NCHRP Project 17-48

HIGHWAY INFRASTRUCTURE AND OPERATIONS SAFETY RESEARCH NEEDS

FINAL REPORT:

APPENDICES

April 2013

Contents

Appendix A. Prioritizing Projects: General Considerations

Prioritize Projects to Align with Strategic Plan

by George Sifri (March 27, 2003)

Search Term: prioritize strategic plans
http://articles.techrepublic.com.com/5100-10878_11-5030443.html

Need for a project selection and priority system
The need for a project selection and priority system stems from the following observations:

- Organizations frequently pursue many projects simultaneously. Almost inevitably, the number of small and large projects in a portfolio exceeds the available resources such as funds, equipment, and competencies.
- Politics exist in every organization and can have a significant impact on project selection.

Without an effective project selection and priority system, the capacity overload coupled with project politics will lead to frustration, confusion, and inefficient use of resources.

Questions that need answers
Some of the questions that we need to tackle when considering a project selection and priority system are:

1. How can we minimize the power of politics?
2. How can we consistently prioritize projects to support the organizational strategy?
3. How can we use the prioritized list of projects to allocate organizational scarce resources?
4. How can the process encourage bottom-up initiation of projects that support organizational goals and strategies?

Projects are the tools for implementing the strategy of the organization. Effective project management starts with selecting and prioritizing projects that support the organizational mission and strategy. Selection and prioritization of projects requires the use of a decision model in association with specific criteria to allocate resources to these projects in order to maximize value added.

Choosing and Deploying a Project Priority Selection System

by George Sifri (April 10, 2003)

Search Term: prioritize strategic plans

http://articles.techrepublic.com.com/5100-10878_11-5030218.html?tag=rbxccnbtr1

Project managers can choose from a relatively large number of project priority and selection models. Identifying a selection model is highly dependent on certain organizational attributes such as industry, risk aversion level, technology, competition, management style, and markets.

Selection models should encompass multiple criteria such as profitability, researching new technology, public image, core competencies, and strategic fit.

The selection process

It is a rare case when project managers "must" select a project. This may occur, however, when the majority of the project stakeholders agree that the project is crucial and needs to be implemented. For all remaining projects, it is desirable to use multiple selection criteria, which link the project to the organizational strategy.

Proposals screening

Proposals for projects come from internal and external sources. In most situations, organizations have more proposals on hand than they can pursue. These proposals have to go through a screening process as shown in the figure below.

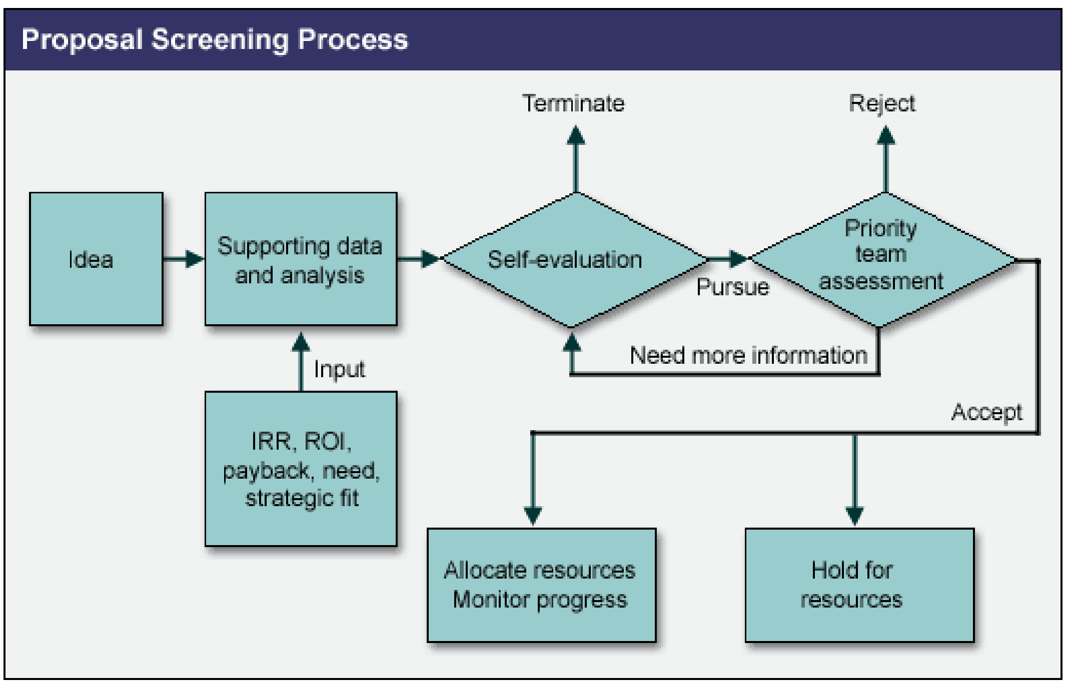


Figure 1. Proposal screening process

The prerequisites for implementing an effective screening process are:

1. Publishing of the selection criteria so that self-evaluations are carried out by sponsors before they are submitted to the priority team.
2. Publishing guidelines and templates for developing a business case, which will facilitate the evaluation process by the priority team.

The priority team

In order to effectively prioritize projects or programs, it is necessary to clarify the roles and responsibilities of the priority team. The priority team is responsible for:

1. Evaluating project proposals on the basis of the selection criteria.
2. Accepting or rejecting proposals.
3. Publishing the score of each proposal and ensuring the process is open and free.
4. Balancing the portfolio of projects for the organization.
5. Evaluating the progress of the projects in the portfolio over time.
6. Reassessing organizational goals and priorities if conditions change.

Selection criteria

Selection criteria should be developed based on the strategic goals of the organization. Failure to select the right factors will render the priority and selection process useless. Examples of selection criteria include:

1. Alignment with core competencies.
2. Alignment with strategic goals.
3. Internal rate of return in excess of (a certain number, say 15 percent).
4. Improvement of customer service.
5. Urgency.

Each criterion may be weighted by its relative contribution and importance to the overall goals and strategic plan. The priority team evaluates each project by its relative contribution or benefit to the selection criteria. Each criterion is assigned a value from the applicable range of scores (e.g., 0 to 10). The total score for a project is then based on the score of each individual criterion as well as the relative weight of each criterion.

Implementing a centralized project priority and selection system provides a comprehensive approach to aligning projects with the overall organizational strategy. The system allows the managements of projects by controlling the use of scarce resources and balancing risks. There is, however, a need to evaluate all projects using the same selection criteria and to enforce the project priority system. Furthermore, maintaining this system so that it remains open and aboveboard is crucial in sustaining its integrity. The priority team needs to communicate which projects are approved project priorities or ranks, status of in-progress projects, and changes in project selection criteria. This type of systematic approach will enable the integration of goals and strategies with a portfolio of projects selected through a proactive process.

Prioritize Your Strategic Initiatives

Search Term: prioritize strategic plans

http://demandmetric.wordpress.com/2009/02/06/prioritize-your-strategic-initiatives/

Strategic planning is a great way to identify which initiatives can add the most value to an organization. The next step is to prioritize initiatives with a systematic method.

What are the Most Important Considerations?

Feasibility

- **Customer Value (CV) -** what value does this deliver?

- **Economic Upside (UP)** – what impact could this have on revenue?
- **Industry Attractiveness (IA)** – How well is this competitively positioned?

Strategic Fit

- **Fit with Goals & Objectives (CG)** – is this aligned to our goals?
- **Ease of Implementation (EI)** – how difficult would this be to do?
- **Skills & Resources (SR)** – do we have the required resources?

Risk

- **Over Forecasted Budget (OB)** – how likely is this initiative to go over-budget?
- **Over Forecasted Timeline (OT)** – how likely is this initiative to go over-time?
- **Technical Risk & Complexity (TR)** – how complicated is this initiative?

Action Plan:

1. **Evaluate each Initiative -** score each initiative based on its feasibility, strategic fit, and risk, to obtain a score out of 100 for each.
2. **Sort Priority Index** – once the scoring process is complete, sort the initiatives by total overall score (highest to lowest).
3. **Delegate & Execute** – once the initiatives are prioritized, start with the most important and urgent projects.
4. **Review** – get into the habit of updating the strategic plan, and revisit the prioritization process to ensure it is producing the desired results.

Bottom-line:

A strategic plan without rigorous prioritization will not be effective. Develop a strong and systematic prioritization process to ensure maximum value from projects, given the time and resource constraints.

Appendix B. Prioritizing Projects: Specific Examples from the Transportation Field

North Carolina Department of Transportation

Transformation Management Team, Final Report, Volume Five: Strategic Planning and Prioritization

Search Term: prioritize strategic plans

http://www.ncdot.org/download/performance/Volume5.pdf

The North Carolina DOT developed a strategic planning and prioritization process toward an overall mission that:

1. Allows NCDOT to create and periodically refresh strategic plans based on its vision, mission, and goals.
2. Gathers input from stakeholders with a systematic process.
3. Generates a transparent system for prioritizing projects, programs, services, and initiatives.

Two outcomes of particular interest to this project include:

1. Three-cycle Strategic Planning Process.
2. Strategic Planning Manual which documents the three-cycle process.

Strategic Planning and Prioritization Guidelines

Three planning cycles were established to set long-term strategic direction and priorities as follows.

1. Every four or eight years, the Strategic Planning Office of Transportation (SPOT) leads a review of their current direction and strategy and recommends any necessary changes for leadership to consider. This effort looks out 30 years and occurs at the change of administration. Activities include refreshing the latest needs and revenue forecasts; collecting internal and external data and gathering input from all of our stakeholders to guide decision making; updating the Department's vision, mission, goals, and objectives; and developing a Strategic Plan which charts the Department's course.
2. Every two years, the Department and each Business Unit update their current strategy and develop a list of prioritized solutions for the next five to ten years. Activities include assessing the current and future operating environment, updating both the Department's and each Business Unit's Strategic Plan, and prioritizing both transportation system and Business Unit solutions to address identified needs. Outputs include:
    a. A set of solutions prioritized without regard for funding restrictions based on an expected outcome (what we need to do).

   b. A set of solutions prioritized with regard for funding restrictions based on an expected outcome (what we can do).
   c. A plan indicating the activities expected to be implemented (what we plan to do). This plan is composed of the Department's budget request and the State Transportation Improvement Program.
3. Annually, Business Units develop Action Plans based on the Strategic Direction and Prioritization processes to help positively influence both the Unit's and the Department's performance results. Action Plans focus on key items flowing directly from the Unit's and Department's performance as it relates to metrics. Activities include reviewing and evaluating the Business Unit's performance; developing and launching an Action Plan for the Unit; and then monitoring the Unit's performance and adjusting the Action Plans as needed.

The Strategic Direction process (8-year) is more of a top-down effort, led by SPOT with direction from NCDOT and State leadership. The Strategic Prioritization process (2-year) is both top-down and bottom-up, led by SPOT using both direction from NCDOT, State leadership, and Business Units. The Action Planning process (annual) is a bottom-up effort, driven by the Business Units.

The following provides an overview of the three cycles. This is followed by a detailed summary of the second cycle (prioritizing strategies), which directly pertains to this research effort.

<u>Set Strategic Direction (8 year frequency)</u>

The Department identified several questions that help to define the overall vision, mission, and goals. The following list identifies the three general questions and the corresponding areas that stems from the answer to each question.

1. What direction do we want go?
   a. NCDOT Aspirations and Initiatives.
2. What is our purpose?
   a. Vision and Mission.
3. What do we want to be in the future?
   a. Goals, Objectives, and Targets.

There are five steps in the Strategic Direction Process.

Step 1: Develop Long-Range Statewide Multimodal Transportation Plan
The first activity of the Strategic Direction Process is to develop a long-range statewide multimodal transportation plan (Statewide Transportation Plan). It is used to establish a long-range blueprint for transportation investment in North Carolina.

Step 2: Collect Pre-Work
"Pre-work" is the collection and evaluation of external and internal views of transportation. External views include transportation-related demographics, trends, and customer input on strategic direction. Internal views include performance and capabilities and gap analysis.

Step 3: Develop Vision & Initiatives
Developing a renewed vision and identifying initiatives is the third activity of the Strategic Direction Process. This is the direction provided by the state leadership and the top leadership of NCDOT.

Step 4: Gather Stakeholder Input

This activity occurs when all interested stakeholders have an opportunity to provide comments on the current mission, values, goals, and objectives. The process for gathering input is complex and the intent is that there are many opportunities to provide input to help determine the overall Direction. At the very least, input is collected directly from Metropolitan Planning Organization (MPO) and Rural Planning Organization (RPO) stakeholders and the public at regularly scheduled meetings. The intent to gather input at these meetings is announced in advance. In addition, input is collected through focus groups and random surveys to provide a representative sample of citizens.

Step 5: Update Mission, Values, Goals, Objectives, and Targets
This is the last activity of the Strategic Direction Process where the Secretary, Board of Transportation, and the Strategic Management Committee update NCDOT's Mission, Values, Goals, Objectives, and Targets.

<u>Develop Strategic Prioritization (2 year frequency)</u>

Criticisms of the previous prioritization process are that it was ad-hoc, reactive, often involved too many decision-makers, and generally was not visible to the stakeholders and the general public. Project selection emphasized local priorities and external inputs at the expense of systematically addressing long-term statewide needs.

The new approach establishes a formal, documented, and visible prioritization process. It is a collaborative effort between Business Units and stakeholders to ensure the right portfolio of projects, programs, services, and initiatives. The approach is data-driven and geared to achieve both short-term and long-term goals and objectives, while working toward the overall vision and mission. Solutions that address the needs are ranked with the appropriate perspective (statewide, regional, or local). This process allows for a possible business case to be made for additional flexibility and funding.

<u>Create Action Plans (1 year frequency)</u>

An Action Plan is used on a daily or weekly basis to work toward the mission and goals. Action plans should include an action item, owner, schedule, budget, goal/metric, and potential barriers. Several questions were identified for this task as well to help develop meaningful action plans.

Overview of Strategic Prioritization Process

The strategic prioritization process involves several steps that are outlined below.

Step 0: Identify Needs and Corresponding Solutions

This step takes place prior to the prioritization process and includes the identification of Business Unit needs and Transportation Infrastructure needs as well as solutions to meet these needs.

- Needs = challenges, obstacles, or voids which impede the Department from achieving its goals, objectives, and/or targets.
- Solutions = projects, programs, services, or initiatives which address one or more needs.

Each Business Unit assesses demographics, trends, resources, legislative and policy changes, finances, and other challenges. Each Business Unit then reviews their performance measures (i.e., targets and results) over the past two years or more and assesses its strengths, weaknesses, opportunities, and threats (current and looking forward ten years). Based on these assessments as well as the Department's overall strategic plan, each Business Unit updates its Strategic Plan and develops solutions for improving performance and/or addressing any challenges. The following are considered in identifying solutions:

- The relative importance and/or danger posed by each strength, weakness, opportunity, and threat.
- The cost-benefit and/or risk assessment analysis for each solution.
- Strengths and opportunities that are natural matches.
- Solutions that affect multiple Business Units should be collaboratively identified.

Transportation infrastructure solutions are compiled from various sources, including planning documents, partners (e.g., MPOs and RPOs), and/or external stakeholders (e.g., general public). During this time, local governments (MPOs & RPOs) also submit their list of prioritized needs to the Program Development Branch, which forwards these needs to the responsible Business Units as appropriate. Local governments will be consulted during the prioritization of other projects as appropriate.

Step 1: Prioritize Business Unit and Transportation Infrastructure Solutions

<u>Prioritizing Business Unit Solutions</u> – The Department has a two-level prioritization process for Business Unit solutions. First, each Business Unit prioritizes its solutions in relation to the Department's mission and goals (in collaboration with other Business Units as necessary). Information on each solution is documented using case templates to effectively compare and rank various types of solutions. Second, the solutions are submitted to the strategic planning office, where they are ranked across the Department based on the advancement of the Department's goals and objectives.

Business Units have both quantitative and qualitative tools to evaluate and prioritize solutions. Business case templates are the summary of the quantitative and qualitative data that support the particular solution. These data include the purpose, benefits, cost, and technical merits, along with subjective elements such as intermodal connectivity, geographic balance, economic importance, and relevance to a particular NCDOT objective. Any risks or potential risks associated with the solution are also included in the templates. The case templates are also used in the next step by the strategic planning office to compare and evaluate needs throughout the Department.

<u>Prioritizing Transportation Infrastructure Solutions</u> – Transportation infrastructure solutions (i.e., specific projects) are ranked and prioritized using a more formal, data-driven process developed by the responsible Business Unit. Each solution is evaluated on the outcome and cost-effectiveness, using a well-defined quantitative scoring tool. Input may include such items as existing pavement condition, volume-to-capacity ratio, crash frequency, operating speed, and the anticipated outcomes of the proposed improvement (e.g., improvement in pavement condition, future volume-to-capacity ratio, crash reduction, or the effect on the entire transportation network). The output is a technical score, such as benefit-cost ratio. Where a quantitative analysis is not feasible, solutions are evaluated and ranked using case templates (similar to ranking of the Business Unit's needs)

While one Business Unit has the primary responsibility for prioritizing a specific component of the transportation system, there is extensive collaboration with other Units and partners, particularly the Transportation Divisions and MPOs and RPOs. Input received from the Board of Transportation, public, and other stakeholders is also considered during the ranking discussions. An impact and implementation prioritization matrix (see figure below) may be used to assist in ranking the projects. This matrix helps to sort projects based on anticipated impact and ease of implementation.

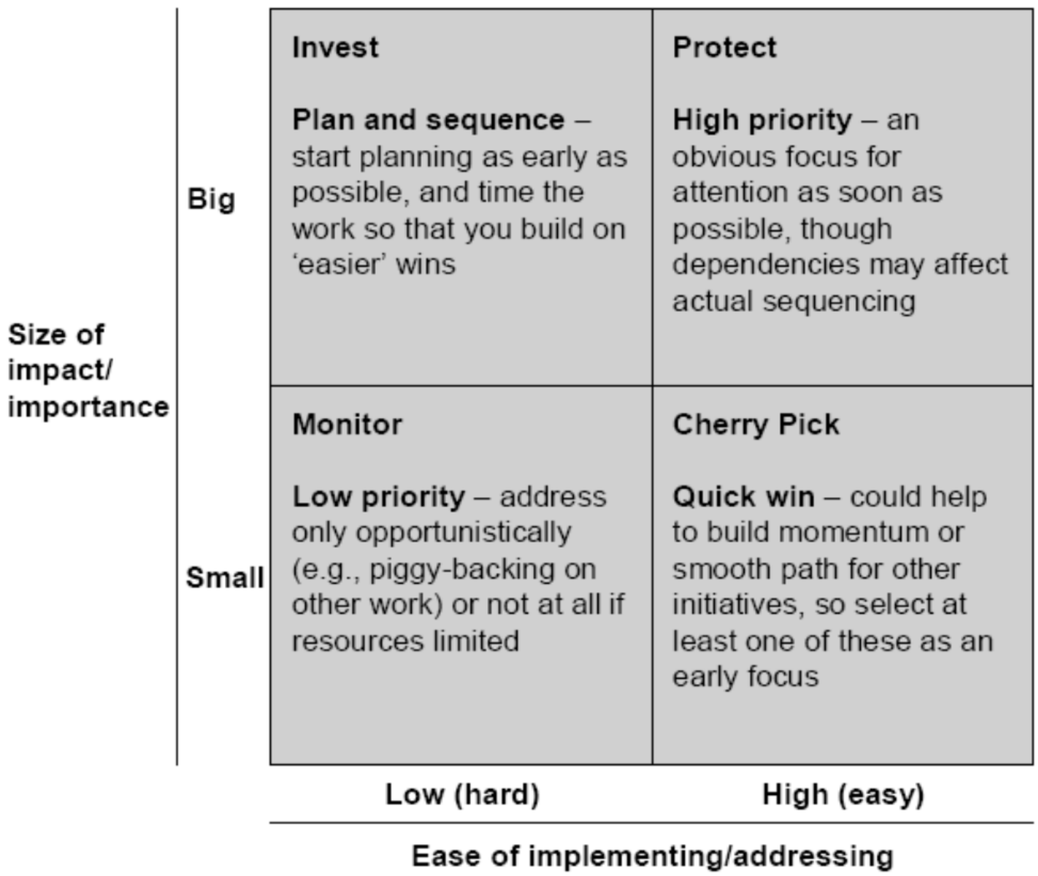


Figure 2. Impact and Implementation Prioritization Matrix

A cost estimate is developed for the transportation solutions based on maintaining the current LOS, achieving the target LOS, and all grades in between. For example, if the current LOS for a particular category is D+ and the target LOS is B-, the responsible Business Unit would submit the following cost information:

- To maintain the current LOS (D+), $100M is needed
- To achieve a C-, an additional $75M is needed ($175M total)
- To achieve a C, an additional $125M is needed ($300M total)
- To achieve a C+, an additional $142M is needed ($442M total)
- To achieve the target LOS (B-), an additional $178M is needed ($620M total)

Transportation infrastructure solutions are described by tier, category, and mode in order to tie the Department's investments directly to performance targets. For example, to achieve a level of service (LOS) *x* for infrastructure health on the statewide tier, *y* improvements would need to be completed, with a cost of *z*.

Step 2: Prioritize Department Solutions

The strategic planning office manages the prioritization process and makes recommendations on the final set of solutions to fund. This involves the consolidation, evaluation, and selection of the infrastructure and business solutions from each Business Unit. The strategic planning office receives and reviews the ranked Business Unit solutions and Transportation Infrastructure solutions with their associated LOS costs. A Department-level list of prioritized Business Unit solutions and a Department-level list of prioritized transportation infrastructure solutions are then developed.

Based on the Department's goals, objectives, and targets, different investment scenarios are developed to determine the correct mix of projects, programs, services, and initiatives to fund. Each investment scenario describes the percentage of funding of the total budget that should be invested in each category, the list of funded Business Unit solutions, the list of funded transportation infrastructure solutions, and the expected performance outcomes. Business Units are consulted during the process to help derive tradeoffs between scenarios (e.g., if $X is spent on bridge replacement, outcome Y could be achieved). SPOT also evaluates obstacles to implement, interdependencies, and the impact of all projects, services, programs, and initiatives.

Investment scenarios are developed at two levels, 1) unrestricted scenarios, and 2) restricted scenarios. The unrestricted scenarios allow the strategic planning office to evaluate options, which show the outcomes that could be achieved if additional funding flexibility and/or additional funding were provided. The scenarios consider current estimated budget and the amount needed to reach desired outcomes (targets). The unrestricted scenarios do not consider laws (such as the equity formula), policies, regulations, and other restrictions which govern how funds can be spent. A preferred unrestricted investment scenario is recommended to the strategic management committee for approval. The management committee reviews each of the scenarios and considers recommendations before selecting the final preferred option. If needed, the management committee can request additional scenarios be developed and evaluated. The outcome of the management committee's recommendation is referred to as the Department's unrestricted prioritized needs – **the investments the Department needs to make**.

The next step is to develop restricted scenarios based on the Department's unrestricted prioritized needs (i.e., match the list of prioritized needs to the available funding with associated restrictions). The Financial Management Division, including the Program Development Branch, work with other Business Units to provide a best-fit of funds with the prioritized unrestricted needs, based on restrictions which govern how the Department's funds can be spent. Restrictions include state and federal laws, regulations, and policies, such as the equity formula and air quality conformity. The outcome of this step is a set of prioritized restricted needs – **the investments the Department can make**.

Step 3: Submit Budget Request and Develop State Transportation Improvement Program

Using the prioritized restricted needs as the basis, the Financial Management Division finalizes the Department's budget request, working with other Business Units and the management committee as appropriate. Similarly, the Program Development Branch works with the management committee, Division Engineers, the BOT, and MPOs to develop the Draft and Final State Transportation Improvement Program (STIP). The approved budget and the Final STIP are the investments the Department plans to make. Following the approval of the budget and adoption of the STIP, each Business Unit will assess its resources to ensure delivery of the solutions.

Specific Considerations within the Strategic Prioritization Process

What gets Prioritized?

All solutions are prioritized or reprioritized every two years, except for activities "locked down." There are times when considerable resources have been invested to plan activities. Assuming the need for the activity still exists and the decision is made to move forward, these activities are considered "locked down” and are not included in the prioritization process, unless a significant change or major event occurs. A project is considered “locked down” if it is listed in the delivery portion of the STIP. The “lock down” designation helps ensure that projects late in the development process are not reprioritized without good cause.

How is the Public Engaged in the Prioritization Process?

The public has multiple opportunities to provide input in the prioritization process. The prioritization process starts with the Department soliciting input on all needs. The Public Involvement and Community Studies Section, working with the Program Development Branch and the Transportation Divisions, conduct biennial input meetings throughout the state. The meeting objectives are to receive comments from citizens, business leaders, and other stakeholders on the Draft STIP and to capture input on what the Department’s priorities should be for the next cycle. The input received at these meetings is provided to the appropriate Business Unit for use in the quantitative and qualitative evaluation process. The public also has opportunities to provide input through the MPOs/RPOs.

How are Board of Transportation Members Involved?

Board of Transportation (BOT) members have input into the prioritization process in several places. The BOT is integrally involved with the update of the Department’s Strategic Plan and ultimately approves the document. The Transportation Divisions take the lead in ranking many different projects on the transportation system, while jointly collaborating on others. The Division Engineers coordinate their efforts with BOT members for their input on and ranking transportation solutions. BOT members also are able to provide input into the MPO and RPO priorities.

How is Risk Incorporated in the Decision-Making Process?

Managing risks are a critical piece in the prioritization process. The decisions and tradeoffs that are made during the process all have an associated risk. Managing risk is incorporated in the prioritization process at multiple points beginning with the first step in assessing the Department’s current and future operating environment. The following questions should be asked initially and also apply to the individual Business Units as they conduct their own analysis:

- What are the Department’s strengths and weaknesses (internal capabilities)?
- What are the Department’s opportunities and threats (external influences)?
- How should the Department’s strengths be used to take advantage of opportunities?
- How should the Department overcome the weaknesses that prevent us from taking advantage of opportunities?
- How should the Department use our strengths to reduce the likelihood and impact of any threats?
- How should the Department address any weaknesses that will make any threats a reality?

Risk assessment is incorporated in the case templates for projects, programs, and services. For each activity, the degree of risk is weighed against the potential impact of the activity. Different types of risks include:

- Risk of environmental challenges.
- Risk of stakeholder opposition.
- Risk of economic impact.
- Risk of harm to reputation.
- Risk of cost overrun.

- Risk of time overrun.
- Risk based on high complexity of project.

The risks associated with each project, program, service, and initiative are carefully considered during the development of various investment scenarios. Potential mitigating strategies are also considered to address these risks.

How Does the Prioritization Process Evolve?

As the prioritization process is embraced and institutionalized within the organization, modifications and adjustments may be necessary over time to further refine the effort. The strategic planning office is responsible for overseeing the prioritization process and making enhancements as needed. Comments and feedback on any improvements should be provided to the Director of the strategic planning office.

Communication

Communication is critical throughout the strategic prioritization process to ensure success and to meet the schedule. Throughout the process, many units collaborate with each other and with other partners, stakeholders, and the public. Items of particular importance include the following.

- The Department's current and future operating environment and performance are clearly communicated with the BOT and are reflected in the Strategic Plan update, which is subsequently communicated to the Business Units.
- Needs of each Business Unit are communicated with other Business Units as appropriate.
- Each Business Unit's strategic plan is communicated to its employees as appropriate.
- The public is clearly informed of the opportunities for input on needs and this input is clearly communicated to the appropriate Business Units.
- The Business Units responsible for ranking solutions collaborate with other Units as appropriate when developing the priority order.
- The Strategic Planning Office collaborates with the Business Units to develop different unrestricted investment scenarios.
- The Strategic Planning Office communicates with the management committee as restricted priorities are developed.

Of most importance, the final report should be clearly communicated and marketed within the Department and to partners, stakeholders, the public, and the media. This document provides visibility of the prioritization process by describing: the input, the scenarios evaluated, the decisions made, the anticipated effects of those decisions, and the need for additional funding and/or funding flexibility.

NATIONAL RESEARCH COUNCIL - TRANSPORTATION RESEARCH BOARD

Search Term: prioritize transportation research

http://onlinepubs.trb.org/onlinepubs/reports/rtealtr.html

On September 4, 1997, a letter was sent to the Honorable John H. Gibbons, Assistant to the President for Science and Technology, outlining four major recommendations that address the following:

1. Sustaining and strengthening the strategic planning process.
2. Strengthening the strategy.
3. Implementing the strategy.
4. Developing a strategic plan for transportation R&D within DOT.

These recommendations were developed by the Committee on the Federal Transportation R&D Strategic Planning Process after reviewing the transportation science and technology (S&T) strategy. The committee was convened by the National Research Council, acting through the Transportation Research Board (TRB), at the request of the Executive Director of the National Science and Technology Council (NSTC) Transportation R&D Committee.

The committee first heard presentations on the objectives, development, and proposed implementation of the strategy, and discussed these topics with members of the Transportation S&T Strategy Team and with representatives of the U.S. Department of Transportation (DOT) and other federal agencies involved in transportation R&D. The committee then met in executive session to deliberate and develop a report.

Notably, the number one recommendation of the committee was to sustain and strengthen the transportation S&T strategic planning process. The first part of the second recommendation was to prioritize proposed R&D activities. The following provides a summary of the committee's recommendation as it applies to this research project.

Recommendation 1
The transportation S&T strategic planning process should be sustained and strengthened.

The transportation S&T strategy offers the potential for ensuring cost-effective R&D focused on the nation's future transportation needs. Federal R&D budgets are limited, and a coordinated approach to R&D and related priorities are essential to obtain a higher return on federal R&D investment.

The transportation S&T strategic planning process should be continued over the long term and institutionalized. Well-directed effort will be needed to support the current planning initiative over the next several years, specifically:

- Involvement of senior administrators and first- and mid-level R&D managers within the federal government to maximize the impact and ownership of the strategy (particularly within DOT).
- Integration of top-down and bottom-up approaches to strategy development to ensure an appropriate focus on high-level objectives, together with identification of related R&D opportunities.
- Limiting of resource requirements for strategic planning by continuing the present collaborative approach involving a small team of partners, together with the involvement of constituent groups.

The strategic planning process itself, and not just its implementation, should be extended to include participants from industry, academia, state departments of transportation, users of transportation systems, and others representing the diverse constituencies in the transportation community. The involvement of a broad spectrum of participants is essential to:

- Identifying the R&D activities most relevant to the nation's future transportation needs, including those in research areas that are not technology-based.
- Identifying and leveraging ongoing transportation-related R&D activities and resources, and eliminating unnecessary duplication.
- Identifying organizations capable of performing the most cost-effective R&D, whether they are in government, industry, or academia.

Greater emphasis should be placed on the iterative nature of the strategic planning process, which should include reviewing previous years' research outcomes, evaluating investment impacts, and incorporating the results of these activities in periodic updating of the strategy. Incorporation of feedback from constituent groups within the transportation community on the achievements and failures from previous planning cycles should be an essential part of this effort.

Recommendation 2

The current transportation S&T strategy should be strengthened in three major ways as the planning process moves forward.

A. The proposed R&D activities should be prioritized. One of the most urgent and important steps to be taken in strengthening the strategy is to prioritize the proposed R&D activities, preferably in cooperation with a broad spectrum of constituent groups. The committee finds it difficult to envisage how the strategy can emerge as a useful tool for guiding federal budget allocations in the absence of established priorities. The transportation R&D portfolio should also be developed further to include schedules and milestones.

B. The strategy should be explicitly linked to transportation R&D budget guidance. It is the committee's hope that the strategy will form the future basis for annual transportation R&D budget guidance from the Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP) to the modal administrations within DOT and to other federal agencies. Without such budgetary influence, the strategy cannot survive as a useful planning tool.

C. The linkages between the vision of a transportation system in 2020 and the proposed R&D agenda should be strengthened, and the role of R&D specific to individual modes should be better articulated. The vision statement developed by the NSTC Transportation R&D Committee calls for "a sustainable and seamless intermodal transportation system that effectively ties America together and links it to the world. It will result from a strengthened partnership among government, academia, and the private sector focused on effective management and renewal of existing infrastructure, strategic deployment of new technologies and infrastructure, and on R&D which supports each of these." R&D specific to individual modes should be clearly identified as a component of the transportation R&D portfolio to avoid possible confusion, not only within DOT, but also at OSTP and OMB.

Recommendation 3

The implementation steps identified in the transportation S&T strategy, including a significant broadening of constituency participation, should be taken now to realize the most important benefits of a coordinated approach to R&D.

Development of the transportation S&T strategy has already resulted in benefits from increased communication among federal research managers. Nonetheless, the committee considers that the most important benefits of the strategy will come from its implementation-particularly through impacts on federal R&D funding allocations-rather than from the planning process.

As with the strategic planning process, the full advantages of strategy implementation will be realized only if the diverse constituencies of the transportation industry are included. There needs to be increased recognition of the fact that most of the nation's transportation assets-both vehicles and infrastructure-are owned and operated by state, municipal, or private groups and individuals, not by the federal government. Implementation of an appropriate set of partnership initiatives, in collaboration with industry, academia, state departments of transportation, and other constituent groups, offers the possibility of developing and implementing new technologies in an expeditious manner and evaluating the overall outcomes of R&D for the transportation system.

Recommendation 4

DOT should develop its own integrated strategic plan for transportation R&D, including budget authority and appropriate management authority and responsibility at the agency level.

DOT's role as a leader in the transportation S&T strategic planning process would be enhanced if the agency had its own coordinated DOT-wide R&D agenda, linked to the nation's future transportation requirements. The committee urged the DOT to develop an integrated department-wide R&D strategic plan that gives attention to the development of an intermodal transportation system, but does not exclude programs specific to individual modes. A department-wide R&D strategic plan could result in increased communication, cooperation, and coordination among modal administrations and mutual benefits for their specific missions. Organizational changes, especially regarding budget and program authority, will probably be needed if such an integrated DOT-wide R&D strategic plan is to be implemented.

Summary and Conclusion

Among the general and specific recommendations and observations resulting from the committee's review and deliberations, two major points emerge:

- There is a need to broaden constituency involvement beyond Washington-based federal agencies in both the transportation R&D strategic planning process and implementation of the strategy.
- There is an urgent need to prioritize the proposed transportation R&D agenda, preferably in cooperation with a broad spectrum of constituents from private companies involved in various aspects of transportation, state and local governments, and the research community. Priorities are essential if the strategy is to become a useful tool for guiding federal budget allocations.

Checklist for a Good Federal Transportation Research Agenda

As part of the committee's letter, appendices and attachments were provided, including a checklist for developing a research agenda. The checklist included the following items:

- Is tied to a vision of the future transportation system, and deals with the present system to create pathways to the future.
- Has a technology scan component.
- Pays attention to the development of an intermodal transportation system but does not exclude programs specific to individual modes.
- Includes research in technology, systems, and institutions.
- Recognizes the importance of conducting research in underlying technologies and concepts that extend across modes and could serve a variety of applications.
- Is efficient, well managed, and pragmatic with respect to funding sources.
- Is ideologically robust and thereby able to survive political change.
- Sets priorities among the research, and includes a portfolio of short-, mid-, and long-term research.
- Includes an appropriate agenda for education and training.
- Takes advantage of the franchise assets of the federal government, as well as the potential for private-sector cost sharing.
- Is consistent with private-sector research, as well as with state and other federal government research programs.
- Supports transportation efficiency and effectiveness in the United States, as well as enhancing U.S. competitiveness in the global marketplace.
- Is related to other parts of the innovation cycle through deployment.
- Is sensitive to "organizational readiness" needed to deploy research results.
- Sufficiently emphasizes validation and deployment and takes advantage of stakeholder commitment to the research and its implementation.

Research and Innovative Technology Administration (RITA)

Search Term: prioritize transportation research

http://www.rita.dot.gov/about_rita/

Process for Coordinating Research

Within the DOT, much of RITA's coordinating function is overseen by the Research, Development and Technology (RD&T) Planning Council. The RD&T Planning Council is an advisory board composed of all of DOT's modal Administrators and chaired by the RITA Administrator. Through its leadership of the Council, RITA managed the creation of the DOT Five-Year RD&T Strategic Plan to guide DOT's research agenda through FY 2010.

The DOT's individual operating administrations continue to conduct research based on their unique agency missions, mandates, and stakeholder needs. The RD&T Planning Council ensures that DOT's research and technology programs are integrated and that they fully support DOT's strategic objectives. Specifically, the Council works to:

1. Prioritize transportation research programs.
2. Identify innovation gaps.
3. Coordinate research and technology efforts within DOT and throughout the transportation community.

Transportation Research Program Administration in Europe and Asia

Search Term: prioritize transportation research

http://international.fhwa.dot.gov/pubs/pl09015/appa.cfm

Elston, D., D. Huft, B.T. Harder, J. Curtis, M.R. Evans, C.W. Jenks, L. McGinnis, H.R. Paul, G. Roberts, E. Wingfield, and J.B. Wlaschin. Transportation Research Program Administration in Europe and Asia. Federal Highway Administration, Office of International Programs, FHWA-PL-09-015, Washington, DC, 2009.

In 2008, a team from the United States conducted an international scan to review and assess administration practices for transportation research. The goal was to identify options for enhancing the administration of transportation research in the United States. The scan focused on program-level activities, including the development of a research framework and setting research priorities.

The scan team visited Belgium, France, Japan, the Netherlands, South Korea, and Sweden. A common theme among the countries is that strategic and policy-driven research frameworks are the standard. Transportation research frameworks are developed at the national level through a strategic process. The frameworks are comprehensive in that they include all aspects of society, not just transportation, and are developed to support national policy goals and objectives. Societal goals are the principle factor influencing the development of the framework, not industrial goals.

The success of these national research frameworks is associated with the involvement and buy-in of stakeholders. Senior-level individuals often play an important role (e.g., champion) in the national program focus and support, but are not the only stakeholders involved in the process. Other stakeholders include members of federal, state, and local government agencies as well as universities, foundations, institutes, private sector, and the general public. It was noted that academic partners play a more integral role in the development of the research framework compared to the United States. Stakeholders are involved from an early stage and work together to align the research framework with a common vision. In this way, there is a sense of ownership among all stakeholders. It was also noted that collaboration begins much earlier in the research process in other countries than in the United States.

Another common factor among the countries visited is the use of a top-down approach with bottom-up input to identify issues and priorities. An example is the Rijkswaterstaat Transport and Navigation Department (DVS) in the Netherlands. In this framework, "corporate considerations linked to policy outcomes are incorporated with regional experiences and linked to daily operations." Workshops are held to help identify research program areas and topics of importance to the field organizations.

Other countries employ multi-tiered strategic planning activities to develop their framework. For example, France develops a mid-range plan that includes its strategic priorities for a four-year period. An example was provided to the scan team, which included five mid-range priorities (each associated with a corresponding research program). Each mid-range priority included approximately 10 research areas with three to four topics per research area, yielding 150 to 200 research problems. A top-down approach is employed in this planning process, but a bottom-up approach is used to identify proposals for describing and conducting the research.

The South Korean system shares some similarities with the French system, but the research framework is established through formalized strategic planning. The scan team refers to this system as a model transportation research framework. The Korean model integrates top-down guidance for long-range strategic direction with bottom-up input for mid-range project identification. The planning processes are very well defined, including a long-range planning process (i.e., innovation roadmap). Under the overall vision, there are five core values that guide seven research and development programs. The overall vision is "contributing to the enhancement of the quality of life in the future society". The seven research and development programs include:

1. Innovation of construction technologies.
2. Advancement of plant technologies.
3. High-tech urban development.
4. Implementation of more efficient transportation systems.
5. Development of future railroad technologies.
6. Advancement of air transportation and logistics.
7. Development of technological infrastructure policies.

The seven programs are developed with consideration for strategic needs, continuity with existing projects, ministerial cooperation, technology trends, and private and public sector demands. The scan team noted that elements of this long-range planning process are familiar to the United States, but keys to the success of the South Korean framework include:

1. Commitment to developing a process.
2. Assuring that the process serves the organization well.
3. Integration with the national strategic framework.

The national research and development policy is compared with the construction and transportation research and development policy every five years. The long-range plan is developed every 10 years and assessed periodically during the 10-year timeframe. A mid-range plan is developed every five years, and action plans and project plans are developed annually.

The scan team noted that an exemplary research framework is one that is accompanied by well-defined processes to create a comprehensive transportation research roadmap. The Japanese framework is one such example. In Japan, the Japanese Cabinet-adopted Long-Term Strategy Guideline provides societal objectives. The Strategic Guideline is used as a guide during the development of the Technology Basic Plan, which is a component of the country's Science and Technology Basic Plan. The Technology Basic Plan is developed under the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) by working groups of councils established through law. Input is obtained through the following activities:

1. Analyzing prior plans.
2. Surveying regional organizations, research institutions, private sector organizations, and industry groups.
3. Conducting management of technology and research and development workshops that include academic experts and other private sector participants.
4. Review of the Innovation Promotion Outline (adopted at the national level).

5. Public comment.

Using the identified problems and societal goals, Japan develops research and development priorities that return results to society, establish a foundation for innovation, and provide international contribution.

The scan team concluded that the United States should conduct a policy study to analyze the current process (i.e., several independently run research programs) and determine the potential benefits of a nationally coordinated research program where greater funds are allocated to a few critical areas. The scan team noted that a national multimodal research framework should be developed through a collaborative effort that has the flexibility to address local and regional issues as well as national issues. Lessons learned from international practices include the use of an integrated top-down and bottom-up approach as well as the need for collaboration with other sectors to ensure overall societal and economic goals are met.

ITS Strategic Plan

Search Term: prioritize transportation research

http://www.its.dot.gov/strat_plan/ppt/strategic_backgroundv2_files/frame.htm

To develop an ITS Strategic Plan, input was gathered from the ITS Program Advisory Committee, USDOT modal staff interviews, and stakeholder engagement. The following general comments were received from stakeholders to guide the development of a strategic plan:

1. Focus the program.
2. Have an overarching direction.
3. Be vocal.
4. Put forward a vision.
5. Engage the community.
6. Technology is outpacing government research.
7. Change the game to leverage private sector innovation.

An overarching vision was established for the ITS Strategic Plan and supported by three strategic initiatives as illustrated in the following figure.

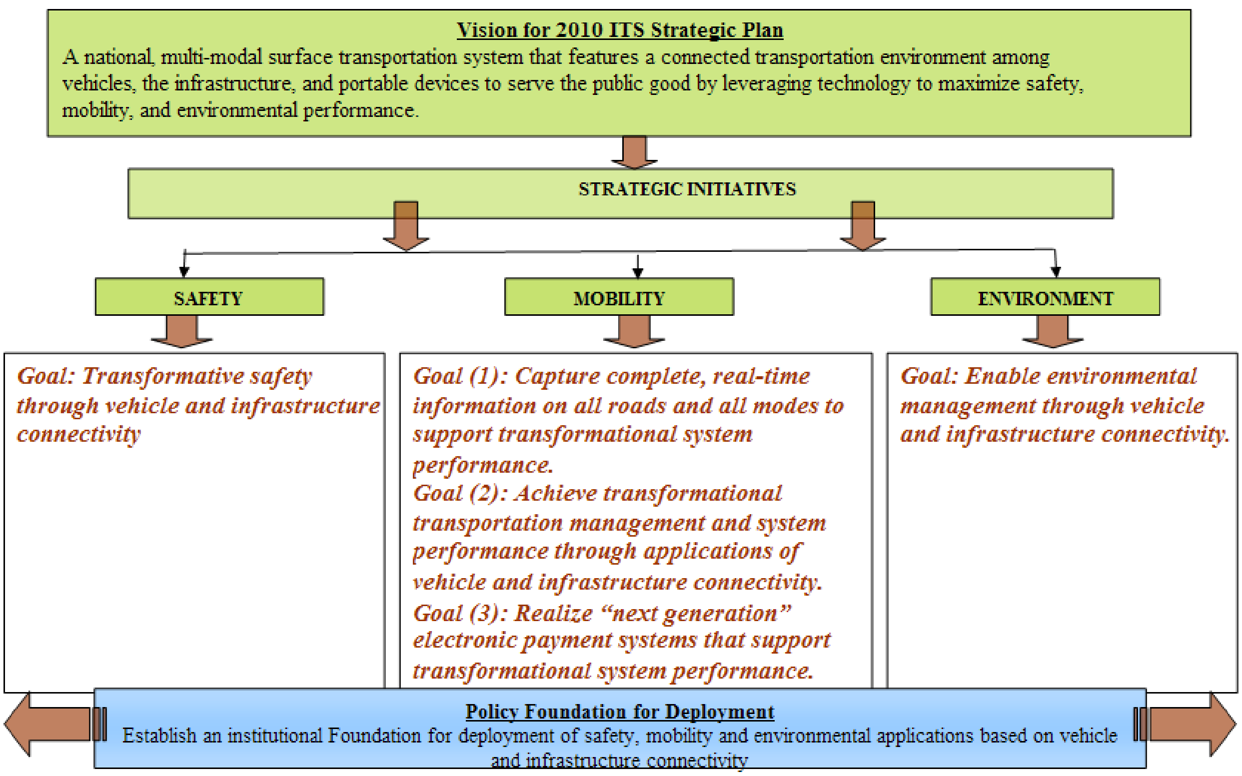


Figure 3. Vision for 2010 ITS Strategic Plan

The development of the ITS Strategic Plan involved the following steps to define their research framework. Dates are identified with each step to illustrate the relative timeframe of events.

1. Senior ITS JPO and USDOT multi-modal staffs establish vision, mission, and goals: April 2009.
2. Form multi-modal teams: April – May 2009.

3. Request for Information (RFI) and public workshop for stakeholder input: May – June 2009.
4. Develop draft ITS research proposals: May – June 2009.
5. Senior ITS JPO and USDOT multi-modal staffs review and provide input: June 2009.
6. Revise ITS research proposals: July – August 2009.
7. Senior ITS JPO and USDOT multi-modal staffs review revised proposals: September – November 2009.
8. ITS Management Council concurrence: December 2009.

Based on input from the stakeholders, the Senior ITS JPO and USDOT multi-modal staffs identified common themes. The following criteria are used for reviewing the proposals in Step 5 (red text indicates critical components):

1. Program proposal must support ITS Program goals and objectives.
2. Focused on large, multi-modal research efforts of national importance.
3. Federal role must be clear and justifiable.
4. Expected to offer a positive, measurable return on investment.
5. Must have champions committed to research success.
6. Will be a market catalyst.
7. Must show strong desire for joint funding so resources can be leveraged for common purposes.
8. Must deliver research results in three to five years, and must be implementable.
9. Must address institutional, regulatory, and policy issues as well as technology issues.

Pedestrian Safety Program Strategic Plan

Search Term: NA

Pedestrian Safety Program Strategic Plan, Background Report (second draft). March 2010.

A Background Report was developed as part of the pedestrian safety program strategic planning process. To develop the report, the project team utilized four main sources of information, including:

1. Data analysis of pedestrian crash and walking trends and expected demographic changes.
2. Literature review of recently published pedestrian safety research and resources.
3. Evaluation of existing FHWA products and dissemination strategies.
4. Stakeholder feedback and expert opinion on research and information needs to advance pedestrian safety efforts.

The methodology for identifying and prioritizing research needs is described in detail as it directly relates to this effort.

Methodology for Identifying and Prioritizing Research Needs

Stakeholder Feedback and Expert Opinion

A one-day stakeholder workshop was conducted to solicit input on needed research and research priorities from a diverse group of stakeholders and pedestrian safety experts. Stakeholders received background information on pedestrian safety trends and research findings before the meeting. To facilitate discussion, the stakeholders were divided into three breakout groups, one of which was assigned the task of prioritizing recommended research initiatives and activities. There were several questions provided to the stakeholders to generate thought and discussion regarding research needs. Examples include:

- What are the predominate types of pedestrian safety problems in your community or jurisdiction?
- What are the missing components (i.e., research or other tools) that are needed to help reduce pedestrian fatalities and injuries?
- Is there an area of research that you would like to learn more about?
- Are there any emerging issues that you believe will become a concern for pedestrian safety in the future?
- Which activities or topics are critical, high, medium, or low priority in terms of assisting you in reducing pedestrian fatalities and improving pedestrian access and mobility? Why?
- Which research projects do you think are most feasible to conduct? Why?
- What major activities or focus areas should be undertaken in the first 5 years? In 5-10 years? In 10 to 15 years?
- Are there opportunities for FHWA to partner with your organization to develop key products/programs or disseminate information?
- Can you think of any potential barriers to implementing this plan? How can these barriers be addressed?
- Are there legal barriers to implementing new or innovative approaches to pedestrian safety?

After the breakout sessions, a list of research topics was compiled. The list of topics included those identified in the workshop as well as all topics previously identified by TRB Pedestrian Committee and listed in the research needs statement database. Each stakeholder ranked each research topic on a scale of 1 to 5, and provided a "top choice" for a research topic within each of the four major topic areas:

1. Problem identification and data collection.
2. Analysis and decision-making.
3. Development and evaluation of countermeasures.
4. Product delivery and technology transfer.

Input from Oversight Group

In this case, the project team served as the oversight group. They were charged with the task of further refining the list of research topics from the stakeholder workshop, taking into account the mission and scope of FHWA's Office of Safety, knowledge of current or past studies documented in the literature, the expertise of pedestrian safety professionals at the FTA and NHTSA, and national pedestrian safety trend data. The following criteria were used to select the highest priority research topics:

- Was the project ranked as a high priority, relative to other topics, by pedestrian safety experts from a range of backgrounds?
- Was the project previously identified as an issue of concern by other organizations (including TRB Pedestrian Committee and Federal agencies)?
- Does the project fill a gap in existing literature or build onto areas where current information is lacking?
- Does the project fit within the jurisdiction and scope of FHWA Turner Fairbank and Office of Safety (i.e., is it primarily oriented to safety and issues related to the built environment, as opposed to education/enforcement/environment/health)?
- Does the project have the potential to address pedestrian safety issues for a wide range of communities, crash types, and citizens?

Based on these criteria, a short list of research topics was developed. Each topic was organized by potential funding timeline (5 years, 10 years, 15 years), based on consideration of the FHWA goals and objectives. There are currently no priorities set within each timeline category.

Literature Review of Existing Research Agendas from Federal Agencies

A number of existing pedestrian safety-related research agendas were reviewed as part of the Pedestrian Safety Program Strategic Plan. An attempt was made to identify state-level pedestrian safety research agendas through a survey of Pedestrian and Bicycle State Coordinators, but none responded. Therefore, the team focused on national research agendas. The following were identified in the Background Report, and further reviewed as part of the current effort to identify research prioritization methods.

- American Association of State Highway and Transportation Officials (AASHTO).
- National Highway Traffic Safety Administration (NHTSA).
- Centers for Disease Control and Prevention (CDC).
- Transportation Research Board Pedestrian Committee (TRB).

AASHTO's Strategic Approach to Safety Tactical Roadmap

http://scohts.transportation.org/Pages/StrategicApproachtoSafety.aspx

AASHTO developed a roadmap that outlines several products and services to support their Strategic Approaches to Safety area. These "strategic" initiatives include "activities that develop comprehensive and sustainable programs and include necessary tools, policies, initiatives, and processes to achieve the fatality reduction goal**."** These activities are generally long-term efforts with the intent to make broad changes in the approach to safety. The SAS roadmap has five major thrust areas:

- Managing safety.
- Information, data improvement, and understanding.
- Evaluation.
- Technology transfer and innovation.
- Awareness.

Each thrust area includes two to four topics that provide further detail on the activities considered for implementation within the next five year period. The roadmap includes a brief description of the thrust areas along with the topics, expected products or services, principal stakeholder groups intended to use the product/service, and anticipated delivery date. The estimated budget to support all of the activities within the roadmap is also identified for the next five year period.

It is recognized that the products of these efforts will be used primarily by State and local governments. Consequently, as stakeholders in this process, it is critical to receive input from State and local agency representatives on the type and level of effort they will undertake so that scarce resources may be applied to the areas that are most critical to achieving the goal. To gather stakeholder input, the roadmap is sent to appropriate stakeholders and they are asked the following question:

"From your perspective, which products or services from the projects listed are of critical, high, medium, or low priority in terms of assisting you to reduce the fatality rate?"

The definitions of critical, high, medium, and low are provided for consistency.

- **Critical:** These products or services are essential to reduce the fatality rate
- **High**: These products or services are very important to reduce the fatality rate.
- **Medium**: These products or services would be of benefit to reduce the fatality rate.
- **Low**: These products or services would have no significant impact.

NHTSA Pedestrian Safety Research Agenda

The National Highway Traffic Safety Administration (NHTSA) strategic goals and focus areas include: passenger vehicle occupants, non-occupants (pedestrians, cyclists, etc.), motorcycle riders, and large trucks and buses. Currently, NHTSA's Office of Behavioral Safety Research (OBSR) is preparing a Five-Year Strategic Behavioral Research Plan. While research initiatives outlined in the plan are targeted for the years 2010 to 2014, resultant research is relevant in both current and future applications.

The research agenda will be formulated based on input from researchers and practitioners from both transportation and non-transportation disciplines. A series of white papers, one on each subject, will be used to establish a thorough understanding of the background on each issue. The white papers will then be used to generate discussion regarding key issues for further research. A few researchers and practitioners will partake in a panel discussion on each target topic's research needs, while others will be invited to comment via a website. The resulting plan will address diverse research needs within the area of pedestrian safety.

CDC Preventing Injuries - Transportation Injuries Research Agenda

Transportation safety (i.e., injuries and fatalities that result from motor vehicle crashes) is one focus area within the CDC. Research priorities are established within transportation safety based on CDC's expertise. For example, reducing alcohol-impaired driving is one priority; the focus on alcohol as a risk factor draws on long-standing efforts to document the effects of alcohol on health and safety. An emphasis on older drivers reflects CDC's focus on "healthy aging." Similarly, the Injury Center's focus on teen drivers takes advantage of CDC's expertise in quantifying and understanding adolescent health risks.

The Injury Center collaborates with other federal agencies, nonprofit organizations, and researchers. They also have a close relationship with all 50 State health departments, local health jurisdictions, and schools of public health. State and local health departments provide important input to develop and implement effective interventions in communities.

While the CDC recognizes that every research priority in their agenda is important, they have identified the six most important priorities based on input from experts in the field. The six most important priorities are those that warrant the greatest attention and intramural and extramural resources from the Injury Center over the next three to five years.

TRB Pedestrian Committee Research Needs Statements

The TRB Pedestrian Committee's Research Needs Statements (RNS) contains more than 100 research needs statements specific to pedestrian research. They were developed over several years with the input of a number of pedestrian safety experts on the committee or research subcommittee. The research topic areas are separated into four major categories:

- Planning and policy.
- Design, operations, and safety.
- Human capacity and sensitivity to environment.
- Society, culture, and behavior.

The research needs are described further by subtopics within the four main categories:

- Facility evaluation.
- Enforcement.
- Crash risk analysis.
- Demand management, generators, and forecasting.
- Land use and urban design.
- Education.
- Health and physical activity.
- ADA (Americans with Disabilities Act).

To further prioritize pedestrian safety research needs, the TRB Pedestrian Committee hosted two workshops to discuss research gaps and make recommendations for future priorities. Using informal brainstorming sessions, attendees were divided into groups to discuss research priorities in the four main research categories (listed above).

A second workshop used a more formal structure in which teams of attendees came up with research gaps in seven main categories. After listing the research needs and presenting the results to the group, each attendee voted on the topics to prioritize them among other research needs. The outcome of the workshop was a prioritized list of research topics.

European Road Transport Research Advisory Council (ERTRAC) Strategic Research Agenda – 2004

http://www.ertrac.org/?m=49&mode=download&id_file=8

Search Term: Prioritize Transportation Research Agenda

The 2020 Vision and Strategic Research Agenda are structured around four pillars. There are inter-dependencies among these areas, which are identified during the planning process. However, research areas are developed separately within each pillar in support of the overall vision. Each pillar is presented with a logical flow from the Vision statements to the targets for 2020, followed by a detailed description of the research areas which need to be addressed to achieve the Vision.

- Mobility, Transport and Infrastructure.
- Environment, Energy and Resources.
- Safety and Security.
- Design and Production Systems.

The general structure of the planning and prioritization process is shown in the figure below. The ERTRAC Plenary group is composed of all stakeholders and is responsible for approving the structure and process for developing the Strategic Research Agenda. There are three groups of stakeholders identified, comprised of the following:

Industry:

- Road and Communication Infrastructure Providers.
- Energy / Fuel Suppliers.
- Vehicle Manufacturers and Suppliers.
- Service Providers.

Research Providers:

- Research Laboratories.
- Universities.

Public Bodies:

- EU Commission.
- Member States.
- City and Regional Governments.

Below the Plenary is a Support Group (i.e., a management-level working body), and a Working Group (i.e., expert support). The Work Group is responsible for developing the content of the Strategic Research Agenda with oversight from the Support Group. The Work Group also consulted with ERTRAC members including infrastructure providers, vehicle and fuel manufacturers and suppliers, non-governmental organizations, Member States, local governments, the European Commission, and other experts throughout Europe. A series of Workshops and ERTRAC internal reviews ensured that consensus was reached on the research themes.

Figure 4. ERTRAC Organizational structure

The Strategic Research Agenda is reviewed and updated regularly to ensure an alignment by the various stakeholders, determine the priorities for action, and identify mutual interests on research areas. Any mutual interests are then formalized and strategic research collaborations focused on a systems approach are developed.

The current (2004) Strategic Research Agenda is the first that follows a true systems approach and integrates all the relevant research areas for a sustainable transportation future. Efforts were made to build upon previous work from other European studies and roadmap projects concentrated on specific transportation themes.

All of the research areas are considered to be priority, but there are differences in the timing, technical difficulty, level of investment, and other factors. As such, the prioritization process is used more to establish timing and difficulty rather than to exclude research areas. To provide quantitative information, an assessment of the "Benefits to Society" and "Difficulty to Achieve" is provided on a scale from 1 to 5 for each of the research areas. These two indicators cannot be used alone to establish the priority of research as each research area is like a component that must be considered as part of a more complex system. These assessment charts are presented for each major research objective across the four pillars. The same topic may appear under more than one objective and may show different levels of benefit depending on the objective to which it is contributing.

The following questions were considered in determining the relative values of the research areas:

Difficulty to Achieve

- **Technical Maturity:** Based on today's state-of-the-art, what is the status of development and how difficult is it to progress the R&D in this area?
- **R&D Implementation Costs:** What is the level of financial investment needed for R&D and for a successful implementation of the breakthrough technologies?
- **Competencies:** Are the competencies which are needed to achieve the objective available in Europe?
- **Time Horizon:** How soon can the technology be expected to contribute?

Benefit to Society

- **Energy and Environment:** How relevant is this R&D area for the critical issues related to energy and environment?
- **Safety:** To what extent does this R&D area improve transport safety?
- **Quality of Life:** Does this R&D area contribute to the quality of life in Europe, apart from safety and environmental aspects?
- **Technical and Economic Competitiveness:** To what extent will R&D in this area improve the competitiveness of the European economy?

The Champion and Supporters for each research area are identified along with the relationship to basic research, applied research, and technical development. The champions take the initiative to lead the research and ensure the implementation of results. Supporters conduct research and develop the technologies that fulfill the needs. The different stages of research are defined as follows.

- **Basic Research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts.
- **Applied Research** is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.
- **Technical Development** is systematic work, drawing on existing knowledge gained from research and/or practical experience that is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

National Occupational Research Agenda (NORA)

http://www.cdc.gov/niosh/nora/

The National Occupational Research Agenda (NORA) is a partnership program to stimulate innovative research and improved workplace practices. Since 1996, NORA has been the research framework for the National Institute for Occupational Health and Safety (NIOSH) and the nation. NIOSH is the steward of NORA and facilitates the work of the Research Councils. There is collaboration from diverse parties to identify the most critical issues in workplace safety and health. Partners work together to develop goals and objectives for addressing these needs. Stakeholder involvement ranges from providing input electronically to volunteering for a Sector Council.

Using a sector-based approach, NIOSH and its partners have formed eight NORA Sector Councils, including one council dedicated to Transportation, Warehousing & Utilities. The councils include participants from academia, industry, labor, and government. Each Council drafts goals, performance measures, and implementation plans for the nation. Research agendas are finalized after considering public comments on the draft. In addition, a Cross-sector Research Council identifies opportunities for common research across sectors.

The following types of information help inform the program's priority setting process:

- The numbers of workers at risk for a particular injury or illness.
- The seriousness of the hazard or issue.
- The probability that new information and approaches will make a difference.

The Caltrans Strategic Research Plan 2008/2009

The California Department of Transportation, Division of Research and Innovation

www.dot.ca.gov/newtech/docs/strategic_research_plan_8-18-09.pdf

The Caltrans Division of Research and Innovation (DRI) is the facilitator of the Department's transportation research program. DRI is responsible for developing and prioritizing the Department's research agenda based on input and support from internal and external stakeholders. DRI engages the entire Department as stakeholders in all aspects of the research process. The following figure illustrates the DRI organizational structure.

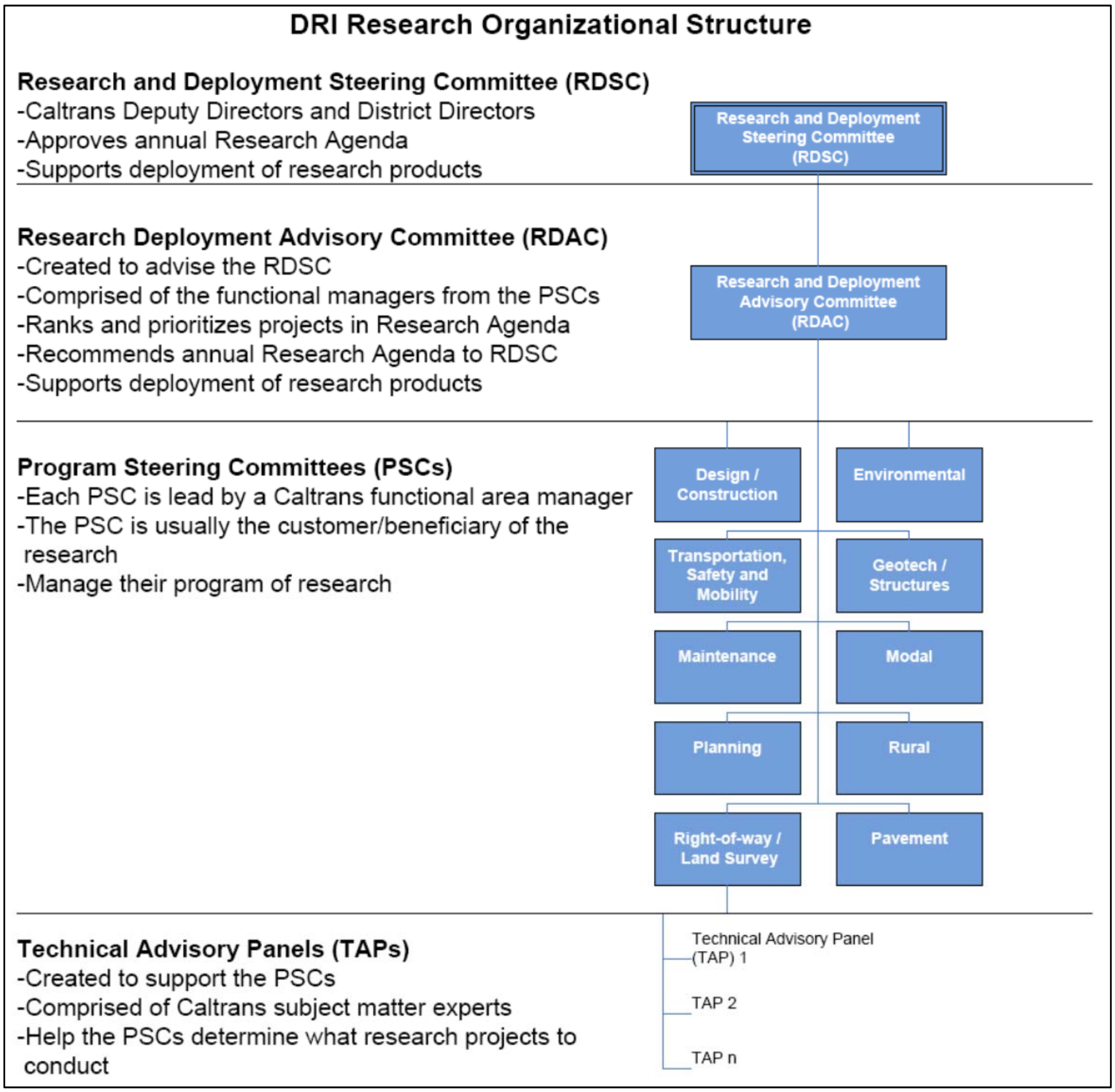


Figure 5. DRI organizational structure

The DRI has adopted a strategic approach to setting a research agenda. The following figure illustrates the difference between the traditional view and strategic view of research. In the traditional view, research agendas are developed in silos by the responsible agency or division. Using a systematic approach, there is collaboration among the groups to develop a single research agenda.

