be effective based on balance of evidence from high-quality evaluations or other sources.
- **Two Stars –** effectiveness still undetermined; different methods of implementing this countermeasure produce different results.
- **One Star –** limited or no high-quality evaluation evidence.

Table 4.1 summarizes the resources discussed above and considered previously in Chapter 3 of this report. The table illustrates the challenge of comparing

information from these sources given the range of rating schemes used and the fact that some sources are quantitative while others are qualitative, and yet others provide both forms of information. To take full advantage of the range of qualitative and quantitative information, this report proposes a unified scoring system for countermeasure effectiveness. The effectiveness score is based primarily on whether the countermeasure has been proven to be effective in reducing injuries and fatalities through reliable studies. Countermeasures classified as proven and showing a certain amount of crash reduction can earn an additional point.

Table 4.1 Comparison of Qualitative and Quantitative Sources of Information on Countermeasure Effectiveness

Source	Location	Metric of Effectiveness	Primarily Covers
Crash Modification Factor Clearinghouse	www.cmfclearinghouse.org, continually updated.	Includes all available Crash Modification Factors. CMFs are rated 1-5 stars to indicate their quality.	Engineering Countermeasures
Highway Safety Manual	www.highwaysafetymanual.org, updated occasionally.	Includes the best available CMFs. A standard error is provided to indicate the reliability of the CMF.	Engineering Countermeasures
NCHRP 622	Not regularly updated.	Provides quantitative percentage reductions in injuries and/or for certain behavioral countermeasures	Behavioral Countermeasures
NCHRP 500 Series	http://safety.transportation.org/guides.aspx, not regularly updated.	Categorized as Proven, Tried, and Experimental	Engineering, Behavioral, Emergency Response
Countermeasures That Work	www.ghsa.org, published annually.	Countermeasures Rated 1-5 stars	Behavioral Countermeasures

Effectiveness Information for Emergency Response Strategies

Very limited information is available regarding the effectiveness of emergency response strategies. A recent reference document on this topic is Volume 15 of NCHRP 500, *A Guide for Enhancing Rural Emergency Medical Services (EMS)*. It outlines four objectives to meet the general goal of improving the responsiveness and quality of care for rural EMS:

1. **Integrate services to enhance emergency medical capabilities;**
2. **Provide or improve management and decision-making tools;**
3. **Provide better education opportunities for rural EMS; and**
4. **Reduce time from injury to appropriate definitive care.**

To achieve these four objectives, the report analyzed 24 strategies for their expected effectiveness. Only one strategy was identified as a proven strategy, which is to utilize technology based instruction for rural EMS training. A study of technology based training (Sanddall, 2004) found differences in pre-training and post-training measurement of knowledge in pre-hospital pediatric care with this training method. Among the remaining 23 strategies, 21 were listed as tried and two as experimental.

Specifically, countermeasures are scored as follows:

- **Three Points – Effective.** Strong evidence exists that the countermeasure reduces certain types of crashes, fatalities, or injuries. If the practitioner desires, an additional point can be provided for proven countermeasures that meet a specific threshold for injury and fatality reduction. In this study, a threshold of 30 percent crash reduction was used (e.g., CMF greater than 0.7)[17] as the cutoff and projects with CMFs above this cutoff were assigned a score of four. This may result in biasing the outcomes towards measures for which quantitative CMFs are available (e.g., engineering measures).
- **Two Points – Somewhat Effective.** Some, but not strong, evidence exists on countermeasure effectiveness.
- **One Point – Unknown Ineffective.** Evidence is unavailable, or studies are inconclusive. Note that this includes both "tried" and "experimental" categories from the NCHRP 500 Series because, although "tried" measures may be commonly applied to improve safety, no valid effectiveness

[17] Selection of this threshold is a matter of judgment and may be adjusted by the practitioner. The practitioner may also chose not to provide additional points for meeting a specific CMF threshold. For reference, the threshold of CMF = 0.7 was selected by mapping the distribution of all CMFs in the FHWA CMF Clearinghouse. Approximately 25 percent of listed CMFs were above 0.7.

evaluations exist. Projects lacking any effectiveness information (qualitative or quantitative) could potentially be removed from the prioritization process and set aside for pilot-testing at this stage.

- **Zero Points (Not Included) – Proven Ineffective Or Detrimental.** Some countermeasures have been proven ineffective or detrimental to safety (for example, skid training programs for beginning drivers). These measures should be eliminated from consideration at the start of the process.

Table 4.2 Translating Measures of Effectiveness

	Source	Highly Effective, Proven	Effective, Proven	Somewhat Effective, Unproven	Unknown or Ineffective
Engineering	Crash Modification Factor Clearinghouse	CMF <0.7 & Quality Score 4-5	0.7 < CMF < 1, & Quality Score 4-5	CMF < 1, & Quality Score 3	CMF≥1 or Quality Score < 3
	HSM	CMF <0.7 & Adjusted Standard Error < 0.2	0.7 < CMF <1 & Adjusted Standard Error < 0.2	CMF <1 & 0.2 < Adjusted Standard Error < 0.4	CMF ≥1 or N/A or Adjusted Standard Error > 0.4 or N/A
Behavioral	Countermeasures that Work	5 stars	4 stars	3 stars	≤ 2 stars or Star Rating Unavailable
	NCHRP 500/NCHRP 17-17(3)		Proven		Tried or Experimental
	NCHRP 622	Proven (Crash Reduction > 30%)	Proven	Likely	Unknown/Uncertain/ Unlikely
	Effectiveness Score	4	3	2	1

Note: Countermeasure CMFs near the threshold of two effectiveness points could include both points in its confidence interval based on the measure's standard error.

The practitioner may have access to locally collected effectiveness information for certain countermeasures not included in the national studies listed in Table 4.2. To assign a score based on this local information, the practitioner will need to assess its quality. This can be done either by calculating a standard error using methods described in Chapter 9 of the Highway Safety Manual, or by assigning a quality rating based on consideration of the study design, sample size, potential bias, and other factors. The CMF Clearinghouse describes some of these considerations in more detail.[18]

Example Effectiveness Scoring

To illustrate application of the effectiveness score, consider three example projects mentioned previously:

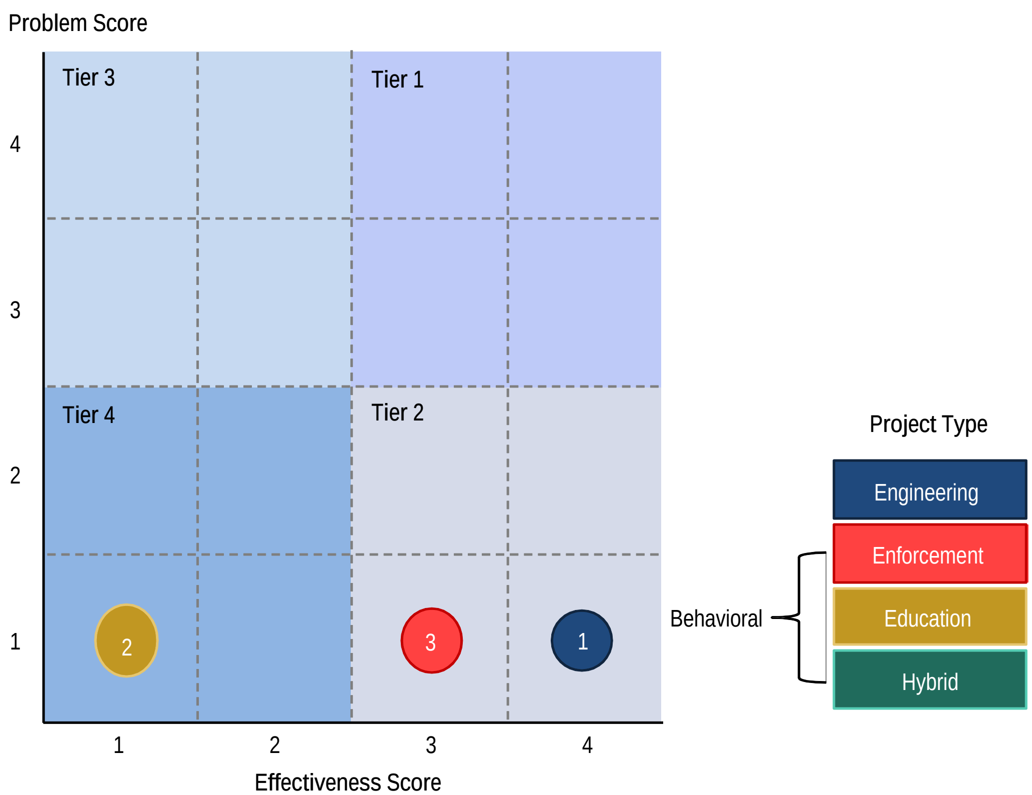
- Shoulder rumble strips – the CMF Clearinghouse lists a CMF of 0.2 for rural runoff road crashes and a quality score of four. This yields an effectiveness score of four (from Table 4.2).
- Motorcycle Safety Training Programs – NHTSA's Countermeasures that Work rates motorcycle safety training program with one star. This yields an effectiveness score of one (from Table 4.2).

[18] Considerations in applying the CMF quality rating are described in the CMF Clearinghouse web site: http://www.cmfclearinghouse.org/sqr.cfm.

- DUI checkpoints – NHTSA's Countermeasures that Work rates DUI checkpoints with five stars, and estimates a typical CMF of 0.8 for alcohol-related crashes. This yields and effectiveness score of three (from Table 4.2).

Figure 4.2 graphically illustrates these scores.

Figure 4.2 Example Effectiveness Scoring



Complications

Several complications can arise when assigning an effectiveness score.

Selecting a Rating for Complex Projects

Proposed safety projects may contain multiple components, and each component may have a different effectiveness in addressing injuries and fatalities. Three ways of addressing this problem are possible:

- If a high-quality, quantitative CMF exists for each component, the Highway Safety Manual recommends that CMFs be multiplied to obtain an estimate of overall crash reduction for the project. This solution is most feasible in the context of the quantitative method discussed in Chapter 3.
- The practitioner can identify the "main" component (either the component intended to be the main purpose of the project or which consumes the largest

share of the project budget). Effectiveness information for this main component is then used to represent the whole project.

- The practitioner can separately assess the effectiveness of each component of the project and assign the highest possible rating to the project based on the most effective component.

Although any of these approaches can be used, the last approach (assigning the effectiveness score based on the highest-scoring component) was used in the example analysis provided in Appendices D and E because it required the least amount of discretionary judgment in obtaining a result.

Selecting the Most Relevant Source

Scoring the project requires the practitioner to match each component of the project to similar types of projects listed in one of the sources in Table 4.2. This can be challenging given that projects proposed locally may only partially match the descriptions of projects evaluated in national studies. Judgment must be applied to perform this matching process.

In some cases, multiple relevant sources of effectiveness information may be available, and the practitioner will need to decide which is the most relevant. For example, multiple CMFs may be listed for a given countermeasure and the practitioner will need to select the most appropriate one. Generally, the Highway Safety Manual is the best place to begin searching for CMFs for engineering countermeasures, since each CMF is accompanied by some description of its applicability to different contexts. Some CMFs may reduce crashes in some contexts but increase them in others. Practitioner awareness of these nuances is important because it enables selecting a score that reflects the local context.

Multiple CMFs also may be provided reflecting reductions in different crash types (e.g., all crashes, fatality crashes, run-off-road crashes, etc.). The practitioner should give priority to the most reliable CMFs (e.g., those with the smallest standard error or the highest quality rating); to CMFs including injuries and fatalities (as opposed to all crashes or property damage only crashes); and CMFs most relevant to the main purpose of the project.

Project Not Well-Defined

In some cases, projects may not be defined sufficiently to allow effectiveness to be determined. For example in the application of the sketch method to North Carolina (Appendix d) projects that include skew angle and superelevation improvements often did not specify the degree of slope or angle adjustment – key inputs for CMF functions specified in the HSM or CMF Clearinghouse. This lack of key project information hindered the calculation of the CMF.

Similarly, it was not possible to identify the safety problems addressed by certain projects due to lack of definition. In many cases, the project applicants did not

specify the types of crashes that a safety improvement would address. Because of the lack of this type of information, several projects were removed from the analysis in Appendix D.

4.3 Step 2: Select a Problem Score

The purpose of this step is to assess the relative size of the population of injuries and fatalities the countermeasure would address. Projects that would address the most significant problems receive a higher score than those that address less significant problems.

Two sketch-level methods are possible for determining the number of potential injuries and fatalities a countermeasure would address. These are referred to as a bottom-up and a top-down approach. The bottom-up approach produces more precise results but requires more information about the project. The top-down approach produces rougher results but requires less information about the project. The latter approach was used in the sample application of this method in Appendices D and E due to limitations in available information on potential impacts of behavioral projects.

Top-Down Approach

The following steps should be followed to implement the top-down approach:

- Select a common geography of analysis for all projects of interest. For example, if the analysis is focusing on projects competing for state-level resources, the common geography would be the state.
- Determine the types of injury (fatality is a type of injury) the countermeasure is meant to address (e.g., alcohol-involved, run-off-road, median-crossover, young driver).
- Many countermeasures will address multiple problems. Use judgment to select the problem with the largest number of injuries and fatalities in the geography of interest. For example, if a countermeasure would address both alcohol-involved and young-driver crashes, but alcohol-involved crashes are much more prevalent in the state, assume that the main purpose of the countermeasure is to address alcohol-involved crashes.
- List all of the main problems (e.g., crash types) addressed by each countermeasure and sort them based on their prevalence (e.g., five-year running average of injuries and fatalities in the state in each category). Break the group into parts and assign the highest score to countermeasures that address the largest problems and the lowest score to countermeasures that address the smallest scale problems.[19]

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[19]The group could be broken into equal parts or based on natural breaks in the data.

Following this process results in each project being assigned a score reflecting the significance of the problem it would address, which is one component of the potential performance of the project. In many states, this process could be further simplified through reference to the Strategic Highway Safety Plan, which identifies the most significant crash problems in the state. A project could then simply be scored by whether it addresses the top SHSP emphasis areas.

Bottom-Up Approach

The bottom-up approach requires estimating the potential numbers of injuries and fatalities addressed by the countermeasure in the specific geography in which it will be implemented. The following steps are used:

- For site-specific projects (most engineering projects), identify the location where the countermeasure will be implemented. Determine the types of injuries and fatalities the countermeasure is intended to address at that site (e.g., run-off-road injury and fatal crashes on rural roads), and calculate the average number of annual crashes typically found at that location or type of location (e.g., five-year running average of run-off-road injury and fatal crashes on rural road segments). Multiply by the expected useful life of the project. This will result in a rough estimate of the maximum number of crashes that could be addressed by the countermeasure (this is referred to as "target crashes" in the engineering field).
- For projects applied at a population level (e.g., most behavioral safety projects), define the number and type of people potentially impacted by the countermeasure over the expected duration of the project, and multiply this by the average frequency of injuries and fatalities among this population to define the maximum number that could be addressed. Table 4.3 illustrates this process with an example project using hypothetical data.
- List all the projects and the maximum number of injuries and fatalities each one could address. Break the group into four roughly equal parts and assign the highest score to countermeasures that address the largest numbers of injuries and fatalities and the lowest score to those that would address the smallest number of injuries and fatalities.

Table 4.3 Example Application of Bottom-Up Method of Estimating the Potential Number of Injuries and Fatalities Addressed by a Countermeasure

Hispanic Population Seat Belt Use Encouragement and Enforcement Program

Project Description	Expected Duration of Impact	Expected Impacted Population	Target Crash Type	Estimated Maximum Number of Crashes Addressed
Year-long program of PSAs on Spanish-language radio programs during peak commute periods; implementation of simultaneous targeted seat belt enforcement on selected corridors	Expected to increase seat belt usage among affected population for two years following the program (three years total)	Hispanics tuned in to that radio station during commute periods (approximately 10,000 unique individuals over duration of campaign)	Unbelted injury and fatality crashes in Hispanic population in a metro area (about 10 crashes annually per 10,000 people)	About 30 crashes maximum could be reduced (10 annual unbelted injury and fatality crashes per year among target population times three-year expected duration of program effectiveness)

Source: Hypothetical example.

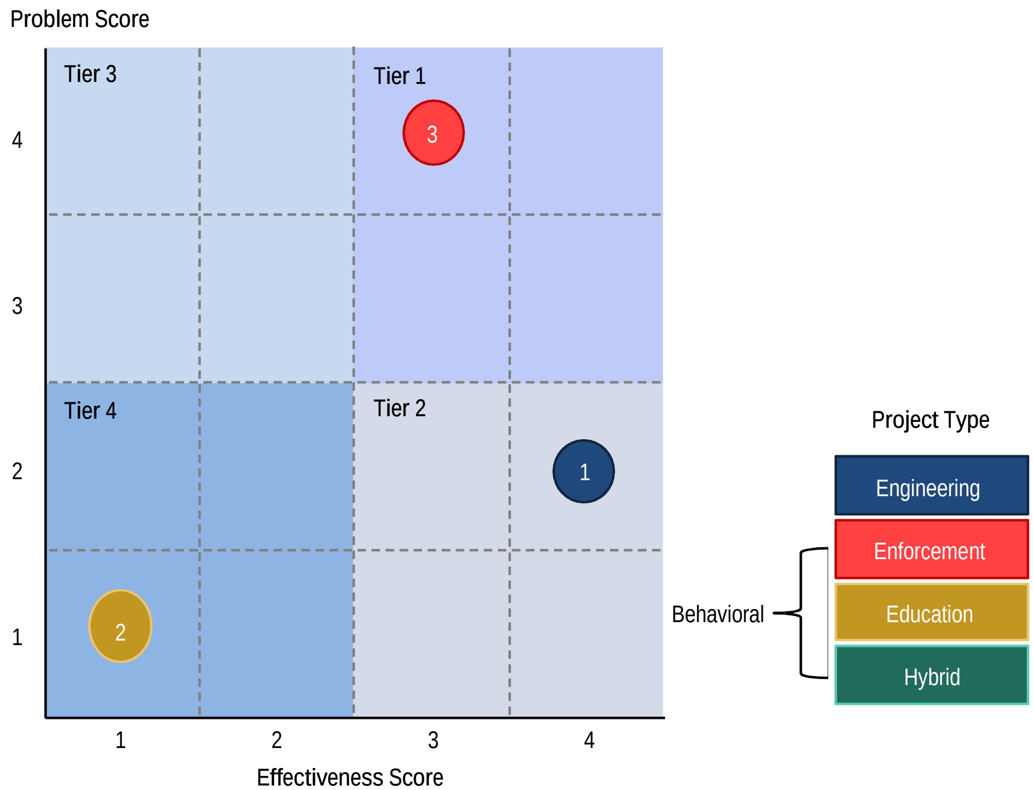
The advantage of this bottom-up method is that it more precisely quantifies the maximum number of crashes potentially impacted by each countermeasure. The disadvantage is that it requires knowing or estimating the number of people potentially impacted by behavioral countermeasures and the expected duration of impact, which may not be well-defined. Lack of information about the targeted population for behavioral measures prevented use of this approach in the two example applications of this method in Appendices D and E. Instead, the top-down method was used.

Regardless of which method is used, this step will result in each countermeasure receiving a score reflecting the relative size of the specific safety problem it would address. Figure 4.3 provides an example of how the score could be assigned for the three example projects, as follows:

- Rumble strips address run-off-road crashes, which represent 100 crashes in this example state; and
- Motorcycle safety training courses which represent 50 crashes in the example state; and
- DUI checkpoints; which represent 400 crashes in the example state.

Based on the example crash data, rumble strips, motorcycle safety training courses, and DUI checkpoints were assigned problem scores of two, one, and four respectively.

Figure 4.3 Example Problem Scoring



4.4 STEP 3: CALCULATE INJURY AND FATALITY REDUCTION (NOT APPLICABLE IN SKETCH METHOD)

In a quantitative analysis, the total potential injury and fatality crash reduction could be calculated by multiplying the countermeasure benefit (crash modification factor from step 1) by the target crash population (from step 2). In the sketch-level method, this step is not performed due to lack of quantitative crash reduction factors for all measures. Instead, the benefit and problem scores are used to graphically illustrate the relative potential of the countermeasure to address different safety problems (see final results in Step 6).

4.5 STEP 4: SELECT A COUNTERMEASURE COST SCORE

The final component of the countermeasure score is its cost score. In the sketch-level method, the cost score is relative to other countermeasures. This is determined by calculating an annualized cost for each measure and grouping measures together into cost categories (one through four). The following steps are followed:

- Define the total cost of the measure (for example, the amount of money being requested in a grant application).
- Estimate the expected duration of countermeasure effectiveness in years. Appendix B summarizes available research on the duration of effectiveness for different types of safety countermeasures. In many cases, information is not available and judgment will need to be applied. For this method, we assume that unless research exists to suggest otherwise, behavioral countermeasures are effective only during the time period that they are implemented and that engineering measures are effective for the useful life of the infrastructure. Lack of information on this topic highlights the need for additional research.
- Divide the total cost of the measure by the expected duration to obtain an annualized cost. Note that in a quantitative analysis, costs would be discounted to obtain a net present value; this sketch-level analysis is simplified to eliminate the need for cost discounting.
- Sort the list of projects by their annual cost. Break the group equal parts and assign the highest score to the highest cost countermeasures and the lowest scores to the lowest cost countermeasures. Alternatively, use the actual annual cost rather than assigning a score.

Figure 4.4 illustrates the assignment of the cost score to the three hypothetical example projects as follows (costs are hypothetical):

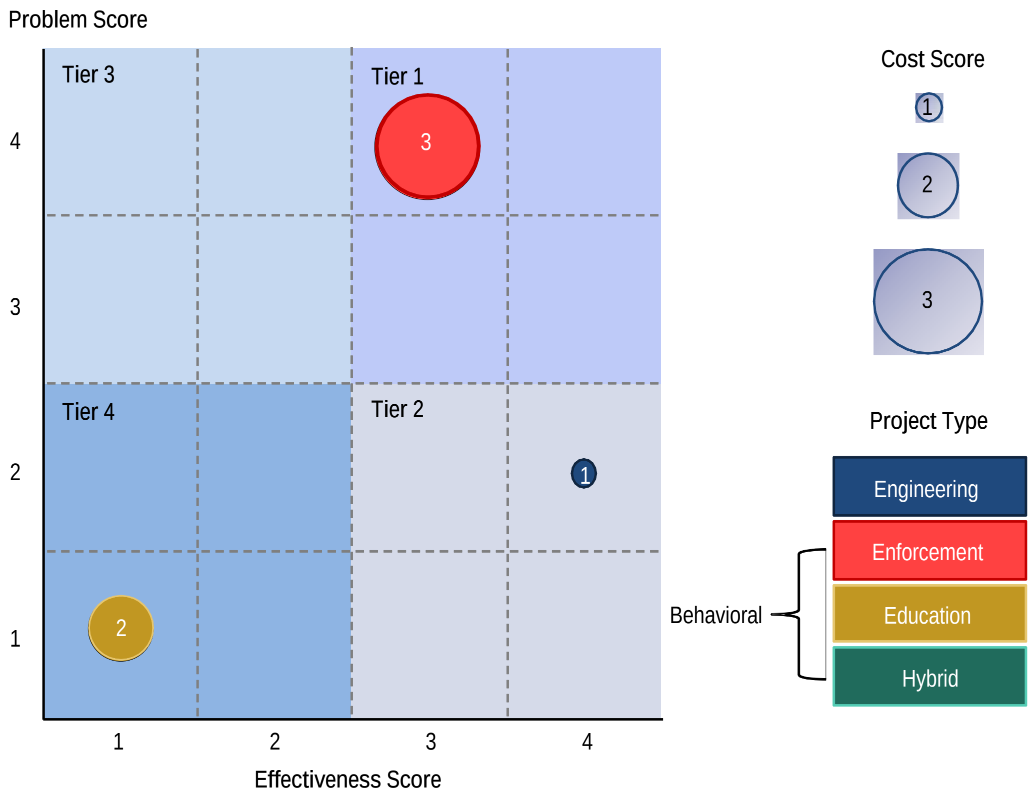
- Rumble strips cost $200,000 and will be effective for 10 years ($20,000 per year);
- Motorcycle training programs cost $50,000 and are assumed to be effective for one year only ($50,000 per year); and
- DUI checkpoints cost $600,000 and are assumed to be effective for three years (the funded year and two additional years, based on research indicating DUI programs can have impacts lasting beyond the conclusion of the program – see Appendix b) for an annual cost of $200,000.

Based on these annualized costs, rumble strips receive a cost score of one; motorcycle training programs receive a cost score of two; and DUI checkpoints receive a cost score of three. The circles are sized to reflect the cost score.

4.6 Steps 5 and 6: Compare Costs and Effectiveness and Prioritize for Implementation

The final step in this sketch process is to compare the effectiveness, size of problem addressed, and relative cost of each countermeasure. This information is compared graphically as shown in Figure 4.4.

Figure 4.4 Example Cost Scoring



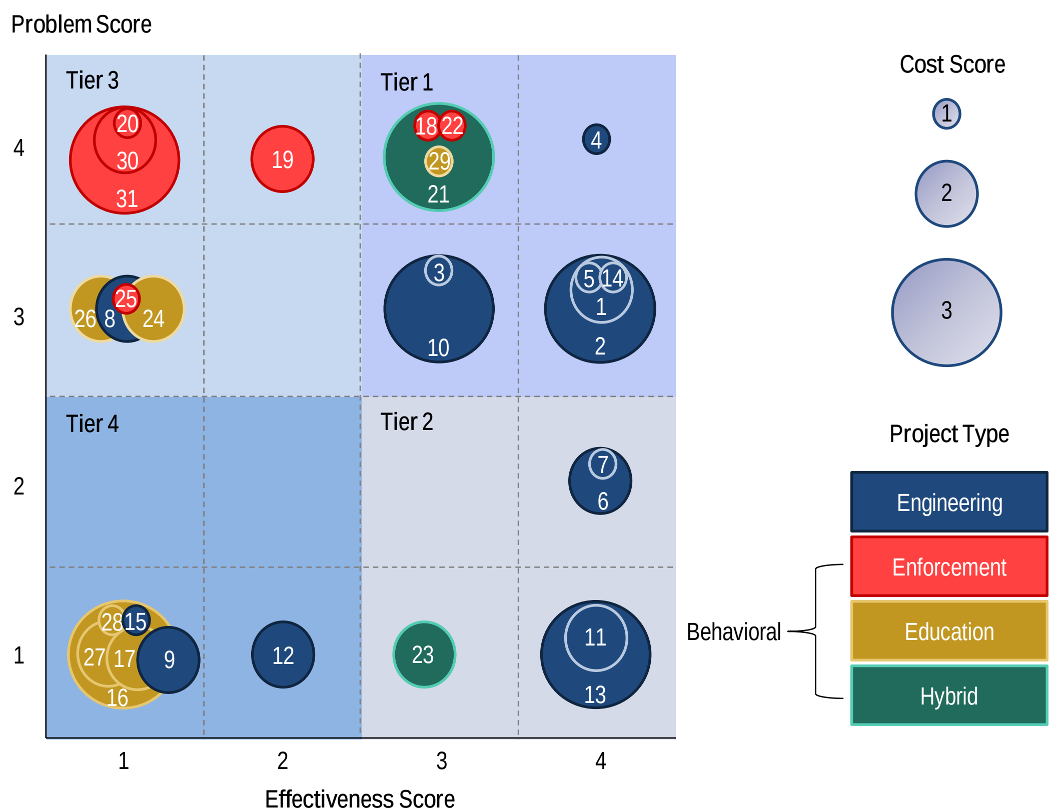
As discussed previously, the four quadrants of the graphic indicate tiers for implementation. This example involves only three projects, but suggests that DUI checkpoints, which are in the upper right hand quadrant (Tier 1), would have the highest priority for implementation as they are highly effective and would address a large number of crashes in the example hypothetical location. Rumble strips are in the lower right-hand quadrant (Tier 2), and would be implemented next. They are highly effective but address a smaller number of crashes. Motorcycle training programs are in the lower left-hand quadrant, and would be implemented last. They address a small number of crashes in this hypothetical location and have not been shown to be effective.

These tiers are intended to separate the most promising projects from the least promising projects. They are not useful for precisely quantifying the specific benefits of individual projects. The quantitative method described in Chapter 3 should be used if more precise results are needed. Additionally, multiple other considerations beyond safety cost-effectiveness arise in when finalizing the prioritized list of projects, such as ease of implementation, available funding, project benefits beyond safety, and others as listed in Chapter 2. Practitioners must use discretion to develop a prioritized list of projects using the results of the sketch method (for example, all top-tier projects could be fully funded and

middle tier projects could be partially funded). The method is not capable of defining the optimal combination of projects to meet a budgetary constraint. This is only possible through application of the quantitative method discussed in Chapter 3 followed by the use of mathematical models or software (see Section 3.6).

Appendices D and E present two example applications of the sketch method to real projects from North Carolina and another example state. Figure 4.5 presents the results from the North Carolina example. Each numbered circle corresponds to a specific project, and the position and size of the circle reflect its cost-effectiveness relative to other projects in the group. For more detail on this example and a list of the projects that were evaluated, see Appendix D.

Figure 4.5 Sketch Method – Example Results from North Carolina (Appendix D)



5.0 Summary and Next Steps

This report has provided several resources to assist safety practitioners in integrating analysis of strategy cost-effectiveness into investment decision-making processes, including a conceptual framework (Chapter 2), and two analysis methods (Chapters 3 and 4). If successfully applied, these resources will help advance the state of the practice towards a comprehensive, data-driven approach towards maximizing the injuries and fatalities reduced for every public dollar invested.

5.1 Implementation Ideas

The following options present several ideas for implementing the framework today.

- Preparers of Strategic Highway Safety Plans could include analysis of the relative cost-effectiveness of proposed strategies by emphasis areas using the sketch method described in Chapter 4.
- Highway Safety Offices could analyze the relative cost-effectiveness of grant applications using the sketch method in Chapter 4. This would likely require the inclusion of detailed questions on grant applications regarding the target crash population and expected strategy effectiveness.
- State Departments of Transportation could use the sketch method in Chapter 4 to compare the relative cost-effectiveness of applications for flex funding.
- Agencies involved in a corridor study could fund a quantitative analysis of the cost-effectiveness of strategies proposed to address problems in the corridor using the quantitative method in Chapter 3.
- Researchers investigating a specific safety issue could apply the quantitative analysis methods in Chapter 3 to compare in detail the likely effectiveness of competing solutions to a specific problem.

5.2 Future Application

Additional research and institutional changes could improve the usefulness of the methods in this document in the future.

Additional Research Needs

The methods presented in this document could be significantly improved for future application if more research were available on the following topics:

- **More effectiveness information for a wider range of project types, including combinations of projects.** Currently, only limited quantitative information exists, especially for behavioral safety and emergency response projects. NCHRP 622 *Effectiveness of Behavioral Safety Countermeasures* was a first step in this direction, and NCHRP 17-60, *Benefit-Cost Methodology for Behavioral Highway Safety Countermeasures* (forthcoming) will build on it. However, synthesis documents are available that draw on existing research. More high-quality before-and-after evaluations of specific safety strategies are needed to significantly advance the state of the practice.
- **Consistent definitions of effectiveness.** A variety of qualitative and quantitative effectiveness measures exist, all with slightly different definitions, such as star effectiveness ratings (*Countermeasures that Work),* proven/tried/experimental designations (NCHRP 500), crash modification factors with standard errors (Highway Safety Manual), crash modification factors with star quality ratings (CMF Clearinghouse) and others. More uniformity in qualitative and quantitative measures of effectiveness is needed to allow apples-to-apples comparisons between different types of safety countermeasures.
- **Uniform cost and useful life assumptions.** Little consistent information is available on typical costs and duration of effectiveness for behavioral safety measures. More primary research on this topic is needed to improve benefit-cost analysis.
- **Better quality crash data.** Evaluating certain types of projects can be very difficult if crash data are inadequate. Particularly, lack of linkage between crash data records and injury and fatality outcomes makes evaluation of emergency response strategies difficult.

Funding Flexibility

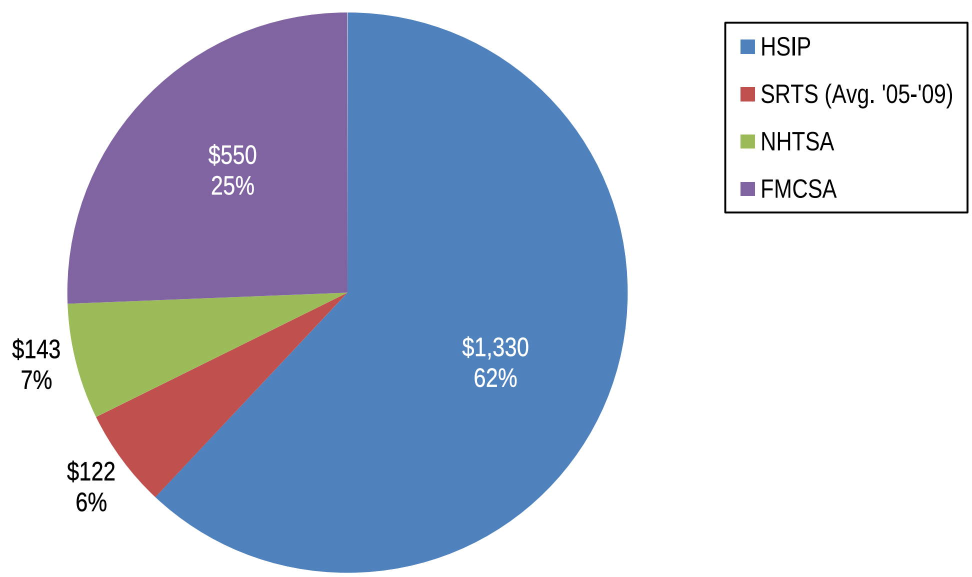
Improving the flexibility of funding for safety would support more cost-effective use of funding. Currently, rigid eligibility requirements for many Federal programs limit emphasis on the most cost-effective solutions, as many of them channel funding to specific solutions if not specific programs and projects. This forces focus on projects that conform to funding requirements rather than those that would deliver the most benefit for the least cost. For reference, Table 5.1 summarizes four safety-focused Federal programs and their funding restrictions.

Table 5.1 Safety Programs Funding Summary

Source	Requirements	Eligibility
Highway Safety Improvement Program (HSIP)	Highway safety improvement project must be consistent with a SHSP, and corrects or improves a hazardous road location or feature, or address a highway safety problem. Projects are eligible if identified through a data-	All countermeasure types.

