EVALUATION OF SOME RESULTS OF THE 2010 AASHTO HIGHWAY SAFETY MANUAL

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ABSTRACT

The 2010 Highway Safety Manual makes it possible to develop multi-annual programs for road safety improvement of highways through the identification of dangerous sites, the diagnosis, the proposal of countermeasures, their economic evaluation, the hierarchical arrangement of projects and the assessment of the efficiency of the improvements made. On the other hand, methodologies are available to be able to generate improvement programs of existing highways through their inspection, having similar objectives and following analogous principles and procedures. In this paper, both the methodology of the Highway Safety Manual and a road safety audit or inspection are applied to the section linking Ciudad Mendoza with Córdoba along the Puebla-Córdoba toll road, and a comparison is made of the outcomes resulting from both approaches.

The comparisons carried out are of the following types:

- Countermeasures recommended between methodologies.
- Cost of the countermeasures.
- Estimated impact of the countermeasures, based on number of deaths and serious injuries prevented.
- Most cost-effective alternatives between methodologies.

In terms of the analysis carried out, an evaluation is made of the applicability of the Highway Safety Manual to the case of the Mexican roads. Some conclusions and recommendations are finally presented.

1. INTRODUCTION

The 2010 AASHTO Highway Safety Manual (HSM) allows the road safety improvement of highway sections through the identification of dangerous sites, the diagnosis, the proposal of countermeasures, their economic evaluation, the hierarchical arrangement of projects and the assessment of the efficiency of the improvements made [1]. In Mexico, the HSM is being already implemented for the safety improvement of highway sections.

Reactive approaches have also been used, such as the attention of conflict points or “black points” that basically follow similar steps to those in the HSM methodology (identification of the “black points”, diagnosis, proposal of countermeasures, etc.). In addition, preventive approaches have been applied such as the road safety audits that, for the case of existing roads they are also known as road safety inspections [2].

In this paper, the HSM methodology is applied to the section Ciudad Mendoza-Córdoba, which corresponds to a stretch with high accident rate along the Puebla-Córdoba toll road, being the latter one of the most congested in the country and a communication axis between the central highlands and the southeastern part of the country. The results thus obtained are compared with those of a safety inspection carried out in that section; the previous, for the purpose of evidencing benefits and disadvantages of using either of the two approaches.

This works deals primarily with the road section delimited by stations km 257+000 (in the vicinity of Ciudad Mendoza) and km 297+000 (in the surroundings of Córdoba). The section belongs to the federal toll road Puebla-Córdoba, which is a divided highway with two lanes in each direction that is operated by the government operating and administrating toll road organization known as "*Caminos y Puentes Federales de Ingresos y Servicios Conexos*" (CAPUFE).

The location of the section is illustrated with black line in Figure 1, as part of the context of the Puebla-Córdoba highway, whose remaining alignment is depicted with red line.

FIGURE 1 Location of the road section Ciudad Mendoza-Córdoba

2. APPLICATION OF THE HIGHWAY SAFETY MANUAL TO THE SECTION

A description is made of the steps followed by the HSM, exactly as they were applied to the road section.

2.1. Section Screening

It includes the following five major steps: (I) establish the focus, (II) determine the population of reference, (III) select the performance measure, (IV) select the screening method and (V) screen and evaluate the results. The activities carried out at the section being studied are described in what follows, in a sequence of the steps referred to before.

2.1.1 Establish the Focus

It implies the identification of the purpose or result desired from the screening of the section. It impacts the required data, the selection of performance measures and the screening methods that can be applied.

In this particular case, the focus consists in the identification of the most dangerous 500-m long segments in each direction, taking into account that a divided highway section with two lanes in each direction is being dealt with.

2.1.2 *Population of Reference*

As mentioned in the previous section, the reference population is constituted by all 500-m long segments in both directions of the Ciudad Mendoza-Córdoba section.

2.1.3 *Performance Measure*

To be able to quantify the degree of risk of each segment, CAPUFE uses the number of equivalent accidents (NEA) that is calculated according to the following expression:

$$NEA = (ACC \times 1) + (M \times 6) + (H \times 2) \qquad \text{Eq. 1}$$

where: ACC = Number of accidents per year, on the average, in the last two years,
M = Number of deaths per year, on the average, in the last two years,
H = Number of injuries per year, on the average, in the last two years.

For each 500-m long segment in each direction, the NEA was estimated on the basis of the reports issued by the Medical Services of CAPUFE, corresponding to accidents occurred in both directions of the section in years 2008 and 2009.

