ROAD SAFETY AUDITS IN MEXICO

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ABSTRACT

The substantial improvement of the highway safety is one of the major concerns among operators of the road infrastructure in different countries.

One strategy that is being implemented in Mexico in the last few years for purposes of reducing the accident rate and its associated consequences refers to the application of Road Safety Audits (RSA).

In past years the *National Center for the Prevention of Accidents* (CENAPRA), and the *Mexican Transportation Institute* (IMT), have implemented training programs for road safety auditors, where one of the objectives is the sound performance of safety inspections.

In 2008, at the request from a concessionaire concerned on how to improve the safety levels of the highways it operates, such a concessionaire asked the IMT to carry out a RSA in its own highway network covering a length of 800 kilometers; for such purpose the IMT, based on the traditional methodology for RSA, developed a process suitable for this type of roads.

The paper presented herein describes the methodology applied for performing the RSA and it contains a summary of each of the activities and the most important final results of the process.

1. INTRODUCTION

The process of implementation of a road improvement (new or improvement of an existing section) comprises several stages, including generally the following ones: preliminary design, executive project, construction, and operation.

The most common procedures for the execution of a RSA likely consider the performance of an audit on the product resulting from each of the previously mentioned stages, with the purpose of identifying possible faults in matters of road safety [1].

Therefore, a RSA Stage 1 can be defined as the process implemented to identify deficiencies in the preliminary project that could generate unsafe road conditions and accidents. It usually represents the last chance to take into account the safety requirements in the management of resources (e.g. for the acquisition of the right of way).

In the RSA Stage 2, aimed at identifying deficiencies in the executive project, the audit focuses on the more detailed aspects of the improvement, considering the geometry of the intersections, the position of the vertical signs, the horizontal signing, the artificial lightning, etc.

RSA Stage 3 should be performed when the construction has been substantially completed and preferably prior to opening for usage. The auditors should examine the improvement from the point of view of the users and they can walk, drive a vehicle or a bicycle along the road for purposes of assessing its operation by the users. RSA Stage 3 should identify deficiencies detected in the RSA Stage 2 that have not been fully attended and reiterate them in the report prepared for such stage.

RSA Stage 4, also known as inspection, is performed when the road is already in operation. This RSA should include a verification of the number of accidents with victims (injured and dead) that occur so as to identify serious problems and implement rapidly pertinent corrections. The report of this RSA should point out the safety problems identified from the analysis of the data on accidents as well as from the observations made during field visits.

Since already operating highways are dealt with, the scope of this work corresponds basically to RSA Stage 4.

2. METHODOLOGY APPLIED FOR ROAD SAFETY AUDITS (RSA)

For the execution of the RSA process, the methodology involving the following steps was developed:

1. Retrieval of the base information (layout drawings and highway alignment, standards and regulations, road traffic data, information on accidents, etc.).

2. Analysis of the base information in each of the roads. The main purposes is to revise compliance with the regulations, the identification and location of sites with a high concentration of accidents ("black points") and of other points requiring a detailed analysis such as intersections, interchanges and special points.

3. Field or "*in situ*" inspection. Diurnal and nocturnal field surveys are made in both directions. In this stage the objective is to analyze the operation of each of the highways under different conditions of visibility, to identify and locate by means of the GPS and of the mobile-map system those elements that could pose a potential safety risk (those related to the operation of the road as well as those related to the infrastructure, the signing and its surroundings). During the "*in situ*" inspection the deficiencies detected in the horizontal and vertical signing, the cross section, the drainage system, the alignment of the road, the retaining devices, the connection between retaining systems, the ramps, the lateral zones and so forth are registered into check lists. A data survey is also carried out by means of a "Safe Curve Speed Indicator", video recording and photographic records.

4. Analysis in the office of all information gathered.

5. Preparation of the final RSA report including the recommendations to solve the problems identified as well as the specific solutions for the audited highway.

2.1. Retrieval of the base information

The concessionaire was asked to provide all information available on the highways to be audited so as to start the diagnosis of each place and, from the outcome, to be able to develop the methodology to be used in the field inspections prior to the beginning of the audit. The information requested is listed as follows:

- Drawings and graphic material of the highway involved (location, and horizontal and vertical alignment)
- Drawings of signing
- Traffics counts
- Information on accidents

In addition to the information delivered, the following information was collected for each of the highways:

- Satellite images
- Traffic counts and classification taken from *Datos Viales* 2007 [2]
- Weather conditions

2.2. Analysis of the information

2.2.1 *Drawings and graphic material*

The drawings were revised by the auditing staff verifying that all elements constituting the road were in compliance with values higher than the minimum established by the standards and regulations for the geometric design of highways [3], locating the most restrictive sites (limited radii of curvature, tangents of short length, very long sustained gradients, improper combination of alignments, etc.) that could pose any safety problem. In those cases where any of the standards was not satisfied, as a function of the road, they were identified graphically and subsequently corroborated in the field inspection.

