MEMORANDUM

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Subject:

A method for ranking a mixed set of independent and mutually exclusive projects for possible adoption in Chapter 8 of the Highway Safety Manual.

Topic:

A procedure to rank a mixed set of independent and mutually exclusive projects with a limited budget is presented. This procedure ranks and selects projects with a limited budget. It assures that the optimum set of independent and mutually exclusive projects is selected. This procedure is recommended for the revised Chapter 8 of the HSM.

Background:

The objective of ranking alternatives is to rank the alternatives that give the greatest return in safety benefits for the project costs invested, that is, the greatest BCR or IBCR. The IBCR method for ranking mutually exclusive projects replaces a previously selected project if the IBCR for a higher cost project is greater than 1. This can mean that a project with a BCR much greater than 1 can be replaced. This procedure assures that projects with the highest BCR or IBCR under consideration are selected. Independent projects and mutually exclusive projects are selected based on the next highest BCR or IBCR, respectively, within the limits of the budget. This assures that the selected projects, within the limit of the budget, achieve the greatest return for the project costs invested.

Procedure:

At each step in selecting the next ranked alternative, independent or mutually exclusive, the alternative with the next highest BCR or IBCR, respectively, is selected in decreasing order. To be considered, mutually exclusive projects must first at one step have one of their set of projects ranked and selected with the highest BCR. These steps in ranking are continued until the budget runs out.

Example:

The example from Chapter 8 of the HSM gives a mixed set of independent and mutually exclusive projects. These can be ranked in stepwise fashion until the budget has been expended.

Mutually Exclusive Projects						
	Benefits (PVB)	**Costs (PVC)**	**Benefit Cost Ratio (BCR)**	**$IBCR_{2\text{-}j}$**	**$IBCR_{1\text{-}j}$**	**Rank Select Projects**
Intersection 2 – Alt 3	-$379,365	$213,195	-1.78			BCR negative
Intersection 2 – Alt 2	$642,734	$213,195	3.01			
(Δ_1-Δ_2)	$3,674,089	$1,286,805		2.86		
Intersection 2 – Alt 1	$4,316,570	$1,500,000	2.88			3 replaces Alt 2
(Δ_4-Δ_2)	$-1,819,441	$14,786,805		-0.12		
(Δ_4-Δ_1)	$-1,854,395	$13,500,000			-0.14	
Intersection 2 – Alt 4	$2,462,175	$15,000,000	0.16			Not ranked <1.0
Independent Projects						
Segment 5	$7,829,600	$3,500,000	2.24			6
Segment 7	$7,000,000	$3,100,000	2.26			5
Segment 6	$6,500,000	$2,750,000	2.36			4
Segment 1	$3,517,400	$250,000	14.1			1
Segment 2	$2,936,700	$225,000	13.1			2

Procedure Setup:

First, the BCRs for all projects, independent and mutually exclusive, must be calculated. For example, for Intersection 2, alternatives 3 and 2, the BCRs are;

$$BCR_{Alt\,3} = \frac{PVB_{Alt\,3}}{PVC_{Alt\,3}} = \frac{\$ - 379{,}365}{\$213{,}195} = -1.78$$

$$BCR_{Alt\,2} = \frac{\$642{,}734}{\$213{,}195} = 3.01$$

Second, the mutually exclusive projects are sorted into increasing project cost order. All projects with BCRs greater than or equal to 1 are considered.

Steps in the Ranking Procedure:

At each step the highest BCR (or IBCR) is selected. A mutually exclusive alternative is considered only after the alternative has been selected, based on its BCR. The following describes the order of selection (or ranking).

Step 1 - The independent project, Segment 1, is selected first and ranked #1, with the highest BCR of 14.1.

Step 2 - The independent project, Segment 2, is selected with the next highest BCR of 13.1, and ranked #2.

Step 3 – The BCR for the mutually exclusive project, Intersection 2, Alt 2, has the next highest BCR of 3.01, so is selected next, and ranked #3. Other higher cost mutually exclusive alternatives for Intersection 2 can now be considered.