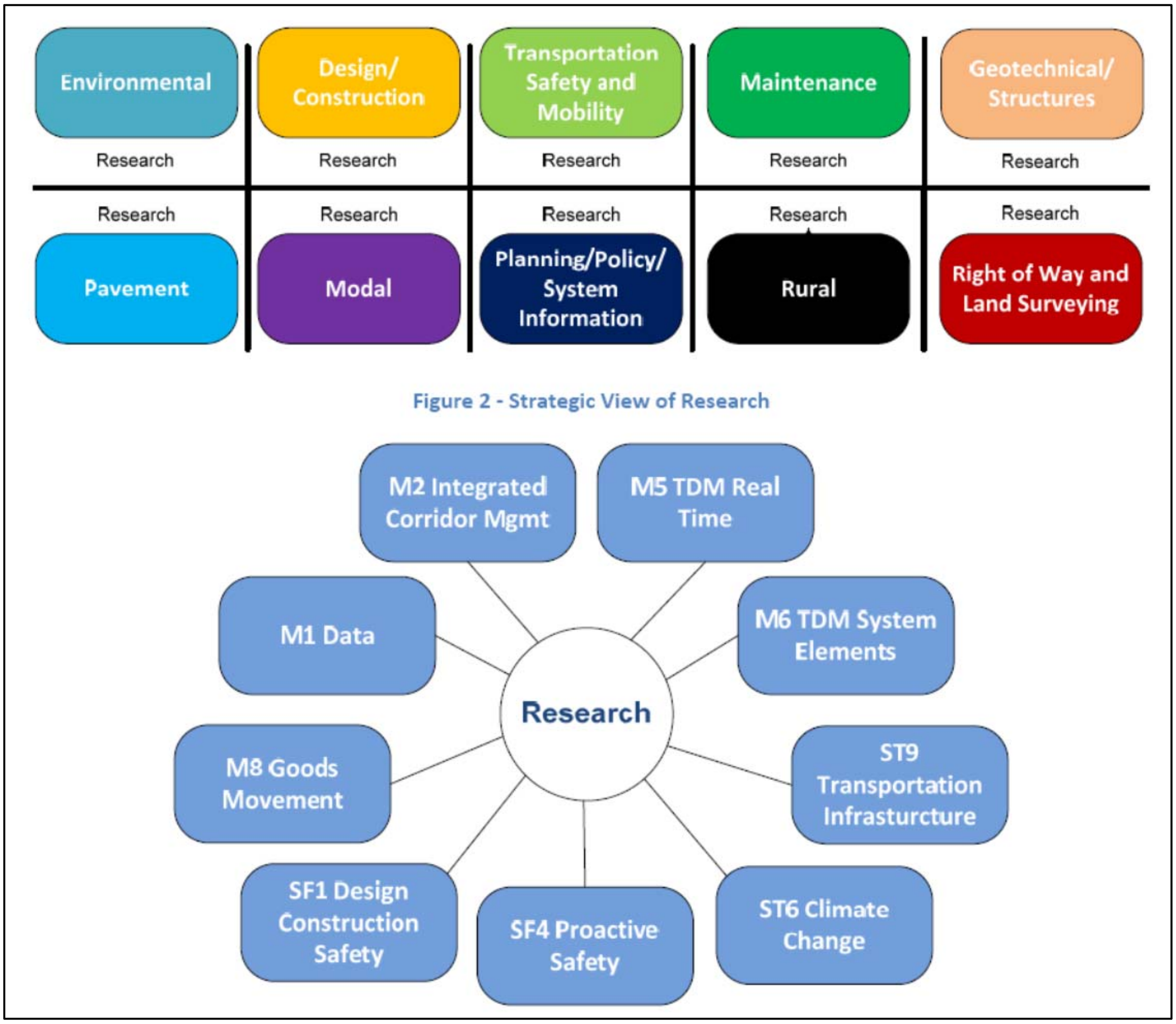


Figure 6. Traditional View of Research

Strategic Research Plan Methodology

The method employed to develop the Caltrans Strategic Research Plan is based on the Department's 2007 – 2012 overall Strategic Plan. The Department overall Strategic Plan identifies five goals: safety, mobility, delivery, stewardship, and service. Each goal has multiple objectives and each objective has multiple strategies to employ in order to achieve the desired objective and, ultimately, the goal.

Strategic Research Plan Workshops

Workshops were held for each goal to provide an opportunity for stakeholder input on the creation of the Strategic Research Plan. DRI identified stakeholders for each goal by reviewing the existing body of Caltrans transportation research. The format of the workshops was to brainstorm research questions for each strategic plan objective. The next step required participants to group and refine questions to identify higher level research questions. Finally, workgroup participants ranked the questions.

In total, 38 research questions were developed across the five goals. The 38 research questions are referred to as the "Strategic Research Questions" (SRQs) because each question relates to research intended to help the Department achieve objectives and goals for the strategic plan. Safety had six research questions, which are shown below as an example:

1. SF1 DESIGN/CONSTRUCTION – What design features and construction standards can be utilized to improve highway safety?
2. SF2 ORGANIZATIONAL/INSTITUTIONAL – What organizational and institutional changes lead to improved safety?
3. SF3 WORKER SAFETY – What tools, technologies, and policies should be researched and implemented to improve administrative and engineering safety controls in the work environment?
4. SF4 PROACTIVE SAFETY – What can Caltrans do to mitigate collisions?
5. SF5 REACTIVE SAFETY – What can Caltrans do once collisions occur?
6. SF6 DRIVER BEHAVIOR – How can we influence/educate drivers to operate their vehicles more safely?

Strategic Research Question Prioritization

As discussed previously, the SRQs were ranked within each goal by the stakeholders during the workshops. While this is useful for guiding research within a goal, Caltrans also ranked all 38 SRQs independent of the goals. DRI developed an online survey to measure dimensions of importance and urgency for each SRQ and invited all workshop participants to complete it. For each SRQ, respondents rated the following statements using a five-point Likert scale to determine level of importance:

1. Important: Answering this SRQ is important.
2. Urgent: Answering this SRQ is urgent.

DRI compiled the results by assigning a score to the Likert response (1 – Strongly Disagree to 5 – Strongly Agree) and averaged all responses. The SRQs with higher rated importance and urgency resulted in a higher average score and the results were used to create a Cartesian product plot. The following figure shows the survey results for Safety, averaged over all responses. Using the results of the survey, Caltrans grouped the SRQs into three categories:

- **Priority SRQs** – Research questions which, when answered, offer the greatest potential for significant achievement of a Caltrans Strategic Plan objective and goal;
- **Best Practice SRQs** – Research questions which, while important, appear best suited to research related to the implementation of existing best practices in the field; and
- **Low Priority SRQs** – Research questions which yield the least potential for substantial advancement with research.

Figure 7. Safety SRQ Survey Results

Caltrans also mapped the existing research agenda to the SRQs to facilitate a gap analysis. The mapping showed that all priority SRQs have at least some funds allocated to research. However, some best practice and low priority SRQs have no funds allocated. The fact that no funds have been allocated to some of the best practice and low priority SRQs is not necessarily an issue because Caltrans seeks to focus resources on the priority SRQs.

Appendix C. Research Priorities in Road Safety – A Value of Information Approach

1. Introduction

Potential research projects on road safety are very many and there is not enough money to do them all. The commissioners of research must decide which of the many potentially worthy projects to fund first. To do so they need a prioritization procedure. Inasmuch a research funding involves the expenditure of public money, the procedure must be defensible. Past efforts were based on the judgment of those participating in the prioritization. Because the ranking was based on the opinion of the invitees, different groups tended to settle on different priorities. The aim here is to develop a prioritization procedure that does not eliminate judgment but provides it with a discipline and, where possible, replaces judgment by data and computation. The premise will be that research has both value and cost; the larger the value per unit of cost the higher should the research project rank.

The costing of a research project may involve uncertainty but presents no conceptual difficulties; not so, the estimation of research value. Personal views about the value of a certain research project will inevitably and legitimately differ. To come to an opinion about the importance of some research one tries to make a mental amalgam of several considerations: what is already known about the subject, how many are the accidents targeted by the research, how many could be eliminated, how costly would countermeasure implementation be, how likely is the implementation of findings, what is the cost of the research, what are the chances of success, etc. Mental amalgams of this kind are difficult to do and impossible to reproduce. It might be possible, however, to put the estimation of research value on an explicit basis. Doing so promises to express some elements of the mental amalgam in numbers and put them in their proper relationship with each other. Such a procedure will give structure and discipline to an otherwise ill defined process. It will clarify what information needs to be had and how it should be combined. Above all, it promises to make it easier to reach consensus.

That research has value in some intuitive sense is clear. However, that one can put a dollar sign to the value of research may come as a surprise. The logical foundation for valuing research comes from a discipline called 'Decision Analysis' and its uses are known as 'Value of Information' methods. Decision and Value are simply linked. Research produces information. The better the information that is used for making a decision the lesser is the chance of making an inferior one. If the consequences of making an inferior decision can be translated into money terms, then the link between value and the information produced by research is immediate. Much of road safety management revolves around decisions: whether to implement some countermeasure, whether to choose a certain road alignment, whether to adopt a standard or warrant etc. Decisions of this sort have consequences which can be translated into money. This is why, in this setting, the decision analysis framework is a good fit.

2. Value of information and research priority; A brief literature review

The Bayesian approach to value of information (VOI[1]) has its foundation in statistical decision theory [see e.g. Schlaifer (1959), Howard (1966), Winkler (1972), Berger (1985), Pratt et al. (1995), Raiffa and Schlaifer (2000), Parmigiani (2002)]. Hammitt and Cave (1995) applied VOI methods to set priorities to research on food safety. Meltzer (2001) notes that the application of VOI methods in medicine faces "theoretical and empirical challenges" but that "the importance of making good decisions about the allocation of resources to medical interventions and medical research suggest that work in this area be an important priority" and quotes support from the IOM (1998) report. Fleurence and Torgerson (2004) review five ways for setting research priority in the delivery of health and conclude that VOI approach is the only appropriate one. Claxton and Sculpher (2006) describe two applications of value of information analysis to inform policy decisions about research priorities in the UK. One is a pilot study for the UK National Coordinating Centre for Health Technology Assessment and the other for the National Institute for Health and Clinical Excellence. In a recent publication (Meltzer, 2009) says that "'Value-of-research' calculations have recently begun to be applied in both academic and policy settings …to determine the value of additional studies on the value of treatments…".

In spite of the air of optimism in the literature, the impression is that VOI methods are used more in the design of research studies than in determination of research priority. Hauer and Geva (1984) applied the VOI approach to the design of a research study in road safety (about the effect of Daytime Running Lights). Thompson and Graham (1996) reviewed VOI in the context of environmental risk. Claxton and Posnett (1996) apply it to trial design (and research priority) in health. The context is similar in Claxton (1999), Yokota and Thompson (2004), and in Briggs et al.(2006). Most applications use the (expected) value of *perfect* information. See e.g. Claxton and Sculpher, 2006; Philips et al., 2006, Colbourn et al., 2007; Bojke et al., 2008. The use of the value of *sample (imperfect)* information analysis is more limited (see e.g. Ades et al., 2004; Willan and Pinto, 2005; Brennan and Kharroubi, 2007ab; Eckermann and Willan, 2008).

3. In road safety, research is for decisions

In the final account, research on road safety is in support of making practical decisions. The decision may be whether to implement some countermeasure or not to do so; to choose one degree of curve for a road instead of another; to coin a certain design standard and not an alternative to it; to adopt a plan or to reject it, to pass a piece of legislation or to drop it, etc. In what follows, these diverse choices will be represented by the generic phrases "implement" or "do not implement." In all these cases rational decisions are influenced by information about what the safety consequences of the contemplated action might be. Information that makes the prediction of safety consequences possible is the product of research.

Of course, not all research in road safety can be linked to a specific decision directly. Thus, e.g., one might undertake research into the relationship between some type of traffic conflict and accidents. The value of the resulting information is of the 'enabling' kind. It enables one to estimate the safety effect of a variety of actions (standards, devices, operational measures etc.) which otherwise would be either impractical or more costly to do. This type of research is one step removed from a specific decision. In this sense it is more fundamental in nature. However, even research that enables one to do research about the effect of decision is still linked to decision-making, albeit indirectly. The same argument applies to research into all surrogate measures (mental workload, driver simulators etc.). Similarly, consider

[1] Acronyms and notation are listed and described in the Glossary section at the end of this report

research the aim of which is to enhance causal statistical modeling. This kind of research is also not linked directly to some specific decision. Nevertheless, one hopes that success in this line of research will enable others to better estimate of safety effect for a variety of causal factors. In this manner even more fundamental research eventually trickles down to making better decisions.

Not everyone will agree with the statement in the title. There are two kinds of research questions: (a) what are the causes of effect(s) and (b) what are the effects of causes. In our context question (a) is about the causes of accidents and injuries while question (b) is about how accident frequency and severity is changed by some action or intervention. The title of this section focuses on question (b) and seems to exclude question (a). Therefore one must ask whether research on question (a) can also be taken as helping to improve decisions. To illustrate, one aim of the naturalistic driving studies in the Strategic Highway Research Program- SHRP2 is to better understand the causes of accidents. The hope is that such an understanding will lead to the formulation of better or novel interventions. This too has value. Thus, e.g., one may get a better handle on the extent and role of distraction and fatigue as causes of accidents and perhaps on the risk of driving in such states. If so, one will make better decisions about potential countermeasures. Thus, to the extent that the road from the naturalistic driving study (or the many other accident causation studies) to the discovery of interventions can be described, such studies too can be linked to decisions.

In short, management consist of decisions, rational decision making rests on information, information comes from research, and therefore the value of research comes from the decisions which it serves. If this chain of reasoning gives rise to a hesitation, it is because decision-making in road safety management does not always fit a purely rational mould. In the VOI framework to be erected and used below, it is 'cost' and 'effect' that are supposed to govern decision making. Reality, alas, is more complex. There are influential road user groups with strong convictions; there is organizational self-interest, professional inertia, and pork-barrel politics etc. all of which exert their pull. What value is there to research if its influence on real-life decision-making is likely to be barely noticeable?

> The first step of any inquiry about the value of a suggested research project is to be clear about what decisions might be improved by the information which that research intends to produce.

This is a weighty question. If cost and effect do not govern decision-making, research has no value. To answer the weighty question one must remember that nowadays most endorse the general desirability of moving road safety management in the direction of being 'evidence-based'. Even this effort to determine research priority by value and cost is a component of the broader evidence-based current. Should then the priority given to a research project be affected by considerations other than cost and effect, something subsumed under the murky concept of 'likelihood of implementation'? Perhaps we will have to distinguish between impediments to implementation that are legitimate and defensible and those that represent attempts to keep decision-making away from the evidence-based realm. Thus, e.g., if the implementation of a countermeasure represents some loss of freedom and such a loss is a part of the 'cost' then likelihood of implementation ought to be considered. Conversely, if implementation is unlikely because it might conflicts with current practice that is not evidence-based then the priority of such research is best left unaffected.

4. Where does the value of research come from?

The question is short but the answer will be lengthy. To keep the line of argument clear it is best to weave it around a story. Assume that someone proposes to do research about the safety effect illumination on access-controlled roads. The aim of the proposed research is to get a better handle on the corresponding Crash Modification Factor, θ. The purpose of this section is to show how a $ value can be attached to this research.

To see what the value of such research might be one must be clear about how the information produced by the research would improve the related decision-making. In this case the decision context is clear: there are many access-controlled roads without illumination. The decision whether to illuminate such a road depends on the balance between the cost (both capital and operating) and the benefit (the reduction in night-time accidents). The expected accident reduction is proportional (1-θ), where θ is the Crash Modification Factor[2].

The value of θ is never known. What information we have about θ comes from past research studies. Each research study yields an estimate of the θ that prevailed in that study. From these estimates one can construct a Probability Distribution Function (PDF) of θ to be denoted by F(θ). How this can be done will be explained later in Chapter 0. The point is that we can know only the PDF of θ, not the actual value of θ that applies in the specific circumstances of a certain project.

Suppose that the θ for illuminating an access-controlled road has the PDF in Figure 8[3]. That is, as far as we know on the basis of previous research, the θ for the aforementioned project and its specific circumstances can be any of the values of θ shown on the horizontal axis; it could be 0.6, 0.8, 1.6 or any other non-negative number. The most we can know from past research is the probability that θ is in some given range. To aid in the interpretation of this kind of graph, the red arrows show that the probability that θ<0.6 is 0.41, that it is somewhere between 0.6 and 0.8 is 0.68-0.41=0.27, and that the probability that θ is larger than 1.6 is 0.01.

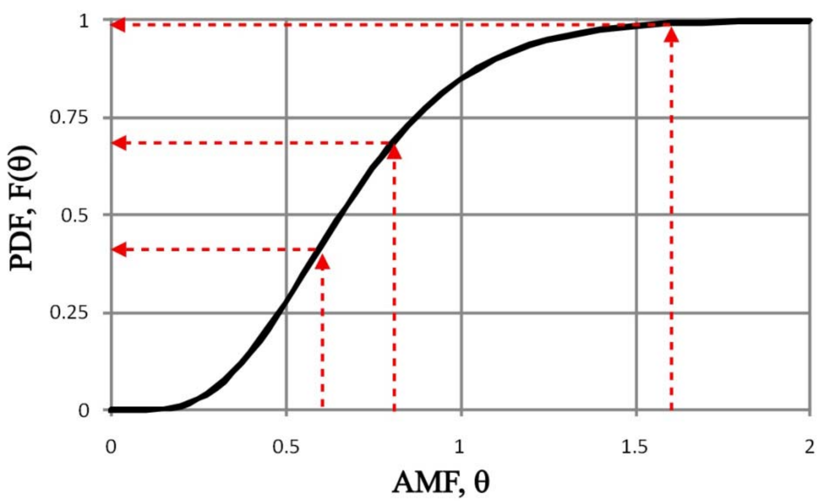


Figure 8. A Probability Distribution Function of θ

The outline of the link between research and decision making is starting to emerge. The decision whether to illuminate hinges on balance between cost and benefit; the magnitude of the benefit depends on θ; and how well θ is known depends on the information produced by research.

---

[2] To illustrate, if on a certain un-illuminated road one expects 6.1 night-time accidents/mile-year and the θ for providing illumination is 0.7 then, with illumination, one expects the same road to have 0.7×6.1=4.3 night-time accidents/mile-year. The accident reduction is 6.1-6.1×0.7=6.1×(1-0.7). Let μ denote the expected number of target accidents. The reduction in expected accidents is μ(1-θ). When θ<1, accidents are expected to be reduced. When θ>1 the reduction is a negative number, i.e. an increase in expected accidents.

[3] The mean of the PDF in Figure 8 is 0.70 and its standard deviation is 0.30. Where mathematical notation is needed the mean of the PDF of θ will be denoted by E{θ} and the standard deviation by σ(θ). Thus, e.g., the expected reduction in expected accidents is μ(1-E{θ}).

4.1 The "Do not illuminate" case

Because the magnitude of θ is never known, decisions are based on 'expected benefits'. The expected 'benefit' is always computed by using the estimate of the *mean* of the PDF (the $E\{\theta\}$). We base our decision on $E\{\theta\}$ not because we think that it will be the same as θ but because doing so consistently will give the best results, on the average. Thus, e.g., using $E\{\theta\}=0.70$, the expected benefit of illumination in this example is a reduction of night-time accidents from 6.1 to 4.3, i.e. of 1.8 accidents/mile-year. Taking the cost of an average night-time freeway accident to be \$20,000, the expected benefit is \$36,000 per mile-year. The total annual cost of freeway illumination is about \$25,000/mile-year. With these values the benefit-cost ratio is 37000/25,000=1.5. If in the given budgetary reality only investments with a benefit cost ratio larger than 2.5 are deemed attractive, the decision should be: "do not illuminate".

Notation: μ expected number of target accidents/year;
a average cost of one target accidents;
c annual cost of countermeasure implementation;
r limiting benefit-cost ratio.

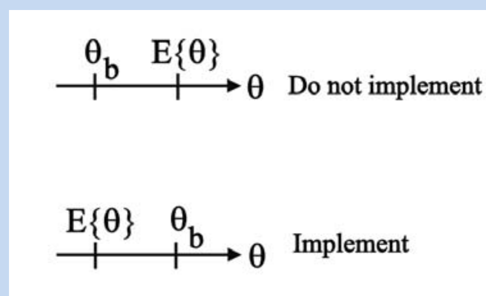
Annual benefit is $\mu(1-\theta)a$

Annual opportunity cost of implementation is rc.

From $\mu(1-\theta_b)a=rc \rightarrow \theta_b=1-(rc/a\mu)$ ... 1

Not to illuminate would be the right decision if θ was indeed 0.70. However, if θ was, say, 0.40 then the benefit would be $6.1\times(1-0.40)\times\$20{,}000=\$73{,}200$. Now the benefit-cost ratio is close to 3 and the decision should be: "illuminate". The transition between "illuminate' to "do not illuminate" occurs at the 'break-even θ', to be denoted by θ_b (see box[4]). When the benefit-cost ratio equals 2.5, $\theta_b=0.49$. For all θ less than 0.49 the decision: "do not illuminate" is the wrong one. As can be seen in Figure 8, the probability that the decision "do not illuminate" is wrong is about 0.25.

The choice between "implement" and "do not implement" depends only on the relative positions of θ_b and $E\{\theta\}$.



It is at this point that the quantitative connection between research and value can be made. Making the wrong decision is associated with a cost. In this example, using the $E\{\theta\}=0.7$, the decision was "do not illuminate". However, should the θ be, say, around 0.40, and this is a real possibility, by deciding not to illuminate one would be foregoing the benefit of not saving 3.66 accidents/mile-year the value of which is $3.66\times\$20{,}000=\$73{,}200$. The cost of spending money on illumination (instead of spending it on some other project where one can get at least \$2.5 in value for \$1 invested) is $\$25{,}000\times2.5=\$62{,}500$/mile-year. Therefore, if θ was in fact 0.40, the consequence of the decision not to illuminate is a loss of \$73,200-\$62,500=\$10,700/mile-year.

The essence of the situation is that θ is never known. We decide on implementation using the estimate of the mean θ. Therefore there is always a chance that the decision is incorrect.

This loss, which is due to having to make the decision on the basis of the estimate of $E\{\theta\}$ instead of on the actual but unknown θ, is a function of θ and will be denoted by $L(\theta)$. If θ is larger than the break-even

[4] For θ_b to be positive μ must not be less than rc/a. With the cost elements of our example, when fewer than 3.12 night-time accidents are expected illumination never pays.

value θ_b the decision not to illuminate is correct and the loss=0. However, if $\theta<\theta_b$ the decision is incorrect, the loss is positive, and increases linearly from \$0 at θ_b to 6.1×\$20,000-\$62,500=\$59,500 at θ=0, as shown in Figure 9.

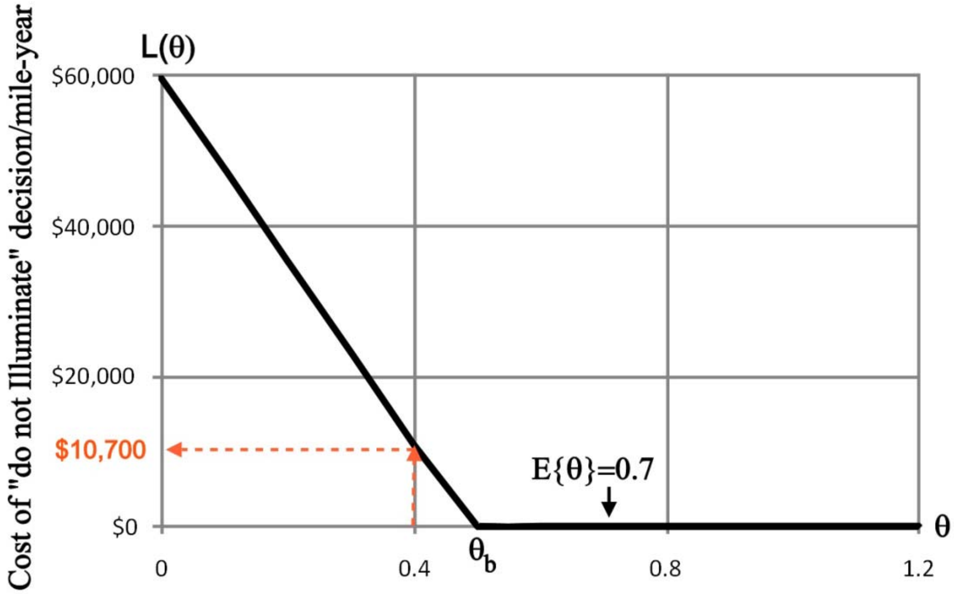


Figure 9. How the annual loss due to the decision "Do Not Illuminate" varies as a function of θ.

While we do not know what θ is in any specific case, we do know the PDF of θ as shown in Figure 8. This enables us to calculate the average or 'expected' loss. To do the computation the distance between 0 and θ_b is divided into small intervals (say, 0.01 wide) and these are numbered 1, 2,…,i,…,n=θ_b/0.01. From the PDF the probability of $p(\theta_i)$ of θ to be in interval 'i' is obtained and from the loss function the $L(\theta_i)$ associated with the mid-point of that interval determined. The expected loss associated with the "do not illuminate" decision is the sum of the products $L(\theta_i)\times p(\theta_i)$ over all n intervals. Parts of the computation are in Table 1.

Table 1. Example of computations when decision is "do not illuminate"

1 i	2 θ_i	3 $p(\theta_i)$	4 $L(\theta_i)$	5 $p(\theta_i)$* $L(\theta_i)$
1	0.0024	1.727E-11	\$59203	\$0.0
2	0.0073	2.194E-09	\$58608	\$0.0
…				
30	0.1439	4.265E-04	\$41,948	\$18
31	0.1488	4.762E-04	\$41,353	\$20
32	0.1536	5.292E-04	\$40,758	\$22
…				
98	0.4755	6.565E-03	\$1,488	\$10
99	0.48	6.613E-03	\$892	\$6

	04			
10 0	0.48 53	6.660E-03	$297	$2
Su ms		**0.262**		**$3786**

The θ_i at the mid-point of each interval is in column 2. Assuming that $F(\theta)$ can be represented by the Gamma PDF, its parameters in Excel[5] are $\alpha=(0.7/0.3)^2$ and $\beta=0.3^2/0/7$. The values in column 3 are those of the Excel function 0.01× GAMMADIST(θ, α, β, FALSE). The values in column 4 are computed using $L(\theta_i)= \mu(1-\theta_i)a-cr$ (with μ=6.1,a=$20,000, c=$25,000 and r=2.5).

That the PDF of θ can be approximated by a two-parameter Gamma distribution is merely a convenient assumption. While the Gamma PDF pertains to the appropriate range of θ (0 to ∞) and can take on a variety of shapes, its use is neither supported nor negated by empirical evidence. For determining research priority it seems to be a sensible assumption to make.

On the basis θ_b=0.49 and E{θ}=0.7 the best decision is not to illuminate. It is, however, the wrong decision if θ happens to be less than 0.49. The expected value of the foregone benefit which is rooted in having to make up one's mind on the basis of E{θ} is $3786.

The nature of this foregone benefit merits elucidation. Suppose that an omniscient creature sells information about what is θ. How much should the decision-maker be willing to pay for this information? If the creature will say that θ=0.9, that information will be worthless; the decision-maker was going to make the 'do not illuminate' decision anyway. However, if the creature will say that θ=0.4 the decision maker will decide differently. The reward for the ability to tailor the decision to the actual value of θ when it is 0.4 is the $10,700 calculated earlier; it is the most the decision-maker should be willing to pay for knowing that θ=0.4. But inasmuch as decision-maker has to say how much he/she would be willing to pay before the creature reveals what θ is, the decision-maker has to weigh the magnitude of the reward by the probability of θ. Therefore the most he/she should be willing to pay for the knowledge of θ is $3786. This is the so called Expected Value of Perfect Information, EVPI. It is in this sense that information about θ has a $ value.

Unfortunately, nobody sells perfect information. However, research can generate information which, while not perfect, can reduce the risk of decisions being incorrect. Imperfect information also has value, albeit less than that of perfect information. It is usually denoted by EVII, the Expected Value of Imperfect Information. Using the logic and computational scheme already developed, there is only a short step from EVPI to EVII.

In explaining how to get from EVPI to EVII we return to the earlier story where someone suggested to do research about the safety effect illumination on access-controlled roads. Suppose that the suggested research is expected to reduce the uncertainty about θ from σ(θ)=0.3 to about σ(θ)=0.25. What would be the value of this research?

All the ingredients of the situation remain as before except that the parameters of the Gamma distribution are now $\alpha=(0.7/0.25)^2$ and $\beta=0.25^2/0/7$. This changes the $p(\theta_i)$ in column 3 of Table 1 and therefore the entries of column 5. Now the sum of column 5 is $2383. The research which reduced σ(θ)

[5] The Gamma probability density function is $\frac{\theta^{\alpha-1}e^{-\theta/\beta}}{\beta^{\alpha}\Gamma(\alpha)}$ for which E{θ}=αβ and σ^2{θ}=$\alpha\beta^2$. From here β= σ^2{θ}/ E{θ} and α= E{θ}/β=[E{θ}/ σ{θ}] .

from 0.3 to 0.25 reduced the annual cost associated with the decision "do not illuminate" by \$3786-\$2383=\$1403/mile of such a road. This then is the EVII of this research.

4.2 The "Illuminate" case

Consider the "to illuminate or not to illuminate" question when the road is expected to have 10.9 night-time accidents/mile-year (instead of 6.1. Now the θ_b=1-(2.5×25,000)/ (20,000×10.9)=0.71 which is larger than 0.7 and the decision is 'illuminate'. With the change of decision comes a change in the loss function. Now there is a loss when θ is larger than 0.71 since with such θ it would be better not to illuminate[6] as is shown in Figure 10.

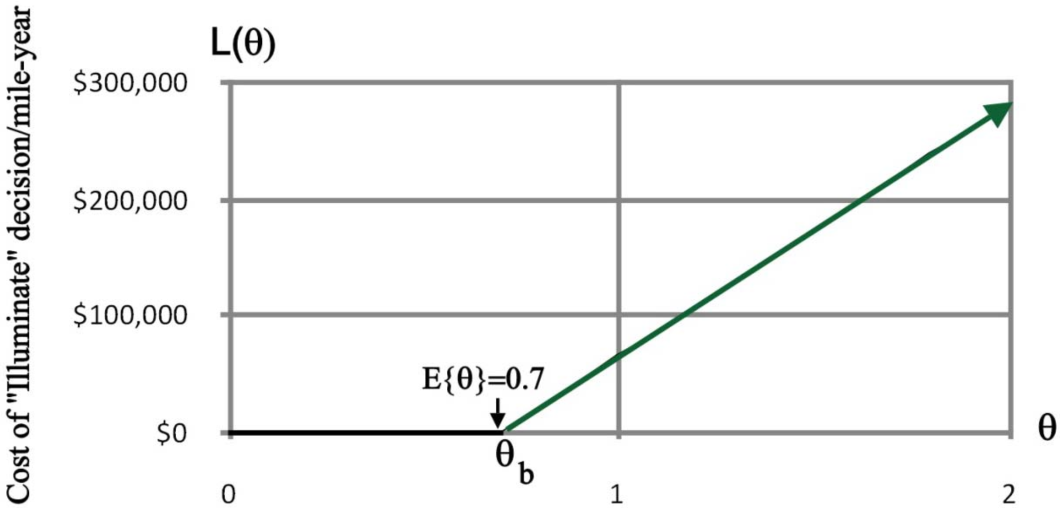


Figure 10. How the annual loss due to the decision "Illuminate" varies as a function of θ.

For the computation of the expected loss that is associated with the 'illuminate' decision we again use intervals of θ that are 0.01 wide and number them 1, 2,…,i,… . Also as before, from the PDF we determine the probability $p(\theta_i)$ of θ to be in interval i[7] and from the loss function determine the $L(\theta_i)$ associated with the mid-point of that interval. The expected loss is the sum of the products $L(\theta_i)\times p(\theta_i)$ over all intervals until the product is sufficiently small, say, less than \$0.1. The computation is illustrated in Table 2.

The Loss Function:

$If\ \theta_b < E\{\theta\}\ then$ "Do Not Implement " and

$$L(\theta) = \begin{cases} \mu a(1-\theta) - cr = \mu a(\theta_b - \theta)\ when\ \theta < \theta_b \\ 0\ otherwise \end{cases}$$

$If\ \theta_b > E\{\theta\}\ then$ "Implement" and

$$L(\theta) = \begin{cases} cr - \mu a(1-\theta) = \mu a(\theta - \theta_b)\ when\ \theta > \theta_b \\ 0\ otherwise \end{cases}$$

... 2

[6] We would be investing c×r=25,000×2.5=\$65,500/mile-year and the benefit is only μ×(1-θ)×a=10.9(1-θ)×20,000=\$218,000×(1-θ)/mile-year, less than \$65,000 when θ>0.71.

[7] $p(\theta_i)=F'(\theta_i)\times$(with of interval i) where θ_i represents the value of θ in interval I and F', the probability density function, denotes the derivative of F.

Table 2. Example of computations when decision is "illuminate"

1 i	2 θ_i	3 $p(\theta_i)$	4 $L(\theta_i)$	5 $p(\theta_i)$* $L(\theta_i)$
1	0.718	1.274E-02	$1090	$13.89
2	0.728	1.253E-02	$3270	$40.98
…				
30	1.008	6.028E-03	$64,310	$387.65
31	1.018	5.827E-03	$66,490	$387.43
32	1.028	5.630E-03	$68,670	$386.62
…				
223	2.938	2.115E-07	$485,050	$0.10
224	2.948	1.987E-07	$487,230	$0.10
225	2.958	1.866E-07	$489,410	$0.09
Sums		**0.426**		**$24,436**

The expected annual loss associated with the decision to illuminate one mile of road on which there are 10.9 night-time accidents/mile-year is $24,436. This is much larger than the loss associated with the decision not to illuminate for a road with 6.1 such accidents per mile-year. The reasons which the decision to "implement" is associated with a larger loss are several. First, there is the cost of implementation (or $25,000/mile-year). Second, in this example the mean of the PDF is close to θ_b so that the probability of the accidents savings not to cover the cost is substantial. Third, if the Gamma PDF is a reasonable approximation to reality, the probability of θ to be larger than 1 (that is that illumination increases night-time accidents) is, in this case, also substantial (about 0.15).

Finally, suppose again that the suggested research is expected to reduce the uncertainty about θ from $\sigma(\theta)=0.3$ to about $\sigma(\theta)=0.25$. With the reduced standard deviation the expected loss is $20,231. The value of this information is $24,436-$20,231=$4205/mile.

4.3 The value of this research.

The proposed research was in aid of the decision of whether or not to illuminate some stretches of access controlled roads. Suppose that there are 1000 miles of such roads where one night-time accident is expected, 800 miles where four such accidents are expected, etc. as shown in column 2 of Table 3. Illumination cannot pay for itself when $\mu<rc/a$; here when the expected number of night-time accidents is less than $2.5\times25,000/20,000=3.1$/mile-year. This is indicated by the zeros in column 3 above the double line. When $\mu=4$ night-time accidents/mile-year, one should illuminate if $\theta<0.22$. The decision (column 4) is not to illuminate as long as the θ_b in column 3 is less than the mean of the PDF (Figure 8), which is 0.7. Using the logic and algorithm already explained one can compute the expected value of perfect information per mile of road when $\sigma=0.3$ and when $\sigma=0.25$. These are shown in columns 5 and 6. Their difference in column 7 is the expected annual value/mile of the research which reduces σ from 0.3 to 0.25. Multiplying these by the number of un-illuminated miles in column 2 and summing over all rows shows that the annual value of this research is about $900,000.

Table 3. Value of Research Computation

1	2	3	4	5	6	7	8
μ. Night-time accidents/mile	Un-illuminated Miles	Break-even θ	Illuminate?	EVPI when σ=0.3	EVPI when σ=0.25	EVII/ mile	EVII*Miles
1	1,000	0.00	No	$0	$0	$0	$0
2	1,000	0.00	No	$0	$0	$0	$0
3	1,000	0.00	No	$0	$0	$0	$0
4	800	0.22	No	$56	$12	$45	$35,708
5	400	0.38	No	$1000	$466	$534	$213,727
6	200	0.48	No	$3465	$2,143	$1,323	$264,520
7	100	0.55	No	$7150	$5,061	$2,090	$208,984
8	50	0.61	No	$11676	$8,924	$2,752	$137,595
9	10	0.65	No	$16744	$13,426	$3,319	$33,187
10	2	0.69	No	$22202	$18,393	$3,809	$7,618
11	0	0.72	Yes	$24416	$20,170	$4,246	$0
12	0	0.74	Yes	$24321	$19,676	$4,645	$0
						Sum =	**$901,339**

The purpose of section 0 was to show where the value of research comes from and how it can be computed. In sum, the safety benefit of a decision depends on the actual θ which pertains to a specific circumstance while the decision itself is made on the basis of the estimated mean θ. Research reduces the average difference between the actual θ and the mean θ. This, in turn, reduces the chance that the decision to implement or not to implement is wrong. The expected $ value associated with the reduced risk of the decision being wrong can be computed.

4.4 Computing the value of proposed research is easy

The medical literature on the use of VOI (Value of Information) methods for determining research priority leaves the impression that implementation is hampered by the amount of research design detail needed and the resulting computational complexity. The complexity seems to stem from attempts to be explicit about the exact statistical model and data which the proposed research might entail. In contrast, the approach described in section 0 is simple and transparent. The key notions which simplify matters are two. First that the purpose of research is to reduce the uncertainty now surrounding the value of the crash modification factor θ. Specifically, that the value of a proposed research comes from reducing the standard deviation of the PDF of θ. Second, that the value of imperfect information (EVII) is the difference between two values of perfect information (EVPI), that without and that with the proposed research. In addition to these notions I am assuming that for the purpose of ranking proposed research the Gamma PDF describes the probability distribution of θ. The requisite computations have been coded in VBA in an Excel spreadsheet in Figure 11.

Cost of one target accident, a =	20000		Mean=	0.7				
Annual cost of illumination/mile, c=	25000		Std=	0.3		Compute Expected Loss		
Night-time accidents/(mile-year), μ =	6.1		Beta=	0.1286				
Limiting B/C ratio, r =	2.5		Alpha=	5.4444		Do not implement	Implement	
					Expected Loss=	*$3,786*		
interval	Midpoint θ	p(θ)	Loss, L(θ)	Weighed Loss p(θ)*L(θ)		interval	Midpoint θ	p(θ)
1	0.005	8.44E-10	$58,890	$0.0				
2	0.015	1.03E-07	$57,670	$0.0				
3	0.025	9.23E-07	$56,450	$0.1				

Figure 11. Part of spreadsheet

After the six data items are entered in the colored part of the spreadsheet and the command button clicked the expected loss is displayed in the frame either under the "Implement" or under the "Do not implement" heading. The VBA code is in the appendix.

4.5 What will be accomplished by doing more research?

The choice between 'implement" and 'do not implement' is always based on the current PDF of θ. If the current PDF is based on little data, poor research designs, and/or the safety consequences of the "implement" decision vary widely from one unit to another, then the standard deviation of the PDF will be large. Conversely, when data are plentiful, research methods solid, and the safety effect of the "implement" decision similar across units, σ will be small[8]. When the results of the proposed new research become know the current PDF will be revised. How this is to be done will be discussed in a separate section. The hope is that the revised PDF will be more tightly packed around the mean, i.e., that the σ will be smaller. The smaller the σ, the larger is the chance that the decision based on E{θ} is the correct one. While the mean of the revised PDF will surely be somewhat different mean than the original one, it can be move in either direction – the most likely revised mean is the original mean!

As noted in section 0, if the literature is a reflection of what Value of Information analysis is being used for, it is usually used to assist in the design of research studies. In contrast, here VOI analysis is used to aid in ranking potential research project in order of priority. This difference in purpose explains a difference in method. When VOI analysis is used for efficient experimental design one does not make assumptions about how the mean of the PDF is going to change; all possible research outcomes are considered and weighted by the prior probabilities. This makes computations complex and unnecessarily so if the aim is only to assess rank proposed research projects by priority. When computing the EVPI of the proposed research in section 0 it was assumed that the new results will leave E{θ} unchanged and reduce σ(θ) from 0.30 to 0.25. This assumption is in line with what is most likely, and eliminates the need for complex modeling and computations.

---

[8] To clarify the meaning of σ being 'large' or 'small', recall that rule of thumb the almost the entire probability mass is within ±3σ of the mean and about 95% of it within ±σ of it. This rule of thumb is good for random variables the PDF of which is Normal, but even for the Gamma PDF it is not a bad approximation. (With E{θ}=0.7 and σ=0.3, P(0<θ<0.7+3×0.3)=0.991 and P(0.7-2×0.3<θ<0.7+2×0.3)=0.948.) Thus, when σ=0.3,, θ could be almost anywhere between, say, 0.1 and 1.3 and such a wide range is of no practical interest. However, if σ=0.05, θ it is likely to be somewhere between 0.6 and 0.8.

5. What factors determine the value of research?

One of the main questions is what exactly should be taken into account when forming an opinion about research priority. The approach to answering the question is now obvious: whatever is needed to compute the $ value of research that is what should be taken into account. To see what information was used in the computation it is best to trace the procedure in section 0 from the final result back to its roots.

Two factors combine to determine the bottom line in Table 3:

Factor 1. The number of units that are affected by the decision categorized by the expected number of target accidents;

Factor 2. The EVII (Expected Value of Imperfect Information) also categorized by the expected number of target accidents.

For the research on the CMF of illumination these factors are shown in Figure 12. I will discuss them in subsections 0 and 0 .

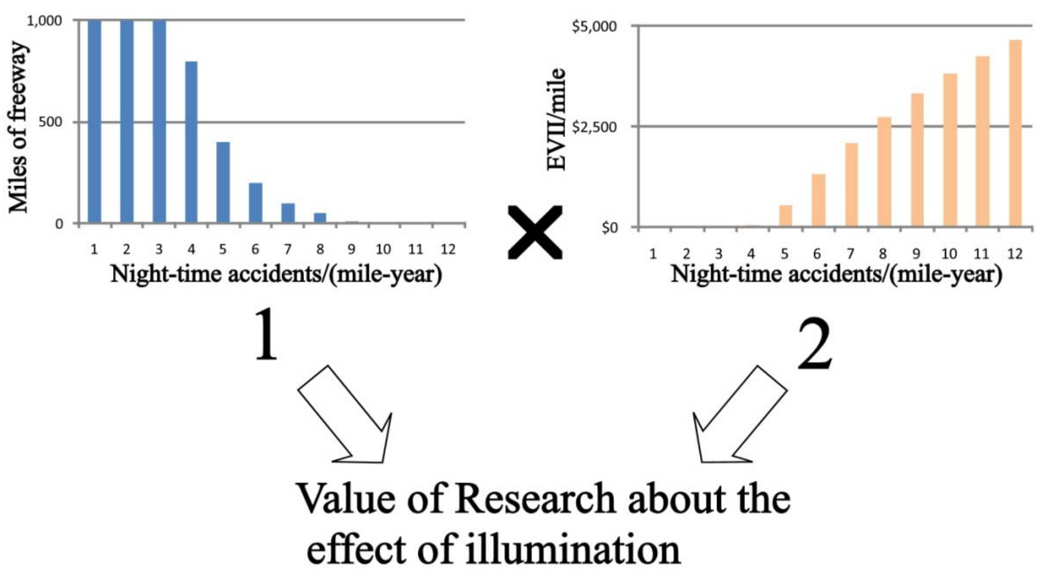


Figure 12. The two factors in the research about the safety effect of freeway illumination

5.1 Factor 1: Number of Units and their Target Accidents.

For factor 1 one has to get data about how many units would be affected by the decision at hand and what is their approximate expected number of target accidents. Thus, e.g., if the proposed research is about the CMF of illuminating limited-access roads, one has to assemble the data about the number of miles of unlit limited-access roads and their expected number of night-time accidents. The purpose is to produce a histogram such as that on the left of Figure 12 and it is not necessary to strive for unnecessary accuracy. It would be sufficient to describe the approximate relationship between AADT and the number of night-time accidents on limited-access roads and estimate the target accidents of a stretch of road on the basis of its AADT.

Agreeing on what accidents are the targets is not always simple. Thus, e.g., for the decision on illumination it was assumed that night-time accidents are the target. This is in line with all published research about the CMF of illumination. However, inasmuch as illumination will require light standards in the median or on the roadside, and these are usually protected by some guard rail or barrier, day-time accidents will also be affected and may need to be considered 'target'. A similar difficulty arises when the proposed research is, e.g., about the CMF for the conversion from 'unprotected' to 'protected' left-turn signal phasing. Inasmuch as the provision of left-turn protection will requires the retiming of all signal phases, all intersection accidents may be considered 'target'.

Complications of this kind are not a bad thing. After all, irrespective of whether one determines the value of some proposed research by judgment or by computation one must be clear about what the target accidents are. Experience with a variety of proposed research projects will, no doubt, introduce refinements and modifications to the procedure in section 0.

5.2 Factor 2: Information needed to compute the EVII

On the right of Figure 12 is the histogram of how EVII depends on the expected number of target accidents. The EVII in column 7 of Table 3 is made up of the two EVPI values in columns 5 and 6. To compute an EVPI one has to determine:

I. The break-even θ (the θ_b);
II. The loss function ($L(\theta)$);
III. The PDF of θ without and with implementation.

Items I and II, the break-even θ and the loss function, require information about three parameters:

- The cost of an average target accident – 'a';
- The annual cost (capital & operating) of implementation – 'c';
- The limiting Benefit/Cost ratio – 'r'.

Determining the cost of an average target accident may involve some digging but is largely unproblematic.

Determining the annual cost of implementation may be simple in some cases and complex in others. Thus, e.g., the information about capital and operating costs of illumination is obtainable from agencies such as state DOTs or large municipalities. I used two independent estimates which turned out to be very similar. Costs of illumination may vary somewhat from place to place and depend on technical detail (e.g. whether one line is to be built in the median or two on both sides of a road). Here as elsewhere, the choice of the appropriate level of detail has to be made in keeping with the purpose of the exercise: that of prioritizing research projects.

For the decision about illumination it was sufficient to consider dollar costs. However, when the decision is about, say, left-turn protection, the cost of delay has to be considered. This will add complexity inasmuch the amount of added delay due to signal retiming will depend on the traffic volume and capacity. Whenever the implementation of a decision will affect the cost to the user the (approximate) link between cost and amount of usage will have to be established.

The third parameter that goes into factors I and II is the limiting benefit/cost ratio (r). Determining the value or 'r' to be used in the research prioritization context is most likely a matter of a few emails and a group decision.

Item III, the PDFs of θ without and with implementation requires knowledge of three parameters. The first two are estimates of the mean and standard deviation of the PDF which comes from the meta-analysis of past research and from judgment. The third parameter is the standard deviation expected after the proposed research is finished. (The most likely estimate of the mean after the proposed research is finished is the estimate of the mean before it is done. Therefore the assumption will be that the mean will remain the same.) A separate section will discuss how the three parameter estimates can be obtained.

5.3 Summary of section 5

The context is provided by a decision whether to implement some action and the proposed research is about a CMF on which the decision depends. Whether one uses judgment to contemplate the merit of the proposed research or uses the kind of computation described in section 0 to estimate the value of the proposed research, the factors in Table 4 must go into the mix.

Table 4. Factors that need to be considered

1	How many units will be affected by the decision and what is their expected frequency of target accidents
2	What is the cost of an average target accidents
3	What is the annual cost of deciding to implement the decision on one unit (perhaps depending on the amount of its usage)
4	What is the limiting benefit/cost ratio
5	What are the mean and standard deviation of θ based on the existing knowledge
6	What is likely to be the standard deviation of θ after the proposed research is completed

This list was distilled from the computational procedure in section 0. It seems to me that just thinking clearly about what factors should be considered when contemplating the merit of some proposed research, most would come up with a similar listing. This reassures me that the computational procedure is sensible and that nothing important was missed.

The procedure in section 0 not only prescribes what information is needed but also specifies how exactly these factors are to be mixed. This can be exploited for gaining the understanding which is required for the formation of sound judgment which is the subject of the next section.

6. Understanding what makes one proposed research more valuable than another

To be able to assign a dollar value to some proposed research is important. However, it is even more important is understand the circumstances that make a proposed research to have high value. Such an understanding helps to think clearly about research prioritization even when it is not based on computation.

Some think that research has to be aimed at knowledge gaps, i.e. at areas where little research was done. This is partly true. Where little research exists the magnitude of θ is uncertain and the risk of incorrect decision-making large. In such circumstances new research is likely to will reduce the uncertainty, about θ. But, there are obviously other considerations. It is now clear, e.g., that when the expected number of target accidents is too small (i.e., when $\mu<rc/a$) there is no value to research at all because the right decision (do not implement) is known without any further inquiry. This is perhaps why many (including those who allocate money to medical research) think that research is best done on issues where there are many target accidents or, in the parlance of public health, where the 'burden of disease' is large. This too is true in some circumstances but only partly so. It is not true, e.g., when the cost of implementing the countermeasure is very large. Reliance on unaided intuition in this complex environment is insufficient. However, the procedure developed and explained in section 0 provides a solid skeleton on which to build understanding and the formation of informed judgment. Having established in section 0 what factors and information elements are needed to think about the merit of a proposed

research, in this section the question is: "What are the circumstances in which the value of research is large, and when it is small?"

To answer this question it is again useful to begin from the endpoint – the rightmost cell in the last row of Table 3- and to trace back the computation to see how the various factors combine to make value.

For a proposed research to have high value three conditions must be met:

I. There must be many units that are subject to the decision in which the CMF plays a role;
II. There must be a large EVPI before the proposed research is done;
III. There must be a much smaller EVPI after the conclusions of the research are in.

6.1 Value = Sum of products

The value in the bottom right cell of Table 3 is the sum of the products in column 8. The product is: EVII × Miles. The EVII is also made up of two components; it is the difference: $EVPI_{\text{before research}}$-$EVPI_{\text{after research}}$. Writing in the product 'Number of Units' instead 'Miles', the value of the proposed research is large if there are many units for which the \$ difference $EVPI_{\text{before the proposed research}}$-$EVPI_{\text{after the proposed}}$ is large.

The purpose of research is to improve decision-making. It is therefore obvious that for the value of research to be large there must be many units (miles of unlit roads, signalized intersection without left-turn protection, narrow bridges, etc) to which the decision applies. It is perhaps less obvious that one should focus on the 'number of units' rather than on 'number of target accidents' or on the 'burden of disease'. Target accidents (per unit) will not be left out. They be seen to enter into the picture when the monetary value of information is captured in the EVPI. This is discussed next.

6.2 What makes for a large EVPI before a proposed research is done?

The computations that go into the EVPI are relatively complex which is why a clear understanding of this component of research value is of essence. To provide a visual interpretation of the computation in Table 1and Table 2 consider the three elements of Figure 13.

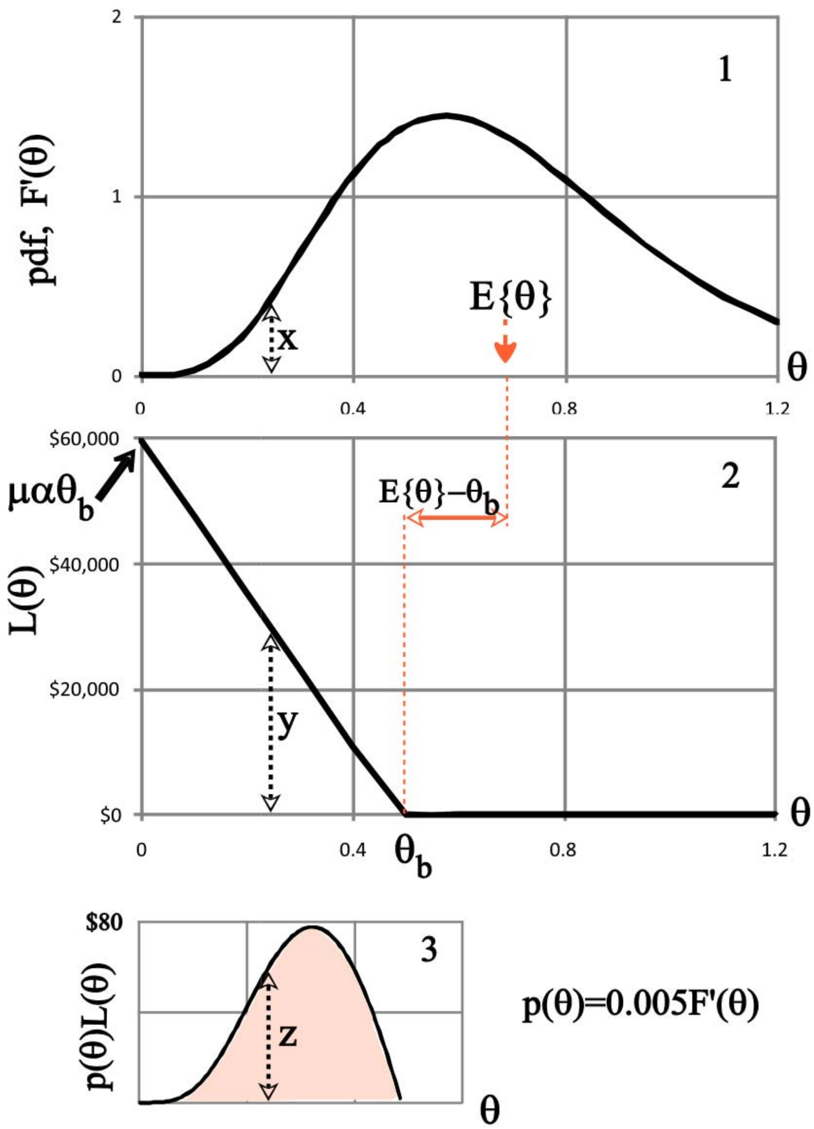


Figure 13. Components of EVPI; what moves what.

The top part (1) is the probability density function of θ; it is the derivative of the PDF in Figure 8 (see footnote 7). The middle part (2) is the loss function from Figure 9. The curve in the bottom part (3) represents the product of the corresponding ordinates from parts 1 and 2 (multiplied by $\theta_b/100=0.0049$). Thus z=0.0049×x×y corresponds to the entries of column 5 in Table 1. The sum of the entries in that column is the EVPI. This EVPI corresponds to the shaded area under the curve in the bottom part of Figure 13. What makes the shaded area large makes for a large EVPI. In broad brush strokes: EVPI will be large when ordinates such as x and y are large and when θ_b is close to E{θ}.

6.2.1 EVPI and the break-even θ.

In your imagination shift θ_b in the middle part of Figure 8 a bit to the left. Doing so also makes 'y' smaller because it lowers the top left corner of the loss function. Thus, shifting θ_b towards 0 makes both the base of the shaded area and its height smaller. Thus, the closer to 0 is θ_b the smaller is the EVPI. The size of the shaded area in this case is roughly proportional to the square of θ_b. To understand why this is so, recall that in Figure 13 the decision was 'do not implement'. That decision is wrong when θ is actually to the left of θ_b. The closer to 0 your imagination moves θ_b , the smaller is the probability that the 'do not implement' decision is wrong and, simultaneously, the smaller is the loss associated with the (wrong) 'do not implement' decision. If there is little chance that added research will change the 'do not implement' decision and the cost of error when it is wrong is small, there is little reason to engage in more research.

Let now θ_b return to its position in Figure 13 and begin shifting it in your imagination towards $E\{\theta\}$. This makes the shaded area (i.e. the EVPI) grow as its base and height both increase. This growth of EVPI continues till θ_b reaches $E\{\theta\}$. It cannot move further to the right because that would change the decision to 'implement'. It follows that the value of research is largest when the break-even θ is close to the mean of the PDF. It is then that the chance of the 'do not implement' decision to be wrong is the largest and therefore so is the interest in reducing the chance and cost of making an incorrect decision.

Thus, it is the distance$|E\{\theta\}-\theta_b|$ (see the middle part of Figure 13) which determines the EVPI. The larger this distance, the smaller is the EVPI and, conversely, the smaller the distance the larger the EVPI. When the distance is large, the chance of the current decision to be wrong is small and the motivation to engage in new research is correspondingly small. Conversely, when the distance is small the chance of the current decision to be wrong is large. This is when new research can have value.

In Figure 13 $E\{\theta\}>\theta_b$ and the decision is "do not implement". If θ_b was to the right of $E\{\theta\}$ (instead of to the left) the decision would be "implement". In a representation of the "implement" situation which is similar to the three-part Figure 13 the only difference would be that the shaded area would extend from θ_b to the right. It would have an infinite tail but, in practical terms the tail would end at about $E\{\theta\}+2$ to 3σ. The essence, however, would be the same: the larger the distance $|E\{\theta\}-\theta_b|$ the smaller the EVPI and EVPI is roughly proportional to $(E\{\theta\}+2 \text{ to } 3\sigma-\theta_b)^2$.

In this subsection your imagination made θ_b move left and right, as if it was a slider on a scale. The EVPI was seen to diminish as the distance between $E\{\theta\}$ and θ_b increased. Now the question is what determines the position of θ_b on this scale, what determines the distance $|E\{\theta\}-\theta_b|$.

6.2.2 The break-even θ and what makes it move.

By equation 1, $\theta_b=1-(rc/a\mu)$. The magnitude of θ_b is seen to depend on three parameters: 'r'-the limiting benefit-cost ratio, 'c'-the annual cost of implementing on one unit, and 'a'- the cost of one target accident. It also depends on μ-the expected number of target accidents on a unit. For the computations in Table 1 I used r=2.5, c=\$25,000/mile-year, a=\$20,000/accident and μ=6.1accidents/mile-year. With these, θ_b was 0.49. How θ_b would change when one of these parameters changes is shown in Figure 14.

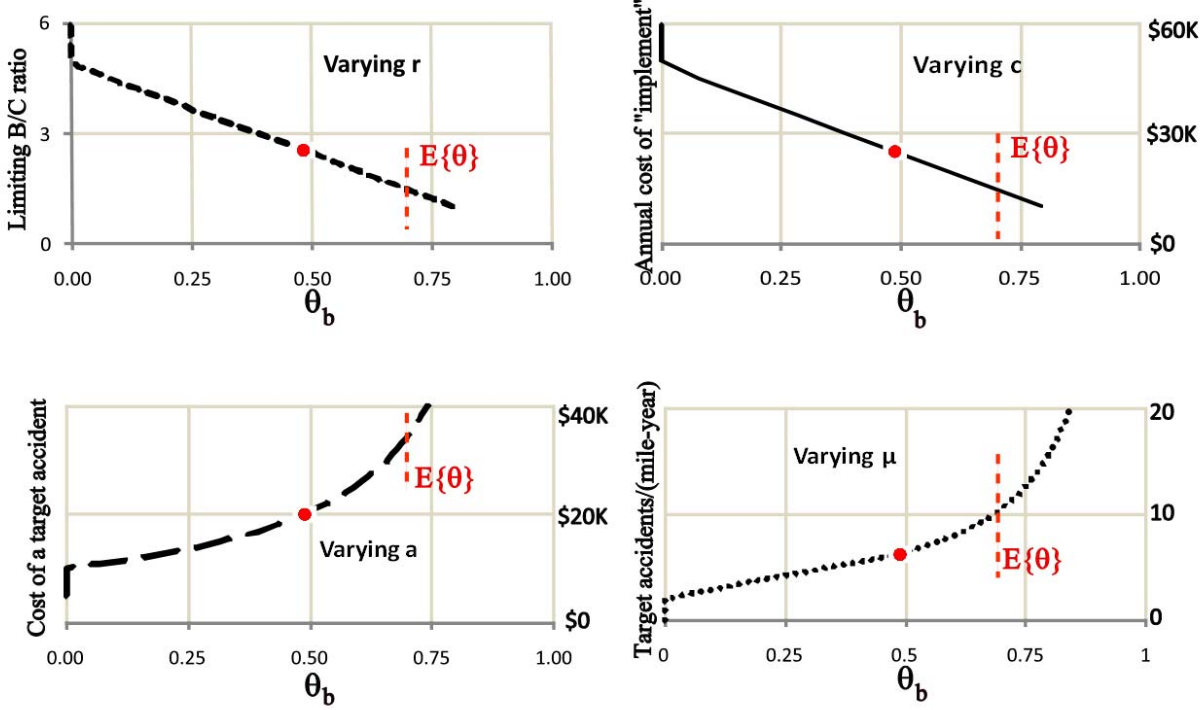


Figure 14. How θ_b changes when r, c, a and μ vary

NOTE: The smaller the distance between E{θ} and θb the larger is the EVPI and the larger is the value of new research.

The top left part shows that when 'r' is large, i.e. when alternative investments offer large benefits for a dollar spent, $\theta_b=0$. That is, with the values of 'c', 'a' and 'μ' stated earlier, even if implementation reduced μ to 0 it still would not pay for itself. Note that all four parts of Figure 14 have a similar vertical tail at $\theta_b=0$. This corresponds to the condition already stated in footnote 4 that no matter what the PDF of θ is, implementation cannot pay if $\mu<rc/a$. In the present case, implementation is out of the question and EVPI=0 (research about θ of no value) when $r>4.9$.

As the little red ball rolls down the dashed line 'r' diminishes, θ_b increases, and EVPI grows. I stopped the red ball from rolling r=2.5 which is where $\theta_b=0.49$. The vertical red line is placed at 0.7 which was the E{θ}used earlier. When $r=(1-E\{\theta\})a\mu/c$ the red ball reaches the dashed vertical line and EVPI reaches its maximum. With the values used in the numerical examples this occurs at $r=(1-0.7)\times 20{,}000\times 6.1/25{,}000=1.4$. As the ball rolls further down the incline the EVPI diminishes. The ball cannot roll much further, it cannot go beyond r=1.

The top right part of Figure 14 is similar to its top left part. Implementation is out of the question is $c>a\mu/r$. In the present case EVPI=0 when c>$49,000. As the ball comes closer to the dashed vertical line the EVPI increases. This increase is due to the fact the chance of the 'do not implement' decision being wrong gets larger and larger. The red ball reaches the dashed vertical line when $c=(1-E\{\theta\})a\mu/r$. This occurs at (1-0.7)×$20,000×6.1/2.5=$15,000/mile-year. At this cost of implementation EVPI is largest. As the ball rolls on beyond the E{θ}and further to its right, the EVPI diminishes. In this region the decision is 'implement'. The further the ball from E{θ} the lesser the chance that it is wrong and the smaller is the cost of the implementation.

In the two bottom graphs of Figure 14 the ball rolls uphill; the larger the cost of a target accident and the larger their expected frequency, the larger is θ_b. There is no value in research about the PDF of θ when a<rc/μ and when μ<rc/a. With the parameter values used here, there is no value in research when a<$10,000 and when μ<3.1 nigh-time accidents/mile-year. As 'a' and 'μ' increase θ_b increases and the ball comes closer to the vertical line which marks the position of E{θ}. The EVPI is largest when a=(rc/μ)/(1-E{θ}) and μ=(rc/a)/(1-E{θ}); this occurs at a=$34,000 and μ=10.4 night-time accidents/mile-year. As 'a' and 'μ' grow further, EVPI diminishes.

6.2.3 EVPI and target accidents

The length of the base of the shaded area in Figure 13 is determined by how far is θ_b from 0. The height of the shaded area is the product of the probability density (x) and the loss function (y). The ordinate y, in turn, is proportional to μ-the expected number of target accidents on a unit. Through its dependence on the loss function the EVPI would be proportional to μ. However, inasmuch a μ also affects θ_b, the EVPI increases more than in proportion to μ in the "do not implement" region and less so in the "implement" region.

6.2.4 The role of the PDF of θ

The top part of Figure 15 shows by the solid curve the Probability Distribution Function of θ with E{θ}=0.7 and σ=0.3 as in Figure 8and another PDF with the same mean but σ=0.25 The corresponding probability density functions are shown in the bottom part of Figure 15. The effect on the value of research value of the three parameters: E{θ}, σ before the proposed research and the smaller σ after the research results are available can now be examined.

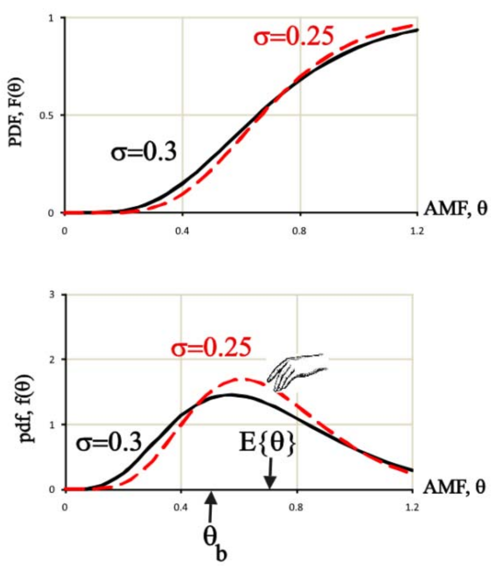


Figure 15. Two PDFs and the corresponding pdfs.

