RESEARCH FOR AN ENVIRONMENTAL INDEX OF NOISE, BASED ON ITS EVOLUTION 2000-2005, ON FEDERAL HIGHWAYS AT QUERETARO STATE IN MÉXICO.

Mendoza J.F.
Senior researcher of Environmental Department – Mexican Institute of Transportation – fernando.mendoza@imt.mx
Rascon O.A.
General Manager – Mexican Institute of Transportation – octavio.rascon@imt.mx
Tellez R.
Coordinator of Transportation Infrastructure – Mexican Institute of Transportation – rodolfo.tellez@imt.mx
Flores M.A.
Associate researcher of Environmental Department – Mexican Institute of Transportation – antonio.flores@imt.mx

ABSTRACT

The Environmental Department of the Mexican Institute of Transportation has done a pilot study in the most important highways at Queretaro State during 2000 and 2005 years, in order to analyze the noise pollution produced by the transport operation.

Furthermore, this study represents the first attempt to construct an "environmental index of noise", which could be used as a reference for the follow-up of this environmental impact in following years and to implement an official standard. In order to calculate the referred "Environmental Index" it was taken in account the global noise generated by the transport operation at the field on each of the studied highways, during 2000 and 2005 years, to observe if that real noise was reduced, equal or increased. Global noise is that produced by vehicles flow during one minute average along the date, and includes engine noise, exhaust system, air cutting and contact between tires and pavement.

The total environmental index of noise and its variation between 2000 and 2005 years and the future following up, it is obtained dividing the Total Real Noise at the field by the OECD permissible standard or official recommendation. Results are shown with detail at the chapter 9.

An important factor was used in this research, involving statistical analysis, comparing results of noise levels, type of pavement, Annual Average Daily Traffic (AADT) and heavy trucks impacts.

Results had shown a significant increment of noise pollution levels in all cases at Mexican highways, including the AADT rates, type of pavement, and kind of vehicles. The final conclusion of this paper, based on the statistical analysis on data collected between 2000 and 2005 years, point that 75 dB(A) is the "real value" to start the regulation of noise pollutions levels and a gradual reduction of 1 dB(A) each year along ten years period, in order to reach the OECD standard of 65 dB(A).

Keywords: Noise pollution levels, analysis of noise, statistical evolution of noise.

1. INTRODUCTION

During the year 2000, the Mexican Institute of Transportation began a research line concerning to noise pollution in some important highways of Mexico at different States, with the purpose to establish an environmental index of noise and to regulate the maximum noise levels under Mexican laws.

This paper shows the case study in highways at Querétaro State. The highways sections were chosen, where the environmental impact produced by the road transport operation, concerning to noise levels there is a possible risk to human health.

There is a strong need to study the total noise produced by the transport operation along the main highways in México and to start a policy or federal regulation, in order to protect the population settled at urban and interurban areas. Consequently, the Environmental Department of the Mexican Institute of Transportation, made a pilot study in most important highways at Querétaro State during 2000 and 2005 years. (Table 1 and Figure 1).

The main purpose of this paper, was to compare values of both studies (2000-2005) and make the analysis of noise pollution levels in the last five years along the same sections of federal highways, with statistical evolution, comparing also the changes or variation in the Annual Average Daily Traffic (AADT), type of pavement and noise produced by the engine vehicle, exhaust system, air cutting and contact between tires and pavement surface.

Table 1. Location of highway sections at Queretaro State

Section	Highway	Route	Direction to
1	México – Querétaro, km 208 + 200	57 D	México
2	México – Querétaro, km 193 + 050	57 D	Querétaro
3	Querétaro – San Luís Potosí, km 26 + 200	57	San Luis Potosí
4	Querétaro – San Luís Potosí, km 12 + 800	57	San Luis Potosí
5	Querétaro – Celaya (Libre), km 10 + 000	45	Querétaro

2. MEASUREMENT METHODOLOGY

The highways were categorized according to their Annual Average Daily Traffic (AADT), traffic loads, topographical location and the possible effects on users and adjacent residential areas. Taking both this information and a preliminary field survey into account, critical highway sections were identified.