Step 4 – All unranked independent projects and the remaining mutually exclusive can be considered for ranking and selection next. The BCRs for the remaining segments and the intersection alternatives are calculated previously as;

BCR of Segment 5 is 2.24

BCR of Segment 7 is 2.26

BCR of Segment 6 is 2.36

BCR of Intersection 2, Alternate 1 is 2.88

IBCR of Alternate 2 to Alternate 1 is 2.86

IBCR of Alternate 2 to Alternate 4 is -0.12

The IBCRs for higher cost projects over Project 2 are;

$$IBCR_{1-2} = \frac{\Delta PVB_{1-2}}{\Delta PVC_{1-2}} = \frac{\$3{,}674{,}089}{\$1{,}286{,}805} = 2.86$$

$$IBCR_{4-2} = \frac{\Delta PVB_{4-2}}{\Delta PVC_{4-2}} = \frac{\$1{,}819{,}441}{\$14{,}786{,}805} = -0.12$$

Intersection 1 for Alternative 1 is selected with a BCR of 2.88 and IBCR of 2.86, and ranked #3. It would be selected based on either measure. Since it is a mutually exclusive project, it replaces Alternative 2, which is currently ranked third.

Note 1: The BCR of 2.88 shows that the total benefits for Alt 1 gives a greater return for the invested total costs, than the incremental benefits over the incremental costs with an IBCR of 2.86.

Note 2: If one of the remaining segments had a BCR greater than 2.88, it would have been selected.

Step 5 – The remainder of the projects with positive BCRs or IBCRs are ranked by their relative values, until the budget is expended. Segment 6 with a BCR of 2.36 is ranked next, as rank 4.

BCR of Segment 5 is 2.24 IBCR of Alt1 to Alt 4 is -0.14

BCR of Segment 7 is 2.26

BCR of Segment 6 is 2.36

Step 6 – Segment 7 with BCR of 2.26 is ranked next, as rank 5

Step 7 – Segment 5 with BCR of 2.24 is ranked last, as rank 6

Selection of Projects with a Budget = $1,000,000:

If the budget were $1,000,000, the selected projects would be;

Rank	Project	Project Cost	Cumulative Project Cost	
1	Segment 1	$250,000	$250,000	
2	Segment 2	$225,000	$475,000	
3	Intersection 2, Alt 1	$1,500,000	$1,975,000 > $1,000,000	No!
3`	Intersection 2, Alt 2	$213,195	$688,195 < $1,000,000	

The procedure would have stopped with only two projects selected, Segments 1 and 2. However, since Alternative 2 had been replaced by Alternative 1, it can be considered. As shown in row 4 of the table, it can be selected for implementation. No other projects can be constructed with the available budget because project costs are too high. A budget of $1,975,000 would be needed to select the Intersection 2, Alternative 1 project.

Conclusion and Recommendation:

It is often assumed that there is no straight-forward method to rank and select a mixed set of independent and mutually exclusive projects. The method defined and demonstrated here can easily rank and select the optimal set of projects for economic effectiveness from mix projects. Projects are added to the selected set based on the next largest BCR or IBCR within available budget constraints.

It is recommended that this approach to rank and select projects for a mixed set of independent and mutually exclusive projects with a limiting budget be added to Chapter 8 of the Highway Safety Manual. The draft of this section of Chapter 8 is given in the appendix following.

APPENDIX

Draft of Section for Chapter 8 on Ranking Mixed Independent and Mutually Exclusive Projects

Ranking and Selection from Mixed Independent and Mutually Exclusive Projects

This technique ranks projects with the highest BCR or IBCR, respectively, for independent and mutually exclusive projects. At each step, the next highest BCR or IBCR is ranked in descending order to achieve the optimal use of the budget.