The shaded area in Figure 13 represents the EVPI. The ordinate 'z' of the shaded area is the product of 'x' and 'y', where 'x' is the ordinate of the pdf. As is obvious from the bottom part of Figure 15, the smaller the σ the smaller are the ordinates of the pdf. The smaller are the x, the smaller are the z, and the smaller is the shaded area and the EVPI. It is through this mechanism that, as research about θ reduces the standard deviation of the PDF of θ, the EVPI diminishes till, as σ approaches 0, so does the EVPI. When σ=0 the implementation decision is always correct and further research has no value. Recall that the expected value of a proposed research is the difference of the EVPI before and after the research results are known. The larger is the difference between σ before and σ after research, the larger is the value of the research.

Imagine now that the hand in Figure 15 pulls the pdf to the right without changing its shape. This leaves σ unchanged moves E{θ} away from θ_b. The effect of increasing the distance between E{θ} and θ_b was discussed in section 0; the larger the distance the smaller the EVPI.

6.3 Summary of section 6.

Three conditions combine to give high value to a proposed research:

I. There must be <u>many units</u> that are subject to the decision in which the CMF plays a role;
II. There must be a <u>large EVPI before</u> the proposed research is done;
III. There must be a <u>much smaller EVPI after</u> the conclusions of the research are in.

The first item is self-evident. However, to understand what affects EVPI and how, item II had to be examined closely. It turned out that:

a. the magnitude of the EVPI is more than proportional to the number of target accidents/unit in the "do not implement region, and less than proportional in the "implement" region.
b. The closer is θ_b to E{θ}, the larger is the EVPI. That is, the highest values of research will be found when the "to implement or not to implement" decision is a close one.
c. The EVPI is roughly proportional to θ_b^2 in the "do not implement" region. Assuming that there is little probability mass beyond E{θ}+2 to 3σ, EVPI is approximately proportional to $(E\{\theta\}+\ 2\ to\ 3\sigma-\theta_b)^2$ in the "implement" region.

The parameters r, c, a and μ combine to determine θ_b and θ_b plays a central role in determining EVPI. How the parameters r, c, a and μ affect EVPI is shown in Table 5.

Table 5. How EVPI depends on the parameters r, c, a, and μ

parameter	EVPI=0 when	EVPI increases when	EVPI is largest when	EVPI diminishes when
r, limiting B/C ratio	r>aμ/c	r diminishes from aμ/c till (1-E{θ})aμ/c	r=(1-E{θ})aμ/c	r diminishes beyond r=(1-E{θ})aμ/c
c, annual cost of implementation	is c>aμ/r	c diminishes from aμ/r till (1-E{θ})aμ/r	c=(1-E{θ})aμ/r	c diminishes beyond c=(1-E{θ})aμ/r
a, cost of a target accident	a<rc/μ	a increases from rc/μ till $a=\frac{rc/\mu}{1-E\{\theta\}}$	$a=\frac{rc/\mu}{1-E\{\theta\}}$	a increases beyond $a=\frac{rc/\mu}{1-E\{\theta\}}$
μ, expected target accidents/unit	μ<rc/a	μ increases from rc/a till $\mu=\frac{rc/a}{1-E\{\theta\}}$	$\mu=\frac{rc/a}{1-E\{\theta\}}$c/a	μ increases beyond $\mu=\frac{rc/a}{1-E\{\theta\}}$

The purpose of the proposed research is to produce a revised PDF of θ. The most likely outcome of the revision is that E{θ}will remain unchanged but σ will be reduced. The effect of reducing σ is to shift some of the probability mass from the tails of the pdf and towards its center. This reduces EVPI because the loss function is high in the tails. Thus, condition III giving new research high value is that the proposed research be able to substantially reduce the σ of the PDF.

7. The variance of θ.

To this point the focus was on two tasks. The first task was to devise a quantitative procedure for computing the monetary value of proposed research. The second task was to extract from this procedure an understanding of what factors determine the monetary value of proposed research and what circumstances or factor combinations make this value large. So as not to impede the flow of the argument little was said about the PDF of the crash modification factor (function) θ. This will be the focus of the present chapter.

To set the stage, recall that, in the final account, research on road safety is in support of making decisions. Each decision can be viewed as being between "implement" or "do not implement." The decision to implement is expected to cause an accident reduction that is proportional (1-θ), where θ is the Crash Modification Factor. In chapter 0 I only said that the value of θ is never known and that what information we have about θ comes from past research studies, that each research study yields an estimate of the θ that prevailed in that study, and that from these estimates one can construct a Probability Distribution Function (PDF) of θ. The main point was that we can know only the PDF of θ, not the actual value of θ that applies in the specific circumstances of a certain project.

References

Ades AE, Lu G, Claxton KP. (2004) Expected value of sample information calculations in medical decision modeling. *Medical Decision Making* 24 (2): 207-227.

Berger JO. (1985). *Statistical decision theory and Bayesian analysis.* Springer Series in Statistics, 2nd.

Bojke L, Claxton K, Sculpher MJ, Palmer S, Philips, Z. (2008) The cost-effectiveness and value of information associated with repeat screening for age related macular degeneration. *Medical Decision Making* 28: 33-43.

Brennan A, Kharroubi SA. (2007a) Efficient computation of partial expected value of sample information using Bayesian approximation. *Journal of Health Economics*. 26: 122-148.

Briggs A, Claxton KP., Sculpher MJ. (2006) *Decision analytic modelling for the evaluation of health technologies*. Oxford University Press., Oxford.

Claxton KP, Posnett J. (1996) *an economic approach to clinical trial design and research priority setting*. *Health Economics*. 5(6): 513-524.

Claxton KP. (1999) The irrelevance of inference: a decision-making approach to the stochastic evaluation of health care technologies. *Journal of Health Economics*. 18: 341-364

Claxton KP, Sculpher MJ. (2006) Using value of information analysis to prioritise health research: some lessons from recent UK experience. *PharmacoEconomics*. 24 (11): 1055-1068.

Colbourn TE, Asseburg C, Bojke L, Philips Z, Welton NJ, Claxton KP, Ades AE, Gilbert RE. (2007) Preventive strategies for group b streptococcal and other bacterial infections in early infancy: cost effectiveness and value of information analyses. *British Medical Journal*. Sep 29;335(7621):655. Epub 2007 Sep 11.

Fleurence RL and Torgerson DJ (2004) Setting priorities for research. *Health Policy* 69: 1–10

Hammitt JK, Cave JAK. (1995): *Research planning for food safety: a value of information approach*. RAND, Santa Monica, USA.

Hauer, E. and Geva, I. (1984). A decision analytic approach to the design of experiments in research on traffic safety. In: Yagar, S. (ed.), *Transport Risk Assessment*. University of Waterloo Press. Waterloo.

Howard RA. (1966). *Information value theory*. IEEE Transactions on Systems, Science and Cybernetics. SSC-2 (1): 22-26.

Institute of Medicine (1998) Scientific Opportunities and Public Needs: Improving Priority Setting and Public Input at NIH. National Academies. The National Academies Press. Washington, D.C.

Meltzer D (2001) Addressing uncertainty in medical cost–effectiveness analysis Implications of expected utility maximization for methods to perform sensitivity analysis and the use of cost–effectiveness analysis to set priorities for medical research. Journal of Health Economics 20, 109–129.

Meltzer DO, Basu Y, and Meltzer HY, (2009) Comparative Effectiveness Research For Antipsychotic Medications: HowMuch Is Enough? If comparative effectiveness research is to guide policy, then it must include evaluations of changes in policy. *Health Affairs* 28, no. 5 794–808.

Parmigiani G. (2002) *Modeling in medical decision making: a Bayesian approach*. Statistics in Practice Series, John Wiley & Sons Ltd., Chichester, UK.

Philips Z, Claxton KP, Palmer SJ, Sculpher MJ. (2006*)* Priority setting for research in health care: an application of value of information analysis to glycoprotein iib/iiia antagonists in non-st elevation acute coronary syndrome. *International Journal of Technology Assessment in Health Care* 22(3): 379-387.

Pratt, J.W., Raiffa, H., Schlaifer, R., (1995). *Introduction to statistical decision theory.* MIT Press, Cambridge, USA.

Raiffa H. and Schlaifer R. (2000) *Applied statistical decision theory.* Wiley Classics Library Series, Wiley-Interscience, New York, USA.

Schlaifer R. (1959) *Probability and statistics for business decisions: an introduction to managerial economics under uncertainty.* McGraw-Hill, New York, USA.

Thompson KM, Graham JD. (1996) Going beyond the single number: using probabilistic risk assessment to improve risk management. *Human and Ecological Risk Assessment*. 2(4): 1008-1034.

Willan AR, Pinto EM. (2005) The value of information and optimal clinical trial design. *Stat Med*. 24:1791-806.

Winkler, R.L., (1972). *An introduction to Bayesian inference and decision.* Holt, Rinehart and Winston, New York.

Yokota F, Thompson K. (2004) Value of information literature analysis: a review of applications in health risk management. *Medical Decision Making*. 24: 287-298.

Glossary

Acronyms

EVII Expected Value of Imperfect Information

EVPI Expected Value of Perfect Information

PDF Probability Distribution Function

VBA Visual Basic for Applications

VOI Value of Information

Notation

a Average cost of one target accident

c Annual cost of countermeasure implementation

F(θ) Probability Distribution Function, P(Θ≤θ)

L(θ) Difference between the foregone benefit and the opportunity costs of implementing the countermeasure.

r The Limiting benefit-cost; how many $ of benefit can the last invested $ generate

Greek Letters

θ Accident (Crash) Modification Factor (or Function)

θ_b That θ at which the benefit-cost ratio=r, the limiting benefit/cost ratio

μ Expected number of target accidents/year.

Appendix D. Estimating the Mean and Variance of CMFs

In a previous appendix, the VOI (Value of Information) approach was described for prioritizing research about Crash Modification Factors (CMFs or, equivalently, θs). It turned out that to determine the value of a proposed research project about some CMF, it is important to know how uncertain we are about the magnitude of that CMF and by how much this uncertainty is likely to be reduced by the proposed research. Section 4 of Appendix C states: "The value of θ is never known. What information we have about θ comes from past research studies. Each research study yields an estimate of the θ that prevailed in that study. From these estimates one can construct a Probability Distribution Function (PDF) of θ to be denoted by F(θ). How this can be done will be explained later …." Section 4.1 of the first report (Appendix C) reduced the problem of constructing the F(θ) to that of estimating its mean (E{θ}) and variance (VAR{θ}).[9] Accordingly, what needs to be done here is to show how this mean and variance can be estimated.

The explanation will be in several steps. To begin, it is important to be clear about what probability distribution we speak about. Next will be a description of how from estimates of θ that were obtained in past research one can estimate the mean and variance of F(θ). Following that I have to provide a procedure for determining by how much a proposed new research is likely to reduce the VAR{θ}. These issues will give rise to several follow-up questions: How to estimate the variance of θ when there is only one past research study or perhaps none; whether to pool several past studies when these pertain to different circumstances or rather to pool only when the circumstances are homogeneous; and how these questions frame the issue of the transferability of CMFs. Inasmuch as new ground is being broken, not all the questions that arise can be answered at this time. The aim is to deal those issues the resolution of which is needed to accomplish the task of assigning priority to proposed research projects.

1. What Probability Distribution Function are we talking about?

Our setting is that of making decisions. The decision is about whether to implement some action. This decision depends, among other things, on what reduction in accidents that action is expected to cause. The expected accident reduction is determined by the Crash Modification Factor, θ. The θ is that which will prevail in the specific circumstances of the contemplated future action. Thus, e.g., if the decision is about whether to illuminate a certain stretch of a limited access road in Colorado two years from now, the relevant θ is that which will apply to that stretch of road, at that time, with its users, and the particular illumination design[10].

Similar decisions were implemented in various locations in the past and their safety consequences were researched and reported on. Each such research study produced an estimate of θ. Every such estimate

[9] This was done by assuming that the PDF obeys the two-parameter Gamma distribution.

[10] Illumination designs differ by where the poles are placed, at what spacing, how these are protected, what the intensity of illumination is etc.

reflects the specific circumstances that characterized that implementation. Estimates of θ usually reveal a certain degree of variability. Some of the variability is 'statistical' in nature and is due to the data, the research method and the sample size used. Another part of the variability is due to differences in the 'circumstances' of implementation; differences in what exactly was done, to what kinds of units, in what environment, to which road users, in what year, etc.

To illustrate, suppose that in the published literature there are only two research studies about the safety effect illumination on access-controlled roads[11]. One study is from Arizona with data from 1992-1995 in which the estimated CMF for night-time injury accidents was 0.75 with a standard error (s) of ±0.04; the other study is from British Columbia with data from 2001-2006 in which the estimated CMF was 0.62 with s=± 0.06. If 'A' stands for Arizona, 'B' for British Columbia, and ^ for "estimate", we have $\hat{\theta}_A = 0.75 \pm 0.04$ and $\hat{\theta}_B = 0.62 \pm 0.06$. That is what we have to guide the aforementioned decision for Colorado. The essential features of the situation are shown in Figure 16.

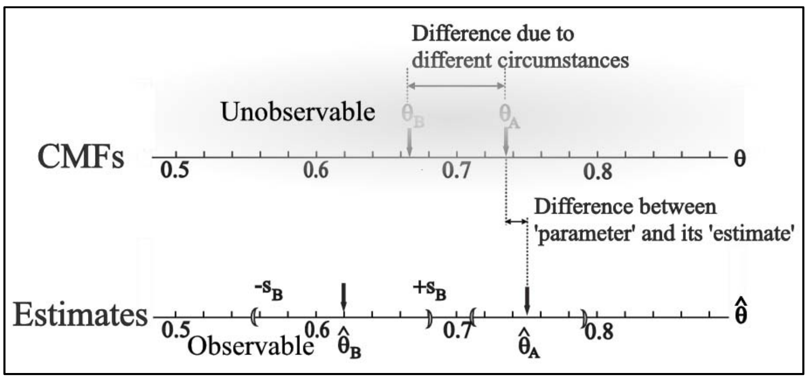


Figure 16. Illustration of Example

The figure consists of two related parts. The estimates, i.e. the values in the numerical example make up the lower part. Thus, e.g., the arrow for the Arizona estimate ($\hat{\theta}_A$) is placed at 0.75 on the $\hat{\theta}$ scale. The two estimates are surrounded by brackets of ±one standard error. The values on this axis are computed from data and are in this sense 'observable'. In the upper part of Figure 16 the arrows show the values of θ_A and θ_B; those are the CMF values on which the estimates in the lower part would converge if they were unbiased and if estimation could be repeated many times under identical conditions. Since this cannot be done, these values are never known and are therefore described as 'unobservable'; it is why they are shown as if they were behind a cloud. The difference between the CMF values θ_A and θ_B is due the many differences between the circumstances of the implementations in Arizona (A) and British Columbia (B). The other differences, those between θ_A and $\hat{\theta}_A$ and between θ_B and $\hat{\theta}_B$ are due to limitations of data, method and sample size and were called 'statistical'. These are the familiar difference between a 'parameter' and its 'estimate'.

The two CMFs in the upper part of Figure 16 were shown as different. This reflects the belief that the same kind of action may affect safety differently under different circumstances[12]. More specifically the belief is that if the CMF of an action or interventions depends on some details of implementation and on some of the traits of the affected units, and when these details and traits vary from one implementation to another, the CMF in these implementations will be almost always different. The complementary belief is that if the safety effect of an action or intervention does not depend on any of the details and unit traits in

[11] In fact very many such research studies exist. I have invented two such studies to keep the illustrations simple.

[12] That is, my point of departure is what in statistics is referred to as the 'random effects' model.

which two implementations differ then the two CMF will be the same. There is no reason to think that the illumination details (see footnote 10) or unit traits (roads, road users, traffic, twilight duration, etc.) in Arizona and British Columbia were the same. Nor is there reason to think that the safety effect of illumination does not depend on these implementation details and unit traits. This is why in this example and also in general it seems sensible to allow for the possibility that the CMFs differ from one implementation to another. Although the estimates in the lower part of Figure 16 do not rule out the possibility that the CMF values in these two implementations were (nearly) the same, if they were this would be an unlikely special case[13].

There could be many research studies about the CMF of illuminating limited access roads, each such study and its θ (CMF). These θs would have mean and a variance. Our task is to use information such as that in the lower part of Figure 16 for estimating what the mean and variance of the θs in its upper part might be. The size of the sample which is available for this estimation is the number of $\hat{\theta}$s from past research studies about the same kind of action. In Figure 16 the sample size is 2.

At this point the circle can be closed. The setting is that of making a decision about some future action. For that purpose we want to know what the θ of that future action might be. The assumption is that that the future will be similar to the past. If so, the θ for the future action will be one of the values from the Probability Distribution Function of past θs. The estimates of θ (the $\hat{\theta}$s) from past research studies and their standard errors (±s) will be the clues from which an estimate of the PDF (the F(θ)) is to be constructed.

2. Estimating the mean and variance of F(θ)

Within the context of Value Of Research determination for research priority it is not necessary to be overly concerned about the functional form of F(θ). As noted in footnote 9 it will be assumed that F(θ) can be adequately represented by the two-parameter Gamma distribution which is completely specified by its mean and variance. Accordingly this section will deal only with the estimation of these two parameters.

2.1 Estimating the Mean of F(θ)

The decision whether to implement some action or intervention is based, among other considerations, on the expected benefit. The expected benefit, in turn, depends on the expected CMF denoted by E{θ}, i.e., the mean of F(θ). This mean is usually estimated use some kind of weighted average of the CMF estimates from past research[14]. This 'weighted average' is the principal number given in the HSM and similar sources and appropriately so[15]. In this section I describe one way of computing a weighted average and of determining its variance.

---

[13] Some might be tempted to ask whether the null hypothesis of equality can be rejected. While it is true that the statistical hypothesis that the two CMFs are the same cannot be rejected, the alternative hypothesis that the two differ by 0.75-0.62=0.13 is much more likely and even more difficult to reject.

[14] The weighting can be by computation or by expert judgment.

[15] The idea is old and was originally associated with the question of how much one should be willing to pay for the opportunity to play a game in which outcomes that materialize with probabilities $p_1, p_2, \ldots, p_i, \ldots p_n$ are associated with money gains $g_1, g_2, \ldots, g_i, \ldots, g_n$. The argument was that one should be willing to pay the up to the expected value of $\sum_1^n p_i g_i$. This was challenged in 1713 by Nicholas Bernoulli (the St. Petersburg paradox). The paradox was resolved 25 years later by his cousin, Daniel Bernoulli who posited that the utility of a money gain is less than proportional to its size. However, within the usual calculus of costs and benefits when the expenditure of

Suppose that we have CMF estimates $\hat{\theta}_1, \hat{\theta}_2, \cdots, \hat{\theta}_i, \cdots, \hat{\theta}_n$ and their standard errors $\pm s_1$, $\pm s_2$,, …, $\pm s_i$, …,$\pm s_n$. Their weighted average is the linear combination $\sum_1^n (w_i/\sum_1^n w_i)\hat{\theta}_i$ in which w_i is the raw weight of the i-th estimate. The variance of this linear combination is $\sum_1^n (w_i/\sum_1^n w_i)^2 VAR\{\hat{\theta}_i\}$. This variance is can is smallest[16] when w_i is proportional to $1/VAR\{\hat{\theta}_i\}$. When this weight is used, the variance of the weighted average is $1/\sum_1^n (1/VAR\{\hat{\theta}_i\})$. In sum, replacing $VAR\{\hat{\theta}_i\}$ by s_i^2

$$\text{Weighted Average} \equiv \bar{\theta} = \sum_1^n \frac{1/s_i^2}{\sum_1^n 1/s_i^2}\hat{\theta}_i$$ **Equation 1**

and

$$V\hat{A}R\{\bar{\theta}\} \equiv s^2\{\bar{\theta}\} = \frac{1}{\sum_1^n 1/s_i^2}$$ **Equation 2**

To illustrate the use of these equations the corresponding computations are in Table 6.

Table 6. Illustration of computations (Invented data)

	$\hat{\theta}$	S	s^2	$1/s^2$	Weights	Contributions to mean
Arizona	0.75	±0.04	0.0016	625	0.69	0.519
B.C.	0.62	±0.06	0.0036	278	0.31	0.191
Sums				903	1	**$\bar{\theta}$ =0.710**

The shaded part of the table contains the data from the earlier example. The next three columns show the computation of the weights. The weighted contribution of each $\hat{\theta}$ is in this case the last column and their sum, the weighted average is 0.71. The variance of $\bar{\theta}$ is estimated to be 1/903=0.0011 and $s\{\bar{\theta}\} = \sqrt{1/903} = \pm 0.03$.

The Arizona data are from 1992-1995, British Columbia data from 2001-2006 and the decision is for illuminating a road in Colorado two years from now. If one could reasonably assume that the θ of illuminating limited access roads was the same in Arizona in the late nineties as in British Columbia in the early two thousands and, furthermore, that the θ will be the same in Colorado in 2012, then one could take the ±0.03 as describing our uncertainty about the θ for Colorado. However, from all we know, so assuming is unreasonable. Therefore, the uncertainty about the θ for the Colorado decision is not the uncertainty about the weighted average and the task is to use the available sample information to estimate the variance of the θs.

2.2 Estimating the Variance of F(θ)

Figure 16 was closely linked to the Arizona-B.C.-Colorado example. Figure 17 is a more generic visualization of the situation.

public money is involved this non-linearity plays no role. This is why such decisions are based on the magnitude of expected values.

[16] See, e.g., Hauer (1997), Observational before4-after studies in road safety. Pergamon. P. 193.

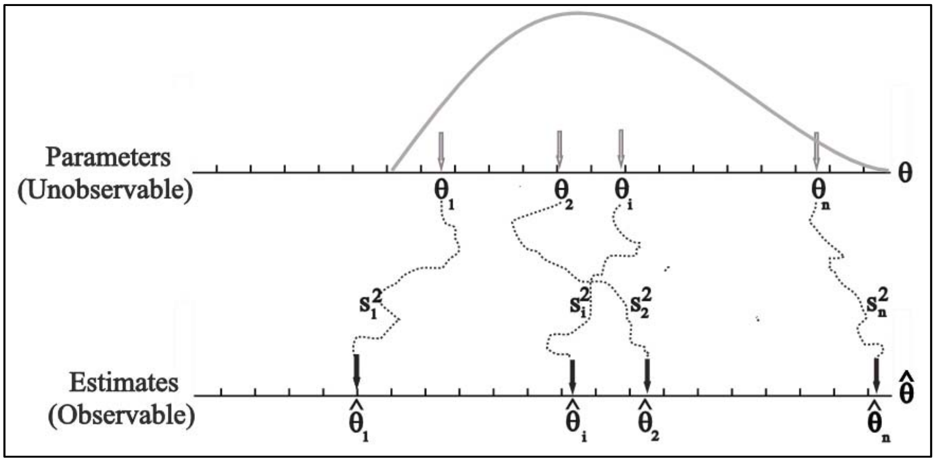


Figure 17. Parameters and their estimates.

The unobservable parameters (the CMFs or θs in our case) form the upper tier of the figure. For each parameter (θ) in the upper tier there is an estimate ($\widehat{\theta}$) in its lower tier. The estimates are 'observable' in the sense that they are computed from observed data. The parameters and their estimates are linked with wiggly lines representing a stochastic link. The nature of this link is that the estimates are unbiased and have finite variances. Estimates of these variances are shown in the figure as s_1^2, s_2^2, …, s_i^2, …, s_n^2.

The figure shows a sample of 'n' parameters. If n was a large number and the θs were sorted into bins by magnitude, the number of parameters in each bin would form a histogram. The normalized histogram could then be approximated by a probability density function, f(θ), such as that shown in Figure 17 by the smooth curve. The definite integral of f(θ) is the probability distribution function F(θ).

Section 0 shows how to estimate E{θ}, the mean of F(θ). In this section the question is how the same sample information can be used to estimate VAR{θ}, the variance of F(θ). Because the θs of the upper tier are inked to the estimates $\hat{\theta}$ in the lower tier, VAR{θ}is related to the $\mathrm{VAR}\{\hat{\theta}\}$. To understand the relationship, imagine first that estimation is without error. If so, the wiggly lines in Figure 17 would be straight and vertical and VAR{θ) would equal $\mathrm{VAR}\{\hat{\theta}\}$. However, estimation always involves error and the estimates $\hat{\theta}$s tend to be more widely dispersed than the parameter θ. This is why $\mathrm{VAR}\{\hat{\theta}\} > VAR\{\theta\}$. The larger the errors of estimation, the larger is the difference $\mathrm{VAR}\{\hat{\theta}\} - \mathrm{VAR}\{\theta\}$. Our aim is to estimate VAR{θ}. The magnitude of $\mathrm{VAR}\{\hat{\theta}\}$ can be estimated from the sample of estimates: $\hat{\theta}_1, \hat{\theta}_2, \cdots, \hat{\theta}_i, \cdots, \hat{\theta}_n$. To get at VAR{θ} it remains to estimate the difference $\mathrm{VAR}\{\hat{\theta}\} - \mathrm{VAR}\{\theta\}$.

The starting point is the law of total variance[17]:

$$\mathrm{VAR}\{\hat{\theta}\} = \mathrm{E}\{\mathrm{VAR}\{\hat{\theta}|\theta\}\} + \mathrm{VAR}\{\mathrm{E}\{\hat{\theta}|\theta\}\} \qquad \textbf{Equation 3}$$

The inner part of the first term on the right-hand-side, $\mathrm{VAR}\{\hat{\theta}|\theta\}$, is the variance of the estimate of θ when the parameter is θ. With this, the first term of the right-hand side of Equation 3, $\mathrm{E}\left\{\mathrm{VAR}\{\hat{\theta}|\theta\}\right\}$, is the mean the estimate variances. The inner expression of the second term of the right-hand-side of Equation 3, $\mathrm{E}\{\hat{\theta}|\theta\}$, is the mean of the estimate when the parameter is θ. As our interest is only in unbiased estimates of θ, $\mathrm{E}\{\hat{\theta}|\theta\} = \theta$ and, therefore, $\mathrm{VAR}\left\{\mathrm{E}\{\hat{\theta}|\theta\}\right\} = \mathrm{VAR}\{\theta\}$. Equation 3 can now be rewritten as:

[17] The law of total variance (or, equivalently, the variance decomposition formula) follow by logic from the axioms of probability. For more detail see e.g. http://en.wikipedia.org/wiki/Law_of_total_variance.

Variance of the estimates of θ= Mean of the variances of the estimates of θ
+Variance of the θs

or $$\mathrm{VAR}\{\hat{\theta}\} = \mathrm{E}\{\mathrm{VAR}\{\hat{\theta}|\theta\}\} + \mathrm{VAR}\{\theta\}$$ **Equation 4**

and, transposing terms, $\mathrm{VAR}\{\theta\} = \mathrm{VAR}\{\hat{\theta}\} - \mathrm{E}\{\mathrm{VAR}\{\hat{\theta}|\theta\}\}$

The first term on the right hand side, $\mathrm{VAR}\{\hat{\theta}\}$, can be estimated by the average of the squared differences $\left(\hat{\theta} - \bar{\theta}\right)^2$. The second term, $\mathrm{E}\{\mathrm{VAR}\{\hat{\theta}|\theta\}\}$, can be estimated by the average of the s^2 .To illustrate, I will again use the Arizona-British Columbia example. As in Table 6 the data are in the shaded part of Table 7.

Table 7. Illustration of computations

	$\hat{\theta}$	S	$\left(\hat{\theta} - \bar{\theta}\right)^2$	s^2
Arizona	0.75	±0.04	0.0016	0.0016
B.C.	0.62	±0.06	0.0081	0.0036
Averages			$\widehat{\mathrm{VAR}}\{\hat{\theta}\} =$ **0.00485**[18]	$\hat{\mathrm{E}}\{\mathrm{VAR}\{\hat{\theta}|\theta\}\}$=**0.0026**

Were it true that the weighted average $\bar{\theta}$ was the same as $\mathrm{E}\{\theta\}$ and the average of the s^2 was known without error, we could estimate $\mathrm{VAR}\{\theta\}$ by $\hat{V}$:

$$\hat{V} = \begin{cases} \text{Sample Variance of of the } \hat{\theta}\text{s around } \bar{\theta} - \text{average } s^2 & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$

or

$$\hat{V} = \begin{cases} \dfrac{\sum_1^n\left(\hat{\theta}_i - \bar{\theta}\right)^2}{n} - \dfrac{\sum_1^n s_i^2}{n} & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$ **Equation 5**

However, inasmuch as $\bar{\theta}$ has a positive variance (the estimate of which is in Equation 2) it has to be added to the mix[19]. Therefore we estimate $\mathrm{VAR}\{\theta\}$ by:

$$\widehat{\mathrm{VAR}}\{\theta\} = \hat{V} + \widehat{\mathrm{VAR}}\{\bar{\theta}\} = \hat{V} + \frac{1}{\sum_1^n 1/s_i^2}$$ **Equation 6**

For the data in Table 7 we have $\hat{V}$ =0.0048-0.0026=0.0022, $\widehat{\mathrm{VAR}}\{\bar{\theta}\} = 1/903 = 0.0011$ and therefore $\widehat{\mathrm{VAR}}\{\theta\}$=0.0033.

---

[18] I am using the sample variance, not the bias corrected sample variance (dividing the sum of squared deviations by n, not by n-1).

[19] Whether it is better to account for the uncertainty about $\bar{\theta}$ as in Equation 6 or, perhaps, by dividing by n-1 instead of by n in Equation 5 is not clear. I would have to investigate this further by writing and testing a simulation code. In order to proceed with the other pressing tasks I will postpone this activity. The attraction of using Equation 6 is that it brings into the process the possibility to reduce $\mathrm{VAR}\{\theta\}$ by reducing the uncertainty around $\bar{\theta}$ through doing additional research.

2.3 Implementing computations on a spreadsheet.

To facilitate the computation of the weighted mean ($\bar{\theta}$) and of $\widehat{\mathrm{VAR}}\{\theta\}$ an Excel 2007 macro-enabled spreadsheet has been prepared with a command button and the corresponding VBA code. The worksheet name is 'Mean, Variance and Option 1'. As shown in Figure 18 , the data are in the yellow-shaded columns A (the study number of identifier) , B (the CMF estimate $\hat{\theta}$) and C (s, the standard error of $\hat{\theta}$). (The data in the blue part are not used for this computation). The program reads in the data till a blank is encountered in column A. To make sure the data has been entered correctly you will be asked whether the number of data points is right. The data re also echoed to the right of column I (not shown in Figure 18). Up to 100 study results can be read in and processed. Once the 'Compute Mean and Variance' button is pressed, the results are displayed in columns H and I. The weighted mean ($\bar{\theta}$) is in I6, the estimate of the variance of the CMF, the $\widehat{\mathrm{VAR}}\{\theta\}$ is in I11.

	A	B	C	D	E	F	G	H	I
1	Past Studies	CMF estimate	±Standard error		Planned Studies	±Standard error			
2	Arizona	0.75	0.04		1	0.03		Estimate Mean and Variance of CMFs	
3	B.C.	0.62	0.06		2	0.03			
4					3	0.03			
5								Results for "Computing Mean and Variance"	
6								**Weighted mean =**	**0.710**
7								Standard error of weighted mean=	0.033
8								Variance of CMF estimates around weighted mean=	0.00485
9								Mean variance of estimates=	0.0026
10								Vhat=	0.0022
11								**Variance of CMFs=**	**0.0034**
12								Standard error of CMFs=	0.058
13									

Figure 18. Spreadsheet with data and command button

3. By how much will be the variance of CMFs reduced by a proposed research

To determine the value of a proposed research project about some CMF we need to know (a) how uncertain we are about the magnitude of that CMF and (b) by how much this uncertainty is likely to be reduced by a proposed research. Item (a) was discussed in the preceding sections; item (b) will be discussed next.

To recapitulate, θs have a distribution with a mean and a variance. The chance of making the wrong decision about whether to implement some countermeasure or action depends on how large is the $\mathrm{VAR}\{\theta\}$[20]. The smaller is the $\mathrm{VAR}\{\theta\}$, the lesser the chance of making an incorrect decision. The magnitude of the value of a new research study about a CMF resides in the amount by which it reduces $\mathrm{VAR}\{\theta\}$.

The $\mathrm{VAR}\{\theta\}$ was shown to consist of two elements: $\mathrm{VAR}\{\bar{\theta}\}$ and V (see Equation 6). The first element ($\mathrm{VAR}\{\bar{\theta}\}$) measures the uncertainty about how different is the weighted mean of the available CMF estimates from E(θ). The more study results go into the determination of the weighted mean, the lesser this uncertainty. The second element (V) reflects that part of the variability of CMFs which is due to differences in the 'circumstances' of implementation[21]; that is, how different will the θs tend to be from

[20] In general the variance of θ is larger than zero and if so, further research has value. In the special case when $\mathrm{VAR}\{\theta\}$ is zero or close to it, further research has no value.

[21] Differences in what exactly was done, to what kinds of units, in what environment, to which road users, in what year, etc.

one instance of implementation to another. The variance due to this source cannot be reduced by doing more and more studies[22]; it can be reduced only by determining how the CMF depends on this or that circumstance of implementation.

Accordingly, there are two ways by which new research can reduce the variance of the CMFs. One is to do additional studies of the safety effect of the same kind of action in a new set of circumstances, studies that produce new unbiased estimates of θ for this kind of action. To illustrate, one could contemplate doing new studies about the safety effect of illuminating limited access roads, in some new locations to add to the studies done earlier in Arizona and British Columbia. The other way to reduce VAR{θ} is for the new study results to clarify how the CMF depends on some circumstance which has heretofore not been considered. To illustrate, if there is reason to think that the difference between the $\hat{\theta}_{\mathrm{Arizona}}$=0.75 and the $\hat{\theta}_{\mathrm{B.C.}}$=0.62 (see Table 6) is due to, say, geographic latitude one may do a new study in one or more intermediate latitudes. If, as a result, θ can be shown to be a function of latitude, then VAR{θ(Latitude)} will be smaller that the VAR{θ} which is common to all latitudes. These two options will be examined separately.

3.1 Option 1: Reducing VAR{θ} by doing more studies

The purpose of doing additional studies is to reduce the VAR$\{\bar{\theta}\}$ by obtaining a more precise estimate of the weighted mean $\bar{\theta}$. In section 0 we showed how E{θ} and VAR{θ} can be estimated using the available CMF estimates $\hat{\theta}_1, \hat{\theta}_2, \cdots, \hat{\theta}_i, \cdots, \hat{\theta}_n$ and their standard errors $\pm s_1$, $\pm s_2$,, …, $\pm s_i$, …,$\pm s_n$. The estimate of E{θ} was the weighted mean, $\bar{\theta}$. If the number 'n' of the available research studies is small and their standard errors large then VAR$\{\bar{\theta}\}$ will be large. Doing additional studies to produce estimates $\hat{\theta}_{n+1}, \hat{\theta}_{n+2}, \cdots, \hat{\theta}_{n+m}$ with standard errors $\pm s_{n+1}$, $\pm s_{n+2}$,…,$\pm s_{n+m}$ will reduce this variance[23] To see by how much the new estimates might reduce the estimate of VAR{θ} consider again Equation 6.

$$\text{Variance Reduction} = \frac{1}{\sum_1^n 1/s_i^2} - \frac{1}{\sum_1^{n+m} 1/s_i^2} \qquad \textbf{Equation 7}$$

The magnitude of standard errors with which θ in the new studies will be estimated (the $\pm s_{n+1}$, $\pm s_{n+2}$,…,$\pm s_{n+m}$) is to some extent in our hands; it is based on what data and resources are available for the proposed research. When a new research is proposed it is possible to declare what precision is aimed at or to anticipate what precision is obtainable.

To illustrate, consider again the invented Arizona-B.C. data in Table 6 in which $\sum_1^2 1/s_i^2$ was 903. If the proposed new study in state X (m=1) will allow one to estimate the θ with s_3=±0.03 then the `new sum ($\sum_1^3 1/s_i^2$) will be 903+1/(0.03)^2= 903+1111= 2014. If so, the reduction in VAR$\{\bar{\theta}\}$ is 1/903-1/2014=0.0011-0.0005=0.0006. By the computations in Figure 18, with only two past data points, the estimated variance of the CMFs was 0.0034 (or, equivalently the standard error of the CMFs was ±0.058). The conduct of the new study promises to reduce this variance to 0.0034-0.0006=0.0028 (and the corresponding standard error to ±0.053). The computations for Equation 7 have been added to the spreadsheet in Figure 18 as shown in Figure. 19.

---

[22] Doing more studies allows one to better estimate the magnitude of V. However, inasmuch as V reflects the variability of circumstances in which some kind of action is implemented, it is, so to speak, a fact of nature. To reduce V one can split the circumstances and estimate the CMFs (and V) for each class of circumstances separately. Thus, e.g., should the CMF of illumination depend on latitude, one could estimate CMF as a function of latitude.

[23] It will also give us a better idea about V, but may or may not reduce it.

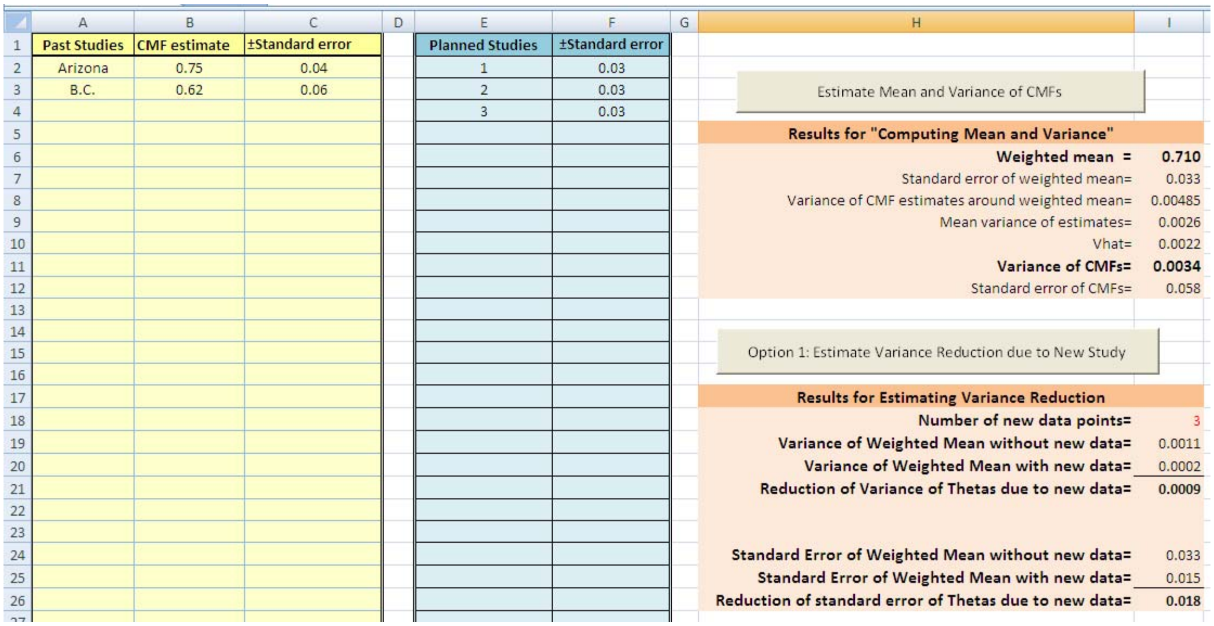


Figure. 19. Computing reduction in VAR{θ} by Option 1.

Enter the data in columns A to F. When you click the "Estimate Variance…" command box the program reads the data pertaining to the existing studies in the yellow part of the spreadsheet and asks you to confirm that the number of data points is correct. If you confirm, the program reads the information about the planned studies in the blue range and again asks you to confirm. The data are echoed in columns K to P (not shown in Figure. 19).With this information the program computes the content in I17:I26. If the planned studies will yield three new estimates of θ each with a standard error of 0.03, we expect $VAR\{\bar{\theta}\}$ to be reduced from 0.0011 to 0.0002. Inasmuch as adding new data by Option 1 does not alter V, this is also the reduction in $VAR\{\theta\}$.In short, it is simple to compute the expected reduction of $VAR\{\theta\}$ which is due to new data points of the same kind as those from past studies. Most CMF oriented research is of the genre.

3.1.1 Option 1: Diminishing marginal returns

Doing another research study about the safety effect of some action will reduce the variance of CMFs significantly when only few such studies have been done in the past. This is illustrated in Table 8 which is based again on the invented Arizona-B.C. illumination example.

When only the Arizona results were available sometimes after 1995, $1/s^2_{Arizona}$ was 625 (see Table 6). By Equation 2, $VAR\{\bar{\theta}\}$at that time would have been estimated at 1/625=0.0016. This is the value in the first row of Table 8. When at a later time the B.C. results came in with $1/s^2_{B.C.}$=278,$VAR\{\bar{\theta}\}$would be estimated at 1/(625+278)=0.0011 as is shown in the next row . If a new study was to be done with s=0.03 the estimate of $VAR\{\bar{\theta}\}$ would be reduced to 0.0005, etc.

Table 8. The diminishing marginal benefit of new studies

	$\sum_1^n 1/s_i^2$	$\widehat{VAR}\{\bar{\theta}\}$
Arizona study	625	0.0016
Both past studies	903	0.0011
One new study with s=0.03	2014	0.0005
Second new study with s=0.03	3125	0.0003

Third new study with s=0.03	4236	0.0002

The point is that, as can be surmised from looking at the equations, in Option 1the marginal benefit of doing a new research study about some CMF is declining. The benefit is largest when there are no past studies about some action and the associated CMF and one cannot have a data-based estimate of E{θ}[24]. The question is how to estimate E{θ} and its standard error when no past research studies exist.

3.1.2 Option 1: When there are no previous studies

In the absence of data one cannot escape the use of expert opinion. To illustrate assume that no study has been published about the safety effect of Pedestrian Countdown Signals[25]. It is likely that experts would agree that E{θ} for this action is not likely to be outside the 0.75-1.25 range. That is, neither a decrease nor an increase of crashes by more than 25% is likely. If this range covers ±2-3 standard deviations, our guess is that $s_{no\ study}$ is about 0.5/(2×2.5)=0.1. If so, our guess is that, with no study available, the VAR{$\bar{\theta}$} is about 0.01. If someone suggests to conduct a research study about the safety effect of Pedestrian Countdown Signals, a study that could estimate the CMF with s_0=±0.05, the new estimate of VAR{$\bar{\theta}$} would be $1/(1/0.1^2+1/0.05^2)$ =1/(100+400)=0.002.

This example suggests that when no past results are available one must use expert judgment in the following manner:

1. Determine what might be the range outside of which E{θ} is very unlikely.
2. Assume that the range covers ±2-3 standard deviations.
3. s_0= (Upper limit of Range-Lower Limit of Range)/ 5.

In sum, Option 1 for reducing VAR{θ} was to do a new study. The variance reduction is accomplished by reducing the uncertainty with which E{θ} is estimated. When past research provides estimates of θ and their standard errors, the procedure described in this section can be used to estimate the amount by which VAR{θ} will be reduced. When no research about this CMF was done the procedure also described in this section can be used.

Most research about CMFs, especially when few past studies have been done, will fall under the rubric of 'Option 1'. However, if a few past studies already exist, and there is still wide uncertainty about what the value of CMF in the next application will, the only way to reduce the uncertainty is to pursue 'Option 2' – to make the CMF a function of circumstances. This is the subject of the next section.

3.2 Option 2. Reducing VAR{θ} by making θ a function of circumstances

Suppose that several past studies about the safety effect of some action or intervention exist, but that VAR{θ} is still quite large. In this situation doing yet another 'Option1' study is not likely to do much good. One must ask: "Why is it that the same kind of action or treatment seems to have diverse results? Can one perhaps divide the study results into groups that have a circumstance in common such that within each group VAR{θ} will be small? Could new research clarify the relationship between the estimates of θ and some causal factors and thereby reduce VAR{θ}?" It will next be shown how making θ a function

[24] Most CMF estimates in the HSM are based on one study which is when the value of research will still tend to be large.

[25] I was told by a safety expert who examined this issue recently that , at present, this is the case.

of a continuous variable[26] can reduce VAR{θ}. The Arizona-B.C. hypothetical example will be developed further to provide context.

3.2.1 Equations and Illustration.

Recall that in Table 6 there are only two past study results. That, in itself, is not a sufficient basis for speculation about why the CMF estimates seem to differ. However, there is other research to suggest that the safety effect of illumination may depend on geographical latitude27. Can it be that a part of the difference between $\hat{\theta}_{\text{Arizona}}$=0.75 and the $\hat{\theta}_{\text{B.C.}}$=0.62 is due to the differences in the latitude of Phoenix (33.5º) and of Vancouver (49.2º)? This question could be answered by estimating θ at a few more geographic latitudes. If the relationship between the θs and latitude will seem regular, then one can estimate the function relating the two, and thereby reduce VAR{θ}. To illustrate, suppose that such new research was done at two more locations with both old and the new results shown in Table 9.

Table 9. Two new estimates (Invented data)

	$\hat{\theta}$	s	Latitude°
Arizona	0.75	±0.04	33.5
B.C.	0.62	±0.06	49.2
New location 1	0.80	±0.02	36.1
New location 2	0.59	±0.02	45.1

Figure 20 is based on the entries of Table 9 and shows how the $\hat{\theta}$s vary with latitude. The two new estimates seem to confirm the speculation that the further north you go the larger is the safety effect of illumination (the smaller is the numerical value of θ).

[26] A similar reduction can be obtained by grouping θs by a categorical variable.

[27] Such speculation would be in line with some evidence claiming that the safety benefit of Daytime Running Lights diminishes with proximity to the equator. M. Koornstra, F. Bijleveld, M. Hagenzieker, (1997) The Safety Effects of Daytime Running Lights. SWOV Institute for Road Safety Research, R-97-36.Leidschendam, The Netherlands

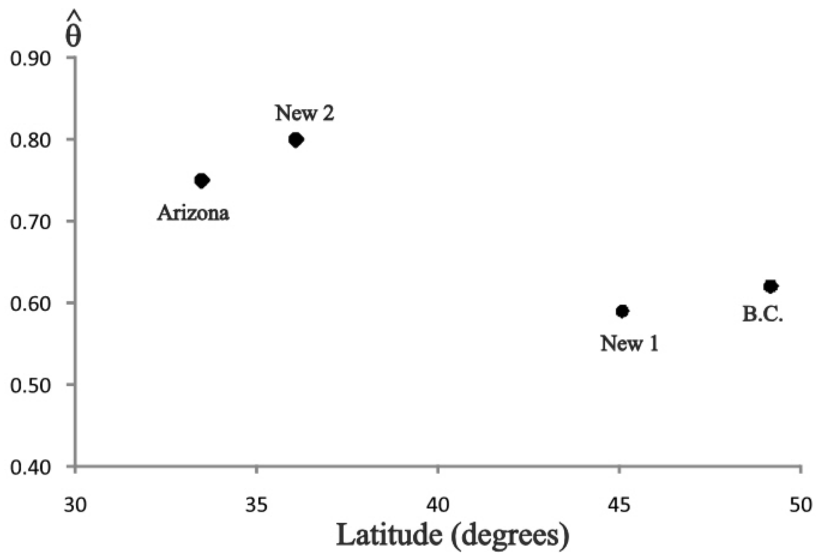


Figure 20. $\widehat{\theta}$ versus Latitude (Invented data)

Assuming that the relationship is approximately linear, an OLS regression line[28] fitted to these data points is shown in Figure 21.

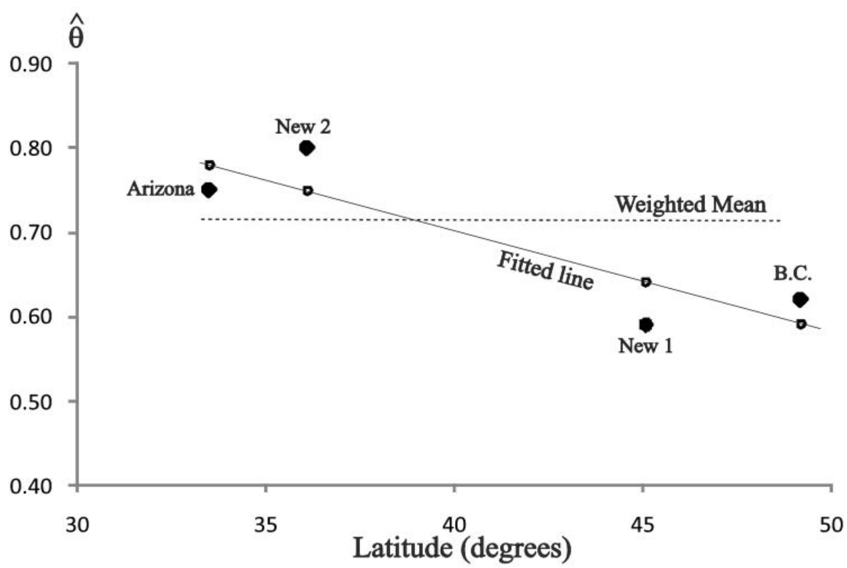


Figure 21. Linear regression to the data in Table 9

The benefit in variance reduction is now plain to see. Under Option 1 estimation of VAR$\{\theta\}$ was based on the average squared difference between the solid circles (the $\widehat{\theta s}$) and the weighted mean - dotted horizontal line29,30. However, when the influence of latitude is considered, the squared differences are

[28] Since the standard errors in Table 9 are not the same, a weighted regression would be in order. However, in the broad context of determining the value of a proposed research such statistical pedantry seems unnecessary. Thus we are assuming that $E\{\theta_i\} = \alpha + \beta x_i$ where α and β are unknown constants and x_i is the value of some variable (here Latitude) for study i. The estimate of $E\{\theta_i\}$ is $\overline{\theta}_i = \widehat{\alpha} + \widehat{\beta} x_i$ where $\widehat{\alpha}$ and $\widehat{\beta}$ are estimates of α and β. With the data in Table 9, $\overline{\theta}_i = 1.18 - 0.0120 x_i$.

[29] The computations by Equation 6 and the related spreadsheet for the data in Table 9 are shown below.

those between the solid circles and the empty circles (the $\bar{\theta}_i$s) on the fitted regression line. Because the fitted line comes closer to the data points than the horizontal line, the squared differences will be much smaller.

The change from computing the squared differences around the weighted mean to computing them around values on the fitted regression line requires a slight modification in Equation 5 and in Equation 6. In Equation 5 the $\bar{\theta}$ will be replaced by $\bar{\theta}_i$, the empty circles in Figure 21. The result is Equation 8. In Equation 6 the estimate of VAR$\{\bar{\theta}\}$ of the weighted mean (see Equation 2) will be replaced by an expression for the estimate of VAR$\{\bar{\theta}_i\}$. The result is Equation 9.

$$\hat{V} = \begin{cases} \text{Sample Variance of of the } \hat{\theta}\text{s around the } \bar{\theta}_i - \text{average } s^2 & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$

or

$$\hat{V} = \begin{cases} \dfrac{\sum_1^n \left(\hat{\theta}_i - \bar{\theta}_i\right)^2}{n} - \dfrac{\sum_1^n s_i^2}{n} & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$

Equation 8

$$\widehat{VAR}\{\theta_i\} = \hat{V} + \widehat{VAR}\{\bar{\theta}_i\}$$

where $\widehat{VAR}\{\bar{\theta}_i\} = \frac{\sum_1^n \left(\hat{\theta}_i - \bar{\theta}_i\right)^2}{n-2}\left[\frac{1}{n} + \frac{(\bar{x}-x_i)^2}{\sum_1^n (\bar{x}-x_i)^2}\right]$

Equation 9

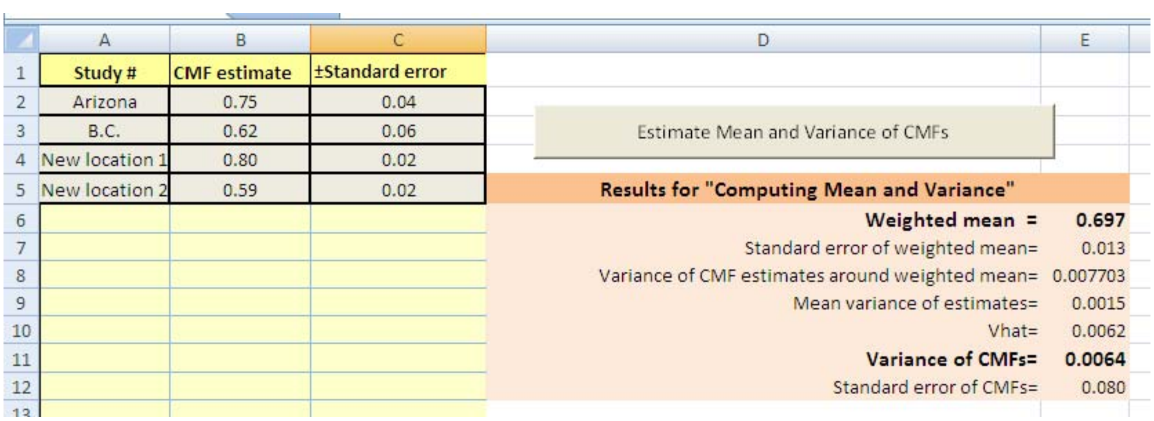
Using data of Table 9 in these equations, the estimates of VAR$\{\theta_i\}$ are in Table 10.

Table 10. Estimates of VAR$\{\theta_i\}$

	$\widehat{VAR}\{\theta_i\}$	$\pm\hat{\sigma}\{\sigma_i\}$
Arizona	0.0023	0.05
B.C.	0.0025	0.05
New location 1	0.0016	0.04
New location 2	0.0014	0.03
Average	**0.0020**	**0.04**

Note that were the dependence on latitude not used, the estimate of VAR$\{\theta\}$ would have been 0.0070 (see footnote 30). When θ is made a function of latitude the average of VAR$\{\theta\}$ is 0.0020. The moral is that when the available CMF estimates exhibit a regular dependence on some variable, making that dependence explicit is an effective way to reduce the VAR$\{\theta\}$ and thereby improving the quality of

[30] The estimate of VAR$\{\theta\}$ based on the older two studies was 0.0034. Now the estimate is 0.0064. The larger the number of studies the more reliable is the estimate VAR$\{\theta\}$.



Study #	CMF estimate	±Standard error		
Arizona	0.75	0.04		
B.C.	0.62	0.06	Estimate Mean and Variance of CMFs	
New location 1	0.80	0.02		
New location 2	0.59	0.02	Results for "Computing Mean and Variance"	
			Weighted mean =	**0.697**
			Standard error of weighted mean=	0.013
			Variance of CMF estimates around weighted mean=	0.007703
			Mean variance of estimates=	0.0015
			Vhat=	0.0062
			Variance of CMFs=	**0.0064**
			Standard error of CMFs=	0.080

decision making. Decision making is improved because when latitude is not taken into account decisions are based on the weighted mean (0.697 in footnote 30) whereas when the decision is tailored to the latitude x_i it is based on $\bar{\theta}_i = 1.18 - 0.0120x_i$. Thus, e.g., if the decision was about illuminating a limited access road at a latitude of 30°, it would be based on expecting a CMF of 1.18-0.0120×30=0.82.

3.2.2 Reducing VAR{θ}by making θ a function of a continuous variable

We can now describe the situation in general terms. Suppose that we have n≥2 past estimates $\hat{\theta}_1, \hat{\theta}_2, \cdots, \hat{\theta}_i, \cdots, \hat{\theta}_n$ and their standard errors $\pm s_1$, $\pm s_2$, …, $\pm s_i$, …,$\pm s_n$. We also have the values of a variable x_1, x_2, …, x_i, …, x_n. There is reason to think that θ is a function of x. However, before one can confidently say that θ is really a function of x (and make statements to that effect in publications), more data points are needed. The proposed research will add 'm' more data points and we need to estimate what would be $\mathrm{VAR}\{\theta_i\}$ with these. Using the 'n' available results in an ordinary linear regression one can estimate the intercept (α) and slope (β) of the fitted line[31] and compute the values $\bar{\theta}_i = \hat{\alpha} + \hat{\beta}x_i$. These can be used to compute the magnitude value of the expression $\sum_1^n (\hat{\theta}_i - \bar{\theta}_i)^2/n$ in Equation 8 and of $\sum_1^n (\hat{\theta}_i - \bar{\theta}_i)^2/n-2$ in Equation 9. The second expression in Equation 8, the $\sum_1^n s_i^2/n$, represents the average squared standard error. If the new research adds estimates with standard errors s_{n+1}, …, s_{n+m}, then this part of Equation 8 will be $\sum_1^{n+m} s_i^2/(n+m)$. With these modification we will have the $\hat{V}$ for the right-hand-side of Equation 9. The $\widehat{\mathrm{VAR}}\{\bar{\theta}_i\}$ part will now be $\frac{\sum_1^n (\hat{\theta}_i - \bar{\theta}_i)^2}{n-2}\left[\frac{1}{n+m} + \frac{(\bar{x}-x_i)^2}{\sum_1^{n+m}(\bar{x}-x_i)^2}\right]$. Thus, with the 'm' new estimates of θ (standard errors and their x values) the $\mathrm{VAR}\{\theta\}$ is estimated by:

$$\hat{V} = \begin{cases} \text{Sample Variance of of the } \hat{\theta}\text{s around the } \bar{\theta}_i - \text{average } s^2 & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$

or

$$\hat{V} = \begin{cases} \frac{\sum_1^n (\hat{\theta}_i - \bar{\theta}_i)^2}{n} - \frac{\sum_1^{n+m} s_i^2}{n+m} & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$

Equation 10

$$\widehat{\mathrm{VAR}}\{\theta_i\} = \hat{V} + \widehat{\mathrm{VAR}}\{\bar{\theta}_i\}$$

$$\text{where } \widehat{\mathrm{VAR}}\{\bar{\theta}_i\} = \frac{\sum_1^n (\hat{\theta}_i - \bar{\theta}_i)^2}{n-2}\left[\frac{1}{n+m} + \frac{(\bar{x}-x_i)^2}{\sum_1^{n+m}(\bar{x}-x_i)^2}\right]$$

Equation 11

Whether the 'm' new data points will confirm that θ is a function of x or not cannot be known beforehand. If the functional dependence is confirmed then $\mathrm{VAR}_{\text{if confirmed}}\{\theta\}$ is estimated by Equation 10 and Equation 11. If the functional relation is not confirmed then estimate $\hat{V}$ by Equation 5 and add $1/\sum_1^{n+m} 1/s_i^2$ to obtain an estimate of $\mathrm{VAR}_{\text{if not confirmed}}\{\theta\}$. If p is the probability that the functional dependence is confirmed then the estimate of $\mathrm{VAR}\{\theta\}$ expected after the new research was completed and 'm' new data points are available is estimated by:

$$\widehat{\mathrm{VAR}}_{\text{Option 2}}\{\theta\} = p\,\widehat{\mathrm{VAR}}_{\text{if confirmed}}\{\theta\} + (1-p)\widehat{\mathrm{VAR}}_{\text{if not confirmed}}\{\theta\}$$

Equation 12

Unless there is evidence to the contrary p can be set at 0.5. The estimated reduction in $\mathrm{VAR}\{\theta\}$ due to the conduct of the new research the intent of which is to confirm a functional relationship is:

$$\widehat{\mathrm{VAR}}_{\text{Option 1 with n data points}}\{\theta\} - \widehat{\mathrm{VAR}}_{\text{Option 2 with n+m data points}}\{\theta\}$$

Equation 13

---

[31] When n=2 a regression line cannot be fitted. In this case the ad-hoc assumption will be that the fitted line passes through the average of the two data points and its slope is half the slope of the line joining the two data points.

3.2.3 Computations

As before, computation is on a spreadsheet. One should fill in the data for the exiting studies in the yellow section and the data for the planned study in the blue section Figure 22). Remember to fill in columns A and F. The VBA code under the command button uses these to determine the number of data points. Click on the command button. If we do two new studies with the characteristics in columns G and H and the results will confirm that there is a relationship the θ for illumination and latitude, one may expect VAR{θ} at the latitude of 33.5° to be 0.0007 and at a latitude of 49.2° to be 0.0015.

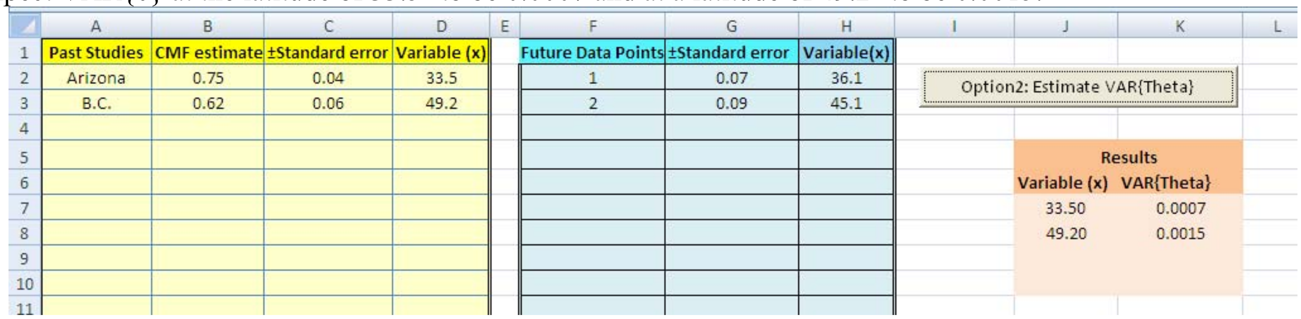


Figure 22. Spreadsheet Example

The program also produces the results in Table 11.

Table 11. Estimates of E{θ} and VAR{θ}

Latitude [°]	$\widehat{E}\{\theta\}$	$\widehat{VAR}\{\theta\}$
25	0.753	0.0006
30	0.732	0.0006
35	0.711	0.0008
40	0.691	0.0010
45	0.670	0.0012
50	0.649	0.0015
55	0.628	0.0019
60	0.608	0.0023
65	0.587	0.0028
70	0.566	0.0033

We can now proceed with the computations for Equation 12. The story was that the decision is to be made for Colorado (the latitude of Denver is about 40°). If the new data is seen to confirm the existence of an orderly and nearly linear relationship between latitude and θ, $\widehat{VAR}_{\text{if confirmed}}\{\theta\} = 0.0010$. If there will seem to be no orderly relations the $\widehat{VAR}_{\text{if not confirmed}}\{\theta\} = 0.0031$. Using p=0.5, $\widehat{VAR}_{\text{Option 2}}\{\theta\} = (0.0010 + 0.0031)/2 = 0.0020$. Going now to Equation 13, if the proposed research will add two data points the expected reduction in VAR{θ} is from 0.0034 (σ{θ}=±0.058) to 0.0020 (σ{θ}=±0.044).

4. Summary

The decisions we face are about whether to implement some action in specific circumstances. These decisions depend partly on what we expect the safety effect of the action to be. What we expect is based on past research; on what was learned about the safety effect of the same kind of action in past implementations. Estimates of safety effect from past implementation reveal a certain degree of variability. Some of the variability is ‘statistical’ in nature and is due to inaccuracies inherent in statistical estimation; another part is due to differences in the ‘circumstances’ of past implementations; what exactly was done, to what kinds of units, in what environment, to which road users, in what year, etc. Therefore, when it comes to deciding about a new implementation we cannot be sure what the θ (the CMF) will be. It will be one of the values from a probability distribution. The estimates of θ from past research studies and their standard errors (±s) are the raw material from which an estimate of the probability distribution of θ is constructed.

Section 0 shows how to estimate the mean and the variance of the probability distribution of θ from the past estimates and their standard errors. The derivations and equations, while complex-looking, yield simple and sturdy results. The results are sturdy because they rely solely on deduction and probability theory; no data-based inductive reasoning is required. It is shown how to compute a minimum variance weighted mean, An expression is given for the variance of the weighted mean and, most importantly, provide a way to estimate the variance of θ. All these are programmed into a spreadsheet. Estimates of θ from past research and their standard errors should be provided. , Click a button to get estimates of the mean and variance of the probability distribution of θs.

Recall that to determine the value of some future research one has to know by how much the conduct of a proposed new research promises to reduce the variance of θ. This difficult question is the subject of section 0. The variance of θ was shown to consist of two elements: The first element measures the uncertainty about how different is the weighted mean from the mean of the probability distribution. The more research results go into the determination of the weighted mean, the lesser is this uncertainty. The second element reflects that part of the variability of θs which is due to differences in the ‘circumstances’ of implementation; that is, how different will the θs tend to be from one instance of implementation to another. The variance due to this source cannot be reduced by doing more and more studies; it can be reduced only by determining how the θs depend on this or that circumstance of implementation.

