Critique of Chapter 8, "Prioritize Projects," HSM 2010

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I. BACKGROUND

There are some primary problems with Chapter 8 of the Highway Safety Manual (HSM). These are;

- The concepts of "independent" and "mutually exclusive" projects are not distinguished and defined.
- The inappropriate use of Net Present Value (NPV) to rank projects when the total project costs are not equal.
- The lack of use of the Benefit Cost Ratio (BCR) to rank and select among independent projects.
- The inappropriate use of Incremental Benefit Cost Ratio (IBCR) to rank a set of independent projects

This paper critically evaluates Chapter 8 of the HSM. First, the fundamental concepts for ranking alternatives for sets of independent and mutually exclusive alternatives are presented. The limitations on the use of NPV for ranking and project selection are explored. The ranking and selection of the alternatives by the NPV and BCR methods are compared. Then, the example problems from the Highway Safety Manual are solved using the fundamental concepts for ranking alternatives for a budget constrained condition. A budget constrained condition is imposed to determine if the ranking order found by the NPV method and the IBCR method are optimal. The analysis with a constrained budget shows which ranking approach yields the higher return for the invested costs.

II. OBJECTIVE OF CHAPTER 8

The objective of Chapter 8 in the HSM is to provide the background information and methods to “Prioritize Projects.” This implies selection of safety projects through ranking of potential alternatives up to the full allocation of the available budget. The selection of projects is performed to receive maximum return in safety dollars for the invested budget dollars, that is, greatest safety benefits for project cost incurred.

A. Decision Criteria

The decision criteria employed to rank and prioritize projects are aimed at achieving economic optimality. Project alternatives are ranked to obtain the most economically efficient program, that is, the greatest return of safety benefits for every dollar of project cost invested, up to the budget available. This is measured by the pooled BCR for all projects selected;

$$\text{Pooled BCR} = \frac{\Sigma \text{ Safety benefits of selected projects}}{\Sigma \text{ Project costs of selected projects}}$$

B. Possible Decision Criteria for Ranking

There are a number of economic evaluation and ranking measures that could be used as measures to evaluate, rank and select safety improvements. These include;

1. <u>Total Project Cost</u> - this should only be used to rank and select projects when project benefits for each project are equal.

2. <u>Net Present Value of Benefits</u> (or Net Present Worth of Benefits) – this should only be used to rank and select projects when total project costs are equal.

3. <u>Rate of Return</u> – this determines the interest rate earned from benefits derived with costs incurred compared to an acceptable rate of return.

4. Benefit Cost Ratio – this determines the dollars in benefit returned for each dollar of costs incurred, and should be used when independent alternatives are compared, ranked and selected.

5. Incremental Benefit Cost Ratio – this determines the incremental monetary safety benefits returned for additional investment in costs for higher cost mutually exclusive alternatives, and should be used to rank and select mutually exclusive alternatives.

C. Definition of “Independent” and “Mutually Exclusive” Projects

The method used to rank and select alternative projects depends on whether they are “independent” or “mutually exclusive.”

1. Independent Projects – these are projects whose performance does not impact the other independent projects, usually at separate sites.

2. Mutually Exclusive – these are projects whose performance precludes the use of other mutually exclusive projects, often at the same site, such as an intersection.

Examples of independent projects are those at separate roadway sections or spots. Mutually exclusive project examples are represented by various alternatives at a railroad crossing, such as, cross bucks with a stop sign, gates with flashing signals, and an over-crossing.

Independent and mutually exclusive projects can occur at a site. For example, the mutually exclusive projects at an intersection could include a left turn signal over a left turn bay, replacement of the intersection with a roundabout, and installation of an interchange. A separate and independent project at this location could be the increased illumination of the intersection and its approaches to improve pedestrian safety.

III. CRITIQUE OF NET PRESENT VALUE (NET PRESENT WORTH) FOR SETTING PRIORITIES

A. Fundamentals of the NPV versus BCR for Ranking Alternatives

The net present value (NPV) method does not give the same level of economic effectiveness as the benefit cost ratio (BCR) method in ranking and selecting independent projects. If project costs are equal, then ranking using NPV is acceptable. The ranking by NPV is based on the largest difference between safety benefits and project costs. The ineffectiveness of using the NPV with different project costs can be significant. This is shown in the table below, Exhibit 1.