2.2.2 *Reports of accidents*

The analysis of the accident reports is used as an aid to the auditors in the determination of areas with potential safety problems. This represents a proactive audit.

A detailed analysis was performed of the accident reports on all of the audited highways for the years for which registries were available, highlighting the number of accidents per year and their monthly evolution, type and cause of the accidents, number of dead and injured people, type of vehicle, climatologic condition and location of the accident.

The location of the accident associated to the cause, class and meteorological condition during the event, facilitate the determination of potential sites in which a high incidence of accidents could be expected ("black points"), namely, places already evidencing safety problems and where the auditing staff has to focus its attention during the field visits. With these data a two-dimensional graph can be developed that shows, with no scale, the total length of the highway, stationing, traveled way, traveling directions and lanes, indicating with a point the location of each accident registered. This graph is known as "Graphical Representation of Accidents". Figure 1 shows a "Graphical Representation of Accidents" corresponding to a highway with the accidents recorded in 2007 and 2008.

As it can be observed in Figure 1, this highway registers an incidence of accidents between the pairs of kilometers 27-28, 28-29, 29-30, 34-35 and 36-37. The site with the largest incidence can be found in the pair 34-35 with 16 accidents, most of them occurring at the left traveled way, in the direction opposite to the stationing, and in the high speed lane for year 2007.

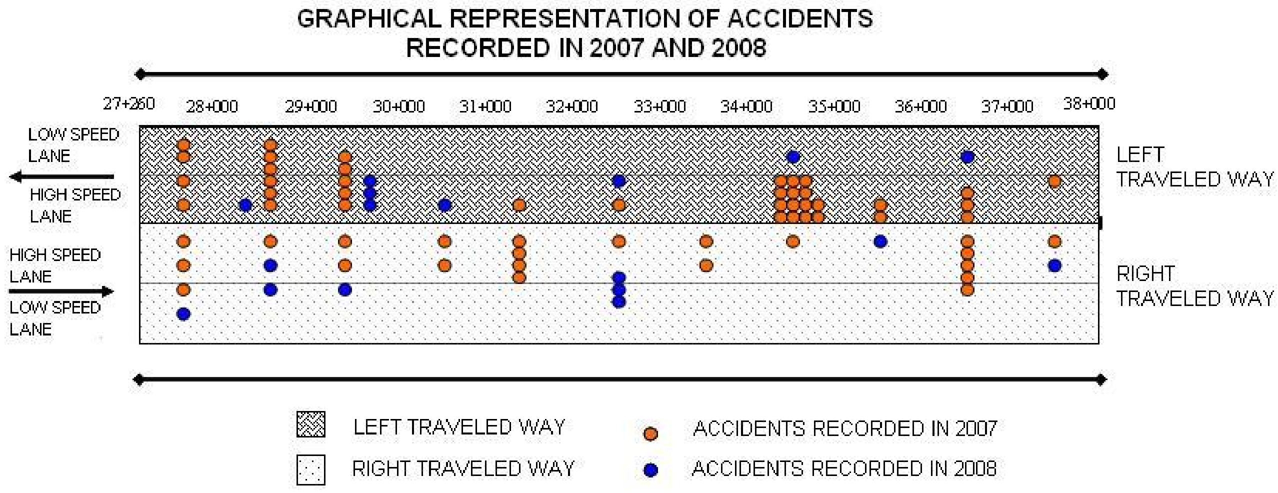

Figure 1 - Graphical Representation of Accidents

After locating some potential sites with a high rate of accidents, the auditing staff verified at the construction drawings that the geometric elements of the roadway have no restriction or that at least they comply with the minimum standards for design so that it is possible to visualize the potential problems prior to the performing of the field inspection to the site.

2.3. Field or "*in situ*" inspection

The field inspection is of vital importance because it provides the auditing staff with knowledge of the existing conditions. Prior to this, the staff should become familiar with the "Check Lists" to as to guarantee an efficient exploration and with it to collect relevant aspects.

The "Check List" is a format used to register the deficiencies detected.

