was also used as well as improvement costs, annual maintenance costs, and service lives of each project. An interest rate of 8 percent was used along with a volume growth rate of 5 percent per year.

Output from the program included information for each improvement project and a listing of all projects in order of benefit/cost ratio that could be used to determine priority rankings based on benefit/cost ratios alone. The largest benefit/cost ratio was 44.01, which was for the addition of exit signs on the left side of I-65 south of Louisville. Projects that had the largest benefit/cost ratios were generally those that had the smallest improvement costs. Projects ranged in cost from $2000 for the left-exit signs to more than $5 million for removal of rock cuts. Several other projects had improvement costs of more than $1 million. The next project (benefit/cost ratio of 33.16) was the installation of diagrammatic signs at the I-65 bridge in Louisville. A total of 41 of the 58 projects had a benefit/cost ratio of 1.0 or higher. This listing also provides a column of cumulative benefit/cost ratios that allows for the selection of projects by the benefit/cost method for a given budget.

The dynamic programming output was also obtained for assumed budgets of $5 million, $10 million, $15 million, $20 million, $25 million, and $30 million. For the $5 million budget, only 15 of the projects were selected; they had a combined benefit/cost ratio of 4.04. The combined benefit/cost ratios for other budgets were 2.88 for the $10 million budget, 2.32 for the $15 million budget, 2.00 for the $20 million budget, 1.80 for the $25 million budget, and 1.55 for the $30 million budget.

SUMMARY

The proposed Interstate Safety Improvement Program for Kentucky has been presented. A compilation of procedures, results, and priority rankings of the recommended improvements has been included. Considerable detail is presented in this report; however, reference should be made to Appendix G of the Kentucky Interstate Safety Improvement Program (8) for a user's guide to assist in the preparation of this program and its expansion into other highway systems. The original intent was to prepare a separate report as a user's guide; however, a more practical approach was taken, and a generalized guide was prepared and references were made to details in a companion report (2).

Evaluation of the Interstate Safety Improvement Program was not covered in this report or in the earlier report (2). Guidelines for the evaluation are presented in the FHWA Federal-Aid Highway Program Manual (1). The basic requirements for an evaluation should include the following:

1. An assessment of the costs and benefits of various means and methods used to eliminate identified hazards,
2. A comparison of accident data before and after the improvements,
3. Basic cost data used for each type of corrective measure and the number of each type of improvement undertaken during the year, and
4. Methods employed in establishing project priorities.

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Review of FHWA's Evaluation of Highway Safety Projects

G.A. FLEISCHER

The Federal Highway Administration has recently funded the development of a guide, Evaluation of Highway Safety Projects, and related training materials, which have been used in almost 30 workshops throughout the United States over the past two years. Evaluation methodology described in these materials is based on six related functions: (a) develop the evaluation plan, (b) collect and reduce data, (c) compare measures of effectiveness, (d) perform tests of significance, (e) perform economic analysis by using either the benefit/cost or the cost-effectiveness technique, and (f) prepare evaluation documentation. The document is described, with particular emphasis on the proposed economic-analysis methodology. Among the specific elements discussed are the following: the significance to decision makers of the benefit/cost and the cost-effectiveness ratios; appropriate notation for the discount factors; restricted use of the end-of-period assumption in the discounting models; appropriate techniques for dealing with project elements that have unequal service lives; discounting cash-flow sequences other than uniform series; discount rate; treatment of risk and uncertainty associated with forecasts of parameter values; and bibliography and list of selected readings.

Attempts to document procedures for the evaluation of publicly financed plans, programs, and projects are not new or novel. The application of these procedures within the context of highway safety has a briefer history, however. The establishment of the National Highway Safety Bureau (NHSB) in 1967, the predecessor agency to the National Highway Traffic Safety Administration (NHTSA), led directly to a new interest in this particular area of application. Recognizing the need for documentation of appropriate methodology, NHSB sponsored two efforts, one by Operations Research Incorporated and the other by the University of Southern California (1,2). The American Association of State Highway and Transportation Officials (AASHTO) funded a similar effort by Roy Jorgensen Associates, and the results were published by the Transportation Research Board in 1975 (3). In addition, the Red Book was revised by the Stanford Research Institute and published by AASHTO in 1978 (4); Section II of this edition describes economic analysis methodology.

These earlier efforts (and others) notwithstanding, the Federal Highway Administration (FHWA) concluded that an appropriate methodology should be developed with the FHWA that would (a) be suitable to the determination of the extent to which individual highway safety projects contribute to the reduction in the frequency, rate, and/or severity of traffic accidents and (b) link these beneficial consequences, if significant, to associated costs. The goal would be to assist "State and local agency personnel improve their ability to select and implement those improvements which provide the highest safety pay-off based on evaluation results of past experiences" (5, p. S-2).

Figure 1. Project purpose listing (sample).