Project	Present Value of Benefits (PVB)	Cost of Improvement (PVC)	NPV	BCR
1.	$5,000,000	$4,000,000	$1,000,000	1.25
2.	$100,000	$10,000	$90,000	10.00
3.	$15,000	$1,000	$14,000	15.00

Exhibit 1 - Example of the Ineffectiveness of NPV for Ranking Safety Projects

The example shows that even though the NPV for a project can be very large, such as $1,000,000 for project 1 at a cost of $4,000,000, it is not the most economic solution. The BCR of 1.25 for Project 1 yields only $1.25 in safety benefits returned per dollar of cost invested. Project 3 with an NPV of only $14,000 and a BCR of 15 is much more effective. It yields $15 in safety benefits per dollar of project costs. Four thousand ($4,000,000 ÷ $1,000) projects like project 3 could be constructed with a return of $60,000,000 (i.e., 4,000 x $15,000) in benefits compared to the $5,000,000 in benefits for Project 1 for the project cost of Project 1. The returns of $15 in benefits for Project 3 to $1.25 in benefits for Project 1 represent their relative value very well. Clearly, the value of the NPV does not represent the most economic investment for ranking, unless project costs are equal.

Ranking of independent projects is conducted best by finding the BCR for each alternative, and then ranking for priority by their relative magnitudes. The largest BCR is ranked #1, and the remaining projects are ranked down to a BCR of 1. At times a lower limit for BCR that is greater than "1" is assigned to be an acceptable BCR to reflect the difficulty in setting assumed monetary values of benefits. In a budget constrained situation, the budget would be allocated to the various projects in rank order, until all funds are allocated. The BCR rank order gives the greatest return in monetary safety benefits per dollar of costs of the selected projects.

B. Critique of the Example Problem, "Table 8-8," from the 2010 HSM

The net present value (NPV) analysis results and the resulting ranking for the set of independent projects for the example problem in the HSM are given. The BCRs and ranking by the BCR for that problem are then calculated and compared. A budget limit is imposed to compare the effectiveness of the ranking by NPV with the BCR ranking.

Exhibit 2 shows the net present value (NPV) analysis for the example problem from the HSM, given in Table 8-8 in the HSM. The projects are rank ordered by descending NPVs. For example, the NPV is calculated for Intersection 2 as;

$$NPV = PVB - PVC$$

$$NPV_2 = \$33,437,850 - \$695,000 = \$32,742,850$$

Independent Projects	Present Value of Benefits ($) (PVB)	Cost of Improvement Project ($) (PVC)	Net Present Value (NPV)
Intersection 2	$33,437,850	$695,000	$32,742,850
Segment 5	$7,829,600	$3,500,000	$4,329,600
Segment 7	$7,000,000	$3,100,000	$3,900,000
Segment 6	$6,500,000	$2,750,000	$3,750,000
Segment 1	$3,517,400	$250,000	$3,267,400
Segment 2	$2,936,700	$225,000	$2,711,700
Intersection 12	$1,800,000	$100,000	$1,700,000
Intersection 11	$1,400,000	$230,000	$1,170,000
Intersection 7	$1,200,000	$200,000	$1,000,000

Exhibit 2 – “Table 8-8 Net Present Value Results”

Source: *Highway Safety Manual*, Chapter 8, pp: 8-10

The NPV rank, benefit cost ratio (BCR), and the BCR ranking are calculated for this example in Exhibit 3.