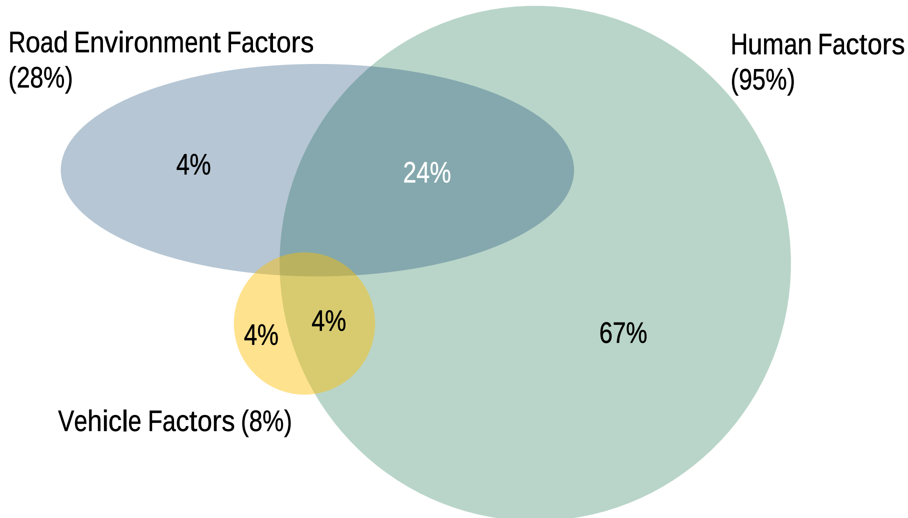
	driven process.	
Transportation Alternatives	Four types of projects are included: • Transportation alternatives (formerly Transportation Enhancements) that mainly target non-motorized modes. • Safe Routes to School • Recreational Trails • Planning and construction of roadways of former interstate routes or other divided highways. Federal funding share for these projects is 80 percent.	Primarily engineering (70 to 90 percent); some education and enforcement
NHTSA Highway Safety Programs	Projects must be approved by NHTSA regional office; must conform to Highway Safety Plan.	Education, enforcement, and information systems
Federal Motor Carrier Safety Administration (FMCSA)	Primarily used to fund programs that enforce or improve compliance with Federal Motor Carrier Safety Regulations.	Enforcement and information systems

Figure 5.1 2010 Federal Safety Programs Apportionment
In Millions of Dollars



Source: American Planning Association, FY 2011 Federal Budget Updates, www.planning.org/features/2010/Federalbudget.htm; FHWA Safety web site, Safe Routes to School Funding, safety.fhwa.dot.gov/saferoutes/funding; and U.S. DOT, FY 2010 Highlights, www.dot.gov/budget/2010/bib2010.htm#fmcsa

Figure 5.2 Crash Factors



Source: NSW Roads and Traffic Authority, 1996.

Figure 5.1 displays the apportionment of funding to these programs, and provides a graphical comparison with the areas of greatest need. As shown in Figure 5.2, road user behavior play a role in 95 percent of crashes but funding to directly address behavioral safety issues, such as impaired driving, represents a relatively small share of Federal funding dedicated to safety.

Appendices

NCHRP 17-46 Draft Final Report

A Comprehensive Framework for 4 E Investment Decisions

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A. Evaluation of Capabilities of Existing Resources for 4 E Problem ID and Comparison

This section discusses the relevance of several analytical tools and research resources to 4 E investment decision-making, including:

- Highway Safety Manual;
- PlanSafe;
- SafetyAnalyst;
- Levels of Service of Safety (LOSS);
- Interactive Highway Safety Design Model (IHSDM);
- NCHRP 500 Series: Guidance for Implementation of the AASHTO SHSP;
- NCHRP 622: Effectiveness of Behavioral Safety Countermeasures; and
- Countermeasures That Work.

For each tool, the intended area of application (e.g., regional, corridor-level, project-level); limitations; availability to practitioners; and relevance to 4 E decision-making is discussed.

A.1 Technical Tools

Highway Safety Manual

Overview and Purpose

The Highway Safety Manual (HSM) provides technical and analytical tools and techniques to quantify the safety effects of decisions in planning, design, operations, and maintenance. The information in the HSM allows agencies to integrate safety into their decision-making processes. Specifically, the manual is intended for practitioners who have an understanding of the transportation safety field at the state, county, metropolitan planning organization (MPO), or local level. The HSM consists of four parts:

- Part A provides an introduction to the HSM and basic information on how to apply the HSM;
- Part B presents roadway safety management process including methods for identifying improvement sites, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation;
- Part C provides the predictive method for estimating expected average crashes on two-lane rural highways, multilane rural highways, and urban and suburban arterials; and
- Part D summarizes the effects in accident modification factors (AMF) of various treatments at roadway segments, intersections, interchanges, special facilities, and roadway networks.

Safety Problem Identification

Chapter 4: Network Screening is a process for reviewing transportation network to identify and rank sites based on how much reduction in crash frequency could be realized in with the a countermeasure implementation. The chapter outlines five steps in Network Screening:

1. Establish the focus of network screening,
2. Identify the network and establish reference populations,
3. Select performance measures,
4. Select screening method, and
5. Screen and evaluate results.

Countermeasure Comparisons and Prioritization

Chapter 8: Project Prioritization indicates that the simplest method of prioritizing among projects for a site or an area using costs and/or effectiveness information is to rank projects based on any of the following metrics, each of which can be obtained from the previous analysis:

- Project costs,
- Monetary value of project benefits,
- Number of total crashes reduced,
- Number of fatal and incapacitating injury crashes reduced,
- Number of fatal and injury crashes reduced,
- Cost-effectiveness index,
- Net present value (NPV), and
- Benefit/cost ratio (BCR).

However, because these methods do not account for competing priorities, budget constraints, or other project impacts, none of these ranking measures, individually, provides sufficient information to establish a complete set of project priorities. Optimization methods are more complicated but will provide information accounting for competing priorities, and will yield a project set that provides the most crash reduction benefits within financial constraints. The HSM summarizes several different optimization approaches, including linear programming, integer programming, and dynamic programming.

Capabilities and Limitations

Although the HSM methods are potentially applicable to a broad range of countermeasures, the focus is on application to engineering measures at specific sites. Few examples are provided of application to behavioral safety measures.

PLANSAFE: Planning-Level Safety Prediction Model

Overview and Purpose

PLANSAFE is a software tool capable of forecasting the safety impacts of engineering and behavioral countermeasure investments under different growth scenarios. It is primarily intended for regional level safety planning. PLANSAFE inputs socioeconomic, demographic, and transportation-related data to predict the safety of traffic analysis zones (TAZ) or larger subareas of a jurisdiction. The PLANSAFE model enables a variety of planning-level activities, such as projecting increases in crashes expected in a given number of years while taking into consideration demographic and land-use changes.[1]

The PLANSAFE software package consists of the main tool and two supplemental tools (a GIS tool and a Census tool) which feed results into the main analysis tool. The tool contains a database of hundreds of engineering countermeasures and their crash reduction factors; and many behavioral countermeasures such as alcohol screening, communication and outreach programs, and child bicycle and pedestrian training. These behavioral countermeasures are assigned effectiveness on a one-to-five rating scale. Users have the option to add countermeasures to the database so long as crash reduction factors or effectiveness ratings are available.

PLANSAFE uses the information on countermeasure effectiveness to provide estimates of safety level and rate with the selected countermeasures implemented at the selected area. PLANSAFE is available (NCHRP 8-44(2)) and being pilot tested in two Florida regions and in Utah.

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[1] NCHRP Report 546.

Capabilities and Limitations

The model can be used to inform the user of safety impacts of alternative investments and to establish future performance targets. As such, it facilitates comparison of potential safety investments under objective conditions allowing for neutral decision-making with a predetermined disciplinary focus. This open format encourages decision-making across multiple disciplines.

SafetyAnalyst

Overview and Purpose

SafetyAnalyst is a set of software tools used by state and local highway agencies to improve the selection of engineering countermeasures at specific sites. It has recently concluded development and was made available in Fiscal Year 2010.

SafetyAnalyst consists of six software programs to analyze the safety performance of specific sites, to suggest appropriate countermeasures, quantify their expected benefits, and evaluate their effectiveness. These six tools are:[2]

- **Network Screening Tool** identifies sites in need of safety improvement;
- **Diagnosis Tool** diagnoses the nature of safety problems at specific sites;
- **Countermeasure Selection Tool** assists users in selecting countermeasures to reduce crash frequency and severity at specific sites;
- **Economic Appraisal Tool** conducts economic appraisals of the costs and safety benefits of countermeasures selected for a specific site;
- **Priority Ranking Tool** provides a priority ranking of sites and proposed improvement projects based on the benefit and cost estimates determined by the economic appraisal tool; and
- **Evaluation Tool** enables the design and application of well-designed before/after evaluations.

Capabilities and Limitations

SafetyAnalyst is intended for engineering applications. It does not support comparison of the effectiveness of non-engineering countermeasures.

Interactive Highway Safety Design Model (IHSDM)

Overview and Purpose

IHSDM is a suite of software analysis tools for evaluating the safety and operational effects of geometric design decisions on highways. IHSDM is a

[2] Source: www.safetyanalyst.org/scope.htm.

decision-support tool that checks highway designs against policy values and provides estimates of a design's expected safety and operational performance. The IHSDM consists of six evaluation modules.

- **Crash Prediction** estimates the frequency of crashes expected on a roadway based on its geometric design and traffic characteristics;
- **Design Consistency** helps diagnose safety concerns at horizontal curves;
- **Intersection Review** identifies potential safety concerns and possible treatments to address those concerns;
- **Policy Review** checks roadway-segment design elements for compliance with relevant highway geometric design policies;
- **Traffic Analysis** uses a traffic simulation model to estimate traffic quality of service measures for an existing or proposed design under variable traffic flows; and
- **Driver/Vehicle** permits the user to evaluate the drivability of a roadway design and to identify existing conditions that could result in loss of vehicle control.

Capabilities and Limitations

The IHSDM is intended for engineering applications. It does not support comparison with non-engineering countermeasures.

Level of Service of Safety (LOSS)

Overview and Purpose

The Level of Service of Safety (LOSS) tool was developed by engineers at the Colorado Department of Transportation. The concept of Level of Service of Safety uses quantitative measures to characterize the safety of a roadway segment in reference to its expected performance.

The LOSS is determined by using the Safety Performance Function to predict the expected number of accidents for a given location, and compare it to the actual number of accidents (including frequency and severity). This is used to rate the road segment as follows:

- **LOSS-I** indicates low potential for accident reduction,
- **LOSS-II** indicates low to moderate potential for crash reduction,
- **LOSS-III** indicates moderate to high potential for crash reduction, and
- **LOSS-IV** indicates high potential for accident reduction.

The LOSS method is intended to:

- Help bring about consensus on the subject of the magnitude of safety problems for different classes of roads;
- Bring the perception of roadway safety in line with reality of safety performance of a specific facility; and
- Provide a frame of reference from a safety perspective for planning major corridor improvements.

Capabilities and Limitations

LOSS is intended primarily to help practitioners establish priorities for safety improvement locations. When paired with companion software (Direct Diagnostics and Pattern Recognition techniques), it can also be used to identify contributing crash factors. This procedure enables assessment of the magnitude and nature of the problem at a given location by identifying overrepresented elements in the crash data, and in that sense could help identify whether a behavioral or engineering solution is more appropriate. However, the tool does not support comparisons of countermeasure effectiveness.[3]

A.2 RESEARCH RESOURCES

NCHRP 500 Series

The National Cooperative Highway Safety Program 500 Series consists of a series of more than 20 guides containing strategies for implementing each of the American Association of State Highway and Transportation Officials (AASHTO)'s SHSP priority emphasis areas.

The guides are designed to support implementation of the 4 E approach within each emphasis area by providing concrete ideas for how the emphasis area applies to the 4 E's. Each guide provides the following information:

- Description of the problem;
- Strategies for addressing the problem (strategies from multiple Es are typically included), information on expected effectiveness; keys to success; potential difficulties; associated measures and data; organizational and policy issues; cost issues; legislative needs; and other topics;

[3] Source: Kononov and Allery, 2003. Level of Service of Safety Conceptual Blueprint and Analytical Framework. Transportation Research Record, Transportation Research Board. http://diexsys.com/PDF/1840-007.pdf.

- A list of related strategies for "creating a truly comprehensive approach" – this typically includes general discussion of how all the "Es" can get involved in implementing the emphasis area; and
- An index of strategies by effectiveness (proven, tried, and experimental); implementation timeframe; and relative cost.

Some guides are more comprehensive than others in covering a range of 4 E implementation strategies. For example, the guide on reducing collisions involving pedestrians[4] focuses on engineering strategies such as provision of sidewalk and curb ramps and discusses behavioral strategies in less detail.

The series also provides a process for how SHSP priorities should be implemented. Step 6, "Evaluate the Alternatives and Select a Plan" includes consideration of the relative effectiveness of different types of 4 E countermeasures. An appendix to the report discusses, in general terms, how alternative countermeasures can be evaluated for their relative cost-benefit, but acknowledges that quantitative comparisons may be very difficult in some cases. It suggests practitioners do one of the following when making comparisons:

- Use published crash reduction factors;
- Use previous research;
- Use results of previous evaluation studies conducted within the jurisdiction;
- Conduct original research; or
- Make best estimates.

Comparisons may be aided by the fact that the 500 Series uses a common typology to compare the effectiveness of all included countermeasures. Countermeasures are classified as "proven," "tried," or "experimental" depending on the quality of the research available to justify their effectiveness.

NCHRP 622

The National Cooperative Highway Safety Program Report 622 (*Effectiveness of Behavioral Highway Safety Countermeasures*) provides information on the effectiveness of educational and enforcement countermeasures. Countermeasures are divided into five categories: proven, likely, uncertain, unknown, and varies. This typology cannot be compared directly to crash reduction factors developed for engineering countermeasures, but provides a first step towards comparison.

[4] Volume 10 of the NCHRP 500 Series.

Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices

"Countermeasures that Work" is a guide to assist State Highway Safety Offices (SHSOs) in selecting effective, science-based traffic safety countermeasures for highway safety emphasis areas. As with NCHRP 500 Series, this guide arranges countermeasures under each emphasis area. It then categorizes each safety improvement as a subgroup within each emphasis area and rates them according to effectiveness. This effectiveness rating is based on published research and consists of five levels:

- **(5 Stars) –** Demonstrated effective by several high-quality evaluations with consistent results;
- **(4 Stars) –** Demonstrated effective in certain situations;
- **(3 Stars) –** Likely effective based on balance of evidence from high-quality evaluations or other sources;
- **(2 Stars) –** Effectiveness still undetermined; different methods of implementing this countermeasure produce different results; and
- **(1 Star) –** Limited or no high-quality evaluation evidence.

As with the NCHRP 622, this typology provides some basis for comparing the effectiveness of behavioral countermeasures, but is not directly comparable to engineering crash reduction factors.

NCHRP 501 – Integrated Safety Management Processes

NCHRP 501 describes a general framework for facilitating an integrated management process across diverse safety agencies. It provides a detailed list of questions practitioners should consider when developing goals, priority emphasis areas, and strategies. It particularly emphasizes the importance of assessing the relative costs and benefits of different strategies, but does not provide specific guidance as to how this should be accomplished.

NCHRP 501 also provides guidance on developing analytical tools to assess the effectiveness of countermeasures for which there is insufficient information, during and after their implementation. These tools include formal evaluation studies (experimental and observational) and alternatives to formal evaluation such as Bayesian analysis, systematic reviews, and subjective assessments. The authors do not discuss the application of these tools in a 4 E decision-making context.

A.3 SUMMARY AND COMPARISON

Among the technical tools and resources described above, PLANSAFE and the NCHRP 500 Series are most useful for the purpose of identifying a full range of 4 E solutions and comparing their relative effectiveness. The other tools, SafetyAnalyst, the IHSDM, and LOSS do not directly support comparisons. The reasons behind these assessments are listed in Table A.1.

Table A.1 Technical Tools and Resources Summary

Source	Description	Applicability
Highway Safety Manual		
PLANSAFE	Software tool for planning-level analysis of countermeasure effectiveness at the area level	• Engineering • Enforcement • Education
SafetyAnalyst	Software tool for site-specific countermeasure benefit and cost analysis	• Engineering
IHDSM	Software tool for geometric-based safety performance analysis	• Engineering
LOSS	Software tool for Identification of sites with promise for safety improvement and identification of contributing crash factors	• Engineering • Enforcement • Education
NCHRP 500 Series	Guidebooks for providing countermeasure assessment based on crash type emphasis area	• Engineering • Enforcement • Education • EMS
NCHRP Report 622	Guidebook on the effectiveness of behavioral countermeasures	• Enforcement • Education
Countermeasures that Work	Guidebook on the effectiveness of countermeasures for different behavioral emphasis areas	• Enforcement • Education
NCHRP 501	Guidebook on implementing integrated safety management processes	• Does not specifically consider application to the 4 E's

B. Countermeasure Duration of Effectiveness

This Appendix briefly reviews available research literature on how the effectiveness of behavioral and engineering safety countermeasures vary over time. This information is important in determining the useful life of countermeasures for benefit/cost analysis.

Available information on the duration of countermeasure effectiveness is limited. Information could not be found for most of the countermeasures included in the sketch-level cost effectiveness prioritization process examples in Appendices D and E. In these cases, it was assumed that behavioral countermeasures are effective only during the implementation period (e.g., a year-long campaign would be effective for a year), and engineering projects are effective for the entire specified useful life of the infrastructure (typically twenty years). This default assumption should be modified as new information emerges on the duration of effectiveness of different types of measures.

B.1 Duration of Effectiveness – Behavioral Safety Countermeasures

In an analysis of the effectiveness of behavioral countermeasures based on NHTSA's 2007 Countermeasures Guide, the 104 measures identified were sorted into four groups, according to the behavior change techniques on which they were based (Preusser et al., 2008). This is a useful conceptual scheme for discussing program effectiveness and effect duration. The four groups and the number of countermeasures in each are as follows:

1. Voluntary actions, used alone (public information, education, mass media, persuasion programs) – 38 measures;
2. Laws, regulations, policies – 30 measures;
3. Laws plus enhancements (usually involving publicity and enforcement) – 18 measures; and
4. Sanctions and treatments (e.g., fines, license suspension, treatment programs) – 18 measures.

All 104 measures are used in the United States in attempts to promote highway safety. Ideally it would be known for each measure whether it is effective in accomplishing that goal, but that is not the case. Many measures are used and relied upon with no evidence from research studies as to whether they are effective, ineffective, or in some cases may have unintended negative effects. Of

the 104 measures, the estimated effectiveness of more than half (52 percent) was rated as unlikely, uncertain or unknown. Only 34 had a rating of proven effectiveness, based on evidence from research meeting scientific standards. There were 13 that were estimated to be "likely" to work, but the research evidence was not conclusive, and three that have been found to have negative consequences, for example, skid training programs for beginning drivers.

Evidence concerning the duration of effectiveness is necessarily based on the 34 proven countermeasures. These were most likely to come from the laws, laws plus enhancements, and sanctions/treatment groups. In the most popular group, voluntary actions, only 4 of the 38 countermeasures (11 percent) were rated as proven, compared with 53 percent in the laws group, 72 percent in the laws plus enhancements group, and 67 percent of the sanctions/treatments.

Basically there are two issues in addressing the duration of countermeasure effects. One concerns the length of time the countermeasure retains its initial positive effects in the population to which is applied. For example, if a program aimed at convincing bicyclists to wear helmets works, how long does that effect last? Highway safety behaviors such as helmet use need to be done on each trip, so programs that have only short term effects are essentially worthless. In many cases it is not possible to answer this question because longer-term effects are not measured.

The second issue is the duration of the countermeasure itself. If a program successfully urging bicycle helmet use is run only one time, for example, as a demonstration program, it may or may not have enduring effects on the population it was applied to, but the effect will not be repeated in future populations of bicyclists. Other countermeasures have longer durations because they are in effect on a permanent basis, for example, laws, or because they are institutionalized in schools so that they are applied to (for example) eighth graders each year, or because they are mandated punishments applied to all law violators. In all of these cases the countermeasures have enduring effects.

Information on duration of the effect on individuals and countermeasure duration effects for several representative countermeasures in each of the four behavior change groups is summarized below. Table B.1 summarizes the information for each group of countermeasures and provides examples.

Table B.1 Summary – Duration of Behavioral Safety Countermeasure Effectiveness for Proven Countermeasures

Type of Measure	General Findings	Specific Examples
Voluntary Measures (e.g., booster seat and belt use promotional programs, child pedestrian safety training)	Few studies have focused on the long-term effects of voluntary programs. Existing studies show short-term effects.	A child bicycle helmet use encouragement program was found to increase helmet use one year following the program (Bergman et al., 1990). Only short-term effects have been reported for booster-seat use programs (Ehiri et al., 2006). The effect of a belt use promotional program in Tennessee appeared to last only as long as the public service announcement intervention itself (Whittam et al., 2006).
Laws (e.g., seat belt use laws; motorcycle helmet laws; graduated driver licensing)	Laws tend to be effective for long periods of time because they stay in place unless repealed, but effectiveness can decline over time if not enforced.	Ontario, Canada's seat belt law resulted in seatbelt usage rates rising from 23 to 75 percent; this fell to 50 percent six months after enactment and then stabilized (Robertson, 1978). Generally motorcycle helmet laws increase helmet usage to close to 100 percent and the benefit remains over time due to the high visibility of the behavior (NHTSA, 2010).
Laws plus enhancements (e.g., Sobriety checkpoints; seat belt enforcement campaigns; speed cameras)	Some evidence that targeted law enforcement programs maintain their effect over a longer duration than the enforcement program itself.	One study found reduction in alcohol related crashes in Tennessee extending at least 21 months after the conclusion of the DUI checkpoint program (Lacey et al., 1999). One study of a year-long targeted seat belt enforcement program in Ottawa found sustained benefits two years following the program (Jonah and Grant, 1985).
Sanctions and Treatments – Alcohol ignition interlocks, brief treatment interventions	Mixed results – some programs have lasting effects while others last only as long as the program is in place.	One study demonstrated sustained benefits for individuals involved in brief intervention programs four years after the program ended (Grossberg et al., 2004). One study of license suspensions found reduced recidivism benefits lasting up to 30 months (about 2.5 years) after the suspension period ended (Lacey et al., 1990). Ignition interlocks appear to only be effective when present in the vehicle (Beirness and Marques, 2004).

Voluntary Actions

- Booster seat promotions,
- Child bicycle helmet use promotions, and
- School pedestrian training programs for children.

It is difficult to change individual behavior through voluntary action programs used by themselves, although this has always been a popular approach. Brief, one-shot programs are rarely successful, and even when they are, the effects are short-lived. For example, in one study, a 50-minute interactive group session reduced self-reported risk taking regarding alcohol use post-program, but reductions were not maintained at six-month follow-up (D'Amico and Fromme, 2002).

The voluntary action programs that do work on their own are typically longer term community programs and/or those that involve children, who do not yet have well-formed ideas about highway safety practices. Booster seat and child bicycle helmet promotions that were multifaceted community coalition programs addressing both parents and children, have had some limited success (Bergman et al., 1990; Ebel et al., 2003). The booster seat program ran for 14 months, the bicycle helmet program for three years. Both somewhat increased the use of safety devices. Booster seat use rose from 13 percent to 26 percent; helmet use increased from 5 percent to 16 percent. However, longer-term effects of the booster seat program were not determined, and none of the other successful booster seat programs in the literature has reported other than short term effects (Ehiri, et al., 2006). The bicycle helmet use study found that one year following the program, helmet use increased from 16 percent to 25 percent.

All of the booster seat and helmet promotion programs that have been run have been one-time-only programs, not repeated in the communities where they were introduced. This limits their effectiveness.

There is also some relevant information from seat belt promotional programs, most of which have failed to increase belt use, but there are exceptions. The exceptions have involved well-crafted intensive public information and education programs that have produced short-term gains. A program of this sort in Greece resulted in a gain in belt use from 5 percent to 10 percent although there was no follow-up (Petridou, et al., 2000). A program in Tennessee, that followed all the guidelines for conducting mass media programs, found an initial decrease in at-fault crashes for teenage drivers, but only for the brief period when the program was running (Whittam et al., 2006). As the authors note, "The effect in the treatment group appeared to last only as long as the PSA intervention itself" (p. 624). These were also one-time programs, not repeated.

Child pedestrian training programs have been successful in improving street crossing behavior and reducing pedestrian collisions (Blomberg et al.,1983). It would be interesting, although difficult, to determine if those whose street crossing behavior was changed are more responsible pedestrians as teenagers

and beyond. The idea of school based programs, however, is that the effect continues in the age-appropriate groups because the training is given to succeeding classes of students. That is, the countermeasure is intended to have lasting effects on the relevant population. In this case, the training materials were made available for continued use, and the costs for the program are minimal, but this did not happen sufficiently.

Laws

- Seat belt use laws,
- Motorcycle helmet use laws, and
- Graduated driver licensing.

Laws have the great advantage that once in force, they stay in place unless repealed and the costs are minimal. They also address wider populations than are targeted in typical voluntary action programs. This does not mean that laws found to result in behavior change have the same effects over time. Effects can vary, depending in part on the amount of publicity about the law and perceived and actual enforcement. The classic example is seat belt laws. When initially enacted, the typical pattern in the United States and Canada was that the highest rates were attained right after the laws went into force, generally in the first month, and the increases were often dramatic. These initial jumps were inevitably followed by declines within a few months, as publicity about the new laws waned and enforcement concerns eased. However, belt use rates remained substantially above prelaw levels. For example, in Ontario, driver belt use was 23 percent in late 1975, just before the law took effect, and 75 percent right after. Six months later, use had dropped to 50 percent and stayed around this level (Robertson, 1978).

Seat belt use rates are now at high levels in both Canada (more than 90 percent) and the United States (mid-80s), aided by the systematic application of highly publicized enforcement programs, to be discussed later. With this boost, belt law effects have greatly increased over time.

It is also possible for positive law effects to decrease over time, if public and law enforcement attention drop from an issue. This may be the case in regard to alcohol-impaired driving, which received tremendous societal attention in the 1980s. Attention subsequently switched to aggressive driving and now distracted driving as primary issues of the day. Administrative license suspension laws are rightly credited with creating general deterrence, which is contingent on public awareness of the laws and the threat of apprehension. A summary of 12 evaluations through 1991 found that these laws reduced alcohol-related crashes by an average of 13 percent (Wagenaar, et al., 2000). A subsequent study, based on 1976 to 2002 data, found a smaller reduction of 5 percent in alcohol crashes (Wagenaar and Maldonado-Molina, 2007). It is quite possible that an evaluation of the general deterrent effect of administrative

license suspension laws based on contemporary data would find effects to be further diminished.

In contrast, motorcycle helmet use laws provide an example of a law that has an immediate and dramatic effect that is unchanging over time. Not wearing a helmet on the roads is highly visible, and helmet laws increase use to close to 100 percent, up from around 50 percent, and it stays there (National Highway Traffic Safety Administration, 2010).

Graduated driver licensing (GDL) laws apply to all beginners who wish to get a license prior to age 18 (in most states). Positive effects, especially among 16-year-olds, are well established (Shope, 2007). Once passed, these laws tend to remain in effect. Law changes in recent years have been nearly entirely designed to strengthen rather than weaken the provisions. As such, this countermeasure affects 16-year olds today as well as those soon to become 16 as well as coming generations.

It is also of interest to know how going through a GDL program affects future driving. That is, do the positive effects at age 16 carry over to positive effects at ages 18 and 19 because of the added time and experience gained in the GDL system. This question is not resolved, as both positive and negative post-GDL effects have been reported (McCartt et al., 2010; Masten and Foss, 2010; Masten et al., 2011)

Laws Plus Enhancements

- Sobriety checkpoint programs,
- Seat belt enforcement programs, and
- Automated enforcement for speed.

Sobriety checkpoints have been found to be effective in supplementing laws against alcohol-impaired driving. They are associated with substantial reductions in alcohol-related crashes. This was confirmed in a systematic appraisal of all qualifying studies conducted by the Centers for Disease Control (CDC), in which it was also concluded that "…the present review provides evidence that sobriety checkpoints maintain their effectiveness over time" (Elder et al., 2002, p. 273). This was based on an analysis of the length of time between initiation of the checkpoint program to the end of the follow-up period, which ranged between 1 and 120 months (median 14 months). Time to follow-up was not related to the extent to which crashes decreased.

Seat belt enforcement programs have been instrumental in increasing belt use in the United States and Canada. These are typically short periods (less than one month) of greatly stepped-up enforcement accompanied by extensive publicity about the enforcement. Cost and manpower issues preclude running these programs on a constant basis. It is well known that intensified belt enforcement campaigns result in spikes in belt use. It is also well known that belt use drops back after the campaign ends but not to pre-campaign levels. A CDC review of

11 enhanced enforcement programs indicated a median drop of 6 percent in the months after the programs ended, but a median 9 percent increase over pre-program levels (Dinh-Zarr, 2001). The premise is that with successive waves of intensified enforcement programs, seat belt use can be ratcheted up to higher and higher levels, and this is basically the way "Click it or Ticket" programs in the United States have operated.

Speed cameras have crash reduction effects that appear to be lasting, as long as the cameras remain in place. In a review of 14 studies, all but one found crash reductions up to three years; one study found sustained longer term effects 4.6 years after the cameras were introduced (Pilkington and Kinra, 2005).

Sanctions and Treatments

- Alcohol ignition interlocks,
- Brief treatment interventions, and
- Suspensions for alcohol violations.

Alcohol ignition interlocks cut DWI recidivism at least in half, and sometimes more, compared with similar offenders without interlocks, based on evaluation data from ten studies (Beirness and Marques, 2004). However, once removed, the effect largely disappears, with interlock and comparison drivers having similar recidivism rates. That is, interlocks are effective when present in vehicles. The program is expected to remain equally effective with newly convicted drivers for as long as the program is in place.

Brief interventions for individuals with alcohol problems have become popular in recent years. They are generally delivered in single sessions in a variety of medical care settings and have been found to be successful in reducing alcohol consumption by persons identified as problem drinkers (National Cooperative Highway Research Program, 2005). Long-term effects have rarely been addressed, save for one study that compared patients who had been randomly assigned to a brief intervention with those receiving standard care. After four years, the brief intervention group was less likely to have been in injury producing motor vehicle crashes (Grossberg et al., 2004).

Other more standard treatment modalities have also been shown to be effective. A review of 215 such programs found an average reduced recidivism rate of 7 to 9 percent (Wells-Parker et al., 1995). Follow-up intervals ranged between 200 and 1,600 days, and within this range, mean recidivism effects were almost identical, indicating continuing effects over this timeframe.

The effects of administrative license suspension laws on general deterrence were discussed earlier. In terms of the effects of suspension on specific deterrence, that is, the extent to which those suspended remain free of alcohol problems, there are also positive effects. Studies have found reductions in crashes and recidivism among those who receive either administrative or judicial suspension, and these reductions continue well beyond the suspension period (Peck, Sadler,

and Perrine, 1985; Stewart, Gruenewald, and Roth, 1989; Voas, Tippetts, and Taylor, 2000). The Stewart study found an effect lasting for at least three years. In another study, an effect on recidivism was present at 3, 6, 18, 24, and 30 months following license suspension, but not at 36 months (Lacey et al., 1990).

Discussion and Conclusions

The question is not whether the behavioral countermeasures under discussion are effective. All of the 12 countermeasures are known to be effective at least in the short term. The question is how well these positive effects hold up in the populations they are applied to, and the extent to which the countermeasure continues to be applied to new populations.

It is clear that one critical factor is how long the intervention lasts. That gives laws and programs such as speed cameras a clear advantage since they can be in effect indefinitely. The effects of laws can vary, either becoming more or less positive over time, because of changes in enforcement and public attention to the law, but the countermeasure itself is always in play. Another key to law effectiveness over time is enforceability, based on the presence of objective criteria and easily observable behavior, which helps explain the immediate and enduring positive effects of motorcycle helmet use laws. Laws where the behavior is not easily observable (e.g., open container laws), or where the criteria are not explicit (e.g., aggressive driving) are not likely to be effective in the first place.

Other countermeasures endure because they continue to be applied to new populations. This includes countermeasures such as interlock programs, brief interventions, and suspensions for alcohol violations. For those going through these and other programs, however, they generally come to an end, for example, the interlock condition ends after a certain period of time. What happens after that is the question in regard to these individuals. Do interventions that go on for longer periods of time have longer-lasting effects on participants? This may be the case for voluntary action programs. It is so difficult to change individual behavior with programs of this type and one of the only ways to do so is through longer-term community coalition efforts. The three-year bicycle helmet program (Bergman et al., 1990) actually had its largest effect one year after the program officially ended, which is inexplicable, but it is probable that some of the community features that bolstered this program continued to operate. Thus, longer-term voluntary action programs that try to build community commitment and support may be most likely to have continuing effects. The short-term effects of most successful voluntary action programs are quite small, however (e.g., the increase in seat belt use in Greece from 5 to 10 percent), and it seems likely that for most voluntary action programs when the stimulus goes, so does the positive effect.

It is possible that longer running sobriety checkpoint programs, more frequent seat belt enforcement programs, longer suspension periods, and longer periods of therapy for those with alcohol problems would strengthen and extend positive

effects. Suspension periods do vary but there is no literature on possible differential effects, there are practical difficulties in mounting more extensive sobriety checkpoint and seat belt enforcement campaigns, and Wells-Parker et al. (1995) reported no differences in initial effect sizes related to number of hours of therapy.

It is notable and impressive that in their present form, sobriety checkpoints, seat belt enforcement programs, suspension for alcohol violations, and treatment for alcohol problems all have effects of longer duration. The evidence for this is solid, although the information available is generally not as detailed or direct as would be preferred for systematically tracking the lasting potential of these countermeasures. The exception is in the case of seat belt enforcement programs, where it is known that although the effects taper, belt use remains higher than prior to the enforcement. There is suggestive evidence that long-term effects of suspension may be no more than three years. It seems likely that sobriety checkpoint effects will decline or disappear over time unless checkpoints are resumed. The extent to which alcohol treatment effects will fade beyond the time periods in the Wells-Parker (1995) review is unknown.

The one countermeasure that loses its effect immediately for program participants is interlocks. This is similar to jail sentences, that appear to have no specific deterrent effect beyond the end of the incarceration (DeYoung, 1997). It has also been found to be the case for license plate impoundment. In one study, positive effects on recidivism were found during the year in which plates were disallowed, compared with those not subject to impoundment. However, in the subsequent two years, those who were subject to plate impoundment reoffended at slightly higher rates than the comparison group, so that beyond three years cumulative recidivism rates in the two groups were virtually equal (Leaf and Preusser, 2011). If little or nothing is done to those who receive these measures to rehabilitate or otherwise convince offenders not to drink and drive, this may be the anticipated outcome.

It is tempting to proclaim a general rule that in the sanctions/treatment group, measures aimed primarily at preventing future driving after drinking (interlocks, jail, plate impoundment, vehicle impoundment, vehicle immobilization) will not have an effect on participants beyond the sanction period (although they most likely would have continuing effects if sanction periods were lengthened), whereas interventions that have initial success in rehabilitating/treating offenders will have more lasting effects. More evidence would be useful. In one study of vehicle impoundment, that tracked offenders up to two years, lower recidivism rates were found both before and after the end of the sanction period (Voas, Tippetts, and Taylor, 1997). The authors question their own findings, speculating that many offenders may not have picked up their vehicles, and noting that "few studies of incapacitation sanctions have produced evidence of a deterrent effect beyond the end of the sanction period" (p. 641).