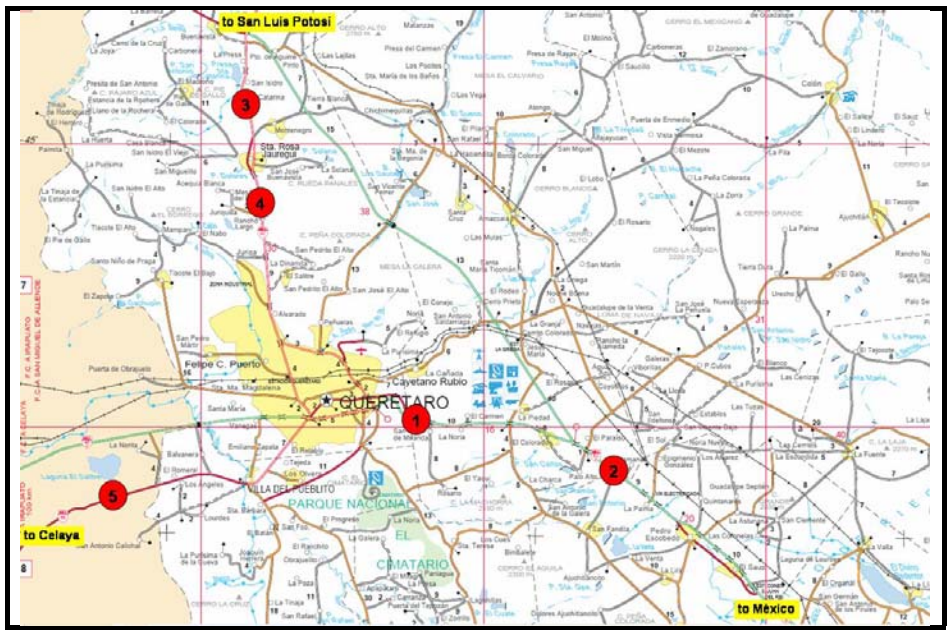

Figure 1. Site highway sections at Queretaro State

At the selected critical sections, noise levels were directly measured under the following considerations:

- Measurements were done out during uninterrupted periods of 7 hours
- Noise measurement can be considered continuous over the period of measurement
- Measurements didn't make under adverse climatic conditions like rain, excessive wind or snow because these variations could affect the results.

The measurement were done with precision sound level meters, on a standard tripod within a distance of 7,5 m of the highway shoulder and 1,5 m over the pavement surface. In order to avoid wind interference, a windscreen on the microphone was used to absorb the wind whistle (Figure 2).

The on site field measurements, were performed with specialized noise measurement equipments during working days between 8:30 and 16:00 hours. The level of equivalent noise (Leq) for 60 seconds and an interval of two minutes were measured, obtaining 450 readings for each point and 2.250 total measurements in 2000 year. The same quantities were done for 2005 year.

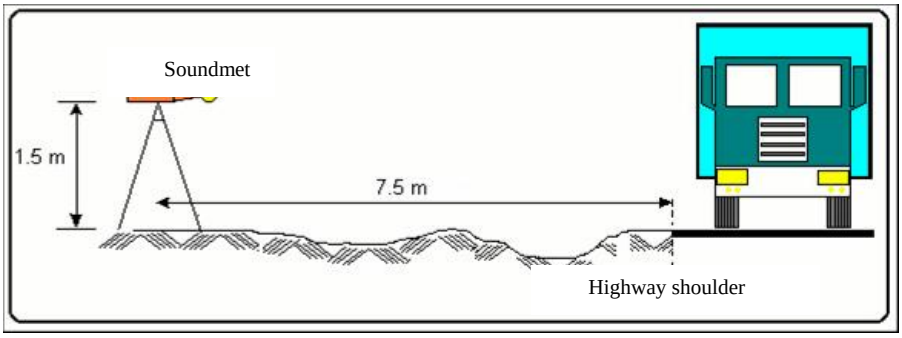

Figure 2. Field measurement noise diagram

The measurement points were chosen within the critical sections. In order to take measurements during transportation in standard operation conditions, the selected point should not be near highway accesses or exits, neither on a step slope nor with obstacles around it which would damp the sound waves. Also, a noise level increment caused by the vehicles velocity, engines, the opening of the exhaust system in step slopes or a dampening caused by tree curtains or topographical place formations was avoided.

Readings of the equivalent sound pressure level (Leq) were taken every 60 seconds. This represents the steady sound level that, over a specified period of time, would produce the same energy equivalence as the fluctuating sound level actually occurring. These readings were afterwards integrated to get the Leq for 7 hours in this case, the Leq total in decibels with ponderation A.