Independent Projects	Present Value of Benefits ($) (PVB)	Cost of Improvement Project ($) (PVC)	Net Present Value ($) (NPV)	NPV Rank	BCR	BCR Rank
Intersection 2	$33,437,850	$695,000	$32,742,850	1	47.1	1
Segment 5	$7,829,600	$3,500,000	$4,329,600	2	2.24	9
Segment 7	$7,000,000	$3,100,000	$3,900,000	3	2.26	8
Segment 6	$6,500,000	$2,750,000	$3,750,000	4	2.36	7
Segment 1	$3,517,400	$250,000	$3,267,400	5	14.1	3
Segment 2	$2,936,700	$225,000	$2,711,700	6	13.1	4
Intersection 12	$1,800,000	$100,000	$1,700,000	7	18.0	2
Intersection 11	$1,400,000	$230,000	$1,170,000	8	6.1	5
Intersection 7	$1,200,000	$200,000	$1,000,000	9	6.0	6

Exhibit 3 – Example Problem form the HSM plus NPV Rankings, BCR and BCR Rankings

Source: *Highway Safety Manual*, Chapter 8, pp: 8-10

The benefit cost ratio for each project is calculated from;

$$BCR = \frac{\text{Present Value of Benefits}}{\text{Present Value of Project Costs}} = \frac{PVB}{PVC}$$

For example, the BCR for Intersection 2 is

$$BCR_{Inter2} = \frac{\$33,437,850}{\$695,000} = 47.1$$

These BCRs are then ranked in descending order.

A comparison of the rankings shows all rankings are different for the NPV versus the BCR rankings except for rank 1. The significance of these rankings can only be realized if a limit is set on the budget. A budget of $7,550,000 is assumed to compare the economic effectiveness of the rankings by NPV versus the BCR rankings. The rankings and selected projects based on NPV within a budget of $7,550,000 are shown in Exhibit 4.

NPV Rank*	Independent Projects	PVB, $	PVC, $	NPV, $	Σ PVC, $
1	Intersection 2	$33,437,850	$695,000	$32,742,850	$695,000
2	Segment 5	$7,829,600	$3,500,000	$4,329,600	$4,195,000
3	Segment 7	$7,000,000	$3,100,000	$3,900,000	$7,295,000
5	Segment 1	$3,517,400	$250,000	$3,267,400	$7,545,000
		Σ $51,784,850	Σ $7,545,000		

Exhibit 4 – NPV Rankings and Selected Independent Projects with a Budget of $7,550,000 for the HSM Example Problem

Source: *Highway Safety Manual*, Chapter 8, pp: 8-10

*Note: NPV rank calculated in Exhibit 3

The highest ranked project, Intersection 2, is selected first and uses $695,000 of the available budget. The second and third ranked projects are selected next, taking up $3,500,000 and $3,100,000 of the budget, respectively. The fourth NPV ranked project, Segment 6, must be bypassed because its cost of $2,750,000 would push the total costs of improvements over the available budget. However, the fifth ranked project can be selected with a cost of $250,000, increasing the total costs of improvements to $7,545,000 < $7,550,000. This set of projects yields a pooled BCR based on NPV of;

$$\text{Pooled BCR}_{\text{NPV}} = \frac{\Sigma \text{ Safety Benefits of Selected Projects}}{\Sigma \text{ Project Costs of Selected Projects}} = \frac{\$51{,}784{,}850}{\$7{,}545{,}000} = \$6.86$$

This amounts to $6.86 of safety benefits received for every dollar of project cost invested, and aggregate safety benefits for all projects selected and budgeted of $51,784,850.

Exhibit 5 displays the results of using the BCR rankings with a budget of $7,550,000 to rank the projects and allocate the budgeted funds. The projects are rank ordered by descending BCR, as shown in Exhibit 3.

BCR Rank*	Independent Projects	PVB, $	PVC, $	Σ PVC, $
1	Intersection 2	33,437,850	695,000	695,000
2	Intersection 12	1,800,000	100,000	795,000
3	Segment 1	3,517,400	250,000	1,045,000
4	Segment 2	2,936,700	225,000	1,270,000
5	Intersection 11	1,400,000	230,000	1,500,000
6	Intersection 7	1,200,000	200,000	1,700,000
7	Segment 6	6,500,000	2,750,000	4,450,000
8	Segment 7	7,000,000	3,100,000	7,550,000
		Σ $57,791,950	Σ $7,550,000	

Exhibit 5 – BCR Rankings and Selected Independent Projects for the HSM Example Problem with a Budget of $7,550,000