Accordingly, there are two ways by which new research can reduce the variance of θ. Option 1 is to reduce the variance of the weighted mean by doing additional studies of the safety effect of the same kind of action in new circumstances. Option 2 is for the new study results to clarify how the θ depends on some circumstance which has heretofore not been considered. These two options were examined separately. For both options I provide the analysis, equations and the computational means for determining what reduction in the variance of θ should be expected. These means should be sufficient for the VOR analysis and prioritization research about the safety effect of actions and interventions.

A by-product of this work is a general insight about research into CMFs. For making good decisions it is important for VAR{θ} to be small. When there is little past research about the θs of some action, VAR{θ} can be large and to conduct a new study about the safety effect of that action can be an effective means to reduce it. However, there soon comes a point at which doing yet another study will be of little use. If VAR{θ} is still large, the best way to reduce it is to find out how θ depends on various circumstances; traffic flow, number of lanes, geographic latitude etc. This direction of CMF-related research deserves more attention.

Glossary

Acronyms

AMF=CMF	Accident or Crash Modification Function or Factor
HSM	Highway Safety Manual
OLS	Ordinary Least Squares
VOI	Value of Information

VOR	Value of research
<u>Notation</u>	
E{θ}	Expected value (Mean) of θ
F(θ)	Probability distribution function of θ
VAR{θ}	Variance of θ
<u>Greek Letters</u>	
α, β	parameters in linear regression
θ	Accident (Crash) Modification Factor (or Function)
$\bar{\theta}$	Weighted average of estimates of θs

Appendix E. Development of Support Tools for Value of Research Calculation

INTRODUCTION

This appendix describes the development of tools to support the calculation of the expected value of research (VOR). The VOR represents a criterion for objectively evaluating alternative research projects and prioritizing them for funding consideration. The VOR procedure is applicable to evaluating projects that each produce a new CMF associated with a specified countermeasure, or projects to improve the accuracy of an existing CMF. The VOR procedure can also be applied to the development of a methodology (e.g., a chapter in Part C of the HSM) by considering the project as developing a collective set of CMFs.

Two key outcomes are realized through the application of the VOR procedure. First, it indicates whether a project will yield a positive return in terms of a safety benefit that offsets the cost of treatment implementation. Second, it can be used to determine the relative rank of alternative projects. Projects that rank highest should be given first consideration for funding. It is recognized that there are many assumptions inherent to the calculation of VOR and that they could impact its accuracy. However, it is rationalized that these assumptions will influence the VOR associated with each alternative project being considered in roughly an equal manner, such that the two key outcomes can still be achieved with reasonable confidence.

The calculation of VOR is based on the concept of an "analysis unit." The discussion herein assumes that this unit is either an intersection or a highway segment. The rationale for these choices is described in the next section.

Table 4 of the First Report (Appendix C) identified the factors needed for the calculation of VOR. These factors are listed in Table 12. The factors are identified in a slightly different manner in Table 12, but are essentially those identified in the First Report (Appendix C).

Project 17-48 is charged with developing a project prioritizing procedure and using it to evaluate alternative research projects, where each project would develop one or more CMFs to describe the effectiveness of a proposed countermeasure. The procedure is envisioned to be used by others (after Project 17-48 is concluded) to maintain and update the list of prioritized research projects. Several hundred alternative "CMF projects" have been identified to date. Some reflection on this number, the factors listed in Table 12, and the resources available for project prioritization (during Project 17-48 and after it ends), suggests that the prioritizing procedure should require no more than two or three hours on average to evaluate one proposed CMF project.

The tools described in this paper and implemented in a spreadsheet were developed to support the VOR calculation such that it can be used to achieve the aforementioned two key outcomes with a reasonable resource investment and reflective of treatment implementation in all applicable states. These tools can be improved by addressing the inherent assumptions or stated limitations when such improvements are identified as necessary. In fact, such improvements are likely and this version of the tools should be considered to be a demonstration version. It is envisioned that these tools will be made more robust during Project 17-48 such that they could be used after the project by a Scientific Advisory Committee (SAC) to update and maintain the prioritized list of alternative CMF projects.

Table 12. Factors Considered in VOR Calculation

Factors	Description
Number of candidate units	Number of highway segments or intersections that *can* be treated with the proposed countermeasure.
Number of affected units	Number of segments or intersections likely to be considered for treatment with the proposed countermeasure.
Crash distribution	Distribution of crashes on treated units.
Cost of target crash	Average cost of the crash that is likely to be prevented by the proposed countermeasure.
Cost of implementation	Average cost (per mile or intersection) to the transportation agency to implement the proposed countermeasure.
Estimated treatment effectiveness	Mean effectiveness of the proposed countermeasure (i.e., CMF) and its standard deviation (before new research is conducted).

One overarching challenge is the need for the VOR calculation to reflect all states in which a proposed countermeasure could be implemented. In this regard, the need for information from transportation agency partners (TAP) is identified. The TAP is envisioned to be a group of engineers that provide agency perspective and information to the prioritization process. Each transportation agency represented in the TAP would have one representative that could be contacted periodically (e.g., annually) by the SAC to obtain some of the information in Table 12. Each state DOT would have membership in the TAP. City and county engineers could also be included.

The discussion in the remaining sections of this paper describe a process, information sources, and tools needed to support the calculation of VOR, given an assumed budget of two or three hours per CMF project. Some tools have been developed. Some decisions still need to be made relative to the assumptions made in developing these tools. The decisions should reflect thoughtful consideration of the desired accuracy of the computed VOR relative to the effort needed by the SAC to implement the "improved" procedure.

Some calculation elements and calibration factors still need to be developed in Project 17-48. They are identified in this paper. Any proposed improvements to the VOR procedure that are likely to result in it requiring more than three hours of effort per project should be carefully considered because they will likely undermine the VOR procedure's implementability.

Even if the remaining issues identified herein are addressed at this time using no more than the collective engineering judgment of the 17-48 team, the resulting VOR procedure will be more defensible and lead to more informed safety investments than any other less formal procedure. The VOR provides a rational, consistent, and scalable procedure for project prioritization--one whose analytic framework can be incrementally improved (and the process streamlined) by the SAC over time.

The VOR procedure consists of (1) data collection, and (2) VOR calculation. The data collection activity will require the most time. The calculations will be automated in software to minimize the calculation time. Data to evaluate countermeasures for widespread application may be collected in advance and used to evaluate multiple countermeasures. Countermeasures applicable to specific locations may require a supplemental SAS run using HSIS or the Highway Performance Monitoring System (HPMS) to insure the input data are appropriate for the countermeasure being considered. As a result, countermeasures for widespread application may take only an hour to evaluate and those for specific applications may take three to four hours to evaluate (where the time needed is dictated by the complexity of the data collection activity).

SOURCES OF INFORMATION

This section describes one or more possible sources of information associated with each factor in Table 1. A source may be an existing database, prior research, or the TAP. In some cases, the data obtained will require some "post-processing" to convert it into the proper form for use in the VOR procedure. The calculations associated with this post processing are also described where appropriate.

A linked crash, road inventory, and traffic database is referred to herein as a highway safety database. The HSIS is considered a highway safety database.

A unit is defined herein as either an intersection or a highway segment. These two entities are typically the basis for SPF development because they are represented in this manner in the highway safety databases used for calibration. This need for unit consistency between the VOR procedure and the SPF stems from the use of the SPF regression results to define the distribution of crashes. This application is described in the section titled Crash Distribution.

A highway mile is not a considered to be an analysis unit because the agencies that develop highway safety databases use criteria other than length to define the spatial limits of a segment. This practice results in segments of varying length (typically ranging from 0.1 mi to 2.0 mi) in highway safety databases. There are a variety of ways to compute a crash rate (with units of crashes/mi) to describe the segments comprising a highway system. However, regardless of the method, the distribution of this rate will be different from that of the distribution of crash count per segment as obtained from a highway safety database.

Number of Candidate Units

The "number of candidate units" is defined as the number of highway segments or intersections that *can be treated* with the proposed countermeasure. The emphasis on "can be treated" is a reminder that all units may not be treated by a countermeasure. This point is discussed more in the section titled Number of Units Treated.

Ideally, a road inventory database would be available for each of the 50 states. The candidate units would be identified directly by consultation of this database and consideration of the countermeasure characteristics. Unfortunately, this option is not currently viable because this type of database is not available. Hence, the challenge here is to find a way to estimate the candidate units for the states and roadways to which the proposed countermeasure is applicable.

Countermeasures for Wide Application

There may be some proposed countermeasures that are applicable to an entire functional class of roadway, possibly in a subset of the states. For example, a project to develop a methodology for evaluating urban arterials effectively represents the development of a “family” of CMFs and a base SPF. This project would have wide application and the candidate units could be broadly defined as the functional classes of “urban principal arterial and urban minor arterial.” Similarly, a project to evaluate the installation of shoulder rumble strips on rural multilane highways would have wide application such that the candidate units could be defined as “rural principal arterial and rural minor arterial.”

When the countermeasure (or methodology) can be widely applied, it should be sufficient to consider the total mileage of one or more functional classes of roadway in the states likely to use the countermeasure (or methodology). The Highway Statistics database (http://www.fhwa.dot.gov /policy/ohpi/hss/index.cfm) provides miles by functional class and state, as needed for this type of application. The conversion of this mileage into an equivalent number of segments is discussed in a later section. It should be noted that the data in the Highway Statistics data are obtained from the HPMS database.

Countermeasures for Specific Application

The number of units that can be treated can be difficult to determine if the countermeasure is specific in its application (e.g., rural two-lane highway curves). For example, consider a countermeasure applicable to three-leg two-way stop-controlled intersections. The number of these intersections is not routinely inventoried by most transportation agencies. Some options to address these situations are described in this subsection.

Option 1. One option is to enlist the help of the TAP to gather information about the number of candidate units in their jurisdiction. This information would be specific to the countermeasure of interest. Collectively, the input from the TAP would describe conditions throughout the US. This information would be requested once a year and pertain to a list of countermeasures (pre-screened by the SAC). The information provided by the TAP will likely be based on their judgment; however, they may certainly consult their agency inventory files if time is available.

Option 2. A second option is to use HSIS to identify the number of candidate units in the HSIS states. These findings would be extrapolated to the remaining states and road types of interest by total mileage ratio.

Option 3. A third option is to use the HPMS. It is the most detailed database available that represents the US street and highway system. A preliminary investigation of HPMS reveals some promise for use in Project 17-48. Its Sample database has many geometry and traffic control variables that can be used to uniquely tailor the estimate of candidate units for each countermeasure being considered. The Sample data are available for only about 7 percent of all segments in the database, so the findings will have to be extrapolated (using the Expansion Factors provided) to estimate the number of units by functional class and state.

If this option is used, techniques will need to be developed for overcoming the limitations in the HPMS database. This activity will require some research in Project 17-48 (probably measured in hours or days) and may logically occur during the initial project prioritization activity in Task 2.

One limitation of the HPMS data is that the Sample data do not include representation of rural minor collectors, rural local roads, and urban local streets. These roads represent about 43 percent of the US street and highway mileage. This finding needs to be confirmed. A possible technique for overcoming this limitation is to extrapolate the trends found in the HSIS data for these roads to all US roads.

A second limitation of the HPMS data is that it does not describe the number of number-of-legs at an intersection. Further, it does not indicate whether the unsignalized intersection is two-way stop-controlled, all-way stop-controlled, uncontrolled, or roundabout. Research is needed to develop a technique for extrapolating the count of unsignalized intersections to each of these important sub-categories. Distribution factors for this technique could be estimated by sampling aerial photographs. It may also be possible to use the TAP to judge these factors for their respective states.

One issue (not a limitation) that was identified in the preliminary examination of the HPMS database is that only about 2 percent of the observations represent “grouped” segments. Yet, these grouped segments contain about 72 percent of the total US road mileage. The “local road” observations consist almost entirely of grouped segments. The grouped-segment observations average 93 miles in length, with a standard deviation of 255 miles.

A second issue is that the ungrouped observations in HPMS represent contiguous highway segments. Collectively, they have variable lengths (like those found in HSIS). However, their average length tends to be longer than that of the segments in HSIS. Thus, they cannot be used to estimate the average segment length in state highway safety databases (the need for this variable is discussed in a later section).

It is possible to use the Sample database to estimate the count of signalized intersections and the count of unsignalized intersections in the US (by state and county, if desired). The standard expansion factors in the Sample database will need to be used to extrapolate the counts to a US estimate. It is possible for an intersection to be counted twice in HPMS, given the method used to record these intersections. However, the likelihood of an intersection being counted twice is small given that only 7 percent of all segments are sampled.

Research was undertaken to confirm the accuracy of estimates of signalized intersection counts extrapolated from the 2008 HPMS database. A ground truth value of 272,000 signalized intersections in the US was cited in the *ITE Journal* (*1*) for 2008. Given the US urban-area population of 240 million persons for that year, these two values equate to a ratio of 1.13 signals per 1000 persons. This ratio is consistent with the ratio of 1.15 signals per 1000 persons found in the data from a 1996 survey of 92 North American cities conducted by ITE District 6. This ratio was used to predict the signal counts for each state, based on the state’s urban population estimate for 2008. The predicted quantity was then compared to the state-by-state estimates obtained from HPMS. A regression analysis indicated that the HPMS estimate should be multiplied by 0.84 to obtain the predicted values. This value should be used to adjust counts of signalized intersections obtained from the 2008 HPMS database.

Countermeasures for Urban Areas. The Deployment Statistics website (http://www.itsdeployment.its.dot.gov/Default.asp) that is maintained by the US DOT’s Research and Innovative Technology Administration (RITA) can be used to supplement Options 2 and 3 when the proposed countermeasure is only applicable to urbanized areas. The information on this website is derived from surveys of the 108 largest metropolitan areas. Survey topic areas include arterial management, freeway management, transit management, public safety, ITS technologies for crash prevention, operations and management. Survey data identify the number of units in the metropolitan area and the number of units treated. A research library describing reported costs and benefits of various treatments is also available on the website.

Recommendation

If a proposed countermeasure is applicable to an entire functional class of roadways, then the Highway Statistics database should be used to define the number of candidate units. If a proposed countermeasure is specific in its application, then three options have been identified. The first choice option would be to use HPMS. If the countermeasure is too specific to be addressed by HPMS, then HSIS would be used and the results are extrapolated to all states. If the countermeasure is too specific for HPMS and HSIS, then the TAP would be used. Regardless, the "depth" of the desired information should be tailored to require no more than two hours to generate for each proposed countermeasure.

Number of Affected Units

The number of affected units is computed by multiplying the number of candidate units by the proportion of those units that will likely be considered for treatment. This proportion can vary, depending on treatment cost, effectiveness, and agency policy. For example, implementation of some countermeasures will be mandated by agency policy as applicable to all units of a specified class (e.g., add signal control to all intersections that satisfy one or more warrants). Other countermeasures will be recognized as good practice and are used at most locations (e.g., replace 8-inch signal indications with 12-inch signal indications). Some countermeasures will be radical and relegated to just those locations found to rank among the most deserving (e.g., red-light enforcement cameras). In fact, the effectiveness of these radical countermeasures may be undermined if they are deployed on a wide scale basis.

The TAP is the best source for information about the proportion of candidate units to which the countermeasure is likely to be applied by an agency.

Crash Distribution

The crash distribution represents the distribution of average annual crashes per unit for the candidate units. It is developed for each proposed countermeasure. The crashes represented in the distribution are referred to as "target" crashes.

The crash distribution used in the VOR procedure should be obtained from a highway safety database. This database would include data for the same states and functional classes represented by the candidate units. The distribution is described by a gamma distribution, with a mean equal to the average annual crashes per unit $E[x]$ and a variance equal to $V[x] - E[x]$ (where $V[x]$ is the variance of the annual crashes per unit).

Ideally, a highway safety database would be available for each of the 50 states. The crash distribution would be developed from these state databases, with consideration of the counter-measure characteristics. Unfortunately, this option is not currently viable because a highway safety database is not readily available for each state. Hence, the challenge here is to find a way to estimate the crash distribution for the states and roadways to which the countermeasure is applicable.

The crash distribution can be for all severities or a selected set of severities (e.g., fatality plus injury). Similarly, it can be for all crash types or for a specific manner of collision (e.g., sideswipe). The severity category should be consistently used for all CMF projects being prioritized to ensure equitable results. Also, to ensure consistency, the analyst must be confident that any subset of crash types that is used includes all crashes likely to be influenced by the countermeasure. *A conservatively safe approach is to include all crash severities and types in the distribution.*

When the crash distribution is needed for all 50 states, the National Automotive Sampling System (NASS) General Estimates System (GES) can be used to confirm (or calibrate) the estimate of average annual crashes (= mean annual crashes per unit x number of units) obtained by using one of the options described in the remainder of this section. GES may be particularly useful when evaluating countermeasures for specific application because it has many of the variables found in typical crash databases (e.g., manner of collision, roadway alignment, number of lanes, speed limit, relation to junction, traffic control device, light condition, etc.). However, GES does not include variables for state or functional class. In 2009, it discontinued the variable indicating rural/urban location. GES contains data for only about 1.0 percent of all crashes in the US, but it provides a weighting factor with each crash record to facilitate the record's extrapolation to a total US crash estimate.

The options outlined in the remainder of this section are based on the assumption that the distribution of annual crashes per unit can be estimated by computing the mean and standard deviation (i.e., the first two moments) of the target crash distribution. One method for predicting these two statistics is to use an SPF and its associated over-dispersion parameter. Variations of this method are discussed in the following subsections.

Countermeasures for Wide Application

This section describes options for defining the crash distribution when the proposed countermeasure is applicable to one or more functional classes of roadway in one or more states.

Option 1. A set of SPFs (and their associated over-dispersion parameters) collectively representing the desired functional classes in each of the subject states is used to estimate the moments of the crash distribution. Each state can be individually evaluated and the resulting VOR for each state added to produce the combined VOR used for prioritization. This option requires access to one SPF (and its associated over-dispersion parameter) for each state and functional class.

Option 2. One SPF (and its associated over-dispersion parameter) for each of the desired functional classes is available for only one state. This SPF is calibrated to each of the other states being considered and used to estimate the mean annual crashes per unit for each state (as well as its variance). A procedure for calibrating this SPF to the other states is described later in this paper. With this approach, the moments of the crash distribution for all states combined is computed and one value of VOR is computed for the combined crash distribution.

Recommendation. At this time, SPFs are not likely available for each state. Their development in Project 17-48 will probably exceed project resources. Hence, the first option may not be feasible at this time, but should be reexamined in future years. For these reasons, the second option is recommended.

Countermeasures for Specific Application

This section describes options for defining the crash distribution when the countermeasure is specific in its application to a unique type of road segments or intersections, crash types, terrain conditions, or geographic locations.

An SPF (and its associated over-dispersion parameter) for one state is the basis of the calculations for each of the options described in this section. This SPF should be calibrated to each of the other states being considered and used to estimate the mean annual crashes per unit for each state (as well as its variance). A procedure for calibrating this SPF to the other states is described later in this paper. With this approach, the moments of the crash distribution for all states combined is computed and one value of VOR is computed for the combined crash distribution.

Option 1. An SPF is developed from the HSIS database for the specific application.

Option 2. A combination of SPFs and CMFs from prior research are used. The CMFs are needed because the SPF alone is not fully consistent with the specific application. For example, consider a countermeasure that is applicable to rural two-lane highway curves. In this case, the SPF in Part C of the HSM combined with the CMF for curve radius could be used to refine the estimate of the crash distribution. The over-dispersion parameter for the SPF is assumed to be descriptive of the crash distribution of the specific application. Note that harmony here requires (1) that the identified candidate units represent the specific application and (2) that the SPF was calibrated with the CMF and they share a common base condition.

Option 3. An SPF from prior research is used, but it is not fully consistent with the specific application. For example, an SPF for rural two-lane highways is used to evaluate a countermeasure applicable to rural two-lane highway curves. With this option, the estimated mean countermeasure effectiveness (discussed in a later section) is adjusted to reflect its overall average effect on the units represented by the SPF. The following equation can be used for this purpose:

$$CMF_o = 1.0\ (1.0 - P_{trt}) + CMF_c\ P_{trt} \tag{1}$$

where,
CMF_o = overall countermeasure effectiveness;
P_{trt} = proportion of highway miles or intersections that are candidate for treatment; and
CMF_c = countermeasure effectiveness at treated units.

Recommendation. The development of the SPF needed for the first option will likely require more than the "budgeted" two or three hours per CMF project. It is noted that if Option 2 was used to identify the candidate units, then this option may be more efficient due to some economy of scale. Regardless, either the second option or third option is recommended for practical reasons, with the choice dependent on circumstances.

Cost of Target Crash

The target crash is that defined by the distribution of crashes and the candidate units, as described in previous sections. The cost of this crash is computed for each proposed countermeasure. It must be representative of the range of severities included in the target crash distribution. The severity of interest is that which describes the maximum injury severity in the crash.

Ideally, a crash database would be available for each of the 50 states. The severity distribution would be identified directly by consultation of this database and consideration of the countermeasure characteristics. Unfortunately, this option is not currently viable because this type of database is not available. Hence, the challenge here is to find a way to estimate the severity distribution for the states and roadways to which the countermeasure is applicable.

Once the severity distribution is identified, the crash costs reported by Council et al. (*2*) can be used to determine the target crash cost. The reported costs should be updated (using the procedure described in the report) to reflect the value of goods and services in the analysis year. NCHRP Project 20-24 is currently developing updated crash costs and may replace those developed by Council et al. when they become available.

The GES database can be used when the severity distribution is needed for all 50 states. GES may be particularly useful when evaluating countermeasures for specific application because it has many of the variables found in typical crash databases (e.g., manner of collision, roadway alignment, number of lanes, speed limit, relation to junction, traffic control device, light condition, etc.). However, GES does not include variables for state or functional class. In 2009, it discontinued the variable indicating rural/urban location.

Countermeasures for Wide Application

This section describes options for defining the severity distribution when the proposed countermeasure is applicable to one or more functional classes of roadway in one or more states.

Option 1. A one-time request for a crash severity distribution is submitted to each state DOT division responsible for crash data. The distribution would identify the proportion of crashes for each of the K, A, B, C, O, severity categories for each functional class of roadway.

Option 2. The HSIS is used to develop an aggregate crash severity distribution by functional class for the HSIS states (perhaps one distribution for northern states and one for southern states). This distribution would be considered to be applicable to the other states. The distribution would identify the proportion of crashes for each of the K, A, B, C, O, severity categories for each functional class of roadway.

Recommendation. It is difficult to assess the likelihood of success with option 1. It is recommended that Option 2 be pursued and the distributions of the HSIS states examined for state-to-state variability. If this variability is significant, then Option 1 could be pursued for the remaining states.

Regardless of the option chosen, the Level 5 costs by speed limit reported by Council et al. (*2*) would be used with the severity distribution to estimate the target crash cost specific to the states and functional class of roadway for which the proposed countermeasure is likely to be applied.

Countermeasures for Specific Application

This section describes options for defining the severity distribution when the countermeasure is specific in its application to a unique type of road segments or intersections, crash types, terrain conditions, or geographic locations.

Option 1. Use HSIS or GES data to develop a severity distribution. This distribution would be specific to the countermeasure of interest, its associated crash type (e.g., sideswipe), and class of roadway (e.g., rural two-lane highway).

Option 2. Use the severity distribution developed for Option 2 in the previous section titled *Countermeasures for Wide Application*. Assume that the distribution is sufficiently similar to that for the specific application for the purpose of VOR calculation.

Recommendation. Some research is needed to assess the incremental accuracy improvement that would result from option 1, relative to option 2. It is recommended that both options be examined for a few, typical countermeasure cases. The resulting target crash costs should then be used to compute the VOR associated with each countermeasure for the option-1 cost and the option-2 cost. These results should then be used to make a judgment as to whether the added rigor of option 1 is justified.

If option 1 is chosen, then the Level 4 costs by speed limit reported by Council et al. (*2*) would be used to estimate the target crash cost. If option 2 is used, then the Level 5 costs by speed limit would be used to estimate the target crash cost.

Cost of Implementation

The cost of countermeasure implementation should represent an annualized cost on a per-unit basis. The initial cost should be annualized over the service life of the project based on an expected service life and typical discount rate for highway investments. A discount rate of 3.0 percent is recommended in the AASHTO publication *A Manual of User Benefit Analysis for Highways* (*3*). The capital recovery factor can be used to compute an annualized initial cost. The total annual cost of the treatment is computed as the sum of the annualized initial cost and the annual maintenance cost.

The TAP is the best source for information about the initial cost, annual maintenance cost, and service life of the countermeasures being considered. This information should be archived by the SAC such that it can be subsequently used to evaluate other countermeasures that are judged to have a similar initial cost, maintenance cost, or service life as countermeasures evaluated in previous years.

Estimated Treatment Effectiveness

The effectiveness of a treatment is characterized by its mean CMF value and the standard deviation of this value. A procedure for estimating the mean and standard deviation of a CMF was described in the December 2010 report by E. Hauer (i.e., Second Report – Appendix D). The CMF is denoted by the variable θ in the Second Report (Appendix D).

The CMF used in the VOR procedure must be consistent with the candidate units, crash distribution, and target crash cost in terms of the class of roadway the countermeasure will likely treat and the crash type it will likely effect. That is, if the crash distribution represents a specific type of unit, then the CMF used should represent the effect of the countermeasure treatment on that type of unit. Alternatively, if the crash distribution represents a more general class of units, then CMF used should represent the effect of the countermeasure on the general class of units. Equation 1 was described previously as means by which a countermeasure for a specific application could be modified so it could be used to evaluate a crash distribution representing a general class of units. A variation of this equation can be used if the crash distribution represents total crashes but the countermeasure will only influence one or more specific crash types (e.g., sideswipe).

Standard Deviation of the CMF

The Second Report (Appendix D) describes two options for estimating the reduction in the variance of the CMF. Option 1, Reducing Var{θ} by Doing More Studies, provides guidance on how to proceed where are no previous studies upon which an estimate of the standard error of the CMF can be based. In this instance, it is stated that expert opinion could be used to identify the range outside of which the expected value of the CMF is very unlikely to occur. This range is then used to compute the standard error of the CMF. It is rationalized that this approach could also be used to estimate the standard deviation of the CMF, provided that a group of experts is used to capture the likely variation for a large region (perhaps even the US, if needed). The following equation is used for this purpose:

$$s_{CMF,b} = \frac{CMF_{upper} - CMF_{lower}}{2 \times 2.5} \tag{2}$$

where,

$s_{CMF,\,b}$ = standard deviation of countermeasure effect before new research;
CMF_{upper} = estimated highest likely value of CMF; and
CMF_{lower} = estimated lowest likely value of CMF.

The TAP is a viable source of information about the likely upper and lower values for the CMF range when no previous studies exist.

After one or two project prioritization cycles have been completed using the expert opinion approach, it may be possible to generalize the magnitude of the range limits being received from the TAP. For example, it may be found that the lowest likely value is typically about one-half the magnitude of the estimated CMF. It may be found that the highest likely value is typically about twice the magnitude of the estimated CMF. If such a predictive relationship emerges, then it could be used in subsequent cycles and the requests for TAP input in this area may be significantly reduced.

If Equation 1 is used to compute an overall countermeasure effect, then the standard deviation of the overall effect is computed as: $s_{CMF,\,b} = P_{trt}\, s_{CMF,c}$ where $s_{CMF,\,c}$ is the standard deviation of CMF_c.

Mean CMF

The Second Report (Appendix D) does not explicitly state that expert opinion can be used to estimate the mean effect of a countermeasure when previous studies are not available. However, it is likely that this was the intent.

The TAP is a viable source of information about the likely mean effect of the countermeasure when no previous study exists.

Standard Deviation After New Research

The Second Report (Appendix D) describes a procedure for computing the standard deviation of the CMF after new research. Specifically, this standard deviation is computed using the following equation:

$$s^2_{CMF,a} = s^2_{CMF,b} - \left(\frac{1}{\sum_1^n 1/s_i^2} - \frac{1}{\sum_1^{n+m} 1/s_i^2} \right) \qquad (3)$$

where,
$s_{CMF,\,a}$ = standard deviation of countermeasure effect after new research;
s_i = standard error of CMF produced in research project i;
n = number of previous studies; and
m = number of proposed new studies.

The term in parentheses is the same as Equation 7 in the Second Report (Appendix D). Within the parentheses, the first term is the variance of the weighted average CMF from previous studies, as computed using Equation 2 of the Second Report (Appendix D).

If it can be assumed that the standard error of the previous and new projects is the same value and that there will be one proposed new study (m = 1) then Equation 3 reduces to:

$$s^2_{CMF,a} = s^2_{CMF,b} - s^2\{\bar{\theta}\}\left(1 - \frac{n}{n+1}\right) \qquad > 0.001\,CMF^2 \tag{4}$$

where,

$s^2\{\bar{\theta}\}$ = variance of the weighted average CMF from previous studies.

The boundary condition identified on the right side of Equation 4 is intended to provide a practical lower limit for the computed variance. The limiting value shown will produce an over-dispersion factor of 0.001 for the gamma distribution of the CMF.

If Equation 1 is used to compute an overall countermeasure effect, then the term in parentheses in Equations 3 and 4 is multiplied by P_{trt}^2.

Summary of Information Needed from TAP

The type of assistance needed from the TAP is identified in Table 13. A more complete description and justification for this information is provided in previous sections.

It is envisioned that the SAC will perform an initial triage on the proposed CMF projects at a specified time in the annual research cycle. Then, they will identify all of the information they need for the collective set of projects being considered for prioritization. One comprehensive information request will then be sent to the TAP. It is likely that the time requested of the TAP for this activity will be about the same as that needed for the project prioritization process in which they are currently involved (although, the VOR procedure may involve less discussion but more detailed information).

PROCEDURE FOR ESTIMATING THE CRASH DISTRIBUTION

Practical considerations of time and data availability will likely preclude the derivation of a crash distribution from the highway safety databases of the collective set of states. Therefore, a procedure has been developed for estimating this distribution using SPFs available from previous research.

Table 13. Information Needed from TAP

Factors	Transportation Agency Partner Assistance
Number of candidate units	Occasional assistance needed. When a proposed countermeasure is specific to a unique application and HSIS or HPMS are not helpful, then each TAP member is asked to provide an estimate of count of candidate units (or the proportion of total units) in the jurisdiction they represent. Aggregation of all TAP input should reflect the entire US.
Number of affected units	Each TAP member is asked to provide an estimate of the proportion of candidate units to which a countermeasure will likely be applied in the jurisdiction they represent. Aggregation of all TAP input should reflect the entire US.
Crash distribution	No assistance needed.
Cost of target crash	No assistance needed.

Cost of implementation	Occasional assistance needed. For those countermeasures with no cost information available, each TAP member is asked to provide an estimate of the initial cost, annual maintenance cost, and service life of each proposed countermeasure. The number of these requests will likely be reduced over time as a "library" of this information is cataloged by the SAC.
Estimated Treatment Effectiveness	Occasional assistance needed. For those countermeasures with no previous research, each TAP member is asked to provide an estimate of the mean effect of a countermeasure and the range outside of which the expected effectiveness of a proposed countermeasure is very unlikely. The members with some familiarity with the countermeasure will likely provide a reply. It is not necessary for all TAP members to provide this information.

Some research is needed to confirm the validity of this procedure and, if needed, calibrate it. In fact, the National Automotive Sampling System (NASS) General Estimates System (GES) can be used for this purpose when the procedure is applied to all 50 states or when it is applied to the subset group of states in each of the four GES regions.

Two alternative procedures are described in this section. The first procedure is based on the use of one SPF (and its associated over-dispersion parameter) for each state to which a countermeasure is envisioned to be applied. Each state would be individually evaluated and the resulting VOR for each state added to produce the combined VOR used for prioritization. This procedure can be used with CMFs for widespread or specific application--provided that the SPF is consistent with the identified candidate units and target crashes.

The second procedure is based on the specification of one SPF for a "base" state. The fatal crash rates reported by state by the Fatality Analysis Reporting System (FARS) are used to calibrate this SPF for use with the other states. This procedure can be used with CMFs for widespread or specific application--provided that the SPF is consistent with the identified candidate units and target crashes.

User Provided SPF

The procedure described in this section uses an SPF (and its associated over-dispersion parameter) to estimate the mean and standard deviation of the crash distribution. As discussed in a previous section, the SPF can predict total crashes for a specified facility type (e.g., rural two-lane highways) or some subset of total crashes (e.g., run-off-road crashes on rural two-lane highway curves). For the reasons discussed previously, it is preferred that the SPF predicts total crashes. If the countermeasure is known to influence only specific crash types, then the CMF value used for the VOR calculation should be adjusted using Equation 1, where the proportion used in the equation is the proportion of "influenced" crash types in the total crash distribution.

Step 1. Gather Input Data

The input data include the following:

- average AADT for all candidate units ($\overline{AADT}$), veh/d;
- average length of segments in road inventory database ($\overline{L}$), mi/seg;
- SPF calibration parameters b_0 and b_1 applicable to candidate units and target crashes;
- over-dispersion parameter for SPF (k), dimensionless;
- total length of candidate segments (M), mi; or number of candidate intersections; and

- proportion of candidate units that will likely be treated (P_t).

The average AADT is an average of all segments that comprise the set of candidate units. It can be estimated using a variety of methods. For example, if the candidate units are specified by functional class, then the Highway Statistics database can be used to compute an average AADT by state (using the reported miles and vehicle-miles data). If the candidate units are defined in a more specific manner, then the HPMS database can be used to compute the average AADT. If the HPMS is used to compute the average AADT, then the estimate should be computed as a "section-length-weighted" average because of the significant number of grouped segments in HMPS (see the related discussion for Option 3 in the Section titled Number of Candidate Units).

The average length of segments in the road inventory database should be representative of the data used to calibrate the SPF. Specifically, it should be computed as an average of the segments in the SPF calibration database.

The over-dispersion parameter should be representative of the data used to calibrate the SPF. It is defined using the following variance function: $V[x] = E[x] + k\,E[x]^2$, where x is the count of crashes per unit. If the SPF was calibrated for segments using $V[x] = E[x] + k_L\,E[x]^2/L$, then the over-dispersion parameter k_L is divided by the average segment length to obtain k (i.e., $k = k_L / \overline{L}$).

Step 2. Compute Mean Annual Crashes Per Unit

The SPF used to compute the mean annual crashes per segment is shown as Equation 5.

$$E[N]_s = f_{c,s} b_o \overline{AADT}^{\,b1}\,\overline{L} \tag{5}$$

with,

$$f_{c,s} = 1.0 + 0.5\,b_1\,(b_1 - 1.0)\,I^2_{AADT} + b_1\,I_{AADT}\,I_L\,r_{AADT,L} \tag{6}$$

where,

$E[N]_s$ = mean annual crashes per segment, crashes/segment/yr;
$f_{c,s}$ = correction factor for segment SPFs;
I_{AADT} = coefficient of variation for AADT (= standard deviation of AADT divided by average AADT);
I_L = coefficient of variation for segment length (= standard deviation of segment length divided by average segment length); and
$r_{AADT,\,L}$ = correlation between AADT and segment length on a segment-by-segment basis.

The correction factor is needed to adjust the estimate from the SPF when it is used in the manner described above. The adjusted estimate of *E[N]* is intended to provide an unbiased estimate of the mean annual crashes per segment, as would be found through examination of a highway safety database.

Some research is needed to define the two coefficients of variation and the correlation statistic using HSIS data. Some preliminary investigation indicates that these statistics are relatively constant among states. However, if they are found to vary significantly by functional class, then this sensitivity should be incorporated in the analysis.

The SPF used to compute the mean annual crashes per intersection is shown as Equation 7.

$$E[N]_I = f_{c,I}\,b_o\,\overline{AADT}^{\,b1}_{maj}\,\overline{AADT}^{\,b2}_{\min} \tag{7}$$

with,

$$f_{c,I} = 1.0 + 0.5\, b_1\, (b_1 - 1.0)\, I^2_{AADT,maj} + 0.5\, b_2\, (b_2 - 1.0)\, I^2_{AADT,\min} + b_1\, b_2\, I_{AADT,maj} I_{AADT,\min}\, r_{maj,\min} \quad (8)$$

where,

$E[N]_I$ = mean annual crashes per intersection, crashes/intersection/yr;

$\overline{AADT}_{maj}$ = average AADT on the major road for all candidate intersections, veh/d;

$\overline{AADT}_{\min}$ = average AADT on the minor road for all candidate intersections, veh/d;

$f_{c,I}$ = correction factor for intersection SPFs;

$I_{AADT,\ maj}$ = coefficient of variation for the major road AADT at intersections;

$I_{AADT,\ min}$ = coefficient of variation for the minor road AADT at intersections; and

$r_{maj,\ min}$ = correlation between AADT on the major and minor roads on an intersection-by-intersection basis.

Some research is needed to define the correlation statistic using HSIS data. It is likely that it is relatively constant among states. However, if it is found to vary significantly by functional class and by number of intersection legs, then this sensitivity should be incorporated in the analysis.

Step 3. Compute Variance of Mean Annual Crashes Per Unit

The variance of the crash distribution is computed using Equation 9.

$$V[N] = k_o\ E[N]^2 \quad (9)$$

with,

$$k_{o,I} = k + (b_1\, I_{AADT,maj})^2 + (b_2\, I_{AADT,\min})^2 + 2\, b_1\, b_2\, I_{AADT,maj} I_{AADT,\min}\, r_{maj,\min} \quad (10)$$

$$k_{o,s} = k + (b_1\, I_{AADT})^2 + (I_L)^2 + 2\, b_1\, I_{AADT}\, I_L\, r_{AADT,L} \quad (11)$$

where, $V[N]$ is the variance of the mean annual crashes per unit, $(\text{crashes/unit/yr})^2$ and k_o is the over-dispersion parameter for the treated units.

The distribution of crashes is computed using a gamma distribution with a mean of $E[N]$ and a variance of $V[N]$. If the analysis unit is intersections, then Equation 10 is used to compute the value of k_o used Equation 9. If the analysis unit is segments, then Equation 11 is used to compute the value of k_o used Equation 9. As an alternative to Equation 10 or 11, the over-dispersion parameter for the database used to calibrate the SPF can be used as an estimate of k_o for the treated units. In this application, k_o is the over-dispersion parameter for the null model (i.e., $N = e^{b0}$) when calibrated with the SPF database.

Step 4. Compute Target Crash Frequency

The target crash frequency for segments is computed using Equation 12.

$$T = \frac{E[N]_s}{\overline{L}}\, P_t\ M \quad (12)$$

where,

T = target crash frequency, crashes/yr;

P_t = proportion of candidate segments at which the treatment is likely to be applied, mi; and

M = total length of candidate segments, mi.

The target crash frequency for intersections is similarly computed. However, the average segment length variable is removed from Equation 12 and the variable *M* is replaced by the count of candidate intersections.

Basic Roadway Information

This procedure is based on the specification of one SPF for a “base” state. The fatal crash rates reported by state by the Fatality Analysis Reporting System (FARS) are then used to calibrate the SPF for use with the other states of interest. This procedure can be used with CMFs for widespread or specific application--provided that the SPF is consistent with the identified candidate units and target crashes.

The procedure described in this section has been developed for only segments at this time. An equivalent procedure for intersections will need to be developed.

Step 1. Gather Input Data

The input data are the same as in Step 1 for the User Provided SPF procedure.

As noted previously for countermeasures suitable for widespread application, the total number of candidate miles can be obtained from the Highway Statistics database. It provides data categorized by state and functional class. The HPMS data can be used for countermeasures for specific application (with the limitations noted previously).

The Highway Statistics database provides the vehicle-miles of travel by state and functional class. These data can be combined with the total mile data to estimate the average AADT by state and functional class. The HPMS data can be used for this purpose for more specific applications.

The HPMS can be used to obtain an estimate of the number of intersections by state and functional class. The sample database is used for this estimate. It contains data for about 7 percent of all segments in the database, so standard expansion factor is used to obtain an estimate of the total number of intersections. A separate estimate is obtained for signalized intersections and for unsignalized intersections. The HPMS does not include data for the number of intersections on rural minor collectors, rural local roads, and urban local streets.

Step 2. Compute SPF Calibration Factor

The SPF calibration factor for segments is computed using Equation 13.

$$C_{s,i,j} = \frac{R_{f,s,i}}{R_{f,s,b}} \left(\frac{\overline{AADT}_{i,j}}{\overline{AADT}_{b,j}} \right)^{1.0-b1} \tag{13}$$

where,

$C_{s,i,j}$ = SPF calibration factor for segments in state *i* and with functional class *j*;
$R_{f,s,i}$ = fatal crash rate for segments in state *i*, crashes/100 million-veh-mi;
$R_{f,s,b}$ = fatal crash rate for segments in base state, crashes/100 million-veh-mi;

$\overline{AADT}_{i,j}$ = average AADT for state i and functional class j, veh/d;

$\overline{AADT}_{b,j}$ = average AADT for the base state b and functional class j, veh/d; and

b_1 = regression coefficient for the AADT term in the SPF.

The derivation of this equation is based on the assumption that, for a given functional class, the proportion of segment-related fatal crashes (i.e., = fatal crashes/total crashes) and the average segment length are the same in each state. The "base" state is the state whose data were used for the SPF's initial calibration. The fatal crash rate for each state can be computed using fatal crash data from FARS and the vehicle-mile data from Highway Statistics.

The fatal crash rate is computed as a statewide average for all functional classes. A rate is not computed for each functional class because of low sample sizes for some classes. The fatal crash rate ratio in Equation 13 is assumed to be the same for each functional class.

The SPF calibration factor for intersections is computed using Equation 14.

$$C_{I,i,j} = \frac{R_{f,s,i}}{R_{f,s,b}} \left(\frac{\overline{AADT}_{maj,i,j}}{\overline{AADT}_{maj,b,j}} \right)^{1.0-b1} \left(\frac{\overline{AADT}_{\min,i,j}}{\overline{AADT}_{\min,b,j}} \right)^{-b2} \tag{14}$$

where,

$C_{I,i,j}$ = SPF calibration factor for intersections in state i and major-road functional class j;

$\overline{AADT}_{maj,i,j}$ = average major-road AADT for state i and functional class j, veh/d;

$\overline{AADT}_{maj,b,j}$ = average major-road AADT for the base state b and functional class j, veh/d; and

$\overline{AADT}_{\min,i,j}$ = average minor-road AADT for state i and major-road functional class j, veh/d;

$\overline{AADT}_{\min,b,j}$ = average minor-road AADT for the base state b and major-road functional class j, veh/d; and

b_i = regression coefficients for the AADT terms in the SPF.

The functional class j used to define the variables for Equation 14 is that of the major road. The functional class of the minor road is indirectly reflected in the minor-road AADT value.

The derivation of Equation 14 is based on the assumption that, for a given functional class, the proportion of intersection-related fatal crashes and the average intersection spacing are the same in each state. The fatal crash rate ratio in Equation 14 is assumed to be the same for each major-road functional class.

Step 3. Compute Mean Annual Crashes Per Unit for Each State

The SPF used to compute the mean annual crashes per segment for each state and functional class is shown as Equation 15.

$$E[N]_{s,i,j} = C_{s,i,j}\ f_{c,s,j} b_0 \overline{AADT}_{i,j}^{b1}\ \overline{L}_{b,j} \tag{15}$$

with,

$$f_{c,s,j} = 1.0 + 0.5\, b_1\, (b_1 - 1.0)\, I_{AADT,b,j}^2 + b_1\, I_{AADT,b,j}\, I_{L,b,j}\, r_{AADT,L,b,j} \tag{16}$$

where,

$E[N]_{s,i,j}$ = mean annual crashes per segment in state *i* with functional class *j*, crashes/segment/yr;
$f_{c,s,j}$ = correction factor for segment SPFs with functional class *j*;
$\overline{L}_{b,j}$ = average segment length for base state *b* and functional class *j*, mi;
$I_{L,b,j}$ = coefficient of variation for segment length for base state b and functional class *j*;
$I_{AADT,b,j}$ = coefficient of variation for AADT for base state *b* and functional class *j*; and
$r_{AADT,L,b,j}$ = correlation between AADT and segment length on a segment-by-segment basis for base state *b* and functional class *j*.

The correction factor $f_{c,s,j}$ is discussed with Equation 6. This factor is computed for each functional class *j* for the base state *b*.

The SPF used to compute the mean annual crashes per intersection for each state and functional class is shown as Equation 17.

$$E[N]_{I,i,j} = C_{I,i,j}\ f_{c,I,j}\ b_o\ \overline{AADT}_{maj,i,j}^{b1}\ \overline{AADT}_{\min,i,j}^{b2} \tag{17}$$

with,

$$f_{c,I,j} = 1.0 + 0.5\, b_1\, (b_1 - 1.0)\, I_{AADT,maj,b,j}^2 + 0.5\, b_2\, (b_2 - 1.0)\, I_{AADT,\min,b,j}^2 + b_1\, b_2\, I_{AADT,maj,b,j} I_{AADT,\min,b,j}\, r_{maj,\min,b,j} \tag{18}$$

where,

$E[N]_{I,i,j}$ = mean annual crashes per intersection in state *i* with functional class *j*, crashes/intersection/yr;
$f_{c,I,j}$ = correction factor for intersection SPFs with functional class *j*;
$I_{AADT,maj,b,j}$ = coefficient of variation for the major road AADT at intersections AADT for base state *b* and functional class *j*;
$I_{AADT,min,b,j}$ = coefficient of variation for the minor road AADT at intersections AADT for base state *b* and functional class *j*; and
$r_{maj,\,min,b,j}$ = correlation between AADT on the major and minor roads on an intersection-by-intersection basis for base state *b* and functional class *j*.

The correction factor $f_{c,I,j}$ is discussed with Equation 8. This factor is computed for each functional class *j* for the base state *b*.

Step 4. Compute Variance of Mean Annual Crashes Per Unit for Each State

The variance of the segment crash distribution for each state and functional class is computed using Equation 19.

$$V[N]_{s,i,j} = k_{o,s,j}\ E[N]_{s,i,j}^2 \tag{19}$$

where $V[N]_{s,i,j}$ is the variance of the mean annual crashes per segment for state *i* and functional class *j*, (crashes/segment/yr)^2. The dispersion parameter $k_{o,s,j}$ is obtained from Equation 20.

$$k_{o,s,j} = k_{b,j} + (b_1\, I_{AADT,b,j})^2 + (I_{L,b,j})^2 + 2\, b_1\, I_{AADT,b,j}\, I_{L,b,j}\, r_{AADT,L,b,j} \tag{20}$$

The variance of the intersection crash distribution for each state and functional class is computed using Equation 21.

$$V[N]_{I,i,j} = k_{o,I,j}\ E[N]^2_{I,i,j} \tag{21}$$

where $V[N]_{I,i,j}$ is the variance of the mean annual crashes per intersection for state i and functional class j, (crashes/segment/yr)^2. The dispersion parameter $k_{o,I,j}$ is obtained from Equation 22.

$$k_{o,I,j} = k_{b,j} + (b_1\ I_{AADT,maj,b,j})^2 + (b_2\ I_{AADT,\min,b,j})^2 + 2\ b_1\ b_2\ I_{AADT,maj,b,j} I_{AADT,\min,b,j}\ r_{maj,\min,b,j} \tag{22}$$

Step 5. Compute the Mean Annual Crashes Per Unit

The results from Step 3 are used to compute the overall mean annual crashes per segment. Equation 23 is used for this purpose.

$$E[N]_s = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\frac{M_{i,j}\ E[N]_{s,i,j}}{\overline{L}_{b,j}}}{\sum_{i=1}^{n}\sum_{j=1}^{m}\frac{M_{i,j}}{\overline{L}_{b,j}}} \tag{23}$$

where,

$E[N]_s$ = mean annual crashes per segment, crashes/segment/yr;
$M_{i,j}$ = total length of candidate segments in state i with functional class j, mi;
n = number of states being considered for treatment; and
m = number of functional classes being considered for treatment.

The target crash frequency for intersections $E[N]_I$ is similarly computed. However, the average segment length variable is removed from Equation 23, $E[N]_{I,i,j}$ is substituted for $E[N]_{s,i,j}$, and the variable M is replaced by the count of candidate intersections.

Step 6. Compute Variance of Mean Annual Crashes Per Unit

The law of total variance is used to derive the equation for computing the variance of the crash distribution. This variance is computed using Equation 24.

$$V[N]_s = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\frac{M_{i,j}}{\overline{L}_{b,j}}\left(E[N]_{s,i,j} - E[N]_s\right)^2}{\sum_{i=1}^{n}\sum_{j=1}^{m}\frac{M_{i,j}}{\overline{L}_{b,j}}} + \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}V[N]_{s,i,j}}{n \times m} \tag{24}$$

where,

$V[N]_s$ = variance of the mean annual crashes per segment, (crashes/segment/yr)^2.

The distribution of crashes is computed using a gamma distribution with a mean of $E[N]_s$ and a variance of $V[N]_s$.

The variance of the crash distribution for intersections *$V[N]_I$* is similarly computed. However, the average segment length variable is removed from Equation 24, *$E[N]_I$* is substituted for *$E[N]_s$*, *$E[N]_{I,i,j}$* is substituted for *$E[N]_{s,i,j}$*, *$V[N]_{I,i,j}$* is substituted for *$V[N]_{s,i,j}$*, and the variable *M* is replaced by the count of candidate intersections. The distribution of crashes is computed using a gamma distribution with a mean of *$E[N]_I$* and a variance of *$V[N]_I$*.

Step 7. Compute Target Crash Frequency

The target crash frequency for segments is computed using Equation 25.

$$T_s = P_{t,s} \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{M_{i,j} \; E[N]_{s,i,j}}{\overline{L}_{b,j}} \tag{25}$$

where,

T_s = target crash frequency for segments, crashes/yr; and

$P_{t,s}$ = proportion of candidate segments at which the treatment is likely to be applied.

The target crash distribution for intersections T_I is similarly computed. However, the average segment length variable is removed from Equation 25, *$E[N]_{I,i,j}$* is substituted for *$E[N]_{s,i,j}$*, and the variable *M* is replaced by the count of candidate intersections.

Step 8. Compute Average Segment Length

The equivalent average segment length that, when combined with the estimated mean annual crashes per segment and total miles, yields an unbiased estimate of the total crash frequency is computed using Equation 26.

$$\overline{L} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} M_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m} \frac{M_{i,j} \; E[N]_{s,i,j}}{\overline{L}_{b,j}}} E[N]_s = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} M_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m} \frac{M_{i,j}}{\overline{L}_{b,j}}} \tag{26}$$

REFERENCES

1. "Traffic Signal Timing and Operations Survey." *ITE Journal.* Institute of Transportation Engineers, Washington, D.C., April 2009, p. 19.

2. Council, F., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries.* Report No. FHWA-HRT-05-051. Federal Highway Administration, Washington, D.C., October 2005.

3. *A Manual of User Benefit Analysis for Highways*. American Association of State Highway and Transportation Officials. Washington, D.C., 2010.

4. Harwood, D.W., D.J. Torbic, K.R. Richard, and M.M. Meyer. *Safety Analyst: Software Tools for Safety Management of Specific Highway Sites.* Report No. FHWA-HRT-10-063. Federal Highway Administration, Washington, D.C., July 2010.

Appendix F. Calibration of Support Tools for Value-of-Research Calculation

INTRODUCTION

This appendix describes the research conducted to quantify the calibration parameters used in the calculation of the expected value of research (VOR). The procedure for calculating the VOR was described in the July 2010 report by E. Hauer (i.e., First Report – Appendix C). The VOR represents a criterion for objectively evaluating alternative research projects and prioritizing them for funding consideration. The VOR procedure is used to evaluate a project that produces new CMFs for a specified countermeasure. It is also used to evaluate a project that improves the accuracy of an existing CMF.

The parameters addressed in this appendix are used in the VOR procedure to derive the crash distribution that forms the basis of the research value estimate. This distribution is intended to represent the collective set of intersections or highway segments at which a proposed countermeasure will likely be applied. The goal in the calibration process was to produce parameter values that are representative of all intersections and segments in the United States. The parameters are identified in the following list.

- Highway Segments
  - Average segment length (as defined in the typical transportation agency's road inventory database)
  - Crash severity distribution
  - Coefficient of variation of AADT
  - Coefficient of variation of segment length
  - Correlation between AADT and segment length
- Intersections
  - Crash severity distribution
  - Coefficient of variation of major road AADT
  - Coefficient of variation of minor road AADT
  - Correlation between major road AADT and minor road AADT

The segment-based parameters were calculated on a segment-by-segment basis. The length of a segment is based on the values specified in the typical state DOT road inventory database. These agencies tend to disaggregate their road system into segments that are bounded by intersections with crossing roads, crossing culverts, bridge decks, cross section changes, and jurisdictional boarders. The segments produced in this manner are relatively small and tend to have a relatively constant (i.e., homogeneous) geometric elements and traffic control features.

The intersection parameters identified in the preceding list were calculated for separate combinations of control type (i.e., signalized or minor road stop control) and number of legs (i.e., three or four).

The parameters for both segments and intersections were separately calculated for each of the following function classes.

- Rural
    - Interstate
    - Other principal arterial
    - Minor arterial
    - Major collector
    - Minor collector
    - Local
- Urban
    - Interstate
    - Freeway and expressway
    - Other principal arterial
    - Minor arterial
    - Collector
    - Local

For intersection applications, the functional class was defined as applying to the major road. The functional class of the minor road was not specified but it was assumed to be either the same as the major road, or of less importance.

The next section of this paper describes the methods used to quantify the highway segment parameters. The second section describes the methods used to quantify the intersection parameters.

SEGMENT CRASH, AADT, AND LENGTH CHARACTERISTICS

This section describes the data and methods used to quantify the highway segment parameters. The data used for calibration were obtained from the Highway Safety Information System (HSIS) maintained by FHWA.

The data for five HSIS states were used to calculate the parameters. These states and the mileage represented in the database are identified in Table 14. These states combine to represent 152,000 miles of roadway. Some cells in the table are not populated because the corresponding functional class was not explicitly recognized in the state's database. In this instance, the class designations used by the state were similar to those listed in the table, but the designation used implied some overlap among the desired functional classes. This trait prevented an accurate reallocation of the data to the desired class categories.

Crash data for the years 2006, 2007, and 2008 were assembled for each state. Table 15 summarizes these crashes by state and functional class. These crashes include all crash severities.

Table 14. Total Miles of Roadway by State and Functional Class

Are a Type	Functional Class	Miles of Roadway by State				
		California	Minnesota	N. Carolina	Ohio	Washington
Rural	Interstate	--	634	538	691	467
	Other principal arterial	--	3,604	1,973	1,785	1,976
	Minor arterial	6,261	6,587	2,213	2,484	1,645
	Major collector	914	14,998	7,453	7,854	1,578
	Minor collector	97	7,550	6,159	1,122	--
	Local	--	6,681	27,708	2	--
Urban	Interstate	--	283	622	697	297
	Freeway and expressway	--	174	420	402	361
	Other principal arterial	--	647	1,774	1,692	397
	Minor arterial	169	2,445	3,288	1,254	211
	Collector	16	2,080	2,582	364	7
	Local	2	11,450	7,753	0	--
	Total:	7,459	57,133	62,483	18,347	6,939

Note:
"--" - observations for this functional class were not available in the state crash database.

Table 15. Total Crashes by State and Functional Class

Are a Type	Functional Class	Three-Year Crash Total by State				
		California	Minnesota	N. Carolina	Ohio	Washingto n
Rural	Interstate	--	6,663	7,319	16,670	6,556
	Other principal arterial	--	10,261	11,354	18,677	10,002
	Minor arterial	31,707	9,215	10,319	21,405	5,385
	Major collector	3,567	7,976	22,746	40,765	3,326
	Minor collector	117	2,507	12,671	2,639	--
	Local	--	2,184	23,473	6	--
Urban	Interstate	--	22,945	28,845	62,680	28,487
	Freeway and expressway	--	8,823	9,337	14,602	11,847
	Other principal arterial	--	10,232	56,271	65,245	15,904
	Minor arterial	3,903	25,922	47,681	27,846	4,146
	Collector	230	8,221	14,090	3,485	32
	Local	22	13,778	13,652	20	--
	Total:	39,546	128,727	257,758	274,040	85,685

Note:
"--" - observations for this functional class were not available in the state crash database.

Segment Length

A regression model was used to quantify the average segment length for various conditions. A preliminary examination of the data indicated that the average segment length in the database varied with functional class. The final form of the model that provided the best fit to the data is shown in the following equation.

$$T_{i,j} = n_{i,j} \times \left(b_1 + \sum_{k=2}^{12} (b_k \times I_k) \right) \tag{1}$$

where,

$T_{i,j}$ = total mileage for state i and functional class j (j = 1: rural interstate, 2: rural other principal arterial, 3: rural minor arterial, 4: rural major collector, 5: rural minor collector, 6: rural local, 7: urban interstate, 8: urban freeway and expressway, 9: urban other principal arterial, 10: urban minor arterial, 11: urban collector, 12: urban local), miles;

$n_{i,j}$ = total number of segments for state i and functional class j, segments;

b_j = regression coefficient for functional class j; and

I_j = indicator variable for functional class j (= 1.0 if functional class j; 0.0 otherwise).

The regression coefficient b_1 equals the average segment length for rural interstates. It has units of "miles/segment." The remaining regression coefficients represent the incremental change in average segment length relative to b_1 for a given functional class. For example, the average segment length for "rural other principal arterial" is obtained by combining (i.e., adding) b_1 and b_2.

There are 51 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 1. The calibrated form of the regression model is shown in the following equation. The coefficient of determination R^2 for the model is 0.92.

$$\begin{aligned} T_{i,j} = n_{i,j} \times \big(& 0.404 - 0.077\, I_2 + 0.197\, I_3 + 0.707\, I_4 + 0.927\, I_5 + 0.303\, I_6 \\ & - 0.254\, I_7 - 0.268\, I_8 - 0.216\, I_9 - 0.119\, I_{10} - 0.052\, I_{11} - 0.203\, I_{12} \big) \end{aligned} \tag{2}$$

The computed average segment lengths are listed in Table 16. The values shown are computed by combining the appropriate regression coefficients from Equation 2.

Table 16. Computed Average Segment Length

Area Type	Functional Class	Average Segment Length, mi/seg
Rural	Interstate	0.404
	Other principal arterial	0.327
	Minor arterial	0.600
	Major collector	1.111
	Minor collector	1.331
	Local	0.707
Urban	Interstate	0.149
	Freeway and expressway	0.135
	Other principal arterial	0.188
	Minor arterial	0.284
	Collector	0.352
	Local	0.200

Severity Distribution

A logistic regression model was developed to quantify the severity distribution. Crash severity was defined using the following categories: K-fatal crash, A-incapacitating injury, B-non-incapacitating injury, C-possible injury, O-property-damage-only crashes. A preliminary examination of the data indicated that there was some correlation between functional class and the proportion of crashes in each severity category. The final form of the model that provided the best fit to the data is shown in the following equation.

$$N_{k,i,j} = N_{i,j} \frac{e^{\beta_{k,j}}}{1.0 + e^{\beta_{k,j}}} \quad (3)$$

with

$$\beta_{k,j} = b_1 + b_{at} I_{urban} + b_2(I_2 + I_8 + I_9) + b_3(I_3 + I_{10}) + b_4(I_4 + I_5 + I_{11}) + b_5(I_6 + I_{12}) \quad (4)$$

where,

$N_{k,i,j}$ = number of crashes of severity category k for state i and functional class j, crashes;
$N_{i,j}$ = total number of crashes for state i and functional class j, crashes;
b_{at} = area type regression coefficient;
I_{urban} = indicator variable for area type (= 1.0 if urban; 0.0 otherwise);
b_j = regression coefficient for functional class j; and
I_j = indicator variable for functional class j (= 1.0 if functional class j; 0.0 otherwise).

It was assumed that crash frequency is Poisson distributed, and that the distribution of the mean crash frequency for a group of observations with similar characteristics is gamma distributed. In this manner, the distribution of crashes for a group of similar observations can be described by the negative binomial distribution. The variance of this distribution is described by the following equation.

$$V[X] = N + \frac{N^2}{K} \quad (5)$$

where,

$V[X]$ = crash frequency variance for a group of observations with similar characteristics, crashes^2;
N = predicted average crash frequency, crashes;
X = reported crash count for y years, crashes; and
K = inverse dispersion parameter (= $1/k$, where k = overdispersion parameter).

The nonlinear regression procedure (NLMIXED) in the SAS software was used to estimate the proposed model coefficients. This procedure was used because Equation 3 is nonlinear. The log-likelihood function for the negative binomial distribution was used to determine the best-fit model coefficients. Equation 5 was used to define the variance function. Equation 5 was calibrated to crash categories K, A, B, and C. The procedure was set up to estimate model coefficients based on maximum-likelihood methods.

There are 51 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 15. The regression coefficients for the calibrated model are listed in Table 17.

Table 17. Regression Coefficients for Segment Severity Prediction

Var.	Functional Class	Regression Coefficients by Severity Category			
		K	A	B	C
b_1	Interstate	-4.542	-3.837	-2.079	-1.744
b_{at}	Urban environment	-1.138	-0.623	-0.404	0.296
b_2	Other principal arterial, urban freeway and expressway	0.150	0.218	0.060	0.125
b_3	Minor arterial	0.304	0.535	0.194	0.105
b_4	Major and minor collector	0.501	0.759	0.361	0.102
b_5	Local	0.545	0.579	0.275	-0.022
Model Statistics					
	Inverse dispersion parameter [1]	8.264	7.548	24.412	8.668
	R^2_k	0.917	0.916	0.973	0.937

A measure of model fit is listed in the last row of Table 17. It is the dispersion-parameter-based coefficient of determination R_k^2. It has a similar interpretation to the traditional coefficient of determination R^2. This statistic was developed by Miaou (1996) for use with data that exhibit a negative binomial distribution. It is computed using the following equation.

(6)

$$R_k^2 = 1.0 - \frac{K_{null}}{K}$$

where,

K_{null} = null inverse dispersion parameter.

The null inverse dispersion parameter K_{null} represents the dispersion in the reported crash frequency, relative to the overall average crash frequency for all observations. This parameter can be obtained using a null model formulation (i.e., a model with no independent variables but with the same error distribution, link function, and offset as used in the regression model).

The coefficients in Table 17 were used with Equations 4 and 7 to compute the severity distribution for each functional class category. The computed proportions for highway segments are shown in Table 18. The proportion of O-category crashes was estimated as $p_O = 1 - p_K - p_A - p_B - p_C$.

$$p_{k,j} = \frac{e^{\beta_{k,j}}}{1.0 + e^{\beta_{k,j}}} \quad \textbf{(7)}$$

where,

$p_{k,j}$ = proportion of crashes in severity category k for functional class j.

Table 18. Computed Severity Distribution for Highway Segments

Area Type	Functional Class	Proportion Crashes by Severity Category				
		K	A	B	C	O
Rural	Interstate	0.011	0.021	0.111	0.149	0.708
	Other principal arterial	0.012	0.026	0.117	0.165	0.679
	Minor arterial	0.014	0.035	0.132	0.163	0.656
	Major collector	0.017	0.044	0.152	0.162	0.624
	Minor collector	0.017	0.044	0.152	0.162	0.624
	Local	0.018	0.037	0.141	0.146	0.658
Urban	Interstate	0.003	0.011	0.077	0.190	0.718
	Freeway and expressway	0.004	0.014	0.081	0.210	0.690
	Other principal arterial	0.004	0.014	0.081	0.210	0.690
	Minor arterial	0.005	0.019	0.092	0.207	0.677
	Collector	0.006	0.024	0.107	0.207	0.657
	Local	0.006	0.020	0.099	0.187	0.688

AADT and Length Statistics

Coefficient of Variation for AADT

A regression model was developed to quantify the coefficient of variation of AADT volume. This coefficient is defined as the standard deviation of AADT volume among segments divided by the average AADT volume for the same set of segments. A preliminary examination of the data indicated that this coefficient varied with functional class. The final form of the model that provided the best fit to the rural data is shown in the following equation.

$$s_{AADT,i,j} = AADT_{i,j} \times (b_1 + b_2 \times j) \quad \textbf{(8)}$$

where,

$s_{AADT,i,j}$ = standard deviation of AADT volume for all segments in state i with functional class j (j = 1: rural interstate, 2: rural other principal arterial, 3: rural minor arterial, 4: rural major collector, 5: rural minor collector, 6: rural local), veh/d;

$AADT_{i,j}$ = average AADT volume of all segments in state i with functional class j, veh/d; and

b_j = regression coefficient.

The final form of the model that provided the best fit to the urban data is shown in the following equation.