3. PREVIOUS STUDIES

The first studies were done in highways at four Mexican states which were selected due to their economical relevance and traffic loads: Querétaro, Jalisco, Nuevo León and Veracruz.

These studies have been published by the Mexican Institute of Transportation (IMT), and include all noise measurement data obtained at highways selected by means of their high traffic volume and possible noise impact.

With these studies, the Environmental Department of the Mexican Institute of Transportation made a proposal for a federal normative, which would regulate and reduce noise generated by the operation of motor vehicles on Mexican highways.

4. MONITORING STUDY

4.1 Summary Queretaro 2000 year

Table 2. Noise levels Study

Section	QUERÉTARO STATE						
	Leq Total	**Leq (hr)**	**L_{10}**	**L_{50}**	**PAVEMENT TYPE**	**AADT**	**SPEED**
1	77,3	80,5	77,0	79,0	Concrete	37.718	110
2	80,6	83,0	80,5	81,5	Concrete	32.325	110
3	76,2	79,0	76,0	77,0	Asphalt	15.716	110
4	78,3	81,0	77,8	79,3	Asphalt	20.843	110
5	75,0	77,8	73,5	76,5	Asphalt	10.564	110
Average Asphalt	**76,5**	**79,3**	**75,8**	**77,6**			
Average Concrete	**79,0**	**81,8**	**78,8**	**80,3**		Date: Year 2000	

4.2 Summary Queretaro 2005 year

Table 3. Noise levels Study

Section	QUERÉTARO STATE						
	Leq Total	**Leq (hr)**	**L_{10}**	**L_{50}**	**PAVEMENT TYPE**	**AADT**	**ROUTE**
1	85,2	85,1	86,1	85,0	Concrete	44.654	57 D
2	88,2	87,9	89,4	87,8	Concrete	48.344	57 D
3	80,7	80,9	83,0	80,0	Asphalt	26.961	57
4	79,4	80,4	82,0	79,5	Asphalt	32.802	57
5	78,4	79,6	81,6	77,0	Asphalt	16.804	45
Average Asphalt	**79,5**	**80,3**	**82,2**	**78,8**			
Average Concrete	**86,7**	**86,5**	**87,7**	**86,4**		Date: Year 2005	

5. NOISE LEVELS COMPARISON 2000 RESPECT TO 2005

The table 4 shows the noise levels results in both studies.

Table 4. Comparison Noise levels 2000 respect to 2005 years

Section	Leq Total		Leq (hr)		L_{10}		L_{50}		Average	
	2000	2005	2000	2005	2000	2005	2000	2005	2000	2005
1	77,3	85,2	80,5	85,1	77,0	86,1	79,0	85,0	78,5	85,3
2	80,6	88,2	83,0	87,9	80,5	89,4	81,5	87,8	81,4	88,3
3	76,2	80,7	79,0	80,9	76,0	83,0	77,0	80,0	77,1	81,1
4	78,3	79,4	81,0	80,4	77,8	82,0	79,3	79,5	79,1	80,3
5	75,0	78,4	77,8	79,6	73,5	81,6	76,5	77,0	75,7	79,1
Average	**77,5**	**82,4**	**80,3**	**82,8**	**77,0**	**84,4**	**78,7**	**81,9**	**78,3**	**82,8**
Standard deviation	**2,13**	**4,16**	**1,98**	**3,57**	**2,55**	**3,29**	**2,00**	**4,39**	**2,15**	**3,84**
Variance	**4,56**	**17,34**	**3,94**	**12,77**	**6,51**	**10,82**	**4,00**	**19,30**	**4,64**	**14,76**

The comparison had shown higher values in 2005 respect to 2000 year, thereby the noise pollution levels are growing. The less increase was 0,2 dB at section 4 for the L_{50}. The higher increase was 9,08 dB at section 1 for the L_{10}. Also it can be observed that the noise levels were higher in concrete pavement respect to asphalt pavement. The average growing of noise recorded in five years for all sections was 0,9 dB per year.

Table 5 shows the annual average daily traffic for each section and its comparison between 2000 and 2005 years, and also the number of heavy trucks in the studied sections on highways.

Table 5. Comparison AADT and Trucks 2000 respect to 2005 years

Section	AADT		Trucks	
	2000	2005	2000	2005
1	37.718	44.654	6.412	11.164
2	32.325	48.344	5.819	14.020
3	15.716	26.961	2.986	4.853
4	20.843	32.802	3.960	5.576
5	10.564	16.804	3.064	3.025

From de same results, can be observed a growth from 16% to 42% for the annual average daily traffic, and for trucks from 8% to 11%.