Source: *Highway Safety Manual*, Chapter 8, pp: 8-10

*Note: BCR rank calculated in Exhibit 3

The highest ranked project, Intersection 2, is selected first taking $695,000 of the budget. The remaining BCR ranked projects are selected in rank order up to the available budget. The pooled BCR for the set of selected projects, based on the BCR ranking is;

$$\text{Pooled BCR}_{BCR} = \frac{\$57{,}791{,}950}{\$7{,}550{,}000} = \$7.65$$

For the example problem from the HSM, the BCR method returns $7.65 for every dollar invested, compared to $6.86 for the NPV rankings for the same problem. The aggregate benefits for all projects selected and budgeted by the BCR method are $57,791,950, compared to $51,784,850 by the NPV method. The small difference in total project costs of $5,000 does not impact the final result significantly.

This comparison shows that the use of NPV rankings in a budget constrained program does not give the optimal allocation of funds. The order of magnitude of the discrepancy between the total return in safety benefits given by the NPV method versus the BCR method depends on the mix of projects and their benefits and costs. The BCR rankings give the optimal selection of independent projects for a limited budget.

IV. INCREMENTAL BENEFIT COST RATIO RANKING

An Incremental Benefit Cost Ratio (BCR) evaluation compares the incremental benefits and incremental costs between a lower cost alternative and a higher cost alternative as a ratio;

$$IBCR = \frac{\Delta(PVB_j - PVB_i)}{\Delta(PVC_j - PVC_i)}$$

where project j has higher project costs than project i

A. IBCR Ranking of Mutually Exclusive Projects

It can only be used on mutually exclusive projects to select an economically optimal set of projects. Proper use of the IBCR method is typically used to select the best project out of a set of mutually exclusive projects. An example of a set of five mutually exclusive projects at a site is shown with their associated benefits (PVB) and costs (PVC). The first two steps in IBCR ranking are shown in Exhibit 6a.

Project	PVB	PVC	BCR (Step 1)	$IBCR_{1B-1A}$ (Step 1)	Selected Project
1A	30,000	10,000	3.0		1A
1B – 1A:	ΔPVB = 30,000	ΔPVC =15,000		2	1B replaces 1A
1B	60,000	25,000	2.4		
1C	80,000	65,000	1.23		
1D	120,000	75,000	1.60		
1E	120,000	100,000	1.20		

Exhibit 6a – IBCR Ranking of Mutually Exclusive Projects, Steps 1 and 2

Step 1:

As the above example shows, the first project, 1A, is selected with a BCR of 3.0.

Step 2:

The second row in the table then shows the calculation of the IBCR for project 1B over project 1A;

$$IBCR_{1B-1A} = \frac{\text{Incremental PVB}}{\text{Incremental PVC}} = \frac{\$60,000 - 30,000}{\$25,000 - 10,000} = \frac{\Delta PVB}{\Delta PVC} = \frac{\$30,000}{\$15,000} = 2.0$$

The $IBCR_{1B-1A}$ of project 1B on project 1A is 2.0 (>1.0), so Project 1A is replaced with Project 1B.

The remaining two steps in the IBCR ranking are shown in Exhibit 6b.

Mutually Exclusive Projects	PVB	PVC	BCR	$IBCR_1$	$IBCR_2$ (Step 3)	$IBCR_3$ (Step 4)	Selected Project
1A	30,000	10,000	3.0				~~1A~~
1B-1A:	ΔPVB = 30,000	ΔPVC = 15,000		2.0			1B replaces 1A
1B	60,000	25,000	2.4				~~1B~~
1C-1B:	ΔPVB = 20,000	ΔPVC = 40,000			0.5		
1C	80,000	65,000	1.23				
1D-1B:	ΔPVB = 60,000	ΔPVC = 50,000			1.2		1D replaces 1B
1D	120,000	75,000	1.60				
1E-1B:	ΔPVB = 60,000	ΔPVC = 75,000			0.8		
1E-1D:	ΔPVB = 0	ΔPVC = 25,000				0	
1E	120,000	100,000	1.20				

Exhibit 6b – IBCR Ranking of Mutually Exclusive Projects, Steps 3 and 4

Step 3:

The IBCRs based on Project 1B are;

Project 1C – IBCR = $\dfrac{\Delta PVB_{1C-1B}}{\Delta PVC_{1C-1B}} = \dfrac{\$20{,}000}{\$40{,}000} = 0.5 < 1.0$

