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# Trends in traffic fatalities in Mexico: examining progress on the decade of action for road safety 2011–2020

**Arturo Cervantes-Trejo · Iwin Leenen · John Stewart Fabila-Carrasco · Roy Rojas-Vargas**

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**Abstract**
*Objectives* We explore demographic, temporal and geographic patterns of 256,588 road traffic fatalities from 1998 to 2013 in Mexico, in context of UŃs decade of action for road safety 2010–2020 (DARS).
*Methods* Combined traffic mortality data and population counts were analyzed using mixed-effects logistic regression, distinguishing sex–age groups, vulnerable and protected road users, and municipal size.
*Results* Rapid growth from 1998 to 2008 in traffic mortality rates has been reversed since 2009. Most deaths averted are among young male protected road users (reduction of 0.95 fatalities per 100,000 per year in males 12–49). In spite of a steady decrease over the full study period, mortality rates remain high in vulnerable road users over 50, with a high mortality rate of 26 per 100,000 males over 75 years in 2013.
*Conclusions* Progress on the reduction of deaths advances in Mexico, in line with DARS targets. National road safety efforts require strengthening. Initiatives should target vulnerable road users, specifically adults >50 years in urban areas. Strengthening of drink driving programs aimed at young drivers/occupants is promising.

**Keywords** Mortality · Road safety · Traffic accidents · Policy programs · Mexico · Generalized linear mixed models

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A. Cervantes-Trejo
Mexicanos Contra la Corrupción y la Impunidad (MCCI), Mexico, Mexico

A. Cervantes-Trejo (✉)
Carlos Peralta Chair of Public Health, Anahuac University, Mexico, Mexico
e-mail: cervantes@post.harvard.edu

I. Leenen · J. S. Fabila-Carrasco
National Institute for Educational Evaluation (INEE), Mexico, Mexico

R. Rojas-Vargas
National Council for Road Safety (COSEVI), San José, Costa Rica

## Introduction

Much has been accomplished over the last 50 years in global efforts for improving road safety and for prevention of road traffic injuries. It is now widely recognized that sustainable mobility and road safety are inextricably linked, and both play a crucial role for the health, progress and development of individuals and of nations. Road traffic fatalities are disproportionately distributed around the world, affecting mostly low and middle income countries. Around 90 % of road casualties worldwide occur in middle income countries, which possess only 54 % of the registered global fleet of vehicles (World Health Organization 2015). Particularly in the region of the Americas, Canada and the United States have approximately 66 % of the vehicle fleet, and account for only 28 % of all deaths from road traffic causes in the region. Conversely, countries in South America account for 20 % of the vehicle fleet and 36 % of traffic-related deaths (World Health Organization 2015). Following the landmark "World report on road traffic injury prevention" (Peden et al. 2004) and the United Nations General Assembly resolution on improving global road safety (United Nations, 2004), strong regional commitments and efforts in the Americas began to emerge, to tackle this enormous public health challenge http://www.genevadeclaration.org/news/news-2010.html).

With a current population of around 121 million persons and with more than 37 million registered vehicles in 2015 (INEGI 2016), Mexico is a middle income country that has experienced an accelerated change in motorized vehicle ownership between 1990 and 2010, as well as a rapid growth in the burden of disease from motorized road transport (Global Road Safety Facility, World Bank 2014). Adding to the populationś risk exposure, rural to urban migration has continued to increase in Mexico, with 78 % of the population currently residing in urban settings (World Bank 2016). In terms of road traffic fatalities, in 2007 Mexico ranked seventh among countries with the most deaths caused by traffic accidents (Peden et al. 2004; Hyder and Bishai 2012; World Health Organization 2009; Cervantes-Trejo and Frausto-Bermúdez 2011). In 2008, Mexico had a high number of road traffic fatalities and more than 350,000 major hospitalizations (PAHO 2013; STCONAPRA 2014). The economic costs of those injuries and deaths were estimated to be more than $10 billion USD annually, or 1.7 per cent of Mexico's GDP (Bhalla 2013).

A latecomer among OCDE countries in terms of road safety national strategies, it was until 2008 that the Mexican Government launched the first ever Mexican Initiative for Road Safety (IMESEVI) whose stated objective was to reduce deaths from road traffic injuries, specifically among children and male youth, applying an evidence-based approach from the public health perspective (see Cervantes-Trejo and Frausto-Bermúdez 2011). IMESEVI was the first sustained effort of national scope, coordinated by the Ministry of Health; it operated during 6 years from 2008 to 2013, with continuous funding and a comprehensive multisectoral approach. Aside federal government funding, technical and financial assistance was provided by World Health Organization and Bloomberg Global Philanthropies as a pilot program carried out in Vietnam and México from 2008 to 2010 (Cervantes-Trejo and Frausto-Bermúdez 2011; Cervantes-Trejo and Leenen 2014a, b, 2015). This pilot was later expanded by the Bloomberg Global Road Safety Initiative and was renamed *Road Safety in 10 Countries* (Hyder and Bishai 2012).