2.1.4 *Screening Method*

Once the value of NEA has been calculated for all segments in both directions, the hierarchal arrangement of the segments in decreasing order of their NEA values was used as the screening method, generating Table 1 which lists the segments that resulted with the highest values of NEA in each direction. In the first column of the table each direction is mentioned, in the second the stationing of each identified segment, in the third the average annual number of accidents recorded in the last two years, in the fourth and fifth the corresponding number of injuries and deaths, in the sixth the NEA for each segment, in the seventh the annual average daily traffic (AADT) registered in *Datos Viales* 2009 [3] for the direction corresponding to the segment and in the eighth a sequential number assigned to each segment depending on its position in the stationing, that increases from Ciudad Mendoza to Córdoba. The direction has no effect on such sequential number because the stationing is the same for both directions. The average vehicular composition in all segments is equal to 70% of light vehicles, 5% of buses and 25% of freight trucks.

2.1.5 *Evaluation of results*

As it can be observed in Table 1, in the direction Ciudad Mendoza-Córdoba a larger number of dangerous segments was identified as well as a higher value of NEA for them, when compared to the opposite direction.

TABLE 1 500-m long segments with the highest NEA in each direction

DIRECTION	SEGMENT	NUMBER OF ACCIDENTS	NUMBER OF INJURIES	NUMBER OF DEATHS	NEA	AADT	SEQUENTIAL No. IN TERMS OF STATIONING
Cd. Mendoza -Córdoba	268.5≤ km < 269.0	40	19	0	78	11,173	7
	267.5≤ km < 268.0	22	20	1	68	7,619	5
	265.5≤ km < 266.0	26	18	0	62	7,619	4
	265.0≤ km < 265.5	26	18	0	62	7,619	3
	291.5≤ km < 292.0	25	13	1	57	11,173	9
	264.5≤ km < 265.0	19	13	0	45	7,619	2
	263.0≤ km < 263.5	6	8	0	22	7,619	1
	272.0≤ km < 272.5	14	3	0	20	11,173	8
Córdoba - Cd. Mendoza	267.5≤ km < 268.0	20	16	1	58	10,926	6
	268.5≤ km < 269.0	10	8	1	32	10,926	7
	296.5≤ km < 297.0	3	8	0	19	12,380	10

Mention should be also made that the segment with stationing 268.5 ≤ km < 269.0 appears to be among the most dangerous, in both directions, because it corresponds to a vehicle stop area at each side of both one-way traveled ways, in which large heavy freight trucks enter and exit slowly, anarchically and with little precaution mixing with through vehicles traveling at high speeds.

2.2. Diagnosis for each Segment

The objective of the diagnosis is the identification of the cause of the accidents and of potential safety problems or accident patterns.

From the data bases of accident reports that were provided by the Medical Services of CAPUFE, for the accidents that occurred in both directions of the section in years 2008 and 2009, Table 2 was generated, in which the average number of accidents experienced in those two years at each segment are classified in terms of their severity and type.

2.2.1 Segment 1

The segment is located in a right horizontal curve with a degree of curvature of approximately 6°30’ (for a speed of 70 km/h). At the end of the curve there exists the access to Río Blanco and Nogales. The width of the lanes falls slightly below the statutory dimensions (smaller than 3.5 m). The width of the shoulder is insufficient (less than 0.5 m the internal and than 2.5 m the external). The horizontal signing at the weaving area is not suitable to chanel the vehicles. The vertical signing is scarce since there are no signs indicating the approach to a semiurban and vehicle weaving zone. There are no devices to assist in delinating the curve alignment. The concrete modules of the central barrier have been crashed and in some cases they are discontinuous, particularly at the weaving area, as it can be observed in Figure 2. A considerable percentage of vehicles exceeding the maximum speeds allowed by the visibility has been detected.