Project 1D – IBCR = $\dfrac{\Delta PVB_{1D-1B}}{\Delta PVC_{1D-1B}} = \dfrac{\$60{,}000}{\$50{,}000} = 1.2 > 1$, “selected”

Project 1E – Is not considered because IBCR for 1D over 1B is over “1,” and is selected

Step 4:

Project 1E would not be selected over Project 1D since the $IBCR_{1E\text{-}1D}$ of Project 1E over Project 1D is “0”. The IBCR based on project 1D is;

Project 1E – IBCR = $\frac{\Delta PVB_{1E-1D}}{\Delta PVC_{1E-1D}} = \frac{0}{\$25,000}$ = 0 < 1.0, therefore not selected

Project 1E is last eligible project so ranking is finished.

Project 1D would be the only project of the mutually exclusive projects to be implemented, if there is adequate budget of $75,000 or more. If the available budget is less than $75,000, but greater than or equal to $25,000, project 1B would be selected.

B. Inappropriate Use of the IBCR Method to Rank Independent Projects

The IBCR method should not be used to rank independent projects. The objective of a safety improvement program is the selection of projects to maximize the safety benefits relative to the project costs within the limits of the budget. The IBCR method compares the incremental benefits with the incremental costs between project pairs. If the IBCR is greater than “1”, the larger cost project is selected and the lower cost project is replaced. The IBCR method continues to search for projects where benefits outweigh costs, i.e., IBCR >1, until the full budget is allocated. This may result in very economic alternatives being dropped when compared to less economic alternatives because the IBCR is greater than “1,” when ranking independent projects. The example in Exhibit 7 demonstrates this.

Independent Projects	PVB	PVC	BCR (Step 1)	$IBCR_1$ (Step 2)	$IBCR_2$ (Step 3)	$IBCR_3$ (Step 4)	Selected Project
(1)	35,000	16,000	2.19				~~1~~
(2)–(1)	ΔPVB = 20,000	ΔPVC = 18,000		1.11			Project 2 replaces Project 1
(2)	55,000	34,000	1.67				
(3)–(1)	ΔPVB = 40,000	ΔPVC = 34,000		1.18			
(3)–(2)	ΔPVB = 20,000	ΔPVC = 16,000			1.25		Project 3 replaces Project 2
(3)	75,000	50,000	1.50				3
(4)–(1)	ΔPVB = 65,000	ΔPVC = 64,000		1.02			
(4)–(2)	ΔPVB = 45,000	ΔPVC = 46,000			0.98		
(4)–(3)	ΔPVB = 25,000	ΔPVC = 30,000				0.85	
(4)	100,000	80,000	1.25				

Exhibit 7 – Example of IBCR Ranking of Independent Projects

<u>Step 1:</u>

The IBCR method would first select Project 1 with a BCR of 2.19.

<u>Step 2:</u>

The IBCRs for the eligible projects to replace Project 1 are;

Project 2 – $IBCR_{2\text{-}1} = \dfrac{\Delta PVB_{2-1}}{\Delta PVC_{2-1}} = \dfrac{\$20{,}000}{\$18{,}000}$ = 1.11 >1.0, "selected" and replaces Project 1

Project 3 – $IBCR_{3\text{-}1} = \dfrac{\Delta PVB_{3-1}}{\Delta PVC_{3-1}} = \dfrac{\$40{,}000}{\$34{,}000}$ = 1.18 > 1.0, but Project 2 is already selected

Project 4 – $IBCR_{4\text{-}1} = \dfrac{\Delta PVB_{4-1}}{\Delta PVC_{4-1}} = \dfrac{\$65{,}000}{\$64{,}000}$ = 1.02 > 1 but Project 2 already selected

Step 3:

The IBCRs for the eligible projects are;

Project 3 – IBCR3-2 = $\frac{\Delta PVB_{3-2}}{\Delta PVC_{3-2}} = \frac{\$20{,}000}{\$16{,}000}$ = 1.25 >1.0, “selected” and replaces Project 2

Project 4 – IBCR4-2 = $\frac{\Delta PVB_{4-2}}{\Delta PVC_{4-2}} = \frac{\$45{,}000}{\$46{,}600}$ = 0.98 < 1.0, Project 3 already selected

Step 4:

The IBCR for the remaining eligible project, Project 4, compared to Project 3 is;

Project 4 – IBC $R_{4\text{-}3}$ = $\frac{\Delta PVB_{4-3}}{\Delta PVC_{4-3}} = \frac{\$25{,}000}{\$30{,}000}$ = 0.85 < 1.0.