Cornerstone efforts of IMESEVI included creating the first National Road Safety Observatory to support epidemiologic surveillance and communications and the first National Drink Driving Program, which was launched in 2008, and focused on setting up sobriety checkpoints (Cervantes-Trejo et al. 2011a). The Observatory provided hard data and analysis on mortality, morbidity and accident records and the National Drink Driving Program included providing funding for equipment, training, and an intensive intersectoral collaborative effort between state, federal and local authorities of the health, transport and police sectors. A diversity of state IMESEVI programs were started in the main metropolitan areas of the country including Mexico City, Guadalajara in Jalisco, Monterrey in Nuevo León, and major cities of Guanajuato, among others. In parallel, an extensive media campaign of national scope, against drunk driving, brought awareness to the perils and dangers of driving under the influence of alcohol, as a major public health concern of national interest.

Alongside these actions, state programs to encourage prevention of road traffic accidents emerged and 32 Road Safety Observatories for surveillance, research and training were formed at state levels, in order to mobilize social and community efforts (Cervantes-Trejo et al. 2011b). The financing and intensity of efforts varied among states, and also included targeted interventions in schools, universities and workplaces, involving policy leaders and using media for communications. Strong support from civil society, private sector, legislators and news media organizations was garnered, including national volunteer groups joining from Mexican Red Cross in all states of the country. On May 11th 2011, Mexico hosted a regional launch of the UŃs decade of action for road safety 2010–2020 (DARS) for the Americas, and the Mexican Congress passed into law the first "National Road Safety Strategy 2011–2020" (Secretaría de Comunicaciones y Transporte 2011). A first of its kind, the National Road Safety Strategy was aligned to the 5 pillars of the Global Plan of Action and set an ambitious national reduction target: to halve the number of road traffic fatalities by 2020 (World Health Organization 2011).

In light of the National Road Safety Strategy and related policy efforts such as IMESEVI, undertaken in México between 2007 and 2014 and given the DARS and the fatality reduction objectives of National Road Safety Strategy 2011–2020, we explore temporal and geographic patterns of road traffic fatalities for a 16-year period (1998–2013), in different age and sex groups, distinguishing between vulnerable (pedestrians, cyclists and motorcyclists) and protected (drivers, other car occupants) road users, in order to assess the direct effects on road fatalities, of the first national road safety program and related interventions.

## Methods

### Data sources

Two sources of public data from the Mexican National Institute of Statistics (INEGI 2015) were used in the current project: (a) national population counts from the 2000, 2005, and 2010 censuses in each of the country's 2456 municipalities, segregated by sex and age, and (b) official mortality registers of Mexico, which provide detailed data on all deceases, including cause of death (classified according to the International Classification of Diseases ICD-10, World Health Organization 2011), exact time of death, municipality and date of registration, and sex and age of the deceased.

Population counts by municipalities from the three census years provided the number of individuals, by sex, divided into 10 age groups (0–11, 12–15, 16–19, 20–23, 24–29, 30–39, 40–49, 50–59, 60–74, and 75 or older. For non-census years between 1998 and 2013, we obtained estimates of these numbers through linear interpolation. From the mortality data base, we extracted all deaths of vulnerable road users (i.e., pedestrians, cyclists, motorcyclists, and users of three-wheeled vehicles, e.g., sidecars, all of which correspond with the ICD-10 categories V00–V39), and obtained the number of deaths in this category for each municipality by sex and each of the ten age groups (henceforth called sex–age groups). Likewise, we calculated the number of deaths in the category of protected road users (i.e., drivers and passengers of cars, light trucks, heavy transport, or bus, corresponding with the ICD-10 categories V40–V79).

By combining both sources of information we obtained a data set with the number of residents as well as the number of fatalities of both vulnerable and protected road users, as registered in each municipality, by sex–age group, for each year included in the study.