(9)

$$s_{AADT,i,j} = AADT_{i,j} \times \left(b_3 + b_4 \times (j-6)\right)$$

where,

$s_{AADT,i,j}$ = standard deviation of AADT volume for all segments in state i with functional class j (j = 7: urban interstate, 8: urban freeway and expressway, 9: urban other principal arterial, 10: urban minor arterial, 11: urban collector, 12: urban local), veh/d.

In Equation 8, the sum of the two regression coefficients $b_1 + b_2$ equals the coefficient of variation c_v for rural interstates. For other functional classes, the second regression coefficient represents the incremental change in the c_v value. For example, the average segment length for "rural other principal arterial" is equal to $b_1 + b_2 \times 2$.

There are 51 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 1. The calibrated form of the regression models is shown in the following two equations. The coefficient of determination R^2 for the model in Equation 10 is 0.69; that for the model in Equation 11 is 0.89.

(10)

$$s_{AADT,rural,j} = AADT_j \times (0.426 + 0.137 \times j)$$

(11)

$$s_{AADT,urban,j} = AADT_j \times \left(0.386 + 0.124 \times (j-6)\right)$$

The computed coefficients of variation are listed in column 3 of Table 19. The values shown are computed using the terms in parentheses in Equations 10 and 11. For example, the coefficient of variation for "rural other principal arterial" is computed as $cv_{rural,\,2}$ = 0.426 + 0.137 × 2 = 0.700. The values in columns 4 and 5 of Table 19 are discussed in the next two subsections.

Table 19. Computed Coefficients for Highway Segments

Area Type	Functional Class	Coeff. of Variation for AADT	Coeff. of Variation for Segment Length	Correlation Coeff. for AADT and Seg. Length
Rural	Interstate	0.563	1.319	-0.082
	Other principal arterial	0.700	1.319	-0.091
	Minor arterial	0.837	1.319	-0.151
	Major collector	0.974	1.319	-0.162
	Minor collector	1.111	1.319	-0.114
	Local	1.248	1.319	-0.067
Urban	Interstate	0.510	1.361	-0.112
	Freeway and expressway	0.634	1.361	-0.037
	Other principal arterial	0.758	1.361	-0.049
	Minor arterial	0.882	1.361	-0.092
	Collector	1.006	1.361	-0.104
	Local	1.130	1.361	-0.034

Coefficient of Variation for Segment Length

A regression model was developed to quantify the coefficient of variation of segment length. This coefficient is defined as the standard deviation of individual segment lengths divided by the average segment length for the same set of segments. A preliminary examination of the data indicated that this coefficient varied with area type. The final form of the model that provided the best fit to the data is shown in the following equation.

(12)

$$s_{L,i,j} = L_{i,j} \times b_1$$

where,

$s_{L,i,j}$ = standard deviation of segment length for all segments in state i with functional class j, miles;
$L_{i,j}$ = average segment length for all segments in state i with functional class j, veh/d; and
b_1 = regression coefficient.

There are 51 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 1. The calibrated form of the regression models is shown in the following two equations. The coefficient of determination R^2 for the model in Equation 13 is 0.89; that for the model in Equation 14 is 0.96.

(13)

$$s_{L,rural} = L \times 1.319$$

(14)

$$s_{L,urban} = L \times 1.361$$

The computed coefficients of variation are listed in column 4 of Table 19. The values shown represent the regression coefficients Equations 13 and 14.

Correlation between AADT and Segment Length

The correlation coefficient for AADT and segment length was computed for each of the 51 combinations of functional class and state shown in Table 14. This coefficient describes the extent of correlation between the AADT and segment length among highway segments in each of the five states identified in Table 14. A positive correlation value indicates that segments with larger AADTs have a longer segment length. The reverse trend is true for a negative correlation value.

An examination of the correlation values for each of the 51 combinations indicates some variation exists among the functional classes. However, the variation does not follow a trend line. As a result, the correlation values for each state were averaged by functional class. The averages computed in this manner are listed in the last column of Table 19. The values are shown to be negative which indicates that segments with larger AADTs tend to have a shorter segment length.

INTERSECTION CRASH AND AADT CHARACTERISTICS

This section describes the data and methods used to quantify the intersection parameters. The data used for calibration were obtained from the Highway Safety Information System (HSIS) maintained by FHWA.

The data for two HSIS states were used to calculate the parameters. These states and the number of intersections represented in the database are identified in Table 20 and Table 21. Table 20 identifies number of intersections with two-way stop control and Table 21 identifies the number of intersections with signal control. These states combine to represent 44,576 intersections.

Crash data for the years 2006, 2007, and 2008 were assembled for each state. Table 22 and Table 23 summarize these crashes by state and functional class. These crashes include all crash severities.

Table 20. Number of Two-Way Stop-Controlled Intersections by State and Functional Class

Area Type	Functional Class	Number of Intersections by State			
		Three Intersecting Leg		Four Intersecting Legs	
		California	Minnesota	California	Minnesota
Rural	Interstate	--	--	--	--
	Other principal arterial	3,735	2,275	1,731	2,746
	Minor arterial	11,633	3,497	3,539	4,331
	Major collector	1,743	556	713	574
	Minor collector	--	8	--	7
	Local	--		--	--
Urban	Interstate	--	--	--	--
	Freeway and expressway	--	--	--	--
	Other principal arterial	--	648	--	687
	Minor arterial	1,054	1,088	283	524
	Collector	66	62	15	18
	Local	--	13	--	7
	Total:	18,231	8,147	6,281	8,894

Note:
"--" - observations for this functional class were not available in the state crash database.

Table 21. Number of Signal-Controlled Intersections by State and Functional Class

Area Type	Functional Class	Number of Intersections by State			
		Three Intersecting Leg		Four Intersecting Legs	
		California	Minnesota	California	Minnesota
Rural	Interstate	--	--	--	--
	Other principal arterial	46	3	145	360
	Minor arterial	114	13	240	117
	Major collector	9	--	28	--
	Minor collector	--	--	--	--
	Local	--	--	--	--
Urban	Interstate	--	--	--	--
	Freeway and expressway	--	--	--	--
	Other principal arterial	--	120	--	1,147
	Minor arterial	50	42	146	434
	Collector	3	--	6	--
	Local	--	--	--	--
	Total:	222	178	565	2,058

Note:
"--" - observations for this functional class were not available in the state crash database.

Table 22. Crashes at Two-Way Stop-Controlled Intersections by State and Functional Class

Area Type	Functional Class	Three-Year Crash Total by State			
		Three Intersecting Leg		Four Intersecting Legs	
		California	Minnesota	California	Minnesota
Rural	Interstate	--	--	--	--
	Other principal arterial	1,016	658	642	1,329
	Minor arterial	2,900	589	1,165	1,156
	Major collector	367	52	269	104
	Minor collector	--	1	--	1
	Local	--		--	--
Urban	Interstate	--	--	--	--
	Freeway and expressway	--	--	--	--
	Other principal arterial	--	408	--	832
	Minor arterial	380	498	96	558
	Collector	20	12	4	2
	Local	--	4	--	1
	Total:	4,683	2,222	2,176	3,983

Note:
"--" - observations for this functional class were not available in the state crash database.

Table 23. Crashes at Signal-Controlled Intersections by State and Functional Class

Area Type	Functional Class	Three-Year Crash Total by State			
		Three Intersecting Leg		Four Intersecting Legs	
		California	Minnesota	California	Minnesota
Rural	Interstate	--	--	--	--
	Other principal arterial	28	6	190	1,017
	Minor arterial	68	27	223	223
	Major collector	6	--	15	--
	Minor collector	--	--	--	--
	Local	--	--	--	--
Urban	Interstate	--	--	--	--
	Freeway and expressway	--	--	--	--
	Other principal arterial	--	334	--	5,470
	Minor arterial	24	83	107	1,851

	Collector	0	--	9	--
	Local	--	--	--	--
	Total:	126	450	544	8,561

Note:
"--" - observations for this functional class were not available in the state crash database.

Minor Road AADT

A regression model was developed to predict the average minor road AADT. A preliminary examination of the data indicated that this AADT varied with intersection control type, major road AADT, and functional class. The final form of the model that provided the best fit to the data for signalized intersections is shown in the following equation.

$$AADT_{minor,\,sig,i,j} = AADT_{major,\,sig,i,j}^{b_1} \times e^{b_0 + b_{at} I_{urban}} \qquad \textbf{(15)}$$

where,

$AADT_{minor,\ sig,i,j}$ = minor road AADT at signalized intersections for state i and functional class j (j = 2: rural other principal arterial, 3: rural minor arterial, 4: rural major collector, 5: rural minor collector, 6: rural local, 9: urban other principal arterial, 10: urban minor arterial, 11: urban collector, 12: urban local), veh/d;
$AADT_{major,\ sig\ i,j}$ = major road AADT at signalized intersections for state i and functional class j, veh/d;
b_{at} = area type regression coefficient;
I_{urban} = indicator variable for area type (= 1.0 if urban; 0.0 otherwise);
b_i = regression coefficients; and
I_j = indicator variable for functional class j (= 1.0 if functional class j; 0.0 otherwise).

The final form of the model that provided the best fit to the data for two-way stop-controlled intersections is shown in the following equation.

$$AADT_{minor,\,twsc,i,j} = AADT_{major,\,twsc,i,j}^{b_1} \times e^{b_0 + b_{at} I_{urban} + b_2 (I_3 + I_{10}) + b_3 (I_4 + I_5 + I_{11}) + b_4 (I_6 + I_{12})} \qquad \textbf{(16)}$$

where,

$AADT_{minor,\ twsci,j}$ = minor road AADT at two-way stop-controlled intersections for state i and functional class j (j = 2: rural other principal arterial, 3: rural minor arterial, 4: rural major collector, 5: rural minor collector, 6: rural local, 9: urban other principal arterial, 10: urban minor arterial, 11: urban collector, 12: urban local), veh/d; and
$AADT_{major,\ twsc\ i,j}$ = major road AADT at two-way stop-controlled intersections for state i and functional class j, veh/d.

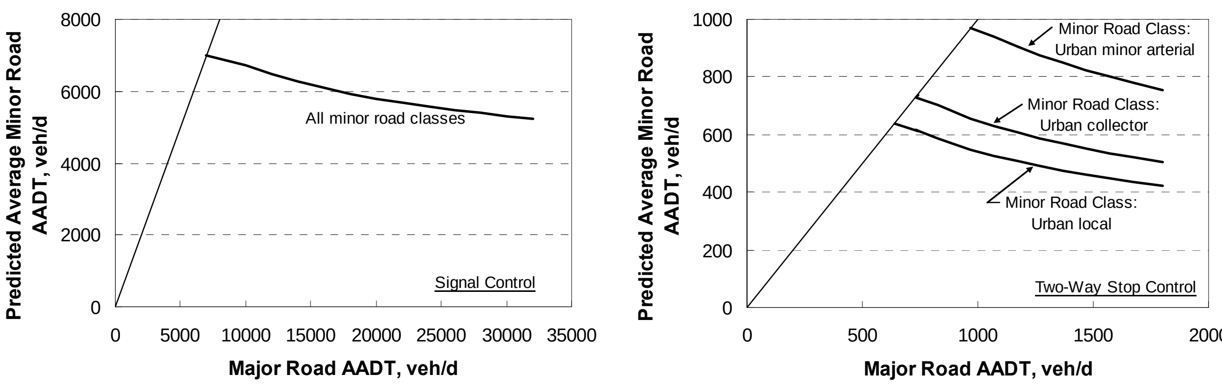
The nonlinear regression procedure (NLMIXED) in the SAS software was used to estimate the proposed model coefficients. The log-likelihood function for the negative binomial distribution was used to determine the best-fit model coefficients. Equation 5 was used to define the variance function for both models. The procedure was set up to estimate model coefficients based on maximum-likelihood methods.

There are 18 signalized intersection observations in the database, and 26 two-way stop-controlled intersection observations in the database. Each observation corresponds to one of the populated cells in Tables 7 or 8. The calibrated form of the regression models is shown in the following two equations. The coefficient of determination R^2_k for the model in Equation 17 is 0.20; that for the model in Equation 18 is 0.62.

$$AADT_{minor,\,sig} = AADT_{major,\,sig}^{-0.214} \times e^{10.464 + 0.318 I_{urban}} \quad (17)$$

$$AADT_{minor,\,twsc,\,j} = AADT_{major,\,twsc,\,j}^{-0.420} \times e^{10.180 + 0.978 I_{urban} - 0.408(I_3 + I_{10}) - 0.809(I_4 + I_5 + I_{11}) - 0.989(I_6 + I_{12})} \quad (18)$$

The relationship between minor road AADT and major road AADT predicted by Equations 17 and 18 are shown in Figures 1a and 1b, respectively. The trend lines in both figures indicate that minor road AADT is lower at intersections with higher major road AADT. This trend is counterintuitive in the sense that the minor road AADT is likely to increase with minor road AADT at a *given* intersection. However, it likely reflects some endogeneity that has led to a confounding effect between major road AADT and other unobserved variables. Nevertheless, it is rationalized that Equations 17 and 18 are accurately portraying the trend between major and minor road AADT that is found in a *group* of "typical" intersections which is acceptable for the VOR application.



a. Signal-controlled intersections. *b. Two-way stop-controlled intersections.*

Figure 1. Predicted minor road AADT as a function of major road AADT and functional class.

Equations 17 and 18 are used to estimate the minor road AADT needed for the intersection SPFs used in the VOR calculation. The AADT for the major road is assumed to equal the average segment AADT that is computed for each functional class using the HPMS database.

Severity Distribution

A logistic regression model was developed to quantify the severity distribution. Crash severity was defined using the following categories: K-fatal crash, A-incapacitating injury, B-non-incapacitating injury, C-possible injury, O-property-damage-only crashes. A preliminary examination of the data indicated that there was some correlation between functional class and the proportion of crashes in each severity category. The final form of the model that provided the best fit to the data is shown in the following equation.

$$N_{k,i,j} = N_{i,j} \frac{e^{\beta_{k,j}}}{1.0 + e^{\beta_{k,j}}} \quad \textbf{(19)}$$

with

$$\beta_{k,j} = b_1 + b_{at} I_{urban} + b_{ct} I_{signal} + b_2(I_3 + I_{10}) + b_3(I_4 + I_5 + I_{11}) + b_4(I_6 + I_{12}) \quad \textbf{(20)}$$

where,

$N_{k,i,j}$ = number of crashes of severity category k for state i and functional class j, crashes;
$N_{i,j}$ = total number of crashes for state i and functional class j, crashes;
b_{at} = area type regression coefficient;
I_{urban} = indicator variable for area type (= 1.0 if urban; 0.0 otherwise);
b_{ct} = control type regression coefficient;
I_{signal} = indicator variable for control type (= 1.0 if signalized; 0.0 otherwise);
b_j = regression coefficient for functional class j; and
I_j = indicator variable for functional class j (= 1.0 if functional class j; 0.0 otherwise).

It was assumed that crash frequency is Poisson distributed, and that the distribution of the mean crash frequency for a group of observations with similar characteristics is gamma distributed. In this manner, the distribution of crashes for a group of similar observations can be described by the negative binomial distribution. The variance of this distribution is described by Equation 5.

The nonlinear regression procedure (NLMIXED) in the SAS software was used to estimate the proposed model coefficients. This procedure was used because Equation 19 is nonlinear. The log-likelihood function for the negative binomial distribution was used to determine the best-fit model coefficients. Equation 5 was used to define the variance function for all models. The procedure was set up to estimate model coefficients based on maximum-likelihood methods.

There are 44 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 22 or Table 23. The regression coefficients for the calibrated model are listed in Table 24. The dispersion-parameter-based coefficient of determination R_k^2 is provided in the last row of this table. It has a similar interpretation to the traditional coefficient of determination R^2. It is computed using Equation 6.

The coefficients in Table 24 were added to Equation 20 and this equation was used with Equation 21 to compute the severity distribution for each functional class category.

$$p_{k,j} = \frac{e^{\beta_{k,j}}}{1.0 + e^{\beta_{k,j}}} \quad \textbf{(21)}$$

where,

$p_{k,j}$ = proportion of crashes in severity category k for functional class j.

The computed proportions for intersections are shown in Table 25 and Table 26 for two-way stop-controlled intersections and signal-controlled intersections, respectively. The "K" and "A" severity prediction models had two few observations for local roads to quantify a regression coefficient for this functional class. So, the computed proportions of "K" and "A" crashes for the collector road class are also used for the local road class. The proportion of O-category crashes was estimated as $p_O = 1-p_K - p_A - p_B - p_C$.

Table 24. Regression Coefficients for Intersection Severity Prediction

Var.	Functional Class	Regression Coefficients by Severity Category			
		K	A	B	C
b_1	Other principal arterial	-3.690	-3.048	-1.775	-1.094
b_{at}	Urban environment	-0.821	-0.939	-0.379	0.052
b_2	Signal control	-1.297	-0.359	-0.233	0.025
b_3	Incremental effect of minor arterial	-0.248	-0.148	0.065	-0.033
b_4	Incremental effect of major and minor collector	-0.796	-0.345	0.073	0.017
b_5	Incremental effect of local	--	--	0.143	-0.050
Model Statistics					
	Inverse dispersion parameter [1]	75.8	7.2	89.1	99.0
	R^2_k	0.996	0.959	0.996	0.996

Table 25. Computed Severity Distribution for Two-Way Stop-Controlled Intersections

Area Type	Functional Class	Proportion Crashes by Severity Category				
		K	A	B	C	O
Rural	Interstate	--	--	--	--	--
	Other principal arterial	0.024	0.045	0.145	0.251	0.535
	Minor arterial	0.019	0.039	0.153	0.245	0.544
	Major collector	0.011	0.032	0.154	0.248	0.555
	Minor collector	0.011	0.032	0.154	0.248	0.555
	Local	0.011	0.032	0.163	0.242	0.551
Urban	Interstate	--	--	--	--	--
	Freeway and expressway	--	--	--	--	--
	Other principal arterial	0.011	0.018	0.104	0.261	0.606
	Minor arterial	0.009	0.016	0.110	0.254	0.611
	Collector	0.005	0.013	0.111	0.258	0.614
	Local	0.005	0.013	0.118	0.251	0.613

Table 26. Computed Severity Distribution for Signal-Controlled Intersections

Area Type	Functional Class	Proportion Crashes by Severity Category				
		K	A	B	C	O
Rural	Interstate	--	--	--	--	--
	Other principal arterial	0.007	0.032	0.118	0.256	0.587
	Minor arterial	0.005	0.028	0.125	0.249	0.592
	Major collector	0.003	0.023	0.126	0.252	0.595
	Minor collector	0.003	0.023	0.126	0.252	0.595
	Local	0.003	0.023	0.134	0.246	0.594
Urban	Interstate	--	--	--	--	--
	Freeway and expressway	--	--	--	--	--
	Other principal arterial	0.003	0.013	0.084	0.266	0.634
	Minor arterial	0.002	0.011	0.089	0.259	0.638
	Collector	0.001	0.009	0.090	0.262	0.637
	Local	0.001	0.009	0.096	0.256	0.638

AADT Characteristics

Coefficient of Variation for Major Road AADT

A regression model was developed to quantify the coefficient of variation of major road AADT volume. This coefficient is defined as the standard deviation of major road AADT volume among intersections divided by the average major road AADT volume for the same set of intersections. A preliminary examination of the data indicated that this coefficient varied with control type and area type. The final form of the model that provided the best fit to the data is shown in the following equation.

(22)

$$s_{AADT,major,i,j} = AADT_{major,i,j} \times \left(b_1 + b_{at} I_{urban} + b_{ct} I_{signal}\right)$$

where,

$s_{AADT,\,major,\,i,j}$ = standard deviation of major road AADT volume for all intersections in state i with functional class j, veh/d;

$AADT_{major,\,i,j}$ = average major road AADT volume of all intersections in state i with functional class j, veh/d;

b_{at} = area type regression coefficient;

I_{urban} = indicator variable for area type (= 1.0 if urban; 0.0 otherwise);

b_{ct} = control type regression coefficient;

I_{signal} = indicator variable for control type (= 1.0 if signalized; 0.0 otherwise); and

b_1 = regression coefficient.

There are 44 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 20 or Table 21. The calibrated form of the regression models is shown in the following equation. The coefficient of determination R^2 for the model is 0.97.

$$s_{AADT,major} = AADT_{major} \times \left(0.786 - 0.125 I_{urban} - 0.232 I_{signal}\right) \quad \textbf{(23)}$$

The computed coefficients of variation are listed in Table 27. The values shown are computed using the terms in parentheses in Equation 23. For example, the coefficient of variation for "rural other principal arterial" with signal control is computed as $cv_{rural,\ signal} = 0.786 - 0.232 = 0.554$.

Table 27. Computed Coefficients for Major Road AADT at Intersections

Area Type	Functional Class	Coeff. of Variation for Major Road AADT by Control Type	
		Two-Way Stop Control	Signal Control
Rural	Interstate	--	--
	Other principal arterial	0.786	0.554
	Minor arterial	0.786	0.554
	Major collector	0.786	0.554
	Minor collector	0.786	0.554
	Local	0.786	0.554
Urban	Interstate	--	--
	Freeway and expressway	--	--
	Other principal arterial	0.660	0.428
	Minor arterial	0.660	0.428
	Collector	0.660	0.428
	Local	0.660	0.428

Coefficient of Variation for Minor Road AADT

A regression model was developed to quantify the coefficient of variation of minor road AADT volume. This coefficient is defined as the standard deviation of minor road AADT volume among intersections divided by the average minor road AADT volume for the same set of intersections. A preliminary examination of the data indicated that this coefficient varied with the number of intersection legs and area type. The final form of the model that provided the best fit to the data is shown in the following equation.

$$s_{AADT,minor,i,j} = AADT_{minor,i,j} \times \left(b_1 + b_{at} I_{urban} + b_{leg} I_{four}\right) \quad \textbf{(24)}$$

where,

$s_{AADT,\ minor,\ i,j}$ = standard deviation of minor road AADT volume for all intersections in state i with functional class j, veh/d;

$AADT_{minor,\ i,j}$ = average minor road AADT volume of all intersections in state i with functional class j, veh/d;

b_{leg} = intersection legs regression coefficient; and

I_{four} = indicator variable for intersection legs (= 1.0 if there are four legs; 0.0 otherwise).

There are 44 observations in the calibration database. Each observation corresponds to one of the populated cells in Tables 7 or 8. The calibrated form of the regression models is shown in the following equation. The coefficient of determination R^2 for the model is 0.93.

(25)

$$s_{AADT,minor} = AADT_{minor} \times \left(1.464 - 0.253 I_{urban} - 0.183 I_{four}\right)$$

The computed coefficients of variation are listed in Table 28. The values shown are computed using the terms in parentheses in Equation 25. For example, the coefficient of variation for "rural other principal arterial" intersection with four legs is computed as $cv_{rural,\,four}$ = 1.464 − 0.183 = 1.281.

Table 28. Computed Coefficients for Minor Road AADT at Intersections

Area Type	Functional Class	Coeff. of Variation for Major Road AADT by Legs	
		Four Intersection Legs	Three Intersection Legs
Rural	Interstate	--	--
	Other principal arterial	1.281	1.464
	Minor arterial	1.281	1.464
	Major collector	1.281	1.464
	Minor collector	1.281	1.464
	Local	1.281	1.464
Urban	Interstate	--	--
	Freeway and expressway	--	--
	Other principal arterial	1.028	1.212
	Minor arterial	1.028	1.212
	Collector	1.028	1.212
	Local	1.028	1.212

Correlation Between Major Road AADT and Minor Road AADT

The correlation coefficient for major road and minor road AADT was computed for each of the 44 combinations of functional class and state shown in Table 20 and Table 21. This coefficient describes the extent of correlation between the two AADTs among intersections in each of the two states identified in Table 7. A positive correlation value indicates that intersections with larger major road AADT also have a minor road AADT. The reverse trend is true for a negative correlation value.

A preliminary examination of the data indicated that the correlation coefficient varied with functional class and control type. The final form of the model that provided the best fit to the data is shown in the following equation.

(26)

$$r_{i,j} = b_1 + b_{ct} I_{signal} + b_2 (I_3 + I_{10}) + b_3 (I_4 + I_5 + I_6 + I_{11} + I_{12})$$

where,

$r_{i,j}$ = correlation coefficient between major and minor road AADT for all intersections in state i with functional class j.

There are 44 observations in the calibration database. Each observation corresponds to one of the populated cells in Table 20 or Table 21. The calibrated form of the regression models is shown in the following equation. The coefficient of determination R^2 for the model is 0.32.

(27)

$$r_{i,j} = 0.192 + 0.148 I_{signal} - 0.159\,(I_3 + I_{10}) + 0.111\,(I_4 + I_5 + I_6 + I_{11} + I_{12})$$

The computed coefficients of variation are listed in Table 29. The values shown are computed using Equation 27.

Table 29. Computed Correlation between Major and Minor Road AADT at Intersections

Area Type	Functional Class	Correlation between Major and Minor Road AADT by Control Type	
		Two-Way Stop Control	Signal Control
Rural	Interstate	--	--
	Other principal arterial	0.192	0.341
	Minor arterial	0.033	0.182
	Major collector	0.303	0.452
	Minor collector	0.303	0.452
	Local	0.303	0.452
Urban	Interstate	--	--
	Freeway and expressway	--	--
	Other principal arterial	0.192	0.341
	Minor arterial	0.033	0.182
	Collector	0.303	0.452
	Local	0.303	0.452

REFERENCES

Miaou, S-P. (1996). *Measuring the Goodness-of-Fit of Accident Prediction Models.* FHWA-RD-96-040. Federal Highway Administration, Washington, D.C.

Appendix G. Safety Research Prioritization Worksheet: User Manual

INTRODUCTION

This user manual provides guidance for the use of the Safety Research Prioritization Worksheet (SRPW). This worksheet can be used to evaluate the potential value of safety projects that are devoted to the development of a crash modification factor (CMF). The equations used for the evaluation are implemented in a Microsoft ® Excel workbook as software (using the Visual-Basic-for-Applications programming language).

The user manual consists of three sections. The first section provides an introduction to SRPW and describes basic interactions with the SRPW software. The second section describes the sequence of steps involved in the evaluation of a proposed research project. It also describes the information needed for an evaluation. The last section provides some application guidance for SRPW.

Overview

SRPW is used to compute the expected value of the information obtained from a proposed research project. This "value of research" (VOR) is derived when the research provides more certainty about countermeasure effectiveness, and this information is then used to guide the decision to implement the countermeasure. The VOR represents a criterion for objectively evaluating alternative research projects and prioritizing them for funding consideration. In general, projects with a higher value are considered to have more promise for cost-effective safety improvement than those with a lower value.

The procedure for calculating the VOR is described in the July 2010 report by E. Hauer (i.e., First Report – Appendix C) and in the December 2010 report by E. Hauer (i.e., Second Report – Appendix D).

Evaluation Scope

The VOR procedure is used to evaluate a research project that produces a new CMF for a specified countermeasure. It is also used to evaluate a project that improves the accuracy of an existing CMF. The CMF can be represented as a factor or a function.

Supplemental procedures are provided to support the evaluation of a CMF intended for wide scale application (e.g., most highway miles in several states). These procedures are developed to support the evaluation of CMFs that are applicable to one or more functional classes of roadways in one or more states. The focus can be on all road segments, all signalized intersections, or all two-way stop-controlled intersections. The evaluation of specific road elements (e.g., curves) or other intersection types (e.g., all-way stop-control, roundabout) requires the analyst to provide a safety performance function (SPF) for that element or type.

Limitations of the VOR Procedure

The VOR procedure has several limitations. Specifically, projects with the characteristics identified in the following list cannot be evaluated using the VOR procedure.

- A project that is intended to produce information other than or, in addition to, a CMF.
- A project that produces a safety prediction method.

The supplemental procedures to support the evaluation of a CMF intended for wide scale application do not address the conditions identified in the following list.

- Intersections on rural minor collectors, rural local roads, or urban local streets.
- All-way stop-controlled intersections, roundabouts, or uncontrolled intersection.
- Intersections with five or more legs.

Terminology

Analysis Unit

The calculation of VOR is based on the concept of an “analysis unit.” This unit is either an intersection or a highway segment. An analysis unit is also referred to herein as a “site.”

Highway Safety Database

A linked crash, road inventory, and traffic database is referred to herein as a highway safety database. The HSIS is considered a highway safety database.

Countermeasure Benefit

Countermeasure benefit equals the reduction in crash costs minus the opportunity cost of countermeasure implementation.

Countermeasure Cost

Treatment cost equals the opportunity cost of countermeasure implementation minus the cost of the change in crash frequency as a result of implementation. The change in crash frequency (and its associated cost) can be positive or negative.

Target Crash

Target crashes are those crashes whose occurrence or severity is likely to be influenced by the implementation of the subject countermeasure.

Value of Research

The value of research is an expected value with units of dollars per year. It represents the sum of the “unmissed countermeasure benefits” and “avoided countermeasure costs” for all candidate sites. An unmissed benefit represents the case where a site that should have been treated was actually treated. A benefit is missed if imperfect information about countermeasure effectiveness is used and the decision is to not treat a site that would truly benefit from treatment.

An avoided cost represents the case where a site that should not have been treated was not actually treated. A cost is not avoided if imperfect information about countermeasure effectiveness is used and the decision is to treat a site that will not truly benefit from treatment.

Getting Started

This section describes the basic interactions needed to complete an evaluation using the SRPW software. It consists of the three subsections identified in the following list.

- **Enabling Macros** - guidance for setting workbook security to enable macros.
- **Navigation** - guidance for selecting and using the worksheets.
- **Entering Data** - guidance for entering data in a worksheet.

Enabling Macros

The SRPW software contains computer code written in the Visual-Basic-for-Applications programming language. It is referred to as “macro” code in Excel®. This code must be enabled when first loading SRPW into Excel. This subsection describes a technique for enabling macros. The technique varies depending on the version of Excel being used.

Enabling Macros in Excel 2003. The following instruction sequence enables macros for Excel 2003. Open the Excel software. From the main screen, click on Tools and then Options. In the Options panel, click on Security, and then click Macro Security. In the Security panel, click on Security Level, and then click the radio button adjacent to Medium (the button will show a black circle). Finally, click Ok to exit the Security Level panel and click Ok to exit the Options panel. This setting should only need to be set once. It will remain effective until this process is repeated and a new security level is selected.

Every time ISATe is opened in Excel, the pop-up box shown above will be displayed. The analyst should click on Enable Macros. ISATe will finish loading and will function as intended.

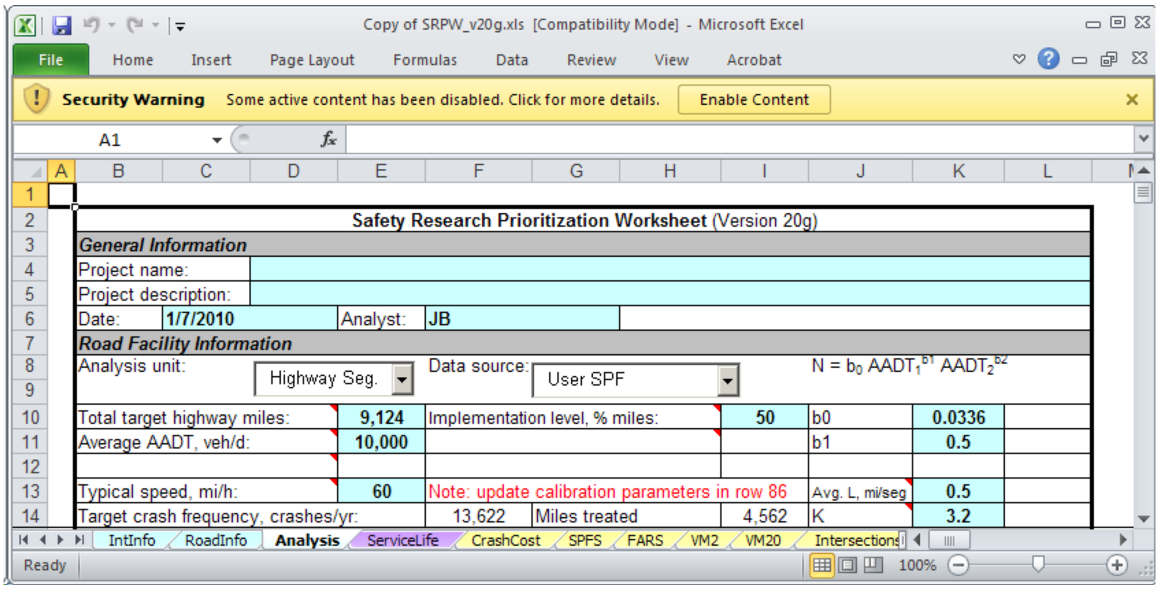
Enabling Macros in Excel 2007 or 2010. The following instruction sequence enables macros for Excel 2007 or 2010.

For Excel 2007, open the Excel software. From the main screen, click on the Office Button and a panel will be displayed. In this panel, click the Excel Options button to bring up the Excel Options panel.

For Excel 2010, click on File, then click on Options to bring up the Excel Options panel.

For Excel 2007 or 2010, while in the Excel Options panel, click on Trust Center, and then click on Trust Center Settings to bring up the Trust Center panel. In this panel, click on Macro Settings and then click the radio button adjacent to "Disable all macros with notification" (the button will show a black circle). Finally, click Ok to exit the Trust Center panel and click Ok to exit the Excel Options panel. This setting should only need to be set once. It will remain effective until this process is repeated and a new security level is selected.

Every time ISATe is opened in Excel, a security warning is displayed. This warning is shown in the screen image shown below for Excel 2010. It is shown near the top. A similar message is shown in Excel 2007. In Excel 2007, the analyst should click on the Options button, click on "Enable this content," and then click Ok. In Excel 2010, the analyst should click on the Enable Content button.



Navigation

The SRPW workbook contains 12 worksheets. To navigate among worksheets, click on the worksheet tabs at the bottom of the workbook window. Each worksheet is identified in following list.

- **IntInfo** - supplemental worksheet. Input data for wide scale intersection applications.
- **RoadInfo** - supplemental worksheet. Input data for wide scale segment applications.
- **CMF** - supplemental worksheet. Input countermeasure information from past projects.
- **Analysis** - main worksheet. Input data for the sites and countermeasure being evaluated.
- **Service Life** - library of service life estimates for selected countermeasures.
- **CrashCost** - default crash cost values.
- **SPFS** - default SPF calibration coefficients for intersections and segments.
- **FARS** - fatal crash counts for each of 50 states in 2008.
- **VM2** - annual vehicle-miles of travel for each of 50 states in 2008.
- **VM20** - road mileage for each of 50 states in 2008.
- **Intersections** - number of intersections for each of 50 states in 2008 and default distribution values.
- **Output** - detailed output from value-of-research calculation.

The Analysis worksheet will be used for every CMF research project evaluation. All data used for the VOR calculation must be entered in this worksheet.

When evaluating a CMF project suitable for wide scale application, the analyst will use either the IntInfo worksheet or the RoadInfo worksheet. The CMF worksheet will be used when there are results from previous similar projects whose results can be used to estimate key countermeasure effectiveness statistics. These three supplemental worksheets are used to compute values needed for the VOR calculations. Any values displayed in these worksheets must be entered in the Analysis worksheet to be used in the VOR calculations. The values in the supplemental worksheets are not directly considered during the value-of-research calculations.

The Service Life worksheet may be consulted to determine the service life of the subject countermeasure. If a value is found in this worksheet, it must be entered in the Analysis worksheet to be used in the VOR calculations. The values in the Service Life worksheet are not directly considered during the value-of-research calculations.

The CrashCost and SPFs worksheets contain default values that should only need to be updated every three or four years.

The FARS, VM2, VM20, and Intersections worksheets contain data that describe the U.S. highway system for 2008. They can be updated periodically. When they are updated, the values in the four worksheets should all reference a common year.

The Output worksheet will not typically be consulted unless there is some question about the accuracy of the VOR value reported in the Analysis worksheet. The data in this worksheet document the VOR calculation for the distribution of implementation sites.

Entering Data

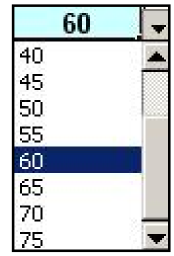
Each of the four worksheets that accept input data is designed in a consistent manner and their use is similar. A sample portion of the Analysis worksheet is shown in Figure 23 to illustrate basic data input considerations.

Safety Research Prioritization Worksheet (Version 20g)						
General Information						
Project name:						
Project description:						
Date:	**1/7/2010**	Analyst:	**JB**			
Road Facility Information						
Analysis unit:	Highway Seg.	Data source:	RoadInfo or IntInfo	$N = b_0\ AADT_1^{b1}\ AADT_2^{b2}$		
Total target highway miles:	**9,124**	Implementation level, % miles:	**50**			
		Average crashes/segment/yr:	**1.50**			
Typical speed, mi/h:	**60**	.		Avg. L, mi/seg	**0.5**	
Target crash frequency, crashes/yr:	13,686	Miles treated	4,562	K	**3.2**	

Figure 23. Analysis Worksheet

In general, the cells with a light blue background are for user input. White cells and grey cells are locked to prevent inadvertent changes to cell content. Yellow or orange cells are provided in some worksheets to designate cells that contain default values or established values that should be updated periodically.

The red triangles in the upper right corner of some cells are linked to supplemental information balloons. Four red triangles are shown in cells on the lower left side of Figure 23. By positioning the mouse pointer over a red triangle, a balloon will appear. In it will be information relevant to the adjacent cell. This information will typically explain more precisely what input data are needed.



A drop-down list is provided for some cells with a light-blue background. When one of these cells is selected, a grey button will appear on the right side of the cell. Position the mouse pointer over the button and click the left mouse button. After clicking on this button, a list of input choices will appear. Use the mouse pointer to select the desired choice, and then click the left mouse button.

The section of Figure 23 titled Road Facility Information shows two drop-down lists. On the right side of each list there is a grey button. Position the mouse pointer over this button and click the left mouse button. After clicking on this button, a list of input choices will appear. Use the mouse pointer to select the desired choice. Then, click the left mouse button.

Several cells in the Road Facility Information section are shown to have a white background and appear to be empty. The macro code is written to change the background color of several of these cells from white to blue and vice versa, as dictated by other input data. For example, if the analyst clicks on the drop-down list for Analysis Unit and selects "Intersection," then the cell with the text "Avg. L, mi/seg" will disappear and the cell to the right will have its background changed from blue to white. This action is intended to simplify the data input process by tailoring the worksheet such that only those cells associated with necessary input data are highlighted with a blue background.

EVALUATION PROCESS

This section describes the activities undertaken for the evaluation of one proposed research project, as described by its research needs statement (RNS).

The first section describes the activities undertaken when evaluating a CMF intended for specific applications. In this context, a CMF for specific application is envisioned to be applied to a unique type of road segment (or intersection), crash type, terrain condition, or geographic location. An example of a specific application would be a CMF for rural two-lane highway curves or a CMF for all-way stop-controlled intersections in mountainous terrain.

The second section describes the activities undertaken when evaluating a CMF intended for wide scale applications. In this context, a CMF for wide scale application is envisioned to be applied to one or more functional classes of roadway in one or more states. This evaluation approach is followed when the CMF is suitable for application to an entire functional class of roadway in most states. For example, a project to evaluate the effect of shoulder rumble strip installation on rural multilane highways throughout several states would have wide application.

The value of the information obtained from the subject research project is obtained at the conclusion of the evaluation process. It represents the value of the research project to the public, should the project be conducted and successfully completed. This value combines the road user benefit derived from a reduction in crash frequency or severity, and the cost of countermeasure implementation.

Evaluating CMFs with Specific Applications

The evaluation of CMFs with specific applications requires the use of the Analysis worksheet. It may include use of the CMF worksheet, and consultation of the ServiceLife worksheet. The default data in the CrashCost worksheet may be updated if desired, prior to evaluating the group of RNS.

Analysis Steps

This section outlines the steps involved in the evaluation of a research needs statement. The steps are considered to be the routine steps used each time an evaluation is undertaken. The recommended sequence of steps is described in the following paragraphs. The specific input data acquired for Steps 1 to 6 are described in the next subsection.

Step 1. Define Analysis Year. The analysis year is defined in this step. It is used to define the appropriate price indices for extrapolating the crash costs from a base year to the analysis year.

Step 2. Acquire Information About Number of Analysis Units. The information acquired during this step is used to compute the expected number of analysis units to be treated with the subject countermeasure.

Step 3. Acquire Data to Estimate Crash Distribution. The information acquired during this step is used to estimate the distribution of average annual crashes per analysis unit. The crashes of interest are those whose occurrence or severity is likely to be influenced by the subject countermeasure. They are referred to herein as "target" crashes. The distribution is described using a gamma distribution with a specified mean and variance. The mean of the crash distribution is computed using an SPF provided by the analyst. The dispersion parameter obtained from the SPF calibration is used to compute the variance of the crash distribution.

Step 4. Acquire Data to Estimate Target Crash Cost. This information is used to compute the average cost of a target crash. This cost is based on the crash severity distribution or, optionally, on the crash "geometry" distribution. Crash geometry is a term used to describe the combined crash type and location, where crash location is specified as "at intersection" or "not at intersection." Default values for average crash costs for each severity (or geometry) category are provided in SRPW.

Step 5. Acquire Implementation Cost Data. This information is used to compute the average annual cost to the transportation agency to implement the subject countermeasure. The cost is computed on a "per mile" basis for countermeasures applicable to segments, and on a "per intersection" basis for countermeasures applicable to intersections.

The initial cost is annualized over the service life of the countermeasure based on an input service life and discount rate. A capital recovery factor is computed, and used to compute the annualized initial cost. The total annual cost of the countermeasure is computed as the sum of the annualized initial cost and the annual maintenance cost.

The total annual cost is multiplied by the limiting benefit-cost ratio provided by the analyst. The product represents the opportunity cost of countermeasure implementation. The opportunity cost is used in the calculation of the value of the information obtained from the subject research project.

Step 6. Acquire Countermeasure Statistics. This information is used to compute the "unmissed countermeasure benefits" and the "avoided countermeasure costs" for all candidate sites. The value of these benefits and costs are a function of the countermeasure's mean effect and its standard deviation. The latter statistic describes the degree of uncertainty regarding the subject countermeasure's effectiveness when implemented at a specific site.

Step 7. Initiate Calculations and Review Results. The Calculate VOR button in the Analysis worksheet is selected to initiate the calculation sequence. The calculations proceed by converting the continuous crash distribution into crash frequency intervals and then identifying the number of sites associated with each interval.

For each interval, the "missed countermeasure benefits" and the "unavoided countermeasure costs" are computed based on the degree of uncertainty associated with the countermeasure effectiveness. This calculation is completed once using the specified level of uncertainty in the countermeasure effectiveness before the research is undertaken. It is repeated a second time using the estimated level of uncertainty after the research is completed. The difference between the outcomes of these two calculations represents the "unmissed countermeasure benefits" and "avoided countermeasure costs" resulting from the proposed research for one interval.

The aforementioned calculation process repeats for each interval of the crash distribution. The value of research is computed as the sum of the "unmissed countermeasure benefits" and "avoided countermeasure costs" for all intervals (i.e., all sites).

Input Data Requirements

The input data needed for the VOR calculations are listed in Table 30. They are described in the following paragraphs.

Table 30. Input Data for CMF's with Specific Applications

Category	Input Data Type by Road Element	
	Segment	Intersection
General	Analysis year	
Number of analysis units	Total target highway miles	Number of target intersections
	Implementation level, %	
Crash distribution	Segment AADT, veh/d	Major road AADT, veh/d
	Average segment length, miles	Minor road AADT, veh/d
	SPF regression coefficients	SPF regression coefficients
	Dispersion parameter from SPF	
Cost of target crash	Typical speed on highway, mi/h	Typical speed on major road, mph
	Crash distribution by severity or by geometry[1]	
	Consumer price index for analysis year	
	Employment cost index for analysis year	
Cost of implementation	Service life, years	
	Discount rate, %	
	Initial cost of project, $/mile	Initial cost of project, $/intersection
	Maintenance cost, $/mile/yr	Maintenance cost, $/intersection/yr
	Limiting benefit-cost ratio	
Countermeasure effectiveness	Mean effect of countermeasure	
	Standard deviation of countermeasure effectiveness before research	
	Estimated standard deviation of countermeasure effectiveness after new research	

Note:
1 - crash geometry describes the combination of crash type and road location.

Analysis Year. The analysis year is typically defined to be the current year. Regardless, the analysis year must be the same for all research needs statements that are being considered for funding in a common year.

Total Target Highway Miles (segment only). This input represents the total mileage of roads that *can be treated* with the subject countermeasure. Each road segment that comprises this mileage is considered to be a candidate for treatment. Not all of the segments may actually be treated.

The number of segments that can be treated can be difficult to determine if the countermeasure is specific in its application. For example, consider a countermeasure applicable to two-lane highway curves. The number of these curves is not routinely inventoried by most transportation agencies. Some options to address these situations are described in the following paragraphs. Other options may exist for some countermeasures.

One option is to enlist the help of the transportation agency partners (TAP) to gather information about the number of candidate segments in their jurisdiction. This information would be specific to the countermeasure of interest. Collectively, the input from the TAP would describe conditions throughout the US.

A second option is to use a highway safety database to identify the number of candidate segments in several states. These findings would then be extrapolated to the remaining states and road types of interest by total mileage ratio, where total state road mileage is obtained from the Highway Statistics database (http://www.fhwa.dot.gov /policy/ohpi/hss/index.cfm).

Number of Target Intersections (intersection only). This input represents the total number of intersections that *can be treated* with the subject countermeasure. These intersections are considered to be candidates for treatment. Not all of the intersections may actually be treated.

The number of intersections that can be treated can be difficult to determine if the countermeasure is specific in its application. For example, consider a countermeasure applicable to three-leg two-way stop-controlled intersections. The number of these intersections is not routinely inventoried by most transportation agencies. Some options to address these situations are described in the following paragraphs. Other options may exist for some countermeasures.

One option is to enlist the help of the TAP to gather information about the number of candidate intersections in their jurisdiction. This information would be specific to the countermeasure of interest. Collectively, the input from the TAP would describe conditions throughout the US.

A second option is to use a highway safety database to identify the number of candidate intersections in several states. These findings would be extrapolated to the remaining states and road types of interest by total mileage ratio.

A third option is to use the Highway Performance Monitoring System (HPMS). It is the most detailed database available that represents the U.S. street and highway system. Its Sample data have many geometry and traffic control variables that can be used to tailor the estimate of candidate intersections for the subject countermeasure. The Sample data are available for only about 7 percent of all segments in the database, so the findings will have to be extrapolated (using the Expansion Factors provided) to estimate the number of intersections by functional class and state.

The Sample data in the HPMS database do not include representation of rural minor collectors, rural local roads, and urban local streets. Also, the Sample data do not describe the number of number-of-legs at an intersection. Further, they do not indicate whether the unsignalized intersection is two-way stop-controlled, all-way stop-controlled, uncontrolled, or roundabout.

Implementation Level. The implementation level is used to determine the number of road miles (or intersections) likely to be treated with the subject countermeasure. It is expressed as a percentage of the target miles (or the target intersections) described previously.

The implementation level can vary, depending on countermeasure cost, effectiveness, and agency policy. For example, implementation of some countermeasures will be mandated by agency policy as applicable to all units of a specified class (e.g., add signal control to all intersections that satisfy one or more warrants). Other countermeasures will be recognized as good practice and are used at most locations (e.g., replace 8-inch signal indications with 12-inch signal indications). Some countermeasures will be radical and relegated to just those locations found to rank among the most deserving (e.g., red-light enforcement cameras). In fact, the effectiveness of these radical countermeasures may be undermined if they are deployed on a wide scale basis.

Segment AADT (segment only). One AADT value representing an average for all of the segments in the target highway miles. If the AADT varies widely among segments, then the desired value can be computed as a weighted average AADT, where the weight used is segment length. A highway safety database can be used to determine this AADT for a representative set of states.

Major and Minor Road AADT (intersection only). One AADT value representing an average of the major road AADT in the set of target intersections. A second AADT value representing an average of the minor road AADT at the set of target intersections. A highway safety database can be used to determine this AADT for a representative set of states.

Average Segment Length (segment only). The average length of the segments represented by the target highway miles. It has units of miles per segment. This value should reflect the average segment length in the data used to calibrate the SPF. It can be estimated using data from a highway safety database that is subset to include only roads with the same characteristics as the target highway miles.

SPF Regression Coefficients (segment only). The coefficients of interest are identified as b_0 and b_1 in the SPF shown in Equation 1. These coefficients are obtained from the best-fit regression model when the SPF is calibrated using data for segments that have the same functional class as the target highway miles. The collective set of segments should also have similar geometric design elements and traffic control features as those segments represented by the target highway miles.

$$N = b_0 \ AADT^{b_1} \tag{1}$$

where,
N = expected crash frequency, crashes/yr; and
$AADT$ = segment AADT, veh/d.

Data from a highway safety database may be used to develop this SPF. Alternatively, a suitable SPF developed for a previous project can also be used.

SPF Regression Coefficients (intersection only). The coefficients of interest are identified as b_0, b_1, and b_2 in the SPF shown in Equation 2. These coefficients are obtained from the best-fit regression model when the SPF is calibrated using data for intersections whose major and minor roads have the same functional class as that of the target intersections. The collective set of intersections should also have similar geometric design elements and traffic control features as the target intersections.

$$N = b_0 \ AADT_1^{b_1} \ AADT_2^{b_2} \tag{2}$$

where,
N = expected crash frequency, crashes/yr;
$AADT_1$ = major-road AADT, veh/d; and
$AADT_2$ = minor-road AADT, veh/d.

Data from a highway safety database may be used to develop this SPF. Alternatively, a suitable SPF developed for a previous project can also be used.

Dispersion Parameter from SPF. This parameter is defined as the inverse dispersion parameter *K*. It is used to describe the variability in the expected crash frequency obtained from Equations 1 or 2. This variability is computed using the following equation:

(3)

$$V[X] = y\,N + \frac{(y\,N)^2}{K}$$

where,

$V[X]$ = crash frequency variance for a group of similar locations, crashes^2;
X = reported crash count for y years, crashes;
y = time interval during which X crashes were reported, yr; and
K = inverse dispersion parameter (= $1/k$, where k = overdispersion parameter).

In some cases, a variable for segment length L is added to the divisor in Equation 3 such that the divisor term is $K_L \times L$. In this situation, the desired dispersion parameter K is computed as the product of calibrated K_L and the average segment length.

This parameter should be obtained from the same source used to obtain the SPF regression coefficients. Specifically, it should be obtained from the results of the regression analysis used to quantify the coefficient values.

Typical Speed on Highway or Major Road. This speed should be considered a typical speed limit for the target highway miles (or for the major road at the target intersections). It is used in the calculation of the target crash cost. The default crash costs in the CrashCost worksheet recognize cases where the speed limit is 45 mi/h or less, and cases where the speed limit is 50 mi/h or more.

Crash Distribution by Severity or Geometry. The crash distribution is described in terms of severity or “geometry.” If the crash distribution is described by severity, then the KABCO severity scale is used. The proportion of crashes for each of the five categories is a required input.

If the crash distribution is described by geometry, then the proportion of crashes for each of the following categories is a required input.

- single-vehicle, pedestrian, at intersection
- single-vehicle, pedestrian, not at intersection
- single-vehicle, animal
- single-vehicle, object
- single-vehicle, parked vehicle
- single-vehicle, rollover
- multiple-vehicle, crossed paths, signalized intersection
- multiple-vehicle, crossed paths, signed intersection
- multiple-vehicle, crossed paths, uncontrolled intersection
- multiple-vehicle, crossed paths, unspecified location
- multiple-vehicle, rear end, signalized intersection
- multiple-vehicle, rear end, signed intersection
- multiple-vehicle, rear end, unspecified location
- multiple-vehicle, rear end, not at intersection
- multiple-vehicle, sideswipe
- multiple-vehicle, opposite direction, signalized intersection
- multiple-vehicle, opposite direction, signed intersection
- multiple-vehicle, opposite direction, unspecified location

- multiple-vehicle, opposite direction, not at intersection
- multiple-vehicle, backing

Data from a highway safety database may be used to develop this distribution. Alternatively, a suitable distribution developed for a previous project can also be used.

The General Estimates System (GES) database can be used when the severity distribution is needed for all 50 states. GES has many of the variables found in typical crash databases (e.g., manner of collision, roadway alignment, number of lanes, speed limit, relation to junction, traffic control device, light condition, etc.). However, GES does not include variables for state or functional class. In 2009, it discontinued the variable indicating rural/urban location.

Consumer Price Index. This input data is designated as the "Annual Average index for CPI-U, All Items" by the Bureau of Labor Statistics. It can be obtained for the analysis year from the following website: http://www.bls.gov/cpi/tables.htm. It is used to update the crash costs in the CrashCost worksheet.

Employment Cost Index. This input data is designated as the index for "not seasonally adjusted, total compensation, total private industry" by the Bureau of Labor Statistics. The index value for December of the analysis year should be used for consistency in the VOR calculation. It can be obtained from the following website: http://www.bls.gov/news.release/eci.toc.htm. It is used to update the crash costs in the CrashCost worksheet.

Service Life. The service life of the countermeasure is used to estimate its annualized implementation cost. A library of service life values for typical projects is provided in the ServiceLife worksheet.

Discount Rate. The discount rate used represents the market rate of return after adjustment for inflation and the real cost of capital. It is the appropriate rate when estimating future costs in terms of current dollar values. A discount rate of 3.0 percent is recommended in the AASHTO publication *A Manual of User Benefit Analysis for Highways* (AASHTO, 2010).

Initial Cost of Project. This input data represents an estimate of the cost of implementing the subject countermeasure in the analysis year. For segments, it has units of dollars per mile. For intersections, it has units of dollars per intersection. The reference year for this cost is the analysis year. That is, the initial cost should be determined as if implementation occurred during the analysis year. Using analysis year costs it will yield an initial cost basis that is consistent with that used to establish the estimated target crash cost.

Maintenance Cost of Project. This input data represents an estimate of the annual cost of maintaining the subject countermeasure. For segments, it has units of dollars per mile. For intersections, it has units of dollars per intersection. The reference year for this cost is the analysis year. That is, the maintenance cost should be determined using rates applicable to the analysis year.

Limiting Benefit-Cost Ratio. The limiting benefit-cost ratio defines the minimum ratio above which a project is determined to be worthy of funding. It represents a desired minimum return for each dollar that is invested.

Mean Effect of Countermeasure. This input data represents the average countermeasure effectiveness based on existing knowledge. It is the CMF value associated the subject countermeasure based on the findings from one or more previous research projects.

The CMF (or CMFs) used as a basis for this input data must be consistent with the target crash frequency defined previously. That is, if the target crashes are a subset of total crashes, then the input data should describe the countermeasure effect on the subset crashes. In contrast, if the target crashes are total crashes, then the input data should describe the countermeasure effect on total crashes.

If the countermeasure effect is expressed as a function of an independent variable, and multiple previous projects are available to define a possible trend with this variable, then a procedure to estimate this input data is identified in the section titled Applications. The remainder of this subsection describes techniques for estimating this input data when the countermeasure effect is expressed as a constant.

No Previous Projects. If there are no previous projects upon which to base this estimate, then it can be based on the use of expert opinion. In this situation, experts are asked to identify the range outside of which the expected value of the CMF is very unlikely to occur. The best estimate of average countermeasure effectiveness equals the range divided by 1.5.

Multiple Previous Projects. If multiple previous projects were conducted such that multiple CMFs are available, then the best estimate of countermeasure effectiveness can be computed using the CMF worksheet.

Standard Deviation before Research. This input data represents the standard deviation of the countermeasure effectiveness based on existing knowledge.

The CMF (or CMFs) used as a basis for this input data must be consistent with the target crash frequency defined previously. That is, if the target crashes are a subset of total crashes, then the input data should describe the countermeasure effect on the subset crashes. In contrast, if the target crashes are total crashes, then the input data should describe the countermeasure effect on total crashes.

If the countermeasure effect is expressed as a function of an independent variable, and multiple previous projects are available to define a possible trend with this variable, then a procedure to estimate this input data is identified in the section titled Applications. The remainder of this subsection describes techniques for estimating this input data when the countermeasure effect is expressed as a constant.

No Previous Projects. If there are no previous projects upon which to base this estimate, then it can be based on the use of expert opinion. In this situation, experts are asked to identify the range outside of which the expected value of the CMF is very unlikely to occur. This range is then used to compute the standard deviation of the CMF. The following equation is used for this purpose:

(4)

$$s_{CMF,b} = \frac{CMF_{upper} - CMF_{lower}}{2 \times 2.5}$$

where,

$s_{CMF,\,b}$ = standard deviation of countermeasure effect before new research;

CMF_{upper} = estimated highest likely value of CMF; and

CMF_{lower} = estimated lowest likely value of CMF.

The Analysis worksheet supports the use of Equation 4 by allowing the analyst to enter CMF_{upper} and CMF_{lower} directly.

Multiple Previous Projects. If multiple previous projects were conducted such that multiple CMFs are available, then the best estimate of the standard deviation can be computed using the CMF worksheet.

Standard Deviation after Research. This input data represents a prediction of the standard deviation of the countermeasure effectiveness based on information obtained from the proposed research.

The CMF (or CMFs) used as a basis for this input data must be consistent with the target crash frequency defined previously. That is, if the target crashes are a subset of total crashes, then the input data should describe the countermeasure effect on the subset crashes. In contrast, if the target crashes are total crashes, then the input data should describe the countermeasure effect on total crashes.

If the countermeasure effect is expressed as a function of an independent variable, and multiple previous projects are available to define a possible trend with this variable, then a procedure to estimate this input data is identified in the section titled Applications. The remainder of this subsection describes techniques for estimating this input data when the countermeasure effect is expressed as a constant.

No Previous Projects. If there are no previous projects upon which to base this estimate, then it can be based on one of two options. One option is to directly estimate this value using judgment or expert opinion using a process similar to that described in the text associated with Equation 4.

A second option is to use judgment or expert opinion to estimate the standard error for the new project. This estimate would reflect some understanding of the likely data collection methods and statistical techniques to be used for the proposed project. In this situation, the following equation can be used to estimate the desired input data with $s\{\bar{\theta}\}$ equal to the estimated standard error for the new project and n equal to 1.0.

(5)

$$s^2_{CMF,a} = s^2_{CMF,b} - s^2\{\bar{\theta}\}\left(1.0 - \frac{n}{n+1}\right) \qquad > 0.001\,CMF^2$$

where,

$s_{CMF,a}$ = standard deviation of countermeasure effect after new research;
n = number of previous projects; and
$s\{\bar{\theta}\}$ = standard error of the CMF from previous projects.

The boundary condition identified on the right side of Equation 5 is intended to provide a practical lower limit for the computed variance.

The Analysis worksheet supports the use of Equation 5 by allowing the analyst to enter the standard error of the CMF from previous projects.

Multiple Previous Projects. If multiple previous projects were conducted such that multiple CMFs are available, then there are two options to estimate the desired input data. One option is to compute this input data using the CMF worksheet and an estimate of the standard error of the CMF for the new research. This approach requires judgment or expert opinion to estimate the standard error of the CMF for the new research.

A second option is to assume that the new research will have a data collection plan and statistical methods that are at least as rigorous as those used in the previous projects such that the standard error from the new project will match that of the previous projects. In this situation, Equation 5 can be used to estimate the desired input data. Equation 2 from the Second Report (Appendix D) is used to compute the "standard error of the CMF from the previous projects."

Evaluating CMFs with Wide Scale Application

The evaluation of CMFs with wide scale application requires the use of the IntInfo or RoadInfo worksheet along with the Analysis worksheet. It may include use of the CMF worksheet, and consultation of the ServiceLife worksheet. The default values in the CrashCost and SPFS worksheets may be updated if desired, prior to evaluating the group of RNS.

Analysis Steps

This section outlines the steps involved in the evaluation of a research needs statement. The steps are considered to be the routine steps used each time an evaluation is undertaken. The recommended sequence of steps is described in the following paragraphs. The specific input data acquired for Steps 1 to 6 are described in the next subsection.

Step 1. Define Analysis Year. The analysis year is defined in this step. It is used to define the appropriate price indices for extrapolating the crash costs from a base year to the analysis year.

Step 2. Acquire Information about Candidate Sites. This information is used to estimate the number of target sites at which the countermeasure is envisioned to be implemented. In this regard, one input data is the identification of which states the countermeasure is envisioned to be implemented. For segments, the estimate is based on information about the functional class of the target sites. For intersections, the estimate is based on information about the functional class of the major road, intersection control type, and number of legs.

Step 3. Identify Crash Distribution Statistics. The information acquired in Step 2 is used to compute the crash distribution statistics. The procedure for making these computations is described in Appendix E. The statistics computed are identified in the following list.

<u>Segment Crash Distribution Statistics</u>

- average crash frequency
- average segment length
- dispersion parameter
- crash distribution by severity

<u>Intersection Crash Distribution Statistics</u>

- average crash frequency
- dispersion parameter
- crash distribution by severity

Step 4. Acquire Data to Estimate Target Crash Cost. This information is used to compute the average cost of a target crash. This cost is based on the crash severity distribution or, optionally, on the crash "geometry" distribution. Crash geometry is a term used to describe the combined crash type and location, where crash location is specified as "at intersection" or "not at intersection." Default values for average crash costs for each severity (or geometry) category are provided in SRPW.

Step 5. Acquire Implementation Cost Data. This information is used to compute the average annual cost to the transportation agency to implement the subject countermeasure. The cost is computed on a "per mile" basis for countermeasures applicable to segments, and on a "per intersection" basis for countermeasures applicable to intersections.

The initial cost is annualized over the service life of the countermeasure based on an input service life and discount rate. A capital recovery factor is computed, and used to compute the annualized initial cost. The total annual cost of the countermeasure is computed as the sum of the annualized initial cost and the annual maintenance cost.

The total annual cost is multiplied by the limiting benefit-cost ratio provided by the analyst. The product represents the opportunity cost of countermeasure implementation. The opportunity cost is used in the calculation of the value of the information obtained from the subject research project.

Step 6. Acquire Countermeasure Statistics. This information is used to compute the "unmissed countermeasure benefits" and the "avoided countermeasure costs" for all candidate sites. The value of these benefits and costs are a function of the countermeasure's mean effect and its standard deviation. The latter statistic describes the degree of uncertainty regarding the subject countermeasure's effectiveness when implemented at a specific site.

Step 7. Initiate Calculations and Review Results. The Calculate VOR button in the Analysis worksheet is selected to initiate the calculation sequence. The calculations proceed by converting the continuous crash distribution into crash frequency intervals and then identifying the number of sites associated with each interval.

For each interval, the "missed countermeasure benefits" and the "unavoided countermeasure costs" are computed based on the degree of uncertainty associated with the countermeasure effectiveness. This calculation is completed once using the specified level of uncertainty in the countermeasure effectiveness before the research is undertaken. It is repeated a second time using the estimated level of uncertainty after the research is completed. The difference between the outcomes of these two calculations represents the "unmissed countermeasure benefits" and "avoided countermeasure costs" resulting from the proposed research for one interval.

The aforementioned calculation process repeats for each interval of the crash distribution. The value of research is computed as the sum of the "unmissed countermeasure benefits" and "avoided countermeasure costs" for all intervals (i.e., all sites).

Input Data Requirements

The input data needed for the VOR calculations are listed in Table 31. The four data types identified by underline are unique to CMFs with wide scale application. They are described in the following paragraphs. The data types that are not underlined are described in the previous section titled Evaluating CMFs with Specific Applications.

Table 31. Input Data for CMF's with Wide Scale Applications

<table>
<tr><th rowspan="2">Category</th><th colspan="2">Input Data Type by Road Element [1]</th></tr>
<tr><th>Segment</th><th>Intersection</th></tr>
<tr><td rowspan="4">General</td><td colspan="2">Analysis year</td></tr>
<tr><td>Functional class of segment</td><td>Functional class of major road</td></tr>
<tr><td colspan="2">States in which the countermeasure is likely to be implemented</td></tr>
<tr><td></td><td>Control type and number of legs</td></tr>
<tr><td>Number of analysis units</td><td colspan="2">Implementation level, %</td></tr>
<tr><td rowspan="3">Cost of target crash</td><td>Typical speed on highway, mi/h</td><td>Typical speed on major road, mi/h</td></tr>
<tr><td colspan="2">Consumer price index for analysis year</td></tr>
<tr><td colspan="2">Employment cost index for analysis year</td></tr>
<tr><td rowspan="5">Cost of implementation</td><td colspan="2">Service life, years</td></tr>
<tr><td colspan="2">Discount rate, %</td></tr>
<tr><td>Initial cost of project, $/mile</td><td>Initial cost of project, $/intersection</td></tr>
<tr><td>Maintenance cost, $/mile/yr</td><td>Maintenance cost, $/intersection/yr</td></tr>
<tr><td colspan="2">Limiting benefit-cost ratio</td></tr>
<tr><td rowspan="3">Countermeasure effectiveness</td><td colspan="2">Mean effect of countermeasure</td></tr>
<tr><td colspan="2">Standard deviation of countermeasure effectiveness before research</td></tr>
<tr><td colspan="2">Estimated standard deviation of countermeasure effectiveness after new research</td></tr>
</table>

Note:
1 - Input data types that are unique to wide scale CMF applications are underlined. All other input data types are common to both wide scale and specific CMF applications.