Therefore, the ranking is complete. Project (3) would be the only project selected by the IBCR ranking procedure. A comparison of the benefits with a $50,000 budget for the IBCR ranking versus the BCR ranking is shown in Exhibit 8.

Projects	PVB	PVC	BCR	BCR Rank	IBCR Rank
1	$35,000*	$16,000*	2.19	1	--
2	$55,000*	$34,000*	1.67	2	--
3	$75,000**	$50,000**	1.50	3	1
4	$100,000	$80,000	1.25	4	--

Exhibit 8 – Comparison of Benefits for a $50,000 Budget by BCR Ranking versus IBCR Ranking, for the Exhibit 7 Example

* Benefits for budget of $50,000 for BCR top ranked projects: ΣPVB=$90,000, ΣPVC=$50,000

** Benefits for budget of $50,000 for IBCR top ranked projects: ΣPVB=$75,000, ΣPVC=$50,000

Two projects, (1) and (2), with the largest BCRs are dropped by the IBCR method, while Project 3 is selected. A budget of $50,000 would pay for construction of Project 3 with $75,000 of benefits, according to the IBCR ranking. However, if the budget of $50,000 were used to construct both Project 1 and Project 2, $90,000 worth of benefits would be provided for the projects selected by the BCR method. Clearly, the IBCR method does not work for ranking and selecting independent projects.

C. Critique of the IBCR Solution in Table 8-10 for the Example Problem in Table 8.8 HSM

The incremental benefit cost (IBCR) method did not rank projects optimally in the new HSM example for a set of independent projects. The IBCR method should not be used to rank and select independent projects. The BCR method is best suited for ranking independent projects.

The rankings obtained in Table 8-10 HSM (Exhibit 9) and shown in Table 8-11 (Exhibit 10) of the HSM uses the IBCR to rank a set of independent projects, based on a method from the literature.[1] However, the IBCR rankings are not optimal for economic effectiveness for the independent projects from the example. These two tables, Table 8-10 and Table 8-11 from the HSM, are reproduced here as Exhibit 9 and Exhibit 10, respectively.

[1] Mak, K.K., and D.L. Sicking, National Cooperative Highway Research Program Report 492; Roadside Safety Analysis Program. NCHRP, TRB, Washington, DC, 2003.

Comparison	Project	$PV_{benefits}$	PV_{costs}	IBCR	Preferred Project
1	Intersection 12	$1,800,000	$100,000	-6	Intersection 12
	Intersection 7	$1,200,000	$200,000		
2	Intersection 12	$1,800,000	$100,000	9	Segment 2
	Segment 2	$2,936,700	$225,000		
3	Segment 2	$2,936,700	$225,000	-307	Segment 2
	Intersection 11	$1,400,000	$230,000		
4	Segment 2	$2,936,700	$225,000	23	Segment 1
	Segment 1	$3,517,400	$250,000		
5	Segment 1	$3,517,400	$250,000	67	Intersection 2
	Intersection 2	$33,437,850	$695,000		
6	Intersection 2	$33,437,850	$695,000	-13	Intersection 2
	Segment 6	$6,500,000	$2,750,000		
7	Intersection 2	$33,437,850	$695,000	-11	Intersection 2
	Segment 7	$7,000,000	$3,100,000		
8	Intersection 2	$33,437,850	$695,000	-9	Intersection 2
	Segment 5	$7,829,600	$3,500,000		

Exhibit 9 – HSM Example of Incremental BCR (IBCR) Ranking of Independent Projects

Source: *Highway Safety Manual*, Chapter 8, Table 8-10, pp: 8-12

According to the method proposed in the HSM, the Intersection 2 would be ranked #1, using the IBCR in a pair wise comparison. Intersection 2 would be dropped out of consideration, and the procedure would be repeated, identifying Segment 5 as the #2 ranked independent project. The rankings resulting from the procedure are given in Exhibit 10.