2.3.1 *Check and verification list*

The use of check lists is helpful to guarantee that all relevant aspects related to safety are taken into account and in no case whatsoever they replace sound judgment, knowledge and experience of the auditor. The safety aspects included in these lists are described as follows:

1. Alignment and cross section. The aspects considered were: visibility distance, design speed, speed limit, road legibility, width of lanes, shoulders, superelevation, slopes and drainage.

2. Auxiliary lanes. In this part an evaluation was made of acceleration and deceleration lanes and returns.

3. Intersections. Aspects considered include location of the intersection, visibility, horizontal signing and design.

4. Lightning.

5. Vertical signing. The elements considered were: general aspects of vertical signing, legibility and support for the signs.

6. Horizontal signing. Elements evaluated were: general aspects of the horizontal signing, marks, delineators and retroreflecting devices, warning signs and delineation of curves.

7. Barriers and lateral clearance zones. The elements analyzed were: lateral clearance, terminals, shock absorbers and visibility of barriers.

8. Pedestrians and bicyclists.

9. Bridges and culverts.

10. Pavements. Aspects considered included defects in the pavement, skid resistance, flooding, and loose rocks and/or material.

11. Provision for heavy vehicles.

12. Water courses and floods. The elements considered were: waterlogging and safety at the edge of the roadway.

13. Miscellaneous. Included are those additional elements regarded by the auditor as a risk such as surroundings of the roadway, temporary works, glaring problem, activities at the edge of the roadway, other safety matters and livestock.

The Verification Lists are printed in a format used by the auditing team during the field inspection to register the deficiencies detected referenced to the station where the problem was found, the number of the photograph taken at the site, and a brief description of the deficiency as well as a possible suggestion to mitigate it. Each auditing team records all of the deficiencies encountered in the highway at the verification list.

2.3.2 *Field surveys*

The field survey of each highway was subsequently carried out, incorporating the following activities:

1. Surveying with GPS of the highway alignment and video recorded registry during a diurnal run in automobile in both directions.

With the daylight video it is possible to observe the alignment to be followed by the highway from the point of view of the driver, with a narrative of relevant facts about the alignment, the signing, the physical and operative conditions, etc.

The information registered with the GPS is processed and visualized in AutoCAD, generating a drawing for each highway. The AutoCAD software facilitates an accurate verification of each highway element such as the total length, distance between curves, degree and radius of curvature, gradients, and so forth. Figure 2 shows how the information obtained with the GPS can be downloaded into the AutoCAD.

2. Identification of sites with high risk of overturning or running off the road at the speed limit, by means of a survey using the “Safe Curve Speed Indicator” by riding in an automobile in both directions.

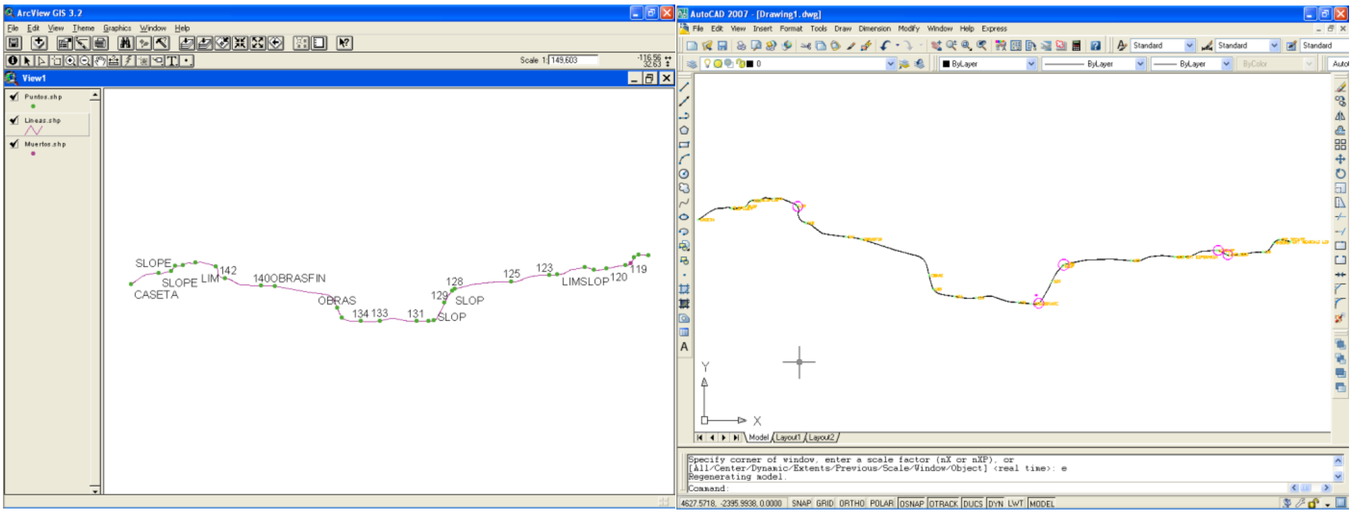

Figure 2 - Information registered with the GPS and subsequently processed in AutoCAD

