COST-BENEFIT ANALYSIS AND COST-EFFECTIVENESS ANALYSIS OF ROAD SAFETY MEASURES IMPLEMENTED IN MEXICAN ROADS

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ABSTRACT

The paper presents the results of the appraisal of a series of road safety measures implemented in Mexican roads during the period 2001-2005. The study identifies the best road safety measures implemented, based on net benefits, their practical effectiveness in reducing accidents, deaths, injuries and property damage. Based on the human capital approach and the International Road Assessment Programme (iRAP) methodology, this study also estimates the Value of Statistical Life and the value of a serious injury for the Mexican case. Evaluation results provide two set of rankings with the best road safety measures, using Cost-Effectiveness Analysis (CEA) and Cost-Benefit Analysis (CBA). The results indicate that signaling is by far the most efficient road safety measure implemented in Mexican roads. Moreover, within the best practice, there are combinations of safety measures where signaling appears in almost every combination. Finally, conclusions and recommendations for further research are given.

1. INTRODUCTION

This paper shows a review of the main methods used for assessing road safety measures. Through cost-benefit analysis and cost-effectiveness, the study identifies the best road safety measures implemented Highways Mexico in recent years, in terms of net profit and its practical effectiveness in reducing accidents, deaths , injuries and property damage. This is done based on a sample comprising improvement projects developed by the General Administration of Technical Services (GDTS) of the Mexican Transportation and Communication Ministry (TCM) for a set of hazardous sites on Federal Highways, and implemented by the General Administration of Road Maintenance (GARM) under the National Programme for Improvement of Hazardous Sites between 2001 and 2005. It also updates the statistical value of life and injuries to the case of Mexico, using the human capital approach.

2. BACKGROUND

Studies of the World Health Organization [1] show that road accidents in 2004 were the cause of 2.2% of deaths worldwide, ranking cause of death 9. By 2030, this figure will be 3.6% and the fifth leading cause of death worldwide.

The high costs of road accidents happening makes it necessary to implement safety measures that significantly reduce the loss of human lives and the costs of resources damaged or lost in accidents. In 2008, 5 398 people were dead and 33 580 were injured in 30 551 accidents taking place on Federal Highways in Mexico [2].

Today, there is a wide range of measures to improve road safety, however, the resources available are not enough to implement all necessary measures at all sites referred to as "hazardous". Therefore, decisions must be made as to which measures to implement and in what locations. It is therefore necessary to justify the selection of actions through the evaluation of their benefits and costs or through cost-effectiveness analysis, so that the measures selected maximize benefits in terms of public health and minimize the costs of road accidents.

3. METHODOLOGIES FOR THE ASSESSMENT OF HIGHWAY SAFETY

For an efficient road safety policy, it is necessary to select the measures that provide the best results to the problem of road safety with the minimum resources required for implementation. The best measure of road safety is not necessarily one that generates the greatest benefits, nor does it requires lower costs for its implementation, but as evaluating and comparing together the benefits and costs, generate greater profits or more effective per unit of investment.

The two main methods for assessing road safety measures are the Cost-Effectiveness (CEA) and Cost-Benefit Analysis (CBA).

3.1. **COST-EFFECTIVENESS ANALYSIS** (CEA)

In the Cost-Effectiveness (CEA) analysis, two or more road safety measures can be evaluated and ranked according to their cost effectiveness on achieving a particular goal (e.g. reductions in accidents).

Unlike Cost-Benefit Analysis (CBA), the CEA expresses the benefits in physical impacts (e.g. reductions in accidents) and not in monetary terms.

In order to evaluate the effectiveness of a road safety measure, the objective of the measure and the quantification of its success must first be defined. The impacts of the measure on the previously defined objective must be assessed in physical terms, for example, the number of accidents that can be avoided by implementing each of the measures. Thus, the total estimated impact of each measure is compared with the cost of implementing them. Thus, the total impacts are expressed per unit cost of implementation (e.g. number of accidents that can be avoided per unit cost of implementation). This makes it possible to compare benefits are not expressed in monetary terms with monetary costs.

In addition to the costs of implementing a road safety measure, the total project cost must include operating and maintenance costs that will occur over the project horizon. Similar to the CBA, present and future costs should be discounted so that they can be compared as related to a base year. Finally, once the costs and impacts of safety measures have been estimated, these can be combined to estimate their corresponding cost-effectiveness through a ratio, as shown in the following equation [3]:

$$CER = E / C \qquad \text{(Ec. 1)}$$

where:

CER = Cost-Effectiveness Ratio

E = Effectiveness of the project

C = Total Project Cost

The CER indicates the units of effectiveness obtained by each unit of cost incurred. A higher CER value indicates greater effectiveness of a particular safety measure. For example, the CER of a particular safety measure can be obtained by calculating the following ratio:

$$CER = \text{Number of prevented accidents} / \text{Total cost of the measure} \qquad \text{(Ec. 2)}$$

Thus, the needed data to estimate the CER of a safety measure are: the estimated number of accidents, deaths or injuries avoided by the safety measure, and the total cost of the measure.