Rank	Project
1	Intersection 2
2	Segment 5
3	Segment 7
4	Segment 6
5	Segment 1
6	Segment 2
7	Intersection 12
8	Intersection 11
9	Intersection 7

Exhibit 10 – Results of Incremental BCR Ranking of Independent Projects from HSM Example

Source: *Highway Safety Manual*, Chapter 8, Table 8-11, pp: 8-12

The rankings returned by the IBCR method described in the HSM, Table 8-11 (Exhibit 10) yields the same rankings found by the NPV method in Exhibit 3, based on Table 8-8, HSM. This ranking by IBCR with a budget of $7,550,000 when compared to the rankings by the BCR method shows the rankings by IBCR are not optimal. Exhibit 11 calculates the sums of the safety benefits and the project costs for the IBCR ranked and selected projects with a limited budget of $7,550,000.

IBCR Rank	Independent Projects	PVB, $	PVC, $	Σ PVC, $
1	Intersection 2	33,437,850	695,000	695,000
2	Segment 5	7,829,600	3,500,000	4,195,000
3	Segment 7	7,000,000	3,100,000	7,295,000
5	Segment 1	3,517,400	250,000	7,545,000
		Σ $51,784,850	Σ $7,545,000	

Exhibit 11 – IBCR Rankings and Selected Projects for the HSM Example with a Budget of $7,550,000

Source: *Highway Safety Manual*, Chapter 8,Tables 8-10 & 8-11, pp: 8-12

The IBCR method yields aggregate safety benefits for the selected and budgeted projects of $51,784,850 and a pooled benefit cost ratio of 6.86 for the selected set of projects with the constrained budget;

$$\text{Pooled BCR}_{\text{IBCR}} = \frac{\Sigma\ \text{Safety Benefits of Selected Projects}}{\Sigma\ \text{Project Costs of Selected Projects}} = \frac{\$51{,}784{,}850}{\$7{,}545{,}000} = \$6.86$$

Earlier, the HSM example problem is ranked using the BCR method, shown in Exhibit 3. Exhibit 5 for the same problem from the HSM shows the pooled BCR for the BCR ranked projects with a budget of $7,550,000 to be 7.65. The aggregate safety benefits for the BCR ranked and budgeted projects are $57,791,950 compared to $51,784,850 for the IBCR procedure. These measures are significantly greater for the BCR method than for the IBCR ranking method. The rankings by the BCR method provide the optimal program for independent projects. The IBCR method is found to be inappropriate for independent projects, as calculated in the HSM example problem.

V. CONCLUSIONS

The foundation concepts of “independent” and “mutually exclusive” projects are defined and discussed. The need to separate projects into these categories is clearly shown.

The fundamental concepts and limitations of ranking by the NPV and BCR are explored. The NPV method can only be used for ranking and selection of projects when the costs of all projects are equal. The solution of the example problem by NPV ranking in Table 8-8 of the Highway Safety Manual does not provide the optimal economic solution. The BCR does provide the optimal economic solution for the example given as Table 8-8 in the Highway Safety Manual, for ranking and selecting independent projects for a budget constrained program. The NPV method should not be used because it considers the difference between the safety benefits and project costs, not the rate of return. The BCR method determines the return of safety benefits for the safety costs invested and is the best method for ranking independent alternatives with a limited budget.

This critique also shows that the incremental benefit cost ratio (IBCR) method cannot be used to rank and select independent projects. The example problem from the HSM, Table 8-10, yields a result for ranking and selection of independent projects for a limited budget that is not economically optimal. The IBCR method is very effective in selecting the best project from a set of mutually exclusive alternatives.

In summary, the results of the evaluation of Chapter 8 in the new HSM show that;

- The BCR method provides the optimal solution for ranking and selecting independent projects within a limited budget.
- The IBCR method can be used to rank and select mutually exclusive projects within a limited budget optimally.
- The NPV method should not be used to rank and select projects for economic optimality.