In conclusion, for participants in countermeasure programs that are successful in changing behavior, initial effects may disappear quickly or may last for a period

of time, in some cases indefinitely, and effects may vary over time. A key factor in assessing duration of effects is the extent to which the countermeasure stays in play, either because it is a law applicable to the general population, or is repeatedly being applied to new populations. In these cases, the duration of effects is greatly magnified, and the primary issue is the cost of maintaining these countermeasures.

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B.2 DURATION OF EFFECTIVENESS – ENGINEERING COUNTERMEASURES

Two major factors influence the effectiveness of engineering safety countermeasures over time. The first is the physical useful life of the infrastructure. This is typically the main consideration used by state departments of transportation (DOT) when assigning a useful life to safety projects for benefit/cost analysis. However, the changes in road user behavior in response to engineering safety countermeasures are also important considerations. Each of these considerations are discussed briefly below, and relevant research findings are presented. In summary, this section finds that:

- Infrastructure useful service life assumptions vary across state departments of transportation, and do not appear to be systematically based on research. This points to the need for additional research to standardize useful life assumptions to allow for more uniformity and comparability in safety benefit cost analysis across the states.
- Several studies have documented the existence of a "novelty effect" in response to engineering safety countermeasures, in which the safety benefits of the countermeasure are greatest immediately after installation, and may

wear off after that. This effect is not well-understood, but studies have been developed for certain types of countermeasures that could inform duration of effectiveness assumptions in benefit/cost analysis. More research is needed to better understand how the novelty effect applies to different types of countermeasures.

More detail on these findings is provided below.

Engineering Countermeasure Service Life

The Federal Highway Administration (FHWA) offers two definitions for engineering project service life. For pavements, service life is defined as "the period over which a pavement section adequately performs its desired function or performs to a desired level of service."[5] For traffic sign reflectivity, the FHWA defined service life as "based on the time required for the retroreflective material to degrade to the minimum retroreflectivity levels."[6] From both definitions, service life can be deduced as the time period duration in which a project serves its intended purpose prior to physical degradation. For example, shoulder rumble strips might only have physical service life of 10 years before the rumbles are worn, and would need to be replaced to maintain functionality. Table B.2 illustrates examples of engineering project physical service life assumed by various state DOTs in their effectiveness evaluation and statewide project prioritization.

While many DOTs apply standard service life assumptions for engineering safety improvements, documented studies and research supporting these assumptions were not readily available. In addition, as shown in Table B.2, service life assumptions for the same treatments varied across DOTs. Finally, some DOTs have more fine grained service life assumptions for comparable projects. For example Illinois has different service life length for various median types. Other DOTs proportionally weight projects with multiple engineering improvements to reflect their combined service life, for example, Arizona DOT has a weighted service life for traffic signs and pavement markings combined that is higher than the two components' service lives individually.

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[5] http://www.fhwa.dot.gov/pavement/healthtrack/pubs/technical/pht01.cfm.

[6] http://safety.fhwa.dot.gov/roadway_dept/night_visib/policy_guide/fhwahrt08026/chapter4.cfm.

Table B.2 DOT Service Life Assumptions (Years) of Engineering Projects

Safety Improvements	Arizona DOT Effectiveness Evaluations[1]	Illinois DOT Strategic Highway Safety Plan[2]	Minnesota DOT – Highway Safety Improvement Program[3]
Install Traffic Signals	10	15	20
Install Road Edge Guardrail	10	10	10
Install Pavement Markings/ Delineators	2	4	2
Traffic Signs	6	6	2
Construct Median for Traffic Separation	20	Raised Median = 15; Raised Reflector Median = 7; Rumble Strip Median = 10	20
Traffic Signs and Pavement Markings/Delineators	10	N/A	N/A

Source:

1 Arizona DOT, http://www.azdot.gov/highways/Traffic/standards/PGP/TM231.pdf.

2 Illinois DOT, http://www.dot.il.gov/safetyEng/01092008_Appendix_F.pdf.

3 Minnesota DOT, http://www.dot.state.mn.us/trafficeng/safety/funding/pdf/2013-14%20HSIP%20Program%20Final.pdf.

A shortcoming of physical service life is its simplification of engineering countermeasures effectiveness. Physical structures do not maintain the same level of crash reduction or safety effectiveness over the course of its physical service life and then cease to exist after that period. For example, geometric improvements such as an extra turn lanes or shoulder widening do not become ineffective upon the end of service life. Further, the effectiveness of the treatment may change over time as a function of physical maintenance of the treatment, changes in traffic volume profiles, or changes in the traveling public's response to the treatment. This last consideration is discussed below.

B.3 BEHAVIORAL CHANGES OVER TIME IN RESPONSE TO ENGINEERING PROJECTS

A limited number of studies examining long-term behavioral responses to engineering projects were identified in this research effort. Several of these studies documented what has been termed a "novelty effect," in which the greatest benefits of the countermeasure are experienced immediately, but wear off or stabilize over time. Several of these studies are discussed below.

Combination of Countermeasures – Signage, Pavement Markings, and Raised Medians

In a study by El-Basuouny and Sayed,[7] the authors compared a linear assumption of the treatment effectiveness over time to a nonlinear "Koyck model" assumption that assumes the novelty effect. The researchers tested treatment effectiveness over various time periods at 25 sample project sites in the greater Vancouver area. The 25 sites had improvements that used a combination of improved signage and pavement markings, upgraded signal heads, additional left turn lanes and raised medians. The "Koyck model" was shown to be a better fit with the observed changes in that treatment effectiveness over post treatment periods. The overall effectiveness was an initial 8.4 percent reduction in annual crash rates that disappeared within two years.

Signage

The goal of signage is to warn and inform motorists of approaching conditions. In Prince William County, Virginia, activated warning signs and pavement loop detectors were installed to reduce side-impact accidents at limited sight-distance intersections.[8] The goal is to enhance driver awareness of vehicles approaching or entering the intersection; this particularly targets speeding vehicles at the intersections. The study made observations during four phases – before, acclimation, four months after, and one year after implementation to assess the longer term effects of the countermeasure. Study results show a dramatic reduction of the proportion of vehicles exceeding 76 kilometers per hour (approximately 47 mph) – from 61 percent before implementation to 19 percent during the acclimation phase. However, past the acclimation phase, the proportion of speeding vehicles rose up to 40 percent after four months, and was sustained at the 40 percent level one year after implementation. In this case the "novelty effect" can be estimated at approximately an additional 20 percent benefit (40 percent minus 19 percent).

The city of San Francisco installed impactable yield signs in the medians adjacent to crosswalks at selected nonsignalized intersections to instruct drivers to yield the right-of-way to pedestrians.[9] Video recordings were taken at these intersections to document changes in driver and pedestrian behaviors, pre-

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[7] El-Basyouny, K., and T, Sayed, Measuring Safety Treatment Effects Using Full Bayes Nonlinear Safety Performance Intervention Functions, Accident Analysis and Prevention, Vol. 45, pp. 152-163, 2012.

[8] NCHRP 17-18(3), The American Association of State Highway and Transportation Officials Strategic Highway Safety Plan – Unsignalized Intersection Collisions: Appendix 1, http://safety.transportation.org/htmlguides/UnsigInter/app01.htm.

[9] Evaluation of Countermeasures: A Study on the Effect of Impactable Yield Signs Installed at Intersections in San Francisco, TSC Research Report, 2007.

installation, one month after installation, and roughly four months after installation. The behavioral changes varied greatly among the four intersections, the greatest increase in percentage of motorists yielding to pedestrians went from 20 percent to 53 percent, while the smallest increase motorists yielding to pedestrians went from 40 percent to 48 percent between pre-installation and one month after installation. No dramatic novelty effects were observed at all four intersections, albeit the entire observation period was only four months long. The observed increase in vehicles yielding to pedestrians was sustained in the period between one month and four months after installation.

Pavement Marking

Virginia DOT installed zigzag pavement marking to reduce serious crashes between vehicles, bicyclists and pedestrians at two highway crossings with multiuse trails.[10] The markings were placed on approach to the crossings to heighten motorists' awareness. Their study analyzed the speeds of approaching vehicles with and without pedestrian or bicyclists present. Speed data were collected using an automatic traffic recorder and LIDAR on four different periods – before, one week after, six months after, and one year after project implementation. Although the two crossings demonstrated overall reduction in vehicle speed, the trend in reduction over time varied by location and distance from the pavement marking to the highway crossing. In the first site, speed was recorded with an automatic traffic recorder and no novelty effect was found. Speeds six months and one year after the implementation were lower than one week after. Speeds at the second site were recorded with LIDAR. In this case, there appeared to be a novelty effect at the six-month period. The mean speeds observed at this site were the lowest at six months after project implementation (ranging from 39.7 to 42 mph), with observed speeds one year after project implementation sustained near speeds after one week of project implementation (between 40.4 and 43 mph). The differences in these two sites could be attributed to different rates in behavioral response to treatment as well as speed observation methods.

Agent studied the effectiveness of transverse pavement markings – pavement markings that are placed perpendicular to the flow of traffic along the edge line and commonly used to alert drivers of potential hazards.[11] A particular section of U.S. Highway 60 in Kentucky had 48 accidents along a curve, with speed mentioned as a contributing circumstance in 36 of the accident. Speed data was collected before application of transverse pavement markings, one week and six

[10] Dougald, L., Best Practices in Traffic Operations and Safety: Phase II: Zig-zag Pavement Markings, Virginia Transportation Research Council, 2010.

[11] Agent, K. R., Transverse Pavement Markings for Speed Control and Accident Reduction, Transportation Research Record: 773, Transportation Research Board, National Research Council, pp. 11-14, 1980.

months after installation. Daytime observations demonstrated higher speed reduction by drivers upon approaching the crossing increase one week after implementation as compared to before implementation (9.3 mph one week after installation versus 2.4 mph before the installation). Six months after the installation, speed reduction decreased slightly, but stayed above speed reduction before implementation at 6.8 mph. The same speed reductions over time were observed for nighttime observations.

Summary

The crash effectiveness of engineering treatments is subject to two factors that may change the effectiveness of the treatment over time:

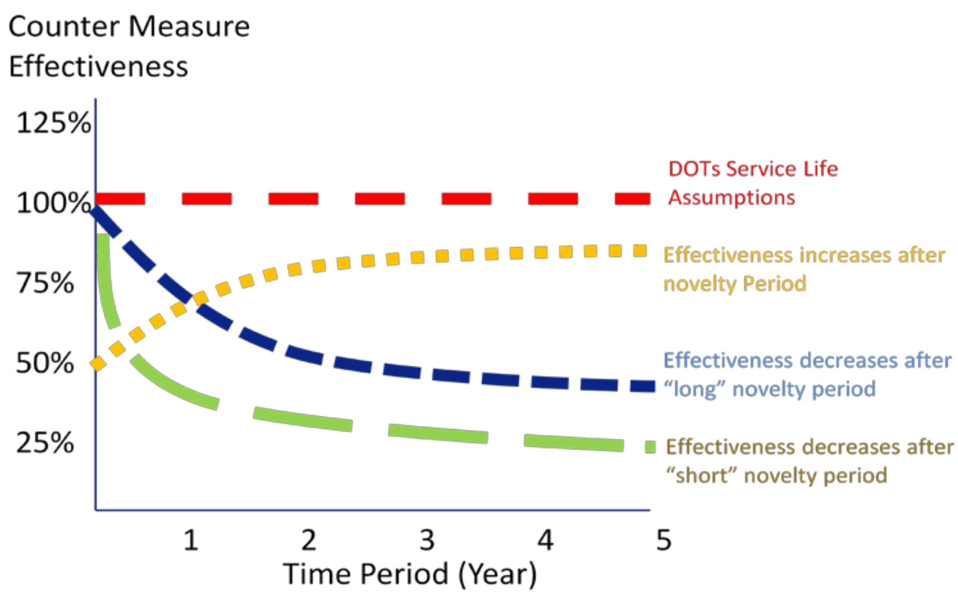
1. **Physical service life –** The time duration in which the physical elements of a countermeasure allow it to serve its intended functions.
2. **Change in behavioral response over time –** Drivers might respond immediately to a treatment or take time to acclimate to the treatment. As shown in Table B.3, the behavioral changes observed by the aforementioned studies varied from no effects, to dramatic effects, to peaking at the "novelty" period and then sustained at a pre-peak level.

Table B.3 Summary of Effectiveness over Time for Selected Engineering Countermeasures

Safety Improvement Type	Location (Sites)	Observation Duration	Behavioral Changes/ Effectiveness Decay Over Time
Combination of improved signage and pavement markings, upgrading signal heads, adding left turn lanes and raised medians	25 Intersections in Vancouver, Canada	2 years	Novelty Effect: Yes
Activated warning signs and pavement loop detectors	One rural intersection in Prince William County, Virginia	1 year	Novelty Effect: Yes
Impactable yield signs	Medians at four intersections in San Francisco, California	4 months	Novelty Effect: No
Zigzag pavement markings	Two rural highway intersections with trail crossings in Northern Virginia	1 year	Site 1: Novelty Effect: No Site 2: Novelty Effect: Yes
Transverse pavement markings	Along a curve section of U.S. Highway 60 in Kentucky	6 months	Novelty Effect: Yes
Activated warning signs and pavement loop detectors	One rural intersection in Prince William County, Virginia	1 year	Novelty Effect: Yes
Impactable yield signs	Medians at four intersections in San Francisco, California	4 months	Novelty Effect: No

The lack of available research into the duration of countermeasure effectiveness means that state DOTs quite often assume a constant value for countermeasure effectiveness. Figure B.1 shows a conceptual demonstration of how the novelty effect may influence countermeasure effectiveness as compared to an assumed constant value. Because of the common assumption that engineering countermeasure has constant effectiveness, in some cases, benefits might be over or underestimated during the physical service life of the treatment. Benefit/cost analysis should incorporate information on the effectiveness of treatments over time as research in this area becomes available.

Figure B.1 Possible Project Effectiveness Over



C. Case Study: Geary Corridor Safety Evaluation

C.1 INTRODUCTION

This case study evaluates the benefits and costs of different approaches to improving safety in San Francisco, California, focusing on the Geary Boulevard corridor. The purpose is to demonstrate the application of the quantitative method for comparing safety countermeasures from across disciplines, as presented in Section 4.0 of this report.

Four countermeasures were selected for comparison (pedestrian engineering improvements, automated enforcement, child pedestrian education programs, and DUI checkpoints). The first two were assumed to be implemented along the Geary Corridor, and the second two assumed to be implemented across the county.

The following considerations drove the selection of countermeasures:

- Desire to represent a range of approaches to safety improvement from across engineering, enforcement, education, and (ideally) emergency response, since the main purpose of the case study was to demonstrate comparison of different types of measures.
- Availability of quantitative information indicating countermeasure effectiveness. For engineering countermeasures, information is available from the FHWA Crash Modification Factors Clearinghouse (1) and the AASHTO Highway Safety Manual's cost benefit analysis procedures for engineering safety countermeasures (2). Information on a limited set of behavioral safety measures is available from NCHRP 622, *Effectiveness of Behavioral Safety Countermeasures* (3). Only countermeasures with quantitative crash reduction information were considered for inclusion. Emergency response approaches were not ultimately included due to lack of quantitative effectiveness information.
- Prior studies indicating the types of countermeasures appropriate for implementation in San Francisco.

The remainder of this case study begins with a general description of the Geary Corridor and an overview of the current safety performance of the corridor, a focus segment within the corridor, and San Francisco City and County. Review of different geographies is necessary because each countermeasure has a slightly different area of application – for example, automated enforcement is applied along the corridor but spillover effects are expected to adjacent areas (4, 5).

Detailed descriptions of selected countermeasures are provided, followed by a demonstration of the quantitative benefit cost analysis method of each based on recent and the most readily available crash and economic data including both crash costs and costs associated with countermeasures. The case study concludes with a brief synthesis of findings.

C.2 GENERAL DESCRIPTION OF CORRIDOR

Geary Boulevard is an important east-west arterial roadway in the City and County of San Francisco serving high volumes of transit, automobile, and pedestrian traffic. San Francisco Municipal Transportation Agency bus service travels along the corridor carrying approximately 50,000 passengers per day (6). Between 30,000 and 65,000 daily auto trips and thousands of pedestrians and bicyclists utilize the corridor daily (7), due to the proximity of high-density land uses including retail services, senior centers, health centers/hospitals, schools, parks and playgrounds and residential areas (8). Additionally, a major new bus rapid transit route is planned for the corridor (7). Given its prominence, the safety performance of the corridor is critical.

One 0.8-mile segment of the Geary Corridor from Cook Street to 9th Avenue is the focus of this case study, because it has been previously identified as a high injury corridor by the San Francisco Pedestrian Safety Task Force (SFPSTF). The posted speed along this section of the corridor is 25 mph, and the 85th percentile speed is about 33 mph (8). Figure C.1, developed by the SFPSTF, illustrates severe/fatal pedestrian injuries on the corridor from 2005 to 2009 (geocoded to the nearest intersection), as well as nearby land uses (hospitals, playing fields, schools, senior centers, commercial properties) along this corridor.

Table C.1 illustrates the frequency of all fatalities and injuries along this segment of Geary, at intersections along the segment, and a one-half-mile buffered zone around the corridor from 2005 to 2010. The table presents fatalities and all injuries resulting from vehicle-vehicle, vehicle-pedestrian, vehicle-bicyclist, and vehicle-only crashes. The number of equivalent fatality and injury *crashes* was not readily available for these geographies at the time of analysis; therefore, crash ratios (injury to injury crash and fatality to fatality crash) for San Francisco (9) were used to convert the number of fatalities and injuries into equivalent crashes (see table footnote).

Figure C.1 Geary Boulevard: Cook Street to 9th Avenue – Vehicle-Pedestrian Injuries *2005 to 2009*

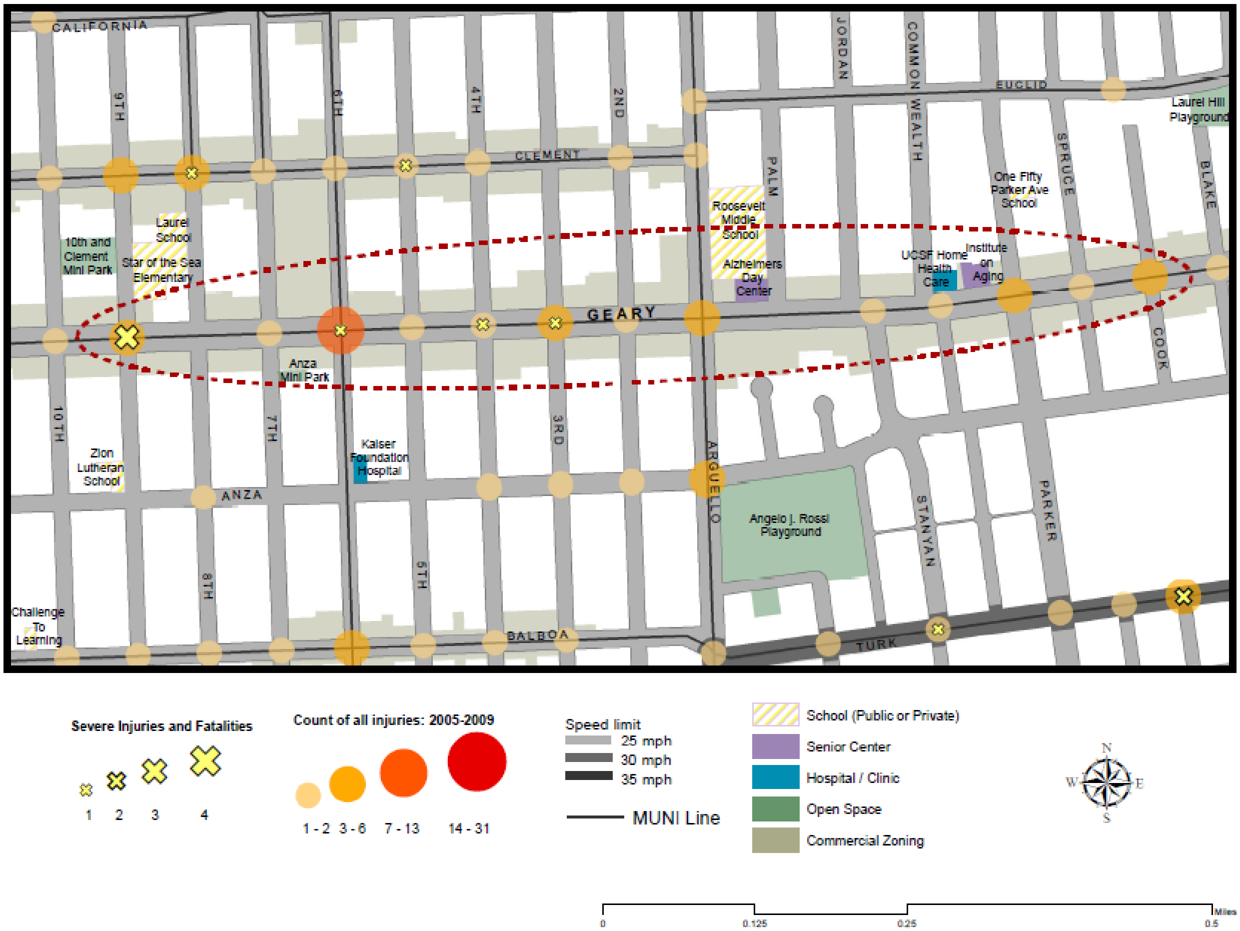


Table C.1 Geary Corridor Segment – Fatalities and Injuries Cook Street to 9th Avenue *2005 to 2010*

	Victims				Crashes (Estimated)	
Location	Total Fatalities	Annual Average Fatalities	Total Injuries	Annual Average Injuries	Estimated Annual Average Fatal Crashes	Estimated Annual Average Injury Crashes
At Intersections[a] on Geary Focus Segment						
Vehicle-Vehicle	0	0.00	67	11.17	0	8.1
Vehicle Only	0	0.00	2	0.33	0	0.2
Vehicle-Pedestrian	1	0.17	33	5.50	0.17	4.0
Vehicle –Bicycle	0	0.00	8	1.33	0	1.0
Total	1	0.17	110	18.33	0.17	13.2
Geary Corridor Focus Segment						
Vehicle-Vehicle	0	0.00	107	17.83	0	12.8
Vehicle Only	0	0.00	6	1.00	0	0.7
Vehicle-Pedestrian	1	0.17	42	7.00	0.17	5.0
Vehicle –Bicycle	0	0.00	11	1.83	0	1.3
Total	1	0.17	166	27.67	0.17	19.9
Within One-Half Mile of Geary Segment						
Vehicle-Vehicle	1	0.17	768	128.00	0.17	92.2
Vehicle Only	0	0.00	34	5.67	0	4.1
Vehicle-Pedestrian	2	0.33	210	35.00	0.33	25.2
Vehicle-Bicycle	2	0.33	98	16.33	0.33	11.8
Total	5	0.83	1110	185.00	0.83	133.3

Source: California Statewide Integrated Traffic Records System (SWITRS) Data Analysis provided by the San Francisco Department of Public Health. Estimated assuming a ratio of 1 fatal crash for each fatality and 0.72 injury crashes for every injury, using San Francisco countywide data 2000 to 2009 (9).

[a] Defined as crashes occurring less than 20 feet from an intersection.

C.3 OBJECTIVES AND METHODS

This research aims to demonstrate the steps in a cost benefit analysis of remedial actions at a site (corridor, region, etc.) involving multiple types of safety countermeasures. The following steps describe the method:

- Select countermeasures to be analyzed representing behavioral and engineering countermeasures applied at the corridor level or a wider geographic scale as appropriate to the type of countermeasure, as determined by the crash history of the site as well as known traffic, operational, and behavioral factors.
- Specify the level of deployment of each countermeasure. For engineering countermeasures, this primarily involves determining where the countermeasure will be implemented (e.g., how many sites). For behavioral countermeasures, it often involves consideration of not only where the countermeasure will be implemented (e.g., across the county, in a portion of the county), but how much investment is necessary to produce crash reductions specified in the research literature (if known). Finally, it can involve consideration of spillover effects – for example, if a countermeasure is implemented in one geographic location, drivers at similar locations may be affected.
- Estimate the crash reduction effectiveness of each countermeasure using available crash modification factors from the safety research literature or other current, reputable sources.
- Specify the time period of during which the countermeasure will be effective. This involves considering not only how long the countermeasure will be operable (e.g., the useful life of new infrastructure or the number of years of funding available for a behavioral strategy), but also how long the countermeasure will remain effective after it is installed or implemented. Some behavioral countermeasures, for example, remain effective even after the funded deployment period.
- Estimate countermeasure costs given the level of deployment.
- Estimate the target injuries and fatalities that could potentially be affected by the countermeasure. This study focuses on fatal and injury crashes and ignores property damage only crashes due to the much higher social and economic costs associated with the former.
- Estimate countermeasure benefits and calculate a benefit cost ratio.

Consideration of all these factors allows comparison of a diverse set of countermeasures implemented at different levels of geography and for different time periods of implementation.

Countermeasure Effectiveness, Level of Deployment, and Costs

Four potential countermeasures were selected as candidates for addressing safety on the Geary corridor and in the surrounding areas of San Francisco:

- Improvement of pedestrian median islands (corridor level);
- Automated enforcement (corridor level and adjacent areas);
- School pedestrian training programs (county level); and
- Sobriety checkpoints (county level).

These countermeasures were selected by drawing on the recommendations of prior studies (6, 7, 8, 10, and 11) and through reference to national studies identifying behavioral countermeasures for which quantitative effectiveness information is available (3 and 12). Each countermeasure is described below along with key assumptions used in the analysis.

Improved Pedestrian Refuges

A recent study of the Geary focus segment (11) recommended provision of improved pedestrian medians to reduce pedestrian exposure to vehicular traffic and provide a refuge for pedestrians crossing the busy arterial roadway. Raised medians are available along the corridor, but at 10 of the 14 intersections in the focus segment the raised medians do not extend into the pedestrian crosswalk. This countermeasure would involve extending existing medians to serve as pedestrian refuges at the 10 intersections. The following describes the assumptions used to calculate the benefits and costs of this countermeasure in the Geary corridor:

- Geographic level of deployment: This case study assumes that medians would be improved at ten intersections along the Geary focus segment to provide a refuge for crossing pedestrians. Two extensions would be provided per intersection (no extensions provided along minor cross-streets).
- Duration of impact: Effectiveness is assumed to remain constant over the expected useful life of the countermeasure (estimated to be twenty years).
- Crash reduction effectiveness: No crash reduction factors could be identified specifically for extension of an existing median into the pedestrian right-of-way at signalized intersections. The closest available factor was 46 percent reduction in pedestrian crashes due to provision of a new median island where none existed previously (12) and this crash modification factor is applied for the case study. Due to the uncertainty regarding the applicability of this CRF to the extension of existing median islands along Geary, it should be treated as an upper bound of the potential crash reduction available from median extensions.
- Cost: According to the San Francisco MTA, provision of a new median island typically costs between $10,000 and $75,000 (13). The lowest end of the cost

range ($10,000) was assumed to be adequate for extending an existing median island into the pedestrian right-of-way. This yields a total cost of $20,000 per intersection (two median extensions provided per intersection) or a $200,000 up-front cost for ten intersections. Medians are assumed not to have landscaping or require ongoing maintenance.

Automated Speed Enforcement

Automated cameras can be used to reduce speeding at intersections and along corridors. Automated cameras record a vehicle's speed using radar or other instrumentation and take a photograph of the vehicle when it exceeds a threshold limit, issuing citations to registered owners or vehicle drivers.

The SFPSTF's High-Injury Corridor Case Study (8) recommended specific enforcement strategies for the Geary focus segment calling for "enforcement activities targeting pedestrian right-of-way" and "enforcement activities targeting vehicle speed." Given the effectiveness of this proven countermeasure and the noted 85^{th} percentile speed of 33 mph in a 25 mph zone, the use of automated speed enforcement represents a logical and defensible safety strategy.

Automated enforcement relies on general deterrence theory to realize the full safety benefit of the program. Operationally, drivers are thought to change their behavior in response to camera-enforced locations, and develop a heightened awareness as to the dangers of risks (financial and safety) of speeding. This means that drivers who hear about the program may change their behavior even if they are not actually ticketed. The following describes the assumptions used to calculate the benefits and costs of this countermeasure if deployed as a pilot program along the Geary focus segment:

- Geographic level of deployment: This case study assumes that mobile speed cameras would be placed along the Geary focus segment. However, spillover effects – that is safety impacts at non-instrumented intersections – are expected and often observed upon careful evaluation. One study documented both positive (e.g., additional crashes reduced) and negative (additional crashes generated due to traffic diversion) effects measured from within 500 meters on either side of the study corridor to within 5 kilometers of the corridor (15). Since spillover effects are well established, this study assumes positive effects would extend to a half-mile buffered area on either side of the corridor. The study further assumes the use of mobile cameras would eliminate the possibility of negative spillover effects, which have been primarily associated with fixed cameras (15).
- Duration of impact: Cameras are assumed to be effective while implemented, and are assumed to be implemented for a twenty-year period (for comparability to other countermeasures).
- Crash reduction effectiveness: Much research has shown automated enforcement programs to be effective (4, 5, 15, 16). A recent review of 35 studies found the typical range of reduction in the proportion of speeding

vehicles in the 10-35 percent, and typical crash reductions of 14 to 25 percent in the vicinity of the cameras (16). For this study, a value of 20 percent reduction in all crashes (representing the midpoint of 14 and 25), is used.

- Cost: The cost of automated speed enforcement depends on the type and number of cameras used. For this study, cameras are assumed to be leased and not purchased. Prior studies have estimated a monthly cost of $2.1k to 2.4k lease of a pole- or cab-mounted camera (12), or an annual cost of approximately $27,000 per camera. Other configuration options include cabinet or trail mounted cameras and configuration for speeding and/or red light running. Another key consideration is the number of cameras used. For this study, it is assumed two cameras would be sufficient to produce crash reductions within the Geary corridor focus segment and buffered area. This is based on prior studies summarized in Table C.2. The two population-based studies suggest approximately 1 camera per 100,000 people is sufficient to produce significant crash reduction. Population within a square-mile buffer of the Geary corridor was not calculated for this study; however, the area represents less than one percent of the land area of San Francisco, which has a population of about 800,000. The corridor study suggests about 1 camera per mile is sufficient along a highway corridor. Taken together, these studies suggest two cameras should be more than sufficient to produce crash reductions along the mile-long segment of Geary from Cook to 9th and in a buffered area around the corridor.

Table C.2 Mobile Speed Enforcement Studies
Levels of Deployment

Study Area	Study Area Population/ Mileage	Time Period	Number of Cameras Used During Study Period	Crash Reduction Percentages
Victoria, Australia (most cameras and population in Melbourne)	4 million people (in 1985)	1983-1991	54 cameras	20% reduction in daytime crashes statewide
Highway Corridor in British Columbia, Canada	22 km (13.7 miles)	1994-1998	12 cameras	16% reduction in all crashes along the corridor
Province of British Columbia, Canada	~3.5 million people average during period	1991-1997	30 cameras	25% reduction in daytime speed-related crashes statewide

Source: Decina et al., 2007 (15). Population figures estimated from the British Columbia Bureau of Statistics (BC Stats) the Australian Bureau of Statistics.

Sobriety Checkpoints

Approximately 10 percent of all crashes in San Francisco involve alcohol use (17). Sobriety checkpoints are a proven effective method for reducing alcohol-involved crashes. Sobriety checkpoints are traffic stops where drivers' level of alcohol impairment is assessed by law enforcement officers. The aim of implementing the checkpoints is to achieve general deterrence for minimizing an undesirable behavior. Motorists are expected to have an increased sense of risk from their increased awareness, resulting in a change in behavior. The following describes the assumptions used to calculate the benefits and costs of this countermeasure if deployed throughout San Francisco as a whole:

- Geographic level of deployment: This case study assumes that checkpoints would be implemented throughout San Francisco.
- Duration of impact: The program is assumed to be put in place for a twenty year period. Some research has suggested that driving under the influence programs remain effective two years after conclusion of the program (e.g., one year of funding provides three years of benefit (18). This assumption is built into the average annual cost estimate.
- Crash reduction effectiveness: A national review of the effectiveness of sobriety checkpoints found programs typically reduce alcohol related crashes by approximately 20 percent (3).
- Cost: Countywide sobriety checkpoint programs were estimated to cost approximately $1.50 per-capita, this is based on a the cost of implementation of a statewide program in Connecticut in 2003 and adjusted to 2010 dollars (3). The value is divided by three to reflect that costs would need to be paid only once in three years, because program benefits are assumed to last two years beyond the conclusion of a one-year program. This yields an annualized cost of $0.50 per resident, or about $400,000 per year given San Francisco's resident population of 800,000.

School Pedestrian Training Programs

A recent national review (3) found school-aged pedestrian training programs for children are a low-cost, proven effective countermeasure for reducing child pedestrian injuries. Programs teach young children about the risks and proper behavior associated with the transport system, such as proper procedure at marked crossings, the dangers of unmarked crossings, the risks of walking at night (visibility concerns), and the lack of protection offered to pedestrians during crashes with motor vehicles.

The SFPSTF's High-Injury Corridor Case Study (8) made recommendations for educational and outreach strategies aimed at pedestrians. With many schools, parks, and playgrounds surrounding the Geary Corridor focus segment (see Figure C.1), attention focused on improving children's pedestrian behaviors.

The following describes the assumptions used to calculate the benefits and costs of this countermeasure if deployed at selected schools throughout the county:

- Geographic level of deployment: This case study assumes that twenty percent of schools in San Francisco would be targeted for inclusion in the program (25 out of 125 middle and elementary schools in San Francisco).
- Duration of impact: It is assumed this program would be funded on an annual basis and that it would remain effective only while funded. This is a conservative estimate reflecting lack of research on the long-term effects of pedestrian safety training programs.
- Crash reduction effectiveness: A national review of behavioral safety countermeasures found estimated child pedestrian safety training programs typically reduce crashes among this population by 12 percent (3).
- Cost: The cost of implementing a pedestrian safety training program at a single school in San Francisco is estimated at $25,000 annually. This estimate is based on a $500,000 Safe Routes to Schools grant funding supporting program deployment at 10 San Francisco elementary schools per year, 2009 to 2011 (19). The total annual cost of implementation at twenty-five schools would be $625,0000.

Estimating Target Crashes

The next step is estimating "target crashes" – that is those crashes that could be influenced by the chosen countermeasures. As stated previously, in this case study, the countermeasures will influence crashes at a variety of spatial scales, and so care must be taken to identify correctly those crashes that can and will be influenced by the safety investments. The following describes the specific assumptions used to estimate target crash estimates.