Page ____ of ____

PROJECT PURPOSE LISTING

Evaluation No. A-1

Date/Evaluator 2/23/77/DDP **Checked by** 2/28/77/HES

Project No. P-1

Project Description and Location(s) *Replace four-way stop sign with two-phased fixed time controller at Broadway and 7th Streets*

Countermeasure(s)/Codes *Traffic Signal Installation (FHWA Code 11)*

Project Purpose	Justification
1. *To Reduce Right Angle Accidents.*	1. *High incidence (32 for 3 years) of right angle type accidents during pre-project period.*
2. *To Reduce Accident Severity.*	2. *Severity of accidents was great (F and I = 50%) due to high approach speeds.*
3. *To Minimize Intersection Delay.*	3. *Studies conducted on 5/76 and 9/76 showed high congestion and significant delay on minor streets.*

To this end a contract was awarded to Goodell-Grivas, Incorporated, in February 1977. (The amount of the award, after subsequent amendments, was approximately $77 500.) Final documentation was submitted to FHWA in the late fall of 1978 and, after certain modifications by that agency, the Procedural Guide was printed in January 1979 (6). The Instructor's Guide, class handout materials, visual aids, etc. were also prepared by FHWA.

From fall 1978 through summer 1980, approximately 27 workshops were conducted throughout the United States. These workshops, organized through the regional offices of FHWA, included participants from state departments of transportation, FHWA, and local road planners. There were approximately 600 participants as of summer 1980. Generally, instructors for the workshops were recruited from among FHWA regional staffs. In some instances, FHWA's Washington personnel served as instructors.

An important feature of this recent effort was a series of concurrent contracts with 24 states to actually put into effect the procedures outlined in the manual. Almost all the 24 states did so, but with mixed results. (A review of the users' experience is beyond the scope of this paper.) In my judgment, the absence of a users' follow-up explains in great part the failure of the earlier NHSB/NHTSA and AASHTO efforts to have any substantial impact.

FORMAT

The principal document is a set of explanatory and reference materials incorporated into a loose-leaf notebook. The main body of the notebook is a six-part discussion of the underlying philosophy, methodology, and techniques. (An overview is presented below.) Appendices include a glossary of terms, sample worksheets and data forms, statistical tables, compound-interest tables for the single-payment and uniform-series present-worth (PW) factors (i = 5, 6, 7, 8, 9, 10, 12, 14, and 16 percent), and a 17-item bibliography. Also included in the notebook are five fully worked out case studies.

OVERVIEW OF METHODOLOGY

In this section we will summarize briefly the principal functions, or elements, of the proposed methodology. The reader is referred to the source document (6) for a more-detailed presentation.

Function A: Develop Evaluation Plan

Step A1: Select the project to be evaluated. Among the selection criteria recommended are current and future highway safety project efforts, project implementation dates, data availability, sufficiency of accident data, and project purpose. A sample worksheet for project purpose is given in Figure 1.

Step A2: Stratify projects, i.e., aggregate similar projects into groups (where warranted), on the basis of countermeasure types and geometric and environmental characteristics.

Step A3: Select evaluation objectives and measures of effectiveness (MOEs). The fundamental objectives to be specified in all evaluations are total accidents, fatalities, injuries, and property damage. A sample worksheet that relates evaluation objectives to MOEs is given in Figure 2.

Step A4: Select the experimental plan most suitable for the evaluation study. Four alternatives are specified: (a) use plan before evaluation and also use after with control, (b) use plan before and after only, (c) use parallel study in which accident experience at the project site is compared with that at a similar control site(s), and (d) use plan be-

Figure 2. Objective and MOE listing (sample).

Page ____ of ____

OBJECTIVE AND MOE LISTING

Evaluation No. A-1

Date/Evaluator 2/23/77/DDP Checked by 2/28/77/HES

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate X or Frequency ____ (fundamental)
1. Total Accidents	1. Total Accidents/MV
2. Fatal Accidents	2. Fatal Accidents/MV
3. Injury Accidents	3. Injury Accidents/MV
4. PDO Accidents	4. PDO Accidents/MV
(project purpose)	(project purpose)
5. Sideswipe Accident	5. Sideswipe Accident/MV
6. Approach Speed	6. Mean Approach Speed

Figure 4. Data requirements form (sample).