Functional Class. This information is used to define the class (or classes) of roadway on which the subject countermeasure is envisioned to be applied. For intersections, this designation applies to the intersecting road considered to be the major road. The functional classes that are considered in SRPW are identified in the following list.

- rural, interstate
- rural, other principal arterial
- rural, minor arterial
- rural, major collector
- rural, minor collector
- rural, local
- urban, interstate
- urban, freeways and expressways
- urban, other principal arterial
- urban, minor arterial
- urban, collector
- urban, local

Implementation States. This information is used to define the states in which the subject countermeasure is envisioned to be implemented. Any combination of the 50 states and the District of Columbia can be considered.

Control Type and Number of Legs (intersection only). This information describes the intersection control type and number of approach legs. The following list identified the categories addressed in the SRPW software.

- signalized intersection, three legs
- signalized intersection, four legs
- two-way stop-controlled intersection, three legs
- two-way stop-controlled intersection, four legs

The wide scale evaluation procedure can be used to evaluate CMFs applicable to the control-type-and-leg combinations identified in the list above. The evaluation of CMFs for those combinations not listed will require the use of the procedure described in the section titled Evaluating CMFs with Specific Applications.

Data Entry

If the wide scale application is used, then data are entered in the IntInfo or RoadInfo worksheets first, depending on whether the CMF is applicable to intersections or road segments.

If multiple previous projects were conducted such that multiple CMFs are available, then the analyst may enter the CMF values and standard errors from previous project to estimate the necessary countermeasure statistics. This worksheet is used before the Analysis worksheet.

Data are always entered in the Analysis worksheet.

The blue input cells are used for data entry. Some cells accept numeric data, which can be typed in directly using the keyboard. Some cells provide a drop-down list of text choices. In this case, the analyst should use the mouse pointer to select the applicable choice.

With a couple of exceptions, data must be entered in every cell highlighted with a blue background. The exceptions are the cells in the General Information section of the Analysis worksheet. These cells are used to document the analysis. Anything (or nothing) can be entered in these cells.

Some input data cells apply only when used with other data elements. SPRW monitors each data entry and will automatically highlight all other applicable data entry cells with a blue background when appropriate. Similarly, it will change the cell background to white for any data elements that are not applicable.

Any data that is entered in a cell that subsequently is changed to a white background (due to changes in other cells) will be ignored by SRPW.

Data entry should proceed from top to bottom to take full advantage of SRPW's ability to highlight applicable data entry cells. That is, data entry should proceed in the direction of increasing row number. Entry in the top-down direction is not a requirement. The only consequence of entering data in a different order is that some data may be entered that is ultimately not needed for a specific RNS evaluation.

Analysis Worksheet

The data entered in the Analysis worksheet is used to calculate the value of the information obtained from the proposed research. The entry of data in this worksheet is straightforward. The section labeled Countermeasure Information has some green cells that are discussed in the next few paragraphs. This section is shown in Figure 24.

Countermeasure Information (use Computing Mean...xlsm to compute values for blue cells, green cells are optional)					
Mean effect of countermeasure:	**0.700**	Lowest likely value of CMF:	**0.490**	Highest likely value:	**0.945**
		Estimated standard dev. before research:		0.139	
Standard deviation of countermeasure effectiveness before proposed research is undertaken:				**0.139**	
Estimated std. error of CMF:	0.100	Std. error of CMF from past studies:	**0.100**	Nbr. of past studies:	**1**
		Estimated standard dev. after new research:		0.120	OK
Estimated standard deviation of effectiveness after the proposed research is completed:				**0.120**	OK
Calculation Results					
Calculate VOR		Total VOR, $/yr:	**$660,137**		
		Calcuation details are provided in the Output worksheet			
Click button above to calculate VOR					

Figure 24. Countermeasure Information Section of Analysis Worksheet

Figure 24 shows that there are three blue input cells in the Countermeasure Information section. If the analyst has the information needed for these three cells, he or she should enter them in the appropriate blue cell and proceed with the evaluation. The remainder of this discussion applies when the analyst does not have the information needed for the two cells associated with the standard deviation inputs (i.e., those on the right side of Figure 24).

The two green cells in the right side of row 2 in Figure 24 identify the lowest and highest likely value of the CMF. As discussed in a previous section, the data input in these two cells can be obtained from expert opinion. There is an equation in the cell labeled "Lowest likely value of CMF" that computes this value as equal to 70 percent of the "mean effect of countermeasure" entered in the blue cell in row 2. Similarly, there is an equation in the cell labeled "Highest likely value of CMF" that computes this value as equal to 135 percent of the "mean effect of countermeasure." These equations can be typed over (i.e., replaced) with data from expert opinion, whenever such data are available.

The values in the two green cells in the right side of row 2 are used in Equation 4 to compute the "estimated standard deviation before research" shown in row 3. If this estimate is acceptable, it can be manually entered in the blue cell in row 4. The percentages (i.e., 70 and 135) were selected to produce a standard deviation equal to 20 percent of the "mean effect of countermeasure." These percentages can vary depending on the similarity of the sites studied.

The two green cells in the right side of row 5 in Figure 24 identify the standard error of the CMF from past studies and the number of these past studies. These two values are used in Equation 5 to compute the "estimated standard deviation after new research shown in row 6. If this estimate is acceptable, it can be manually entered in the blue cell in row 7.

IntInfo and RoadInfo Worksheets

The data entered in the IntInfo and RoadInfo worksheets is used to define the functional class and states to which the subject countermeasure is envisioned to be applicable. The data entry format for the

RoadInfo worksheet is shown in Figure 25. It is very similar to that in the IntInfo worksheet. Only the first few states in the States section are shown in Figure 25.

Road Types to which Countermeasure is Applicable						
Area Type	Functional Class	Proportion Miles Appplicable	Miles	Veh-Miles (millions)	Average AADT	Crashes per Year
Rural	Interstate	0	0	0	0	0
	Other Principal Arterial	0	0	0	0	0
	Minor Arterial	0	0	0	0	0
	Major Collector	1	418,229	186,139	1,219	229,267
	Minor Collector	1	262,607	55,019	574	67,886
	Local	1	2,036,217	131,697	177	178,746
Urban	Interstate	0	0	0	0	0
	Freeways and Expressways	0	0	0	0	0
	Other Principal Arterial	0	0	0	0	0
	Minor Arterial	0	0	0	0	0
	Collector	0	0	0	0	0
	Local	0	0	0	0	0
		Overall	2,717,053	372,855	376	475,899

States to which Countermeasure is Applicable					
State	Proportion Miles Appplicable	Miles	Veh-Miles (millions)	Average AADT	Total Crashes per Year
Alabama	1	68,893	12,888	513	21,055
Alaska	1	10,725	1,123	287	1,254
Arizona	1	34,018	6,166	497	8,369
Arkansas	1	81,886	7,459	250	13,951
California	1	72,086	15,328	583	14,942
Colorado	1	62,168	4,484	198	4,496
Connecticut	1	5,772	1,958	929	1,812
Delaware	1	3,025	1,127	1,021	1,262

Figure 25. Road Type and States Sections of the RoadInfo Worksheet

As with the Analysis worksheet, data are entered in the IntInfo and RoadInfo worksheets using the blue cells. A value ranging from 0 to 1 (inclusive) can be entered in each cell. For the Road Types section, a value of "0" indicates that the countermeasure is not envisioned to be applicable to the associated functional class. A value of "1" indicates that it is envisioned to be applicable to the all miles (or intersections) of the specified function class. A value between 0 and 1 indicates the proportion of the miles to which the countermeasure is applicable. A similar interpretation is applied to the values entered in the States section.

The sections shown in Figure 25 are also provided in the IntInfo worksheet, although they are specific to the number of intersections. The IntInfo worksheet also includes the Intersections section shown in Figure 26. This section is used to indicate the proportion of each combination of control type and legs to which the subject countermeasure is envisioned to be applicable.

Intersections to which Countermeasure is Applicable			
Control and Legs	Proportion Mile Appplicable	Nbr. Intersections	Crashes per Year
Signalized Intersection, 3-Leg	1	4,880	2,942
Signalized Intersection, 4-Leg	1	14,203	13,673
Two-Way Stop Controlled Intersection, 3-Leg	1	158,679	23,912
Two-Way Stop Controlled Intersection, 4-Leg	1	88,830	33,256
	Overall	266,592	73,784

Figure 26. Intersection Section of the IntInfo Worksheet

CMF Worksheet

The data entered in the CMF worksheet is used to compute the three input values for the Countermeasure Information section of the Analysis worksheet. The data entry format for this worksheet is shown in Figure 27. It is very similar to that in the Analysis worksheet. Only the top half of the CMF worksheet is shown in Figure 27. The bottom half of the worksheet is used to compute the effectiveness statistics when they are a function of an independent variable. This portion of the worksheet is described in the section titled Applications.

Countermeasure Effectiveness Statistics

General Information			
RNS name:			
RNS description:			
Date:	**1/7/2010**	Analyst:	**JB**

Crash Modification Factors							
Number	**Past Project Description**	**CMF Estimate**	**Standard Error**		**Planned Project Description**		**Standard Error**
1	**Arizona**	**0.75**	**0.100**		**Project 1**		**0.03**
2	**B.C.**	**0.62**	**0.100**		**Project 2**		**0.03**
3			**0.000**				
4			**0.000**				

Calculation Results *(Use bold values in Analysis worksheet)*			
	Statistic	**Based on Past Projects**	**Based on All Projects**
A	Weighted average countermeasure effectiveness (Equ. 1):	**0.685**	
B	Variance of weighted average effectiveness (Equ. 2):	0.005	0.000413
C	Variance of CMF estimates around weighted mean (first term Equ. 5):	0.004225	0.004225
D	Average variance of standard errors (second term of Equ. 5):	0.01	0.01
C-D	Variance of CMFs (Equ. 5):	0	0
C-D+B	Adjusted variance of CMFs (Equ. 6):	0.005	0.000413
	Variance reduction:	0.004587156	
	Adjusted standard deviation of CMF:	**0.070711**	**0.020319**

Figure 27. Input and Results Sections of the CMF Worksheet

As with the Analysis worksheet, data are entered in the CMF worksheet using the blue cells. The section labeled Crash Modification Factors in Figure 27 is used to input data from past projects and, optionally, for the proposed (i.e., planned) research project. Columns 2, 3, and 4 in this section are used to describe the data from past projects. There is an equation in column 4 that provides an estimate of the standard error. It should be replaced by the reported standard error whenever it is available. Data for two previous projects are shown. The worksheet will allow the analyst to enter data for up to 20 previous projects, although only four of these rows are shown in Figure 27.

Columns 6 and 8 in the section labeled Crash Modification Factors in Figure 27 are used to describe data for the proposed project. Data are proposed to be collected in two locations. The worksheet will allow the analyst to enter data for up to 20 locations.

The data entered in the blue cells are used with the equations described in the Second Report (Appendix D) to compute the statistics shown in the section titled Calibration Results. Only three of the values shown are needed for the VOR calculation. They are highlighted in bold font in the CMF worksheet. They are identified in the following list.

- Weighed average countermeasure effectiveness. This value is entered in cell e43 of the Analysis worksheet.
- Adjusted standard deviation of CMF (based on past projects). This value is entered in cell j45 of the Analysis worksheet.
- Adjusted standard deviation of CMF (based on all projects). This value is entered in cell j48 of the Analysis worksheet.

APPLICATIONS

This section provides information to assist in the application of SRPW for RNS evaluation. It consists of three sections. The first section describes the default values provided in SRPW. The second section describes the road inventory and fatal crash data used in the IntInfo and RoadInfo worksheets. The third section outlines a technique for evaluating RNS describing the need for evaluating crash modification functions.

Default Values

Yellow or orange cells are provided in the CrashCost and SPFS worksheets to designate cells that contain default values that should be updated periodically. The same set of default values should be used to evaluate all candidate research projects for a common funding cycle. This approach will ensure an equitable basis for comparing the VOR of alternative projects.

Crash Costs

The crash costs used in SRPW represent the comprehensive cost of a crash. The comprehensive cost estimates include the monetary losses associated with medical care, other resources used, lost work, and non-monetary costs related to the reduction in the quality of life. The default comprehensive crash costs were obtained from Table 10 of the report by Council et al. (2005). They are provided in the CrashCost worksheet. The base year for these costs is 2001.

Safety Performance Functions

The SPFs are used in the IntInfo and RoadInfo worksheets to estimate composite crash distribution statistics that represent all of the states in which the subject countermeasure is envisioned to be implemented. A procedure for using these SPFs to estimate the composite crash distribution statistics is described in Appendix E.

The default coefficients are provided in the SPFS worksheet. SPF coefficients are provided for segments and for the four intersection types listed in Figure 26. The segment SPFs have the form shown in Equation 1. The intersection SPFs have the form shown in Figure 24.

A separate set of segment SPF coefficients is provided for each of the 12 functional classes listed in Figure 25. Intersection SPF coefficients are provided for all functional classes except rural interstate, urban interstate, and urban freeways and expressways. All total, coefficients for 48 SPFs are provided in SRPW. The SPFs provided in SRPW were calibrated using HSIS data for Minnesota and Ohio (Attachment 1 describes the SPFs that were estimated).

The default dispersion parameters accompany the SPF coefficients. One parameter is provided for each SPF.

Crash Distribution by Severity

The crash distribution by severity is used in the IntInfo and RoadInfo worksheets to estimate a composite severity distribution that represents all of the states in which the subject countermeasure is envisioned to be implemented.

The default distribution values are provided in the SPFS worksheet. Distributions are described for segments and for the four intersection types listed in Figure 26. All distributions use the KABCO scale.

A separate segment distribution is provided for each of the 12 functional classes listed in Figure 25. Intersection distributions are provided for all functional classes except rural interstate, urban interstate, and urban freeways and expressways. All total, 48 distributions are provided in SRPW. The distributions were developed using HSIS data for several states. Their development is described in Appendix F.

AADT and Segment Length Characteristics

The AADT and segment length characteristics for segments include the statistics in the following list.

- coefficient of variation for AADT
- coefficient of variation for segment length
- correlation coefficient for AADT and segment length

The AADT and segment length characteristics for intersections include the statistics in the following list.

- coefficient of variation for major road AADT
- coefficient of variation for minor road AADT
- correlation coefficient for major road AADT and minor road AADT

The default characteristic values are used in the IntInfo and RoadInfo worksheets to estimate the composite crash distribution that represents all of the states in which the subject countermeasure is envisioned to be implemented. A procedure for using these characteristics to define the composite crash distribution is described in Appendix E.

The default characteristics are provided in the SPFS worksheet. Values are provided for segments and for the four intersection types listed in Figure 26.

Segment characteristics are provided for each of the 12 functional classes listed in Figure 25. Intersection characteristics are provided for all functional classes except rural interstate, urban interstate, and urban freeways and expressways. All total, 48 sets of characteristic values are provided in SRPW. The values were developed using HSIS data for several states. Their development is described in Appendix F.

Intersection Type Distribution

Default values are provided in the Intersections worksheet to describe the proportion of intersections that are two-way stop controlled and the proportion of intersections that have three legs. The latter proportion is categorized by functional class.

The default proportions are used in the IntInfo worksheet to estimate the number of intersections of each control type and number of legs. The distributions were developed using HSIS data for Minnesota.

Road Inventory and Fatal Crash Data

Yellow or orange cells are provided in the FARS, VM2, VM20, and Intersections worksheets to designate cells that contain established values that should be updated periodically. The same set of established values should be used to evaluate all candidate research projects for a common funding cycle. This approach will ensure an equitable basis for comparing the VOR of alternative projects. All values described in this section should be concurrently updated to reference a common year.

Fatal Crash Data

Fatal crash data are used in the IntInfo and RoadInfo worksheets to estimate composite crash distribution statistics that represent all of the states in which the subject countermeasure is envisioned to be implemented. A procedure for using these data with the SPFs to estimate the composite crash distribution statistics is described in Appendix E.

The default fatal crash data are provided in the FARS worksheet for each state for year 2008. They were obtained from the Fatality Analysis Reporting System (http://www-fars.nhtsa.dot.gov/Main/index.aspx).

The fatal crash data are separately categorized as segment-related and intersection-related crashes. Intersection-related crashes are defined as crashes using the following field elements for "relation to junction."

- intersection (non-interchange)
- intersection related (non-interchange)
- intersection (interchange area)
- intersection related (interchange area)

All crashes not designated as intersection related were considered to be segment related.

Highway System VMT and Mileage

The highway system vehicle-miles-traveled (VMT) and total mileage are used in the IntInfo and RoadInfo worksheets to estimate composite crash distribution statistics that represent all of the states in which the subject countermeasure is envisioned to be implemented. A procedure for using these data with the SPFs to estimate the composite crash distribution statistics is described in Appendix E.

The default VMT and total mileage data are provided in the VM2 and VM20 worksheets, respectively, for each state and functional class combination for year 2008. They were obtained from the Highway Statistics database (http://www.fhwa.dot.gov /policy/ohpi/hss/index.cfm). The data in the Highway Statistics database are derived from the HPMS database by FHWA.

Number of Intersections

The number of intersections data is used in the IntInfo worksheet to estimate composite crash distribution statistics that represent all of the states in which the subject countermeasure is envisioned to be implemented. A procedure for using these data with the SPFs to estimate the composite crash distribution statistics is described in Appendix E.

The default number of intersections is provided in the Intersections worksheet for each state and functional class combination for year 2008. They were obtained from the HPMS database using the Sample database and the appropriate expansion factor.

Evaluating Crash Modification Functions

The Second Report (Appendix D) describes a procedure for estimating the countermeasure effectiveness statistics when the CMF value is correlated with an independent variable. The CMF worksheet can be used to automate the calculation of these statistics. This procedure assumes that the relationship between the CMF value and independent variable is linear.

As a first step, the CMF values and standard errors from two or more previous projects are needed. They are entered in the Crash Modification Factors section of the CMF worksheet, as shown in Figure 5. The estimated standard error of the CMFs to be developed in the proposed (i.e., planned) project are also entered in this section.

As second step, the independent variable associated with each CMF from a past project is identified and entered in the section titled Crash Modification Function. It is shown in Figure 6. Column 5 in this section is used to enter the independent variable associated with the past projects. Data for two previous projects are shown. The worksheet will allow the analyst to enter data for up to 20 previous projects, although only four of these rows are shown in Figure 28.

Column 9 in the section labeled Crash Modification Function in Figure 28 is used to enter the independent variable associated with the proposed project. Data are proposed to be collected in two locations. The worksheet will allow the analyst to enter data for up to 20 locations.

Crash Modification Function								
Probability that the functional dependence is confirmed				0.5				
Number	Past Project Description	CMF Estimate	Standard Error	Indep. Variable	Planned Project Description		Standard Error	Indep. Variable
1	**Arizona**	**0.75**	**0.04**	**33.5**	**Location 1**		**0.03**	**36.1**
2	**B.C.**	**0.62**	**0.06**	**49.2**	**Location 2**		**0.03**	**45.1**
3		**0**	**0**				**0**	
4		**0**	**0**				**0**	

Calculation Results *(Use bold values in Analysis worksheet)*			
	Statistic	**Based on Past Projects**	**Based on All Projects**
A	Average countermeasure effectiveness:	0.685	
B	Variance of weighted average effectiveness (Equ. 9):	0.002113	0.001056
C	Variance of CMF estimates around weighted mean (first term Equ. 8):	0.001056	0.001056
D	Average variance of standard errors (second term of Equ. 8):	0.0026	0.0026
C-D	Variance of CMFs (Equ. 8):	0	0
C-D+B	Adjusted variance of CMFs (Equ. 9).	0.002113	0.001056
	Variance reduction:	0.00105625	
	Adjusted standard deviation of CMF:	0.045962	0.0325
Predicted Values Based on Combined Results			
	Predicted average countermeasure effectiveness:	**0.6975**	
	Predicted adjusted variance of CMFs (Equ. 12):	0.002735	0.001813
	Predicted variance reduction:	0.000921971	
	Predicted adjusted standard deviation of CMF:	**0.052298**	**0.042581**

Figure 28. Input and Results Sections of the CMF Worksheet when Evaluating Functions

The data entered in the blue cells are used with the equations described in the Second Report (Appendix D) to compute the statistics shown in the section titled Predicted Values Based on Combined Results (i.e., the last five rows in Figure 28). Only three of the values shown are needed for the VOR calculation. They are highlighted in bold font in the CMF worksheet. They are identified in the following list.

- Predicted average countermeasure effectiveness. This value is entered in cell e43 of the Analysis worksheet.
- Predicted adjusted standard deviation of CMF (based on past projects). This value is entered in cell j45 of the Analysis worksheet.
- Predicted adjusted standard deviation of CMF (based on all projects). This value is entered in cell j48 of the Analysis worksheet.

REFERENCES

AASHTO (2010). *A Manual of User Benefit Analysis for Highways*. 3rd Edition. American Association of State Highway and Transportation Officials. Washington, D.C.

Council, F., E. Zaloshnja, T. Miller, and B. Persaud. (2005). *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries.* Report No. FHWA-HRT-05-051. Federal Highway Administration, Washington, D.C.

Appendix H. Limiting Driveway Access at Intersections - Application of Value-of-Research Evaluation

INTRODUCTION

The objective of this paper is to document a value-of-research (VOR) evaluation for a specific safety treatment. The treatment under consideration is the removal of major-street driveway access for a corner business property at an urban or suburban signalized intersection. Specifically, the driveway on the major street would be removed and driveway access on the minor street would be preserved, or added if not previously existing.

To conduct the VOR analysis, the following seven questions must be answered:

1. How many units will be affected by the decision?
2. What is the frequency of target crashes?
3. What is the cost of an average target crash?
4. What is the annual cost of deciding to implement the decision on one unit?
5. What is the limiting benefit/cost ratio?
6. What are the mean and standard deviation of the CMF based on existing knowledge?
7. What is likely to be the standard deviation of the CMF after the proposed research is completed?

These questions were originally stated in Table 4 of the July 2010 report by E. Hauer (i.e., First Report – Appendix C).

In the next part of this paper, these questions are addressed in separate sections. In each section, the question is answered in the context of the aforementioned safety treatment. One exception is Question 5. The limiting benefit/cost ratio is established at 2.5. It is rationalized to be representative of the value most transportation agencies use when choosing among alternative projects.

VALUE OF RESEARCH EVALUATION

This part of the paper describes the analysis undertaken to apply the VOR procedure developed by E. Hauer, as described in the First Report (Appendix C). Each of the sections in this part address one or more of the seven questions that must be answered to compute the VOR for a safety treatment.

Number of Affected Units

The first question in the VOR evaluation process is the determination of the number of units that will be affected by the treatment. For this analysis, a "candidate unit" is defined as one corner of an urban or suburban signalized intersection. An "affected unit" is a candidate unit that has a business located at the corner and that business has a driveway on the major street and frontage to the minor street (possibly even a driveway to the minor street). The only driveways of interest in this regard are driveways located within 250 ft of the intersection.

Number of Signalized Intersections

It is estimated that there were 272,000 signalized intersections in the US in urban and suburban areas (*1*) in 2008. The US urban-area population for the year 2008 was 240 million persons (*2*). These two values yield a ratio of 1.13 signals per 1000 persons. This ratio is consistent with the ratio of 1.15 signals per 1000 persons found in the data from a 1996 survey of 92 North American cities conducted by ITE District 6.

Driveway Count and Land Use Type Distribution

Driveways at a sample of urban and suburban intersections in Texas were counted and categorized by land use. Aerial photography (available on the Internet) was used for this purpose.. A total of 180 intersections were included in the sample database. Of these intersections, 19 (or 11 percent) had three approach legs and 161 (or 89 percent) had four approach legs. By extrapolation, these percentages yield an estimate of 28,711 three-leg intersections and 243,289 four-leg intersections in the US. They are shown in column 3 of Table 32.

Table 32. Number of Affected Units

Location	Intersection Legs	Signalized Intersections	Candidate Units/Intersection	Number of Candidate Units	Number of Affected Units
Texas	3	19	2	38	11
	4	161	4	644	308
	Total:	180	--	682	319
US	3	28,711	2	57,422	16,622
	4	243,289	4	973,156	465,422
	Total:	272,000	--	1,030,578	482,044

A three-leg intersection has two candidate units and a four-leg intersection has four candidate units. The total number of candidate units was computed using these numbers and the total number of signalized intersections. The results are shown in column five of Table 32. The number of candidate units in the sample database is 682. It is estimated that there are 1,030,578 candidate units in the US.

Aerial photography was used to examine the candidate units in the sample database and determine which of them satisfied the criteria to be considered an "affected unit." A total of 319 affected units were identified. It equates to about 47 percent of the 682 candidate units. Applying this percentage to the US candidate units yields an estimate of 482,044 affected units. The distribution of affected units by number-of-intersection-legs is shown in the last column of Table 32.

Although peripheral to the identification of affected units, it is noted that 1122 driveways exist at the 180 intersections in the sample database. These driveways are located within 250 ft of the intersection. About 85 percent of these driveways served business land uses. The land-use distribution of driveways in the sample database is illustrated in Figure 29.

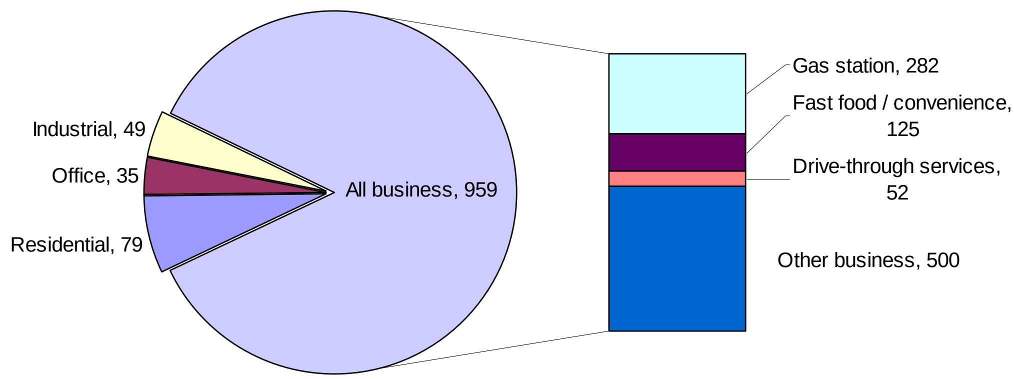


Figure 29. Driveway Land-Use Distribution

Crash Distribution

This section addresses question 2 in the list of questions in the Introduction. The crash distribution of interest is the distribution of business-driveway-related crashes at one corner of a signalized intersection (i.e., at one affected unit). The mean and variance of this distribution were estimated using an SPF calibrated with crash data for the intersections in the sample database. A subsequent part of this paper describes the development of the SPF. Its use for estimating the number of business-driveway-related crashes at signalized intersections in the US is described in this section.

The mean crash frequency for the typical corner (with a business) at a signalized intersection was computed using the calibrated SPF. The average AADT for typical major and minor streets was used for this calculation. The AADT coefficient of variation was used to adjust the predicted crash frequency to reflect the variation in AADT among urban streets. The average number of driveways on the major and minor streets in the sample database was also used in the calculation. The mean of the crash distribution is represented by the total of the predicted driveway crashes on the major and minor streets at a common intersection corner. This total is shown as an underlined value in column 4 of Table 2 for two evaluation scenarios. The evaluation scenarios are:

- Scenario 1 - One driveway is moved from the major street to the minor street. It is closed on the major street and a new driveway is opened on the minor street.
- Scenario 2 - One driveway is closed on the major street and all business traffic uses an existing driveway on the minor street.

As suggested by the column headings in Table 33, the mean of the crash distribution is estimated using the SPF for a "before" treatment condition. The data cited in the table for the "after" condition are discussed in a later section. The standard deviation of the predicted crash frequency is also discussed in a later section.

Table 33. Mean Crash Frequency of Crash Distribution

Variable	Before			After		
	Major St.	**Minor St.**	**Total**	**Major St.**	**Minor St.**	**Total**
Average AADT	20,000	10,000		20,000	10,000	
Coeff. of Variation I_{AADT}	0.54	0.70		0.54	0.70	
Scenario 1 - One driveway moved from major street to minor street						
Business driveways	1.3	1.2	2.5	0.3	**2.2**	2.5
Predicted crashes/yr N^1	0.418	0.147	0.565	0.096	0.270	0.366
Standard deviation of N	0.185	0.050	0.191	0.043	0.092	0.101
Scenario 2 - One driveway eliminated from major street (all traffic relocated to existing minor street driveway)						
Business driveways	1.3	1.2	2.5	0.3	**1.2**	1.5
Predicted crashes/yr N^1	0.418	0.147	0.565	0.096	0.147	0.244
Standard deviation of N	0.185	0.050	0.191	0.043	0.050	0.066

Note:
1 - Predicted crashes are injury (plus fatal) crashes only. Property-damage-only crashes are not included.

The mean crash frequency of the distribution is that representing the before condition identified in Table 33 (as a total for both the major and minor street driveways). Its value is 0.565 injury (plus fatal) crashes per year. This value was inflated to include an estimate of the property-damage-only crashes by dividing it by the proportion of injury (plus fatal) crashes. This proportion is 0.639 in the sample database. This process resulted in an estimated mean crash frequency of 0.884 crashes per year (= 0.565/0.639).

The variance of the crash distribution is computed using Equation 1.

$$V[N] = k_o \ E[N]^2 \tag{1}$$

where, $V[N]$ is the variance of the mean annual crashes per unit, $(\text{crashes/unit/yr})^2$ and k_0 is the over-dispersion parameter for the treated units. The over-dispersion parameter k_0 is estimated as the over-dispersion parameter for the null model (i.e., $N = e^{b0}$) when calibrated with the sample database (note that this parameter is not equal to the over-dispersion parameter k associated with the SPF). The value obtained from this calibration is 2.44.

Cost of Target Crash

This section addresses question 3 in the list of questions in the Introduction. The cost of a driveway-related crash in the vicinity of a signalized intersection was computed using the severity distribution of these crashes for 180 signalized intersections in Texas. Crash data for a five-year period were used to develop the distribution. This distribution is shown in Table 34.

Table 34. Driveway-Related Crash Cost at Urban and Suburban Signalized Intersections

Crash Severity Category	Crash Cost, $ [1]	Crash Frequency, cr/5years	Crash Proportions	Crash Cost, $
Fatal	4,491,105	0	0.000	0
Incapacitating injury	239,900	38	0.029	6,943
Non-incapacitating injury	76,500	226	0.172	13,168
Possible injury	49,125	575	0.438	21,513
Property damage only	8,610	474	0.361	3,108
Total:		1313	1.000	44,732

Note:
1 - Costs in 2008 dollars. Based on severity cost estimates developed by Council et al. (*3*) for speed limit of 45 mph or less, updated to 2008 dollars using the recommended procedure.

The comprehensive cost of each crash severity was computed using cost estimates reported by Council et al. (*3*). The estimated cost of a driveway-related crash at a signalized intersection is $44,732. This cost represents a weighted average cost, where the weight is the crash proportion.

Cost of Implementation

This section addresses question 4 in the list of questions in the Introduction. There are two costs associated with the removal or relocation of a driveway. One cost is the construction cost. The second cost is that incurred as lost sales by the businesses that lose some of their driveway access. This cost can be sizable when the business has a significant proportion of its sales stemming from pass-by traffic. Hence, it is necessary to include the annual loss in sales along with construction cost to accurately account for the total cost of driveway relocation or removal.

Cost of Lost Sales

Some research has been conducted on the business impacts of access management decisions. One common access management treatment is to add a raised median, which has the effect of limiting driveway access to right-turn movements. Gluck et al. (*4*) acknowledge that access restrictions have the greatest impact to land uses that have a significant portion of their customers arrive as pass-by trips. They report that pass-by trips account for about 55 percent of gasoline service station customers and about 45 percent of customers at fast-food restaurants or drive-through-window businesses. It is logical that a majority of these trips arrive via the major street access point for a business located at an intersection corner (as opposed to the minor street access it may have).

Eisele and Frawley (*5*) conducted a before/after case study of a street where a raised median was added. The business impacts were quantified using a variety of criteria, including customer volume, gross sales, property values, and employee counts. They reported finding a 2.4 percent reduction in gross sales for gas stations.

Generally, businesses are entitled to compensation if a portion of their land is taken by the state for highway right-of-way acquisition, though laws among the states vary in terms of compensation for the taking of driveways. For partial takings of property, compensable damages are determined through the process of appraising the property's value change, as described in documents like TxDOT's *Right-of-Way*

Appraisal and Review Manual (*6*). To estimate compensable damages resulting from a change in driveway access, it is necessary to estimate the annual profits made by the convenience store before and after the change.

To compute the annual profit of a convenience store, it is necessary to obtain the following three quantities:

- annual number of gallons of fuel sold,
- retailer profit margin per gallon sold, and
- percent of convenience store revenue derived from fuel sales.

The National Association of Convenience Stores has published the following statistics for the year 2009 (*7*):

- The average convenience store sold 121,000 gallons of fuel per month.
- Retailer profit margins were between one and three cents per gallon of fuel sold.
- Fuel sales contributed to about 27.3 percent of the average convenience store's profits.

These statistics were used to estimate the loss in annual profit associated with the removal of a business's access to the major street. One scenario assumed a 5.0 percent loss in annual sales. This value is based on the value of 2.4 percent reported by Eisele and Frawley (*5*), as described previously. However, the 2.4 percent value reflects the loss in sales when access to a driveway is limited to right-turn movements. It is multiplied by two (and rounded) to represent the loss in sales when all turn movements are prevented (as is the case with a driveway removal).

A second scenario was based on an analysis of pass-by trip percentages. It was assumed that the major-street driveway that is being removed served 70 percent of the pass-by trips. Pass-by trips were estimated to represent 55 percent of the business's customers. It was also assumed that only five percent of the pass-by customers who had used the major street driveway would be willing to divert to the minor street driveway to access the business (the other customers would go to another, more convenient business). These percentages combine to predict a 37 percent reduction in customers and associated sales as a result of the driveway removal ($= 0.55 \times 0.70 \times [1.0 - 0.05]$).

Table 35 describes the calculation of annual profit for the typical gas station (or business whose gas sales represent a significant portion of sales). The columns describe three scenarios: (1) no loss in annual sales (base case), (2) 5.0 percent loss in annual sales, and (3) 37 percent loss in annual sales). The second to last row indicates that a 5.0 percent loss in annual sales translates into an annual profit loss of $5,319. A 37 percent loss in sales translates into an annual profit loss of $38,906. The average of these two values is $22,113. It is considered to be a typical value suitable for the VOR evaluation.

Table 35. Average Cost of Driveway Access Loss

Category	Profit and Loss by Percent Loss in Annual Sales		
	0.0	5.0	37.0
Annual fuel sales, gal/yr	1,452,000	1,379,400	920,931
Annual fuel profit at 0.02 $/gal, $/yr	29,040	27,588	18,419
Annual non-fuel profit, $/yr	77,334	73,467	49,049
Total annual profit, $/yr	106,374	101,055	67,468
Loss in annual profit, $/yr		5,319	38,906
Average loss in annual profit, $/yr		22,113	

Cost of Construction

If the removal of the major-street driveway makes it necessary to build a replacement driveway on the minor street, the cost of building this driveway must also be considered. According to cost estimate data from the State Departments of Transportation for Texas and Washington, the cost of a concrete driveway is about $35-$40 per square yard (*8, 9*). Using the high end of this range, a driveway of 250 square yards in size would cost $10,000.

Estimated Implementation Cost

Annualizing the construction cost over a service life of 20 years (with a 3.0 percent discount rate) results in an equivalent value of $672 per year. Adding it to the average profit loss computed previously, yields an estimated treatment implementation cost of $22,785 per year.

Estimated Treatment Effectiveness

This section addresses questions 6 and 7 in the list in the Introduction section. With regard to question 6, the data in Table 2 were used to estimate the mean treatment effectiveness and its standard deviation. Specifically, the mean treatment effectiveness (i.e., CMF value) is computed as the total predicted crashes in the after period divided by the total predicted crashes in the before period. The resulting CMF is 0.648 for Scenario 1 (= 0.366/0.565) and 0.431 for Scenario 2 (= 0.244/0.565).

The standard deviation of the CMF before new research $s_{CMF,b}$ was computed using the following equation:

$$s_{CMF,b} = CMF\left(\frac{s^2_{N,tot,a}}{N^2_{tot,a}} + \frac{s^2_{N,tot,b}}{N^2_{tot,b}}\right)^{0.5} \tag{2}$$

where,

$s_{CMF,b}$ = standard deviation of countermeasure effect before new research;
$s_{N,tot,a}$ = standard deviation of major + minor predicted crashes for after period, crashes/yr;
$s_{N,tot,b}$ = standard deviation of major + minor predicted crashes for before period, crashes/yr;
$N_{tot,a}$ = major + minor predicted crashes for after period, crashes/yr; and

$N_{tot,b}$ = major + minor predicted crashes for before period, crashes/yr.

The values used in this equation are listed in the "Total" columns of Table 2.

Equation 2 assumes that the variability of the numerator term in the CMF calculation (i.e., the total predicted crashes in the after period) is independent of that in the denominator term. It yields an estimate of $s_{CMF,b}$ that is considered representative of the variability in the CMF value due to random events and unknown systematic sources both within and among sites throughout the US. Using the data in Table 2, the value of $s_{CMF,b}$ for Scenario 1 is 0.283 and it is 0.186 for Scenario 2.

The answer to question 7 requires two calculations. First, the standard error of the CMF $s\{\overline{\theta}\}$ was computed using the following equation:

$$s\{\overline{\theta}\} = CMF\left(\frac{s^2_{N,tot,a}}{N^2_{tot,a}} + \frac{s^2_{N,tot,b}}{N^2_{tot,b}} - 2\,\frac{s_{N,tot,a}}{N_{tot,a}}\frac{s_{N,tot,b}}{N_{tot,b}}\right)^{0.5} \tag{3}$$

This equation assumes that the numerator and denominator in the CMF calculation are perfectly correlated, as would be the case when the treatment is applied to a specific site. It yields an estimate of $s\{\overline{\theta}\}$ that is considered representative of the variability in the CMF value due to random events and unknown systematic sources within sites. Using the data in Table 2, the value of $s\{\overline{\theta}\}$ for Scenario 1 is 0.041 and it is 0.030 for Scenario 2. These values can be increased by a "method correction factor" ranging from 1.5 to 2.0 to account for additional uncertainty due to the derivation of the CMF from a regression model using cross section data (*10*).

Second, the estimated standard deviation after new research $s_{CMF,\,a}$ was computed using the following equation:

$$s_{CMF,a} = \left(s^2_{CMF,b} - 0.5\,s^2\{\overline{\theta}\}\right)^{0.5} \tag{4}$$

where $s_{CMF,\,a}$ is the standard deviation of countermeasure effect after new research.

This equation was previously described as Equation 4 in Appendix E. It is based on Equation 7 in the Second Report (Appendix D). Equation 4 yields an estimate of $s_{CMF,a}$ of 0.277 for Scenario 1 and 0.181 for Scenario 2. A method correction factor of 2.0 was used to inflate the standard error of the CMF.

Value of Research Results

The VOR was computed using the procedure described in the First Report (Appendix C). Specific input values are defined in the previous sections of this paper. The computed VOR for the two scenarios is listed below:

- Scenario 1 : $23,100,000
- Scenario 2 : $14,800,000

If it can be assumed that one-half of the affected units are consistent with Scenario 1 and the remaining units are consistent with Scenario 2, then an average VOR of **$18,950,000** is considered representative of the proposed research. This amount will be realized as a road-user benefit if all 482,044 units are evaluated using the results of the new research, and the deserving ones treated.

It is noted that only 25,600 of the affected units (5 percent) are expected to be deserving of treatment. The remaining 95 percent of the affected units are not likely to have a sufficiently high crash frequency to make driveway removal cost effective. This finding highlights the importance of having an accurate estimate of the mean and standard deviation of the crash distribution for VOR analysis (alternatively, it indicates that the VOR is sensitive to the mean and standard deviation).

ESTIMATION OF CRASH DISTRIBUTION

This part of the paper describes the development of predictive models for estimating the mean and standard deviation of the business-driveway-related crash distribution. These models were calibrated using the crash data for the intersections in the sample database of 180 Texas intersections. The previous part describes their use for estimating the number of business-driveway-related crashes at signalized intersections in the US.

The model calibration described in this part of the paper is based on injury (plus fatal) crashes. There are two main reasons for this focus. The first reason relates to the variation in crash reporting threshold among Texas counties. A preliminary evaluation of property-damage-only (PDO) crashes in the database indicated a wide variation in their representation in the crash distribution for each of the counties represented. This variation is likely to be the result of differences among enforcement agencies in the degree of adherence to the state's legal reporting threshold. This variation in PDO crash representation will cloud the search for association between road inventory factors and crash frequency. In contrast, fatal and injury crashes are more consistently reported among agencies in Texas.

Model Development

This section describes the safety predictive models and the methods used to calibrate them. Two models were calibrated. One was used to predict crash frequency for the major street and one was used to predict crash frequency for the minor street. The models shared some regression coefficients because it was rationalized that their value should be the same when calibrated using either major-street data or minor-street data. The use of common coefficients in multiple models required the use of a multivariate regression modeling approach. With this approach, the regression analysis evaluated both models simultaneously and used the total log-likelihood statistic for both models to determine the best fit calibration coefficients. The following regression model form was used to facilitate the multivariate regression analysis of the combined models:

$$N_{maj} = \left(D_{maj,bus} + D_{maj,non}\right)\left(e^{b_{bus}}\ P_{maj,bus} + 1.0\,[1.0 - P_{maj,bus}]\right)\left(\frac{AADT_{maj}}{1000}\right)^{b_1}\ e^{b_0 + b_{ch}\ I_{maj,ch}} \tag{5}$$

$$N_{\min} = \left(D_{\min,bus} + D_{\min,non}\right)\left(e^{b_{bus}}\ P_{\min,bus} + 1.0\,[1.0 - P_{\min,bus}]\right)\left(\frac{AADT_{\min}}{1000}\right)^{b_1}\ e^{b_0 + b_{ch}\ I_{\min,ch}} \tag{6}$$

with

$$P_{maj,bus} = \frac{D_{maj,bus}}{D_{maj,bus} + D_{maj,non}} \tag{7}$$

$$P_{\min,bus} = \frac{D_{\min,bus}}{D_{\min,bus} + D_{\min,non}} \tag{8}$$

where,

N_{maj} = predicted average driveway-related crash frequency for the major street, crashes/yr;
N_{min} = predicted average driveway-related crash frequency for the minor street, crashes/yr;
$D_{maj,bus}$ = count of business driveways on the major street, crashes/yr;
$D_{min,bus}$ = count of business driveways on the minor street, crashes/yr;
$D_{maj,non}$ = count of non-business driveways on the major street, crashes/yr;
$D_{min,non}$ = count of non-business driveways on the minor street, crashes/yr;
$P_{maj,bus}$ = proportion of driveways on the major street that serve business, crashes/yr;
$P_{min,bus}$ = proportion of driveways on the minor street that serve business, crashes/yr;
$AADT_{maj}$ = annual average daily traffic volume on the major street, veh/d;
$AADT_{min}$ = annual average daily traffic volume on the minor street, veh/d;
$I_{maj,ch}$ = indicator variable for right-turn channelization on the major street (= 1.0 if channelization present; 0.0 otherwise), veh/d;
$I_{min,ch}$ = indicator variable for right-turn channelization on the minor street (= 1.0 if channelization present; 0.0 otherwise), veh/d; and
b_i = various calibration coefficients.

The count of driveways on a given street is a two-way count, where the driveways are counted on both sides of the street. The count includes all driveways that are within 250 ft of the intersection.

The dependent variable for the calibration is the count of driveway-related crashes on a given street and that occur within 250 ft of the intersection. In this regard, the basic analysis unit is a 500-ft length of street segment with a signalized intersection in the middle of the segment. It was assumed that a segment's driveway crash frequency is Poisson distributed, and that the distribution of the mean crash frequency for a group of similar segments is gamma distributed. In this manner, the distribution of crashes for a group of similar segments can be described by the negative binomial distribution. The variance of this distribution is:

$$V[X] = y\,N + \frac{(y\,N)^2}{K} \tag{9}$$

where,

$V[X]$ = crash frequency variance for a group of similar locations, crashes^2;
N = predicted average crash frequency, crashes/yr;
X = reported crash count for y years, crashes;
y = time interval during which X crashes were reported, yr; and
K = inverse dispersion parameter (= $1/k$, where k = overdispersion parameter).

Calibration Data

The calibration database included 180 signalized intersections located in urban or suburban areas of Texas. Three years of crash data were identified for each intersection. The analysis period is 1999, 2000, and 2001. Traffic volume, driveway count, channelization presence, and other geometric data were collected for each intersecting street at the collective set of intersections. A total of 485 injury (or fatal) crashes are represented in the database. Only driveway-related crashes are included in the database, as identified in the crash report.

Statistical Analysis Methods

The nonlinear regression procedure (NLMIXED) in the SAS software was used to estimate the proposed model coefficients. This procedure was used because the proposed predictive model is both nonlinear and discontinuous. The log likelihood function for the negative binomial distribution was used to determine the best-fit model coefficients. Equation 9 was used to define the variance function for both models. The procedure was set up to estimate model coefficients based on maximum-likelihood methods.

Model Calibration

The predictive model calibration process was based on a multivariate regression modeling approach, as discussed in the section titled Model Development. With this approach, the two component models are calibrated using a common database. The database assembled for calibration included two replications of the original database. The dependent variable in the first replication was the reported crashes on the major street. The dependent variable in the second replication was the reported crashes on the minor street.

The results of the multivariate regression model calibration are presented in Table 5. Calibration of this model focused on injury (plus fatal) crash frequency. The Pearson χ^2 statistic for the model is 351, and the degrees of freedom are 354 (= $n - p$ = 358 −4). As this statistic is less than $\chi^2_{0.05,\,354}$ (= 399), the hypothesis that the model fits the data cannot be rejected. The R^2 for the model is 0.14. An alternative measure of model fit that is better suited to the negative binomial distribution is R_k^2, as developed by Miaou (*11*). The R_k^2 for the calibrated model is 0.52.

Table 36. Predictive Model Statistical Description

Model Statistics		Value		
	R^2 (R_k^2):	0.14 (0.52)		
	Scale Parameter φ:	0.98		
	Pearson χ^2:	351 ($\chi^2_{0.05,\,354}$ = 399)		
	Inverse Dispersion Parameter K:	0.86		
	Observations n_o:	358 segments (485 injury + fatal crashes in 3 years)		
Calibrated Coefficient Values				
Variable	**Inferred Effect of...**	**Value**	**Std. Dev.**	**t-statistic**
b_{bus}	Business driveway presence	2.410	1.0637	2.3
b_{ch}	Right-turn channelization presence	0.115	0.0986	1.2
b_0	Non-business driveway presence	-8.080	1.0925	-7.4
b_1	AADT	1.481	0.1474	10.0

The calibrated SPFs were used to derive a CMF for driveway change using the following equation:

$$CMF = \frac{N_{tot,a}}{N_{tot,b}} \tag{10}$$

with

$$N_{tot,a} = \overline{N}_{\min,a} + \overline{N}_{maj,a} \quad (11)$$

$$N_{tot,b} = \overline{N}_{\min,b} + \overline{N}_{maj,b} \quad (12)$$

$$\overline{N}_{\min,a} = f_{c,\min}\ N_{\min,a} \quad (13)$$

$$\overline{N}_{maj,a} = f_{c,maj}\ N_{maj,a} \quad (14)$$

$$\overline{N}_{\min,b} = f_{c,\min}\ N_{\min,b} \quad (15)$$

$$\overline{N}_{maj,b} = f_{c,maj}\ N_{maj,b} \quad (16)$$

$$f_{c,maj} = 1.0 + 0.5\, b_1 (b_1 - 1.0)\, I^2_{AADT,maj} \quad (17)$$

$$f_{c,\min} = 1.0 + 0.5\, b_1 (b_1 - 1.0)\, I^2_{AADT,\min} \quad (18)$$

where,

$\overline{N}_{\min,i}$ = mean driveway-related crash frequency for the minor street during period i ($i = a$ for after or b for before), crashes/yr;
$\overline{N}_{maj,i}$ = mean driveway-related crash frequency for the major street during period i, crashes/yr;
$N_{min,i}$ = predicted average driveway-related crash frequency for minor street period i, crashes/yr;
$N_{maj,i}$ = predicted average driveway-related crash frequency for major street period i, crashes/yr;
$f_{c,maj}$ = correction factor for the major street prediction;
$f_{c,min}$ = correction factor for the minor street prediction;
$I_{AADT,\ maj}$ = coefficient of variation for major-street AADT (= standard deviation of AADT divided by average AADT); and
$I_{AADT,\ min}$ = coefficient of variation for minor-street AADT (= standard deviation of AADT divided by average AADT).

Equation 10 describes the change in safety on one intersection corner as a result of a change in driveway count. The numerator of this equation is computed using Equation 11. The first term in this equation represents the predicted crash frequency on the side of the corner that fronts on the minor street N_{min}. The other term represents the predicted crash frequency on the side of the corner that fronts on the major street N_{maj}. The two terms in Equation12 have similar interpretation.

The predicted average driveway-related crash frequency for the minor street $N_{min,i}$ is computed using Equation 5. The value for the after period $N_{min,a}$ is based on the driveway count in the after period. That for the before period $N_{min,b}$ is based on the driveway count in the before period. A similar interpretation applies to the predicted averages for the major street. The AADT for both streets is assumed to be the same for the before and after periods.

Equation 12 is used to estimate the mean of the driveway crash distribution for VOR calculation. The mean of the minor street crash distribution for the US $\overline{N}_{\min,i}$ is computed using Equation 15 (and Equation 13). The value of $N_{min,i}$ used in this equation is based on Equation 6 with each input variable set at an overall average value representative of the US. A similar interpretation applies to the use of Equation 16 (and Equation 14) for the major street. The estimated average AADT and count of business driveways for the US are provided in Table 2. These averages are based partially on the data in the sample database and partly on the AADTs for urban arterial streets in the Highway Statistics database (http://www.fhwa.dot.gov/ policy/ohpi/hss/index.cfm). The values obtained from Equations 11 to 16 are listed in Table 2.

The correction factor $f_{c,min}$ is used in Equations 13 and 15 to adjust $N_{min,i}$ such that the computed mean $\overline{N}_{\min,i}$ is not biased by the variability in AADT among urban streets on US highways. This adjustment is based on the coefficient of variation in AADT I_{AADT} which was estimated using the sample database. The computed coefficient values from this database are listed in Table 2. A similar adjustment is applied to Equations 14 and 16 for the major street.

The combination of Equations 5, 6 and 10 through 16 yields the following CMF for business driveways, after cancellation of common terms and setting f_c equal to 1.0.

$$CMF = \frac{D_{maj,bus,a}\ e^{b1\ln(AADT_{maj}/1000)} + D_{\min,bus,a}\ e^{b1\ln(AADT_{\min}/1000)}}{D_{maj,bus,b}\ e^{b1\ln(AADT_{maj}/1000)} + D_{\min,bus,b}\ e^{b1\ln(AADT_{\min}/1000)}} \tag{19}$$

An examination of Equation 19 indicates that the CMF value is a function of driveway count for the before and after periods on both the major and minor streets. It is also a function of the AADT on both of these streets. The only regression coefficient represented in the equation is b_1, which implies that the standard error of the CMF is a function of the standard error of b_1.

By substitution of Equations 5 and 6 in Equations 13 and 14 and combining with Equation 11, the standard error of $N_{tot,a}$ based on variability in b_1 is computed as:

$$s_{N,tot,a} = s_{b1}\left(\left[N_{\min,a}\ln(AADT_{\min}/1000)\right]^2 + \left[N_{maj,a}\ln(AADT_{maj}/1000)\right]^2\right)^{0.5} \tag{20}$$

This equation represents a first-order approximation of the standard error based on the first two terms of the Taylor series expansion of Equation 11. The correction factor f_c is equal to 1.0. A similar equation can be derived from Equation 12 to estimate $s_{N,tot,b}$. The value of s_{b1} is provided in Table 5. The values computed from Equation 20 (and its counterpart from Equation 12) are listed in Table 2.

REFERENCES

1. "Traffic Signal Timing and Operations Survey." *ITE Journal.* Institute of Transportation Engineers, Washington, D.C., April 2009, p. 19.

2. U.S. Census Bureau. *Population Estimates*. Archives. http://www.census.gov/popest/archives/. Accessed March 11, 2011.

3. Council, F., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries.* Report No. FHWA-HRT-05-051. Federal Highway Administration, Washington, D.C., October 2005.

4. Gluck, J., H. Levinson, and V. Stover. *NCHRP Report 420: Impacts of Access Management Techniques.* Transportation Research Board, Washington, D.C., 1999.

5. Eisele, William L., and William E. Frawley. *Assessment of Economic Impacts at Selected Raised Median Installation Locations in Texas and Development of Recommended Methodology for Economic Impacts Estimation*. Report FHWA/TX-01/3904-5. Texas Transportation Institute, College Station, Texas, 2000.

6. *Right-of-Way Appraisal and Review Manual*. Texas Department of Transportation, Austin, Texas, 2006.

7. *Motor Fuel Sales Fact Sheet*. National Association of Convenience Stores, January 2011. http://www.nacsonline.com/NACS/News/FactSheets/Motor%20Fuels/Pages/MotorFuelSales.aspx. Accessed March 10, 2011.

8. *Statewide Construction Average Low Bid Unit Price*. Texas Department of Transportation. ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/bidprice/as1458.txt. Accessed March 10, 2011.

9. *Unit Bid History*. Washington State Department of Transportation. http://www.wsdot.wa.gov/biz/contaa/uba/bid.cfm. Accessed March 10, 2011.

10. Bahar, G. *Methodology for the Development and Inclusion of Crash Modification Factors in the First Edition of the Highway Safety Manual*. Transportation Research Circular E-C142. Transportation Research Board, Washington, D.C., 2010.

11. Miaou, S.P. *Measuring the Goodness-of-Fit of Accident Prediction Models.* FHWA-RD-96-040. Federal Highway Administration, Washington, D.C., 1996.

Appendix I. The Value of Non-CMF Research

1. Introduction

In a preliminary analysis report, the following statement was made: *"In the final account, research on road safety is in support of making practical decisions. The decision may be whether to implement some countermeasure or not to do so; to choose one degree of curve for a road instead of another; to coin a certain design standard and not an alternative to it; to adopt a plan or to reject it, to pass a piece of legislation or to drop it, etc. ... In all these cases rational decisions are influenced by information about what the safety consequences of the contemplated action might be. Information that makes the prediction of safety consequences possible is the product of research."* How to estimate the value of research about the safety consequences of some action was the subject of the first two preliminary reports. Inasmuch as its product is a Crash Modification Function or Factor it will be referred to as: <u>'CMF-research'</u>.

However, not all research in road safety is about the safety consequences of some action. As I wrote earlier: *"... one might undertake research into the relationship between some type of traffic conflict and accidents. The value of the resulting information is of the 'enabling' kind. It enables one to estimate the safety effect of a variety of actions (standards, devices, operational measures etc.) which otherwise would be either impractical or more costly to do. This type of research is one step removed from a specific decision. In this sense it is more fundamental in nature. However, even research that enables one to do research about the effect of decision is still linked to decision-making, albeit indirectly. The same argument applies to research into all surrogate measures (mental workload, driver simulators etc.)*

Similarly, consider research the aim of which is to enhance causal statistical modeling. This kind of research is also not linked directly to some specific decision. Nevertheless, one hopes that success in this line of research will enable others to better estimate of safety effect for a variety of causal factors. In this manner even more fundamental research eventually trickles down to making better decisions."

"*...one aim of the naturalistic driving studies in the Strategic Highway Research Program- SHRP2 is to better understand the causes of accidents. The hope is that such an understanding will lead to the formulation of better or novel interventions. This too has value. Thus, e.g., one may get a better handle on the extent and role of distraction and fatigue as causes of accidents and perhaps on the risk of driving in such states. If so, one will make better decisions about potential countermeasures. Thus, to the extent that the road from the naturalistic driving study (or the many other accident causation studies) to the discovery of interventions can be described, such studies too can be linked to decisions."*. I will call such research <u>'Fundamental'</u> (rather than 'basic', 'exploratory' or 'enabling'). Fundamental research makes the tools that help us to do CMF research, may help us to understand crash occurrence and prevention, and to identify promising interventions.

As shown in the first two reports, the task of assigning a monetary value to CMF-research turned out to be doable. In this (third) the task of assigning a monetary value to 'fundamental research' was addressed.. Fundamental research' is broadly defined and its boundaries fuzzy. A few specific 'fundamental research' topics will be considered to see where their value might come from. After the completion of these studies, a more general approach for assigning value to 'fundamental research' may emerge.

The value of research into the following three 'fundamental research' topics will be examined:

1. Research to define a good conflict.
2. The preparation of 'Artificial Realistic Data' to determine how reliable are the CMFs obtained by multivariate models for two-lane rural roads.
3. Estimating SPFs (for urban multilane road with more than 4 lanes).

2. Research to define a good conflict

2.1 About traffic conflicts

Traffic conflicts are events of some kind. What event will be considered a traffic conflict is a matter of definition. A good conflict definition has to have two properties:

Property 1. It makes it possible to estimate the rate of conflict occurrence cheaply and accurately;

Property 2. The ratio 'p' defined by equation 1 is nearly the same everywhere and at all times.

$$p \equiv P(\text{Accident}|\text{Conflict}) = \frac{\text{Expected accidents in time period T}}{\text{Number of conflicts during T}} = \frac{\mu \times T}{N}$$

$$\mu = \text{expected number of accidents per unit of time,}$$

$$T = \text{duration of a time period,} \qquad \mathbf{1}$$

$$N = \text{number of conflicts during T.}$$

Once research finds a good conflict definition and when the corresponding 'p' and VAR{p} are reliably estimated[32], the number of accidents expected on a unit during T can be estimated by the product $\hat{p} \times \widehat{N}$. This, in turn, allows for screening[33] and for CMF estimation, when doing so using accident counts is less practical. Another use of a good conflict definition is for safety diagnosis and treatment development. Because a well-defined conflict event is proportional to expected (target) accidents, one may hope that if a measure reduces the number of conflicts it will also reduce the number of accidents in the same proportion.

Screening, CMF estimation, diagnosis and treatment development are all linked to decision-making. In this manner research about traffic conflicts is in aid of decisions and its value comes from improving the quality of these decisions. We will explore how to determine the value of traffic conflicts research in a specific setting. The setting will be that of pedestrian-vehicle conflicts in crossings. Inasmuch as value comes from making better decisions, and decisions are based on CMFs, the narrow context will be that of using the conflict for estimating CMFs for Pedestrian Countdown Signals.

2.2 The value of a CMF for pedestrian countdown signals.

At this time not much seems to be known about the safety effect of replacing the usual Walk-Don't Walk signals by pedestrian countdown signals. One reason for this paucity of information is that accidents to pedestrians in crossings at signalized intersections are rare and reliable accident-based studies are difficult to do. It would be useful to have a good conflict definition for this purpose; one that would allow one to (1) cheaply collect information about the number of conflicts shortly before and after the

---

[32] Estimates will be denoted by ^.

[33] By 'screening' I mean the activities by which units are arranged in order of priority for safety-related interventions.

installation of pedestrian countdown signals, and (2) use the ratio of before and after conflicts to estimate the corresponding CMF.

The value of research about this CMF can be determined be the approach described in the first two reports. A précis of the approach is given below.

The decision is whether to replace the usual pedestrian signal by a countdown signal. To find the value of research about the corresponding CMF we need several pieces of information.

> <u>Factor 1:</u> What is the number of crosswalks at signalized intersections categorized by the expected number of pedestrian accidents/year.
>
> <u>Factor 2-components I and II:</u> To determine what is the break-even θ and the loss function we need:
>
> 'a'-the cost of an average pedestrian accident (at crosswalk of signalized intersection);
>
> 'c'-the annual cost of replacing the usual signals by countdown signals;
>
> 'r'- the limiting Benefit/Cost ratio.
>
> <u>Factor 2- component III</u>: We need the mean and variance of the two PDFs of θ. The first PDF pertains to what we know about the safety effect of replacing the usual pedestrian signal by a countdown signal. A competent colleague tells me that, at this time, no trustworthy information exists. If that is so, one could would assume that the mean of θ is 1.00 and its standard deviation is about 0.1. (A decrease or increase by more than 30% is unimaginable). The second PDF pertains to what is likely to be known after the conduct of the proposed research. As has been done earlier, based on what we now know, the best guess is to assume that the mean of θ will not change. The new research (conducted using the newly developed conflict definition for pedestrians crossing at signalized intersections) is intended to reduce the standard deviation of θ. By how much the standard deviation is likely to be reduced will depend on how much effort is required to collect conflict data and on how small is VAR{p}.

In sum, the value of the proposed research can be ascertained in the usual manner. However, it must be noted that the proposed research consists of two linked but separate parts. The first part is the development of the <u>instrument</u>; the search for a good conflict definition for pedestrian crossings at signalized intersections. The second part of the proposed research consists of using that instrument for reducing the uncertainty about CMF which pertains to the action of replacing the usual pedestrian signals by countdown signals. Thus, when the value of research is determined in 'the usual manner' it pertains to both parts together. For the first part (the 'fundamental' research) to have value, the second part (the CMF-research) must also be done. How then can value be attached to the fundamental research alone?

2.3 The main features of fundamental research

Before attempting an answer to the question of how to assign value to this fundamental research it is important to highlight its main feature. If one will succeed in defining a good conflict for pedestrian crossings at signalized intersections then the same conflict definition could be used for many other CMFs. Thus, e.g., one may want to know the CMF of prolonging or shortening the time allotted for the pedestrian phase; or one may need a pedestrian CMF for of altering the (vehicle) intergreen duration; or one may want to know how pedestrian safety will be affected by disallowing conflicting right or left turns, or one may wish to ascertain the safety effect of a crossing guard, of a publicity campaign, etc. It is also possible that the same good conflict definition identified in the first part of the proposed research can help with various CMFs at pedestrian crossings at un-signalized and mid-block intersections. These (pedestrian) CMFs may deal with the safety effect of illumination, stop line placement, provision of refuges and many the other decisions and interventions for which good CMFs are not available.

This is perhaps the main feature of fundamental research: that it will be of use in the enhancement of many different CMFs. Therefore the monetary value of fundamental research must somehow come from the monetary value of research about the many CMFs the precision of which can be enhanced by the use of the instrument.

The problem is that it is difficult to foresee all the future uses of an instrument. Just as it was difficult to foresee the future uses of the FARS or HSIS data bases when these were first set up or to foresee what will be learned from the SHARP2 data, so one cannot enumerate the future uses of a good pedestrian conflict definition.

2.4 The value of this research

We now return to the question of how to ascribe monetary value to the fundamental research about a conflict definition when tangible value is obtained only when CMFs are improved when instrument is used. To help us think clearly about the value of this kind of instrument (here the development of a conflict for pedestrian countdown signals) consider the hypothetical illustration in the tables below.

Table 38. Project priority without the conflict definition research

Project	Value	Cost	Value/Cost
A	50	1	50
B	100	4	25
C	7	0.5	14
D	5	0.5	10
E	49	7	7
...	...	...	...

Table 37. Project priority with the conflict definition research

Project	Value	Cost	Value/Cost
A	50	1	50
B	100	4	25
PC	10	0.5	20
C	7	0.5	14
D	5	0.5	10
E	49	7	7
...	...	...	...

In both tables the research projects (A, B, C, etc.) are ranked by how much value one gets per unit of research cost. The larger the monetary value one gets per unit of research cost, the higher the priority of that research project. If the conflict definition research was not done, getting a better CMF estimate for pedestrian countdown signal by relying of accident counts would be costly, perhaps impractical. This is why such a research project is not amongst the top-ranking projects of Table 38. However, if the conflict development project was done, and if it succeeded in defining a sufficiently good pedestrian conflict, then the pedestrian countdown signal CMF project (denoted PC) might be highly cost-effective as is shown by its rank in Table 37.

Suppose for now that we have a research budget of 6 units. With such a budget one would get 50+100+7+5=162 research value units without the conflict definition research (Table 38), and one would get 50+100+10+7=167 research value units if the conflicts research was done and was a success (Table 37). In this illustration, performing and succeeding in the fundamental research added 5 units of value. This is the source of its value.