6. STATISTICAL ANALYSIS OF NOISE LEVELS

In order to study noise pollution levels evolution, using a statistical analysis. Lineal regression was made with noise levels equivalents 2000 against 2005. Figure 3 shows the tendency of noise levels equivalents, with correlation coefficient around 0,77 to 0,85. This tendency shows evolution in relation to noise levels, then increase in noise pollution levels is expected.

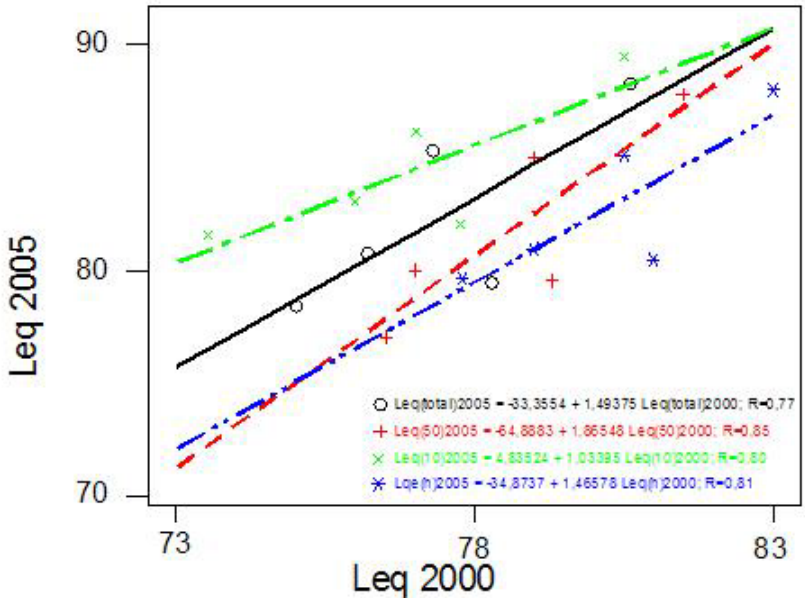

Figure 3. Relationship between noise levels 2000 - 2005

Figure 4 shows lineal regression of noise levels equivalent and the annual average daily traffic for year 2005. This lineal regression has a correlation coefficient from 0,89 to 0,96. The line tendency allows estimate noise levels with an increase for every study section. With this lineal regression, the noise levels increase 2,96; 3,26; 2,26 y 2,54dB for each 10.000 vehicles more respect to AADT.

Figure 5 shows lineal regression of noise levels equivalent for year 2005 and the annual average daily traffic only for heavy trucks in the same year. In comparison between figure 4 and figure 5, we can see a better correlation coefficients for each tendency line. The correlation coefficient is from 0,972 to 0,993. With this lineal regression the noise levels incremented 0,69; 0,76; 0,88; y 0,94dB for each 1.000 vehicles more respect to AADT for trucks.

Comparing figure 5 versus figure 6, the increase tendency is similar in both years, 2000 respect to 20005.

Figure 6 shows the lineal regression of the noise levels for year 2000 and the annual average daily traffic only for trucks in same year.