Table 8-12. BCR and IBCR Ranking Mixed Independent and Mutually Exclusive Projects

Mutually Exclusive Projects						
	Present Value of Benefits (PVB)	Present Value of Cost (PVC)	Benefit Cost Ratio (BCR)	$IBCR_1$	$IBCR_2$	Selected Project
Intersection 2 – Alt 3	$-379,365	$213,195	-1.78			BCR negative
	(Alt 3 dropped with negative BCR)					
Intersection 2 – Alt 2	$642,734	$213,195	3.01			~~Rank #3~~
{A1-A2}	ΔPVB = $3,673,836	ΔPVC = $1,286,805		2.86 > 1		Alt 1 replaces Alt 2 Rank #3
Intersection 2 – Alt 1	$4,316,570	$1,500,000	2.88			
{A4-A2}	ΔPVB = -$1,819,441	ΔPVC = $14,786,805		-0.12		
{A4-A1}	ΔPVB = -$1,854,395	ΔPVC = $13,500,000			-0.14	No
Intersection 2 – Alt 4	$2,462,175	$15,000,000	0.16			{Not ranked <1.0}
Independent Projects						
Segment 1	$3,517,400	$250,000	14.1			1
Segment 2	$2,936,700	$225,000	13.1			2
Segment 5	$7,829,600	$3,500,000	2.24			6
Segment 6	$6,500,000	$2,750,000	2.36			4
Segment 7	$7,000,000	$3,100,000	2.26			5

* NPV Rank shown for comparison with BCR rank

Step 1 - Calculate the BCRs for all projects. Section 7.6.1.2 illustrates the process for calculating the BCR for each project.

Step 2 - Organize projects by project cost. The mutually exclusive projects are ordered, as shown in Table 8-12.

Step 3 - Rank the project with the highest BCR, independent or mutually exclusive, first. That is Segment 1 with BCR = 14.1, as rank #1.

Step 4 - Rank and select the next highest BCR, or IBCR, that is Segment 2 with BCR = 13.1, as rank #2.

Step 5 - Rank and select the next highest BCR, or IBCR, that is Intersection 2, Alternative 2 with BCR = 3.01, as rank #3. Since it is mutually exclusive, other higher costs mutually exclusive projects for Intersection 2 can now be considered.

Step 6 - Rank and select the next highest BCR, or IBCR, for higher cost mutually exclusive alternatives for Intersection 2.

The eligible independent projects are;

Segment 5 – BCR = 2.24

Segment 6 – BCR = 2.36

Segment 7 – BCR = 2.26

The eligible mutually exclusive projects at Intersection 2 are;

Alternative 1 – $BCR_1 = 2.88$

Alternative 1 – $IBCR_{1\text{-}2} = \frac{\$3{,}673{,}836}{\$1{,}286{,}805} = 2.86$

Alternative 4 – $IBCR_{4\text{-}2} = -0.12$

Alternative 1 has the highest BCR, so it is selected and ranked next. It is a mutually exclusive project for Intersection 2. Intersection 2, Alternative 2 is already ranked #3, so Alternative 1 will replace Alternative 2 and be ranked #3.

Step 7 Rank and select the next highest BCR, or IBCR, for higher cost mutually exclusive projects for Intersection 2.

The eligible independent projects are;

Segment 5 – BCR_5 – 2.24

Segment 6 – BCR_6 – 2.36

Segment 7 – BCR_7 – 2.26

The remaining mutually exclusive alternative has a IBCR that is negative, and therefore not eligible;

Alternative 4 – $IBCR_{4\text{-}1} = \frac{\Delta PVB_{4-1}}{\Delta PVC_{4-1}} = \frac{\$ -1{,}854{,}395}{\$13{,}500{,}000} = -0.14$

Therefore, Segment 6 with $BCR_6 = 2.36$ is ranked #4.

Step 8 - Rank and select the next highest BCR, or IBCR. The only mutually exclusive alternative has a negative IBCR and therefore is not eligible.

The eligible independent projects remaining are;

Segment 5 – BCR_5 – 2.24

Segment 7 – BCR_7 – 2.26

Therefore, Segment 7 with a $BCR_7 = 2.26$ is ranked #5

Step 9 - Rank Segment 5 as #6, since it is the only eligible project remaining, with a BCR of 2.24.