TABLE 2 Classification of average accidents per year in each segment in terms of severity and type

DIRECTION *	SEGMENT No.	No. OF ACCIDENTS	ACCIDENTS RANKED BY SEVERITY			TYPE OF ACCIDENT**																
			WITH DEATHS	INJURIES ONLY	DAMAGES ONLY	1	2	3	4	5	6	7	8	9.1	9.2	9.3	9.4	9.5	10	11	12	13
CdM-C	1	6	0	2	4	1	0	0	0	0	0	2	0	0	0	0	0	2	1	0	0	0
CdM-C	2	19	0	8	11	4	2	0	0	1	0	7	0	1	0	0	0	1	2	1	0	0
CdM-C	3	26	0	7	19	1	1	0	1	0	0	4	0	0	8	0	0	1	10	0	0	0
CdM-C	4	26	0	6	20	1	1	0	1	0	0	4	0	0	8	0	0	1	10	0	0	0
CdM-C	5	22	1	3	18	2	1	0	0	0	1	0	0	0	0	0	0	0	16	0	2	0
C-CdM	6	20	1	7	12	6	0	0	0	6	0	1	0	0	1	0	0	1	3	0	2	0
CdM-C	7	40	0	13	27	5	0	0	0	0	0	3	0	0	3	0	1	1	24	0	2	1
C-CdM	7	10	1	5	4	2	1	0	0	2	0	1	1	0	1	0	0	1	0	0	0	1
CdM-C	8	14	0	3	11	0	0	2	0	1	0	0	0	0	1	0	0	0	10	0	0	0
CdM-C	9	25	1	5	19	9	3	0	0	1	0	0	0	0	1	1	3	0	6	0	1	0
C-CdM	10	3	0	1	2	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0

*CdM-C: Cd. Mendoza-Córdoba, C-CdM: Córdoba-Cd. Mendoza
**Types of accidents are defined as follows:

1 Rear-end collision
2 Multiple rear-end collision
3 Lateral collision
4 Head-on collision
5 Side collision
6 Fall from motorcycle
7 Collision against concrete central barrier
8 Collision against livestock
9 Collision against object in the wearing course
9.1 Tree
9.2 Rock
9.3 Tire
9.4 Provisional signing
9.5 Others
10 Road run-off
11 Road run-off and fall off a cliff
12 Overturning on the wearing course
13 Running over

FIGURE 2 Discontinuous concrete central barrier in Segment 1

2.2.2 Segment 2

The site is located in a left horizontal curve with a degree of curvature of approximately 5°00’ (for a speed of 60 km/h). The width of the lanes is found slightly below the standard dimensions. The width of the shoulders is insufficient. The bridge before the curve has no external shoulder and therefore its cross section decreases along this structure (see Figure 3). The concrete modules of the central barrier have been shattered and in some cases they lack the necessary continuity. In this curve there are no inlets at the median to capture the runoff coming from the one-way traveled way bound for Córdoba, and therefore such runoff crosses toward the one-way traveled way of the other direction generating problems to the vehicles moving along such traveled way at the site of the curve.

FIGURE 3 Reduction in the cross section of the bridge at Segment 2

2.2.3 Segment 3

The segment is located in a left horizontal curve with a degree of curvature of approximately 5°00' (for a speed of 60 km/h). The width of the lanes is found slightly below the standard dimensions. The width of the shoulders is insufficient and this provides the driver a feeling of narrowness, in addition to have a very high cut on the side of the external shoulder. This segment evidences rock fall problems coming from the cut slope, probably due to the unstable condition of the slope itself (see Figure 4). Some concrete modules of the central barrier in this segment have been hit.

FIGURE 4 Cut slope at Segment 3

2.2.4 Segment 4

The segmento is located in a right horizontal curve with a degree of curvature of approximately 6°00' (for a design speed of 60 km/h). The width of the lanes is slightly smaller than the standard dimensions. The width of the shoulders is insufficient. The segment lacks protective devices in its respective drainage works (side ditches and culverts). The horizontal signing include marks with logarithmic spacing before the horizontal curve that fails to comply with the suitable spacing, and shows faded paint. Vertical signing is scarce. In what refers the retaining devices, the central concrete barrier that separates the two one-way traveled ways evidences poor condition and lacks continuity in several parts, as can be observed in Figure 5. The visibility in this segment is very reduced and it is not suitable for the operating speeds registered.

FIGURE 5 Condition of the central barrier in Segment 4

2.2.5 Segment 5

The segment is located along a right horizontal curve with degree of curvature equal to approximately 6°00' (for a design speed of 60 km/h). The width of the lanes falls slightly below the regulation dimensions. The shoulder width is insufficient and there is also a rather high cut on the right side. In this site the two one-way traveled ways are split to accommodate a campment of CAPUFE, as well as a detachment of the Federal Police (PF), corresponding this segment to the one-way traveled way from Puebla toward Córdoba as shown in Figure 6. A U-turn also exists at this place as well as an exit loop passing through the lower part of a vehicular overhead crossing bound for the city of Orizaba. This site is characterized by accidents due to the weaving between the vehicles taking the exit loop to Orizaba and those leaving the U-turn and heading toward Córdoba. At the horizontal signing in the segment there are marks with logarithmic spacing that fail to comply with the suitable spacing, in addition of being faded. The visibility at this site is very poor both along the curve and at the weaving zone, being the visibility insufficient for the speeds of the through vehicles and of those that weave.