Page ____ of ____

DATA REQUIREMENTS LISTING

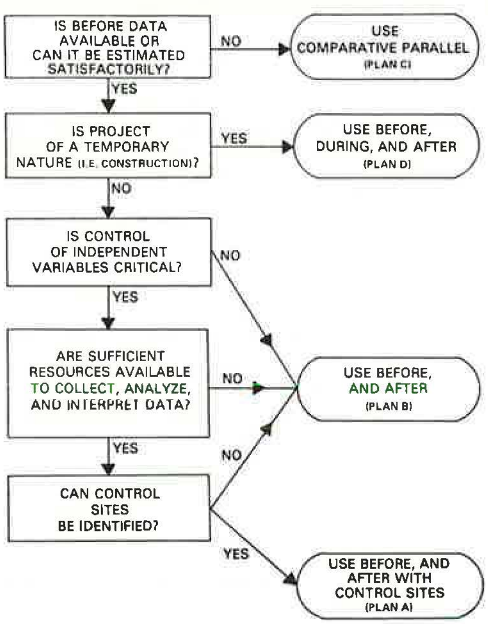
Evaluation No. A-1

Date/Evaluator 2/23/77/DDP Checked by 2/28/77/HES

Experimental Plan Before and After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Total Accidents Stratified by Severity	1. 3 years before (5/73 to 5/76) and after (5/77 to 5/80) project implementation for five sites.
2. Run-off-Road accidents stratified by lighting condition (night vs. day)	2. 3 years before (5/73 to 5/76) and after (5/77 to 5/80) project implementation for five sites.
3. Average annual daily traffic	3. For each year (5/73 thru 5/80) of the analysis for five sites.

Figure 3. Experimental plan selection.



fore, during, and after study. The rationale for this plan selection is summarized in Figure 3.

Step A5: Determine the data variables to be collected. At a minimum, these should include

1. For each project or group of projects, total cost (construction, labor, equipment rental, overhead, etc.); and
2. For the analysis periods, (a) number of years of accident data, (b) total number of accidents, (c) number of fatal accidents, (d) number of property-damage-only (PDO) accidents, and (e) number of vehicles for spot or intersection locations and vehicle miles of travel (VMT) for roadway section locations.

[Parenthetically, it may be noted at this point that the Summary specifies the collection of "complete accident history for at least three years before and after implementation" (5, p. S-11), whereas the Procedural Guide specifies the data be collected "for the analysis periods" (6, p. A-30). There appears to be some inconsistency here.]

Step A6: Determine the magnitude of the data needs, which includes estimates of sample size requirements for each data set. The form used for listing data requirements is shown in Figure 4.

Function B: Collect and Reduce Data

Step B1: Select the control sites.

Step B2: Collect data before study.
Step B3: Collect data after study.

Function C: Perform Comparison of MOEs

Step C1: Prepare data summary tables as illustrated in Figure 5.

Step C2: Calculate the percentage of change in the MOEs by estimating the expected values under the do-nothing assumption and then comparing the actual (observed) with the expected values. The worksheet for these steps is also given in Figure 5.

Function D: Perform Statistical Test of Significance

Step D1: Test accident MOE variables.

Step D2: Perform other statistical tests, especially those dealing with traffic performance characteristics. Among the statistical tests discussed in this section of the Procedural Guide are the F-test, t-test, test of proportions, and tests based on the chi-square and Poisson distributions.

Function E: Perform Economic Analysis

Function E is to be performed "whenever a statistically significant reduction in an MOE was observed in previous Function D" (6, p. S-22).

Step E1: Select the appropriate economic analysis technique, either the benefit/cost (B/C) or cost/effectiveness (C/E) ratio. The latter should be used when accident reduction effects are not expressed in monetary terms.

Step E2: Perform the B/C ratio technique (when all consequences are expressed in monetary terms). The B/C ratio technique consists of the following steps (the step numbers do not necessarily correspond to the numbers in the sample worksheet shown in Figure 6):

1. Determine initial implementation costs, i.e., design, construction, right-of-way, etc.
2. Determine net annual operating and maintenance costs. (Road user costs are ignored.)
3. Determine the annual safety benefits in terms of the number of fatal, injury, and PDO accidents prevented.
4. Assign a dollar value to each benefit category. "If a set of cost figures has been adopted by the agency, they should be used in the analysis and documented in the analysis report" (6, p. E-5). Included for possible use are 1975 cost data reported in a NHTSA document (7) and 1976 estimates reported by the National Safety Council (8). These are as follows:

Category	NHTSA (1975 $)	NSC (1976 $)
Fatality	287 175	125 000
Injury (avg)	3 185	4 700
PDO	520	670

5. Estimate the service life of the project, i.e., "that period of time [for] which the project can be reasonably expected to impact accident experience" (6, p. E-7). Selected service-life criteria used by FHWA are provided in an appendix.
6. Estimate the salvage value of the project or improvement at the end of its service life.
7. Determine the appropriate interest rate to be used in discounting future consequences. No particular rate is proposed. However, "an annual interest rate of 10% may be used when standard policies do not dictate otherwise" (6, p. E-10).
8. Calculate the B/C ratio based on either the equivalent uniform annual cost (EUAC) and equivalent uniform annual benefit (EUAB) or on the present worth of costs (PWOC) and the present worth of benefits (PWOB). The authors of the guide assert that the present-worth formulation "cannot be used for projects that have multiple countermeasures with unequal service life" (6, p. E-12). A sample B/C analysis worksheet is shown in Figure 6.