Median Island Extensions

- Median island extension would be placed at ten of the fourteen intersections, or 71 percent of intersections (10/14 = 71 percent) along the focus segment (remaining four intersections already have treatments).
- All pedestrian-vehicle related injuries and fatalities at targeted intersections could potentially be affected.
- Approximately 0.17 vehicle-pedestrian fatality and 4 vehicle-pedestrian injury crashes per year occur on average on all intersections in the focus segment combined (Table C.1). Because the median extensions will be placed at 71 percent of the intersections, it is estimated that 71 percent of pedestrian crashes could be affected (0.12 fatality and 2.8 injury crashes potentially affected).

Automated Speed Enforcement Cameras

- Two mobile speed enforcement cameras would be placed along the target segment.
- Cameras could potentially affect all fatality and injury crashes in a half mile buffered area surrounding the segment (estimated 0.83 fatality and 133 injury crashes on average per year, from Table C.1).
- Crashes outside the buffered area could also be affected, but are not included in the analysis to maintain a conservative estimate.

Countywide Pedestrian Training Programs

- Twenty percent of schools in San Francisco would be targeted for inclusion in the program (25 out of 125 middle and elementary schools in San Francisco).
- In 2009, 21 fatal and 699 injury crashes involving pedestrians occurred in San Francisco (9). Approximately 7 percent of these, or 1.5 fatal and 49 injury crashes, are estimated to have involved child pedestrians. This estimate was derived using the ratio of child (age less than 15) pedestrian injuries and fatalities to all pedestrian injuries and fatalities in San Francisco in 2009 (17).
- If 20 percent of schools are included in the pedestrian training program, about 20 percent of the total number of child pedestrian crashes, or 0.3 and 10 fatal and injury crashes, respectively, could potentially be addressed each year.

Sobriety Checkpoint Program

- The program would involve a countywide comprehensive program hiring officers (over-time) to conduct a systematic program of checkpoints.
- Alcohol-involved injury and fatality crashes would be affected. On average in San Francisco between 2005 and 2009, 3.2 fatal and 145.6 injury driving under the influence crashes occurred annually (9).
- Two comprehensive sobriety checkpoint programs involving associated publicity campaigns in Maryland and Delaware resulted in an average of 35 percent of the local population hearing of the program (20). It is assumed that the same level of awareness could be achieved among San Francisco residents, and this would result in approximately 35 percent of alcohol-related injuries and fatalities being potentially addressed by the program (1 fatality and 51 injury crashes annually).

Calculating Benefits and Costs

Table C.3 illustrates the calculation of benefit/cost ratios for each countermeasure. While all safety investments will impact the corridor, engineering countermeasures (pedestrian refuges) installed in the corridor will influence crashes only within the focus subsegment. Automated enforcement is assumed to impact the subsegment and crashes within a 0.5 mile buffer. Pedestrian and DUI countermeasures impact crashes at the county level.

Crash reductions are calculated by multiplying the target fatality and injury collisions listed in the second and third columns of the table by the crash reduction factors in the fourth column. These are converted to monetary benefits by multiplying by unit fatality and injury costs. The unit fatality crash cost of $5.4 million is drawn from a NHTSA review of crash costs (21). The unit injury cost is based on the weighted average severity of injuries occurring in the half-mile buffered area around the Geary focus segment, also using injury collision costs from the NHTSA review (21). These are converted to net present value of benefits using a 20 year implementation period and a discount rate of 4 percent.

Countermeasure costs are also summarized in the table and converted to a net present value over a twenty year implementation period. The net present benefit and cost ratio is then provided in the final column, showing that all selected safety investments have positive benefit to cost ratios, and importantly ratios greater than unity. The highest benefit to cost is associated with the automated speed enforcement pilot project, followed by pedestrian median extensions, sobriety checkpoints, and lastly pedestrian school training programs.

Table C.3 Corridor Safety Improvements
Assuming 20-Year Implementation Period for All Countermeasures

[a] Derivation of countermeasure CRF documented in section C.3.

Countermeasure and Scale of implementation	Estimated Annual Target Crashes		Estimated Annual Crash Reduction			Estimated Net Present Worth of Benefits			Estimated Net Present Worth of Costs			
	Fatality Crashes	Injury Crashes	Crash Reduction Factor[a]	Estimated Fatality Crash Reduction (CRFxFat)	Estimated Injury Crash Reduction (CRFxInj)	Fatality Crash Benefit (Unit Cost $5,389,000)	Average Injury Crash Benefit (Unit Cost $384,000)	Total Estimated Net Present Benefits[b]	Capital Costs (Initial)	Annual Ongoing Costs	Total Estimated Net Present Costs[b]	BCR
Pedestrian Median Extensions[c]	0.12	2.8	46%	0.06	1.29	$297,473	$664,608	$13,074,992	$200,000	N/A	$200,000	65
Automated Speed Enforcement Cameras[c]	0.83	133.0	20%	0.17	25.94	$872,210	$13,382,460	$193,725,612	N/A	$54,000	$733,878	264
School Pedestrian Training Program[d]	0.30	10.0	12%	0.04	1.20	$194,004	$619,200	$11,051,708	N/A	$625,000	$8,493,954	1
Sobriety Checkpoints[d]	1.00	51.0	20%	0.20	10.20	$1,077,800	$5,263,200	$86,176,259	N/A	$400,000	$5,436,131	16

[b] Project costs and benefits are converted to a net present value using a 4 percent discount rate and assuming each project is implemented for twenty years. Net present value factor for a 20 year series = 13.59

[c] Implemented along the Geary focus segment (including spillover effects within a 0.5 mile buffer for automated enforcement).

[d] Implemented throughout the county.

C.4 DISCUSSION AND AREAS OF UNCERTAINTY

All cost benefit studies require assumptions across a variety of steps. The assumptions in this analysis are described and justified throughout the report. Some of the more uncertain assumptions are discussed below, along with sensitivity analysis.

Uncertain CRF for Pedestrian Median Extensions

A CRF for pedestrian median extension at a signalized intersection was not available. The most similar available CRF was used (provision of a new median at an uncontrolled marked crossing with CRF of 46 percent). However, even if the actual CRF is much lower for median extensions (for example, 10 percent), the benefit/cost ratio for this strategy would still be high (BCR of 18), given the low up-front costs and long project life.

Uncertain Extent of Spillover Effects for Automated Enforcement

Automated enforcement is assumed to have positive spillover effects to adjacent intersections, based on literature showing that programs typically effect intersections within 500 m to 2.5 km on either side of the targeted corridor (15). This study conservatively assumes positive spillover effects to intersections within a ½ mile buffer on either side of the corridor. The potential for broader spillover effects beyond the corridor are ignored, although broader impacts have been shown in some studies. Automated enforcement can also have negative spillover effects if drivers are aware of fixed camera locations and avoid them, causing higher crash rates on adjacent streets (15). This study assumes mobile cameras would be implemented to avoid negative spillover effects, which have been primarily associated with fixed cameras.

Uncertain Costs for Automated Enforcement

Automated enforcement is assumed to cost $27,000 annually per intersection to lease cameras. If cameras are purchased instead of leased, the cost-benefit ratios could change significantly. Additionally, automated enforcement programs are frequently revenue-positive to the implementing agency (22) e.g., fines equal or more than offset implementation costs; therefore, the cost-benefit ratio to the implementing agency is very high. Nevertheless, the public still bears the cost of program implementation.

Uncertain Duration of Effectiveness for Pedestrian Training Programs

Pedestrian training programs were assumed to be effective only while funded, due to limited research on the long-term impacts of these types of programs. However, it is possible that multiple years of pedestrian safety education could produce changes in children's habits that could last well after program completion. This area deserves further study as the assumption of no lasting effects reduces the benefit to cost ratio.

Conclusions

This case study defined a methodology that allows comparison of the benefits and costs of engineering and behavioral countermeasures simultaneously. It demonstrates several important points:

- First, a careful and comprehensive analysis will involve a large number of assumptions. These assumptions may involve a significant level of uncertainty, and thus need to be clearly documented in the process. The assumptions include details of the spatial and temporal influence of countermeasures, and countermeasure costs and benefits. In particular, the amount of time countermeasures remain effective after implementation, and the level of deployment necessary to produce crash reductions documented in the research literature, are subject to significant uncertainty and deserving of further research. It is anticipated that much debate will ensue over analysis assumptions, and thus detailed documentation will be necessary to defend and support an analysis.
- A second insight is that benefit-to-cost results are quite sensitive to assumptions. Given this sensitivity, it may be advisable to use ranges of assumptions and estimate the benefit to cost ratios at the median, upper, and lower assumed values. This approach will lead to more informed decision-making, especially if the set of countermeasures if controversial.
- Thirdly, a sensible safety investment program is likely to involve both engineering and behavioral safety investments for a large majority of projects. This is evident because of the fundamental knowledge linking a majority of crashes to behavioral factors. Linking both behavioral and engineering factors in a single benefit/cost analysis is a useful exercise, as it is likely to engage multiple safety stakeholders, will assist in identifying flexible funding sources, and will serve to transfer knowledge between engineers and behavioral safety specialists.

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D. Application of Sketch Method – North Carolina

D.1 INTRODUCTION

This appendix demonstrates the application of the sketch method for comparing 4 E safety investment decisions to safety projects in North Carolina. It shows that the method results in comparison of the relative cost effectiveness of strategies drawn from different safety disciplines (engineering, education, and enforcement).

It is organized into the following sections:

- Method overview;
- Selection of representative engineering and behavioral projects;
- Method application;
- Results; and
- Challenges in framework application and information collection.

Method Overview

Section 3.0 of the main report body described the sketch method for comparing the cost effectiveness of safety countermeasures. Figure D.1 reiterates the major steps in the method, including analysis of countermeasure effectiveness (effectiveness score); estimation of the relative size of safety issues addressed by the countermeasures (problem score); and estimation of countermeasure costs over the expected duration of effectiveness of the project (cost score).

Figure D.1 Steps in Comparing Countermeasures
Quantitative and Sketch-Level Process Outcomes

Comparing Countermeasure Cost-Effectiveness	
Quantitative Process	Sketch-Level Process
Step 1: Select and Define Countermeasure Effectiveness	
Identify crash modification factors	Estimate crash reduction effectiveness (effectiveness score)
Step 2: Define Target Injury and Fatality Crashes	
Estimate potential injury and fatality crashes affected	Estimate relative size of injury and fatality populations addressed (problem score)
Step 3: Estimate Fatality and Injury Reduction	
Estimate total injuries and fatalities reduced by type or severity.	Not applicable
Step 4: Estimate Countermeasure Costs Over Time Period of Interest	
Calculate cost of implementing and maintaining countermeasure (dollars)	Estimate and score relative countermeasure costs (relative cost score)
Step 5: Compare Costs and Effectiveness	
Apply discount rates and calculate cost effectiveness or cost benefit ratio	Illustrate cost and effectiveness scores
Step 6: Prioritize Countermeasures for Implementation	
Rank by cost-effectiveness or use optimization tools	Rank in tiers by qualitative scoring index

Selection of Representative Projects

The North Carolina Department of Transportation provided project descriptions for this example analysis, including 156 behavioral (education and enforcement) projects drawn from the Governor's Highway Safety Program (GHSP) project applications for the fiscal year (FY) 2012, and 74 engineering projects drawn from NCDOT's 2010 High Hazard Elimination program applications.

Not all projects were evaluated. Instead, projects were grouped into representative categories, and two to three representative projects were selected from each category and scored. Projects also were selected to represent the variations in cost and scope within each category. For engineering projects, the groups were based on similar safety improvements:

- Median improvements;
- Directional crossover and channelization;
- Turn lanes;
- Superelevation improvement;
- Roadway widening;
- Shoulder improvements;
- Traffic signal improvements;
- Pavement marking improvements; and
- Streetlight repair/upgrades.

For behavioral projects, the groups were based on projects addressing similar behavioral safety issues:

- Child protection safety;
- Local traffic enforcement/education;
- Alcohol impairment enforcement/education;
- Motorcycle safety;
- Young driver outreach;
- Hispanic outreach; and
- Law enforcement training/equipment upgrades.

Tables D.1 and D.2 show the representative projects and provides brief descriptions. NCDOT provided more detailed descriptions for each project than what is shown.

Table D.1 Representative Engineering Projects

Project No.	Description
1	Construct a raised median with fencing along Grove Street and N. Eastern Blvd, and provide upgraded pedestrian accommodations along both streets.
2	Provide two lines of single face guardrail in the median of U.S. 220 from NC 68 to the Virginia state line for approximately 18.26 miles.
3	Modify the existing crossover by constructing a mainline directional crossover with median U-turn locations approximately 1,000 feet north and south of SR 1135.
4	Installing a roundabout in place of the existing intersection to help alleviate all types of crashes.
5	Construct left-turn lanes on all approaches of the intersection and install a traffic signal.
6	Widen NC 27 to provide a continuous center left-turn lane.
7	Construct a northbound left-turn lane on NC 58 at SR 1626 (Fairfield Dairy Road). Overlay NC 58 with OGAFC from a point 0.18-mile south of SR 1626, northward for 1.0-mile to just north of the northern most curve along this section. Restripe section of NC 58 with thermoplastic markings and install centerline pavement markers.
8	Widen U.S. 70 westbound for a third travel lane.
9	Widen SR 1140 to 24 feet from SR 1124 to a point 0.50-mile southwest of U.S. 70 and overlay incorporating "Safety Edge" pavement edge treatment to reduce drop-off hazards. Stripe roadway to provide 11-foot travel lanes and one-foot paved shoulders. Install raised centerline pavement markers. Upgrade all signing to current standards.
10	Widen roadway to provide for 11-foot travel lanes along with two-foot paved shoulders plus a minimum four-foot grass shoulders for 7.4 miles.
11	Install shoulder guardrail on NC 226 from SR 1794 in McDowell County to the Rutherford/Cleveland County line.
12	Extend the acceleration ramp and widen the shoulder along the east side of the I-95 northbound lanes from the Nash County Rest Area ton SR 1524. Overlay roadway, acceleration ramp, and taper with NovaChip from just south of the rest area exit gore northward to SR 1524. Projects include replacement of pavement markings, milled rumble strips, clear zone improvement, and installation of snow-plowable pavement markers as required.
13	Replace sections of concrete pavement as needed and provide longitudinal grooving, 5 miles in each direction at identified high wet crash concentrations within 21-mile length of I-40. Install shoulder rumble strips (four shoulders total) for 21 miles.
14	Install a traffic signal at NC 50 and SR 1844.
15	Realign SR 1515 to provide a continuous movement, and realign SR 1540 being under stop sign control.

Table D.2 Representative Behavioral Projects

Project No.	Project Description
16	Fund national CPS classes, CPS technician training, CPS educational/marketing; host CPS conference; CPS seat simulator and equipment.
17	Provide special needs seats for distribution. Attend conferences and educate public (i.e., Mountain State Fair) with CPS expertise.
18	Seat restraint enforcement (at least two seatbelt checking stations a month); sporadic speed enforcement (once a quarter); public info/educational program (two each month), such as child safety seat training/clinic.
19	Dedicated traffic safety and enforcement unit (at least two daytime and two nighttime checkpoints a month; aggressive patrols), also will provide education events. Funding for traffic safety officers. Decrease the incidences of impaired driving through aggressive DWI enforcement.
20	Purchase in-car camera video system for training aids to increase DWI arrest. Utilize in-car video as evidence in court.
21	Conduct 36 education events with the Breath Alcohol Testing (BAT) Mobile Unit Program; fund full-time BAT coordinator position; provide training to law enforcement agencies on conducting a checkpoint; purchase additional BAT mobile testing unit to increase total checkpoint by 47 annually, result in additional 217 DWI arrests, and 8 additional educational events.
22	30 MEMS units for monitoring high-risk defendants/DWI offenders while awaiting trial.
23	Promotional items for Key to Life (underage alcohol prevention program), and travel expense mobile enforcement team in targeted areas. The enforcement consists of saturated patrols and/or alcohol compliance checks.
24	Train motorcycle safety coaches, purchase 18 motorcycles for training sites, augment training coaches at existing sites, and expand to new sites.
25	Train officers in Bike Safe NC training, and conduct motorcycle daytime and nighttime checking station per month.
26	Driver's education consultant to provide guidance on driver education program implementation.
27	Meeting room rental for Student leadership Conference.
28	Fatal vision goggles for youth outreach to middle school and college age students.
29	Utilize 11 regional coordinators throughout NC to distribute materials and outreach Hispanic Community. Increase Latinos' awareness to safety issues with bilingual materials, two presentations, two interviews, and at least two child safety seat checks through Spanish-language media.
30	Crash investigation training, speed measurement instruction, promotional materials, RADAR and LIDAR units for enforcement training programs.
31	Technology purchases – improve safety/effectiveness of enforcement with 69 dual antenna radars, 10 LIDAR units, 100 digital cameras, and 50 trackers.

Within the set of behavioral projects provided by NCDOT, certain projects would not be expected to have a direct effect on improving traffic safety. These projects strengthen the administrative, research, data, and technical capabilities of an agency, and were labeled capacity-building activities. For example, to hire legal assistants to assist with prosecution processes for DWI cases or to hire programmers to improve eCitation data processing would improve the capabilities of an agency. However, the effectiveness of these projects in terms of crash reduction could not be determined, but could be evaluated separately as suggested in Section 2.5 of this report.

D.2 SELECT EFFECTIVENESS SCORE

The first step in evaluating these representative projects is to assign a score of one to four (four being the most effective) to represent the potential effectiveness of the countermeasure. The process for assigning a score involves looking up effectiveness information in the national safety research literature and assigning a score based on the uniform effectiveness typology presented in Table D.3. For engineering projects, this analysis employs a process that identifies the crash modification factor (CMF) of each project component and examines the studies that produce these factors. For behavioral projects, this analysis employs a process that estimates crash reduction effectiveness based on countermeasure effectiveness ratings from behavioral safety research.

Table D.3 Measures of Effectiveness*

	Source	Highly Effective	Effective	Somewhat Effective	Unknown or Ineffective
Engineering	Crash Modification Factor Clearinghouse	CMF <0.7 and Quality Score 4-5	0.7 < CMF < 1, and Quality Score 4-5	CMF < 1, and Quality Score 3	CMF≥1 or Quality Score < 3
	HSM	CMF <0.7 and Adjusted Standard Error < 0.2	0.7 < CMF <1 and Adjusted Standard Error < 0.2	CMF <1 and 0.2 < Adjusted Standard Error < 0.4	CMF ≥1 or N/A or Adjusted Standard Error > 0.4 or N/A
Behavioral	Countermeasures that Work	5 stars	4 stars	3 stars	≤ 2 stars or Star Rating Unavailable
	NCHRP 500/NCHRP 17-17(3)		Proven		Tried or Experimental
	NCHRP 622	Proven (Crash Reduction > 30%)	Proven	Likely	Unknown/Uncertain/Unlikely
	Effectiveness Score	4	3	2	1

Note: Countermeasure CMFs near the threshold of two effectiveness points could include both points in its confidence interval based on the measure's standard error.

Engineering Projects

The effectiveness of engineering countermeasures is evaluated according to the CMF[12] and its reliability. This information is drawn from two main sources: the AASHTO 2010 Highway Safety Manual (HSM) and the FHWA Crash Modification Factors Clearinghouse (see Table D.2). The HSM measures the reliability of the CMF with a standard deviation, and the CMF Clearinghouse with a quality score.

Countermeasures drawn from the HSM receive the highest score if they have low CMFs (CMF < 0.7) and a low standard deviation. Measures drawn from the CMF Clearinghouse receive the highest score if they have a low CMF (CMF < 0.7) and a CMF quality score of 4 or 5 (representing the highest-quality studies).

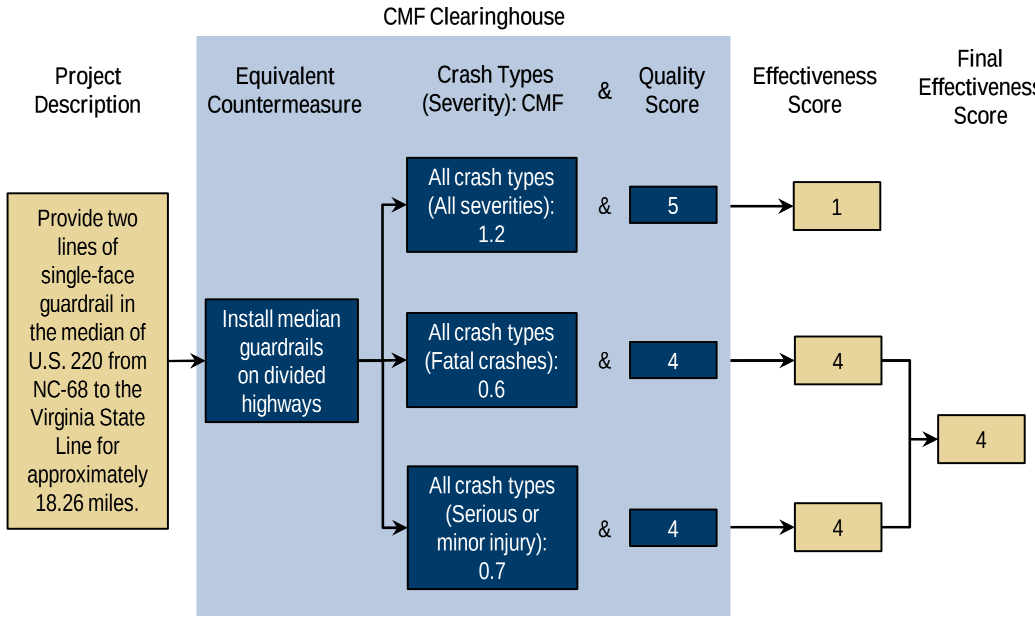
Although the process of looking up an applicable CMF and its reliability for each project seems straightforward, several complications can arise, as discussed below.

Several Applicable CMFs with Directional Conflicts

For certain countermeasures, several CMFs are applicable. For example, in Figure D.2, installing median guardrail on separated highways increased CMF for all crashes, however, decreased the CMF for fatal and serious injury crashes. In these cases, the effectiveness score is assigned based on the decrease in fatal and serious injury crashes.

[12] CMFs were rounded to the nearest tenth (0.1) in the application of this process.

Figure D.2 Engineering Project Effectiveness with Directionally Conflicting CMFs



Several Project Components with Different CMFs

Many engineering projects have multiple safety countermeasure components and equivalent CMFs. In these cases, the effectiveness score was assigned based on the score of the most effective component (see Figure D.3). Although other methods could be used (for example, the HSM recommends multiplying CMFs), this was judged preferable. More explanation of this approach is provided in Section 3.0 of the main body of this report.

Table D.4 shows the application of this scoring method by identifying the most effective component of each engineering project, and the component's effectiveness score. Note that the CMFs in Table D.4 have been rounded to the nearest tenth value to account for crash reduction variability that might render an effective countermeasure ineffective or vice versa.

Figure D.3 Engineering Project Effectiveness with Multiple Countermeasure Components

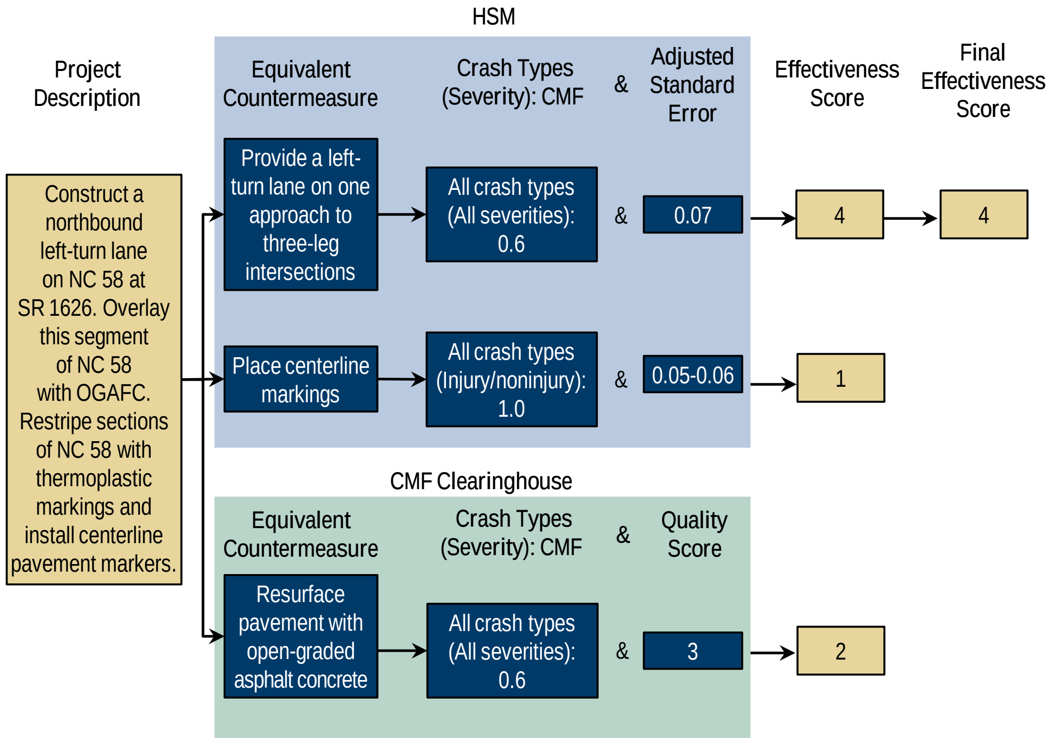


Table D.4 Effectiveness Score of Engineering Projects

Project No.	Project Description	Most Effective Project Component	Source[a]	Setting (Roadway Type)	Crash Type (Severity)	CMF	Adjusted Standard Error (Applies to HSM only)	Quality Score (Applies to CMF Clearinghouse)	Effectiveness Score
1	Raised median and pedestrian improvements	Provide a raised median	HSM	Urban (two lanes)	All types (injury)	0.6	0.1	N/A	4
2	18.26 miles of single face guard rail	Install median guardrails on divided highways	CMF Clearinghouse	Not specified (principal arterial other)	All (fatal)	0.6	N/A	4	4
3	Directional crossover with median U-turn	Replace direct left turn with right turn/U-turn	HSM	Unspecified (unsignalized intersections-access points)	All types (all severities)	0.8	0.1	N/A	3
4	Roundabout in-lieu of existing intersection	Convert stop controlled intersection for a modern roundabout	HSM	Rural (one lane)	All types (all severities)	0.3	0.04	N/A	4
5	Left Turn Lanes on All Approaches and Install a Traffic Signal	Provide a left-turn lane on two major road approaches to four-leg intersections	HSM	Rural (four-leg, minor road stop controlled intersection)	All types (severity)	0.5	0.04	N/A	4
6	Provide a continuous center left-turn lane	Introduce TWLTL (two-way left turn lanes) on rural two-lane roads	CMF Clearinghouse	Rural (two lanes)	All	0.6	N/A	5	4
7	Left-turn lane and pavement friction treatment	Provide a left-turn lane on one approach to three-leg intersections	HSM	Rural (minor-road, stop-controlled three-leg intersection)	All types (all severities)	0.6	0.07	N/A	4
8	Widen for a third travel lane	Four -to five-lane conversion	CMF Clearinghouse	Principal arterial other freeways and expressways	All	1.1	N/A	1	1
9	Install raised centerline pavement markers and upgrade existing signage	Place Centerline Markings	HSM	Rural (two lanes)	All-types (injury/non-injury)	1	0.05-0.06	N/A	1

Project No.	Project Description	Most Effective Project Component	Source[a]	Setting (Roadway Type)	Crash Type (Severity)	CMF	Adjusted Standard Error (Applies to HSM only)	Quality Score (Applies to CMF Clearinghouse)	Effectiveness Score
10	Add two-foot paved shoulders plus a minimum four-foot grass shoulders for 7.4 miles	Add two-foot paved shoulder	HSM	Rural (two lanes)	Single vehicle run-off, multiple vehicle head on, opposite direction sideswipe, and same direction sideswipe (all severities)	0.9	N/A[a]	N/A	3
11	Install shoulder guard rail	New guardrail along embankment	CMF Clearinghouse	Not specified	Run-off-road (serious injury, minor injury, fatal)	0.5	N/A	5	4
12	Extend the acceleration ramp and install snow-plowable RPM	Install snowplowable, permanent RPMs	HSM	Rural (four-lane freeways with AADT between 20,000 and 60,000)	Nighttime all types (all severities)	0.9	0.3	N/A	2
13	Install shoulder rumble strips (4 shoulders total) for 21 miles	Install continuous, milled-in shoulder rumble strips	CMF Clearinghouse	Rural (multilane divided)	All types (all severities)	0.2	N/A	4	4
14	Convert existing stop control intersection to signalized	Converting stop control to signal control	HSM	Rural (Three leg and four leg)	All types (all severities)	0.6	0.03	N/A	4
15	Realign routes for continuous movement	Install stop sign on minor approach of an unsignalized intersection	CMF Clearinghouse	Not specified	All	1.2	N/A	3	1

[a] The HSM provides a crash modification factor function for modifying shoulder width; however, the function does not have a standard error. Since all CMFs in the HSM have a quality score of 3 to 5 stars, we assume a quality score of 4 stars. In this case, CMFs from the HSM between 0.7 and 1.0 with a quality score of 4 receive an effective score of 3.

Note: Countermeasure CMFs near the threshold of two effectiveness points could include both points in its confidence interval based on the measure's standard error.

Behavioral Projects

This analysis aims to match each behavioral project to the closest equivalent countermeasure, as described in national safety research literature, including NHTSA's Countermeasures that Work; NCHRP 17-18(3); the NCHRP Report 500 series; and NCHRP Report 622 (see Table D.1). As with engineering projects, the effectiveness scores of behavioral projects range from one (least effective) to four (most effective). Note that because few quantitative CMFs are available for behavioral projects, few behavioral projects can achieve a score of 4, which requires a CMF of < 0.7.

Like engineering projects, behavioral projects also frequently have multiple countermeasure components with varying effectiveness scores. As with engineering projects, the overall effectiveness score for the project was based on the highest scoring component (see Figure D.4).

Figure D.4 Behavioral Project Effectiveness with Multiple Countermeasure Components

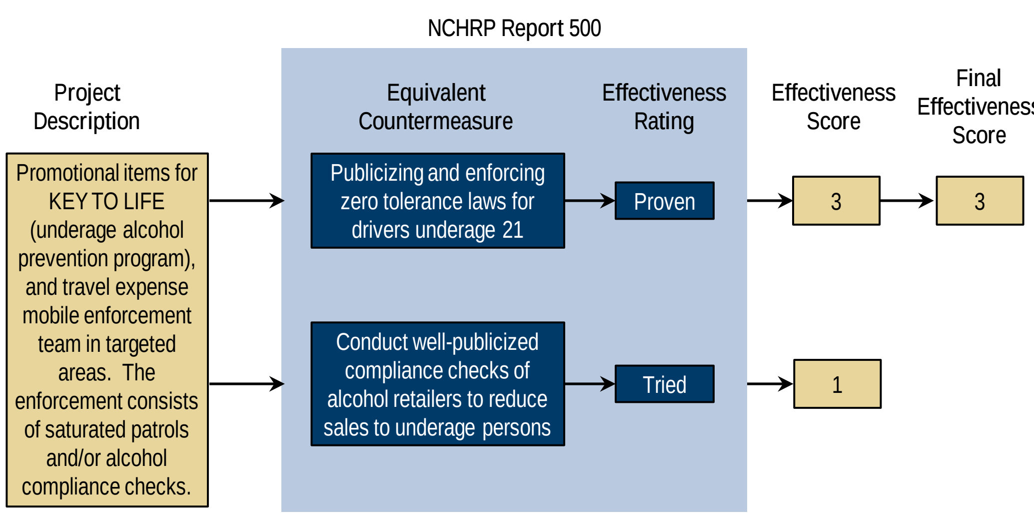


Table D.5 shows the application of this scoring method by identifying the most effective component of each behavioral project and its effectiveness score.

Table D.5 Effectiveness Scores of Behavioral Projects

Project No.	Project Description	Most Effective Component(s)	Source of Measures	Effectiveness Rating	Equivalent Effectiveness Score
16	Child protection safety training and outreach	Provide community locations for instruction in proper child restraint use, including both public safety agencies and health care providers that are always available.	NCHRP Report 500: Vol. 11	Tried	1
17	Special needs seat distribution and conference/state fair outreach	Child restraint distribution program	Countermeasures That Work	Two stars	1
		Communications and outreach strategies for booster seat use	Countermeasures That Work	Two stars	
18	Local traffic safety enforcement (seatbelt, speed, and child safety seat)	Conduct highly publicized enforcement campaigns to maximize restraint use	NCHRP Report 500: Vol. 11	Proven	3
		Use targeted conventional speed enforcement programs at locations known to have speeding-related crashes	NCHRP 17-18(3)	Proven	
19	Dedicated traffic safety unit (traffic safety and DWI enforcement)	Integrated enforcement	Countermeasures That Work	Three stars	2
20	Purchase in-car video to increase DWI arrest and to use for prosecution	Other enforcement methods: new technology – in-car video	Countermeasures That Work	Two stars	1
		Enhancing DWI detection through DWI patrols and related traffic enforcement	NCHRP Report 500: Vol. 16	Tried	1
21	Breath Alcohol Testing (BAT) mobile unit program (check pts and outreach)	Preliminary Breath Test Devices (PBT)	Countermeasures That Work	Four stars	3
22	Mem units for monitoring high-risk DWI offenders	Monitor all convicted DWI offenders closely	NCHRP Report 500: Vol. 16	Proven	3
23	Underage alcohol prevention outreach and enforcement	Publicizing and enforcing zero tolerance laws for drivers under age 21	NCHRP Report 500: Vol. 17	Proven	3

Project No.	Project Description	Most Effective Component(s)	Source of Measures	Effectiveness Rating	Equivalent Effectiveness Score
24	Purchase motorcycles for training and expand motorcycle safety training facility	Ensure that licensing and rider training programs adequately teach and measure skills and behaviors required for crash avoidance	NCHRP 17-18(3)	Tried	1
		Motorcycle rider training	Countermeasures That Work	One star	
25	Conduct motorcycle safety check points	Target law enforcement to specific motorcycle rider impairment behaviors that have been shown to contribute to crashes	NCHRP 17-18(3)	Tried	1
		Increase awareness of the consequences of aggressive riding, riding while fatigued or impaired, unsafe riding, and poor traffic strategies	NCHRP 17-18(3)	Tried	
26	Improvement of driver education program implementation	Improve content and delivery of driver education/ training	NCHRP 17-18(3)	Experimental	1
		Pre-licensure driver education	Countermeasures That Work	One star	
27	Meeting room rental for young drivers safety conference	Alcohol-impaired and drugged driving – youth programs	Countermeasures That Work	Two stars	1
28	Fatal alcohol Goggles (for underage alcohol prevention outreach)	Alcohol-impaired and drugged driving – youth programs	Countermeasures That Work	Two stars	1
29	Hispanic driver safety outreach and child safety seat check	Provide enhanced public education to population groups with lower than average restraint use rates	NCHRP Report 500: Vol. 11	Proven	3
30	Crash investigation training, radar and LIDAR for enforcement training program	Other enforcement methods	Countermeasures That Work	Two stars	1
		High-visibility enforcement	Countermeasures That Work	Two stars	
31	Technology purchase to improve enforcement (radars, cameras, and trackers)	Other enforcement methods, including Radar/LIDAR units	Countermeasures That Work	Two stars	1

D.3 SELECT PROBLEM SCORE

This step examines the relative magnitude of safety problems targeted by a project (the problem score). The problem score is determined using a top-down method that first identifies the type of safety problem the project would address, and then scores the significance of that safety problem on a statewide level. This method assumes that practitioners are interested in looking strategically at statewide safety problems and prioritizing projects based on whether they address significant statewide safety problems.