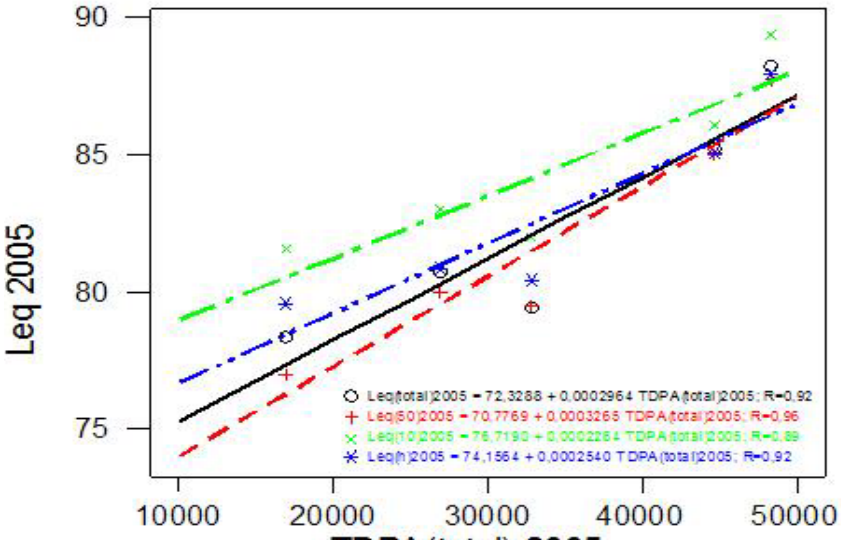

Figure 4. Relationship between noise levels 2005 against AADT

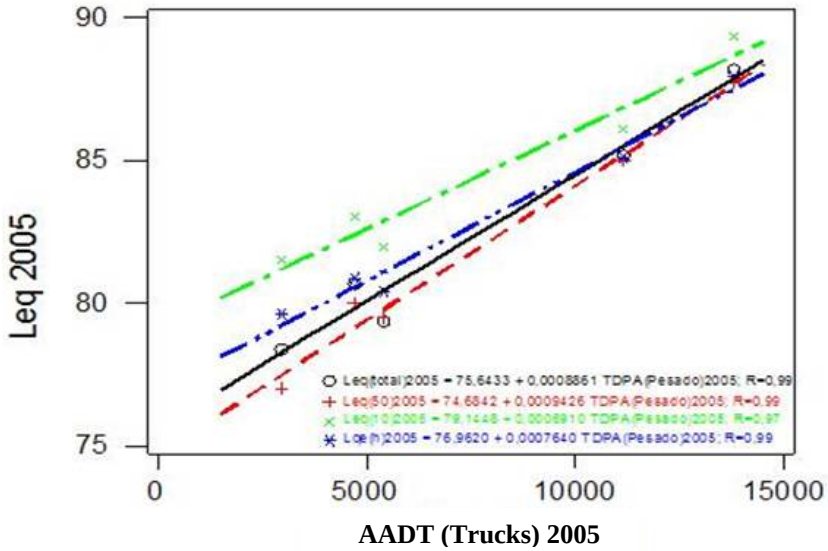

Figure 5. Relationship between noise levels 2005 against AADT (Trucks)

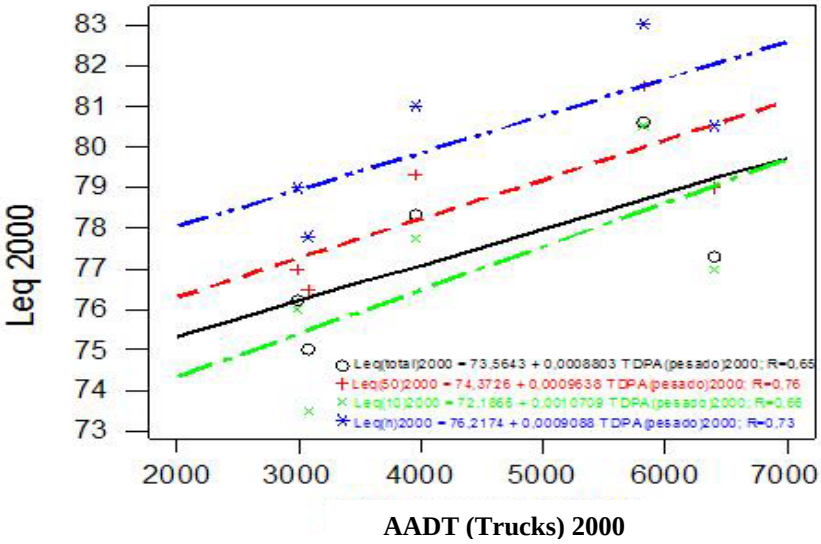

Figure 6. Relationship between noise levels 2000 against AADT (Trucks)

7. TYPE OF PAVEMENT

Noise levels were founded different in relation to the pavement type. Table 6 shows the results respect to each noise study in Querétaro State. Noise levels are loudly in highways where the superficial surface was made with concrete pavement (rigid pavement).

Table 6. Noise levels in relation to pavement type

State	Leq Total	Leq (hr)	L_{10}	L_{50}	PAVEMENT TYPE	Year
Querétaro	76,5	79,3	75,8	77,6	Asphalt	2000
Querétaro	79,0	81,8	78,8	80,3	Concrete	2000
Querétaro	79,5	80,3	82,2	78,8	Asphalt	2005
Querétaro	86,7	86,5	87,7	86,4	Concrete	2005

Results listed in the table 6 for the noise levels equivalent, conclude the importance of noise levels regarding to pavement surface, because the difference between asphalt pavement and concrete pavement in noise levels are highly relevant. In the year 2000, the noise levels difference (Leq Total) between both pavements is 2,5dB and for year 2005 is 7,2 dB.