The “Safe Curve Speed Indicator” is an instrument to measure the lateral acceleration (in degrees) of a vehicle running at certain speed while negotiating a horizontal curve. Depending on the radius and on the superelevation of the curve, the “Safe Curve Speed Indicator” is capable of showing whether the speed for negotiating the curve does not represent any risk of overturning or of loss of control of the vehicle. This device is fitted with a small steel ball placed inside a glass tube filled with water mounted on a graduated steel plate that is fastened to the car. Figure 3 depicts a “Safe Curve Speed Indicator”.

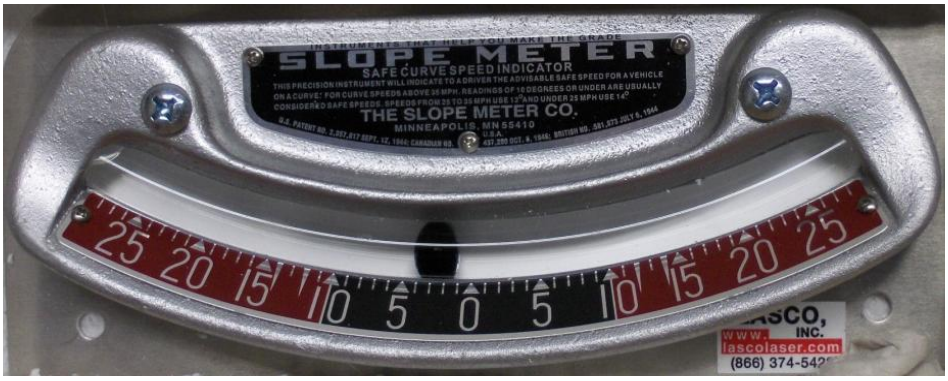

Figure 3 - Safe Curve Speed Indicator

The area colored in red (from 10 to 28 degrees) indicates that the speed to negotiate the curve can represent a certain risk of overturning or running off the road, whereas the intermediate zone shown in black (from 0 to 10 degrees) represents a safe speed to negotiate the curve.

The procedure used to operate this device during the field surveys is described as follows:

A first complete run (round trip) was carried out following the whole length of the highway at the maximum speed limit. During the survey, one person of the auditing team kept on taking readings of the degrees marked by the instrument when negotiating each curve. If the reading registered by the steel ball inside the device fell within the range covered by the red zone, such reading was registered and annotated, whereas another person of the same team located the site with a point in the GPS indicating the reading taken. With this method it was possible in the office to locate the curve that could potentially evidence problems of overturning or running off the road.

3. Daylight surveys in both directions of the highway registering deficiencies observed in the verification lists and photographic recording of such deficiencies.

This part of the work was executed by two independent teams of auditors, each of them constituted by two auditors, traveling the highway in different vehicles. Each auditing team drove over the shoulder at a moderate speed (not higher than 20 km/h) to observe the safety deficiencies of all elements involved in the roadway, stopping at each site, registering the deficiency and the observations in the verification lists and taking a photograph as a reference.

4. Registry of spot speeds for each type of vehicle at different sites in each traveling direction.

In the course of this activity spot speeds were registered at different sites of the highways for the purpose of determining the variations in the operative speed with which the vehicles travel along the traffic lanes. The most suitable points to register the speeds were determined. According to the site, speeds were also recorded at the exit of the main road and/or at entrances to it. For the case of platoons, only the speed of the first vehicle was measured. A sample of no less than 120 speeds was registered at each site. This field study is very useful to determine the desirable speed for drivers and the levels of violation of the maximum speed limits allowed at each segment. This stage of the work was performed with the help of speed measuring equipment constituted by two speed guns: one radar like and the other a laser beam.

5. Registry of the conditions at nighttime by video recording in nocturnal runs driving an automobile in both directions.

With the nocturnal video it is possible to observe the suitable operation of the lighting and signing devices of the highway from the point of view of the driver, with a narrative of occurrences related to the retroreflecting degree of the raised markers, marks on the pavement, painting of the structures, vertical signing, lighting conditions, visibility of toll booths, etc.