To determine the significance of a particular safety problem statewide, this analysis examined the average annual number of fatal and serious injuries (K&A) crashes from 2008 to 2010 in North Carolina; this is shown as the vertical bars in Figure D.5.[13] A safety problem is assigned a subjective statewide problem score from one to four as indicated in the bold outlined box at the top of Figure D.5; one being the safety problem with the lowest number of fatal and serious injuries. Note that the thresholds for the statewide problem score categories are based on natural breaks in the data and are subject to individual judgment.

An engineering or behavioral project often addresses more than one safety problem or crash type. When this occurred, a score was assigned for each safety problem addressed by the project, and the highest score was selected to represent the project. For engineering projects, the funding application specified the most common crash patterns for the project segment or intersection, and this was used to assign the score. Figure D.6 illustrates an example of a roundabout proposed at an intersection experiencing primarily angle, rear end, and fixed object crashes. The problem score is given to a project based on the largest statewide crash pattern or highest statewide problem score it addresses. In this case, the roundabout is given the score for fixed object crashes.

[13] Highway Safety Research Center at the University of North Carolina at Chapel Hill.

Figure D.5 Statewide Problem Score Based on Annual Fatal and Serious Injuries Crashes

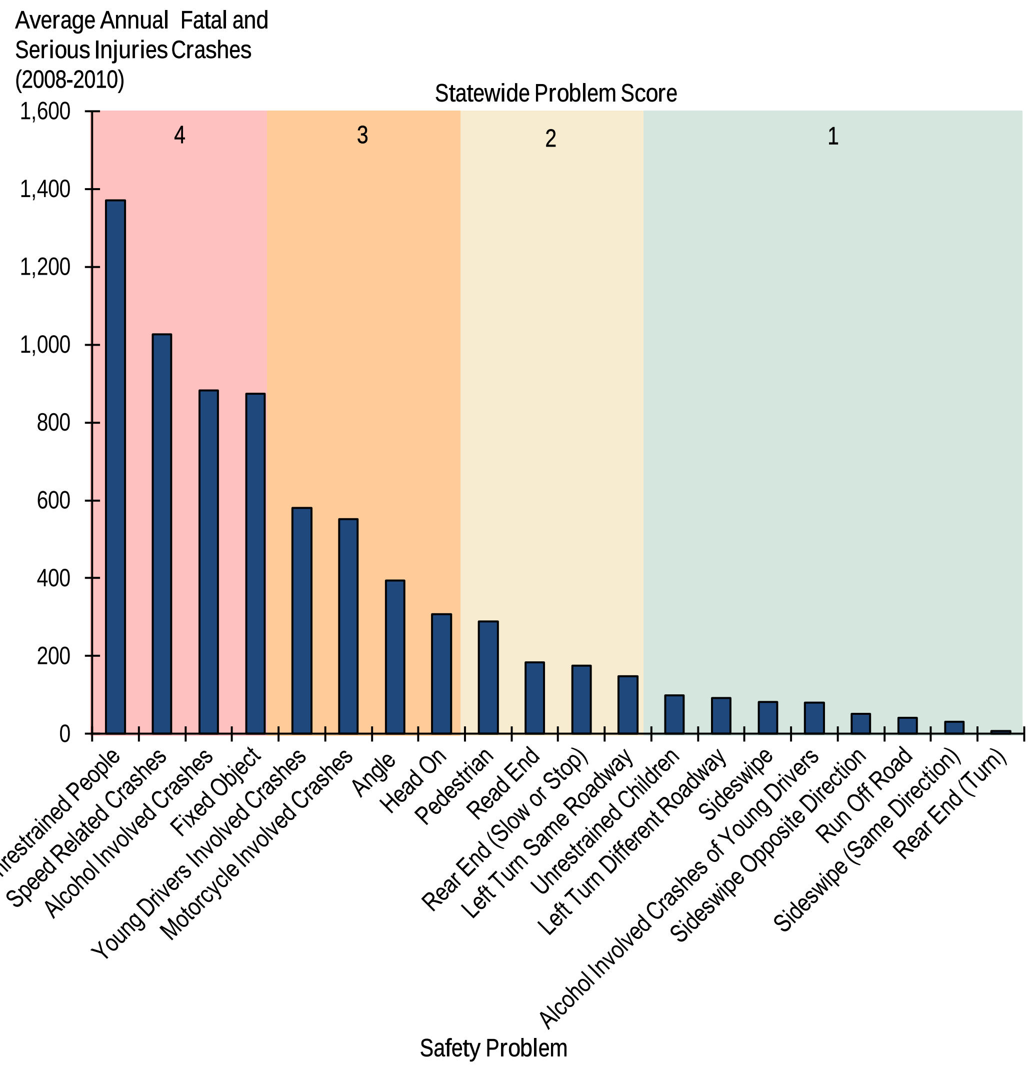


Figure D.6 Engineering Project Targeting Multiple Safety Problems

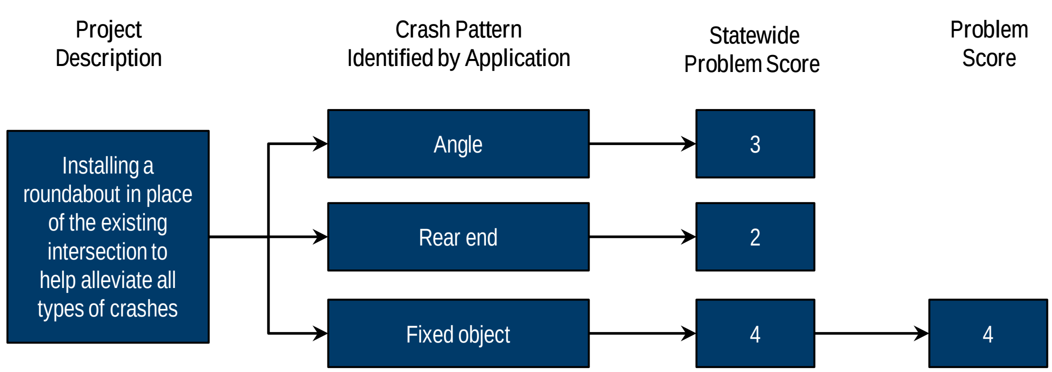


Table D.6 shows the application of this scoring method by identifying the most significant statewide safety problem of each engineering project, and its problem score.

Table D.6 Problem Score of Engineering Projects

Project No.	Project Description	Most Significant Statewide Problem	Problem Score
1	Raised median and pedestrian improvements	Angle/left-turn different roadway	3
2	18.26 miles of single face guard rail	Head on	3
3	Directional crossover with median U-turn	Angle	3
4	Roundabout in-lieu of existing intersection	Fixed object	4
5	Left-turn lanes on all approaches and install a traffic signal	Angle	3
6	Provide a continuous center left-turn lane	Rear end	2
7	Left-turn lane and pavement friction treatment	Rear end	2
8	Widen for a third travel lane	Angle	3
9	Install raised centerline pavement markers and upgrade existing signage	Sideswipe opposite direction	1
10	Add two-foot paved shoulders plus a minimum four-foot grass shoulders for 7.4 miles	Angle	3
11	Install shoulder guard rail	Runoff road	1
12	Extend the acceleration ramp and install snow-plowable RPM	Runoff road	1
13	Install shoulder rumble strips (four shoulders total) for 21 miles	Runoff road	1
14	Convert existing stop control intersection to signalized	Angle	3
15	Realign routes for continuous movement	Runoff road	1

For behavioral projects, this analysis identified the types of targeted safety problems based on the countermeasures listed in each project application. Again, the rationale is to assign the problem score to a project based on whether it addresses some of the key statewide safety problems. Most behavioral projects only addressed one type of crash. However, as shown in Figure D.7, if a project is identified as addressing multiple types of crashes, the highest statewide problem score is used as the project's problem score.

Figure D.7 Behavioral Project That Targets Multiple Safety Problems

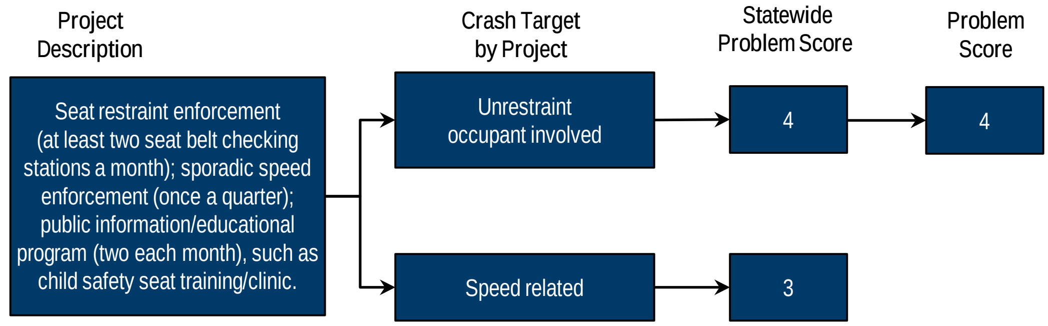


Table D.7 shows the application of this scoring method by identifying the most significant statewide safety problem of each behavioral project and its problem score.

Table D.7 Problem Score of Behavioral Projects

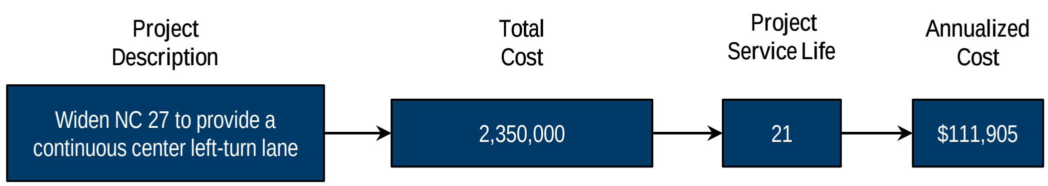
Project No.	Project Description	Most Significant Statewide Problem	Statewide Problem Score
16	Child protection safety training and outreach	Crashes that involve unrestrained children	1
17	Special needs seat distribution and conference/state fair outreach	Crashes that involve unrestrained children	1
18	Local traffic safety enforcement (seatbelt, speed, and child safety seat)	Speed-related crashes	4
19	Dedicated traffic safety unit (traffic safety and DWI enforcement)	Speed-related crashes	4
20	Purchase in-car video to increase DWI arrest and to use for prosecution	Alcohol-involved crashes	4
21	BAT mobile unit program (check pts and outreach)	Alcohol-involved crashes	4
22	Mem units for monitoring high-risk DWI offenders	Alcohol-involved crashes	4
23	Underage alcohol prevention outreach and enforcement	Alcohol-involved crashes of young drivers	1
24	Purchase motorcycles for training and expand motorcycle safety training facility	Motorcycle-involved crashes	3
25	Conduct motorcycle safety check points	Motorcycle-involved crashes	3
26	Improvement of driver education program implementation	Young drivers-involved crashes	3
27	Meeting room rental for young drivers safety conference	Alcohol-involved crashes of young drivers	1
28	Fatal alcohol Goggles (for underage alcohol prevention outreach)	Alcohol Involved Crashes of Young Drivers	1
29	Hispanic driver safety outreach and child safety seat check	Crashes that involve unrestrained people	4

Project No.	Project Description	Most Significant Statewide Problem	Statewide Problem Score
30	Crash investigation training, Radar, and LIDAR for enforcement training program	Speed-related crashes	4
31	Technology purchase to improve enforcement (radars, cameras, and trackers)	Speed-related crashes	4

D.4 SELECT COST SCORE

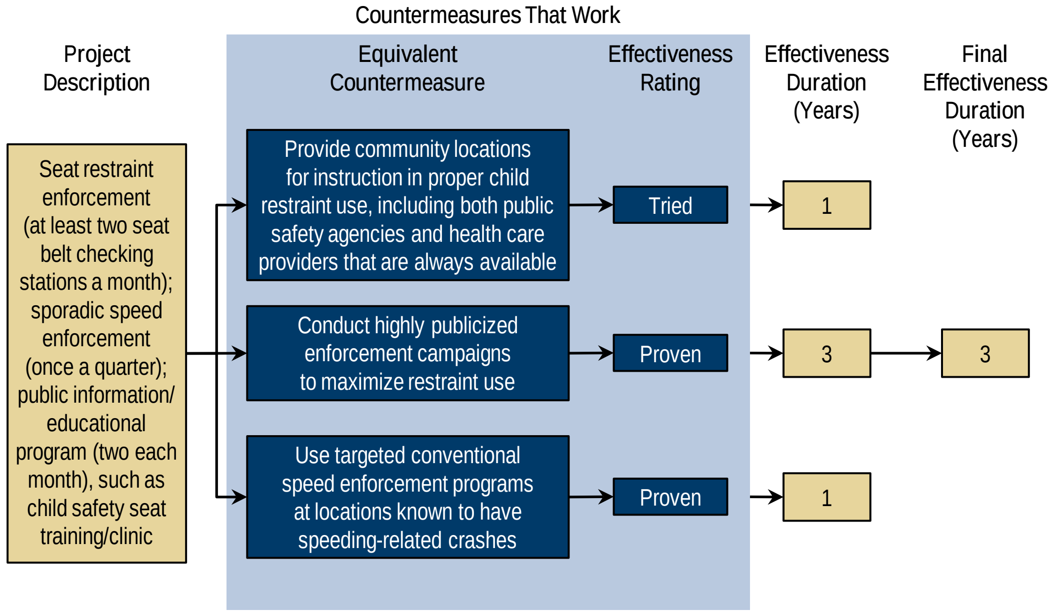
In this step, the total engineering or behavioral project cost is annualized over the duration of the project to compare projects with varying service lives. For engineering projects, the annualized cost is the total project cost divided by the project's service life as provided by the applicant's funding application (see Figure D.8).

Figure D.8 Engineering Project Annualized Cost



Behavioral projects were requesting a single year of funding, so the funding request was used as the annual cost. However, some types of behavioral projects are expected to have impacts lasting beyond the conclusion of the program. Appendix B summarizes research on the duration of effectiveness of behavioral measures. Based on this research, the duration is assumed to be two years for DUI checkpoints and three years for seatbelt enforcement programs. All other behavioral projects are assumed to have effectiveness duration of one year. If a project has multiple countermeasure components, the overall project effectiveness duration is represented by the longest effectiveness duration of all components (see Figure D.9).

Figure D.9 Behavioral Project Annualized Cost



Using this method, this analysis calculated an annualized cost for all engineering and behavioral projects in the case study. This annualized cost is the basis of assigning a cost score from one to three; one being a project with less than $50,000 in annualized cost; two being a project with annualized cost from $50,000 to $120,000; and three being a project with annualized cost greater than $120,000. These thresholds are assigned based on "natural breaks" in the data points and are subject to individual judgment. Table D.8 shows the application of this scoring method by assigning cost score according to annualized cost values.

Table D.8 Cost Score of Engineering and Behavioral Projects

Project No.	Project Description	Total Cost	Project Service Life	Annualized Cost	Cost Score
Engineering Projects					
1	Raised median and pedestrian improvements	1,966,500	30	65,550	2
2	18.26 miles of single face guard rail	3,400,000	15	226,667	3
3	Directional crossover with median U-turn	650,000	20	32,500	1
4	Roundabout in-lieu of existing intersection	650,000	26	25,000	1
5	Left-turn lanes on all approaches and install a traffic signal	314,000	19	16,526	1
6	Provide a continuous center left-turn lane	2,350,000	21	111,905	2
7	Left-turn lane and pavement friction treatment	400,000	17	23,529	1
8	Widen for a third travel lane	1,017,500	20	50,875	2
9	Install raised centerline pavement markers and upgrade existing signage	1,200,000	20	60,000	2

Project No.	Project Description	Total Cost	Project Service Life	Annualized Cost	Cost Score
10	Add two-foot paved shoulders plus a minimum four-foot grass shoulders for 7.4 miles	10,854,884	26	417,496	3
11	Install shoulder guard rail	1,200,000	10	120,000	2
12	Extend the acceleration ramp and install snow-plowable RPM	1,175,000	20	58,750	2
13	Install shoulder rumble strips (four shoulders total) for 21 miles	7,780,000	10	778,000	3
14	Convert existing stop control intersection to signalized	50,000	10	5,000	1
15	Realign routes for continuous movement	390,000	21	18,571	1
Behavioral Projects					
16	Child protection safety training and outreach	564,129	1	564,129	3
17	Special needs seat distribution and conference/ state fair outreach	118,160	1	118,160	2
18	Local traffic safety enforcement (seatbelt, speed, and child safety seat)	16,980	3	5,660	1
19	Dedicated traffic safety unit (traffic safety and DWI enforcement)	93,759	1	93,759	2
20	Purchase in-car video to increase DWI arrest and to use for prosecution	24,000	1	24,000	1
21	BAT mobile unit program (check pts and outreach)	445,000	1	445,000	3
22	Mem units for monitoring high-risk DWI offenders	46,580	1	46,580	1
23	Underage alcohol prevention outreach and enforcement	55,000	1	55,000	2
24	Purchase motorcycles for training and expand motorcycle safety training facility	79,680	1	79,680	2
25	Conduct motorcycle safety check points	28,950	1	28,950	1
26	Improvement of driver education program implementation	117,980	1	117,980	2
27	Meeting room rental for young drivers safety conference	12,000	1	12,000	2
28	Fatal alcohol Goggles (for underage alcohol prevention outreach)	900	1	900	1
29	Hispanic driver safety outreach and child safety seat check	73,900	3	24,633	1
30	Crash investigation training, Radar and LIDAR for enforcement training program	83,690	1	83,690	2
31	Technology purchase to improve enforcement (radars, cameras, and trackers)	214,000	1	214,000	3

D.5 Cost-Effectiveness Comparison of Engineering and Behavioral Projects

The effectiveness, problem, and annualized cost scoring process combine to present a picture of relative project cost effectiveness. Table D.9 presents the final scores for each project.

Table D.9 Cost Effectiveness of Engineering and Behavioral Projects

Project No.	Project Description	Effectiveness Score	Problem Score	Cost Score
Engineering Projects				
1	Raised median and pedestrian improvements	4	3	2
2	18.26 miles of single face guard rail	4	3	3
3	Directional crossover with median U-turn	3	3	1
4	Roundabout in-lieu of existing intersection	4	4	1
5	Left-turn lanes on all approaches and install a traffic signal	4	3	1
6	Provide a continuous center left-turn lane	4	2	2
7	Left-turn lane and pavement friction treatment	4	2	1
8	Widen for a third travel lane	1	3	2
9	Install raised centerline pavement markers and upgrade existing signage	1	1	2
10	Add two-foot paved shoulders plus a minimum four-foot grass shoulders for 7.4 miles	3	3	3
11	Install shoulder guard rail	4	1	2
12	Extend the acceleration ramp and install snow-plowable RPM	2	1	2
13	Install shoulder rumble strips (four shoulders total) for 21 miles	4	1	3
14	Convert existing stop control intersection to signalized	4	3	1
15	Realign routes for continuous movement	1	1	1
Behavioral Projects				
16	Child protection safety training and outreach	1	1	3
17	Special needs seat distribution and conference/state fair outreach	1	1	2
18	Local traffic safety enforcement (seat belt, speed and child safety seat)	3	4	1
19	Dedicated traffic safety unit (traffic safety and DWI enforcement)	2	4	2
20	Purchase in-car video to increase DWI arrest and to use for prosecution	1	4	1

Project No.	Project Description	Effectiveness Score	Problem Score	Cost Score
21	BAT mobile unit program (check pts and outreach)	3	4	3
22	Mem units for monitoring high-risk DWI offenders	3	4	1
23	Underage alcohol prevention outreach and enforcement	3	1	2
24	Purchase motorcycles for training and expand motorcycle safety training facility	1	3	2
25	Conduct motorcycle safety check points	1	3	1
26	Improvement of driver education program implementation	1	3	2
27	Meeting room rental for young drivers safety conference	1	1	2
28	Fatal alcohol Goggles (for underage alcohol prevention outreach)	1	1	1
29	Hispanic driver safety outreach and child safety seat check	3	4	1
30	Crash investigation training, Radar and LIDAR for enforcement training program	1	4	2
31	Technology purchase to improve enforcement (radars, cameras, and trackers)	1	4	3

Tiering Projects for Implementation

The results shown in tabular form in Table D.9 also can be displayed graphically with circle size representing the cost score, and x and y axes representing the effectiveness and problem scores, respectively, as shown in Figure D.10. Note that in this figure, all projects located in the same dashed line grid cell have the same effectiveness and problem scores regardless of their positions in the cell. Figure D.11 is another way of looking at the results, where projects are represented by slices of a pie, where size of the slice is proportional to the annualized cost of the project.

Figures D.10 and D.11 group projects into tiers for implementation, as follows:

Tier 1 – Most Effective, Largest Problems

Tier 1 projects should be prioritized before the other tiers as they could deliver the most benefits and address the most significant problems. About the same number of engineering and behavioral projects falls into Tier 1, as well as projects of varying cost levels. Note, however, that within Tier 1, no behavioral projects receive the highest effectiveness score of 4 (indicating a CMF of <0.7 and high reliability), which is due to the fact that quantitative crash modification factors are unavailable for most behavioral measures. As a result, the highest possible effectiveness score for a behavioral countermeasure in many cases was

3. Figure D.11 shows that Tier 1 has the largest total tier annualized cost at $1.31 million. Some examples of Tier 1 projects include the following:

- Install roundabout in place of existing intersection;
- Raised median and pedestrian improvements;
- Local traffic safety enforcement (seatbelt, speed, and child safety seat); and
- BAT mobile unit program (alcohol checkpoints and outreach);

Tier 2 – Most Effective, Smaller Problems

Tier 2 projects would be prioritized after Tier 1 as they address less significant problems, but are equally as effective. However, it should be noted that Tier 2 projects have higher cost scores of 2 to 3. This might be because Tier 2 projects are predominantly engineering projects. The total annualized cost for Tier 2 projects is $1.09 million (Figure D.11). Some examples of Tier 2 projects include:

- Left-turn lane and pavement friction treatment;
- Install shoulder rumble strips; and
- Underage alcohol prevention, outreach, and enforcement

Tier 3 – Less Effective, Larger Problems

Tier 3 projects would follow Tier 2 projects as even though they address significant problems, it is uncertain whether they would be as effective as projects in Tiers 1 and 2. These projects also could be submitted for further evaluation or pilot testing to confirm their effectiveness. Tier 3 has predominantly behavioral projects and a total annualized cost of $0.69 million. Some examples of Tier 3 project include:

- Widen roadway for a third travel lane;
- Purchase motorcycles for training and expand motorcycle safety training facility; and
- Technology purchase to improve enforcement (radars, cameras, and trackers).

Tier 4 – Less Effective, Smaller Problems

Finally, Tier 4 projects would have the lowest priority as they are not as effective and target less significant problems. These projects also could be submitted for further study or evaluation to confirm their effectiveness. Tier 4 has predominantly behavioral projects that have education or outreach components, and a total annualized cost of $0.83 million. Some examples of Tier 4 projects include:

- Realign routes for continuous movement;
- Child protection safety training and outreach; and
- Special needs seat distribution and conference/state fair outreach.

Figure D.10 Cost Effectiveness of Engineering and Behavioral Projects with Prioritization Tiers

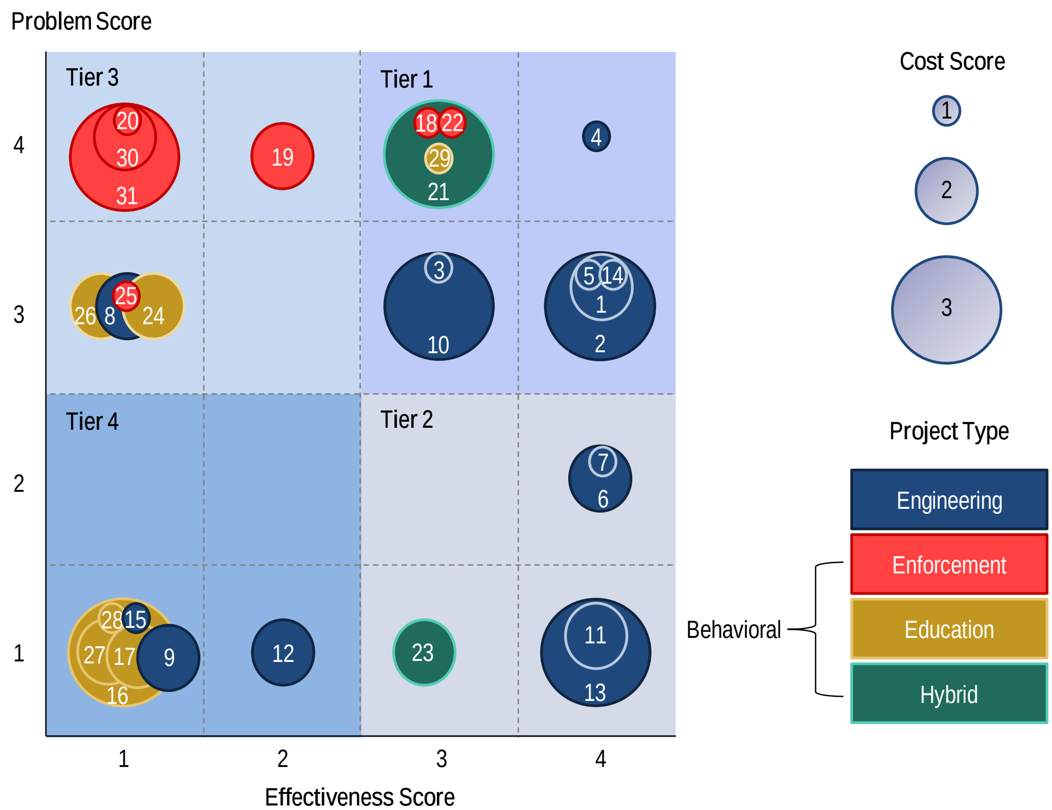
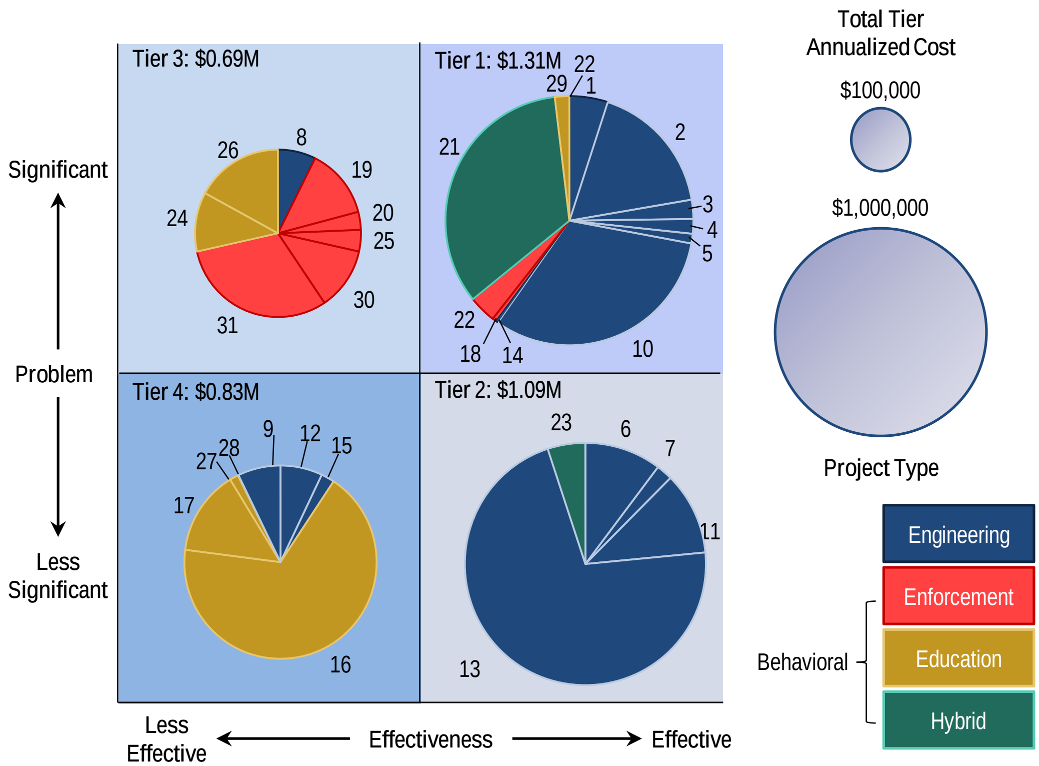


Figure D.11 Cost Effectiveness of Engineering and Behavioral Projects with Tier Annualization Cost Project Type



Comparison to North Carolina Benefit/Cost Analysis

The project prioritization tiers can be compared with benefit/cost ratio NCDOT calculates to determine the funding prioritization for engineering projects. The benefit/cost ratio is the project injury and fatality reduction benefits divided by the project cost, both of which are discounted over the project's useful life.

Table D.10 organizes the engineering projects by prioritization tier and their associated NCDOT benefit/cost ratio. As shown in Table D.10, the project benefit/cost ratio varied across the different project tiers. Several reasons explain these discrepancies:

- First, the sketch method highlights projects proven effective by numerous high-quality research studies. That is, the effectiveness score is primarily a function of the quality of the CMF, judged by the quality of studies that produced it, rather than the CMF value. By contrast, NCDOT relied on the CMF alone in calculating project benefit.
- Second, the sketch method scored the magnitude of the problem the project would address through analysis of state-level crash data, rather than crash data from the specific site being targeted. This was done primarily to allow comparison to behavioral measures, for which no estimates could be obtained regarding the number of people or crashes to be impacted in the

geographic area targeted for implementation. See Section 3.0 in the main body of the report for more discussion of this issue.

- Third, the sketch method did not divide project benefits by project costs, because quantitative benefits and costs were not estimated. Instead, the annualized cost score is visualized by the size of the circle corresponding to the project.

Ultimately, the sketch-level method has a different purpose than NCDOT's method of ranking based on benefits and costs. The sketch method demonstrates which projects would address the most significant statewide problems most effectively in comparison to behavioral projects. The NCDOT ranking method calculates the benefits and costs of engineering improvements implemented at specific sites.

Table D.10 Comparison of NCDOT Engineering Project Benefit/Cost Ratio with Prioritization Tier

Project No.	Project Description	Tier	NCDOT B/C Ratio
1	Raised median and pedestrian improvements	1	26.12
2	18.26 miles of single face guard rail	1	3.69
3	Directional crossover with median U-turn	1	4.28
4	Roundabout in-lieu of existing intersection	1	5.95
5	Left-turn lanes on all approaches and install a traffic signal	1	3.46
10	Add two-foot paved shoulders plus a minimum four-foot grass shoulders for 7.4 miles	1	3.26
14	Convert existing stop control intersection to signalized	1	3.93
6	Provide a continuous center left-turn lane	2	5.9
7	Left-turn lane and pavement friction treatment	2	14.54
11	Install shoulder guard rail	2	3.09
13	Install shoulder rumble strips (four shoulders total) for 21 miles	2	3.13
8	Widen for a third travel lane	3	12.38
12	Extend the acceleration ramp and install snow-plowable RPM	4	30.18
15	Realign routes for continuous movement	4	8.67
9	Install raised centerline pavement markers and upgrade existing signage	4	7.24

D.6 Challenges and Limitations

Several challenges and limitations were noted in the development of this case study. They are briefly listed below and discussed in detail in the main body of this report (Section 3.0). Difficulties included the following:

- Determining which projects should be classified as indirect/capacity-building activities and removed from analysis;
- Assigning effectiveness and problem scores for projects with multiple components;
- Matching complex projects to close equivalent project types in the national literature to obtain an effectiveness score;
- Assigning effectiveness scores for projects lacking CMFs or where no close equivalent has been studied in the national literature;
- Assigning scores with limited information due to lack of detail on project applications;
- Assigning scores to projects where a local CMF was provided on the project application, but no information was provided on the quality of the CMF or the studies behind it;
- Determining the size of the crash population expected to be impacted by specific behavioral measures; and
- Determining annualized project costs for behavioral projects where the duration of impact is unknown.

E. Application of Sketch Method – State II

E.1 Introduction

This appendix demonstrates the application of the sketch method to data provided by a state Department of Transportation (DOT) which desired not to be named directly. It illustrates how the method results in comparison of the relative cost-effectiveness of strategies drawn from engineering, education, and enforcement safety disciplines.[14] It is organized into the following sections:

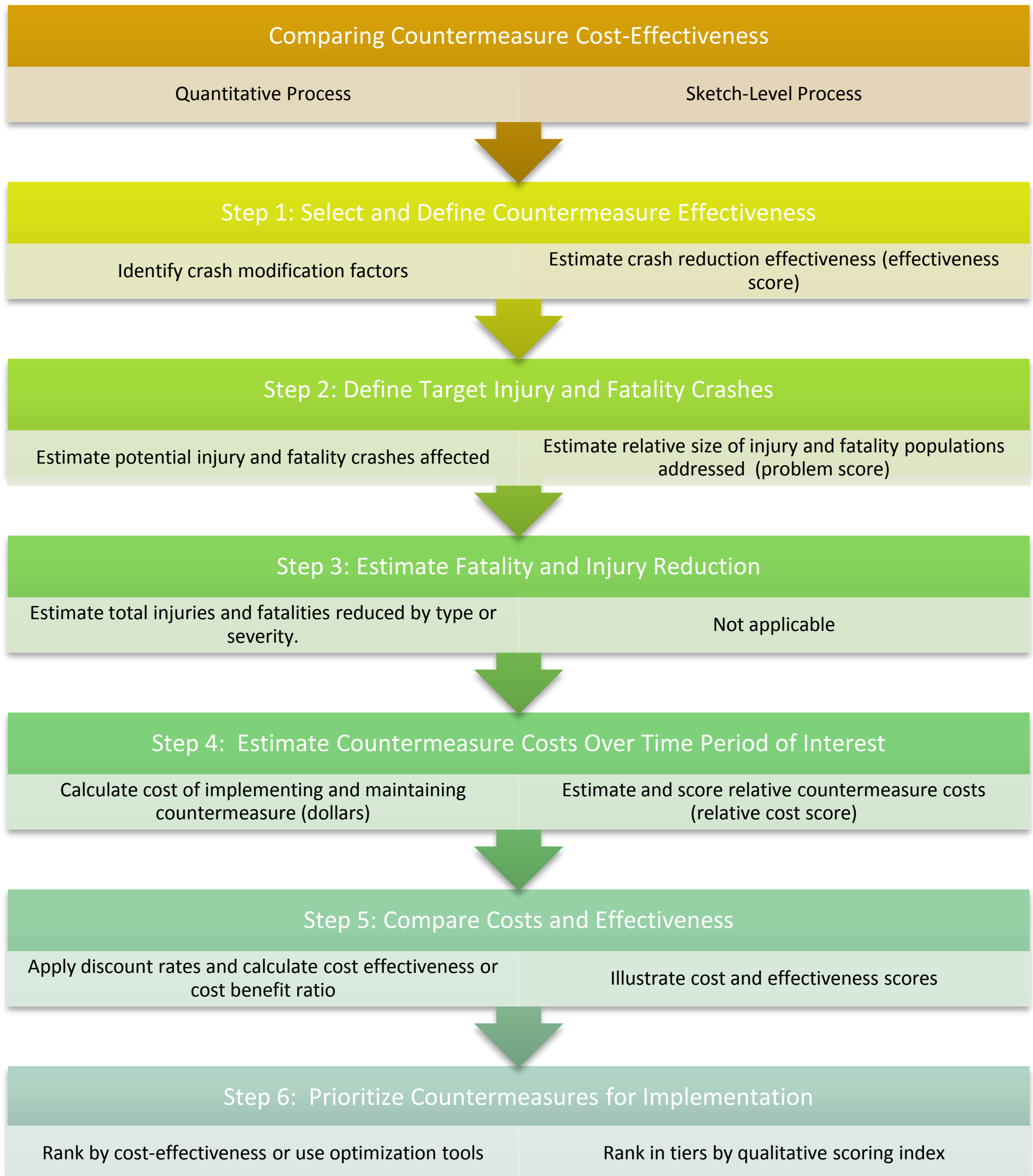
- Method overview;
- Engineering and behavioral projects overview;
- Method application;
- Results; and
- Challenges in framework application and information collection.