## Statistical analysis

These data were analyzed, separately for both types of road users and for each sex–age group, using a multilevel logistic regression model (see, e.g., Snijders and Bosker 2012; Wong and Mason 1985). The model is similar to the one used by Leenen and Cervantes-Trejo (2014) in the study of temporal and geographic trends in homicides and suicides. At the lowest level of the model, the number of fatalities of the type and sex–age group under study in municipality $i$ during year $t$, denoted $Y_{it}$, is assumed to follow a binomial distribution

$$Y_{it} \sim \mathrm{Bin}(n_{it}, \mathrm{p}_{it}),$$

with $n_{it}$ the number of residents of the given sex–age group in municipality $i$ during year $t$ and the probability $\pi_{it}$ (i.e., the probability that an individual from this subpopulation is killed in a traffic accident), being parametrized by the following function:

$$\log\left(\frac{\pi_{it}}{1-\pi_{it}}\right) = \beta_{0i} + \sum_{j=1}^{m} \beta_{ji}\left[\max\left(t, \tau_j\right) - \tau_{j-1}\right] I\left(t < \tau_{j-1}\right).$$

This means that the log-odds are modeled as a piecewise linear function, with $m$ pieces and breakpoints $\tau_0, \tau_1, \ldots, \tau_m$ that indicate the years where the respective linear pieces start and end, with $\tau_0 \equiv 2013$ and $\tau_m \equiv 1998$. The indicator function $I(expression)$ equals 1 if *expression* is true, and 0 otherwise. It follows that the parameter $\beta_{0i}$ can be interpreted as the log-odds of being killed in a traffic accident in municipality $i$ during the year 2013 and the parameters $\beta_{ji}$ ($j = 1, \ldots, m$) indicate how these log-odds change (per year) between the years $\tau_j$ and $\tau_{j\text{-}1}$.

At the second level of the model, we consider variation among municipalities with respect to the temporal evolution, as expressed by the $\beta_{ji}$ ($j = 0, \ldots, m$), by specifying for each of the latter parameters:

$$\beta_{ji} = \gamma_{0j} + \gamma_{Sj}X_{Si} + \gamma_{Mj}X_{Mi} + \gamma_{Lj}X_{Li} + \gamma_{Bj}X_{Bi} + u_{ji},$$

where the $X_{\mathrm{S}i}$, $X_{\mathrm{M}i}$, $X_{\mathrm{L}i}$, and $X_{\mathrm{B}i}$ are dummy/binary variables that, respectively, indicate whether municipality $i$ is small (i.e., with the overall number of inhabitants being lower than 10,000), medium-sized (between 10,000 and 100,000 inhabitants), large (between 100,000 and 500,000 inhabitants), or big (over 500,000 inhabitants); the $\gamma\gamma$-parameters, which, for identification purposes, include the restriction $\gamma_{\mathrm{S}j} + \gamma_{\mathrm{M}j} + \gamma_{\mathrm{L}j} + \gamma_{\mathrm{B}i} = 0$ for any $j$, express the differences among the four sizes of municipality with respect to the temporal evolution parametrized by the β parameters in the level-1 equation. The random effects vector $(u_{0i}, u_{1i}, \ldots, u_{mi})'$ is assumed to follow a multivariate normal distribution, with means 0 and a positive-definite covariance matrix $\mathbf{\Sigma}$ and accounts for the residual variance among municipalities.

In total, we fitted for each sex–age group and type of road users, 471 variants of the above model. These variants correspond to different values for $m$ and $\tau_1, \ldots, \tau_{m-1}$. In particular, we varied $m$ from 0 to 4 and considered, for each value of $m$, all possible combinations for the associated (integer) breakpoints, which satisfy $1998 < \tau_1 < \tau_2 < \cdots < \tau_{m-1} < 2013$. Among these 471 variants, we selected the model with the best fit according to the Bayesian Information Criterion (Schwarz 1978; Zucchini 2000).

All models were fitted by means of the PROC GLIMMIX procedure of SAS Version 9.4, using maximum likelihood estimation based on the Laplace approximation (SAS Institute 2013).

# Results

## Descriptive statistics

Table 1 presents national population size, number of fatalities in vulnerable and protected road users, and associated rates per 100,000 inhabitants, for males and females in each year in Mexico, from 1998 to 2013. To get an overall picture of the evolution over time, Fig. 1

**Table 1** Nationwide population sizes, number of fatalities in vulnerable and protected road users, and associated rates per 100,000 inhabitants, for males and females in each year (Mexico, 1998–2013)