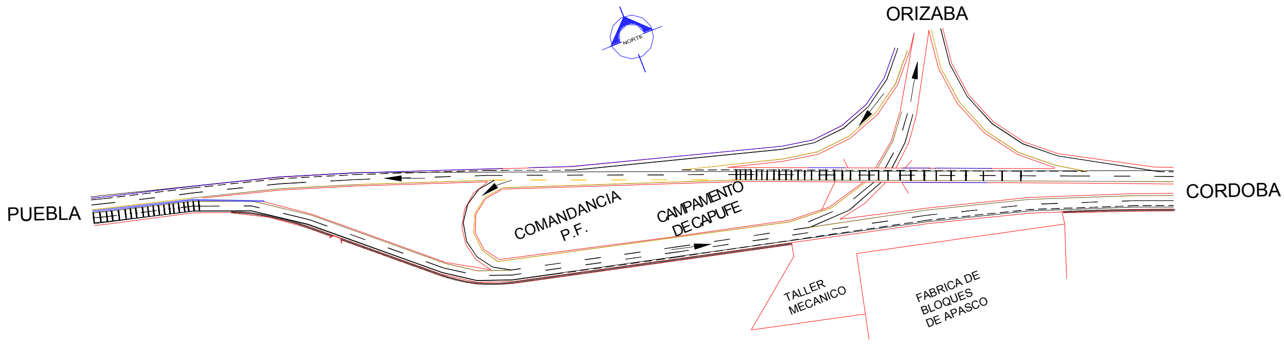

FIGURE 6 Weaving of vehicles at Segment 5

2.2.6 Segment 6

This segment is located at the same site than the previous segment, but along the one-way traveled way from Córdoba to Puebla as shown in Figure 6. The width of lanes and shoulders falls quite below the standard dimensions. There is coincidence in this segment, in a very short length, of the incorporation of the road coming from Orizaba, which has no acceleration lane, as well as the weaving of vehicles coming from Orizaba and taking the U-turn, with those going through toward Puebla. The horizontal signing is in poor condition due to lack of maintenance and presents low reflection rate at all lane separating lines, shoulders and logarithmic lines (see Figure 7).

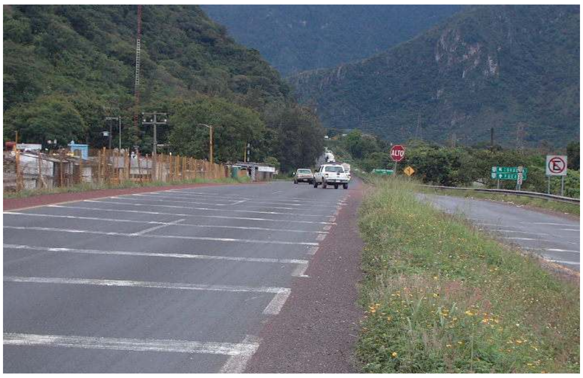

FIGURE 7 Horizontal signing in poor condition at Segment 6

2.2.7 Segment 7, in both directions

This segment is located at a straight stretch with descending vertical grade in the one-way traveled way bound for Córdoba and with upgrade slope at the one-way traveled way bound for Pueba. Lane and shoulder widths are satisfactory. In both one-way traveled ways of the segment there are commercial and service areas that constitute an irregular stop, being the main users the operators of freight trucks. As it can be observed in Figure 8, these vehicles park in two lanes encroaching the shoulder; there is also a steady stream of pedestrians crossing the road. There is no retaining element separating the vehicles parked at the stops from the normal flow of the roadway, and no pedestrian bridge or pedestrian protecting barrier are available. The horizontal signing is in poor condition. There are not some preventive and restrictive signs to inform drivers about the presence of the truck stop and of the services, nor to restrict parking over the shoulders.