Method Overview

Section 4.0 of the main report body described the sketch method for comparing the cost-effectiveness of safety countermeasures in detail. Figure E.1 reiterates the three major steps in the method used to prioritize countermeasures for implementation, including analysis of countermeasure effectiveness; estimation of the relative size of safety issues addressed by the countermeasures; and estimation of countermeasure costs over the expected duration of effectiveness of the project.

[14] The state DOT did not provide any emergency safety projects for this evaluation application.

Figure E.1 Steps in Comparing Countermeasures
Quantitative and Sketch-Level Process Outcomes



Engineering and Behavioral Projects Overview

The state DOT provided project descriptions for this example analysis, including 18 engineering projects drawn from the DOT's Highway Safety Improvement Program (HSIP) for the fiscal years (FY) 2007 to 2010, and 22 behavioral (education and enforcement) projects drawn from the DOT's Strategic Highway Safety Plan (SHSP) flex funding review for 2012. The resulting comparison of

projects is a hypothetical comparison that has not been used by the DOT's staff in any planning or policy applications.

One of the challenges encountered in this analysis was the availability of reliable documentation on countermeasure effectiveness. It was not possible to identify reliable crash modification factors (CMF) for nine of the 18 engineering projects and one of the 22 behavioral projects because of inadequate project effectiveness information as documented later in this appendix. Practitioners implementing this method will also likely experience this challenge. Therefore, to demonstrate the implications of this on the analysis results, but to avoid skewing the results of this case study, two engineering projects with inadequate effectiveness information were included in this evaluation – the remaining seven were eliminated from the analysis. The two projects included are highlighted in pink in Table E.1. Tables E.1 and E.2 show the 11 engineering and 21 behavioral projects, respectively that were evaluated.

Table E.1 Engineering Projects

Project No.	Description
1	Install signal system to replace existing two-way stop controlled intersection
2	Construct median island on an 0.3 mile segment of an urban arterial
3	Median slope flattening and installing cable barrier on a multilane divided highway
4	Construct median island on the northern leg of an urban arterial intersection
5	Construct centerline and edge line rumble strips throughout the State
6	Rural highway slope flattening, widening, and guardrail moved out
7	Rural highway slope flattening, widening, and guardrail removed
8	Construct roundabout on a former stop controlled rural intersection
9	Median slope flattening and installing cable barrier on a rural multilane divided highway.
31	Modify median island and add a second left turn EB and WB lane at the intersection of two urban arterials
32	Modify median island restricting certain lefts on an urban arterial

Table E.2 Representative Behavioral Projects

Project No.	Project Description
10	Enforcement campaigns for each of the Critical Emphasis Area teams
11	Increase public awareness and increase usage and proper installation of child safety seats
12	Radio and TV ads to raise DUI awareness
13	Programs to promote walking or biking to school
14	Funding for adequate seating for spectators to participate in Every 15 Minutes event (DUI among High School students)
15	Data analysis and DUI saturation checkpoints

Project No.	Project Description
16	Pedestrian enforcement and education campaign
17	Intersection enforcement and education campaign
18	Highway patrol enforcement campaign targeting Critical Emphasis Areas
19	Educating new drivers ages 15 to 21
20	Education and awareness campaigns for 14- to 21-year old drivers
21	Market and implement PACE (young adult driver's education) program, including outreach, publicity, and partnering
22	Purchase media for traffic safety campaigns
23	Data-driven high-visibility intersection enforcement events
24	Workshops for juveniles that have been convicted of DUI
25	Overtime for officers to enforce intersection laws, and seat belt usage laws
26	Educational messages on bus shelters, backs of bus coaches, and through employer-based publications
27	Assist five community agencies with their traffic safety efforts
28	PACE (Young adult driver's education) program implementation in two counties
29	Enforcement, Communication Campaign, Do the Ride Thing membership drives, Education, Sponsorship Drive, Data Collection
30	Enhance existing Driver Education and Motorcycle Safety Programs at a local community college (new drivers)

E.2 Select Effectiveness Score

The first step in evaluating projects is to assign a potential countermeasure effectiveness score. The score will range from one to four (four being the most effective). The process for assigning a score involves reviewing effectiveness information in the national safety research literature and assigning a score based on the uniform effectiveness typology presented in Table E.3. For engineering projects, the analysis process identifies the crash modification factor (CMF) of each project component and examines the studies that produce these factors. For behavioral projects, crash reduction effectiveness estimates are based on countermeasure effectiveness ratings from behavioral safety research. These research are discussed in detail in Appendix B.

Table E.3 Measures of Effectiveness

	Source	Highly Effective	Effective	Somewhat Effective	Unknown or Ineffective
Engineering	Crash Modification Factor Clearinghouse	CMF <0.7 and Quality Score 4-5	0.7 < CMF < 1, and Quality Score 4-5	CMF < 1, and Quality Score 3	CMF≥1 or Quality Score < 3
	HSM	CMF <0.7 and Adjusted Standard Error < 0.2	0.7 < CMF <1 and Adjusted Standard Error < 0.2	CMF <1 and 0.2 < Adjusted Standard Error < 0.4	CMF >1 or N/A or Adjusted Standard Error > 0.4 or N/A
Behavioral	Countermeasures that Work	5 stars	4 stars	3 stars	≤ 2 stars or Star Rating Unavailable
	NCHRP 500/NCHRP 17-17(3)		Proven		Tried or Experimental
	NCHRP 622	Proven (Crash Reduction > 30%)	Proven	Likely	Unknown/Uncertain/ Unlikely
	Effectiveness Score	4	3	2	1

Note: Countermeasure CMFs near the threshold of two effectiveness points could include both points in its confidence interval based on the measure's standard error.

Engineering Projects

The effectiveness of engineering countermeasures is evaluated according to the value of the CMF[15] and the CMF reliability. This information is obtained from two main sources: the AASHTO 2010 Highway Safety Manual (HSM) and the FHWA Crash Modification Factors Clearinghouse (see Table E.2). The HSM measures the reliability of the CMF with a standard error, and the CMF Clearinghouse with a quality score.

With the HSM, countermeasures receive the highest effectiveness score if they have a low CMF (CMF < 0.7) and a low standard error. Using the CMF Clearinghouse, countermeasures receive the highest score if they have a low CMF (CMF < 0.7) and a CMF quality score of 4 or 5 (representing the highest-quality studies).

Although the process of looking up an applicable CMF and its reliability for each project seems straightforward, many engineering projects could involve multiple project components and equivalent CMF values or CMF values. For this analysis, the effectiveness score was assigned based on score of the most effective countermeasure or project component (See Figure E.2). In the case illustrated below, install centerline rumble strips is the most effective component of the project, and therefore, its effectiveness score represents the overall project

[15]CMFs were rounded to the nearest tenth (0.1) in the application of this process.

effectiveness score. Although other methods could be used (for example, the HSM recommends multiplying CMFs), this was judged preferable as it streamlines the process of scoring project effectiveness. More explanation of this approach is provided in Section 3.0 of the main body of this report.

Figure E.2 Engineering Project Effectiveness with Multiple Countermeasure Components

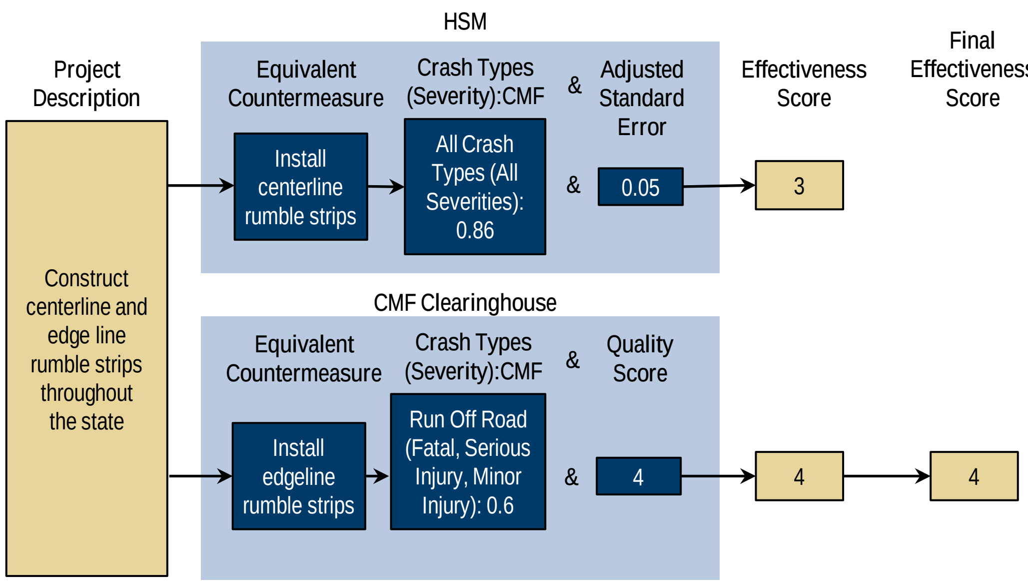


Table E.4 shows the application of this scoring method by identifying the most effective component of each engineering project, and the component's effectiveness score. Note the CMFs in Table E.4 have been rounded to the nearest tenth value to account for crash reduction variability that might render an effective countermeasure ineffective or vice versa.

Table E.4 Effectiveness Score of Engineering Projects

Project No.	Description	Most Effective Project Component	Source	Setting (Roadway/ Intersection Type)	Crash Type (Severity)	CMF	Adjusted Standard Error (Applies to HSM Only)	Quality Score (Applies to CMF Clearinghouse)	Effectiveness Score
1	Install signal system to replace existing two-way stop controlled intersection	Convert Stop Control to Signal Control	HSM	Urban (major road speed limit at least 40 mph; four leg)	All types (All severities)	1.0	0.09	N/A	1
2	Construct median island on an 0.3 mile segment of an urban arterial	Replace TWLTL with raised median	CMF Clearinghouse	Urban (All Roadway Type)	Angle, Fixed Object, Head On, Rear end, Run-off-road, Sideswipe, Single vehicle (All severities)	0.8	N/A	3	2
3	Median slope flattening and installing cable barrier on a multilane divided highway	Install Cable Median Barrier	HSM	Unspecified (Multilane divided highways with AADT of 20,000 to 60,000)	All types (Injury)	0.7	0.1	N/A	3
4	Construct median island on the northern leg of an urban arterial intersection	Replace TWLTL with raised median	CMF Clearinghouse	Urban (All Roadway Type)	Angle, Fixed Object, Head On, Rear end, Run-off-road, Sideswipe, Single vehicle (All severities)	0.8	N/A	3	2
5	Construct centerline and edge line rumble strips throughout the State	Install Edgeline Rumble Strips	CMF Clearinghouse	Rural (Not specified)	Run-off-road (Fatal, Serious Injury, Minor Injury)	0.6	N/A	4	4
6	Rural highway slope flattening, widening, and guardrail moved out	Widen paved shoulder by 2 feet	CMF Clearinghouse	Rural	All types (All severities)	0.9	N/A[1]	N/A	3
7	[redacted] Rural highway slope flattening, widening, and guardrail removed	Flatten side slopes and remove guardrail	CMF Clearinghouse	All (All)	All(All)	0.6	N/A	2	1
8	[redacted] Construct roundabout on a former stop controlled rural intersection	Convert two-way stop controlled intersection to roundabout	CMF Clearinghouse	Rural (Not specified)	All types (All severities)	0.3	N/A	5	4
9	[redacted] Median slope flattening and installing cable barrier on a rural multilane divided highway	Install Cable Median Barrier	HSM	Unspecified (Multilane divided highways with AADT of 20,000 to 60,000)	All types (Injury)	0.7	0.1	N/A	3
31	Modify median island and add a second left turn EB and WB lane at the intersection of two urban arterials	No equivalent countermeasure	N/A	N/A	N/A	N/A	N/A	N/A	1
32	Modify median island restricting certain lefts on an urban arterial	No equivalent countermeasure	N/A	N/A	N/A	N/A	N/A	N/A	1

Note: Countermeasure CMFs near the threshold of two effectiveness points could include both points in its confidence interval based on the measure's standard error.

Qualitative Process – Behavioral Projects

The behavioral project analysis aims to match each behavioral project to the closest equivalent countermeasure as described in national safety research literature, including NHTSA's Countermeasures that Work; NCHRP 17-18(3); The NCHRP Report 500 series; and NCHRP Report 622 (See Table E.3). These safety research literature are described in detail in Appendix B. As with engineering projects, the effectiveness scores of behavioral projects range from one (least effective) to four (most effective). Note that because few quantitative CMFs are available for behavioral projects, few behavioral projects can achieve a score of 4, which requires a CMF of < 0.7.

Similar to engineering projects, behavioral projects also frequently have multiple countermeasure components with varying effectiveness scores. The overall effectiveness score for behavioral projects was also based on the highest scoring component (See Figure E.3).

Figure E.3 Behavioral Project Effectiveness with Multiple Countermeasure Components

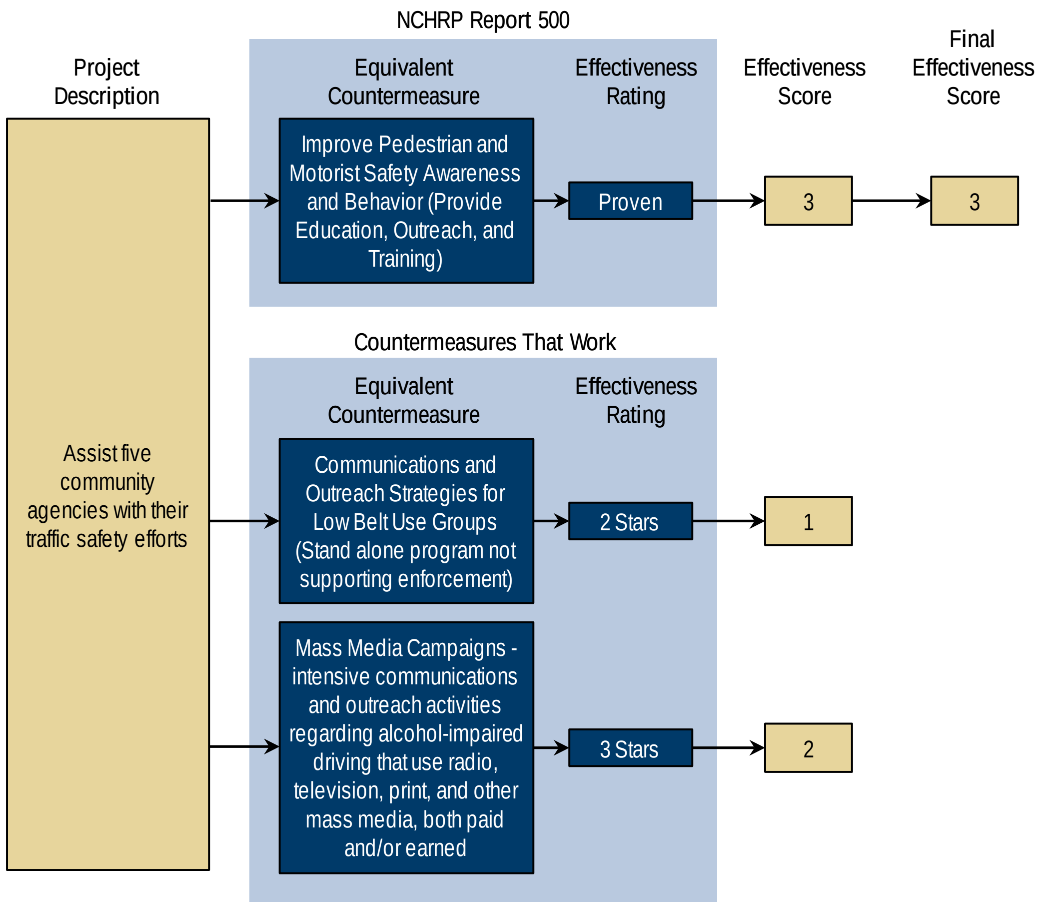


Table E.5 shows the application of this scoring method by identifying the most effective component of each behavioral project and its effectiveness score.

Table E.5 Effectiveness Score of Behavioral Projects

Project No.	Project Description	Corresponding Countermeasures	Source	Effectiveness Rating	Effectiveness Score
10	Enforcement campaigns for each of the Critical Emphasis Area teams	Saturation Patrols – large number of law enforcement officers patrolling a specific area for a set time to increase visibility of enforcement, as well as to detect and arrest impaired drivers.	Countermeasures that work	Four stars	3
11	Increase public awareness and increase usage and proper installation of child safety seats	Inspection Stations – Places or events where parents and caregivers can receive associated from certified Child passenger safety technicians.	Countermeasures that work	Two Stars	1
12	Radio and TV ads to raise DUI awareness	Mass Media Campaigns – intensive communications and outreach activities regarding alcohol-impaired driving that use radio, television, print, and other mass media, both paid and/or earned.	Countermeasures that work	Three stars	2
13	Programs to promote walking or biking to school	Elementary-age child pedestrian training – Equip school-age children with knowledge and practice to enable them to walk safely in environments with traffic and other safety hazards.	Countermeasures that work	Three stars	2
14	Funding for adequate seating for spectators to participate in Every 15 Minutes event (DUI among High School students)	Underage Drinking and Alcohol-Impaired Driving – Youth Programs.	Countermeasures that work	Two stars	1
15	Data analysis and DUI saturation checkpoints	Saturation Patrols – large number of law enforcement officers patrolling a specific area for a set time to increase visibility of enforcement, as well as to detect and arrest impaired drivers.	Countermeasures that work	Four stars	3
16	Pedestrian enforcement and education campaign	Improve Pedestrian and Motorist Safety Awareness and Behavior (Provide Education, Outreach, and Training).	NCHRP Report 500: Volume 10	Proven	3
17	Intersection enforcement and education campaign	Integrated Enforcement – alcohol impaired/speeding/seat belt.	Countermeasures that work	Three stars	2
18	Highway patrol enforcement campaign targeting Critical Emphasis Areas	Saturation Patrols – large number of law enforcement officers patrolling a specific area for a set time to increase visibility of enforcement, as well as to detect and arrest impaired drivers.	Countermeasures that work	Four stars	3
19	Educating new drivers ages 15 to 21	Post-Licensure or Second-Tier Driver Education – teach safety-related information, building on the on-road experience that the students have acquired in their initial months of driving.	Countermeasures that work	One Star	1
20	Education and awareness campaigns for 14- to 21-year old drivers	Post-Licensure or Second-Tier Driver Education – teach safety-related information, building on the on-road experience that the students have acquired in their initial months of driving.	Countermeasures that work	One Star	1
21	Market and implement PACE (young adult driver's education) program, including outreach, publicity, and partnering	Post-Licensure or Second-Tier Driver Education – teach safety-related information, building on the on-road experience that the students have acquired in their initial months of driving.	Countermeasures that work	One Star1	1
22	Purchase media for traffic safety campaigns	Communications and Outreach Strategies with supporting enforcement.	Countermeasures that work	Five stars	4

Project No.	Project Description	Corresponding Countermeasures	Source	Effectiveness Rating	Effectiveness Score
23	Data-driven high-visibility intersection enforcement events	Aggressive Driving and Speeding – High-Visibility Enforcement.	Countermeasures that work	Two stars	1
24	Workshops for juveniles that have been convicted of DUI	Underage Drinking and Alcohol-Impaired Driving – Youth Programs.	Countermeasures that work	Two stars	1
25	Overtime for officers to enforce intersection laws, and seat belt usage laws	Integrated Enforcement – alcohol impaired/speeding/seat belt.	Countermeasures that work	Three stars	2
26	Educational messages on bus shelters, backs of bus coaches, and through employer-based publications	Improve Pedestrian and Motorist Safety Awareness and Behavior (provide Education, Outreach, and Training).	NCHRP Report 500: Volume 10	Proven	3
27	Assist five community agencies with their traffic safety efforts	Improve Pedestrian and Motorist Safety Awareness and Behavior (provide Education, Outreach, and Training).	NCHRP Report 500: Volume 10	Proven	3
28	PACE (Young adult driver's education) program implementation in two counties	Improve content and delivery of driver education/training.	NCHRP 17-18(3): Reducing Collisions Involving Young Drivers	Experimental	1
29	Enforcement, Communication Campaign, Do the Ride Thing membership drives, Education, Sponsorship Drive, Data Collection	Alcohol deterrence enforcement – saturation patrols.	Countermeasures that work	Four stars	3
30	Enhance existing Driver Education and Motorcycle Safety Programs at a local community college (new drivers)	Improve Pedestrian and Motorist Safety Awareness and Behavior (provide Education, Outreach, and Training).	NCHRP Report 500: Volume 10	Proven	3

E.3 Select Problem Score

This step examines the relative magnitude of safety problems targeted by a project (the problem score). The problem score is determined using a top-down method that first identifies the type of safety problem the project would address, and then scores the significance of that safety problem on a statewide level. This method assumes practitioners are interested in looking strategically at statewide safety problems and prioritizing projects based on whether they address significant statewide safety problems.

To determine the significance of a particular safety problem statewide, this analysis examined the average annual number of statewide fatal and injury crashes from 2007 to 2010, shown as the vertical bars in Figure E.4. For the analysis, a safety problem was assigned a subjective statewide problem score from one to four as indicated in the bold outlined box at the top of Figure E.4; one being the safety problem with the lowest number of fatal and serious injury crashes. Note that the thresholds for the statewide problem score categories were based on natural breaks in the data and are subject to individual judgment.

An engineering or behavioral project often addresses more than one safety problem or crash type. When this occurred, a score was assigned for each safety problem addressed by the project, and the highest score was selected to represent the project. For engineering projects, the DOT's safety engineers outlined the crash types that would be mitigated with project implementation, and this was used to assign the score. Figure E.5 illustrates an example of a median island proposed on an arterial roadway experiencing primarily left turn, angle, and pedestrian crashes. The problem score was assigned to a project based on the largest statewide crash pattern or highest statewide problem score it addresses. In this case, median island construction was given the score for angle crashes.

Figure E.4 Statewide Problem Score Based on Annual Fatal and Injury Crashes

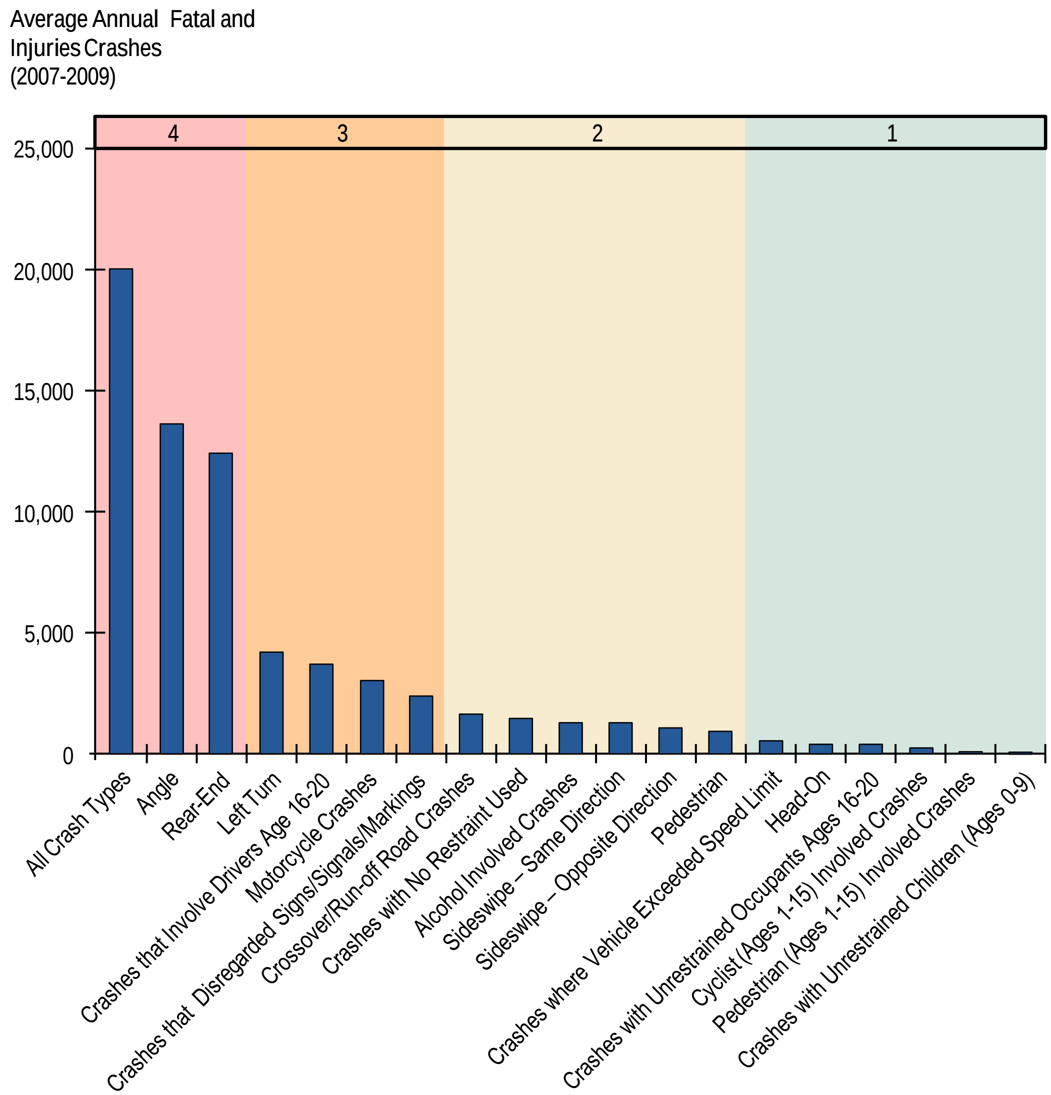


Figure E.5 Engineering Project Targeting Multiple Safety Problems

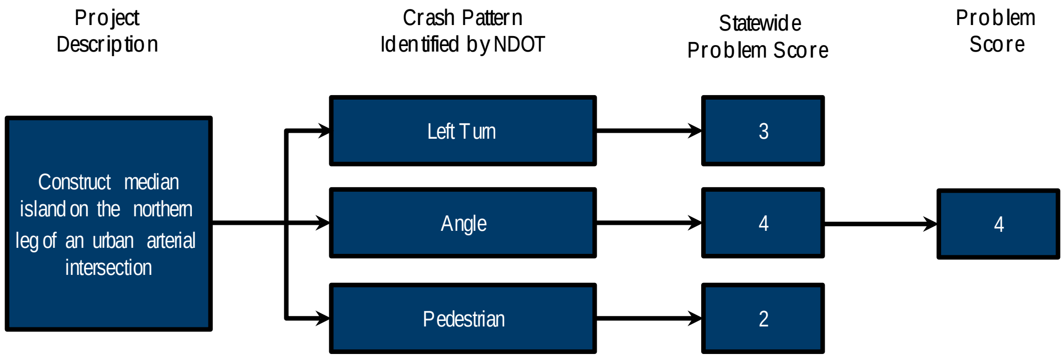


Table E.6 demonstrates the application of this scoring method by identifying the most significant statewide safety problem of each engineering project and its problem score.

Table E.6 Problem Score of Engineering Projects

Project No.	Description	Most Significant Statewide Problem	Statewide Problem Score
1	Install signal system to replace existing two-way stop controlled intersection	Angle	4
2	Construct median island on an 0.3 mile segment of an urban arterial	Left Turn	3
3	Median slope flattening and installing cable barrier on a multilane divided highway	Crossover/ run-off road	2
4	Construct median island on the northern leg of an urban arterial intersection	Angle	4
5	Construct centerline and edge line rumble strips throughout the State	Crossover/ run-off road	2
6	Rural highway slope flattening, widening, and guardrail moved out	Crossover/ run-off road	2
7	Rural highway slope flattening, widening, and guardrail removed	Angle	4
8	Construct roundabout on a former stop controlled rural intersection	All	4
9	Median slope flattening and installing cable barrier on a rural multilane divided highway.	Crossover/ run-off road	2
31	Modify median island and add a second left turn EB and WB lane at the intersection of two urban arterials	Angle	4
32	Modify median island restricting certain lefts on an urban arterial	Angle	4

For behavioral projects, this analysis identified the types of targeted safety problems based on the countermeasures listed in each project's application. Again, the rationale is to assign the problem score to a project based on whether it addresses some of the key statewide safety problems. Most behavioral projects evaluated only addressed one type of crash. However, as shown in Figure E.6, if

a project is identified as addressing multiple types of crashes, the highest statewide problem score is used as the project's problem score.

Figure E.6 Behavioral Project That Targets Multiple Safety Problems

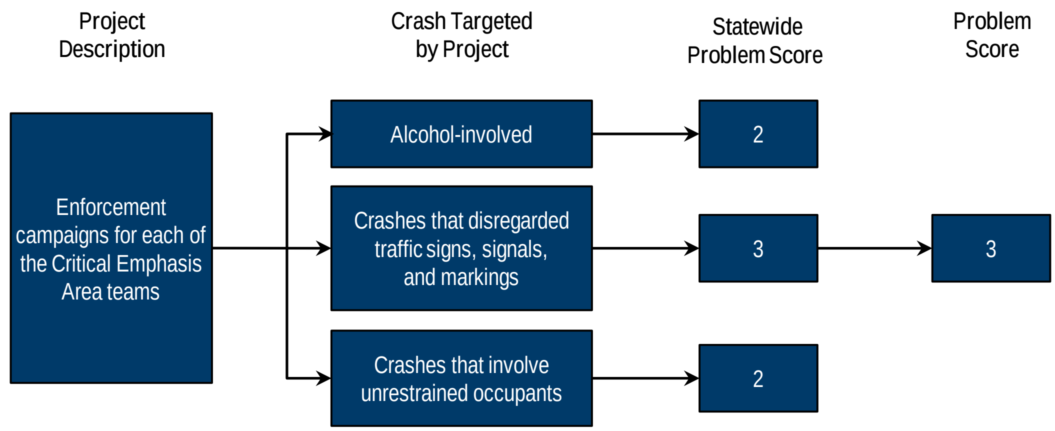


Table E.7 shows the application of this scoring method by identifying the most significant statewide safety problem of each behavioral project and its problem score.

Table E.7 Problem Score of Behavioral Projects

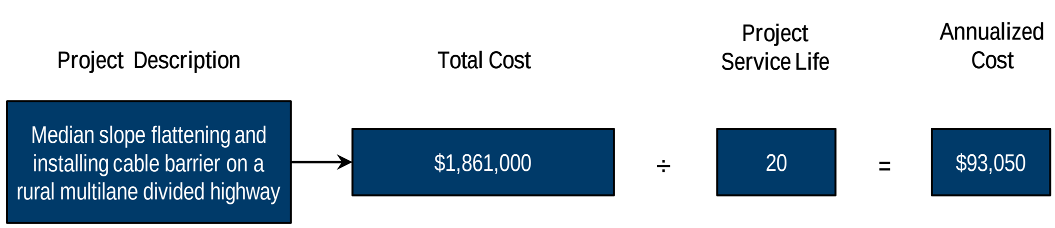
Project No.	Project Description	Targeted Statewide Problem	Statewide Problem Score
10	Enforcement campaigns for each of the Critical Emphasis Area teams	Crashes that disregarded traffic signs, signals, markings	3
11	Increase public awareness and increase usage and proper installation of child safety seats	Crashes that involve unrestrained children (ages 0-9)	1
12	Radio and TV ads to raise DUI awareness	Crashes with alcohol involvement	2
13	Programs to promote walking or biking to school	Crashes involving young cyclists (ages 1-15)	1
14	Funding for adequate seating for spectators to participate in Every 15 Minutes event (DUI among High School students)	Crashes involving young drivers (ages 16-20)	3
15	Data analysis and DUI saturation checkpoints	Crashes with alcohol involvement	2
16	Pedestrian enforcement and education campaign	Crashes involving pedestrians	2
17	Intersection enforcement and education campaign	Crashes that disregarded traffic signs, signals, markings	3
18	Highway patrol enforcement campaign targeting Critical Emphasis Areas	Crashes that disregarded traffic signs, signals, markings	3
19	Educating new drivers ages 15 to 21	Crashes involving young drivers (ages 16-20)	3
20	Education and awareness campaigns for 14- to 21-year old drivers	Crashes that involve unrestrained occupants (ages 16-20)	1

Project No.	Project Description	Targeted Statewide Problem	Statewide Problem Score
21	Market and implement PACE (young adult driver's education) program, including outreach, publicity, and partnering	Crashes involving young drivers (ages 16-20)	3
22	Purchase media for traffic safety campaigns	Motorcycle crashes	3
23	Data-driven high-visibility intersection enforcement events	Crashes where vehicles exceeded speed limit	1
24	Workshops for juveniles that have been convicted of DUI	Crashes with alcohol involvement	2
25	Overtime for officers to enforce intersection laws, and seat belt usage laws	Crashes that disregarded traffic signs, signals, markings	3
26	Educational messages on bus shelters, backs of bus coaches, and through employer-based publications	Crashes involving pedestrians	2
27	Assist five community agencies with their traffic safety efforts	Crashes that involve unrestrained occupants	2
28	PACE (Young adult driver's education) program implementation in two counties	Crashes involving young drivers (ages 16-20)	3
29	Enforcement, Communication Campaign, Do the Ride Thing membership drives, Education, Sponsorship Drive, Data Collection	Crashes with alcohol involvement	2
30	Enhance existing Driver Education and Motorcycle Safety Programs at a local community college (new drivers)	Crashes that involve unrestrained occupants	2

E.4 Select Cost Score

In this step, the total engineering or behavioral project cost is annualized over the duration of the project to compare costs of projects with varying service lives. For engineering projects, the annualized cost is the total project cost divided by the project's service life as provided by the applicant's funding application (See Figure E.7).