What this illustration demonstrates is that the value of fundamental research is in increasing to cost-effectiveness of a research program. What CMF-research was costly or impossible without the instrument, may be cost-effective when it is done and succeeds. The more numerous are the CMF-research projects that make use of the instrument and are of sufficiently high priority to be funded, the larger is the value advantage of these CMF-research projects over the project bumped lower on the priority list, the larger is the value of that fundamental research.

This understanding suggests a defensible step-by-step way to estimate the value this kind of fundamental research.

- Create table A (similar to Table 38) in which only those CMF research projects are listed which can be done without the new instrument[34]. Plot a graph of cumulative research value on the ordinate against cumulative research cost on the abscissa.
- Create table B for those CMF research projects make use of the new instrument.
- Merge the two tables to create a new prioritized project list (similar to Table 37). Plot the same kind of graph as in Step 1.
- The difference between the ordinates of the two graphs at the abscissa that may be a realistic annual research budget is the annual value of the fundamental research, if it was a success.
- Multiply the value from step 4 by the probability that the fundamental research is a success.

While this five-step may be a defensible way for estimating the value of this kind of fundamental research, it is not an easy or practical one. The main difficulty is the need to create Table B (in Step 2). To do so would require the estimation of a monetary value for a potentially large number of different CMFs[35]. An attempt will be made (in section 0) to simplify the five-step while retaining its conceptual integrity. Another difficulty resides in step 5 in which one has to somehow estimate the probability of this fundamental research to succeed. This is linked with the question of how good has to be the conflict definition so that a conflict study can produce sufficiently good CMF estimates. Research about traffic conflicts has a long history. While some pedestrian conflict definitions have been suggested and used, it is not clear whether they are 'sufficiently good' for the conduct of CMF research. The clarification of these issues is the subject of the next section.

2.5 What standard error of a CMF, what conflict definition?

The analysis in this section will be as simple minded as is commensurate with the overall purpose, that of ranking research projects by priority. A somewhat more elaborate analysis can be found in Hauer and Gårder (1988). However, as that paper was examining the question of the validity of the traffic conflicts technique, not of CMF estimation, to have a more complete analysis additional work may be needed.

The story line is this: To estimate the CMF for the conversion from the usual pedestrian signal display to a countdown signal it is suggested to count the number of conflicts during equivalent[36] 'before conversion' and 'after conversion' periods at a set of crossings. Denote these counts by N_A and N_B where

---

[34] This will be generated anyway in order to rank CMF-research projects. However, it has to be available before the ranking of fundamental research can begin.

[35] E.g., a CMF of prolonging or shortening the time allotted for the pedestrian phase, a CMF for of altering the (vehicle) intergreen duration; a CMF for disallowing conflicting right or left turns, a CMF for using a crossing guard, a CMF for a walk-safe publicity campaign, etc.

[36] By 'equivalent I mean that the counts were conducted during the same hours of the day and days of week and that vehicle and pedestrian volume counts were conducted to allow adjustment for differences in exposure.

A and B stand for 'after' and 'before'. The CMF is defined as μ_A/μ_B and, using equation 1, it can be estimated by:

$$\widehat{CMF} = \frac{\hat{\mu}_A}{\hat{\mu}_B} = \frac{p_A N_A}{p_B N_B} \quad \textbf{2}$$

As noted earlier, for a conflict definition to be 'good', 'p' must be nearly the same everywhere and at all times. If it can be assumed the p_A and p_B are nearly the same then

$$\widehat{CMF} = \frac{\hat{\mu}_A}{\hat{\mu}_B} \cong \frac{N_A}{N_B} \quad \textbf{3}$$

However, if p_A and p_B are not close, then the ratio p_A/p_B in equation 2 may not be close to 1 and therefore the ratio N_A/N_B may be not be a good estimate of the CMF. To provide a quantitative measure of what may be considered 'good' I will assume that p_A and p_B come from the same probability distribution, one that has a variance of VAR{p}. The smaller is VAR{p} the better the conflict definition.

Now some useful results can be obtained. The numerator and the denominator in equation 2both have the form p×N. If p and N are statistically independent random variables then the variance of the product p×N is approximately $p^2VAR\{N\}+N^2VAR\{p\}$. In this expression VAR{N} reflects the fact that the number of conflicts counted may not be the same as the number of conflicts occurring. This difference is particularly important when observers have to decide whether a conflict occurred. Using the method of statistical differentials[37] and the expression for VAR{p×N} it can be shown that

$$VAR\{\widehat{CMF}\} \cong CMF^2\left(\frac{p_A^2 VAR\{N_A\}+N_A^2 VAR\{p\}}{(p_A N_A)^2}+\frac{p_B^2 VAR\{N_B\}+N_B^2 VAR\{p\}}{(p_B N_{AB})^2}\right)$$

The two summands inside the brackets will be roughly the same. To simplify I replace p_A and p_B by their average p, N_A and N_B by their average N, and $Var\{N_A\}$, $Var\{N_B\}$by their average VAR{N}. Now,

$$VAR\{\widehat{CMF}\} \cong 2CMF^2\left(\frac{VAR\{N\}}{N^2}+\frac{VAR\{p\}}{p^2}\right) \quad \textbf{4}$$

Numerical example:

Assume that conflicts are counted by simulation or by digital detection from videos and therefore VAR{N} is negligibly small. Assume further that we have a choice between conflict definition '1' for which we expect 1 accident in 100,000 conflicts with a standard deviation of ±0.2 accidents and conflict definition '2' with 10 accidents/100,000 conflicts with a standard deviation of ±1 accident[38]. Thus $p_1=10^{-5}$, $VAR\{p_1\}=0.04\times10^{-10}$, while $p_2=10^{-4}$ and $VAR\{p_2\}=10^{-10}$. A before and after traffic conflicts study is to be done at crossings where the usual pedestrian signals will be converted to countdown signals[39]. If the CMF for the conversion is about 1, and when conflict definition '1' is used, $VAR\{\widehat{CMF}\} \cong 2\times0.04\times10^{-10}/10^{-10}$ or $\sigma\{\widehat{CMF}\} \cong \sqrt{0.08} = \pm0.28$. If conflict definition '2' is used, $VAR\{\widehat{CMF}\} \cong 2\times10^{-10}/10^{-8}$ or $\sigma\{\widehat{CMF}\} \cong \sqrt{0.02} = \pm0.14$

---

[37] See Hauer (1997), p.69-70.

[38] These accident-to-conflict ratios are based on Baker (1972)

[39] If these crossings tend to have 3 pedestrian accidents/year during the period of the day during which conflicts will be counted then, with definition 1 we expect 3×100,000×2/365=1644 conflicts in a 'before' or 'after' period; with definition 2 we expect 3×100,000×2/(10×365)=164 conflicts in a 'before' or 'after' period.

When writing about Factor 2-III in section 0 it is speculated that the standard error of the CMF for countdown signals cannot be larger than about 0.1, less than what can be obtained by either of the two conflict definitions. There is not much point in doing a conflict study if the result is less accurate than an educated guess. Thus, one lesson from this example is that if conflicts are to be used to estimate CMFs one has to find a conflict definition with a sufficiently small VAR{p}. How small must be the VAR{p} for a conflict definition to be useful?

If conflicts are counted with negligible error then equation 4 can be rewritten as

$$\sigma\{\widehat{CMF}\} \cong 2CMF\frac{\sigma\{p\}}{p} \qquad \mathbf{5}$$

That means that if one aims to estimate a CMF with a standard error of not more than ±X% then the standard error of 'p' must be not more than about ±(X/2)%. This is a tall order. To illustrate, conflict definition '1' had a 'p' of 1 accident/100,000 conflicts. If the CMF is about 1, and we want the CMF estimate obtained by a conflict study to have a standard error of, say, 0.05 (not a very ambitious goal) then we have to be sure that the standard error of 'p'[40] for conflict definition '1' is less than 2.5% of p, i.e., 0.025/100,000.

What is the chance that the proposed research will find a conflict definition with a small-enough σ{p}? This question has to be answered for step 5 in section 0. The basis for the answer is knowledge of the history of research on such matters and the ideas of the research proposal. If, e.g., the research proposal was based on automatic interpretation of images then, in my opinion, there is about a 50% chance of success.

By now the necessary elements are in place to tackle the original question.

2.6 The value of finding a good conflict definition for pedestrian crossings.

Suppose that someone proposes a research project the aim of which is to develop a good pedestrian conflict definition. The budget of the proposed research is based on the promise to find a definition for which $100\times\frac{\sigma\{p\}}{p} = \pm 2.5\%$ so that (assuming that VAR{N} is negligible) the standard error of estimated CMFs would be about ±0.05. The question is what is the annual value of this research?

It was stated earlier that that the main feature of fundamental research is that it may be used for many actions, interventions and the associated CMFs. Several CMF's were discussed that would benefit from a good conflict definition for pedestrian crossings and noted that the many potential uses of this instrument are difficult to foresee. The previous section described a coherent but less than practical approach to the valuation of fundamental research. The main difficulty was the onerous task of estimating the $-Value of many CMFs. In addition, judgment was required to guess at the chance of successfully developing the instrument (and what the research budget might be).

To simplify the five-step procedure requires replacing computations by plausible approximations and judgment. To preserve the conceptual integrity of the five-step, the questions below need to be answered:

1. What will be average value/cost ratio of the research projects that make use of the instrument and of the research projects that will be displaced by these from the priority list?

[40] This is not the place for explaining how σ{p} is to be estimated. Suffice to say that one has to obtain accident and conflict counts for many units. Each accident-conflict pair is a data point. The variation of the data points around the regression line (through the origin) that remains after accounting for the randomness in accident counts and the sampling error in conflicts can be used to estimate σ{p}.

2. If the fundamental research succeeds, how many CMF-research projects that make use of the instrument will be annually in amongst the funded projects?
3. What is the chance of success in developing the instrument?

Numerical Example:

Suppose that the value/cost ratio of the projects that make use of the instrument is about 1.5 times that of the projects which they displace; that the value/cost ratio of the displaced projects is 10/1; and that the average cost of a research project is $50,000/annum. Suppose further that if the instrument development succeeds we expect to see annually 3 research projects that make use of the instrument on the 'funded projects' list. With these assumptions, the value of the displaced projects is 3×10×50,000=$1.5 million/year and the value of replacing these by projects that make use of the instrument is (1.5-1)×$1.5 million=$750,000 per year, if instrument development succeeds. If the chance of success in the instrument development research is 50% the expected annual value of this research is 0.50×$750,000.

This example shows how the computation can be made up is a few simple elements. Any divergence of opinion that may arise will now be about one or more elements, not about the judgment as a whole. Still, the question is how the requisite judgments about these elements can be made?

To assess by how much larger is the value/cost ratio of the projects that make use of the instrument than that of the projects displaced by it (1.5 in the example above) one has to do the value/cost analysis of one or more new projects. This is what was done in the two tables of section 0. Thus, e.g., once the CMF-research projects are ranked and the value and cost are computed for a conflict study of pedestrian countdown signals, the value/cost ratio difference for this kind of project can be calculated and considered indicative of what is obtainable in similar CMF-research projects.

To get an idea of the value/cost of the displaced project (10/1 in the example above) one has to look at the ranked list of CMF-projects and pick a ratio from the last projects that might be funded considering a yearly safety research budget.

The most difficult guess is that of how many projects of the CMF-research list might be displaced every year by projects which the instrument renders more cost effective. If one can list at least N projects which all promise to have value/cost ratios that are larger than those projects now on the CMF-ranked list that would be funded, one should be able to venture and opinion.

2.7 Section 2. Lessons, Issues and observations

It is possible to assign monetary value to this FR. Research the purpose of which is to define a good pedestrian conflict is 'fundamental research' (FR). FR has value because the instrument will facilitate the conduct of cost-effective CMF research[41]. The question was whether it is possible to assign a monetary value to FR the aim of which is to develop a good pedestrian conflict. It is possible to do so.

Can one make the monetary value computation practical? The computation of the monetary value of research about this instrument requires considerable effort. One has to compile a list of CMFs the standard error of which can be reduced by the use of the instrument; one has to provide the logic and the analysis which makes it possible to determine by how much the use of the instrument can reduce the standard error of the CMFs on the list, and for each CMF on the list one has to determine the value of this

[41] It may also have value if it leads to insight about the process of accident occurrence or to the identification of fruitful countermeasures. I have not examined these sources of value.

reduction and the cost of research in the usual manner. This effort may be deemed too large if its only purpose is to assign priority to research about the instrument. Some ad-hoc shortcuts may be suggested by which the computation can become practical.

Research ‘Idea’ vs. “Project’. To assess the monetary value of this FR will require the exercise of judgment. One will have to form an opinion about the chance of finding a good conflict, about the number of CMFs for which it will be useful, about the excess value of these CMF-research projects over those that are displaced by them etc. This raises the question of what needs to be known before the importance of a potential research project can be rationally contemplated, and who should provide the requisite information. This question is a facet of the ‘research idea’ versus ‘research project’ issue discussed in our recent conference call.

To illustrate, someone might suggest the research idea that : “We should do research the aim of which is to define a good pedestrian conflict because there are many actions and interventions that impact on pedestrian safety but estimating the associated CMFs by relying on accident data is not practical”. As a ‘research idea’ this is entirely reasonable. Should it go into the prioritization hopper in this form or should its proponents have to do some preparatory spadework?

The proponents can legitimately have an opinion about the merit of such a research idea. Persons of a select group, after having the idea explained to them, can also form an opinion, even vote about its priority. However, if the ‘preparatory spadework’ is not done, it will always remain unclear what was the basis of their opinions. This was the likely reason why previous attempts at road safety research prioritization were deemed unsatisfactory and why NCHRP17-48 came into being. The raw gut feeling of experts may not be a sufficient basis to justify the expenditure of public money on research. Even in a mostly computation-based procedure expert opinion may be required about some items, but information about the number of crashes that could be affected by a CMF, about its break-even value, about how many standard errors separate it from the mean CMF etc. should be common ground. The aim is not to eliminate judgment but to replace it by facts and logic where possible.

We now know that to have an informed opinion about the attraction of this research idea one should be clear about: The actions and interventions and the CMFs that could be improved if we had a good pedestrian conflict; about the number of target accidents for each such action or intervention and how well their CMFs are now known; about how good must be the conflict definition for it be capable of improving the CMF estimates; about what are the chances of defining a sufficiently good pedestrian conflict, etc. Once this kind of information is available it can be used to form opinions and/or as input into computation. We conclude therefore that those who funded NCHRP 17-48 and wanted us to propose a rational research prioritization scheme implied that research should be not prioritized on the basis raw expert gut feeling; that some spadework about the influential facts and factors should be prepared before prioritization is attempted.

Our mandate is to deal with research prioritization. However, it may not be possible for us to entirely avoid dealing with the broader issues of (a) what must be known before the importance of a research idea or project can be assessed, either qualitatively or by computation and (b) Who should provide what information and at what stage of the process.

We will have to explain and educate. A major goal in this project is to develop a computational procedure for prioritizing research. While doing so it is important to emphasize an understanding of what factors need to be considered and how. This understanding is important even when a full-fledged computation is not used. One must expect that the activity of prioritizing research will take place at many levels and organizations. Therefore thought should be given to an education and technology transfer function, that of explaining what needs to be considered and how to persons who need this knowledge.

FR increase the monetary value of CMF-Research. The approach for assigning value to the kind of fundamental research discussed in section 0 is embodied in the five-step of section 0. The central idea is that use of the new instrument will bring into the research priority list CMF-research that would otherwise not be there. By doing so we will get more value for research dollars spent. This increase is the value of the new instrument.

The monetary value of the FR is proportional to the number of CMF-Research projects that use it. The main characteristic of an instrument such as a conflict definition is that it can reduce the uncertainty about the CMFs of several actions or interventions. The value of such an instrument is proportional to the number of CMFs that can be improved by it. Therefore, to judge or to quantify the attraction of research about an instrument of this kind, one must consider the number of CMFs to which it is likely to be applied and the number of projects which it is likely to bring into the priority list.

Determining whether the instrument will be useful. As was shown in section 0, a conflict definition will reduce the variance of a CMF only if conflicts can be counted cheaply, accurately, and if VAR{p} is smaller than a definable target value. It would be unwise to spend research money on developing an instrument if there is little chance that it will be capable of reducing the variance of CMFs. It follows that before considering the merits of an fundamental research it is necessary (and in this case was possible) to determine the features of the instrument that will make it useful. Once these features are ascertained one can judge the prospects for its success.

Unplanned benefit. When starting on this project hoped that the decision analytic framework will prove useful. It was not clear what the obstacles will be, whether they can be surmounted, and what will Be the challenges. Struggling with the topic of section 0 resulted in providing the rudiments a theory of how conflicts can be used for CMF estimation. This theory helps to provide useful guidance for future research about traffic conflicts; a kind of unplanned benefit.

Better research as a byproduct of Value Analysis. At the beginning there was the idea that it is possible to assign value to research when its purpose is to improve practical decisions making. This idea is now bearing some expected and some unexpected fruit. Whether the expected fruit – the computation of the monetary value of research - will be adopted remains to be seen; this depends, in part, of your collective opinions. The fruit that, for me, is unexpected is the emerging insight that the usefulness of road safety research efforts might be enhanced if the conduct of research was preceded by an explicit monetary value analysis. The monetary value analysis provides a discipline of thought by which the proponent of the research and its sponsor will assure themselves and others that the research is worthwhile and doable. It will give the proponent and the sponsor the confidence that money and effort are well spent and furnish the standard of quality by which the research results will be judged.

3. The value of research to create an ARD[42] generation tool

For many actions it is impractical to estimate CMFs by a before-after study. This is why most of what we know about the safety effect of alignment, curvature, sight distance, lane width etc. comes from comparisons between sites that differ in the feature of interest. The problem is that no two sites differ in only that feature and therefore the attribution of how they differ in safety to the feature of interest is problematic. Many believe that by fitting a function of many variables to cross-section data one can tell how the variables of interest affect safety. They use CMF estimates obtained by such means to guide professional practice. Others doubt that one can obtain usable CMF estimates from cross-section data by

[42] **A**rtificial **R**ealistic **D**ata

the statistical techniques that are now available. If their skepticism is well founded, much of what is now in the HSM, in the CMF clearinghouse and in Elvik's Handbook would have to be revised.

The ARD is intended to be a touchstone, a way to resolve this dispute, an engine for progress. The intent is to create artificial but realistic data sets to be made available to modelers whose task will be to discover the causal effect of some variables of interest which is known only to those who generated the data. Once several modelers will attempt to discover the causal effect of some such variables it will become clear to what extent they succeeded. It may also become clearer which modeling approaches are promising and, perhaps, how statistical modeling could be improved.

The research about a pedestrian conflict definition discussed earlier in section 2 was said to be 'fundamental'; it aimed to create the 'instrument' by which various CMFs could be more efficiently estimated. That instrument was only one step removed from CMF-research. Its value came from the potential of placing more value-efficient projects near the top of the research priority list. The research that leads to the creation of an ARD generation tool to be discussed here also aims to bring forth an instrument. The purpose of this instrument is to evaluate and improve another instrument –statistical modeling- that is then used in CMF-research. Thus, the ARD research is two steps removed from CMF-research.

Where does the value of the ARD generation tool come from? Suppose that the ARD generation tool has been created and ARDs given to modelers for CMF estimation. Two outcomes can be envisioned.

a. It is possible that we will find that the resulting CMF estimates are approximately unbiased and that their standard error 's' is about what we now think it is[43].

b. It is also possible that the resulting CMF estimates are biased and therefore likely to have large root-mean-square error[44] (RMSE).

Should outcome (a) materialize nothing would change in our valuation of CMF-research. Therefore there would be no value to the effort to create and ARD generation tool and using it in modeling. Should outcome (b) materialize one can expect two consequences.

The first consequence of outcome (b) is that we will know the RMSEs of those CMFs that are based mostly on multivariable regression. Because these RMSEs are likely to be large, the value of research about the corresponding CMFs may be much larger than we now think it is[45, 46]. With these revised values of research we will check whether, with what we now know about study design and with the modeling methods now used, some new research projects about these CMFs will climb to the top of the priority list.

---

[43] A third possible outcome might be that the standard error is of the CMF estimates is substantially less than what we now think it is (see Appendix for a description of how 's' is now estimated). As this outcome is unlikely to be the source of much value, I will disregard it.

[44] Until now the standard error was used (in its meaning of estimate of standard deviation) to describe the accuracy of a CMF estimate. Here I change to root-mean-square-error because it is possible that the CMF estimates obtained by multivariable regression for the kind of data that can be measures and is available suffers from a systematic bias.

[45] I describe how we now estimate the standard error of regression-based CMF in section 0.

[46] With outcome (b) the expected value of perfect information of research about the CMFs now based on multivariable regression is certain to increase. However, whether EVII will also increase will depend on whether we can come up with better study designs and/or modelling methods.

If they do, then the value of the work invested in creating and applying the ARD generation tool will be, as earlier, due to the increased value of the CMF-research for a given research budget.

The second consequence of outcome (b) will be the realization that some important CMF estimates are poor and, as a result, the decisions based on these CMFs have a good chance of being wrong. This will provide the impetus for research that aims to improve the instruments by which one can estimate CMFs from cross-section data. If these instruments can be improved they will be later used in research to reduce the RMSE of such CMFs. CMF-research projects that were not feasible before the methodological improvements may now climb into the top region of the research priority lists. Thus, the value-giving chain is that work on the ARD generating tool will lead to improved methods for CMF estimation from cross-section data which, if successful, will led to high value CMF-research that will replace lesser value projects in the priority list.

The corresponding flowchart is in Figure 30. The green boxes are research activities, projects and programs, the yellow boxes show items that contain value generated by CMF-research and the red boxes are for outcomes that have no value. The components will next be described that make up the value of the ARD-related research.

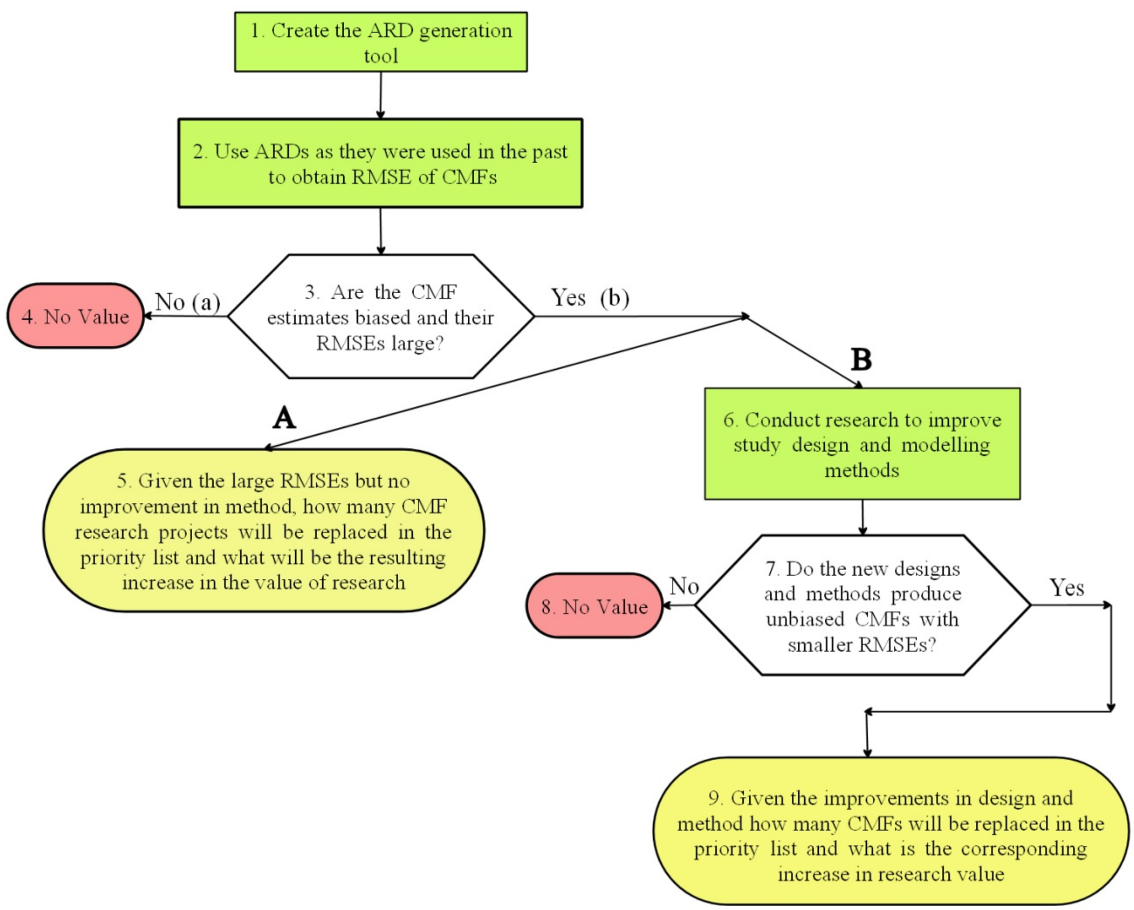


Figure 30. ARD Flowchart

Whether the outcome will be No (a) or Yes (b) cannot be said. If (a) materializes then VOI=0 as shown by item 4 in the figure. Therefore,

$$\text{VOI=P(outcome is b)×(VOI | outcome is b)} \quad \mathbf{6}$$

The (VOI | outcome is b) is made up of two parts. One part (A) is the value of research about those CMFs based mainly on cross-section data that, using study design and modeling methods now available, will make it to the top of the priority list because their RMSE is larger than we thought. Call it 'Part A'. The other part is the value of research about the CMFs that are based on cross-section data that, using *improved* future methods will make it to the top of the priority list. Call this 'Part B'. Whether the methods can be improved and by how much they will reduce the RMSE is now unclear. Thus,

$$\text{VOI= P(outcome is b)×(VOI | outcome is b) =} \quad \mathbf{7}$$

$$\text{= P(outcome is b)×[Part A + P(methods can be improved and RMSE reduced)×(Part B)]}$$

I would give outcomes (a) and (b) an even chance and the probability that the methods can be improved so that the RMSE is substantially reduced a more than even chance, perhaps 70%. If so,

$$\text{VOI= 0.5×Part A + 0.35×Part B} \quad \mathbf{8}$$

Several observations follow. First, inasmuch as no one can know these probabilities it is already clear that use of judgment is unavoidable. Second to get the value in item 5 (Part A), one has to develop the ARD generation tool and also to apply it in the manner indicated in item 2 of Figure 30. If eventually the benefit of the ARD research is to be compared to its cost (such as when it comes to ranking by priority) the cost has to be of items 1 and 2 together. It follows that, at this time, it is difficult to determine how to assign value to the 'develop ARD generation tool' project alone.

Third, doing the two projects in items 1 and 2 will yield more benefits than is captured by Part A (item 5). Without first doing 1 and 2 one cannot get to the benefit in item 9 (Part B). So that investing in the research of 1 and 2 is associated with the entire benefit of item 5 and with part of the benefit in item 9. It follows that one cannot assign value to item 1 alone nor can it be ranked; items 1 and 2 must be considered as one research project. The value of research 1&2 could be the value of item 5 + a portion of the value in item 9, say, in proportion to cost of 1&2/cost of 1&2&6. This ad-hoc rule is not attractive because, if the research in 6 is not undertaken, the value in 9 will not materialize.

These complications, so it seems, are characteristic of fundamental research. There is a sequence of research actions and a related sequence of research values all linked with a set of outcome probabilities. Here the complications are a reflection of the fact that the ARD project aims to create an instrument which is to be used to improve another instrument which, in turn, can then be applied in CMF-research. There seems to be only one defensible way to compare benefits and costs: compare the cost of 1+2+6 to the benefits of 5+9 (weighed by the appropriate probabilities as in equations 7 and 8.

The next questions are whether it is useful to estimate the values of 'Part A' and Part B', whether it is possible to do so, and, if yes, how this can be done. These questions are discussed in sections 0 and 0 below.

3.1 Part A: The value of knowing the RMSE of regression-based CMFs.

If the ARD generation tool was available then one could get a more reliable estimate of the RMSE of regression-based CMFs than what is now available. To illustrate how, suppose that the current CMF for 'grade' comes from multivariable regressions, and that the standard error of that CMF is now listed as 's'. We can use the ARD to produce data of the same kind as that on which the current CMF was based. To generate this data we would use a CMF for grade that is known to those who prepared the ARD but not to those who will use it for estimating the CMF by multivariable regression. The ARD is then given to an analyst whose task is to estimate that CMF. The analyst will run a multivariable regression and tell us what is the estimated CMF (and the t-statistic of the corresponding regression parameter). Thus, we now have one true CMF and one estimate of this CMF. The same procedure can be repeated with several ARDs and analysts. As a result we will have several differences between true and assumed CMF. From these we compute the RMSE with which this CMF can be estimated by now available methods. It can also be compared to the $s=s_{ideal}\times MCF$ (see footnote 44. In this manner we will determine the correspondence between the two for the 'road grade' CMF. Of course, the same procedure, data, and multivariate regressions can be used for the CMFs of all the variables in the regression (lane width, shoulder width, curvature, etc.)

Two conclusions follow. First, as noted earlier, for the benefit of the ARD generation tool to materialize, the ARDs must have been used by the modelers. Therefore when comparing benefits to costs, one must consider also the cost of doing the regression modeling projects in item 2 of Figure 30. Second, that part of the value of the ARD research which is discussed in this section - the value of knowing the RMSE of regression-based CMFs - is similar to that discussed in the preceding section: namely, that some projects now on the priority list might be replaced by other projects with higher value per unit of cost. The value of the ARD research would then come from the increased value of new CMF-research done using the current methods of study design and modeling.

To estimate this value one has to know:

1. What will be average value/cost advantage of the research projects that will enter the annual priority list over those projects which they replace if we will know the RMSE but without advances in study design or regression modeling methods.
2. How many such projects will there be?

It is not clear how these estimates can be produced in some quantitative way. The only feasible option seems to be for informed experts to discuss and then to provide their best guess. Thus, Part A in equations 7 and 8 would be based entirely on judgment.

The question may be asked whether there is advantage in making separate judgments on each building block of equations 7 and then doing the arithmetic of combining them, instead of making one composite guess about the entire VOI on their left-hand side. Questions of this kind must have been asked by others. Thus, e.g., when estimating the number of persons in a theatre, will one do better by a glance to guess how many rows and seats per row there might be or casting a glance at the entire hall and guessing on that basis? Other disciplines may have answers to this kind of question. It is likely that the more clearly specified are the components of an issue, the easier it is to venture an informed guess. This is why I lean towards the use of the logical framework in Figure 30 and the decomposition into building blocks which are later assembled into equations.

3.2 Part B: The value CMF-research using improved methods

Should it turn out that CMF estimates which are based on cross-section comparisons and were obtained by currently available modeling techniques are very unreliable (the Yes or (b) branch out of item 3 in Figure 30), we will be inclined to search for better study designs and improved modeling techniques (item 6). This fundamental research effort, if successful, will lead to much CMF-research. Such CMF-research will have value and may make it to the top of research priority lists by replacing other projects with lesser value per unit cost. I called the value of this research: 'Part B' (item 9 in Figure 30).

Now the value-giving chain begins with the ARD generation tool and the program of giving ARDs to researchers. This is followed by work to show that using the methods by which the current CMFs were estimated one gets large RMSEs. If so, then there must be a program of research to find better study designs and modeling methods for extracting CMFs from cross-section data. If that program is a success then there will be many actions for which the CMF-research will have high value and low cost. These will enter, perhaps dominate, the research priority lists for some time and replace other projects of lesser value/unit cost.

The costs are of items 1, 2, 6 + the cost of the CMF-research. The value is that of replacing on the priority list some lesser value/unit cost CMFs with higher value/unit cost CMFs. To estimate this value one has to give answers to the same two bullets as in section 0. Namely, how many such CMFs are likely to be on an annual list and what their excess value is likely to be. Discussion by expert and collective judgment will be required.

3.3 Section 3. Lessons, Issues and Observations

A graph is needed such as Figure 30. As shown in Figure 30, the ARD tool does not lead directly to CMF-research. To get to the first source of value (item 5), another piece of fundamental research must be completed. The general lesson I draw from this is that when the 'instrument' does not enable CMF-research directly (as was the case with the pedestrian conflict definition) the value of that instrument emerges only from a joint consideration with other pieces of fundamental research. If so, to contemplate the cost and value of fundamental research it is helpful and necessary to clarify the linkages and probabilities by a graph similar to Figure 30.

Which way can we judge better? In CMF-research, it was possible to rely mostly on data and computation. In the conflict-definition project reliance on data and computation, while possible, was not practical. In the ARD project it is clear that one will be guided mostly by judgment. The question is whether judgment is better when the linkages are laid out as in Figure 30 and one is passing judgment about several clearly articulated building block or when one attempt to judge cost and value without such decomposition. I believe there is merit to decomposing, structuring and articulating. (It is likely that projects such as SHARP2 and the Truck Causation Study would be a better if something like Figure 30 was done at the planning stage).

Collecting suggestions provided by others is not enough. In our project (NCHRP 17-48) we are assembling suggestions about what research projects (ideas?) should be prioritized. Doing so is important. However, the list will be very incomplete. The reason is that the people making these suggestions think in terms of gaps, needs, and current issues. To illustrate, it is unlikely that anyone will suggest research into the CMF of, say, lane-width in spite of the fact that past research indicates (at the time it was done) that 11.5' is safer than 12'. It would be cheap to make lanes narrower if doing so will improve safety. However, the suggestion to do research on lane width will not come up. Similarly, it is not likely that someone will suggest research into the safety effect of horizontal curves on urban roads. Everyone continues to assume that what we know about rural two-lane roads applies to urban roads too. There is a hint that this is untrue. If so then in urban areas we may be building large radius curves for no good reason. However, the issue will not come up from the sources from which we gather our suggestions. The question is whether it is up to us to add research ideas to the list?

And so, one issue we ought to reflect on, and perhaps make recommendations about, is the question of how a research topic comes to be considered for prioritization. While suggestions from various quarters are one legitimate channel, other channels need to be considered. The channel being brought to our attention is a direct result from our framework. We have a long list of CMFs in the HSM and elsewhere and we have estimates of their standard errors. We should take one CMF after another and see how high added research about it would place on the priority list.

Value depends on cost. To rank projects we will need an estimate of research cost. The cost of research depends on what accuracy it promises. The dollar value of a proposed research also depends on accuracy and hereby on cost. We mentioned this issue in one of our conference calls. It should not drop out of sight.

3.4 Appendix

At this time the standard error of a CMF that comes from a multivariable regression is obtained in two stages (see, Bahar, 2010). First one computes the 'ideal'[47] standard error (s_{ideal}) the magnitude of which depends mostly on how good and extensive are the cross-section data. The next step is to account for the potential deficiencies of the multivariable regression by multiplying the s_{ideal} by a 'Method Correction Factor'[48] (MCF). That is, the standard error of a CMF derived from a multivariable regression on cross-section data is the product $s=s_{ideal}\times MCF$. This ad-hoc procedure may contain the right ingredients. However, the magnitude of both the s_{ideal} and of the MCF is in doubt. The s_{ideal} is based on the assumption that all important variables are in the model and that the model equation truly represents the phenomenon. Neither assumption is true. The MCF is just a guess. In addition, one finds often finds that the regression parameters of the same variable but obtained by different researchers differ widely[49]. One also finds that CMFs obtained from before-after studies often do not support those estimated from multivariable regressions on cross-section data. For these reasons one may suspect that when's' is estimated by the HSM procedure it may be widely off the mark.

4. Estimating SPFs (for urban multilane roads with more than 4 lanes).

A recent meeting (AASHTO, August 2010) dealt with the question of research project priority. After an exchange of opinion the following list was established by vote:

---

[47] When results of regression modeling are published authors often describe the statistical precision of parameter estimates by $s_{parameter}$ of by giving a t-statistic for that parameter. One can calculate $s_{parameter}$ by:$s_{parameter}$= Parameter Estimate/t-statistic. To illustrate, suppose you have Accident frequency = $\alpha(AADT)^{0.9}(\text{Lane width})^{-0.7}$ and $t_{statistic\ \text{for lane width parameter}}$=-0.82. That means that $s_{\text{lane width parameter}}$=-0.7/-0.82=0.85. (If the authors did not describe the statistical precision of the relevant parameter, it is suggested to use t-statistic=0.5.) Suppose that we want to know the CMF for lane widening from 11' to 12'. The corresponding ratio of accident frequencies is $(11/10)^{-0.7}$=0.93; this is the estimate of the CMF. If we used parameter estimate+1s (-0.7+0.85=0.15), we would obtain $(11/10)^{0.15}$=1.01; if we used parameter estimate -1s (-0.7-0.85) we would obtain $(11/10)^{-1.55}$=0.86. If so, the CMF±1s_{ideal} for this lane widening is 0.93±(1.01-0.86)/2. That is s_{ideal} of this CMF is ±0.075.

[48] From Bahar (2010, p.11)

TABLE 4 Method Correction Factors for Regression Cross-Section Studies

Key Study Characteristic	Method Correction Factor
All potential confounding factors have been accounted for by variables of the regression in an appropriate functional form	1.2
Most potential confounding factors have been accounted for by variables of the regression in an appropriate functional form	1.5
Several important confounding factors were accounted for, and functional form is conventional	2
Few variables used and functional form is questionable	3
Severe lack of information published regarding study data study and findings	5

Continuing the example from footnote 47, if the regression accounted for several potential confounders and used the conventional log-linear form the standard error of this CMF would be estimated at ±0.075×2=±0.15.

[49] In spite of the common practice of changing the variables or model form if a counterintuitive regression parameter materializes.

- SPFs for Urban multilane, greater than 4 lanes[50]
- Bikes, pedestrians, roadside (data collection and analysis)
- CMF application when multiple ones are used
- SPFs for Roundabouts
- SPFs for Urban collectors/local roads

The estimation of several Safety Performance Functions is prominent in the list. I chose the first of these to be the last case to be examined in this report.

The premise of our prioritization procedure is that research has value if it improves decision-making. Therefore, to link research to value, one must be clear about the decisions which the proposed research will support and improve. Here the question is what are the decisions which require the use of SPFs in general and, specifically, the SPF for urban roads with more than four lanes.

The search for value in this case may seem artificial. It is likely that the main reason for which the three SPF made it to the top of the AASHTO list is that they are needed to plug gaps in the first edition of the HSM. One could perhaps argue that the HSM would be more widely used if it was more complete and that such wider use would improve safety-related decisions. However, such an argument does not amount to much more than asserting that plugging an SPF hole in the HSM is very important. This raises the question whether the ranking of all research projects should be on the basis on an estimate of value or, alternatively, whether the priority of some projects should be based on other indices of importance. The answer to this question will depend, partly, on whether progress can be made towards assigning value to this and similar research projects.

4.1 What are SPFs used for?

Part C of the HSM (AASHTO 2010) - Predictive Method - provides a method for estimating the expected average[51] crash frequency of a site. The method is said to be "most applicable when developing and assessing multiple solutions for a specific location" (AASHTO 2010, 1-3). By the Predictive Method the number of crashes per year expected at an average site ($N_{predicted}$) is the product of three factors. The first factor is the number of crashes expected at an average site with pre-specified features (N_{SPF}). This is provided by the SPF. The second factor is made up of a product of CMFs. This is a bridge between the pre-specified features implied by the SPF and the features of the site at hand. The third is a calibration constant used to account for differences between jurisdictions and time periods. In short,

$$N_{\text{predicted}} = N_{\text{SPF}} \times (\text{Product of CMFs}) \times (\text{Adjustment for time and jurisdiction}) \qquad 9$$

When for some site crash counts are available, one can estimate the expected number of crashes for that site ($N_{expected}$) by combining the $N_{predicted}$ and the crash count ($N_{observed}$) using the EB approach (AASHTO 2010, 3-24). When crash counts are not available one assumes that $N_{expected}=N_{predicted}$.

Thus, an SPF is instrumental in estimating the number of crashes expected at a site. If an SPF for that kind of site is not available, and when the need to have an estimate of $N_{expected}$ for this site arises, one must base the estimate on crash counts only (if available). Thus, the question of what decisions would be improved if an SPF was available hinges on knowing what decisions require the knowledge of $N_{expected}$.

The following common activities require knowledge of $N_{expected}$:

---

[50] From the minutes: "Dan Turner: biggest decision that States are making is to expand urban/suburban 4 lanes to 6 or 8 lanes; very expensive ROW. Vote taken – multilane is a high priority."

[51] The HSM uses the phrase 'expected average' frequency. What is meant by 'average' is that it is for an average site of some kind, not a specific one.

Screening. Here one estimates the $N_{expected}$ of all units of a network. Thus knowledge of the SPF for urban multilane road with more than 4 lanes might improve the screening of such roads. The task will be to assign value to this improvement.

Diagnosis. Whether knowledge of $N_{expected}$ will lead to improved diagnosis and prescription of remedy is a moot question. Therefore, I am inclined not to pursue this part of the 'research value'.

Assessment of future safety consequences. To estimate what will be the safety consequences of some treatment or design change at a site, one needs to have an estimate of $N_{expected}$ and multiply it by the corresponding CMF.

CMF research. When estimating what was the safety effect of some treatment in the past, in particular when regression-to-mean is a threat, one may need to have an SPF for the reference population. It is doubtful that the general-purpose SPFs in the HSM are sufficiently specific for this purpose and therefore will not pursue this source of value[52].

Thus, in what follows, will be an attempt to assign value to the project of estimating an SPF for urban multilane roads with more than 4 lanes because (a) it may improve decisions about 'network screening' and (b) improve the 'assessment of future safety consequences'.

4.2 What value of the SPF[53] comes from improved network screening?

The purpose of network screening is to identify sites the safety of which can be cost-effectively improved. The usual assumption[54] is that the potential for safety improvement is proportional to either $N_{expected}$ or to the difference between $N_{expected}$ what is considered normal for similar sites. For both one needs an estimate of $N_{expected}$. Old practice relied on crash counts and crash rates for that purpose. More recent practice is to use EB estimates. The advantage of EB is that it dampens fluctuations which are due to the randomness of crash counts. This advantage is most evident when the ranking is weighted by severity[55]. Thus, one may assume that with the SPF available, the sites selected for diagnosis and perhaps treatment might lead to more cost-effective projects than if screening was done on the basis of crash counts alone. If so then the value of having the SPF is the difference:

$$\begin{array}{l}\text{Safety benefit of treatments at sites selected using EB (and the SPF) –}\\ \text{Safety benefit of treatments at sites selected using only crash counts}\end{array} \qquad 10$$

We are assuming that the cost of the treatments would be the same in both cases. The amount of benefit (with or without an SPF) will be proportional to the number of sites treated. Three pieces of information are needed to assign a value to the expression in equation 10.

---

[52] Frank Gross disagrees with this opinion thinking that it may be better to use a less than perfect SPF than to live with an RTM bias. When this is correct depends on the extent of the RTM bias and the degree to which the SPF deviates from the appropriate reference group. D. Lord explored this issue in a recent paper. Besides, he choice is not always that of using a bad SPF or none at all.

[53] For urban multilane roads with more than 4 lanes.

[54] The problem is that there is almost no evidence to suggest that sites identified by either criterion yield more cost-effective treatments than would sites selected by other means.

[55] Without EB estimation one or two fatal crashes can lift any site to the top of the list

1. The first is an estimate of how many treatment projects that are triggered by the screening of urban multilane roads with more than 4 lanes are done per year. This can be ascertained by making some inquiries. Denote this number by n_{trt}.
2. The second piece of information necessary is the safety benefit and cost of an average project of this kind. This too, perhaps, can be obtained by phoning knowledgeable practitioners. Denote the safety benefit b_{avg} .
3. The last, and the most difficult-to-get piece information, is how much more benefit one may expect at sites selected using the EB method than at sites selected on the basis of crash counts. I am not aware of research that can answer this question[56]. If I had to venture a guess, it would be 5%-10% because it is expected that projects selected by EB to be less vulnerable to the randomness inherent in a few severe crashes. Denote the percentage by i_{EB}.
4.

With these three pieces of information in hand the annual value of having an SPF which is due to more effective screening would be:

$$\text{Annual VOI} = n_{trt}\times b_{avg}\times i_{EB} \qquad \mathbf{11}$$

4.3 What value comes from better assessment of future safety consequences?

Consider a project to add lanes to a certain four-lane urban road. In this context there are two plausible sources of value to the proposed SPF research. The first source is related to the decision whether or not to add lanes. The second source of value is in the design-decisions for the expanded road. Next is a discussion of the two seriatim.

The addition of lanes is usually motivated by capacity, not by safety considerations. Still one of the relevant considerations is perhaps how safety would change were lanes added. One may think that, were the SPFs for four a more-than-four lane roads available, to predict the safety consequences of lane additions by comparing the ordinates of the two SPFs at the future traffic flow(s). This, however, is not a realistic scenario. The reason why lanes are to be added is that without the added capacity the road could not carry the future flow. One cannot read of the four-lane road SPF what the number of accidents would be for a flow it cannot carry. To predict the number of accidents if lanes were not added one would have to examine network-wide changes in traffic and thereby in safety. We conclude that knowing the SPF for urban roads with more than 4 lanes will only seldom help in the estimation of the future safety benefits of lane additions. This is why we will disregard this source of value.

The second source of value comes from making better design decisions for the to-be designed road. To estimate the annual safety benefit of some design decision (e.g., whether and how to illuminate, what should be the lane width, how to accommodate access, etc.) one has to use the form $N_{expected}\times(1\text{-CMF})$. Since we are now speaking of a future road, $N_{expected}=N_{predicted}$ as given by equation 9. This brings us back to the framework developed in the first report (Appendix C). The main difference is that in the first report (Appendix C) we were concerned with the uncertainties of the CMFs (the θ) while here the concern is about the uncertainties surrounding $N_{expected}$. In the notation of the first report (Appendix C), $N_{expected}=\mu$.

Suppose, e.g., that the question is whether to go with 10' or 11' lanes. As before, the annual benefit is $\mu(1-\theta)a$ and the annual[57] opportunity cost is rc. Now μ is the number of target accidents expected with 10' lanes during a representative year of the project life; θ is the CMF for going from 10' to 11' lanes; 'a' the

---

[56] Nor do I know of much research about whether screening leads to more cost-effective projects than other means of selection.

[57] Because traffic will change over the lifetime of the project μ should represent the annual number of target crashes for a representative year near the project mid-life

average cost of a target accidents, ‘c’ the annual cost of having the wider lanes; and ‘r’ the limiting benefit-cost ratio.

$$\text{From } \mu(1-\theta)a = rc, \rightarrow \mu_b = \frac{rc}{(1-\theta)a} \text{ is the breakeven value of } \mu \qquad 12$$

If $\mu<\mu_b$ one should choose 10’ lanes, otherwise 11’ lanes should be considered. The chance of deciding in error arises because we cannot be sure what μ will be. We can predict what μ will be either by an extrapolation of accident history (call it μ_{exp}) or, more accurately, by using a traffic projection and the to-be-modeled SPF (call it μ_{SPF}). The two predictions have probability distribution functions $F(\mu_{exp})$ and $F(\mu_{SPF})$. We are assuming that both methods of prediction are unbiased and that the variance of the prediction that relies on the SPF is smaller.

If we predict that $\mu<\mu_b$ when, the opposite will turn out to be true, we would have made an erroneous decision to go with 10’ lanes when 11’ lanes would have been the better choice. Conversely, if we predict $\mu>\mu_b$ when, the opposite will turn out to be true, we would have made an erroneous decision to go with 11’ lanes when 10’ lanes would have been the better choice. In either case, if an erroneous decision is made it has a cost associated with it. As in the first report (Appendix C), there is a loss function L(μ), except that now it is a function of μ, not of θ. Using the loss function and L(μ) and the PDFs of μ the one can compute the expected loss without and with the SPF being available. The reduction in expected loss will then be the value of having the SPF for the purpose of deciding what the lane width should be.

The choice of lane width is not the only design decision to be made in this road-widening project. When re-designing the road for adding lanes, several design decisions will have to be made. Every such decision would be better if μ was predicted using the SPF (& the traffic flow prediction). Therefore, for the value of having an SPF (for urban roads with more than 4 lanes) is the sum of the corresponding EVIIs over all relevant design decisions.

Furthermore, the specific road widening project I focused on is not the only such project to be carried out in a year. It follows that the value of having an SPF for the purpose of assessing the future consequences of the design decisions associated with adding lanes to four-lane urban roads is given by:

$$\text{Annual VOI} == \sum_{\text{all such projects in a year}} \left(\sum_{\text{all design decisions in such projects}} \text{EVII}_{\text{design decision i}} \right) \qquad 13$$

The simplification of equation 13 is, as before, the product:

(Average annual number of lane addition projects) ×
(Average number of design decisions in a lane-addition project) × **14**
(Average EVII for a design decision)

4.4 Section 4. Lessons, issues and observations

Reaffirming the principle. Research about the SPF of urban roads with more than 4 lanes was on the top of the AASHTO priority list, perhaps because this is one of the gaps in the HSM. The question is whether this is a sufficient reason for giving this SPF research high priority or, whether all research projects should compete for priority in terms of their estimated value per unit cost?

It is not easy to come up with a convincing argument why plugging a gap in the HSM is important except to argue that doing so will improve decision-making. If improved decision-making is the goal, then one should be able to say how the availability of this SPF will make for better decisions. This is exactly what has been done. Once it is clear how some research can improve decision-making, one can give it value. The conclusion is that plugging a gap in the HSM (or any other gap) is in itself not a valid consideration for priority; priority derives from value vs., cost considerations, and value comes from improved decision-making.

In this, we are only reaffirming the principle that one should spend public money on research in road safety if it produces value by allowing better decisions to be made on how public money is spent. If we lose sight of this principle and allow the use of considerations that cannot be linked to such value, then we are in danger of opening the floodgates to the same kind of difficulties that plagued prioritization attempts in the past.

It is entirely possible that the priority of a research project in road safety should be influenced by considerations other than their value and cost. However, proponents of such additional consideration criterion should be able make a convincing case which is not rooted in benefit to decision-making.

The importance of the 'first step'. In the first report (Appendix C: box, page C-6) it was said that "The first step of any inquiry about the value of a suggested research project is to be clear about what decisions might be improved by the information which that research projects intends to provide." This dictum proves its importance repeatedly; especially so when it comes to fundamental research. In section 0 I asked: what is this SPF to be used for? The answer identified four common activities that may require knowledge of the SPF (Screening, Diagnosis, Assessment of future safety consequences, and CMF research.). After consideration, it was judged that two of these are unlikely to benefit from the availability of the SPF. Others may indentify additional activities and perhaps differ in their judgment of relevance. The point is that judgment cannot be eliminated and that one should claim the prioritization procedure is fully objective and quantitative. The merit of the aforementioned 'first step' is in the discipline which it imposes. One must think through and describe the possible sources of value, be explicit about their relevance, and thereby make it possible for others to discuss, agree, or modify.

Judgment and decomposition into factors. One of the sources of value stemming from having an SPF for urban roads with more than four lanes is that it might improve the safety outcome remediation based on the screening of such roads. Equation 11 tells that in this case research value is a product of three factors. Estimates of the first two could perhaps be based on inquiries. The third factor (the percent increase of treatment benefit if sites selected using the EB method rather than using only crash counts) is, at present, pure speculation. Clearly, in this case, the estimate of the value of having an SPF is based largely on judgment. Therefore one must ask whether there is merit in the decomposition of research value into three factors. Could one not form just as good a judgment without decomposition into factors?

It is thought that decomposition into factors makes it easier to form an opinion. To illustrate, the first factor listed in equation 11 is an estimate of how many treatment projects are triggered annually by the screening of urban multilane roads with more than four lanes. At present I have no idea. It would be difficult to make a global judgment about the value of having this SPF available for screening without knowing whether there is much screening of these roads and whether there are few or many treatment projects as a result. After making some inquiries, one will be better informed. A similar case could be made for the other two factors. It seems that merely writing down the important factors and clarifying how these enter into the computation imposes a discipline and framework that makes substantive discussion possible.

Judgment, quantification and prioritization process. The previous report stated the principle that research priority should be based on research value and cost, and that research value comes from better decision-making. For CMF-research the value could be computed from information that was mostly data based. Although some inputs required judgment, the general impression was that of a data-driven computation. This is not true for fundamental research. The principle of basing research priority on value and cost is retained, and the discipline which comes from having to say how research results will improve decision-making is even more prominent. However, reliance on data for the quantification of the identified factors is reduced and often replaced by opinion and judgment. To illustrate, while one may find data about 'miles of un-illuminated freeways' or the 'CMF for rumble strips' one will not find data about 'the number of remedial treatments triggered by the screening of multilane urban roads' or about 'the increase in remedial treatment effect when screening makes use of an SPF'. The realization that research prioritization cannot be strictly data driven, and that judgment must play a role, has implications about the prioritization process.

The process should consist of two parts: (a) preparation by technical staff and (b) prioritization by a small committee. The role of part (a) is to prepare the information for part (b). This information will, for each project, describe in what way the research can enhance decision-making (directly or indirectly), provide the data needed for computing research value and cost, list the judgments required and suggest what they might be, and compute the value and cost. Members of the committee will discuss the information provided and amend it as they see fit. After a few rounds of (a) and (b), closure may be expected.

<u>The value of safety prediction research.</u> The first source of the SFP value was from better screening. The second (and main) source of the SPF value comes under the rubric of 'improved ability to assess future safety consequences; in the present context, the ability to consider safety in the various design decisions arising in lane-addition projects for urban four-lane roads.

When thinking about how to estimate this value it was realized that there is a very close parallel between research the purpose of which is to reduce that uncertainty about the θ (the CMF-research) and research the aim of which is to reduce the uncertainty about μ, the number of accidents predicted to occur at some future time. After all, the safety benefit of implementing the treatment of design decision is the product μ(1-θ). The two variances, VAR{μ} and VAR{θ}, play identical roles in determining the cost of making incorrect decision. Research has the aim of which is to reduce VAR{μ} 'Prediction research'.

It became obvious that the procedures we used to assign value to CMF-research are very similar to what has to be used to assign value to research that enables us to better predict the number of accidents. While, up to now we classified research projects as 'CMF-research' and 'Other-research' now we can split off the 'Other' category all those research projects the aim of which is to improve our ability to predict how many accident we expect at some future time. This category will consist not only of research projects associated with various SPFs; it will entail also projects to improve prediction methods, to enhance data quality and availability etc. This will peel off a large number of projects from the 'Other-research' category and make it possible to assess their value by a largely computational procedure.

Recall that to express the safety benefit in $-terms, the product μ(1-θ) had to be multiplied by 'a' – the average cost of a target accident. This value too is surrounded by uncertainty and thereby another category of research projects can be peeled off the 'Other-research' group. In short, many more project types can be brought into the orbit of computational value determination.

5. Summary and Conclusions.

The premise is that safety research has value if it makes for better decisions. The monetary value of research is the amount by which its results can increase the net benefit[58] of safety-related projects. In the first two reports I wrote about how to estimate the monetary value of CMF-research. Inasmuch as CMFs are directly linked to decisions about whether to implement some action, getting to the monetary value of CMF-research was relatively straightforward.

[58] Net Benefit is the difference between the benefit and cost of projects.

In this report addressed how monetary value can be assigned to research that is variably called 'basic', 'enabling', or 'exploratory'. As it was not clear how to come to grips with this broad research category, it seemed best to select a three specific research topics[59] hoping that after the completion of these études some general insights will emerge. The 'Lessons, Issues and Observation' for each of the études are in sections 00, and 0. This section will discuss the more general insights.

5.1 Kinds of research

We started out thinking about two kinds of research; CMF-research as opposed to the catch-all 'Non-CMF-Research' into which we put 'basic', 'enabling', or 'exploratory' research. It now seems that a better distinction can be made.

Research about a CMF has value because it helps to determine the safety benefit of a future action. The safety benefit of a future action is:

$$\begin{gathered}\$\text{Safety Benefit of Future Action} = \\ =(\text{Expected Future Target Crashes})\times(1\text{-CMF})\times(\text{monetary value of a Target Crash})\end{gathered} \quad \mathbf{15}$$

When thinking about the value of the SPF research (see Section 0 in this report) it was realized that its main use is to predict the *Expected Future Target Crashes*. Research that allows us to better predict the expected future target crashes plays the same role in determining the $Safety Benefit as research about the CMF. The same can be said for research about the *monetary value of target crashes*. Thus, while we initially focused only on CMF-research as linked directly to decisions, we should have thought so of all three factors above.

It makes sense to call research that aim of which is to reduce the uncertainty about any of these three factors that make up the safety benefit as Applied research.). All other safety research, and especially that which creates instruments that help us do applied research, is "Fundamental Research" (FR).

5.2 The Value Tree.

"Fundamental Research" creates instruments that make applied research projects feasible, cheaper, or more accurate. Thus, e.g., the development of a pedestrian conflict makes it feasible to estimate a CMF for Pedestrian Countdown Signals; estimating a SPF allows us to better predict relevant target accidents; the ARD may lead to better techniques of modeling and thus lead to better SPFs and CMFs.

Value can be assigned to applied research projects because these reduce the expected cost of making bad decisions. Unless an 'instrument' can be used for applied research projects it has no source of value. Thus, applied research projects are the fruit that grows on the Fundamental Research Value Tree. Two such Value Trees are shown in Figure 31. One for Instrument=Pedestrian Conflict, the other for Instrument=ARD. The FRs in the value trees are shown as square and diamond boxes, branches that yield no fruit end in red ovals, and the applied research fruit is shown as yellow ovals.

[59] The three topics were: 1.Research to define a good conflict; 2.The preparation of 'Artificial Realistic Data' to determine how reliable are the CMFs obtained by multivariate models for two-lane rural roads; 3.Estimating SPFs (for urban multilane road with more than 4 lanes

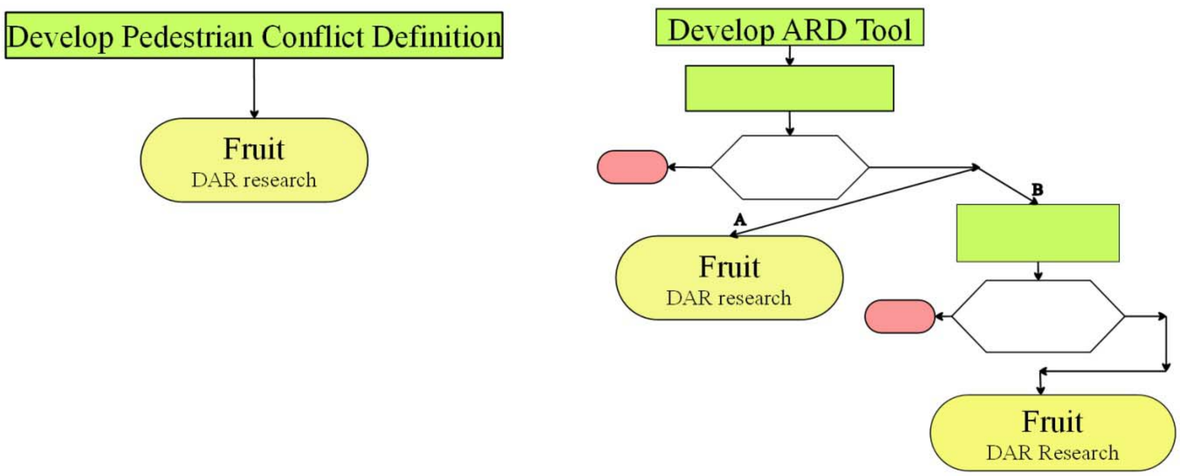


Figure 31. Value trees

The Pedestrian Conflict Definition FR is just one step away from the applied research projects (e.g., that of getting a CMF for pedestrian countdown signals). In this case, for any given research budget one can determine what would be the value of applied research projects 'with' and 'without' a suitable Pedestrian Conflict Definition. The difference between these two values is the value of the Pedestrian Conflict Definition project, were it to succeed.

As seen on the right-hand-side of Figure 31, the development of the ARD tool is the first of several FR projects; it leads to two different applied research fruits; and is several FR steps away from them. I do not see at this time how the value from these fruits can be apportioned to the various FR projects[60]. What can be done at this time is to consider the entire value tree as a *program* of FR projects and attribute the increase in the value of the fruit jointly to all the required FR projects.

5.3 Estimating the value of fundamental research

The question was how to attach value to research about an instrument or set of instruments. As indicated above, without the instrument(s) we can create a list of Applied Research Topics) that is arranged in the order of declining Research Value/Unit Research Cost; call it the 'Without Instrument(s) List'. With the instrument(s) available one would be able to create a different prioritized list; call is the 'With Instrument(s) List'. To make the 'With Instrument(s) List' one would take the 'Without Instrument(s) List' and insert into it some research projects made attractive in terms of Research Value/Unit Research Cost due to the availability of the instrument(s). This is why, for any given research budget, the 'With Instrument List' will have more total research value than the 'Without Instrument List'. The difference in total research value for a given research budget is the monetary value of research about the instrument(s).

The 'Without Instrument(s)' list has to be created in any case and the way for doing so is clear. The task here is to foresee what might be the value and cost of the research projects made possible by the instrument(s), and what are the chances of the FR projects to succeed. While one could produce a list of foreseeable applied research projects that make use of the instrument(s) and determine the value and cost of each, the list would be incomplete and long. This is why doing so is not practical. The use of judgment cannot be avoided neither here nor when assessing the chance of success in developing the instrument(s).

[60] It is possible that with more thought a rational procedure could be found.

The formation of judgment requires both work and experience. Thus, e.g., to form an opinion about the value and cost of some applied research project made feasible by the instrument(s), one may have to rely on prior experience with the value analysis of similar projects or, in the absence of such experience, to select a few representative applied research projects and do a full value analysis. Similarly, to form an opinion about the chance of success, one must be familiar with the history of relevant research.

5.4 Which DAR projects have high value?

To form an opinion about the value of applied research projects made feasible by new instrument(s) it may help to briefly discuss the question of which applied research tend to have high value. The value of applied research is the product of two factors:

$$\text{Applied research value} = (\text{Value for a typical project in which the applied research results are used}) \times (\text{No. of such projects}) \quad \textbf{16}$$

The first factor in equation 16 is large when:

A. Project is costly;
B. Target crashes in a project are many;
C. The 'Mean CMF' is close to the 'Break-Even CMF';
D. The uncertainty about the CMFs[61] is large;
E. New research can substantially reduce the standard deviation.

The second factor in equation is large when there are many projects (miles of road, intersections, etc.) in which the results of the applied research can be used.

What determines the applied research value is the interaction of these considerations. I do not have, at this time, a back-of-the-envelope calculation to replace the value analysis procedures described in the first two reports.

5.5 Information to aid judgment

It is not possible to reduce the process of research prioritization to a wholly computational exercise. The reasons are several: the data for the computation is not always available; for Fundamental Research projects the valuation of many applied research projects would require too much effort; one cannot possibly envision all future applied research projects for which some instrument will be useful; it is the essence of research that its results are not known beforehand and its chance of succeeding is uncertain, etc. It follows that the task of deciding on a research program ranked in order of priority will require judgment.

What is possible is to aid the exercise of judgment by providing it with a framework, discipline, and useful facts. Doing so limits the need for judging research projects as a whole, makes it easier to have a fruitful exchanges of views about well-defined subject matter, and provide for a smoother way to a consensus that is replicable[62]. This assumes that the task of prioritization will be performed by a group of qualified persons- a Ranking Committee- whose aim is to research consensus after discussion. Therefore

---

[61] It is not the uncertainty about the Mean CMF, the values listed in the HSM or the Clearinghouse that counts. What counts is how uncertain we are about the CMFs in future implementations. The CMF in a future application comes from a probability distribution which has a standard deviation. It is this standard deviation that measures our uncertainty about that the CMF will be in an application. This standard deviation is entirely different (in concept and magnitude) from the standard error of the estimate of the Mean CMF.

[62]. Consensus is replicable if when different groups are given the same candidate research projects they are likely to produce similarly ranked prioritized lists.

the question is how the information about candidate research projects is to be prepared for Ranking Committee so that consensus is replicable and easy to reach.

The information for the Ranking Committee has to be prepared by Technical Staff. Thus, for each applied research project, the Technical Staff will prepare the input items required for Jim's spreadsheet. They will provide a brief description of how each input was generated and a list of assumptions made. The Technical Staff will examine the relationship between the cost of the proposed applied research and corresponding value.

For each FR project or program the Technical Staff will prepare its Value Tree and explain it to the Ranking Committee. For each fruit in the value tree the staff will prepare a description of the applied research projects which the fruit may contain, their number, and an estimate of their typical value/unit cost. The technical staff will provided estimates for the costs and chances of success for all FR elements of the Value Tree.

When I explored the value of a pedestrian conflict definition it is necessary to write down some equations about how conflict counts would facilitate the estimation of a CMF, how good must be the conflict definition for the CMF to be useful etc. (see sections 0and 0). Only with this preparatory work completed could I examine what might be the cost of the proposed research, what could be its value, and what its chances to succeed. This kind of activity, when necessary, may also be a part of the preparation. In short, replicable prioritization requires preparation.