FIGURE 8 Irregular parking of freight trucks at Segment 7

2.2.8 Segment 8

This segment is located in a straight section where there is a directional exit bound for Jalapilla that has a transition to channel vehicles, followed by a left curve with a degree of curvature of 4°10’ (with a radius of 275 m). The combination of the curve and of the abutment of the overhead crossing represent a risk for speeding drivers (see Figure 9). There are neither marks nor protective elements for the structures, such as in the case of the abutment of the vehicular overhead crossing.

FIGURE 9 Trajectory projecting towards the right abutment of Segment 8

2.2.9 *Segment 9*

This segment is located in a straight section with descending vertical grade followed by a left curve with a degree of curvature of 2°06', succeeded by another straight stretch. Between the first straight sector and the start of the curve there is an incorporation coming from Córdoba and right at the end of the curve the exit bound for Córdoba and to the town of La Luz is located; then, just after the second straight section there exists an incorporation coming from La Luz. Between the incorporation coming from Córdoba and the exit there exist a vehicular overhead crossing, with a distance of 120 m for the weaving. The width of the lanes and of the shoulder falls below the regulatory dimensions. The segment operates as a vehicle interchange in which at the weaving area, long waiting lines form to take the exit to Córdoba (see Figure 10). The through vehicles fail to decrease their speed in spite of the existence of the logarithmic lines. The combination of the abutment for the overhead crossing and the left curve represent a risk for the speeding drivers.

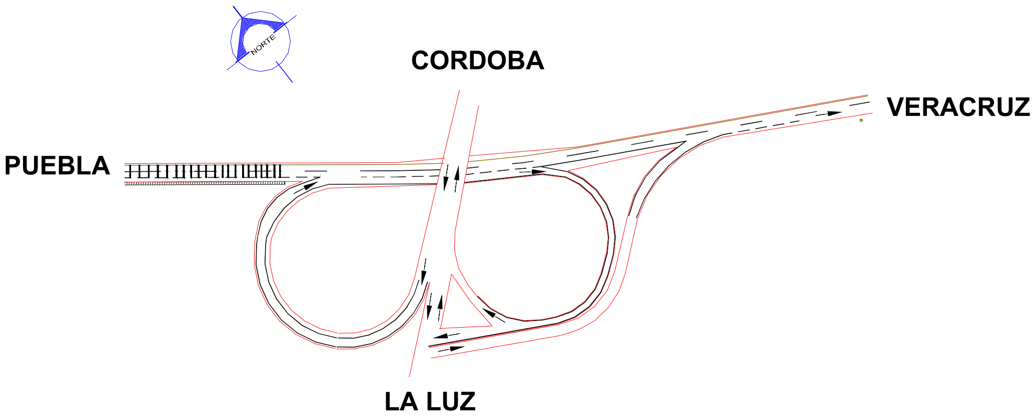

FIGURE 10 Operation at Segment 9

2.2.10 *Segment 10*

The segment is located at a straight stretch with upwards vertical slope. The segment contains in the first place an exit bound for Amatlán followed by an incorporation originating in the same place. Vehicles coming from Amatlán are incorporated into the expressway under an angle such that they have minimum visibility to be able to incorporate safely, with an additional disadvantage of a thick vegetation and the lack of an acceleration lane to be able to negotiate suitably the incorporation. This problem causes the vehicles to incorporate into the expressway at low speeds (see Figure 11). The horizontal signing is poor. There are neither certain preventive vertical signs, nor marks and protection devices for the structures.

FIGURE 11 Conditions of the incorporation into the expressway at Segment 10

2.3 Countermeasure Proposal

It was carried out considering the factors that contribute to accidents as evidenced in the diagnosis and in Table 2. Table 3 summarizes the countermeasures proposed for each alternative generated for each segment. In some segments it was regarded as sufficient the proposal of a low investment alternative constituted by simple and economic measures, whereas in more complex segments an alternative of this type was proposed together with other that also includes a high investment infrastructure (for instance, the construction of a bridge, of a vehicle interchange, etc.). As an example of the latter, Figure 12 shows the high-investment alternative corresponding to segments 5 and 6. As it can be observed, such alternative is based on the construction of a vehicle interchange at the main access to Orizaba.