Step E3: Perform the C/E technique (when safety benefits are not expressed in monetary terms). The C/E technique consists of the following steps:

1. Determine initial implementation costs;
2. Determine net annual operating and maintenance costs;
3. Select the units of effectiveness to be used in the analysis, e.g., the average number of accidents prevented per year;
4. Determine the yearly (nonmonetary) benefits for the project;
5. Estimate the service life;
6. Estimate the net salvage value;
7. Determine the appropriate interest rate;
8. Calculate either EUAC or PWOC [the authors assert that PWOC should not be used when countermeasures have unequal service lives; however, EUAC is "appropriate for both unequal and equal service lives" (6, p. S-26)];
9. Calculate the average annual benefit $\overline{B}$ in the desired units of effectiveness:

$$\overline{B} = \sum_{y=1}^{m} B_y/m \tag{1}$$

Figure 5. MOE data comparison worksheet (sample).

Page ____ of ____

MOE DATA COMPARISON WORKSHEET

Evaluation No. C-1
Date/Evaluator 8/22/77/MUL Checked by 8/29/77/HES
Experimental Plan Before - After with Control

MOE Data Summary	Control Before (B_{CF})	Control After (A_{CF})	Project Before (B_{PF})	Project After (A_{PF})	Expected After Rate X or Freq. ___	Percent Reduction (%)
Accidents:						
(Fundamental)						
(3 Years)						
Total Accidents	30	21	24	21		
Fatal Accidents	9	6	12	3		
Injury Accidents	12	6	12	6		
PDO Accidents	9	9	0	9		
(Project Purpose)						
Total ROR Accidents	15	12	12	9		
Exposure (3 Years)						
units: ___V, or _M_VM	5.01	5.37	3.93	4.74		
MOE Comparison Rate X or Frequency ___	B_{CR}	A_{CR}	B_{PR}	A_{PR}	E_R	(%)
Total Accidents/MVM	5.99	3.91	6.11	4.43	3.99	-11.0
Fatal Accidents/MVM	1.80	1.12	3.05	0.63	1.90	66.8
Injury Accidents/MVM	2.40	1.12	3.05	1.27	1.42	10.6
PDO Accidents/MVM	1.80	1.68	0	2.53	0	-
Total ROR/MVM	2.99	2.23	3.05	1.90	2.27	16.3

Figure 6. B/C analysis worksheet (sample).

Evaluation No: CS-3
Project No: P-3
Date/Evaluator: 8-9-77/GCD

1. Initial Implementation Cost, I: $ 450,000
2. Annual Operating and Maintenance Costs Before Project Implementation: $ 0
3. Annual Operating and Maintenance Cost After Project Implementation: $ 2,500
4. Net Annual Operating and Maintenance Costs, K (3-2): $ 2,500
5. Annual Safety Benefits in Number of Accidents Prevented:

Severity	Expected	- Actual	= Annual Benefit
a) Fatal Accidents (Fatalities)	8.8	1.3	7.5
b) Injury Accidents (Injuries)	22.9	8.7	14.2
c) PDO Accidents	26.1	15.0	11.1

6. Accident Cost Values (Source NSC):

Severity	Cost
a) Fatal Accident (Fatality)	$ 125,000
b) Injury Accident (Injury)	$ 4,700
c) PDO Accident	$ 670

7. Annual Safety Benefits in Dollars Saved, $\bar{B}$:

5a) x 6a) = 7.5 × $125,000 = $937,500
5b) x 6b) = 14.2 × $4,700 = $66,740
5c) x 6c) = 11.1 × $670 = $7,437
Total = $ 1,011,677

8. Services life, n: 20 yrs
9. Salvage Value, T: $ 0
10. Interest Rate, i: 10 % = 0.10

11. EUAC Calculation:

CR_n^i = 0.1175
SF_n^i = 0.0175
EUAC = I (CR_n^i) + K - T (SF_n^i)
= $450,000(0.1175) + $2,500 - 0 = $55,375

12. EUAB Calculation:

EUAB = $\bar{B}$
= $1,011,677

13. B/C = EUAB/EUAC = $1,011,677/$55,375 = 18.3

14. PWOC Calculation:

PW_n^i =
SPW_n^i =
PWOC = I + K (SPW_n^i) - T (PW_n^i)

N/A

15. PWOB Calculation:

PWOB = $\bar{B}(SPW_n^i)$

16. B/C = PWOB/PWOC =

where $\bar{B}_y$ is benefits in project year y and m is number of years since project implementation; and

10. Calculate the ratio of annualized project costs to average annual benefits. A sample C/E analysis worksheet is shown in Figure 7.

Function F: Prepare Evaluation Documentation

Step F1: Organize evaluation study materials.
Step F2: Assess the project in terms of its degree of success.
Step F3: Determine reasons for project failure, if indicated.
Step F4: Identify evaluation results for inclusion in the aggregate data base.
Step F5: Discuss and document the evaluation study results.