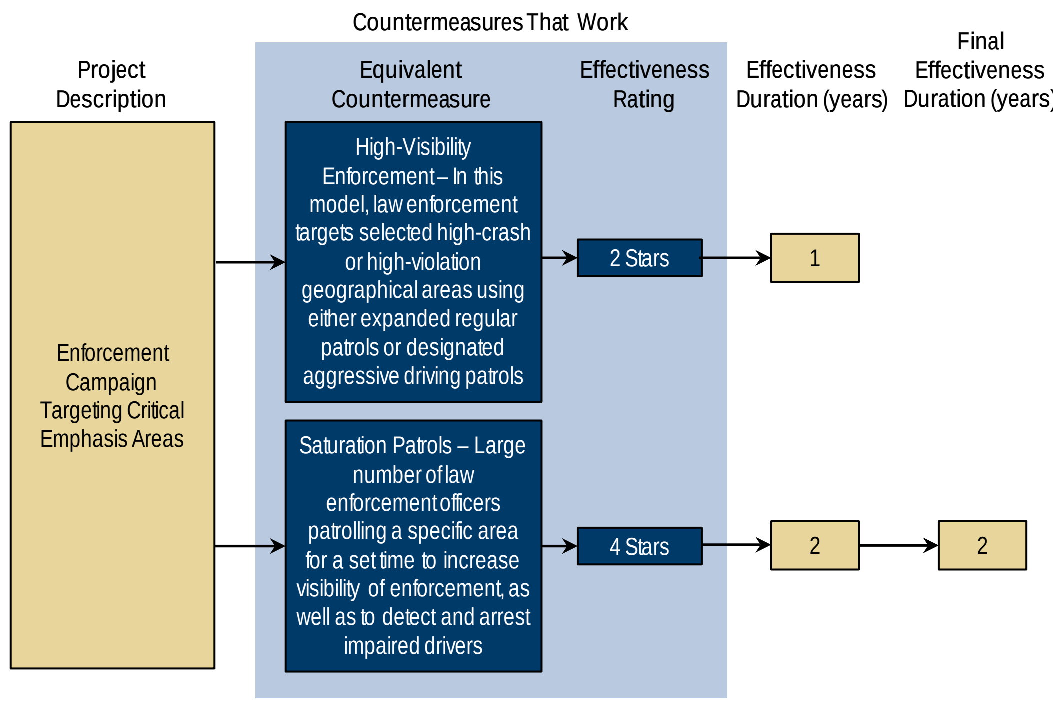
Figure E.7 Engineering Project Annualized Cost



Behavioral projects were requesting a single year of funding, so the funding request was used as the annual cost. However, some types of behavioral projects

are expected to have impacts lasting beyond the conclusion of the program. Appendix B summarizes research on the duration of effectiveness of behavioral measures. Based on this research, duration of effectiveness is assumed to be two years for DUI checkpoints and three years for seat belt enforcement programs. All other behavioral projects were assumed to have effectiveness duration of one year. If a project has multiple countermeasure components, the overall project effectiveness duration was represented by the longest effectiveness duration of all components (See Figure E.8).

Figure E.8 Behavioral Project Annualized Cost



An annualized cost for all engineering and behavioral projects in the case study was calculated using this method. The annualized cost was the basis for assigning a cost score from one to three: one being a project with less than $70,000 in annualized cost; two being a project with annualized cost from $70,000 to $175,000; and three being a project with annualized cost greater than $175,000. These thresholds were assigned based on “natural breaks” in the data points and are subject to individual judgment. Table E.8 shows the application of this scoring method by assigning cost score according to annualized cost values.

Table E.8 Cost Score of Engineering and Behavioral Projects

Project No.	Project Description	Total Cost	Project Service Life	Annualized Cost	Cost Score
Engineering Projects					
1	Install signal system to replace existing two-way stop controlled intersection	$327,000.00	20	$16,350.00	1
2	Construct median island on an 0.3 mile segment of an urban arterial	$156,000.00	20	$7,800.00	1
3	Median slope flattening and installing cable barrier on a multilane divided highway	$1,861,000.00	20	$93,050.00	2
4	Construct median island on the northern leg of an urban arterial intersection	$14,000.00	20	$700.00	1
5	Construct centerline and edge line rumble strips throughout the State	$1,804,000.00	5	$360,800.00	3
6	Rural highway slope flattening, widening, and guardrail moved out	$3,957,000.00	20	$197,850.00	3
7	Rural highway slope flattening, widening, and guardrail removed	$271,000.00	20	$13,550.00	1
8	Construct roundabout on a former stop controlled rural intersection	$1,860,000.00	20	$93,000.00	2
9	Median slope flattening and installing cable barrier on a rural multilane divided highway.	$1,576,000.00	20	$78,800.00	2
31	Modify median island and add a second left turn EB and WB lane at the intersection of two urban arterials	$247,000.00	20	$12,350.00	1
32	Modify median island restricting certain lefts on an urban arterial	$82,000.00	20	$4,100.00	1
Behavioral Projects					
10	Enforcement campaigns for each of the Critical Emphasis Area teams	$33,073.68	1	$33,073.68	1
11	Increase public awareness and increase usage and proper installation of child safety seats	$6,140.00	1	$6,140.00	1
12	Radio and TV ads to raise DUI awareness	$13,500.00	1	$13,500.00	1
13	Programs to promote walking or biking to school	$130,485.01	1	$130,485.01	2
14	Funding for adequate seating for spectators to participate in Every 15 Minutes event (DUI among High School students)	$2,500.00	1	$2,500.00	1
15	Data analysis and DUI saturation checkpoints	$83,250.00	2	$41,625.00	1
16	Pedestrian enforcement and education campaign	$50,000.00	1	$50,000.00	1
17	Intersection enforcement and education campaign	$50,000.00	1	$50,000.00	1
18	Highway patrol enforcement campaign targeting Critical Emphasis Areas	$50,731.52	2	$25,365.76	1
19	Educating new drivers ages 15 to 21	$33,176.00	1	$33,176.00	1
20	Education and awareness campaigns for 14- to 21-year old drivers	$14,223.00	1	$14,223.00	1
21	Market and implement PACE (young adult driver's education) program, including outreach, publicity, and partnering	$163,030.00	1	$163,030.00	2
22	Purchase media for traffic safety campaigns	$630,000.00	1	$630,000.00	3
23	Data-driven high-visibility intersection enforcement events	$200,000.00	1	$200,000.00	3
24	Workshops for juveniles that have been convicted of DUI	$17,867.57	1	$17,867.57	1
25	Overtime for officers to enforce intersection laws, and seat belt usage laws	$57,600.00	1	$57,600.00	1
26	Educational messages on bus shelters, backs of bus coaches, and through employer-based publications	$331,444.00	1	$331,444.00	3
27	Assist five community agencies with their traffic safety efforts	$79,237.00	1	$79,237.00	2
28	PACE (Young adult driver's education) program implementation in two counties	$72,992.00	1	$72,992.00	2
29	Enforcement, Communication Campaign, Do the Ride Thing membership drives, Education, Sponsorship Drive, Data Collection	$43,749.00	1	$43,749.00	1
30	Enhance existing Driver Education and Motorcycle Safety Programs at a local community college (new drivers)	$147,354.00	1	$147,354.00	2

E.5 Cost-Effectiveness Comparison of Engineering and Behavioral Projects

The effectiveness, problem, and annualized cost scoring processes combine to present a picture of relative project cost-effectiveness. Table E.9 presents the final scores for each project.

Tiering Projects for Implementation

The results shown in tabular form in Table E.9 also can be displayed graphically with circle size representing cost score, and x and y axes representing the effectiveness and problem scores, respectively, as shown in Figure E.9. Note that in this figure, all projects located in the same dashed line grid cell have the same effectiveness and problem scores regardless of their positions in the cell. Figure E.10 is another way of looking at the results, where projects are represented by slices of a pie, where size of the slice is proportional to the annualized cost of the project.

Figures E.9 and E.10 group projects into four tiers for implementation, as follows:

Tier 1 – Most Effective, Largest Problems

Tier 1 projects should be prioritized before the other tiers as they could deliver the most benefits and address the most significant problems. As shown in Figure E.10, Tier 1 has the largest total tier annualization cost at $1.14 million. Note that a majority of this total tier cost is composed of two large safety education and engineering projects that would be implemented statewide. Some examples of Tier 1 projects include the following:

- Construct centerline and edgeline rumble strips throughout the State;
- Purchase media for traffic safety campaign throughout the State; and
- Enforcement campaigns for critical emphasis area teams.

Table E.9 Cost-Effectiveness of Engineering and Behavioral Projects

Project No.	Description	Effectiveness Score	Problem Score	Cost Score
Engineering Projects				
1	Install signal system to replace existing two-way stop controlled intersection	1	4	1
2	Construct median island on an 0.3 mile segment of an urban arterial	2	3	1
3	Median slope flattening and installing cable barrier on a multilane divided highway	3	2	2
4	Construct median island on the northern leg of an urban arterial intersection	2	4	1
5	Construct centerline and edge line rumble strips throughout the State	4	2	3
6	Rural highway slope flattening, widening, and guardrail moved out	3	2	3
7	Rural highway slope flattening, widening, and guardrail removed	1	4	1
8	Construct roundabout on a former stop controlled rural intersection	4	4	2
9	Median slope flattening and installing cable barrier on a rural multilane divided highway.	3	2	2
31	Modify median island and add a second left turn EB and WB lane at the intersection of two urban arterials	1	4	1
32	Modify median island restricting certain lefts on an urban arterial	1	4	1
Behavioral Projects				
10	Enforcement campaigns for each of the Critical Emphasis Area teams	3	3	1
11	Increase public awareness and increase usage and proper installation of child safety seats	1	1	1
12	Radio and TV ads to raise DUI awareness	2	2	1
13	Programs to promote walking or biking to school	2	1	2
14	Funding for adequate seating for spectators to participate in Every 15 Minutes event (DUI among High School students)	1	3	1
15	Data analysis and DUI saturation checkpoints	3	2	1
16	Pedestrian enforcement and education campaign	3	2	1
17	Intersection enforcement and education campaign	2	3	1
18	Highway patrol enforcement campaign targeting Critical Emphasis Areas	3	3	1
19	Educating new drivers ages 15 to 21	1	3	1
20	Education and awareness campaigns for 14- to 21-year old drivers	1	1	1
21	Market and implement PACE (young adult driver's education) program, including outreach, publicity, and partnering	1	3	2
22	Purchase media for traffic safety campaigns	4	3	3
23	Data-driven high-visibility intersection enforcement events	1	1	3
24	Workshops for juveniles that have been convicted of DUI	1	2	1
25	Overtime for officers to enforce intersection laws, and seat belt usage laws	2	3	1
26	Educational messages on bus shelters, backs of bus coaches, and through employer-based publications	3	2	3
27	Assist five community agencies with their traffic safety efforts	3	2	2
28	PACE (Young adult driver's education) program implementation in two counties	1	3	2
29	Enforcement, Communication Campaign, Do the Ride Thing membership drives, Education, Sponsorship Drive, Data Collection	3	2	1
30	Enhance existing Driver Education and Motorcycle Safety Programs at a local community college (new drivers)	3	2	2

Tier 2 – Most Effective, Smaller Problems

Tier 2 projects are prioritized after Tier 1 as they address less significant problems, but are equally as effective. Tier 2 projects are predominantly engineering and education projects. Total tier annualization cost for Tier 2 is $1.01 million (Figure E.10). Some examples of Tier 2 projects include the following:

- Median slope flattening and installing cable barrier on a multilane divided highway;
- Enhance existing Driver Education and Motorcycle Safety Programs at a local community college; and
- DUI data analysis and saturation check points.

Tier 3 – Less Effective, Larger Problems

Tier 3 projects follow Tier 2 projects, and even though they address significant problems, it is uncertain whether these projects would be as effective as projects in Tiers 1 and 2. Total tier annualization cost is $0.43 million (Figure E.10). Compared to the other tiers, Tier 3 projects tend to be lower in cost. As shown in Figure E.9, most Tier 3 projects have annualized costs lower than $70,000. Some examples of Tier 3 projects include the following:

- Construct median island on the northern leg of an urban arterial intersection;
- Pedestrian enforcement and education campaign; and
- Overtime for officers to enforce intersection laws, and seat belt usage laws.

Tier 4 – Less Effective, Smaller Problems

Finally, Tier 4 projects have the lowest priority as they are not as effective and target less significant problems. These projects also could be submitted for further study or evaluation to confirm their effectiveness. Tier 4 predominantly includes behavioral projects with education or outreach components. Total Tier 4 annualization cost is $0.43 million. Some examples of Tier 4 projects include the following:

- Programs to promote walking or biking to school;
- Workshops for juveniles that have been convicted of DUI; and
- Data-driven high-visibility intersection enforcement events.

Figure E.9 Cost-Effectiveness of Engineering and Behavioral Projects with Prioritization Tiers

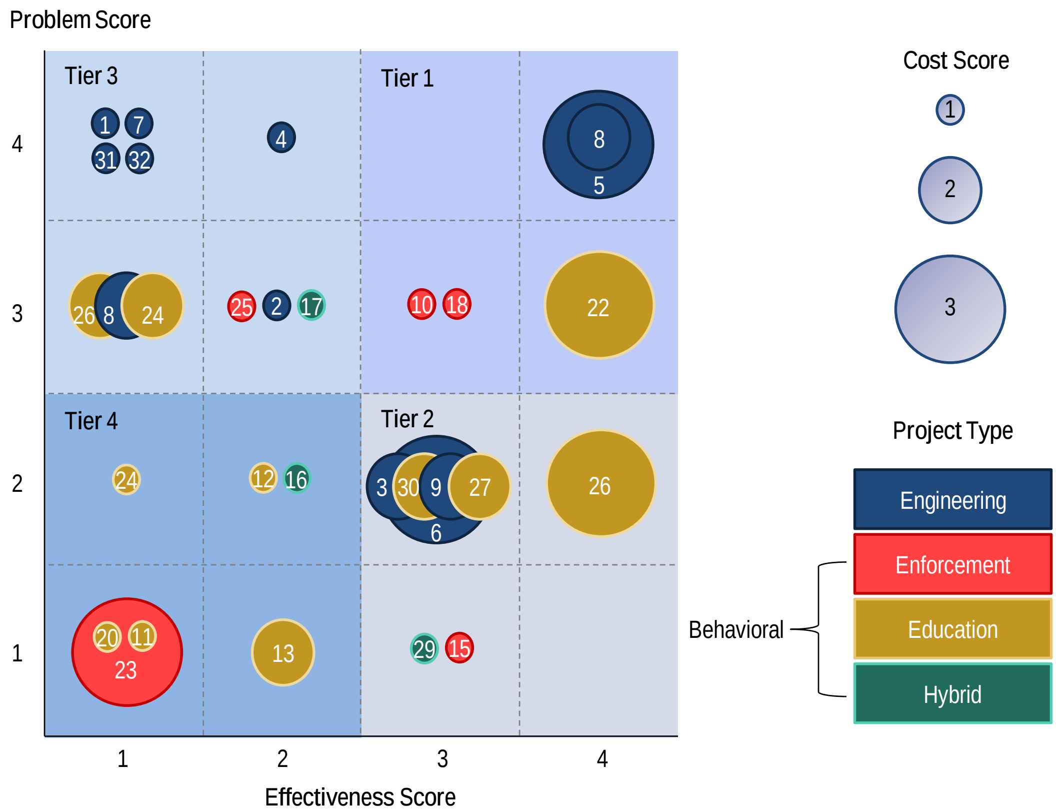
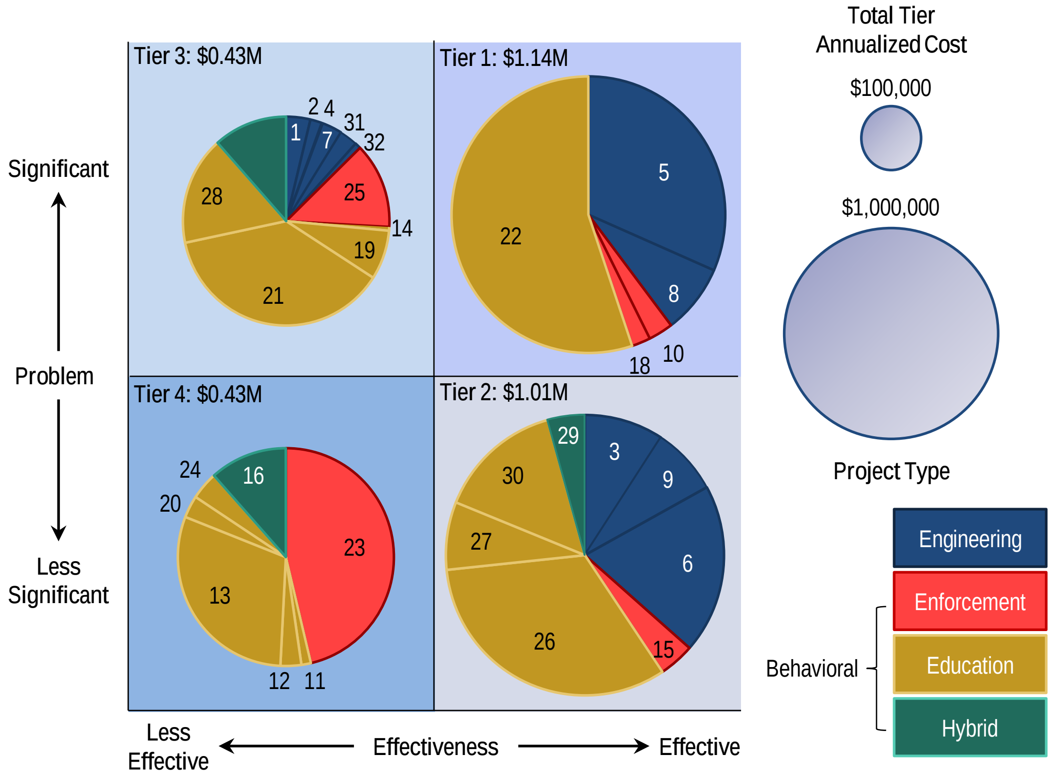


Figure E.10 Cost-Effectiveness of Engineering and Behavioral Projects with Tier Annualization Cost Project Type



E.6 Challenges and Limitations

Several challenges and limitations were noted in the development of this case study. These are briefly listed below and discussed in detail in the main body of this report (Section 3.0). Difficulties included:

- Determining which projects should be classified as indirect/capacity-building activities and removed from analysis;
- Assigning effectiveness and problem scores for projects with multiple components;
- Matching complex projects to close equivalent project types in the national literature to obtain an effectiveness score;
- Assigning effectiveness scores for projects lacking CMFs or where no close equivalent has been studied in the national literature;
- Assigning scores with limited information due to lack of detail on project applications;

- Assigning scores to projects where a local CMF was provided on the project application, but no information was provided on the quality of the CMF or the studies behind it;
- Determining the size of the crash population expected to be impacted by specific behavioral measures; and
- Determining annualized project costs for behavioral projects where the duration of impact is unknown.

F. Marketing Materials

Memorandum

TO: Mark Bush, Transportation Research Board

FROM: Susan Herbel, Ryan Greene-Roesel, Cambridge Systematics

DATE: November 19, 2012

RE: Marketing Materials for NCHRP 17-46

In July 2012, the technical advisory panel for NCHRP 17-46, *A Comprehensive Analysis Framework for Safety Investment Decisions,* decided to use remaining research budget to create marketing materials associated with the completed research products. This document contains the marketing materials, which include:

1. A short article summarizing the research results;
2. A longer article summarizing the research results;
3. An article on the importance of funding flexibility in highway safety and its relationship to the research results;
4. A short webinar presentation on the research results (attached separately as a PowerPoint file); and
5. A longer webinar presentation on the research results (attached separately as a PowerPoint file).

Additionally, the research team prepared an submitted an article on the research results for the 2013 Transportation Research Board Annual Meeting, noting that the research is ongoing and has not yet been fully approved by the research panel.

Goal and Audience

To successfully implement NCHRP 17-46, A Comprehensive Framework for Safety Investment Decisions, key stakeholders (transportation planners, state highway safety offices, state safety engineer, and elected officials) need to be educated on the framework contents and the benefits to be realized by adopting a comprehensive decision-making process. The goal is to increase awareness of the potential for the 4 E decision-making framework in identifying and prioritizing 4 E strategies and countermeasures with the greatest potential for improving safety, and to educate transportation safety stakeholders how to access and implement the NCHRP framework.

Marketing materials and dissemination mechanisms are targeted to "early adapters." Early adapters are safety engineers and transportation safety planners who are most likely to use safety results at the leading edge. These early adapters include safety engineers and transportation and safety planners at all levels. In addition, the materials could be targeted at elected officials who must break down the funding silos that currently prevent 4 E decision-making. Table 1 contains a full list of potential primary and secondary audiences for the marketing materials.

Table 1. Primary and Secondary Audiences for Marketing Materials

Primary Audiences	Secondary Audiences
State Departments of Transportation	FHWA Division Offices
State Safety Engineer	NHTSA Regional Offices
Transportation Planners	AASHTO, SCOHTS Safety Management Subcommittee
Local Transportation Agencies	Institute of Transportation Engineers (ITE)
Transportation Planners	Local Technical Assistance Program (LTAP)
Safety Engineers	National Association of County Engineers (NACE)
Metropolitan/Regional Planning Organizations (Planners)	Transportation Research Board (TRB)
Transportation Planners	Governors Highway Safety Association (GHSA)
Highway Safety Offices	Association of Metropolitan Planning Organizations (AMPO)
402 Highway Safety Planners	National Association of Regional Councils (NARC)
Elected Officials	National Association of Counties (NACo)
	National Conference of State Legislatures (NCSL)

1. Summary Article on Research Results – Short Version

A Comprehensive Framework for Safety Investment Decisions

Road safety professionals are under pressure to deliver increased results for limited resources. Though injuries and fatalities have decreased in recent years, they are rising again at the same time that agencies are suffering budget cuts. The need is greater than ever to find cost-effective strategies for reducing injuries and fatalities. Yet many agencies are limited by funding eligibility requirements and institutional silos that prevent focus on the most cost-effective solutions. And while some areas of safety practice, such as project prioritization for the Highway Safety Improvement Program, require consideration of cost effectiveness or cost-benefit, others do not. State strategic highway safety plans and behavioral safety plans do not typically attempt to prioritize strategies by their cost effectiveness.

NCHRP Research Project 17-46, A Comprehensive Analysis Framework for 4 E Safety Investment Decisions, advances the state of road safety practice by developing and illustrating greater use of cost-effectiveness analysis in safety project prioritization and strategic planning involving the 4 E's of safety (education, engineering, enforcement, emergency response). The research resulted in the development of a conceptual framework and two methods (a quantitative method and a sketch method) for better integrating 4 E strategy cost-effectiveness comparisons into safety investment decision-making processes.

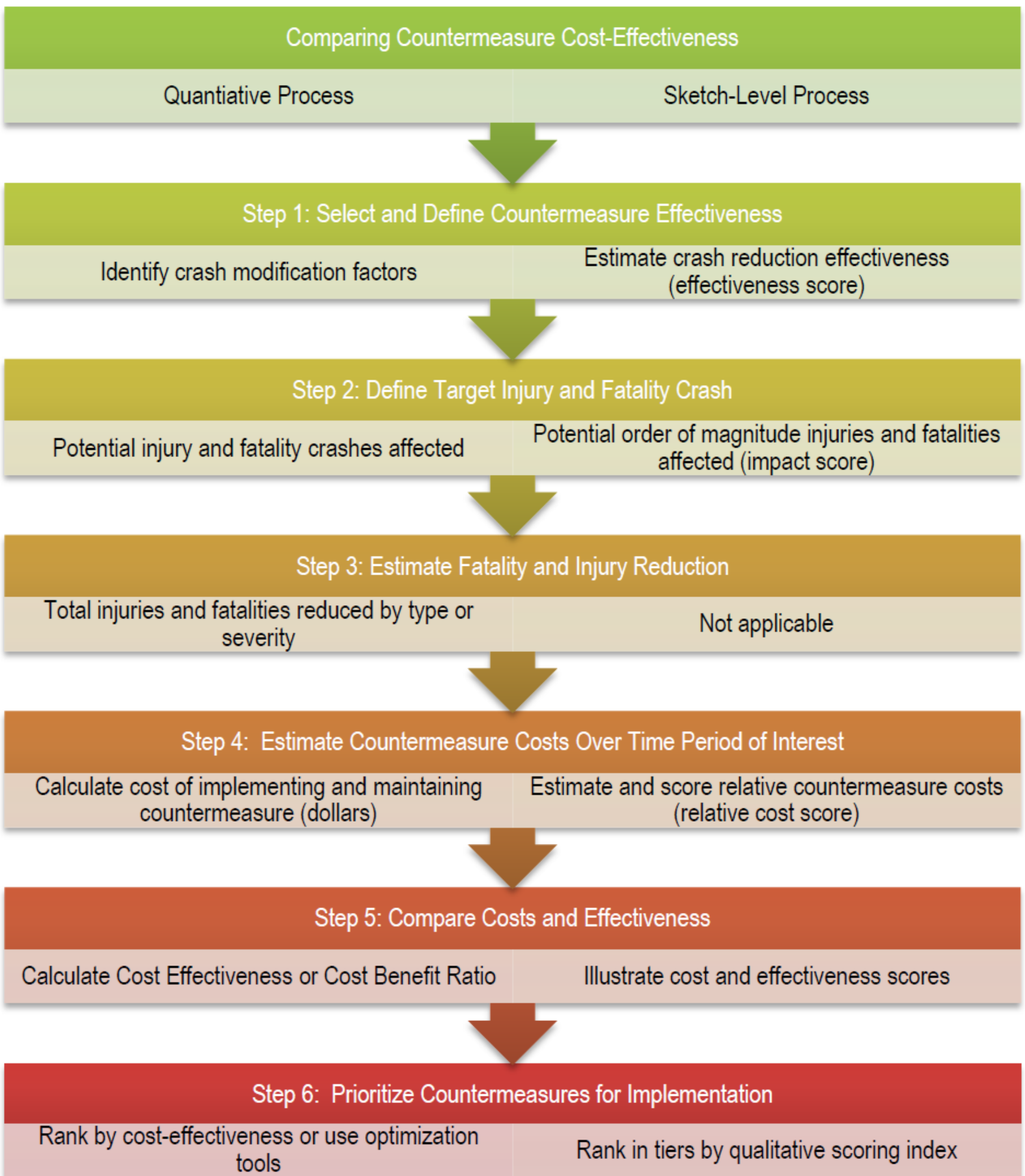
The framework and methods can be applied in several contexts, including 1) strategic planning, such as strategy prioritization in Strategic Highway Safety Plans or regional highway safety plans; 2) prioritization for safety project grant funding by Highway Safety Office staff and road safety engineers; and 3) corridor planning, where local engineers, planners, and behavioral safety specialists, such as persons involved in road safety audits or corridor planning studies, could use the quantitative methods to compare the cost-effectiveness of safety strategies in a specific corridor.

The conceptual framework for cost-effective 4 E investment decision-making consists of four steps. The first step is to establish a guiding group of individuals or leaders committed to promoting cost-effective solutions to safety problems. Step 2 identifies 4 E strategies to address safety issues using crash data analysis and supporting tools. Step 3 compares and prioritizes safety strategies according to cost-effectiveness and other considerations. The research proposes two methods for comparing the cost-effectiveness of safety countermeasures: a sketch-level method and a quantitative method. Step 4 involves implementation and evaluation of the selected strategies.

Figure 1.1 shows the approach to the two cost-effectiveness analysis methods presented in the research. The quantitative method is appropriate when a quantitative result is desired and sufficient research and data exists to allow quantitative assumptions for all variables in the analysis, including crash modification factors, duration of effectiveness, geographic extent of effectiveness, costs, and so forth. The sketch-level method is appropriate when quantitative information is incomplete or when detailed results are not required. Conceptually, the sketch-level method involves:

- Calculating an effectiveness score indicating the relative effectiveness of the countermeasure;
- Calculating a problem score indicating the relative size of the target crash population potentially affected by the countermeasure; and
- Calculating a cost score indicating the annualized cost of the countermeasure relative to other measures.

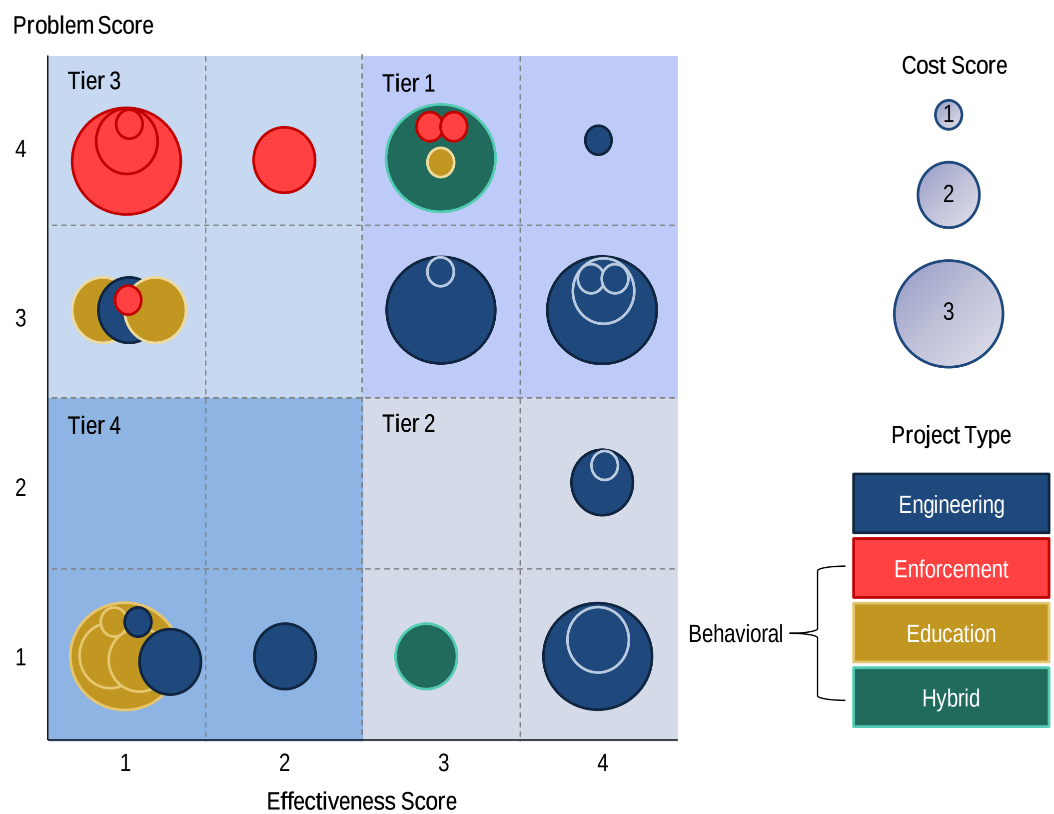
Figure 1.1 Overview of Methods for Safety Cost-Effectiveness Comparisons



These three scores are used to graphically illustrate relative countermeasure costs, effectiveness and potential impact, and to group countermeasures into tiers by relative priority. Figure 1.2

illustrates example results from the research, where each countermeasure examined is represented by a circle, and the circle's color indicates the countermeasure type (e.g., engineering, enforcement, education). Countermeasures in the top right-hand quadrant of the figure (Tier 1) are the most effective and would address the most prevalent crash types, suggesting they should receive higher priority than projects in other tiers.

Figure 1.2 Cost-Effectiveness of Engineering and Behavioral Projects with Prioritization Tiers



The sketch and quantitative prioritization methods can be used together. For example, state safety stakeholders can use the sketch method to identify the most promising safety strategy types for inclusion in the Strategic Highway Safety Plan. Strategies need not be defined in great detail for this high-level prioritization process to occur. Then, implementing agencies such as the state DOT and Highway Safety Office could further prioritize amongst the top-tier strategies using the quantitative method, which requires careful definition of each countermeasure's costs, geographic area of implementation, effectiveness, and so forth.

2. Summary Article on Research Results – Long Version

NCHRP 17-46 – A Comprehensive Analysis Framework for Safety Investment Decisions

Traffic incidents and crashes involve multiple contributing factors affecting the mission and work of many disciplines and agencies, highlighting the need for multidisciplinary and multi-agency approaches. Determining which individual countermeasure will produce the greatest reduction in fatalities and serious injuries is challenging; however, it is even more difficult to assess which *set or mix of countermeasures* are most effective. Prior to this research, analysis efforts were primarily focused on determining project prioritization within a specific discipline, e.g., engineering, enforcement, education, etc. This research attempts to move the analysis forward and provide guidance on determining priorities across a range of disciplines and countermeasures.

Introduction

In an environment of resource constraints, public agencies strive to focus resources on the most cost-effective investments. Within the road safety field, this means giving preference to strategies that deliver the greatest injury and fatality reduction for the least cost. State Department of Transportation (DOT) engineers typically calculate benefit/cost ratios for safety countermeasures funded through the Federal Highway Safety Improvement Program (HSIP), but no such requirement exists for behavioral safety countermeasures. In addition, state Strategic Highway Safety Plans (SHSP) do not typically compare the cost-effectiveness of candidate safety strategies across disciplines.

NCHRP Research Project 17-46, *A Comprehensive Analysis Framework for 4 E Safety Investment Decisions,* advances the state of road safety practice by developing and illustrating the greater use of cost-effectiveness analysis in safety project prioritization and strategic planning involving the 4 E's of safety (education, engineering, enforcement, emergency response). The research resulted in the development of a conceptual framework and two methods (a quantitative method and a sketch method) for better integrating 4 E strategy cost-effectiveness comparisons into safety investment decision-making processes. Although the framework can be applied in a range of safety analyses, it is intended primarily for: 1) **strategic planning**, where engineers and planners involved in preparing strategic safety planning documents (e.g., Strategic Highway Safety Plan, regional highway safety plan) could use the framework and methods to inform the approach and to prioritize safety strategies in these documents; 2) **prioritization for grant funding,** where Highway Safety Office staff and road safety engineers could use the sketch method for prioritizing grant applications and compare applications for behavioral safety strategies; and 3) c**orridor planning**, where local engineers, planners, and behavioral safety specialists, such as persons involved in road safety audits or corridor planning studies, could use the quantitative methods to compare the cost-effectiveness of safety strategies in a specific corridor.