Table 4 reproduces the cost of the alternatives corresponding to each segment (column 3) and it shows the percentage of deaths and serious injuries prevented as a result of the smaller accident rate, estimated according to the HSM for each alternative (column 4). Such percentage was applied to the number of deaths and injuries in Table 1, therefore obtaining the reduction in the number of deaths and serious injuries in the base year. The annual benefits derived from the implementation of an alternative were calculated by multiplying such reduction obtained by its respective social cost. For purposes of this work, average unit costs per serious injury and death equal to 100 thousand and 400 thousand dollars, respectively, were used [4]. Column 5 of Table 4 shows the monetary value of the benefits thus obtained in the first year of operation for each alternative of every segment. Subsequently, an estimation was made of the Net Present Value (NPV), the Benefit-Cost Ratio (BCR) and the Internal Return Rate (IRR); assuming an analysis horizon of 20 years; a mean traffic growth rate (MTGR) of 5.95%, based on the analysis of the vehicular flow along the segment in the last five years; and a Discount Rate (DR) of 10%, which is a typical value required by the development banks (World Bank, Inter-American Development Bank) for credit applications before them. These three indicators are shown in the last three columns of Table 4. As it can be observed, all alternatives show a high economic feasibility, but the high investment one (alternative 2) becomes less profitable than the low investment one (alternative 1) for segments 5, 6 and 9; therefore, the selection of the high investment alternatives in comparison with the low investment ones should be sought for by incorporating other benefits in addition to the improvement of the highway safety (reduction of delays, of contaminating emissions, etc.).

With the most cost-effective measures for all segments, a reduction in the annual frequency of deaths and serious injuries of 10.34 is obtained for the section.

TABLE 3 Countermeasures proposed for each improvement alternative generated for each segment

DIRECTION *	SEGMENT	ALTERNATIVE	COUNTERMEASURES	TOTAL COST (US$)
CdM-C	1	1	Improvement of horizontal and vertical signing, building of a central barrier (New Jersey), lateral steel barrier (triple wave), rumble strips, concrete slab, widening of lanes and shoulders	231,837.42
CdM-C	2	1	Improvement of horizontal and vertical signing, building of a central barrier, lateral steel barrier (triple wave), rumble strips, water collecting culverts at central barrier, widening of lanes, shoulders and bridge	300,521.08
		2	Improvement of left curve alignment and of the horizontal and vertical signing, building of a central barrier, lateral steel barrier (triple wave), rumble strips, water collecting culverts at central barrier, widening of lanes, shoulders and bridge	364,601.15
CdM-C	3	1	Stabilization of right lateral slope, improvement of horizontal and vertical signing, rumble strips, widening of lanes and shoulders	89,892.02
CdM-C	4	1	Improvement of horizontal and vertical signing, building of a lateral steel barrier (triple wave), rumble strips, water collecting culverts at central barrier, widening of lanes and shoulders	103,531.04
		2	Improvement of right curve alignment and of horizontal and vertical signing, building of a lateral steel barrier (triple wave), rumble strips, water collecting culverts at central barrier, widening of lanes and shoulders	199,531.15
CdM-C	5	1	Improvement of horizontal and vertical signing, rumble strips, widening of lanes and shoulders	79,434.12
		2	Vehicle interchange, improvement of horizontal and vertical signing, rumble strips, widening of lanes and shoulders	4,649,526.31
C-CdM	6	1	Implementation of accelerating lane, improvement of horizontal and vertical signing, building of lateral steel barrier (triple wave), rumble strips, widening of lanes and shoulders	135,844.55
		2	Vehicle interchange, improvement of horizontal and vertical signing, rumble strips, widening of lanes and shoulders	4,709,637.10
CdM-C C-CdM	7	1	Implementation of accelerating and decelerating lane, improvement of horizontal and vertical signing, building of lateral steel barrier (triple wave), rumble strips, widening of lanes and shoulders and building of separated sidewalks at roadway	359,164.70
CdM-C	8	1	Implementation of decelerating lane, improvement of horizontal and vertical signing, building of lateral steel barrier (triple wave), rumble strips, widening of lanes and shoulders	144,201.04
CdM-C	9	1	Implementation of accelerating lane, pavement rehabilitation, improvement of horizontal and vertical signing, building of lateral steel barrier (triple wave), rumble strips, widening of lanes and shoulders	240,463.69
		2	Vehicle interchange, improvement of horizontal and vertical signing, building of lateral steel barrier (triple wave), rumble strips, widening of lanes and shoulders	5,014,068.36
C-CdM	10	1	Structural analysis of railroad bridge, implementation of accelerating and decelerating lane, improvement of horizontal and vertical signing, rumble strips, widening of lanes and shoulders	291,041.97