CRITIQUE

Significance of B/C Ratio

As noted above, the proposed procedure calls for the determination of a B/C ratio in those instances in which the traffic safety consequences, especially the costs of deaths and injuries, are expressed in monetary terms. There are two alternative equations:

$$B/C = EUAB/EUAC \quad \text{(annualized approach)} \tag{2}$$

$$B/C = PWOB/PWOC \quad \text{(present-worth approach)} \tag{3}$$

See Figure 6 (steps 13 and 16) for illustration.

The authors do recognize that there are a number of analysis techniques other than the B/C ratio method--for example, (internal) rate of return and net present worth. They also indicate, quite correctly, that "any project that has a benefit/cost ratio greater than 1.0 is considered economically successful" (6, p. E-3). Unfortunately, they do not emphasize that the B/C ratios do not reflect the relative desirability of alternative projects. Indeed, the point is not made at all in either the Summary or the Procedural Guide. In the absence of such a caveat, it is not only possible but likely that unsophisticated users will attempt to rank-order projects on the basis of their respective B/C ratios.

Significance of C/E Ratio

"An alternative to the benefit/cost technique is to determine the cost to the agency of preventing a single accident and then deciding whether the project cost was justified. This is the cost/effectiveness technique" (6, p. E-3).

There are two problems, at least, when one uses this technique. The first arises from the fact that a unique C/E value can only be derived when there is a unique MOE for the project. As illustrated in Figure 7, for example, the reduction of 10.6 accidents per year is effected by an EUAC of $13 216 (step 9) or a C/E value of $1250 per accident prevented (step 11). But suppose an EUAC of, say, $13 200 resulted in a reduction of two injury accidents and eight PDO accidents per year. A unique expression for the C/E value is not possible unless the equivalency between injury and PDO accidents is specified. It should be noted that the authors do recognize this problem: "This [C/E] can only be

Figure 7. C/E analysis worksheet (sample).

Evaluation No: CS - I

Project No: P - I

Date/Evaluator: 12-3-77 / ABE   Checked by: 12/10/77/HES

1. Initial Implementation Cost, I: $ 80,000

2. Annual Operating and Maintenance Costs Before Project Implementation: $ 0

3. Annual Operating and Maintenance Costs After Project Implementation: $ 200

4. Net Annual Operating and Maintenance Costs, K (3-2): $ 200

5. Annual Safety Benefits in Number of Accidents Prevented, $\bar{B}$:

Accident Type	Expected - Actual = Annual Benefit
Total Accidents (3 Years)	133.0 - 101
Total Accidents/Yr.	44.3 - 33.7
Total	44.3 - 33.7 = 10.6

Accidents Prevented per yr. = 10.6

6. Service Life, n: 10 yrs.

7. Salvage Value, T: $ 0

8. Interest Rate: 10 % = 0.10

9. EUAC Calculation:

CR_n^i = 0.1627

SF_n^i = 0.0627

EUAC = I (CR_n^i) + K - T (SF_n^i)

= 80,000 (0.1627) + 200 - 0 = $ 13,216

10. Annual Benefit:

$\bar{B}$ (from 5) = 10.6

11. C/E = EUAC/$\bar{B}$ = $13,216/10.6 ≅ $1,247 ≈ $1,250

12. PWOC Calculation:

PW_n^i = ______

SPW_n^i = ______   N/A

PWOC = I + K (SPW_n^i) - T (PW_n^i)

13. Annual Benefit

n (from 6) = yrs.

$\bar{B}$ (from 5) = accidents prevented per year

14. C/E = PWOC(SF_n^i)/$\bar{B}$

performed for one type of accident at a time" (6, p. E-3).

The second problem--perhaps more important than the first--is that C/E values are useful in selecting from among alternatives in only three very special situations: dominance in both costs and effectiveness, projects that have equal effectiveness, or projects that have equal costs (9). Otherwise, given two or more projects with unequal costs and effectiveness, the relative attractiveness of these alternatives is not reflected by their respective C/E ratios.

It is not entirely clear what the authors would have the users do with the resulting C/E values. The discussion in the text appears incomplete. Their intent may be inferred, however, by reference to the sample problems in the Procedural Guide. At the end of one of these problems, there is the statement: "The results of this analysis may be interpreted by comparing this C/E value with those from other competing highway safety projects" (6, p. E-19). Exactly how this comparison is to be done and its validity are unclear. Certainly it is not correct to rank-order alternative projects solely on the basis of their C/E values.