Conceptual Framework

A multidisciplinary approach to safety planning is well established in the safety field. Federal transportation legislation requires states to adopt a 4 E approach in the development of SHSPs and the Federal Highway Administration (FHWA) Office of Safety references the 4 E approach in its mission statement. This is accepted as best practice, but beyond information sharing, attending summits, and occasional coordination on projects, many safety professionals are uncertain about the relationship between the 4 E approach and resource allocation decisions. The conceptual framework provided here fills that gap by focusing specifically on integrating a 4 E approach into investment decision-making. The intent is not to create "yet another" safety framework, but to assist practitioners in understanding how they can integrate 4 E tradeoff analysis into existing safety programming processes.

Figure 2.1 shows the conceptual framework for cost-effective 4 E investment decision-making. The first step in the framework is to establish a group of individuals or leaders committed to promoting cost-effective solutions to safety problems who will guide the process. Leadership also is responsible for identifying goals and performance measures to focus attention on reducing injuries and fatalities. Specific actions include: 1) identifying transportation safety as a priority by high-level leaders, 2) maximizing funding flexibility, 3) emphasizing the SHSP, and 4) conducting pilot applications of multidisciplinary project management teams.

Step 2 identifies 4 E strategies to address safety issues. In this step, crash data are evaluated to define major crash trends and descriptive statistics. Crashes are characterized using descriptive statistics such as number, type, and severity of crashes by various demographic, environmental, and roadway characteristics. The evaluation also summarizes various aggregate-level trends such urban or rural crashes, crashes categorized by driver demographics, pedestrian and bicycle safety, etc. Similar to an SHSP analysis, the results are used to characterize crash conditions in the community, identify the most critical issues, and inform goal identification. The analysis results are presented and discussed in a comprehensive manner considering all disciplines to support subsequent multidisciplinary solutions.

Step 3 compares and prioritizes safety strategies by cost-effectiveness and other considerations. A number of questions related to such things as legal feasibility, political support, technical capacity of the staff, co-benefits associated with the safety strategies, cost, benefit/cost ratios and cost-effectiveness may be considered as part of safety project prioritization. The research proposes two methods (sketch-level and quantitative) for comparing the cost-effectiveness of safety countermeasures.

Figure 2.2 shows the approach to these two methods. The quantitative method is appropriate when detailed, quantitative results are desired and sufficient data exists to make quantitative assumptions for all variables in the analysis, including crash modification factors, duration of effectiveness, geographic extent of effectiveness, costs, and so forth. The sketch-level method is appropriate when quantitative information is unavailable or when detailed results are not required. Table 2.1 shows the major differences in the two methods.

Step 4 focuses on the implementation of selected strategies and the evaluation of the results.

Figure 2.2 Overview of Methods for Safety Cost-Effectiveness Comparisons

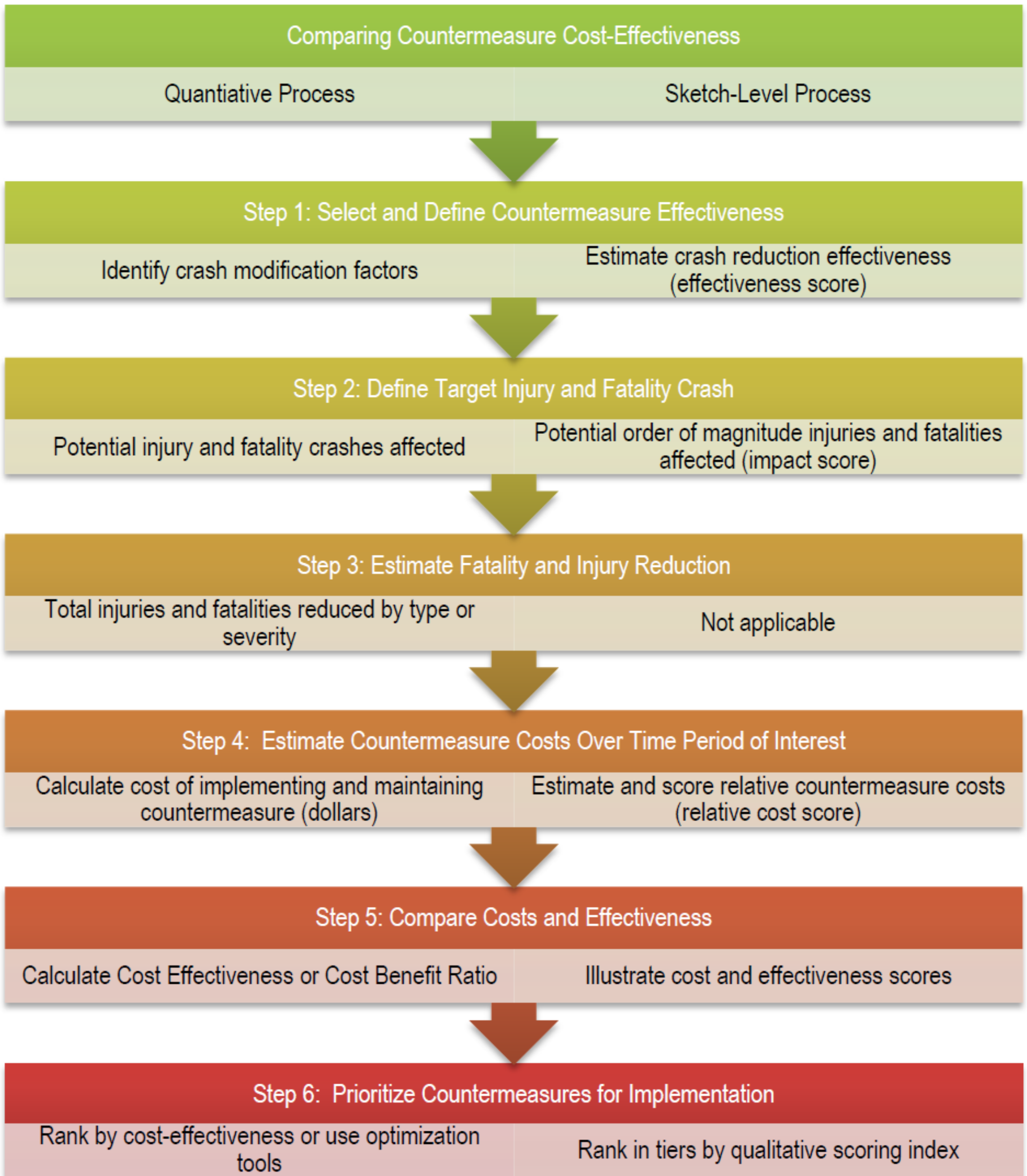


Table 2.1 Cost-Effectiveness Method Comparison

	Quantitative Method	Sketch Method
Information Needs	Quantitative effectiveness information (e.g., Crash Modification Factors) for all countermeasures Geographic extent and duration of countermeasure impacts Project costs (initial and ongoing) for all countermeasures	Quantitative or qualitative effectiveness information (e.g., CMF, star quality rating) Information on type of crashes to be addressed by the project Project cost information Duration of countermeasure effectiveness
Process	Calculate cost-effectiveness	Score projects based on relative cost-effectiveness
Results	Cost-effectiveness ratio for each project	Graphical illustration of relative project cost-effectiveness
Best For	Evaluating a small number of projects in-depth	Evaluating a large number of projects at a high level
Possible Contexts	Corridor study, focused policy analysis, prioritization of projects where quantitative information is available for all projects.	Prioritizing projects as part of a strategic planning process or a project prioritization process where quantitative information on project effectiveness is limited (e.g. prioritization of behavioral safety projects).

Quantitative Approach for Evaluation

Quantitative analysis is used routinely to compare safety countermeasures. The *Highway Safety Manual (HSM*), for example, contains a chapter on economic appraisal of safety investment decisions and covers both benefit/cost and cost-effectiveness analysis procedures. Where data are available and monetary benefits and costs can be determined, the approach to an analysis is straightforward:

1. Define the effectiveness of each countermeasure in reducing injuries and fatalities;
2. Define the target crashes to be affected by the countermeasure(s) of interest;
3. Assess magnitude of crash frequency and fatality/injury reduction;
4. Assess the costs of achieving reductions over the time period of interest;
5. Assess cost-effectiveness; and
6. Rank or package countermeasures for implementation.

Monetizing benefits is desirable for two reasons. Some countermeasures may result in immediate injury and fatality benefits while others may not yield benefits for several years. By monetizing benefits, any increased uncertainty regarding benefits that occur in the more distant future can be incorporated into the analysis through the use of discount rates or sensitivity analysis. In addition, monetization allows calculation of a benefit/cost ratio (BCR). The BCR

indicates whether the investment is economically justified (e.g., monetized discounted benefits exceed monetized discounted costs) and allows comparison among similar types of projects. In this case, it is appropriate to include any project benefits beyond safety (e.g., mobility, environment) so the full impact of the project can be included in the benefit/cost analysis.

Monetizing benefits, however, presupposes that one can predict the reduction in crashes that will occur given the use of a countermeasure or alternatively the number of future crashes that will occur in the absence of the countermeasure. This can be estimated using software tools for crashes on specific facilities, procedures in the *Highway Safety Manual*, or analysis of historical crash data. The *Highway Safety Manual* is useful because it provides tools for estimating existing and future crash frequency and severity as a function of traffic volume, roadway characteristics, and roadway length for segments.

The crash modification factor (CMF) is an important concept in the analysis because it is used to determine the effectiveness of a safety treatment. The CMF is a multiplicative factor used to calculate the expected change in crash frequency and/or severity associated with implementing a safety countermeasure. Selecting CMFs should consider several factors:

- **Crash Severity –** Countermeasure effectiveness should take into account the degree to which the countermeasure reduces severe crashes. Focusing on fatal and severe injury crashes can have far greater economic and social benefits than reducing property damage only crashes, which contribute very little to overall monetary loss or nonmonetary time, pain, grief, suffering, etc.

- **Reduced Countermeasure Effectiveness Over Time –** Some countermeasures lose effectiveness over time. For engineering countermeasures, this could occur because of driver adaptation and familiarity (e.g., warning signs drivers may only notice at first), poor facility maintenance (e.g., infrequent striping), or other causes. For behavioral countermeasures, this could occur if a program has no lasting effects on behavior after the funding period.

- **Combining Safety Countermeasures –** The Highway Safety Manual (HSM) recommends combining the effects of multiple countermeasures by multiplying their CMF values. This assumes the countermeasures are independent. Currently, no definitive information exists about how many CMFs may be theoretically multiplied together; therefore the HSM provides guidance to consider whether the countermeasures being implemented are independent and advises against multiplying more than three independent CMFs.

The quantitative analysis leads to prioritization, which entails ranking projects based on any of a number of metrics, including: project costs, monetary value of project benefits, number of total crashes reduced, number of fatal and incapacitating injury crashes reduced, number of fatal and injury crashes reduced, cost-effectiveness index, net present value (NPV), and BCR.

Quantitative methods such as benefit/cost analysis allow for detailed comparisons among countermeasures, but are not always available due to data deficiencies or insufficient analysis time. In some cases, crash modification factors are not known or no basis exists for making assumptions. In others, only qualitative information on countermeasure effectiveness might be available. In such instances, sketch-level, semi-qualitative comparisons may be appropriate.

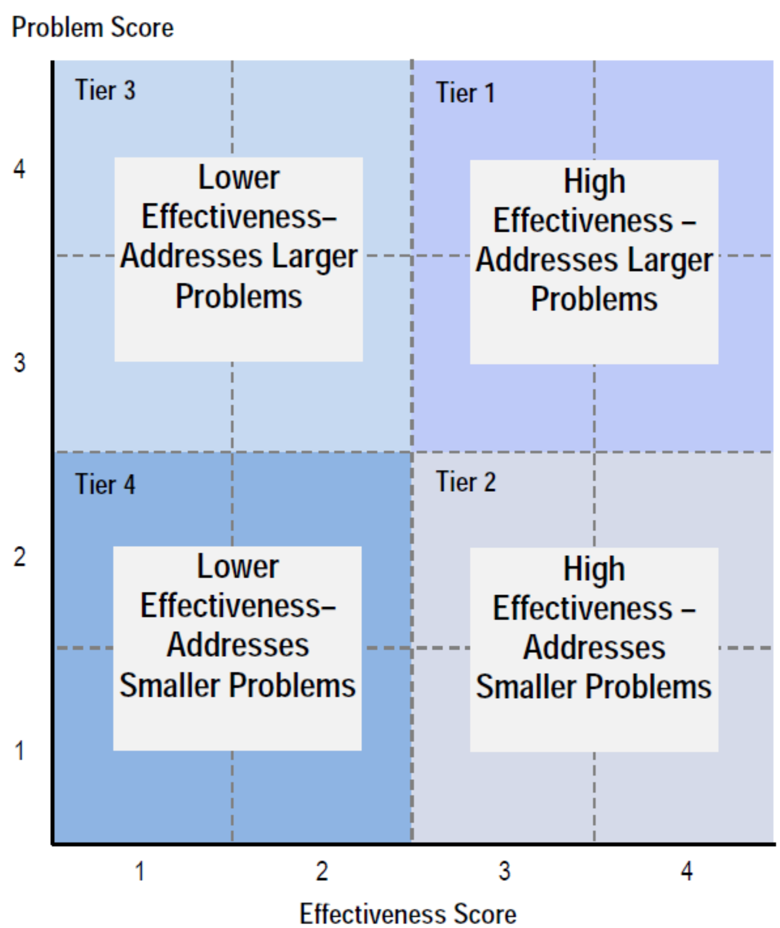
Sketch-Level Analysis

This research developed a sketch-level method for ranking countermeasures by cost-effectiveness using a mix of qualitative and quantitative information. Conceptually, this method involves:

- Calculating an effectiveness score indicating the relative effectiveness of the countermeasure;
- Calculating a problem score indicating the relative size of the target crash population potentially affected by the countermeasure; and
- Calculating a cost score indicating the annualized cost of the countermeasure relative to other measures.

These three scores are used to graphically illustrate relative countermeasure costs, effectiveness and potential impact, and then countermeasures are grouped into tiers by relative priority (Figure 2.3).

Figure 2.3 Project Prioritization Tiers



Estimating an effectiveness score entails looking up effectiveness information in the national safety research literature and assigning a score (Figure 2.4). For engineering projects, this analysis identifies the CMF of each project component and examines the studies that produce these factors. For behavioral projects, this analysis employs a process that estimates crash reduction effectiveness based on countermeasure effectiveness ratings from behavioral safety research. For certain countermeasures, several CMFs are applicable. For example, installing median guardrail on separated highways increased the CMF for all crashes, however, decreased the CMF for fatal and serious injury crashes. In these cases, the effectiveness score is assigned based on the decrease in fatal and serious injury crashes; that is, the crash reduction context that results in the highest benefit.

Figure 2.4 Range of Effectiveness Score

	Source	Highly Effective, Proven	Effective, Proven	Somewhat Effective, Unproven	Unknown or Ineffective
Engineering	Crash Modification Factor Clearinghouse	CMF <0.7 & Quality Score 4-5	0.7 < CMF < 1, & Quality Score 4-5	CMF < 1, & Quality Score 3	CMF≥1 or Quality Score < 3
	HSM	CMF <0.7 & Adjusted Standard Error < 0.2	0.7 < CMF <1 & Adjusted Standard Error < 0.2	CMF <1 & 0.2 < Adjusted Standard Error < 0.4	CMF ≥1 or N/A or Adjusted Standard Error > 0.4 or N/A
Behavioral	Countermeasures that Work	5 stars	4 stars	3 stars	≤ 2 stars or Star Rating Unavailable
	NCHRP 500/NCHRP 17-17(3)		Proven		Tried or Experimental
	NCHRP 622	Proven (Crash Reduction > 30%)	Proven	Likely	Unknown/Uncertain/ Unlikely
	Effectiveness Score	4	3	2	1

The problem score examines the relative magnitude of safety problems targeted by a project. The problem score is determined using a top-down method that first identifies the type of safety problem the project would address, and then scores the significance of that safety problem on a statewide level. This method assumes practitioners are interested in looking strategically at statewide safety problems and prioritizing projects based on whether they address significant statewide safety problems.

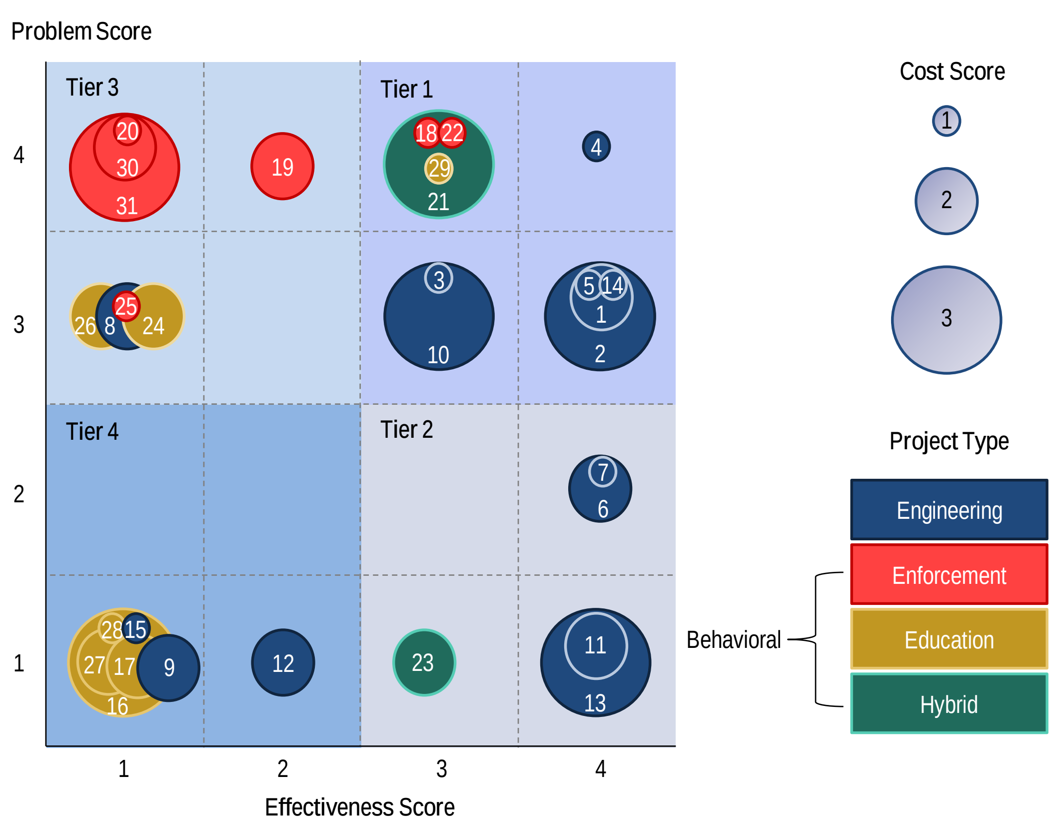
To determine the significance of a particular safety problem statewide, a safety problem is assigned a subjective statewide problem score from one to four; one being the safety problem category with the lowest number of fatal and serious injuries. Thresholds for the statewide problem score categories are based on natural breaks in the data and are subject to individual judgment.

Similarly for the cost score, an annualized cost for all engineering and behavioral projects is estimated, and a cost score of 1 to 3 is assigned. Cost thresholds again are assigned based on "natural breaks" in the data points and individual judgment.

The results of such an analysis are shown in Figure 2.5, where data from North Carolina were used to determine which countermeasures were most effective given the safety problems facing the State. Tier 1 projects should be prioritized before the other tiers since they would deliver the most benefits and address the most significant problems. In the case of North Carolina, about the same number of engineering and behavioral projects fall into Tier 1, as well as projects of varying cost levels. Some examples of Tier 1 projects include:

- Install roundabout in place of existing intersection;
- Raised median and pedestrian improvements;
- Local traffic safety enforcement (seatbelt, speed, and child safety seat); and
- Blood Alcohol Testing mobile unit program (alcohol checkpoints and outreach);

Figure 2.5 Cost-Effectiveness of Engineering and Behavioral Projects with Prioritization Tiers



The project prioritization tiers were compared with the BCRs the North Carolina DOT (NCDOT) calculated to determine funding prioritization for engineering projects. The BCR was defined as the project injury and fatality reduction benefits divided by the project cost, both of which were discounted over the project's useful life. When BCRs were compared to the ranking resulting from the cost-effectiveness analysis, the project BCR varied across the different project tiers. In other words, in some cases, projects with low benefit/cost ratios were highly ranked in the cost-effectiveness results. Two major reasons explain these discrepancies:

First, the sketch method highlights projects' proven effectiveness from numerous research studies. That is, the effectiveness score is primarily a function of the quality of the CMF, judged by the quality of studies that produced it, rather than the CMF value. By contrast, NCDOT relied on the CMF alone in calculating project benefit.

Second, the sketch method scored the magnitude of the problem the project would address through analysis of state-level crash data, rather than crash data from the specific site being targeted. This was done primarily to allow comparison to behavioral measures, for which no estimates could be obtained regarding the number of people or crashes to be impacted in the geographic area targeted for implementation.

Summary

The methods described above, which rely on professional judgment and the results of safety research, provide analysis capability for a variety of decision-making contexts. Preparers of SHSPs could include analysis of the relative cost-effectiveness of proposed strategies by emphasis areas using this method. Highway Safety Offices could analyze the relative cost-effectiveness of grant applications and state DOTs could compare the relative cost-effectiveness of applications. Agencies involved in a corridor study could fund a quantitative analysis of the cost-effectiveness of strategies proposed to address problems in the corridor using the quantitative method. Researchers investigating a specific safety issue could apply the quantitative analysis methods to compare in detail the likely effectiveness of competing solutions to a specific problem.

The example from North Carolina illustrates the value of the sketch analysis method as it relates to the comparison of behavioral strategies with engineering countermeasures. It is simply an attempt to develop a program of investments that allocates limited resources to those actions that produce the most effective result in terms of safety outcomes.

The methods presented in this document could be significantly improved for future application given research on the following topics:

- **More effectiveness information** for a wider range of project types, including combinations of projects. Currently, only limited quantitative information exists, especially for behavioral safety and emergency response projects. NCHRP 622 Effectiveness of Behavioral Safety Countermeasures was a first step in this direction, and NCHRP 17-60, Benefit/Cost Methodology for Behavioral Highway Safety Countermeasures (forthcoming) will build on it. However, synthesis documents are available that draw on existing research. More high-

quality before-and-after evaluations of specific safety strategies are needed to significantly advance the state of the practice.

- **Consistent definitions of effectiveness. A** variety of qualitative and quantitative effectiveness measures exist, all with slightly different definitions, such as star effectiveness ratings (Countermeasures that Work), proven/tried/experimental designations (NCHRP 500), crash modification factors with standard errors (Highway Safety Manual), crash modification factors with star quality ratings (CMF Clearinghouse) and others. More uniformity in qualitative and quantitative measures of effectiveness is needed to allow apples-to-apples comparisons among different types of safety countermeasures.

- **Uniform cost and useful life assumptions.** Little consistent information is available on typical costs and duration of effectiveness for behavioral safety measures. More primary research on this topic is needed to inform benefit/cost analysis.

- **Better quality crash data.** Evaluating certain types of projects can be very difficult if crash data are inadequate. Particularly, lack of linkage between crash data records and injury and fatality outcomes makes evaluation of emergency response strategies difficult. However, the results of NCHRP 17-57 are intended to make progress in establishing data linkages.

3. Safety Funding Flexibility White Paper

"Let me see if I've got this straight: in order to be grounded, I've got to be crazy and I must be crazy to keep flying. But if I ask to be grounded, that means I'm not crazy anymore and I have to keep flying." – Capt. John Joseph Yossarian, Catch 22 by Joseph Heller

This article discusses constraints limiting flexible use of road safety funds and describes how research developed as part of NCHRP 17-46, *A Comprehensive Analysis Framework for Safety Investment Decisions,* can provide first steps toward more flexible and cost-effective safety investment decisions.

The Need for Cost-Effective Safety Solutions

Crashes are rarely caused by a single event. It is usually a series of events or actions. For instance, a car approaches a horizontal curve going too fast for conditions. The driver fails to notice the sharp radius of the curve because he is talking on his cell phone. The car misses the curve and runs off the road. Multiple contributing crash factors were associated with the crash, including the behavior of the driver and the design of the roadway.

The multifaceted nature of crashes suggests many possible solutions. For instance, when speeding is a problem at an intersection, solutions could include additional signage, a roundabout, or an enforcement campaign with an education component accomplished through earned media and materials distributed to homes and businesses in the area. However, analysis of the relative cost-effectiveness of these solutions is rare in the road safety field. Rigid eligibility requirements associated with road safety funding limit emphasis on the most cost-effective solutions. In the case of the intersection above, a roundabout might be selected principally because of funding available for roundabouts rather than analysis of the relative cost-effectiveness of a range of solutions.

Despite the efforts to improve the multidisciplinary approach to road safety and break down the barriers amongst the various disciplines, funding with few exceptions is siloed among the 4 E's of safety – engineering, enforcement, education, and emergency response. This approach creates a Catch-22, or a situation in which a desired outcome or solution is impossible or difficult to attain because the rules restrict the ability to implement the most effective approaches.

Obtaining the most injury and fatality reduction for limited safety dollars is ever more critical due to dwindling resources for transportation. Safety competes with a variety of other important transportation programs, including maintenance, congestion, construction, and environment. While the demand for funding within these programs continues to increase, the available funding is shrinking. Surface transportation improvements are financed from a variety of user fees, general taxes, special purpose taxes, and private charges. The majority of funding comes from the Highway Trust Fund, which is financed primarily through fuel taxes. In January 2012, the Congressional Budget Office (CBO) reported the fund will face insolvency

sometime during 2014.[1] This looming crisis puts added pressure on safety professionals who must think of ways to stretch limited safety funding further to achieve the same reduction in injuries and fatalities.

Historical Safety Funding Silos

Funding for safety improvements has historically been divided among multiple agencies, each which imposes strict eligibility requirements. At the Federal level, three branches of the U.S. Department of Transportation (DOT) manage highway safety grant funds. These agencies include the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), and the Federal Motor Carrier Safety Administration (FMCSA).

FHWA manages the Highway Safety Improvement Program (HSIP), the National Highway System (NHS), Congestion Mitigation and Air Quality (CMAQ), and the Surface Transportation Program (STP). All of these programs have potential safety impacts and, in theory, all funding is eligible for safety improvements. However, the core safety program is the HSIP.

The purpose of the HSIP, which was added as a core Federal-aid funding program in 2005, is to achieve a significant reduction in traffic fatalities and serious injuries on all public roads. The program emphasizes a data-driven, strategic approach to improving highway safety that focuses on results. A highway safety improvement project corrects or improves a highway safety problem, such as a hazardous road location. To obligate funds under the HSIP (23 U.S.C. §148), a state must develop and implement a strategic highway safety plan (SHSP), and produce a program of projects or strategies to reduce safety problems and evaluate the plan on a regular basis.

NHTSA oversees the Highway Safety Program, which focuses on specific priorities, including increasing safety belt use, reducing impaired driving, improving data collection and analysis, reducing rollover crashes, and improving vehicle compatibility. The agency is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes by setting and enforcing safety performance standards for motor vehicles and equipment and through grants to state and local governments designed to address unsafe road user behaviors. NHTSA investigates safety defects in motor vehicles; sets and enforces fuel economy standards; helps state and local communities reduce the threat of impaired drivers and other dangerous driving behaviors; promotes the use of safety belts, child safety seats, and air bags; investigates odometer fraud; establishes and enforces vehicle anti-theft regulations, and provides consumer information on motor vehicle safety topics. The agency also serves as a clearinghouse for safety-related information to the public. Each year, NHTSA publishes annual crash statistics and provides an extensive overview of fatalities and injuries occurring on the nation's highways.

The Federal Motor Carrier Safety Administration's (FMCSA) primary mission is to prevent commercial motor vehicle-related fatalities and injuries. Administration activities contribute to ensuring safety in motor carrier operations through strong enforcement of safety regulations,

[1] The Budget and Economic Outlook, 2012-2022, Congressional Budget Office, January 31, 2012, page 126.

targeting high-risk carriers and commercial motor vehicle drivers; improving safety information systems and commercial motor vehicle technologies; strengthening commercial motor vehicle equipment and operating standards, and increasing safety awareness. To accomplish these activities, the Administration works with Federal, state, and local enforcement agencies, the motor carrier industry, safety interest groups, and others.

The majority of funding in the overall surface transportation bill, and the vast majority of highway funding, goes to the "core" highway programs: interstate maintenance (IM), national highway system (NHS); surface transportation program (STP); highway bridge and bridge maintenance (HBRR); congestion, mitigation, and air quality (CMAQ); and the highway safety improvement program (HSIP). Table 3.1 briefly summarizes these programs and the most recent funding apportionment for each.

Table 3.1 Safety Programs Funding Summary

Source	Description	FY 2013	FY 2014
Highway Safety Improvement Program (HSIP)	HSIP supports projects that improve the safety of road infrastructure by correcting hazardous road locations, such as dangerous intersections, or making road improvements such as adding rumble strips. It also includes a $220 million set aside for the Rail-Highway Grade Crossing Program.	$2.39 billion	$2.41 billion
NHTSA Highway Safety Programs	NHTSA promotes safety by addressing driver behaviors that contribute to crashes (e.g., driving while intoxicated, speeding, and distracted driving), and through addressing the safety aspects of passenger vehicles (e.g., requiring seat belts, air bags, and electronic stability control).	$670 million	$680 million
FMCSA Programs	FMCSA is responsible for safety in the commercial motor vehicle industry, including commercial interstate freight trucking and charter bus passenger travel. FMCSA promotes safety by addressing commercial driver qualifications and activities, such as work hours, and by addressing the condition of commercial motor vehicles.	$342 million	$345 million
Transportation Alternatives	This program combines Recreational Trails, Safe Routes to Schools, Transportation Enhancements, and certain other eligible programs.	$809 million	$820 million

Recent Progress Toward More Flexible Funding

Recent changes have improved the flexibility of Federal safety funding. The previous transportation bill, the Safe, Accountable, Flexible, Efficient Transportation Equity Act – A Legacy for Users (SAFETEA-LU) provided additional flexibility for states to use HSIP funds for public awareness, education, and enforcement activities. Under SAFETEA-LU, a state could use up to 10 percent of its HSIP apportionment for these projects if they certified the state met its railway-highway crossing and HSIP infrastructure needs. Few states took advantage of this provision, but some did, e.g., the Nevada Department of Transportation (DOT). The agency used a portion of the flex funds to support an extension of the national media campaigns for safety belts and impaired driving, as well as initiatives targeted at the State's large Latino population.

SAFETEA-LU also required states to create a multidisciplinary Strategic Highway Safety Plan encompassing solutions from all 4 E's of safety (engineering, enforcement, education, emergency response). This requirement emerged from the recognition that fatalities and serious injuries had remained stagnant for more than a decade. Leaders looked to the experience of other countries, such as Great Britain and Australia and saw that a multipronged approach to safety involving a broad range of safety stakeholders could be successful. The key was getting people out of their silos and working together.

The recently passed replacement to SAFETEA-LU, MAP-21, further improves safety funding flexibility. While it does not mention flex funding, it defines a highway safety improvement project as any strategy, activity, or project on a public road consistent with the data-driven SHSP and corrects or improves a hazardous road location or feature or addresses a highway safety problem. MAP-21 provides an example list of eligible activities, but HSIP projects are not limited to the list. Workforce development, training, and education activities are also eligible.[2]

These improvements are useful, but implementation challenges remain. HSIP funds, though more flexible, continue to be controlled by state DOTs, which traditionally focus on infrastructure solutions. Few states have created the institutional capacity to oversee identification and prioritization of multidisciplinary safety solutions. Additionally, Federal requirements are inconsistent with respect to requiring consideration of cost-effectiveness in grant funding eligibility. The need remains to take the multidisciplinary approach to the next level – a fully flexible funding system that allows states to implement the most effective combination of solutions.

NCHRP 17-46 Framework for Flexible Safety Investment Decisions

NCHRP 17-46, A Comprehensive Analysis Framework for Safety Investment Decisions, provides resources to help take multidisciplinary safety funding to the next level. In anticipation of greater safety funding flexibility, it suggests how state agencies can work together to focus funding on the most cost-effective solutions. It provides a four-step framework for cost-effective multidisciplinary safety decision-making.

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[2] Highway Safety Improvement Program (HSIP) Fact Sheet, Federal Highway Administration, MAP-21 web site, 2012.

The first step in the framework is to establish a group of individuals or leaders committed to promoting cost-effective solutions to safety problems who will guide the process. Leadership also is responsible for identifying goals and performance measures to focus attention on reducing injuries and fatalities. Specific actions include: 1) identifying transportation safety as a priority by high-level leaders, 2) maximizing funding flexibility, 3) emphasizing the SHSP, and 4) conducting pilot applications of multidisciplinary project management teams.

Step 2 identifies 4 E strategies to address safety issues. In this step, crash data are evaluated to define major crash trends and descriptive statistics. Crashes are characterized using descriptive statistics such as number, type, and severity of crashes by various demographic, environmental, and roadway characteristics. The evaluation also summarizes trends on various aggregate-level such as urban or rural crashes, crashes categorized by driver demographics, pedestrian and bicycle safety, etc. Similar to an SHSP analysis, the results are used to characterize crash conditions in the community, identify the most critical issues, and inform goal identification. The analysis results are presented and discussed in a comprehensive manner considering all disciplines to support subsequent multidisciplinary solutions.

Step 3 compares and prioritizes safety strategies by cost-effectiveness and other considerations. A number of questions related to such things as legal feasibility, political support, technical capacity of the staff, co-benefits associated with the safety strategies, cost, benefit/cost ratios, and cost-effectiveness may be considered as part of safety project prioritization.

Step 4 focuses on the implementation of selected strategies and the evaluation of the results.

Figure 3.1 Cost-Effective 4 E Investment Decision-Making

Additionally, NCHRP 17-46 proposes two methods (sketch-level and quantitative) for comparing the cost-effectiveness of safety countermeasures. The quantitative method is appropriate when detailed, quantitative results are desired and sufficient data exists to make quantitative assumptions for all variables in the analysis, including crash modification factors, duration of effectiveness, geographic extent of effectiveness, costs, and so forth. The sketch-level method is appropriate when quantitative information is unavailable or when detailed results are not required. These methods can be used to more effectively and efficiently address road safety issues using multidisciplinary, multimodal, multiagency solutions.

Future Steps Toward Fully Cost-Effective Safety Decision-Making

NCHRP 17-46 provides resources to help advance the state of the safety practice toward more cost-effective investment decision-making. However, implementation of the methods may be challenging for many states given the continuation of agency funding silos. Future policy changes at the state and Federal levels would be needed to allow full implementation. Some changes could include:

- Creation of new state or Federal safety grant funding sources that would allow different solutions (engineering, enforcement, emergency response, education) to compete for scarce resources on the basis of their cost-effectiveness.
- Further improvements to the flexibility of existing state and Federal funding sources.
- Increased Federal-level emphasis on cost-effectiveness as a key criteria for prioritization of safety strategies.
- Further research to help support data-driven analysis of the relative cost-effectiveness of different safety solutions.