*CdM-C: Cd. Mendoza-Córdoba, C-CdM: Córdoba-Cd. Mendoza

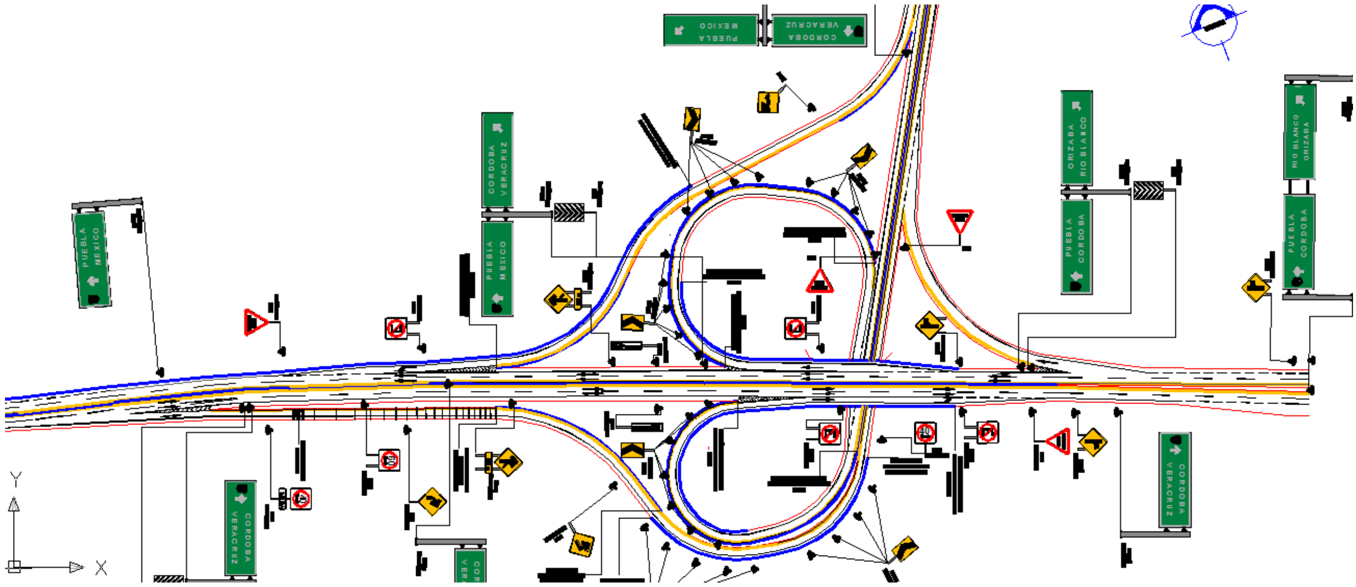

FIGURE 12 Proposal of vehicle interchange to Orizaba

TABLE 4 Benefit cost analysis for the alternatives of each segment

SEGMENT	ALTERNATIVE	TOTAL COST (US$)	REDUCTION OF DEATHS AND SERIOUS INJURIES (%)	BENEFITS IN THE FIRST YEAR OF OPERATION (US$)	BCR	NPV (US$)	IRR
1	1	231,837.42	11.01	95,355.00	4.48	965,420.91	32.28%
2	1	300,521.08	8.19	116,545.00	4.23	1,159,439.64	30.13%
	2	364,601.15	49.50	678,080.00	20.27	8,400,217.68	164.03%
3	1	89,892.02	6.32	116,545.00	14.13	1,411,239.43	112.82%
4	1	103,531.04	7.26	137,735.00	14.50	1,671,062.13	115.90%
	2	199,531.15	48.99	932,360.00	50.93	11,911,085.36	419.75%
5	1	79,434.12	5.38	158,925.00	21.81	1,975,996.85	176.84%
	2	4,649,526.31	90.54	2,299,115.00	5.39	24,401,504.85	39.88%
6	1	135,844.55	7.26	169,520.00	13.60	2,046,623.97	108.40%
	2	4,709,637.10	90.54	1,917,695.00	4.44	19,359,346.21	31.91%
7	1	359,164.70	8.19	275,470.00	8.36	3,160,290.82	64.68%
8	1	144,201.04	7.26	21,190.00	1.60	103,740.30	6.79%
9	1	240,463.69	8.19	158,925.00	7.20	1,783,491.55	55.03%
	2	5,014,068.36	90.54	1,631,630.00	3.55	15,267,685.42	24.37%
10	1	291,041.97	7.26	63,570.00	2.38	480,452.39	14.20%