Notation

Four compound-interest factors are included in the Procedural Guide: (a) capital recovery, (b) sinking fund, (c) series PW, and (d) single-payment PW. The four factors and their algebraic formats are given in the first two columns of Table 1 (i is the interest rate; N is the number of interest periods for compounding and discounting). Unfortunately, the superscript-subscript notational scheme adopted by the authors (third column of Table 1) is old-fashioned. The American National Standards Institute (ANSI) Committee Z94 recommended two standardized notational schemes in 1970--mnemonic and functional (10). These are shown in the last two columns of Table 1. Virtually all engineering economy textbooks published during the past decade have adopted one of these two schemes. (The new ANSI committee report, to be published shortly, will recommend universal adoption of the functional notation.)

End-of-Period Convention

The evaluation models described in the Procedural Guide imply the end-of-period convention for cash flows and compounding and discounting. For example, the series PW factor is used to determine the equivalent present value of annual safety benefits as well as the equivalent present value of net annual operating and maintenance costs. Specifically,

$$PWOC = I + K(P/A, i, N) - T(P/F, i, N) \quad (4)$$

$$PWOB = \bar{B}(P/A, i, N) \quad (5)$$

where

I = initial implementation cost,
K = net annual operating and maintenance costs,
T = salvage value,
$\bar{B}$ = annual safety benefits in dollars saved,
N = service life,
(P/A, i, N) = uniform-series PW factor, and
(P/F, i, N) = single-payment PW factor.

These formulations imply that annual effects--operating and maintenance costs and safety benefits--occur at the end of each period. These implications, or assumptions, are unwarranted. Annual operating and maintenance costs, for example, are likely to occur at a number of times within the year, say, quarterly, monthly, or daily. And safety benefits, in a statistical sense, are distributed uniformly over the year. Thus a more-reasonable discounting model should provide for continuous cash flows within the year with continuous discounting at effective interest rate i. (As a rule of thumb, the

Table 1. Comparison of notational schemes.

Factor	Algebraic Format	Notational Scheme		
		FHWA	Mnemonic	Functional
Capital recovery	$i(1+i)^N/[(1+i)^N-1]$	CR_{ni}	(CR, i, N)	(A/P, i, N)
Sinking fund	$i/[(1+i)^N-1]$	SF_{ni}	(SF, i, N)	(A/F, i, N)
Series PW	$[(1+i)^N-1]/i(1+i)^N$	SPW_{ni}	(SPW, i, N)	(P/A, i, N)
Single-payment PW	$1/(1+i)^N$	PW_{ni}	(PW, i, N)	(P/F, i, N)

continuous model is more accurate than the end-of-period model when there are at least four cash flows within the period.)

The discount models proposed in the Procedural Guide are easily modified to reflect the continuous-cash-flow assumption. One simply uses the correction factor i/ln(1+i) in those instances in which there are at least four occurrences within the year. Thus,

$$PWOC = I + K[i/\ln(1+i)](P/A,i,N) - T(P/F,i,N) \quad (6)$$

$$PWOB = \overline{B}[i/\ln(1+i)](P/A,i,N) \quad (7)$$

The magnitude of the correction factor is a nonlinear function of the interest rate. When i = 10 percent, for example, i/ln(1+i) = 1.049. That is, the end-of-period assumption understates the annual consequences by about 5 percent. This error, I believe, is not insignificant.

Treatment of Unequal Service Lives

The authors properly draw the attention of users to potential problems created when projects contain multiple countermeasures that have unequal service lives. They are quite correct in stating: "While the economic evaluation of a completed project does not involve comparison of alternatives, the determination of present worth of costs for improvements with unequal service lives becomes a problem similar to the issue of comparison of alternative projects" (6, p. E-8). The governing principle here is that all alternatives must be measured over a common planning horizon in order for differences between alternatives to be fully and fairly assessed. Thus, if a component of a project has a service life n that is shorter than the life of the project itself N, the analyst must assess the consequences between periods n and N to complete the evaluation.

After making this point, the authors assert that only the annualized B/C formulation can be used for projects that have multiple countermeasures with unequal service lives; the PW formulation cannot be used. Put somewhat differently, the authors' position is that the B/C ratio must be based on the annualized approach: B/C = EUAB/EUAC. This instruction is misleading, if not incorrect. It stems from a failure to appreciate fully the assumption inherent in the annualized formulation.

Either the annualized or the PW formulation, properly applied, can lead to valid analysis in the presence of alternatives (or components) that have unequal lives. This can be illustrated by a very simple numerical example. Consider two alternatives, X and Y, with cash flows as follows:

Alternative	End of Period 0	1	2	3	4
X	-100	40	40	40	40
Y	-80	60	60		

(For ease of calculation, we will assume that i = 0. This simplification has no bearing on the underlying principles, but it does simplify the arithmetic.) It may be readily seen that

$$PWOB(X) - PWOC(X) = 60 \quad (8)$$

$$PWOB(Y) - PWOC(Y) = 40 \quad (9)$$

$$EUAB(X) - EUAC(X) = 60/4 = 15 \quad (10)$$

$$EUAB(Y) - EUAC(Y) = 40/2 = 20 \quad (11)$$

Which of the above is correct? Is X preferred to Y or is Y preferred to X? The answer is that no conclusion can be drawn because the analysis is incomplete at this point. If we adopt the assumption that a replacement for Y will be implemented at the end of two periods and if this replacement (Y') is identical in every respect to the original Y, then the net PW of this four-period sequence of cash flows for Y and its successor (Y') is 40 + 40 = 80 and its net benefit per period is 80/4 = 20. Now the alternatives may be compared by either the annualized or the PW formulation because the planning horizon is constant for both:

$$PWOB(X) - PWOC(X) = 60 \quad (12)$$

$$PWOB(Y+Y') - PWOC(Y+Y') = 80 \quad (13)$$

$$EUAB(X) - EUAC(X) = 60/4 = 15 \quad (14)$$

$$EUAB(Y+Y') - EUAC(Y+Y') = 80/4 = 20 \quad (15)$$

It will be noted, of course, that the proper conclusion would have been determined initially by simply using the annualized formulation. But this is so only because of this critical assumption: Replacement(s) for the shorter-lived investment is (are) identical in every respect to the original investment. This assumption is commonly employed in engineering economy textbooks, homework, exams, etc., and students form the unfortunate impression that the annualized approach always yields valid results when one is dealing with unequal lives of components of the analysis.

Parenthetically, it may be noted that the criteria used in the preceding paragraph to illustrate this issue are

1. Maximize (net PW) = max (PWOB - PWOC), and
2. Minimize (net EUAB) = min (EUAB - EUAC).

These were selected because of the intention here to focus on the issue of unequal lives, and these two criteria avoid the ranking problem that arises when the B/C ratio method is used. To demonstrate that the principle outlined above is also valid when the B/C criterion is used, observe the formulations in Table 2. (Note that the B/C ratios for Y and Y+Y' are equal because of our earlier assumption of identical replication. This will only be true under this particular condition.) The two alternatives of interest here are X and Y+Y'. Since each results in a B/C ratio greater than unity, each is preferred to the do-nothing alternative. To determine whether Y is preferred to X (or, more precisely, to determine

Table 2. Analysis by using B/C criterion.

		Formulation	
Alternative	Life	PW	Annualized
X	4	PWOB/PWOC = 160/100 = 1.6	EUAB/EUAC = 40/25 = 1.6
Y	2	PWOB/PWOC = 120/80 = 1.5	PWOB/PWOC = 60/40 = 1.5
Y + Y′	2 + 2	PWOB/PWOC = 240/160 = 1.5	PWOB/PWOC = 60/40 = 1.5

whether Y+Y' is preferred to X), the incremental B/C ratio must be computed:

Incremental	Formulation	
Computation	PW	Annualized
Benefits	240 - 160 = 80	60 - 40 = 20
Costs	160 - 100 = 60	40 - 25 = 15
B/C ratio	80/60 = 1.33	20/15 = 1.33

In either formulation, the B/C ratio exceeds unity, and thus, on the basis of this criterion, alternative(s) Y+Y' is (are) preferred to alternative X.

The criticality of the identical-replication assumption may be illustrated by a simple extension of the above example. Suppose that the replacement (Y') to the original Y costs 110 units at the start of the third period. Other cash flows are the same:

	End of Period				
Alternative	0	1	2	3	4
Y	-80	60	60		
Y'			-110	60	60

Now the comparison with X is as follows:

$$PW(X) = 60 \quad (16)$$

$$PW(Y + Y') = 50 \quad (17)$$

$$EUAB(X) = 60/4 = 15 \quad (18)$$

$$EUAB(Y + Y') = 50/4 = 12.5 \quad (19)$$

Without careful attention to the cash flows associated with the replacement(s), simplistic use of the annualized approach may lead to improper results.

Because the identical-replication assumption is seldom justified outside the artificial world of textbooks, it is recommended that analysts consider carefully the cash-flow consequences between the end of the service life of the shorter-lived investment and the end of the planning horizon. Otherwise, serious errors could result.

Time Distribution of Costs and Benefits

The proposed procedure does not give guidance to users as to the proper treatment of costs and benefits when they vary over the planning horizon (life of the project). Both the annualized (uniform-series) and PW formulations as proposed by the authors infer that annual operating and maintenance costs, as well as annual safety benefits, occur uniformly at the end of each year throughout the planning horizon. Specifically,

$$B/C = \overline{B}/[I(A/P, i, N) + K - T(A/F, i, N)] \quad (20)$$

or

$$B/C = [\overline{B}(P/A, i, N)]/[I + K(P/A, i, N) - T(P/F, i, N)] \quad (21)$$

where (A/P, i, N) is the capital recovery factor and (A/F, i, N) is the sinking fund factor.