With the nocturnal video it is possible to detect elements at the lateral zone that can be seen during daylight without difficulty but that in conditions of scarce lighting require a certain type of retroreflecting device to improve their visibility. In Figure 4, the picture at the left shows the pier of a pedestrian bridge at the lateral zone that, during the day can be observed with no problems; at night, however, the picture at the right that corresponds to the same bridge pier evidences poor visibility.

2.4. Office work

The analysis in the office of each highway included the following activities, briefly described herein:

Figure 4 - Visibility comparison of a structure during the day and at nighttime conditions

1. Geo-referenced drafting of the highway and map of its geographic location in the country, including general data such as nomenclature as part of the classification system of federal highways issued by the *Secretaría de Comunicaciones y Transportes* or Ministry of Communications and Transports (SCT), initial and final stationing, length, speed limit, cross section in each direction, annual average daily traffic (AADT), wearing surface, etc.

2. Cumulative distribution of the frequencies of spot speeds measured at each site for each type of vehicle and identification of risk factors related to the speed regime along the highway.

Based on the spot speeds measured at different parts of the audited highways, it was possible to obtain the mean, minimum and maximum speed per type of vehicle, as well as the determination of the 85 percentile (operative speed) in terms of the cumulative frequencies of the speeds registered for all of the vehicles analyzed.

3. Identification of unsafe sites based on surveys using the “safe curve speed indicators” and development of recommendations for the improvement of these sites (for instance, reduction of the speed limit, speed control measures, etc.).

As it was previously mentioned, during the surveys with the “safe curve speed indicators”, points were located with GPS whenever the indicator of the instrument fell in the red zone (higher than 10 degrees) this meaning that the combination between the radius and the superelevation in those curves even traveling at the maximum speed limit could represent the possibility of the vehicles to experience overturning or run off of the road.

4. Detailed analysis of accidents, identifying sites with the highest accident rate, most common types, main causes, etc., as related to the deficiencies registered in the verification lists, the photographic records and the videos taken during the daylight and nighttime runs.

The work in this part of the study consisted in relating the information gathered in the field to the sites with high incidence of accidents previously located. A detailed review was made of the photographic records and daylight and nighttime videos analyzing the causes and most common types of accidents and verifying if such causes were associated to the deficiencies registered by the auditors in the verification lists.

5. Provide a detailed account along the stationing in both directions of the deficiencies registered at the verification lists, the photographic reports, videos and recommendations to correct them.

This part comprised the review of the photographic report, one photograph at a time, in consecutive order according to the stationing and in each traveling direction, comparing the notes contained in the verification lists with the suggested recommendations of each auditing team related to each picture and verifying the videos both diurnal and nocturnal, in each case, to corroborate the observations in the photographs and in the verification lists. From this comprehensive analysis, the auditing team indentified the deficiencies and/or problems, proposed some recommendations and suggestions to improve or correct the deficiency at each of the sites inspected.

2.5. Development of the audit report

The report prepared from each audit included the following parts:

1. Presentation or cover.
2. Auditing team.
3. Geographic positioning.
4. Description of the segment.
5. Characteristics of the RSA.
6. Operating speeds.
7. Analysis of accidents.
8. Safe curve speed indicators.
9. General recommendations.
10. Field inspection.
11. Suggestions.
12. Program of massive and priority actions.

3. CONCLUSIONS

The methodology applied has the advantage of being able to be implemented in all stages of all types of roads but, in this case, it was focused on existing highways.

As a result of the application of the auditing process it was possible to obtain a program of priority and massive actions focused obviously in improving road safety. Along these lines, the RSA report should contain a series of recommendations that can be adopted in one of these two ways:

1. Correct one at a time the deficiencies identified at each site, an action that can be regarded as treatment of specific sites.

2. Identify sites with common problems, i.e. those where deficiencies become repetitive, and in this way launch programs for each type of problem along the highway or at the road network.

When launching of a program of massive actions it is necessary to identify the most frequently required actions and, as mentioned before, those actions arise from repetitive deficiencies along the roadway (e.g. inadequate containment elements, visibility problems in signing, zones free of obstacles, etc.) that, as a result of their frequent occurrence in the road may pose a risk. Additionally, once the actions referred are identified, it is necessary to rank them by priority to get the best from the financial resources and to apply them at sites where a potential risk exists of experiencing accidents with victims or at places where they had already appeared, so that both the resources and the actions are aimed to eliminate and/or reduce the consequences of accidents.

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