The need for preparation is, perhaps, what distinguishes between a 'research need', a 'research idea', and a 'research project'. A 'research need' is a statement about what we need to know so as to better carry out our safety management responsibilities. One cannot say which of two research needs is more important without ascertaining their monetary value and cost. Thus, prioritization can take place only after the 'Need' was made into a 'Project'. 'Needs' cannot be prioritized; only 'Projects' can. Similarly, a 'research idea' is a suggestion about how to do something novel or how to do it better. To say which of two research ideas should have priority one has to be able to describe the monetary value and cost of both. Thus, prioritization can take place only after the 'Idea' was made into a 'Project'. 'Ideas' cannot be prioritized; only 'Projects' can.

5.6 Collecting suggestions about research needs and ideas

What is the list of suggested research ideas (needs, gaps) which we are to arrange in order of priority? It will come from a variety of sources. It is suspected, however, that most suggestions will be made by people who think in terms of gaps, needs, and current issues. As discussed in section 0 the suggestions to do research on the CMF for, say, lane width or horizontal curve radius will not come up. And yet, were these suggested, they might make the top of the list. Should we not make recommendations about how research topics should come up for prioritization? One source of research projects is particularly important. We have a long list of CMFs in the HSM and elsewhere and we have estimates of their standard errors. We should take one CMF after another and see how high added research about it would place on the priority list.

5.7 Reaffirming the principle

The principle guiding this work is that the spending of public money on (safety) research is justified by value by which research results make for better decisions about how large amounts of public money are spent on managing road safety. If we lose sight of this principle and allow the use of considerations that cannot be linked to such value, then we are in danger of opening the floodgates to the same kind of difficulties that plagued prioritization attempts in the past.

6. References

AASHTO (2010). Highway safety manual. 1st edition. American Association of State Highway and Transportation Officials. Washington, D.C.

Bahar, G. (2010).Methodology for the Development and Inclusion of Crash Modification Factors in the First Edition of the Highway Safety Manual. Transportation Research Circular E-C142. Transportation Research Board.

Baker, W.T., (1972). An evaluation of the traffic conflicts technique, Highway Research Record 384, Highway Research Board, National Academy of Sciences, Washington, D.C.,pp.1-8.

Hauer, E. and Gårder, P., (1986). Research into the validity of the traffic conflicts technique, Accident Analysis and Prevention, Vol. 18, No. 6, 471-481.

E. Hauer, (1997). Observational before-after studies in road safety. Pergamon.

7. Glossary

<u>Acronyms</u>

ARD Artificial Realistic Data

CMF Crash modification factor or function

EVII Expected Value of Imperfect Information

EVPI Expected Value of Perfect Information

MFC Method correction factor

PDF Probability Distribution Function

RMSE Root mean square error

VOI Value of Information

<u>Notation</u>

a Average cost of one target accident

b_{avg} The safety benefit of an average project that was triggered by screening.

c Annual cost of countermeasure implementation

$F(\theta)$ Probability Distribution Function, $P(\Theta \leq \theta)$

i_{EB} By how many % would b_a increase is screening was done by an EB method that is based on the SPF

$L(\theta)$ Difference between the foregone benefit and the opportunity costs of implementing the countermeasure.

n_{trt} Number of treatment projects that are triggered by the screening of urban multilane roads with more than 4 lanes are done per year.

N Number of conflicts during T

$N_{expected}$ Number of crashes expected to occur at a site

$N_{observed}$ Number of crashes observed (reported) at a site

$N_{predicted}$ Number of crashes per year expected at an average site with known features

N_{SPF} Number of crashes expected at an average site with pre-specified features

P $P(\text{Accident}|\text{Conflict})=\frac{\text{Expected accidents in T}}{\text{Number of conflicts in T}}$

$P(X|Y)$ Probability of event X if event Y occurred

r The Limiting benefit-cost; how many \$ of benefit can the last invested \$ generate

s_{ideal} Standard error of CMF due only to random error is data

T Duration of a time period

<u>Greek Letters</u>

θ Accident (Crash) Modification Factor (or Function)

θ_b That θ at which the benefit-cost ratio=r, the limiting benefit/cost ratio
μ Expected number of target accidents/year.
μ_b Breakeven value of μ
μ_{exp} Expected target accident projection based on extrapolation of past crash history
μ_{SPF} Expected target accident projection based on traffic prediction and the SPF

Appendix J. Sources for Obtaining Research Topics and Issues

Source of Potential Research Topics/Issues	Mechanism for Extracting Topics
Applied Research	
Research needs, as defined in the *Toward Zero Deaths: a National Strategy on Highway Safety* effort being led by AASHTO and FHWA.	Review of Plan and review of topic-area white papers (Project to develop white papers is led by Team Member Hugh McGee)
Knowledge gaps identified in the *Highway Safety Manual* (HSM)	At end of each Chapter in Part D of the HSM, there is a section on treatments where more research is needed. In addition, several CMFs in the HSM are not supported by details about their source studies such as exposure, target crash, site and roadway specification, area type, etc. These were also considered and developed for different scenarios of applications (i.e., two lane-rural roads, urban arterials, etc.)
Knowledge gaps identified in work plan for 2nd edition of the HSM (NCHRP 20-07(279))	Contact Dr. Dan Turner, project PI and 17-48 oversight panel member
High-priority knowledge gaps identified in NCHRP Report 617, *Accident Modification Factors for Traffic Engineering and ITS Improvements*	Review of report (Team Members Council, Srinivasan, Hauer and Bonneson are authors of this report.) Note that this project included a survey of State DOT safety engineers for research topic ideas. Responses were from 34 States.
Research Problem Statements from key TRB committees	Problem statements from committees are located at http://rns.trb.org/. We will contact key committees not represented in the list of statements.
Unfunded high-priority NCHRP projects	Obtain from TRB staff (Chris Hedges or Chuck Niessner)
Input from FHWA's Exploratory Advanced Research (EAR) program	Contact David Kuehn (david.kuehn@dot.gov), EAR program manager, and Kunik Lee (Kunik.lee@dot.gov), EAR program coordinator in Safety R&D.
Input from FHWA Office of Safety and Office of Safety R&D on unfunded needs	Contact Ray Krammes (FHWA Safety R&D and Project Panel Liaison) and Mike Griffith (FHWA Office of Safety) for information and additional contacts.
Input from FHWA Safety R&D ITS Safety Program on unfunded needs	Contact Greg Davis (gregory.davis@dot.gov), ITS Safety Program Manager

Research topics identified in FHWA's *Pedestrian Strategic Safety Plan (draft)*	Obtain report from author (and 17-48 PI) Charlie Zegeer
Topics identified by the National Highway Research and Technology Partnership	Review of *Highway Safety Research: A National Agenda (*2002), including "Highway Infrastructure and Operations" section of Appendix. http://onlinepubs.trb.org/onlinepubs/rtforum/safety_agenda_july_2001.pdf
AAA Foundation for Traffic Safety's *Traffic Safety Issues of the Future: A Long Range Research Agenda*, (2006)	Review of report – http://www.aaafoundation.org/pdf/FuturesReport.pdf
Knowledge gaps identified in Special Report 292 review of white papers	Review Appendix B, *Comments on Individual Projects Described in White Papers Commissioned by the Federal Highway Administration*
Research needs identified in FHWA's Highway Safety Information System (HSIS) project for potential internal research (unpublished)	Review listing prepared by HSIS project staff, including Team Members Srinivasan and Council
SHRP2 prioritized listing of run-off-road and intersection research topics	Review draft report: *S02 Integration of Analysis Methods and Development of Analysis Plan. Phase 1 Report*. University of Iowa (2009) (Team member Council has access to the report.)
Knowledge gaps identified by international research organizations	Contact staff at each of the following – • Australia and New Zealand – Austroads; Monash University Accident Research Centre; VicRoads; Land Transport New Zealand • Canada- Transport Canada; Traffic Injury Research Foundation (TIRF) • France - INRETS (Institut National de Recherche sur les Transports et leur Sécurité) The French National Institute for Transport and Safety Research • Germany - BASt (Bundesanstalt für Straßenwesen) Federal Highway Research Institute • The Netherlands - SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid) Institute for Road Safety Research • Norway- TØI (Transportøkonomisk institutt) Institute of Transport Economics • Sweden – VTI (Statens väg-och transportforskningsinstitut) Swedish National Road and Transport Research Institute • United Kingdom- Department for Transport and Transport Research Laboratory • Multi-national sites – OECD (Office of Economic Development), International Transport Forum/ Joint Transport Research Centre), Word Health Organization, others.
Research needs	Contact: Kim Eccles, VHB

identified by Panel for pooled fund study on low-cost treatments	
Basic Research	
AAA Foundation for Traffic Safety's *Traffic Safety Issues of the Future: A Long Range Research Agenda*, (2006).	See above
Research Problem Statements from key TRB committees	See above
FHWA plans for research in Exploratory Advanced Research Program (EARP)	See above
FHWA unfunded ITS Safety research	See above
SHRP 2 listing of research topics	See above
Inputs from international research organizations	See above
Knowledge gaps identified in Special Report 292 review of white papers	See above
Research needs identified in (draft) TRB Circular, "*Theory, Explanation, And Prediction In Road Safety: Identification Of Promising Directions and a Plan For Advancement.*" This concerns a TRB/FHWA workshop on ""Future Directions in Highway Crash Data Modeling" held in 2008.	Obtain from team member Jim Bonneson who organized and chaired the workshop and authored the Circular.

Appendix K. Potential stakeholder-reviewers for the proposed National Agenda research topics

<table>
<tr><th>Potential Stakeholder/Reviewer</th><th>Potential Contact Mechanism</th></tr>
<tr><td colspan="2">Applied Research</td></tr>
<tr><td>Project Panel</td><td>Direct contact</td></tr>
<tr><td>AASHTO:
• Standing Committee on Highway Traffic Safety
• Standing Committee on Highways:
  o Subcommittee on Traffic Engineering
  o Subcommittee on Design)
• Standing Committee On Research
• Subcommittee on Safety Management
• Standing Committee for Performance Measurement (looking at safety)</td><td>• Contact AASHTO (Kelly Hardy) and determine best method for contact</td></tr>
<tr><td>FHWA:
• Office or Safety R&D
• Office of Safety
• Experimental Advanced Research Program
• Office of Operations and Office of Safety R&D IntelliDrive staff</td><td>• Contact through Project Panel Liaison Ray Krammes
• Contact Mike Griffith
• Contact David Kuehn (david.kuehn@dot.gov), EAR program manager, and Kunik Lee (Kunik.lee@dot.gov), EAR program coordinator in Safety R&D.
• Contact Greg Davis (gregory.davis@dot.gov), FHWA Safety R&D ITS Safety Program Manager</td></tr>
<tr><td>State Highway Engineer (who will pass it on to appropriate staff, we hope)</td><td>List serv for State Highway Engineers</td></tr>
<tr><td>State DOT Safety Engineers</td><td>Obtain list serv from Project Panel member Tom Welch</td></tr>
<tr><td>University Research Centers:
• University Transportation Centers
• Other university safety research centers
• Key individual researchers</td><td>• Obtain email list of contacts from RITA
• Develop list based on team knowledge
• Develop list based on team knowledge</td></tr>
<tr><td>National Committee on Uniform Traffic</td><td>List serv for the National Committee on Uniform</td></tr>
</table>

Control Devices (NCUTCD) Research Subcommittee	Traffic Control Devices (NCUTCD) Research Subcommittee
Institute of Transportation Engineers (ITE) Traffic Engineering Committee and Traffic Safety Council	List serv for the Institute of Transportation Engineers (ITE) Traffic Engineering Committee Contact with ITE staff
Insurance Institute for Highway Safety	Unclear at this point since their roadway safety expert, Richard Rhetting, no longer works there. Contact Adrian Lund, President, and ask him to forward it.
AAA Foundation for Traffic Safety	Contact Peter Kissinger, President and CEO (202.638.5944)
American Traffic Safety Services Association	Contact Executive Director
FMCSA	Contact Ken Leonard, Research Director.
NHTSA	Contact FHWA Liaison Ray Krammes to find out if there is a key “roadway research liaison” in NHTSA. Otherwise, we will work with him and others to determine the most appropriate NHTSA contacts (e.g., for pedestrian and bike safety, ITS, older drivers, etc.)
LTAP Coordinators	Contact Marie Walsh and Keith Knapp
Basic Research	
Project Panel	Direct contact
AASHTO – *We are requesting assistance from the Project Panel here. Who would be appropriate AASHTO reviewers of potential basic research issues?*	Assistance from Project Panel on appropriate contacts.
TRB Committees – Note that the following are potential contact committees. Other may be added based on research topics in the master list: <u>Key Basic Research Committees</u> • ABJ80 Statistical Methodology and Statistical Computer Software in Transportation • ANB20 Safety Data, Analysis and Evaluation <u>Other Possible Basic Research Committees</u> • ANB25T Task Force on the Development of the Highway Safety Manual • ANB10 Transportation Safety Management • ANB75T Task Force on Roundabouts • AFB10 Geometric Design • AFB20 Roadside Safety Design • AFB30 Low-Volume Roads	We would contact TRB Staff Representative for these committees to determine (1) if they would be appropriate reviewers for *infrastructure and operations safety research*, and (2) whether other committees should be added. We would then work through the Committee Chairs.

• AFB50T Task Force on Context Sensitive Design/Solutions (CSD/CSS) • AHB30 Vehicle-Highway Automation • AHB55 Work Zone Traffic Control • AHB60 Highway/Rail Grade Crossings • AHB65 Operational Effects of Geometrics • ANF10 Pedestrians • ANF20 Bicycle Transportation • ANF30 Motorcycles and Mopeds	
FHWA: • Office or Safety R&D • Office of Safety • Experimental Advanced Research Program • Office of Operations and Office of Safety R&D IntelliDrive staff	See above.
University Transportation Centers and university research centers	See above
List of attendees to TRB/FHWA Workshop on "Future Directions in Highway Crash Data Modeling"	List is in Appendix B of TRB (draft) circular, "*Theory, Explanation, And Prediction In Road Safety: Identification Of Promising Directions and a Plan For Advancement.*

Appendix L. NCHRP Unselected RNSs Which Were Submitted in September, 2011

There were 73 RNSs not selected for funding in 2011; their links and titles are shown below. These RNSs were considered by the project team when assembling the list of all potential RNS topics for prioritization.

Unselected Problems:

1. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-A-01_377.aspx
   Transportation Investments and the Economy: Broadening the Scope and Enhancing the Methodology

2. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-01_378.aspx
   Combining Data Collection for State DOT's Existing Management Systems and HPMS Submittals

3. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-02_379.aspx

   Using Pavement Management Systems to Improve Decision Making
4. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-05_380.aspx

   Solutions to Minimize the Impacts of Roadway De-Icing Materials on Freshwater Systems
5. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-08_381.aspx
   Developing Adaptation Strategies for Impacts of Climate Change to Transportation Infrastructure

6. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-10_382.aspx
   Field Evaluation of Reflected Noise for Sensitive Receptors Across from a Noise Barrier

7. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-11_383.aspx
   Integrating Existing and Emerging Transportation Data Collection Activities to Maximize Analytical Capacity.

8. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-12_384.aspx
   To determine and develop the Best Practices for Consultation under Section 106 of the National Historic Preservation Act

9. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-13_385.aspx
   Impact of the Bridge Structures on Migratory Birds

10. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-14_386.aspx Does Direct Lighting from Vehicles Affect Nesting Sea Turtles?

11. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-15_387.aspx Understanding Market Based Land Use Preferences and Their Impact on Transportation

12. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-16_388.aspx Further Refinement and Implementation of a Habitat Quality Index

13. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-17_389.aspx Wildlife Crossing: an assessment of current practices and determination of best management policies for Department of Transportation

14. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-18_390.aspx Strategies to Reduce Arterial Fuel Consumption and Vehicular Emissions

15. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-B-21_391.aspx Addressing Global Climate Change by Utilizing Wetlands for Carbon Sequestration

16. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-04_392.aspx Improvement or Development of Corrosion Inspection Techniques for Highly Stressed High Strength Wires Used in Bridge Structures

17. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-07_393.aspx Review of the basis for rehabilitation design using the MEPDG.

18. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-08_394.aspxDeveloping design criteria for cost-effective multi-lane loop ramp design

19. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-09_395.aspx"Study of Vehicle Paths on Horizontal Transition Curves"

20. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-11_396.aspx Determining the Validity of Network Pavement Condition Data

21. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-12_397.aspx MEPDG Inputs for Warm Mix Asphalts

22. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-13_398.aspx Development of Guidelines for Consideration of Temperature Effects in Rigid Pavement Deflection Analysis

23. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-14_399.aspx Develop Guidelines for the Design and Construction of Ultra-Thin Asphalt Concrete Overlays

24. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-15_400.aspxQuantification of Benefits of Including Subsurface Drainage in Flexible and Rigid Pavements

25. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-16_401.aspxDemonstration of a Cost-Effective In-Service Evaluation Process for Semi-Rigid Longitudinal Barrier Systems

26. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-19_402.aspxGuidance for Curbs Used in Conjunction with Crash Cushions and Guardrail End Terminals

27. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-C-20_403.aspxDevelopment of Design Standards and Guidance for Separated Bikeways Adjacent to Roadways

28. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-02_404.aspx Pavement Smoothness Acceptance Levels

29. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-03_405.aspx Improved Test Methods for Construction Quality Control

30. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-04_406.aspx Guide for Measuring the Response of Pavement Structures

31. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-05_407.aspx Tire-Pavement Noise as a Construction Quality Indicator

32. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-06_408.aspx Modified Portland Cement Concrete for Crack Free Bridge Decks

33. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-08_409.aspx Development of an accurate mathematical model for predicting Alkali Silica Reaction damage in concrete.

34. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-09_410.aspx Best Practice Guide for the Design, Placement, Compaction, and QC of Aggregate Bases

35. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-10_412.aspx Optimizing Flexible Pavement Performance Based on Aggregate Physical Properties

36. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-13_414.aspx Development of a User-Friendly Environmental Life-Cycle Assessment Tool Kit for Sustainable Pavements

37. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-14_415.aspx Reduced Energy and Carbon Footprints for Sustainable Paving-Grade Concrete

38. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-16_416.aspx Beyond Escalation Clauses and Price Indexing – Effective Asphalt Risk Management

39. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-D-17_417.aspx Improved Installation Practices for Pavement Edgedrains

40. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-E-01_418.aspx "Culvert and Storm Drain Inspection Manual and Management System"

41. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-E-02_419.aspx Field Verification of the Application of Partially Grouted Riprap to Protect Bridge Piers

42. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-E-03_420.aspx "Design and Load Rating of Culverts Under Heavy Axle Loads"

43. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-E-04_421.aspx "Modulus-based Quality Control in Culvert Backfill Installation"

44. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-E-05_422.aspx Design Methods for Laterally Loaded Piles and Pile Groups near Mechanically Stabilized Earth Walls

45. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-E-06_423.aspx Assessing Corrosion in Two-Stage Mechanically Stabilized Earth Walls

46. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-F-06_424.aspx Cross Asset Funding Investment Strategies for Maintenance

47. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-02_425.aspx Effectiveness of Behavioral Highway Safety Countermeasures: Turning Research into Practice

48. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-03_426.aspxInstitutionalizing Safety Workforce Development

49. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-07_427.aspx Information and Data to Support Improved Safety Management and Communication of Safety Needs

50. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-08_428.aspx Strategies for Improving the Safety of Horizontal Curves

51. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-10_429.aspxRetroreflectivity Standards for Transverse Markings

52. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-11_430.aspxCountdown Pedestrian Signals: Is the Flashing Hand Necessary?

53. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-12_431.aspxBusiness Logo Signing

54. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-14_432.aspxAddressing Needs of Private Property in the MUTCD

55. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-15_433.aspxTraffic Signal “Yellow Trap”

56. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-16_434.aspxImproved Prediction of Light-Emitting Diode (LED) Dynamic Message Sign (DMS) Legibility

57. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-17_435.aspx What Information Should Be Provided to Pedestrians Regarding Pedestrian-Activated Beacons?

58. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-20_436.aspx Motorcycle Safety: Acoustically Enhanced Helmets and Accident Avoidance

59. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-21_437.aspx Understanding an Emerging Collision Trend: How Does Freeway Width, Access & Complexity Affect Safety (and Driver) Performance?

60. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-23_438.aspxAdvanced Work Zone Traffic Control Using Real Time-Travel Time Data

61. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-24_439.aspxPEDESTRIAN OPERATIONS AND SAFETY AT SIGNALIZED INTERSECTIONS

62. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-25_440.aspx Enhancing Critical Lane Volume Analysis by Incorporating Intersection Geometry.

63. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-26_441.aspxAssessing the Influences of Roadway and Roadside Attributes on Driver Behavior, Speed, and Safety with Online-Deliverable Casewise Visual Evaluation (CAVE) Methodology

64. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-27_442.aspx Intersection Traffic Control with IntelliDrive-Enabled Networks

65. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-28_443.aspxSafety Impacts of Publicly Maintained Rest Areas

66. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-30_444.aspx Data Fusion for Improved Detection of Congestion Onset and Travel Time Estimation

67. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-32_445.aspxMethods to Improve Physical Conditions for Pedestrians Along Existing Roads

68. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-33_446.aspxAutomated Pedestrian Safety Analysis Using Video Data

69. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-34_447.aspx
Quantitative Assessment Tool and Conflict Management for Sidepaths

70. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-35_448.aspx
Design Options to Reduce Turning Motor Vehicle / Bicycle Conflicts at Intersections.

71. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-G-36_449.aspx
Development of an All-User Detection-Based Intersection Signal System Capable of Intelligent Traffic Management

72. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-SP-01_450.aspx
University-Level Education in Public Involvement
http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-SP-03_451.aspx
Develop Technologies for Unmanned Aircraft for State Departments of Transportation

73. http://www.trb.org/NCHRP/Pages/NCHRP_Unselected_Problem_2011-SP-04_452.aspx
Accelerating Development of a Common DOT Language

Appendix M. Draft List of Research Topics

This appendix contains the list of all research topics that were considered for the prioritization effort. The topics are grouped by category.

Access management (20 Research Titles)

- Access Management in the Vicinity of a Freeway Interchange
- Determining The Economic Value of Roadway Access Management
- Develop a Crash Modification Factor (CMF) for:
    - business districts or residential
    - changing width of existing median (freeway, expressway, suburban arterial
    - closing or relocate access points in intersection functional area (urban, suburban, rural)
    - driveway or access density near intersections
    - Eliminating Left Turns at Driveways
    - increasing median width (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - installing median barriers (freeway, expressway, urban arterial, suburban arterial)
    - Intersection spacing
    - modifying access point density (rural multi-lane highway, expressway)
    - modifying the level of access control on transportation network (urban, suburban, rural)
    - openings on four-lane divided roads
    - providing a raised median (rural two-lane road, freeway, expressway, suburban arterial)
    - providing corner clearance (urban, suburban, rural)
    - reducing number of median crossings and intersections (rural two-lane road, rural multi-lane highway, expressway, urban arterial, suburban arterial)
- Enhanced Research On The Traffic Safety Impacts of Access Management
- Incorporating Traffic Safety Risk Management into the Asset Management Process
- Operational and Safety Impacts of Four- and Six-Lane Sections with Raised Medians Versus Two-Way Left Turn Lanes
- Operational Impacts of Access Management

Advanced technology and ITS (14 Research Titles)

- Creating Valuable User Information When Complex Incidents Occur In Transportation Management Centers
- Develop a Crash Modification Factor (CMF) for:
    - installing changeable "Queue Ahead" warning signs (rural two-lane road, rural multi-lane highway, expressway, urban local street or arterial, suburban arterial)
    - installing changeable accident ahead warning signs (rural two-lane road, rural multi-lane highway, expressway, urban local street or arterial, suburban arterial)
    - installing changeable fog warning signs (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - Installing Dynamic Advance Warning Flashers "Red Signal Ahead"
- Develop Truck and Bus Cooperative Automation Systems that can be Deployed on Their Own Lanes
- Evaluate Safety of Self-Explaining Roads

- Evaluation of Automated Speed Enforcement Technologies
- Evaluation of Dynamic Speed Sign Technologies
- Improve Crash Location Data
- Indirect Visibility Systems (IVSs) on Buses
- Length-Based Vehicle Classification
- Quantifying the Costs and Benefits of Red Light Camera Enforcement
- Transit Security Systems Lessons Learned

Alignment (16 Research Titles)

- Crash Harm per Freight Ton-Mile for Different Large Truck Configurations
- Criteria for Consistent Design and Safe Operation of Low-Volume Roads in Level and Mountainous Terrains
- Determining curve radius using GIS
- Develop a Crash Modification Factor (CMF) for:
    - changing vertical grade (urban two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - improving superelevation of horizontal curve (urban two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - modifying horizontal curve radius (rural two-lane road, urban two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - modifying tangent length prior to curve (rural two-lane road, urban two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - substandard features (i.e. broken back curves)
    - the safety effect of grade and vertical curves
- Horizontal/Vertical alignment interaction
- Investigation of Alternative Geometric Design Highway Design Processes: Strategic Research Program - Project 1: Development of a Research Program to Refine Geometric Design Models and Process
- Investigation of Alternative Geometric Design Highway Design Processes: Strategic Research Program - Project 2: AASHTO Design Criteria and Design Model Research
- Investigation of Alternative Geometric Design Highway Design Processes: Strategic Research Program - Project 3 Alternatives to the AASHTO Design Process
- Operational and Safety Benefits of Spiral Transitions
- Superelevation Criteria for Steep Grades on Sharp Horizontal Curves
- Vehicle Paths on Horizontal Transition Curves

Bicyclists (32 Research Titles)

- Bicycle Research Needs for National Parks and Public Lands
- Design Options to Reduce Turning Motor Vehicle / Bicycle Conflicts at Intersections
- Determining the Extent of Wrong-way Riding on Sidewalks and Adjacent Roadways
- Develop a Crash Modification Factor (CMF) for:
    - paving highway shoulders for bicycle use (rural two-lane road, rural multi-lane highway, suburban arterial)
    - installing raised bicycle crossing (urban, suburban, rural)
    - modifying pavement color for bicycle crossings (urban, suburban, rural)
    - placing "slalom" profiled pavement markings at bicycle lanes (urban, suburban, rural)
    - providing bicycle boulevards (urban arterial, suburban arterial)
    - providing bicycle facilities at interchange ramp terminals (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)

    - providing bicycle lanes or wide curb lanes at intersection (urban, suburban, rural)
    - providing dedicated bicycle lanes (urban arterial, suburban arterial)
    - providing separate bicycle facilities (urban arterial, suburban arterial)
    - providing shared bus/bicycle lanes (urban arterial, suburban arterial)
    - re-striping roadway to provide bicycle lanes (urban arterial, suburban arterial)
- Development of a Bicycle and Pedestrian Safety Prediction Methodology
- Development of a Bicycle Safety Prediction Methodology
- Development of Design Standards and Guidance for Separated Bikeways Adjacent to Roadways
- Exposure Measures of Bicyclists to Crashes
- Impact of Continuing to Mark Bicycle Lanes Through an Intersection
- Impacts of Social and Environmental Factors on the Need for Funding Bicycling Infrastructure
- Legibility of Various Bicycle-related Signs, Symbols, and Markings.
- Measures of Bicyclist Exposure to Non-motor Vehicle Crashes
- Methodology for Bicycle Network Analysis
- Methods to Increase Bicycle Transportation on Department of Defense facilities
- Motorists Perceptions of Bicyclists on Roadways
- Operational Guidance for Bicycle-Specific Traffic Signals
- Prediction Methodology for Cyclist Route Choice Using Revealed and Stated Preference Data
- Reducing Pedestrian and Bicycle Collisions with Trains
- Safety and Operational Impacts of Raised Medians on Bicyclists
- Safety and Operational Impacts Of Properly Designed Bike Lanes
- Safety Effects of Separated Bikeways
- The Comparative Safety Effects of Requiring Drivers to Merge into a Bike Lane

Data Management (11 Research Titles)
- Data warehouse and archived data
- Develop Users Guide for Data
- Examine Effectiveness of Using Medical Cost Data to Enhance Highway Safety Studies
- Examination of crash maneuvers within crash types for critical car/truck crash situations
- Exposure Data to Support Improved Truck Crash Risk Estimates
- Guidelines for Conducting Business Process Reviews for Successful Data Integration Projects to
- An Evaluation of Data Management Practices in Indian Country
- CMV Crash Risk by Time-of-Day
- Developing Valid Estimates of Motorcycle Vehicle Miles Traveled
- Open Architectures to Support Data Integration Projects
- Synthesis for Visualizing Roadway, Traffic, and Crash Data Integration

Evaluation Methods (13 Research Titles)
- Develop/test procedures to identify locations for cost-effective programs of systemwide improvements
- Demonstrate Application of Surrogates and an Understanding of Safety Issues
- Develop Procedures for Constructing Structural Models for Safety Prediction
- Development of Driver Behavior Models for Structural Modeling
- Document the State of the Art in Structural Modeling
- Evaluate and Validate Candidate Surrogate Measures
- Framework for Developing and Testing the Adequacy of Alternative Models or Modeling Methods
- Improved Methods for Applications of CMFs

- Motorcycle Crash Causation Study
- Prediction Models for Crash Types and Severity Levels
- Surrogate Scoping Effort – Definition, Criteria, Needs and Priorities
- Safety Evaluation of the 13 Controlling Criteria for Design
- Taxonomy of Crash Prediction Models: Strengths, Weaknesses, Applications

Highway lighting (1 Research Title)

- An Examination of Roadway Feature Identification Lighting versus Designed Lighting Systems

Interchange design (12 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - designing interchange with crossroad above freeway (one quadrant, SPUI, directional)
    - freeway Interchanges (SPF and CMFs)
    - increasing horizontal curve radius of ramp roadway (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - increasing lane width of ramp roadway (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - increasing length of weaving areas between adjacent entrance and exit ramps (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - modifying interchange spacing (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - modifying ramp type or configuration (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - providing right-hand exit and entrance ramps (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - redesigning interchange to provide collector-distributor roads (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - redesigning two-lane-change merge/diverge area to one-lane-change (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
- One and Two-lane Ramp Loop Design
- Ramp Design as a System

Intersection geometry (21 Research Titles)

- Define risk at signalized intersections at urban boundaries
- Develop a Crash Modification Factor (CMF) for:
    - converting four-leg intersection to two three-leg intersections (urban, suburban, rural)
    - full turns with parallel acceleration lane
    - increasing intersection median width (urban, suburban, rural)
    - Non-signalized J turns
    - providing a left-turn lane on approaches to four-leg intersections (urban, suburban, rural)
    - providing a left-turn lane on approaches to three-leg intersections (urban, suburban, rural)
    - providing a right-turn lane on approaches to an intersections (urban, suburban, rural)
    - providing a two-way left-turn lane (rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - providing channelized left-turn lanes at four-leg intersections (urban, suburban)
    - providing channelized left-turn lanes at three-leg intersections (urban, suburban)
    - removing right-turn channelization at signalized intersections
    - replacing direct left-turns with right-turn/U-turn combination (urban, suburban, rural)
    - right-turn treatments (channelization with different angles of incidence to cross street)
    - roundabouts (in urban setting)

    - the effects of protected/permissive left turn signal phasing
- Develop Predictive Methods for Additional Intersection Types
- Reconsidering Intersection Skew Angles, Safety, and Operations
- Roundabouts
- Safety Effects of Congestion Treatments
- Safety Impacts of Intersection Sight Distance

Intersection traffic control (25 Research Titles)
- Develop a Crash Modification Factor (CMF) for:
    - converting minor road stop control to all-way stop control (urban, suburban, rural)
    - converting stop control to signal control (urban, suburban, rural)
    - Leading vs. Lagging protected left-turns in relation to pedestrian crashes
    - LED signal heads
    - mid-block crossing – signalization
    - modifying change and clearance interval (urban, suburban, rural)
    - modifying left-turn phase (urban, suburban, rural)
    - permitting right-turn on red (urban, suburban, rural)
    - placing transverse markings on roundabout approaches (urban, suburban, rural)
    - prohibiting left-turns and/or U-turns with "No Left Turn", "No U-Turn" signs (urban, suburban, rural)
    - providing actuated control (urban, suburban, rural)
    - providing advance warning flashers and warning beacons (urban, suburban, rural)
    - providing advance overhead guide signs (urban, suburban, rural)
    - providing advance static warning signs and beacons (urban, suburban, rural)
    - Providing Signal Coordination
    - providing Stop Ahead pavement markings (urban, suburban, rural)
    - removing unwarranted signal on one-way streets, i.e. convert from signal to stop control on one-way streets (urban, suburban, rural)
    - signal clearance intervals
    - signal head backplates
    - split phasing
    - the effects of protected left-turn phasing at high-speed rural intersections
- Engineering Countermeasures to Reduce Red-Light Violations and Related Crashes
- Safety effects of late-night flash mode at signalized intersections
- Safety effects of two-way flashers at stop controlled intersections
- Traffic Signal Phase Sequencing for Efficiency and Safety

Network Safety (4 Research Titles)
- Highway Safety as an Asset: Incorporating Safety Performance Metrics in State Level Planning and Programming
- Integrating Safety into Regional Capital Improvement Programming Processes: Best Practices and Recommended Procedures
- Safety Analysis Tools for the Metropolitan Planning Level

  How Do We Convince the Locals to Participate in Statewide Highway Safety Data Programs?

On-street parking (1 Research Title)
- Operational and Safety Impacts of Angle versus Parallel versus Back-in Parking

Pedestrians (73 Research Titles)
- Accessible Pedestrian Signals
- Automated Pedestrian/Vehicle Conflict Video Data Collection

- Automobile Parking and Pedestrian Safety: A Search for a Unifying Frame of Reference
- Best Practices and Pedestrian Safety Concerns Related to Transit Access in Urban Areas
- Best Practices for Pedestrian Facility Maintenance
- Case Studies of Model City/County Ordinances that Support a Vibrant Pedestrian Network
- Cost-effective Retrofits for High-Speed Multilane Arterial Roads for Pedestrians
- Create SRTS model or demo/case studies to SRTS
- Design, Safety, and Operational Considerations of Pedestrian Treatments at Intersections
- Determining Factors that Increase Crashes, Injuries, and Perceived Risk at Midblock Locations
- Develop a Crash Modification Factor (CMF) for:
    - Adding Midblock Pedestrian Signal
    - installing overhead electronic signs with pedestrian-activated crosswalk flashing beacons (urban arterial, suburban arterial)
    - installing pedestrian countdown signals (urban, suburban, rural)
    - installing pedestrian refuge islands or split pedestrian crossovers (urban arterial, suburban arterial)
    - installing pedestrian signal heads at signalized intersections (urban, suburban, rural)
    - installing pedestrian-activated flashing yellow beacons with overhead signs and advance pavement markings (urban arterial, suburban arterial)
    - Installing Raised Crosswalk (non-intersection)
    - installing raised pedestrian crosswalks (urban arterial, suburban arterial)
    - installing stop lines and other crosswalk enhancements (urban, suburban, rural)
    - marking crosswalks at uncontrolled locations, intersections or mid-block (rural two-lane road, urban arterial, suburban arterial)
    - modifying pedestrian signal head (urban, suburban, rural)
    - narrowing roadway at pedestrian crossing (urban, suburban, rural)
    - Pedestrian Enhancements (HAWK, Refuge Areas, etc.)
    - Pedestrian hybrid beacon at mid-block crossing
    - pedestrian refuge areas
    - providing a raised median or refuge island at marked and unmarked crosswalks (urban arterial, suburban arterial)
    - providing a raised or flush median or center TWLTL at marked and unmarked crosswalks (urban arterial, suburban arterial)
    - providing a sidewalk or shoulder (urban arterial, suburban arterial)
    - providing exclusive pedestrian signal timing plan (urban, suburban, rural)
    - providing leading pedestrian interval signal timing pattern (urban, suburban, rural)
    - providing pedestrian facilities on ramp terminals (trumpet, one quadrant, diamond, SPUI, partial cloverleaf, full cloverleaf, directional)
    - providing pedestrian overpasses and underpasses (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - providing wide curb lanes (urban arterial, suburban arterial)
    - school bus routes
    - school zone related countermeasures
    - using alternative crosswalk markings at mid-block locations (rural two-lane road, urban arterial, suburban arterial)
    - widening median (rural multi-lane highway, urban arterial, suburban arterial)
- Develop Guidelines for Pedestrian Midblock Crossings
- Development of an All-User Detection-Based Intersection Signal System Capable of Intelligent Traffic Management
- Effect of Hand-Held Communication Device Use on Pedestrian Safety
- Effectiveness of Various Mid-block Crossing Treatments

- Effects of New Pedestrian Facilities on Pedestrian Exposure
- Effects of Traffic Signals on Pedestrian Behavior and Safety
- Enhancing Travel Surveys for Non-Motorized Travel
- Evaluate Safe Routes to School-related bicycle measures effect on safety of bicyclists
- Evaluating Methods for Collecting Pedestrian Exposure Data
- Evaluating of Automated Pedestrian Detection Technologies
- Evaluating the Effects of Red Light Cameras, Speed Monitors, and other Automated Enforcement Technology on Pedestrian Crashes
- Evaluation of Automated Pedestrian Detection Technologies
- Evaluation on MUTCD Devices for Pedestrians
- Guidelines for the Provision of Sidewalks
- How Quiet Cars and Roads Effect Hearing Impaired Pedestrians
- How School Site Locations and Design Impact Pedestrian Safety
- Identification and Prioritization of High Pedestrian Crash Locations/Areas
- Identification and Use of Pedestrian Facility/Safety Funds
- Impact of Pedestrian Distractions on Pedestrian Crashes
- Improving the Collection Process for Pedestrian Crash Data
- Increasing the Safety of Interactions Between Pedestrians and Large Commercial Vehicles (Trucks and Buses) in Urban Areas
- Integrating Pedestrian Considerations into Traffic Signal Design
- Intersection Design To Accommodate Pedestrian Crosswalk Cross Slope
- Methods to Improve Physical Conditions for Pedestrians along Existing Roads
- Pedestrian Crash Reduction Factors
- Pedestrian Visibility at a Roundabout
- Pedestrian-Vehicle Conflicts Near Schools
- Race/Ethnicity Evaluation for Pedestrian Morbidity and Morality
- Relationships Between Land Use, the Built Environment, and Pedestrian Safety
- Research on the Effects of White Lighting in Reducing Pedestrian Nighttime Crashes and to Evaluate Emerging Lighting Technologies in Real World Conditions
- Safety and Health Issues of Recumbent and Low-profile Bikes.
- Systematic Data Collection of Crashes on Shared Use Pathways
- The Effect of Roadway Features on Pedestrian Crashes on Urban and Suburban Corridors
- The Effect of Roadway Features on Vehicle Speeds
- Understanding Diverse Vision Needs of Pedestrians
- Using National Exposure Data to Examine the Relationship Between Pedestrian Exposure and Safety

Railroad grade crossings (10 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - installing crossbucks (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - installing four-quadrant automatic gates (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - installing four-quadrant flashing light signals (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - installing pre-signals (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - installing vehicle-activated strobe light and supplemental lights (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)

    - providing constant warning time devices (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
- Economic Effects of Highway-Rail, At-Grade Crossing Crashes
- Highway-Rail Grade Crossing Warning Devices for Pedestrians and Bicyclists
- Identify Effective Interventions that Prevent Injuries Related to Switching Activities
- Installation of Stop and Yield Signs at Grade Crossings

Roadside (28 Research Titles)
- Are Roadways and Related Structures a Detriment to Safety in the Airport Environment
- Barrier System Maintenance Procedures
- Changing Vehicle Fleet: Are Roadside Barriers Suitable for Modern Fleet? Assessment to Improve the Compatibility of Vehicles and Roadside Safety Hardware
- Crash Walls vs. Guard Rails in Urban Transit Projects
- Develop a Crash Modification Factor (CMF) for:
    - animal crash activity in 2-lane rural segments
    - Flattening Sideslopes
    - guardrail elimination
    - hazards within clear zone (i.e. mast arms, utility poles, non-mountable curbs)
    - increasing clear roadside recovery distance (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - increasing distance to roadside features (rural multi-lane highway, expressway, urban arterial, suburban arterial)
    - increasing the distance to utility poles and decrease utility pole density (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - installing roadside barriers along embankments (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - installing snow fences for the whole winter season (rural two-lane road, rural multi-lane highway, freeway, expressway)
    - Presence of Safety Hardware (Roadside Barriers, Sign Supports) Adjacent to Roadways
    - reducing roadside hazard rating (rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - Remove Roadside Obstacles (urban)
    - Roadside memorials
- Develop a Safety Design for Parallel Drainage Ditches
- Develop and Evaluate Treatments to Reduce Tree-Related Crash Injuries
- Development of a Safer Concrete Barrier
- Development of Guidelines for Determining Guardrail Length of Need
- Effectiveness of Traffic Barriers on Non-level Terrain
- Guidelines for Slope Traversability
- Identification of Landscape and Roadside Properties that Contribute to Increased Roadside Safety
- Measures of Validity for Roadside Safety Modeling
- Offset of trees and other vegetation
- Probability of Utility Pole Collisions
- Problem ID of guardrail rupture/failure

Roadway (32 Research Titles)
- Conversion of Two-Lane to Three-Lane cross sections
- Design Fires in Tunnels

- Determining Actual Cost of Performing Routine & Preventive Maintenance Operations on Highway Systems
- Develop a Crash Modification Factor (CMF) for:
    - modifying lane widths (freeway, expressway, urban arterial, suburban arterial)
    - adding a travel lane
    - adding lanes by narrowing existing lanes and shoulders (rural multi-lane highway, expressway, urban arterial, suburban arterial)
    - applying elements of self-explaining roadway design (urban, suburban, rural)
    - applying elements of transportation safety planning in transportation design (urban, suburban, rural)
    - applying preventative chemical anti-icing during the whole winter season (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - converting one-way streets to two-lane, two-way streets (urban, suburban, rural)
    - converting two-way streets to one-way streets (urban, suburban, rural)
    - crash migration from left-turn from segment to intersection
    - deficient sight distance
    - factors for pleasure routes, commuter routes, commercial corridors, recreational routes
    - implementing network-wide engineering consistency (urban, suburban, rural)
    - median acceleration/refuge lane
    - pavement condition
    - Pavement Surface Friction
    - raising the state of preparedness for winter maintenance (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - road surface conditions/weather differences
    - roughness of roads
    - snow/ice conditions
- Development of AASHTO LRFD Guide Specifications for Rehabilitation and Strengthening of Existing Highway and Rail Transit Tunnels
- Development of National Service Level Criteria for the Interstate and National Highway System
- Effect of traffic calming on pedestrian crashes
- Lane versus shoulder width for roads in narrow pavements (less than 24 feet)
- Life Cycle Analysis of Designing Highways for Safety
- Prototyping Roadway Engineering Improvements to Reduce Drunk Driving Crashes
- Prototyping Roadway Engineering Improvements to Reduce Motorcycle Crashes
- Safety and Operational Tradeoffs of Freeway Lane and Shoulder Widths
- Three-Dimensional Approach for Measuring Pavement Macrotexture
- Wet Weather Crash Reduction; Effect of improving roadway friction systemwide

Roadway delineation (17 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - Adding Advance Curve Warning Signs/On Pavement Markings
    - Bott's dots
    - high speed TWLTL on rural 2-lane highways
    - In pavement lighting for pedestrian crossings
    - installing chevrons signs on horizontal curves (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - installing edgelines, centerlines, and post-mounted delineators (urban arterial, suburban arterial)
    - installing plowable permanent raised pavement markers, RPMs (rural multi-lane highway, expressway, urban arterial, suburban arterial)

    - installing post-mounted delineators (rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - placing centerline and edgeline markings (urban arterial, suburban arterial)
    - placing centerline markings (rural multi-lane highway, urban arterial, suburban arterial)
    - placing converging chevron pattern markings (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - placing edgeline and directional pavement markings on horizontal curves (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - placing standard edgeline markings (rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - placing wide edgeline markings (rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - providing distance markers (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - sharrows (shared lane markings)
- Evaluate Road Departure Countermeasures and Identify New Countermeasures

Roadway signs and traffic control (4 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - installing signs to conform to MUTCD (rural two-lane road, rural multi-lane highway, freeway, expressway, urban local street or arterial, suburban arterial)
    - Flexible or Movable Signing For Preventing End of Queue Accidents
- Improve Roadway-related Inventory and Operations Data
- Safety Effects of Reversible Flow Lanes

Roadway User (2 Research Titles)

- Road-User Adaptation to Safety Treatments
- Uniform Police Reporting of Motorcycle Accidents

Shoulder treatment (14 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - Adding Edgeline Rumble Stripes
    - adding or widen paved shoulder (freeway, expressway, urban arterial, suburban arterial)
    - Application of Safety Edge Treatment
    - Continuous Shoulder Rumble Strips on Rural Two-Lane Roads
    - installing centerline ruble strips (urban two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - installing continuous shoulder ruble strips (rural two-lane road, urban two-lane road, expressway, urban arterial, suburban arterial)
    - installing continuous shoulder rumble strips and wider shoulders (rural two-lane road, urban two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - installing curbs (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - installing rumble strips on intersection approaches (urban, suburban, rural)
    - installing transverse rumble strips (rural two-lane road, urban two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - modifying shoulder type (rural multi-lane highway, rural frontage road, freeway, expressway, urban arterial, suburban arterial)

    - the effect of edgeline markings (wider markings, wet reflective tape, and profile markings)
- Safety effects of shoulder treatments not involving full paving
- Shoulder paving and widening

Speed management (15 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - applying several traffic calming measures to a road segment (suburban arterial)
    - conducting enforcement to reduce red-light running (urban, suburban, rural)
    - deploying aerial enforcement (urban, suburban, rural)
    - deploying mobile patrol vehicles (urban, suburban, rural)
    - deploying radar and laser speed monitoring equipment (urban, suburban, rural)
    - deploying stationary patrol vehicles (urban, suburban, rural)
    - implementing area-wide traffic calming (suburban, rural)
    - installing drone radar (urban, suburban, rural)
    - installing transverse rumble strips for traffic calming (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - modifying posted speed limit (urban, suburban, rural)
    - reducing posted speed limit through school zones during school times (rural two-lane road, rural multi-lane highway, urban arterial, suburban arterial)
    - speed or speed limits
- Speed Prediction Models for Rural Multilane Highways and Urban and Suburban Arterials
- The Effect of Roadway Features on Vehicle Speeds
- Transition Zones - Design from High-Speed to Low-Speed Rural Sections

Work zone (5 Research Titles)

- Develop a Crash Modification Factor (CMF) for:
    - modifying work zone duration and length (rural two-lane road, rural multi-lane highway, expressway, urban arterial, suburban arterial)
    - predictive methods for maintenance and construction zones
    - using crossover closure or single lane closure (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - using Indiana Lane Merge System, ILMS (rural two-lane road, rural multi-lane highway, freeway, expressway, urban arterial, suburban arterial)
    - work zone traffic control devices

Appendix N. Revised RNS Form for Researchers

SAFETY RESEARCH NEEDS STATEMENT
(To be used by individual researchers and TRB research committees. State/local agencies will use the NCHRP form.)
PART 1

(The following is a three-part form to be used in the submission of new research needs/topics. Please fill out Part 1, which will then direct you to either Part 2 or Part 3.)

I. **RESEARCH TOPIC TITLE**

A suggested title (e.g., "Effectiveness of rumble strips on two-lane rural roads"; "Development of crash surrogates for intersection-related rear-end crashes")

II. **TYPE OF RESEARCH**

Determine whether the research is either (1) Applied or (2) fundamental research, using the definitions below. Then check the appropriate box. (This decision is not always clear-cut. Please provide your best judgment.)

Directly-applicable safety research will produce either:

(a) An improved estimate of the safety effect of a decision which pertains to road design, traffic control, treatment implementation, etc., Thus, e.g., one may want to have a better idea about the safety effect of paving shoulders on two-lane roads or of increasing the cycle time in signal networks – new or improved Crash Modification Factors (CMFs)

(b) An improved estimate of expected future target crashes for the decisions in (a); e.g., how many crashes/year would be affected by the paving for two-lane road shoulders? How many by changing the cycle time of coordinated signals? (This improved estimate may be the result of more predictive crash models.)

(c) An improved estimate of the societal cost of the target crashes for the decisions in (a)

Fundamental research is research that develops novel or presently unused actions and tools to be used in directly applicable research. Examples are: how driver behaviors are affected by roadway design; developing valid crash conflicts that can be used to estimate safety effect and CMFs; developing improved statistical modeling methods, improved crash or inventory data collection methods, or the exploration of alternative economics theories or methods to estimate crash costs.

Check the appropriate box.

☐ This research is applied
GO TO PART 2. (Note: Part 2 is a modified version of AASHTO Standing Committee on Research problem statement.)

☐ This research is fundamental research – GO TO PART 3

PART 2

RESEARCH PROBLEM STATEMENT FOR APPLIED *RESEARCH*

I. RESEARCH PROBLEM STATEMENT

A description of the problem or need – one or more paragraphs explaining the reason for the research. Be explicit about project-related decisions that the intended research product will improve and about the primary target crashes affected by the decision. If possible, provide an estimate of how many such target crashes occur in the US in one year.

II. LITERATURE SEARCH SUMMARY

To avoid duplication with other current or past research, the problem submitter must provide a <u>summary</u> of the results of a literature search. At a minimum, searches should be conducted on the TRID database (http://trid.trb.org). Reviews of literature through 2008 conducted for the Highway Safety Manual can be found on the Crash Modification Factor Clearinghouse at http://www.cmfclearinghouse.org/collateral/HSM_knowledge_document.pdf. Please describe how your proposed research is expected to improve on what knowledge now exists. If no search is performed, please comment on why it was not needed.

If the research is about the safety effect of some treatment (e.g., the development of a Crash Modification Factor), in addition to the literature summary, please answer the following three questions:

a. Does this treatment appear in the first edition of the Highway Safety Manual? If yes, enter the category within the HSM listing where this research topic would fall and the estimated CMF and standard deviation. (e.g., HSM knowledge on rumble strips is in Volume 3, section 13.9, page 13-32. While there are acceptable CMFs for shoulder rumble strips on freeways and multilane-rural highways, there are no CMFs for two-lane rural roads.)

b. Does this treatment appear in the CMF Clearinghouse? If yes, list the estimated CMF and star rating. If there are multiple CMFs for the same treatment, list only the one with the highest number of stars (e.g., There is a four-star CMF of 0.74 for run-off-road crashes on rural two-lane roads in British Columbia (Sayed, et al., 2010). There are ratings for edgeline rumble strips (installed with resurfacing) for Principal Arterial Other Freeways and Expressways, but none for non-freeways.)

c. Does the treatment appear in *The Handbook of Road Safety Measures,* Second Edition (2009), Elvik, Rune, et al.? If yes, list the page number, the "Best Estimate" percent reduction and the confidence interval (e.g., Page 462 indicates that shoulder rumble strips reduce all accidents by 10% (-21; +4) and road departure accidents by 16% (-41: +20). But there is no information on effects on two-lane rural roads.)

III. RESEARCH OBJECTIVE AND METHODOLOGY

A statement of the specific research objective, defined in terms of the expected final product that relates to the general problem statement in Section I above. Also provide limited discussion of how the research will be successfully conducted including specific tasks necessary to achieve the objective and a brief discussion of any issues (e.g., threats to validity, availability of data, data collection difficulties) that must be overcome to insure that the research is successful. The following questions should be answered in the discussion:

- Are there potential threats to validity of the results (e.g., regression to the mean)? If so, list.

- Are data available to conduct the research?
    - If yes, specify the source or indicate that the data are proprietary.
    - If no, are data collection techniques and equipment available to collect the needed data, or will it be necessary to develop methods and/or equipment?

IV. ESTIMATE OF REQUIRED FUNDING AND RESEARCH PERIOD

Recommended Funding:

An estimate of the funds necessary to accomplish the objectives stated in III above. As a general guideline, the present cost (2011) for research usually averages about $200,000 for 100 percent of a professional employee's time per year. This figure represents a fully loaded, professional rate that would include an individual's direct salary and benefits and an agency's overhead or indirect costs. Average rates for supporting staff might be approximately one-half those of professionals. Depending on the type of research, the estimate should be modified for any unique expenses such as the purchase of materials, extensive physical testing or computer time, data collection and extraordinary travel.

Research Period:

An estimate of the number of months of research effort (including one month of review time) necessary to the accomplishment of the objectives in III above.

V. URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

Statements about the urgency of this research and the potential payoff (couched in benefit/cost terms if at all possible) from achievement of project objectives should be given.

A statement should be included that further describes the anticipated product(s) from the research (e.g., new or improved CMF for XXXX, improved crash cost estimates). The anticipated steps necessary for implementation of the research product should also be delineated (e.g., Will a new Chapter or section need to be submitted for consideration by the AASHTO and TRB Highway Safety Manual Committee? This information should be as specific as possible (e.g., a change in the AASHTO Green Book). Any institutional or political barriers to implementation of the anticipated research products should also be identified.

VI. DATE AND SUBMITTED BY

Show date submitted and a statement of the specifics (name, title, affiliation, address, telephone number, e-mail address) of the person(s) having developed the problem in all its detail.

PART 3
PROBLEM STATEMENT FOR *FUNDAMENTAL RESEARCH*

I. RESEARCH PROGRAM DESCRIPTION

A description of the problem or need—one or more paragraphs explaining the reason for research.

II. CURRENT LEVEL OF KNOWLEDGE

Briefly describe recent research on this topic. Provide key references. Define what is presently insufficiently known.

III. RESEARCH OBJECTIVE AND METHODOLOGY

A statement of the specific research objective, including the specification of the expected outcomes of the research. What new knowledge will be developed? Also provide limited discussion of how the research will be successfully conducted including specific tasks necessary to achieve the objective and a brief discussion of any issues (e.g., threats to validity, availability of data, data collection difficulties, new analysis methods needed) that must be overcome to insure that the research is successful. The following questions should be answered in the discussion:

- Are there potential threats to validity? If so, list.
- Are data and methods available to conduct the research?
    - If yes, specify the source or indicate that the data and/or methods are the intellectual property of the proposer/proposing agency.
    - If no, are data collection techniques and equipment available to collect the needed data, or will it be necessary to develop methods and/or equipment?

IV. RELATIONSHIP TO APPLIED RESEARCH

By answering the following questions, describe how the proposed fundamental research will facilitate the conduct of applied research, make it cheaper and more accurate.

a) What are the decisions which impact safety that will be improved by the envisioned results of this fundamental research? If these decisions are related to specific crash types, specific location types or other specific targets, please list them.

b) For the safety decisions listed in (a) what makes them currently less than acceptable? That is, specify examples of current CMFs, estimates of expected future crashes or crash costs are currently less than acceptable and why.

c) What other research will have to be successfully completed before the results of this proposed fundamental research can be implemented in applied research projects?

d) Specify how the proposed fundamental research will lead to improvements in future decisions. How will it improve or make less expensive the current CMFs, estimates, or crash costs?

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

Recommended Funding:

An estimate of the funds necessary to accomplish the objectives stated in III above. As a general guideline, the present cost (2011) for research usually averages about $200,000 for 100 percent of a professional employee's time per year. This figure represents a fully loaded, professional rate that would include an individual's direct salary and benefits and an agency's overhead or indirect costs. Average rates for supporting staff might be approximately one-half those of professionals. Depending on the type of research, the estimate should be modified for any unique expenses such as the purchase of materials, extensive physical testing or computer time, data collection and extraordinary travel costs.

Research Period:

An estimate of the number of months of research effort (including one month of review time) necessary to the accomplishment of the objectives in III above.

VI. DATE AND SUBMITTED BY

Show date submitted and a statement of the specifics (name, title, affiliation, address, telephone number, e-mail address) of the person(s) having developed the problem in all its detail.

Appendix O. Prioritization Questions for Technical Advisory Group

1. What percent of urban signalized intersections are candidates for exclusive (scramble-timed, Barnes Dance) pedestrian signals? (RNS 46.4): _______%

2. What percent of urban signalized intersections have 2-or-more parallel turn lanes (e.g., dual left-turn lanes)? (RNS 46.9): _______%

3. What percentage of your rural, multi-lane road mileage would be a candidate for continuous shoulder rumble strips? (RNS 95.2, 95.3): _____%

4. What percent of your road mileage with 5 or more lanes would be a candidate for using reversible lanes due to differences in peak-hour traffic flows? (RNS 160): _____%

5. What percent of your wet-weather crashes occur due in part to low pavement friction that could be treated with surface friction treatments? (RNS 167.3, 167.4): _____%

6. What is the percentage of rural, 2-lane roads, rural multi-lane roads, and freeways and expressways have embankments that create a potential safety problem for motorists, but do not presently have roadside barriers? (RNS 181.1, 181.3):

_____% of rural, 2-lane roads

_____% of rural, multi-lane roads

_____% of rural freeways and expressways

7. What is the percentage of curve mileage which has a superelevation that doesn't meet current AASHTO guidelines? (RNS 182): _____%

8. What is the percentage of curve mileage on rural two-lane roads and multi-lane roads which currently do not have post-mounted (or other types of) roadside delineators, which could be a candidate for such a treatment? (RNS 189.1, 189.2)

____ % of rural 2-lane roads

____% of rural, multi-lane roads

9. What is the percentage of curve mileage on rural, 2-lane roads where the curves of interest do not have centerline markings, edgeline markings, or post-mounted delineators? (RNS 193.1):
____% on rural 2-lane roads

10. What percentage of rural 2 lane and rural multilane road mileage could be eligible for being treated with pavement markings (such as converging chevron pattern markings) to reduce vehicle speeds? (RNS 198.1, 198.2):

____% on rural, 2-lane roads

____% on rural, multi-lane roads

11. What percent of your horizontal curves would be candidates for installation of a new advance traffic control device to reduce vehicle approach speeds? (RNS 203.3): _____%

12. What percent of your urban and suburban arterial mileage would be candidates for the addition of a sidewalk? (RNS 206): ______%

13. What percent of your arterial road intersections in urban and suburban areas would be a candidate for installing a raised pedestrian crosswalk? (RNS 207.1): _____%

14. What percentage of pedestrian crossings would be eligible for roadway narrowing, using bulb outs (i.e., curb extensions) and/or other similar treatments? (RNS 244): ____%

15. What percentage of locations could be eligible for improved lighting to reduce pedestrian crashes?(RNS 329): ____%

16. What percent of curves on rural 2-lane and multi-lane roads would be candidates for advance warning devices? (RNS 510.1): ____%

17. What percent of traffic signals at urban intersections are NOT timed in conformance with Institute of Transportation Engineers (ITE) guidelines? (RNS 574.3, 574.4): ____%

18. What percentage of rural, 2-lane road mileage; rural, multi-lane road mileage; freeway/expressway mileage; and urban/suburban arterial street mileage has 8-inch edgelines (compared to 4-inch or 6-inch edgelines)? (RNS 580.1, 580.5):

___% of rural, 2-lanre road mileage

____% of rural, multi-lane road mileage

____% of freeway/expressway mileage

____% of urban/suburban arterial street mileage

Person who completed this questionnaire: ________________________________

Name of your Organization: ____

Phone Number: ____

e-mail address: ____

Please e-mail or FAX questionnaire responses by close of day, September, 5th, 2012 to:

Charlie Zegeer

(919) 962-8710 (FAX)

charlie_zegeer@unc.edu

Please call Charlie at (919) 962-7801, if you have any questions.

Thank you very much for providing input to NCHRP 17-48

Appendix R. Countermeasure Cost Compilation

Introduction

The team for NCHRP Project 17-48 developed a tool by which research projects could be prioritized based on a “value of research” (see Appendix E). One of the inputs needed for this tool was the cost of the countermeasure (i.e., infrastructure improvement) in question. As a part of the process of gathering information to assign a cost to each countermeasure being evaluated, the team assembled a sizeable database of countermeasure costs. This database is made available as one of the project deliverables.

Countermeasure costs often vary greatly from city to city and state to state. This document (and associated database) is intended to provide meaningful estimates of infrastructure costs by collecting up-to-date cost information from states and cities across the country. By collecting countrywide cost information, this database should contain useful information for any state or city, even if costs from that particular state or city are not specifically included for a given treatment.

The accompanying Excel database (“17-48 Countermeasure Cost Compilation.xlsx”) provides general estimates and cost ranges for infrastructure improvements. It needs to be understood, however, that costs can vary widely from state to state and also from site to site, depending on many factors. Therefore, the cost information contained in this report should be used only for estimating purposes and research prioritization - not necessarily for determining actual bid prices for a specific infrastructure project.

Information Sources

Beginning with bid-letting summaries or price indices from states across the country, infrastructure costs were identified and entered into a database. Bid-letting sheets were usually available from State Departments of Transportation web sites, which contain a range of costs based on local contractor bids. In some cases, however, only one bid, or an average of all bids, is listed. In this situation, either the range of bids or the single bid is included in the database. While the project team attempted to use the most up-to-date bid letting and pricing sheets available, the availability of bid letting summaries varies from state to state. As such, some information in the database dates from 2009 or earlier. Most of the costs, however, are from 2010, 2011, or 2012. All costs are provided in the source year dollars. Thus, anyone using this information will need to adjust the dollar amount to the current year using the United States Consumer Price Index published by the Bureau of Labor Statistics.

For some treatments, particularly newer innovative treatments, cost information was not included in bid letting sheets. To ensure that costs for were included for as many treatments as possible, HSRC researchers also conducted targeted searches of selected infrastructure measures, using conventional search engines as well as searching state and city websites. The source of data as well as a hyperlink is included in most of the cost entries in the database. Drawing from city plans, manufacturer pricing information, and other sources, these targeted searches provide information that was otherwise unavailable from other sources.

After costs were compiled, interviews were conducted with Department of Transportation employees in various states to validate the cost averages. Team members contacted the safety, engineering, or construction divisions of State Departments of Transportation (DOT) in North Carolina, Tennessee, Florida, Nebraska, Wyoming, Ohio, and California to determine what information is included in the costs. According to these State DOTs, the costs found in Bid Letting or Bid Tabulation Sheets include labor, materials, mobilization costs (though mobilization costs were often bid separately as well), and contractor profits, effectively making the treatment cost a complete "in the ground" cost.

Key Assumptions

In order to provide cost estimates for some treatments, team members made certain assumptions, given in the bulleted list below.

- General assumptions:
    - Costs are assumed to include engineering, design, mobilization, and furnish and installation costs.
- Specific assumptions for estimating purposes (where linear distances of sidewalk, bikeway or bike lane, etc. are used):
    - All bike lanes are five feet in width.
    - Wide curb lanes are four feet in width.
    - Separated bikeways are eight feet in width.
    - Multi-use paths, whether paved or unpaved are eight feet in width.
    - All sidewalks are five feet in width and are 4" in depth.

Database Field Descriptions

The database includes the following fields of information for each cost item:

- Countermeasure Name – the title of the countermeasure (e.g., install sidewalk)
- Countermeasure Description – the details of the countermeasure (e.g. Portland Cement)
- Category – general category of the countermeasure
- Initial (Total) Cost – if a single total cost is provided, it is included here
- Annual (Maintenance) Cost – if provided, how much the countermeasure costs to maintain, usually per year
- Low End of Cost– if a range of costs is provided, the lowest cost
- High End of Cost – if a range of costs is provided, the highest cost
- Cost of ROW – the cost of purchasing right-of-way, if provided and applicable
- Cost Unit – the unit to which the cost is linked (e.g. lump sum, each, per mile, per linear foot, per square yard, etc.)
- Estimated Service Life – the number of years of estimated service life provided in the information source
- Information State – the state name of the information source, in postal code format
- Information Source– the title of the information source, usually a bid letting sheet or specific research paper

- Information Source Year – the year of the cost information. This date can be used to adjust the cost figures to a current index year.
- Page Number within Document – the page within the information source that contains this cost
- Link to Source – the reference URL for the source of the countermeasure cost
- Number of Lanes Road 1 – the number of through travel lanes on the primary road on which the countermeasure was installed. At intersections, this would be the major road.
- Speed Limit Road 1 – the speed limit in miles per hour on the primary road
- Number of Lanes Road 2 – the number of through travel lanes on the secondary road. At intersections, this would be the minor road.
- Speed Limit Road 2 – the speed limit in miles per hour of the secondary road

Database users should understand that these costs were taken from various sources across the country and that costs may vary between states and also by the quantity purchased. Generally, costs per unit (square yard, linear foot, each, etc.) may vary widely depending on the size of the order, with larger quantities usually leading to lower per unit costs.

While information was not available for all 50 states, most states in the U.S. do have publicly accessible cost information. If no cost information was available for a certain state, efforts were made to include information from a nearby state or a city within that state. It is useful to note that while these infrastructure costs constitute, in most cases, the most up-to-date information available, these are cost estimates. The changeable nature of estimating infrastructure costs means that these data only provide a general idea of what any treatment may cost for a specific location.