There are, however, several other patterns of consequences that the analyst may well encounter in real-world problems. Let C_j be the magnitude of the consequence in the jth period. Compound-interest factors exist in the engineering economy literature for the following sequences:

1. Uniform: $C_1 = C_2 = \ldots = C_N$;
2. Arithmetic gradient: $C_{j+1} = C_j + G$, where G is the amount of periodic increase or decrease; and
3. Geometric gradient: $C_{j+1} = (1+a)C_j$, where a is the rate of period increase or decrease.

In the event that the consequences from period to period are not described by one of these well-behaved series (i.e., the consequences are irregular), the following models may be used:

$$PW = \sum_{j=i}^{N} C_j(1 + i)^{-j} \quad (22)$$

$$\text{Equivalent uniform annual amount} = (A/P, i, N) \sum_{j=i}^{N} C_j(1 + i)^{-j} \quad (23)$$

Our point here is that the computational models provided in the Procedural Guide, based on the uniform-series assumption, are overly simplified. Actual experience or projections are likely to be best described by arithmetic or geometric gradient series or, more likely, by the generalized formulation, which also accommodates an irregular pattern of consequences. Thus it is recommended that the economic models be modified as follows:

$$B/C = PWOB/PWOC = \sum_{j=1}^{N} B_j(1 + i)^{-j}/[I - T(1 + i)^{-N} + \sum_{j=i}^{N} K_j(1 + i)^{-j}] \quad (24)$$

where all notation is as defined earlier except that B_j is the annual safety benefits in dollars in the jth period and k_j is the cost of operations and maintenance in the jth period.

Note that the above formulation assumes that all elements of costs and benefits occur at the end of their respective periods. (The initial cost, it is assumed, occurs in a lump sum at the beginning of the first period.) In the event that the continuous-cash-flow convention appears more appropriate, the factor for converting from end of period to during period is simply i/ln(1+i).

Discount Rate

As noted previously, the authors suggest that "an annual interest rate of 10% may be used when standard policies do not dictate otherwise" (6, p. E-10). The justification for this value is not provided, however. [The figure of 10 percent is probably based on the 1971 recommendation of the U.S. Office of Management and Budget (11).] Some additional substantiation would be welcome. In any event, my view, admittedly without proof, is that the 10 percent rate understates the true marginal cost of capital in the United States at the present time.

Risk and Uncertainty

The principal focus of the manual is the historical performance of highway safety projects and improvements. Nevertheless, it is clear that evaluations of past efforts are relevant insofar as they affect future decisions. To determine that some previously implemented project or improvement has been cost-beneficial or cost-effective is a sterile exercise unless this information can be used with respect to future decisions about similar or identical investments. To put this somewhat differently, a successful past decision should be replicated in the future, assuming, of course, that the future will yield the same consequences as those previously experienced.

It is this last assumption that is most troubling. There is no assurance that future consequences will in fact be repeated. The reduction of an average of five injury accidents per year over the past six years, for example, may not be repeated over the next six years (or even 20 years) because of a variety of factors: changes in traffic density, vehicle speeds, weather conditions, vehicle design characteristics, and so on. Forecasts of specific costs of operation and maintenance over a 20-year planning horizon may or may not be reasonably accurate. The elements of the analysis--operational results and unit costs--are random variables. The user should be advised to recognize this inherent variability and deal with the issue formally in the analysis. Surprisingly, with the singular exception of the use of sensitivity analysis for the discount rate, this issue of risk and uncertainty is not addressed in the manual. (Note that this issue is separable from the question of statistical significance of observed phenomena.)

References

Short lists of suggested readings are included in each section of the Procedural Guide. In the Economic Analysis section, Function E, there is a list of eight references. There is also a 17-entry bibliography included among the appendices.

Unfortunately, neither the suggested readings nor the bibliography contain annotated references, and thus the user has no guidance as to how they are to be used. The references are uneven in quality. They are addressed to quite different issues, even within the same list of suggested readings, and not all of the text of certain individual references is relevant. The user needs some help, and the manual provides none.

It should also be noted that many of the references in the suggested readings are incomplete. Only the author, title, and date are given. In the absence of publisher information, including mailing address, the interested reader has no way of knowing how to obtain the reference.

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Optimal Allocation of Funds for Highway Safety Improvement Projects

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In the allocation of funds and the scheduling of projects, alternative improvements for all possible locations must be evaluated in a multiyear framework in order to optimize the effectiveness of the entire highway safety improvement program within the constraint of a given budget. A procedure is developed that can be used for optimal allocation of funding available for highway safety improvement projects on a statewide basis. In the model, the reduction in the total number of accidents is the measure of effectiveness. The constraints include total funding available each year. The model formulation can consider carry-over of unspent funds. A stochastic version of the model is also discussed. A variety of other conditions required by or associated with the policies and objectives of the transportation agency can also be formulated as binding constraints. The application of the model is illustrated. Through a series of sensitivity analyses the impact of the funding level on the effectiveness of a hypothetical highway safety program is evaluated.