The main advantage of CER is to be a simple technique that focuses on the effects on safety, so it does not require monetary valuation of these effects. However, this technique has the disadvantage that can only be used for the ranking of measures on a common basis of effectiveness (reduction of accidents, or deaths reduction, or reduction of serious injury or minor injury reduction, or reduction of property damage), e.g., in the estimation of effectiveness it is not possible to consider simultaneously different types of accidents (deaths, serious injuries, with minor injuries and property damage).

3.2. Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis (CBA) aims to determine whether a project is economically efficient and how efficient it is (and if the objective changes could increase their efficiency). Among the most commonly used efficiency measures are [4]:

1. The Project Net Present Value (NPV)
2. The benefit-cost ratio (BCR)
3. The Internal Rate of Return (IRR)

The meaning of the above measures is well known.

In the case of specific actions to improve road safety, the rate of return of the first year (RRFY) is often used. The RRFY of a project or road safety measure is obtained as follows:

$$RRFY = RCA * 100 / \text{Cost of implementation of the measure} \qquad \text{(Ec. 3)}$$

where:

RCA = Reduction in the cost of accidents in the first year of operation of the measure (profits).

If a measure has a RRFY less than the discount rate specified, this means that it is profitable to undertake such a measure in that year. The RRFY does not provide a rigorous evaluation criteria because it ignores any benefits or costs after the first year, but its use has been advocated in high uncertainty projects (such as road safety engineering projects) on the basis that in these: (I) the estimation of benefits beyond the first year is difficult, and (II) a very high rate of return for the first years is obtained (over 100%), making it unnecessary to use a more sophisticated decision criteria. The RRFY is an index that provides, more than a rigorous economic evaluation technique, a gross means to prioritize projects [5].

One of the biggest problems of CBA is to obtain valid and reliable monetary values for the relevant effects or benefits. Therefore, it is important to distinguish between cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA). In the first case, the cost of implementing a safety measure is compared with its effects, where the effects of the measures are not expressed in monetary terms. In the case of cost-benefit analysis, the evaluation result is obtained by comparing costs with benefits, both expressed in monetary terms.

The CBA is particularly useful when there are multiple policy objectives or when policy objectives are in conflict. Among the data required to perform the CBA are: the costs of implementing the safety measure as well as the benefits derived from the costs of prevented accidents in terms of deaths, injuries and property damage and other measurable effects (environment, travel time, vehicle operation, etc.).

It should be noted that the monetary valuation of human life that is made in this technique remains controversial and difficult, but inevitable. In general, the valuation of accidents is complex, since they generate a variety of impacts on people and society, among which the following can be mentioned:

- Medical and hospital costs
- Loss of future gross domestic product
- Grief, pain and suffering
- Material losses
- Police costs and rescue services
- Insurance
- Legal costs

3.3. Statistical Valuation of Life

A recent study by the “International Road Assessment Programme (iRAP)" [6] obtains through linear regression analysis, the statistical value of life in terms of income and the estimation method, where there are two main methods for estimating the statistical value of life: the willingness to pay approach and the human capital approach as a loss of product. The first is an ex ante approach, which attempts to assess the willingness to pay of society to avoid death, injury and property damage as a result of road accidents. The second is an ex post method, which estimates the value of human life as a function of the potential future contribution of people in generating wealth [7]. For this study, the human capital approach or gross production method is used. This is because in Mexico there are not reliable studies available about statistical valuation of life using the willingness to pay approach.

Thus, the statistical value of life can be determined through the following equation estimated by iRAP:

$$\text{Log (SLV)} = 2.519 + 1.125 * \log(\text{GDP per capita}) + 0.496*(\text{Method}) \qquad \text{(Ec. 4)}$$

where:

SLV	=	Statistical Value of Life
GDP	=	Gross Domestic Product
Method	=	1 if the willingness to pay approach is used or 0 if the human capital approach as a loss of product is used

It should be noticed that the estimate of the above equation by multiple linear regression technique resulted in a determination coefficient of 97%.

Therefore, in the case of Mexico, the Statistical Value of Life for 2008 is:

$$\text{Log (SLV)} = 2.519 + 1.125 \log(7{,}608) = 288{,}691 \text{ U.S. dollars (3.15 million pesos)}$$

Also, iRAP recommends as a reasonable approximation to consider that the value of an injury is about 25% the Statistical Value of Life. Therefore, in the case of Mexico, the average value of an injury for 2008 is about 72,173 dollars (790 thousand pesos).

4. ACB & ACE OF ROAD SAFETY MEASURES IMPLEMENTED

Information was gathered for 421 hazardous sites in the Federal Highway Network within the National Programme for Improvement of Hazardous Sites during the period 2001 to 2005.