8. INTERNATIONAL STANDARDS RECOMENDATION

The Organization for the Economic Cooperation and Development (OECD) takes the economic implications of policies against traffic noise into account and hence, proposes maximum noise values to be achieved within a 5 to 10 year period. As shown in table 7, the acceptable maximum value for the diurnal time in an existing highway is 65 dB(A).

Table 7. Recommended Maximal Noise Values

Acceptable levels proposed by OECD (Leq, limits on front residential zones)			
Leq (day)		Leq (night)	
New Highway	Existing Highway	New Highway	Existing Highway
60+/-5 dB(A)	65+/-5 dB(A)	50-55 dB(A	55-60 dB(A)

Currently, there are only four federal standards for noise emission control in Mexico. These standards have established maximum noise values for new motor vehicles and motorcycles, fixed sources, and vehicles which is taken at verification centers; results are obtained by measuring only the tailpipe noise emissions from static vehicles under controlled engine conditions. Hence, the Mexican Institute of Transportation proposed time ago an official standard for regulate the noise pollution on Mexican Highways, traveling at the project speed limits and during the operation of the total traffic flow.

9. ENVIRONMENTAL INDEX OF NOISE

The "Environmental Index of Noise" (EIN) proposed for Mexican Highways, represent the level of equivalent noise measured on field sites in highways at Queretaro State, above the acceptable value by OECD.

$$EIN = \frac{Leq(total)}{65dB(A)}$$

Table 8 shows EIN for each highway in both studies.

Table 8. Environmental index of noise

Section	**Leq Total**		**Index of Noise (EIN)**	
	2000	**2005**	**2000**	**2005**
1	77,3	85,2	1,19	1,31
2	80,6	88,2	1,24	1,36
3	76,2	80,7	1,17	1,24
4	78,3	79,4	1,20	1,22
5	75,0	78,4	1,15	1,21
Average	**77,5**	**82,4**	**1,19**	**1,27**

The average of EIN increased 0,08 in five years. For each section, the minimum value was 0,02 and the maximum value was 0,12. However, the average EIN in 2000 year show 19% more respect the international noise values in order to protect the human health.

10. CONCLUSIONS

This study represents the first attempt to construct an "environmental index of noise", which could be used as a reference for the follow-up of this environmental impact in following years and to implement an official standard. The average of EIN increased 0,08 in five years. However, the average EIN in 2000 year show 19% more respect the international noise values in order to protect the human health.

This paper presents the results of the measurements carried out and the statistical analysis done as well as the corresponding conclusions and recommendations generated. A brief summary of this is as follows:

1. The noise, already being loud, got louder on all the sites in this period from 2000 to 2005, with varying rates among the sites.
2. A good positive statistic correlation was found for the four Leq values of year 2005 as compared to those in year 2000, thus confirming that noise increase along the time.
3. A good positive statistic correlation was found between the four Leq indexes and the AADT, thus suggesting a future increase of noise levels based on all kinds of traffic (light, medium and heavy), due to an increasing AADT.
4. A good positive correlation was found between the four Leq indexes and the AADT just for the "heavy traffic", suggesting as well a future increase of noise levels.
5. Recorded noise in both years turned out to be greater in the site with rigid pavement (México – Querétaro Highway, Km 193+050) in comparison to the asphalted pavement sections.
6. The final conclusion of this paper, based on the statistical analysis on data collected between 2000 and 2005 years, point that 75 dB(A) is the "real value" to start at the Mexican highway, as a result of Querétaro state studies.

Based on these findings, the recommendation suggested by this research, in view of the fact that noise levels exceeds international standards in any case and the increasing trend found of the noise along with the time and the AADT, including the heavy traffic, it is required to create and to issue a norm aimed to keep noise into internationally accepted levels on the Mexican Highways.

The official standard proposal for this by the Mexican Institute of Transport, is to start by imposing a Leq total upper limit of 75dB, and a gradual reduction of 1dB each year along a ten years period, in order to reach the Organization for Economic Co-operation and Development (OECD) standard of 65dB for the daylight schedule on sections crossing by residential zones.

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