3. SAFETY INSPECTION OF THE SECTION

A stage-four audit was performed at the section; it is also known as highway safety inspection [2] and includes retrieval of base information (location drawings and highway alignment, standards and regulations, road data, accident reports, etc.), the review and evaluation of such information (reviewing compliance with regulations, the sites of concentration of accidents or “black spots”, etc.), the in-situ inspection of the segment under day and night conditions and the registry, in checking lists, of deficiencies detected (in signing, cross section, drainage, shock absorbers, etc.), and the generation of improvement programs (massive and priority measures). Table 5 summarizes the countermeasures generated for each segment after applying this approach. The fourth column of the table contains the percentile reduction of deaths and serious injuries obtained in this case for each segment. To be able to assess this percentage the iRAP [5] methodology was used. This methodology takes into account the effect of the countermeasures in head-on collisions, road run-offs and lateral collisions at intersections, considering the vehicles as user type, because this is the user type for which comparisons are made between methodologies in this paper. With the set of countermeasures recommended for all segments, a reduction in the annual rate of deaths and serious injuries of 9.12 is obtained for the section.

As it becomes evident after comparing Tables 3 and 5, by using the road inspection methodology (that involves a linear continuous review and a quick detection of deficiencies), the countermeasures derived from them are simpler and generally cheaper that those obtained from more comprehensive analyses derived from the implementation of the HSM. The comparison between the percentage reduction in the number of deaths and injuries for the low-cost alternative in the fourth column of Table 4 and the equivalent percentage shown in the fourth column of Table 5 indicates that comparable impacts are predicted between both methodologies.

TABLE 5 Countermeasures and results obtained for each segment inspected

DIRECTION*	SEGMENT	COUNTERMEASURES	REDUCTION IN DEATHS AND SERIOUS INJURIES (%)	TOTAL COST (US$)	BCR
CdM-C	1	Installation of right and left lateral barriers, improvement of alignment and signing at intersection and improvement of general alignment of segment	7.2	42,213.38	17.86
CdM-C	2	Installation of right and left lateral barriers	7.1	78,726.15	15.35
CdM-C	3	Installation of left lateral barrier	2.9	47,235.69	14.46
CdM-C	4	Installation of right and left lateral barriers	4.7	78,726.15	14.07
CdM-C	5	Installation of right and left lateral barriers	1.0	47,235.69	5.82
C-CdM	6	Widening of shoulder, installation of right and left lateral barriers and improvement of alignment and signing at the intersection	12.6	218,010.77	12.86
CdM-C C-CdM	7	In both directions it is proposed to build the central barrier and install right and left lateral barriers as well as separate sidewalks at the roadway	8.4	508,570.92	4.32
CdM-C	8	Installation of central divide and of right and left lateral barriers	23.5	175,559.31	5.26
CdM-C	9	Installation of right and left lateral barriers	3.6	125,961.85	5.24
C-CdM	10	Installation of right and left lateral barriers and improvement of alignment and signing at intersection	12.7	167,141.69	7.96

*CdM-C: Cd. Mendoza-Córdoba, C-CdM: Córdoba-Cd. Mendoza

CONCLUSIONS AND RECOMMENDATIONS

Because of the nature of the approach in each methodology, the results obtained from the implementation of the HSM, in the case of existing highways, are generally more detailed and accurate than those derived from a highway safety audit or inspection. Because of the same reason, whereas the HSM leads to consider low and high investment alternatives, those derived from an inspection basically correspond to low investment actions (although from the visual inspection of complex problems in the audit, the recommendation usually follows to carry out further and more comprehensive studies aimed at resolving those particular problems). The assessment of the impact of the countermeasures between both methodologies resulted comparable. The cost of the countermeasures derived from the audit is generally smaller than that of the alternatives derived from the application of the HSM (even for the case of low investment alternatives).

Whereas the values of the crash modification factors (or CMFs) resulted reasonable, the prediction of the annual rate of accidents underestimated quite notoriously the actual frequency of accidents occurred at each segment. For this reason, it is strongly recommended to apply the HSM methodology based on actual accident rates rather than on those obtained from the safety performance functions (or SPFs).

Because of their impact in human life and in social welfare, the highway safety improvements, such as those made on the infrastructure, are generally quite cost efficient (with high values of NPV, BCR and IRR).

Finally, the experience gained from the application of the HSM presented in this paper indicates that the Highway Safety Manual is a highly useful, reliable and applicable tool for the development of programs intended to improve safety of Mexican highways.

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