For each of the previous sites, a report containing a "before and after" study on the implementation of improvements and road safety measures for one year before (e.g., the number of accidents, deaths, injuries and material losses produced by accidents) and one year after the implementation of road safety measures. This study was obtained from the General Administration of Technical Services and/or General Administration of Road Maintenance. It provides information on the location, type of hotspot, type of improvement, date of the start of operation of the measure and the actual cost of the work. This information was put into a database for purposes of computation and the analysis in this work.

Based on the 421 hazardous sites considered, Table 1 summarizes the improvement types implemented in each type of hotspot.

By using the accident statistics, the costs of implementing the safety measures and the statistical values of life and injury, both the CER and the RRFY were calculated for each site. Due to constraints on available information, both previous rates were calculated in order to estimate the impact one year after the start of operation of the measure.

TABLE 1
Frequency distribution by improvement type and hotspot

Type of improvement	**Type of hotspot**							
	Curve	Tangent	Inter-change	Site or point	U Turn	Access	At grade inter-section	Others
Signing	59	33	15	5	3	2	2	5
Interchange	1	2	36	0	0	0	0	1
Road surface	6	0	0	0	0	0	0	1
Alignment	7	1	0	0	0	0	0	0
Curves	56	0	0	0	0	0	0	0
Combination of the above	55	44	17	1	4	1	3	61
Total	**184**	**80**	**68**	**6**	**7**	**3**	**5**	**68**

Table 2 shows the ten most effective safety measures from the standpoint of cost-effectiveness analysis. In this study, the cost-effectiveness ratio (CER) was calculated as the ratio between the reduction of deaths as a result of the implementation of the measure, and the cost of implementing the measure in million pesos. The values shown represent the average of the largest CER by type of measure. It should be noticed that "Signing" proved to be by far the most effective safety measure with a reduction of about 150 deaths per million dollars invested, exceeding by more than 150% the second most effective measure: “Speed reducers and signing”. In fact, some of the most effective measures are in turn a combination of safety measures, where signing is part of that combination.

TABLE 2
Ranking of safety measures based on their cost-effectiveness

No.	Countermeasure	Cost-effectiveness
1	Signing	149.90
2	Speed reducers and signing	58.96
3	Eliminate direct access from secondary roads	47.95
4	Superelevation and widening of curves	35.48
5	Signing and improving the geometry in U turns	33.76
6	Signing and signalization of intersections	32.51
7	Placement of roadside barriers and signing	22.93
8	Improved alignment	18.19
9	Intersection modernization	14.52
10	Improving the road surface and signing	12.41

Furthermore, Table 3 shows the ten most efficient safety measures from the economic point of view, e.g. using the Cost-Benefit Analysis. In this case, the indicator used is the rate of return of the first year (RRFY), which, as noted above, is defined as the ratio between the reduction in the cost of accidents in the first year of operation of the measure (benefits) and its construction cost. The values shown represent the average for the cases with the greatest RRFY by type of measure. As in the case of CEA, “Signing” proved to be the most effective safety measure, exceeding by more than 150% the second most efficient measure: "Eliminate direct access from secondary roads" and "Signing and improving the geometry in U turns". It is also noted that some of the most efficient measures are likewise a combination of safety measures, where signing is part of that combination.

TABLE 3
Ranking of safety measures based on their cost-benefit

No.	Proposed solution	RRFY
1	Signing	606.34
2	Eliminate direct access from secondary roads	245.47
3	Signing and improving the geometry in U turns	235.28
4	Speed Reducers and signing	146.88
5	Superelevation and widening on curves	127.70
6	Placing full-backs and signing	106.30
7	Devices for traffic control	89.34
8	Improving the road surface and signing	84.25
9	Intersection modernization	59.46
10	Improved alignment	58.49

CONCLUSIONS AND RECOMMENDATIONS

The two main methods for assessing road safety measures are the Cost-Effectiveness (CEA) and Cost-Benefit Analysis (CBA).

From estimates of CER and RRFY for the 421 cases considered, the type of improvement “signing” (improvement or placement of signs) was the most effective (highest CER), as well as the most efficient (highest RRFY).

Also, the types of improvements that resulted more effective in reducing fatalities were, besides the “Signing”, the "Speed reducers and signing " and " Eliminate direct access from secondary roads”.

In the case of safety measures that resulted more efficient from an economic point of view were, besides “Signing”, "Eliminate direct access from secondary roads" and "Signing and improving the geometry in U turns."

In order to improve the assessment of the effectiveness and efficiency of the safety measures implemented in Mexico's Federal Highways, it is recommended to extend the period for the "before and after” studies. In this case, a year (before and after the improvement) was used because this was the period used by the General Administration of Technical Services (GDTS) and General Administration of Road Maintenance (GARM). However, to improve reliability in estimating the effect of the improvement it is recommended in the literature to use from 3 to 5 years before and from 3 to 5 years after [8].

Another important recommendation is to include in the analysis, information on the safety measures implemented in Mexico's Toll Roads.

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