| Year | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | Population count | Fatalities in road users | | Population count | Fatalities in road users | |
| | | Vulnerable count (rate) | Protected count (rate) | | Vulnerable count (rate) | Protected count (rate) |
| 1998 | 47,201,666 | 4894 (10.4) | 6498 (13.8) | 49,412,151 | 1278 (2.6) | 1753 (3.5) |
| 1999 | 47,457,624 | 4779 (10.1) | 6581 (13.9) | 49,714,147 | 1267 (2.5) | 1758 (3.5) |
| 2000 | 47,713,583 | 4765 (10.0) | 6616 (13.9) | 50,016,144 | 1264 (2.5) | 1771 (3.5) |
| 2001 | 48,225,500 | 4686 (9.7) | 6616 (13.7) | 50,620,136 | 1334 (2.6) | 1809 (3.6) |
| 2002 | 48,737,418 | 4661 (9.6) | 7081 (14.5) | 51,224,129 | 1260 (2.5) | 2100 (4.1) |
| 2003 | 49,249,335 | 4673 (9.5) | 7269 (14.8) | 51,828,122 | 1310 (2.5) | 2106 (4.1) |
| 2004 | 49,761,253 | 4603 (9.3) | 7578 (15.2) | 52,432,114 | 1280 (2.4) | 2147 (4.1) |
| 2005 | 50,273,170 | 4820 (9.6) | 8221 (16.4) | 53,036,107 | 1227 (2.3) | 2336 (4.4) |
| 2006 | 51,189,582 | 4927 (9.6) | 8542 (16.7) | 53,925,147 | 1201 (2.2) | 2549 (4.7) |
| 2007 | 52,105,994 | 4668 (9.0) | 7695 (14.8) | 54,814,187 | 1127 (2.1) | 2304 (4.2) |
| 2008 | 53,022,407 | 4729 (8.9) | 9100 (17.2) | 55,703,227 | 1201 (2.2) | 2427 (4.4) |
| 2009 | 53,938,819 | 5080 (9.4) | 9245 (17.1) | 56,592,267 | 1219 (2.2) | 2661 (4.7) |
| 2010 | 54,855,231 | 4771 (8.7) | 8580 (15.6) | 57,481,307 | 1162 (2.0) | 2512 (4.4) |
| 2011 | 55,313,437 | 4945 (8.9) | 8658 (15.7) | 57,925,827 | 1179 (2.0) | 2295 (4.0) |
| 2012 | 55,771,643 | 5367 (9.6) | 8470 (15.2) | 58,370,347 | 1260 (2.2) | 2452 (4.2) |
| 2013 | 56,229,854 | 5123 (9.1) | 7628 (13.6) | 58,814,860 | 1134 (1.9) | 2036 (3.5) |

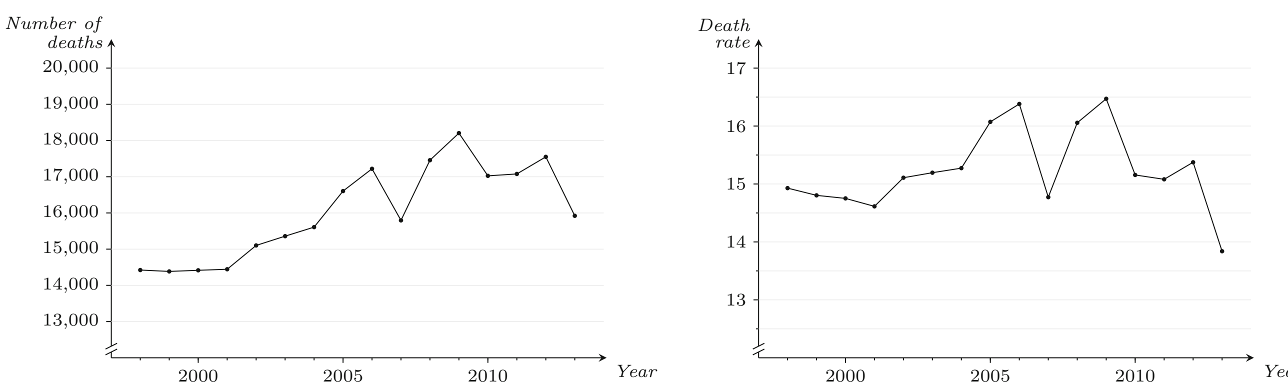


**Fig. 1** Overall absolute number of deaths (*left panel*) and death rate per 100,000 Mexican inhabitants (*right panel*) due to traffic accidents (ICD-10 categories V00–V79) (Mexico, 1998–2013)

displays absolute numbers (left panel), and rates (right panel), across both sexes and both type of road users. Number of deaths increased by 29 % from 14,423 in 1998 to 18,205 in 2009; even after controlling for the growing population, the increase between 1998 and 2009 remains strong, with death rates rising 15 % (from 14.9 to 16.5 per 100,000). The segregated numbers in Table 1 further show that the decrease in deaths rates which began in 2009 is mainly attributed to protected road users (with the death rate decreasing about 22 % between 2009 and 2013), whereas death rates for the vulnerable group stay approximately at the same level (going from 5.7 to 5.4 in the same period). Following, we will differentiate mortality statistics by different sex–age groups and their geographic distribution.

## Trends in different sex–age groups

Tables 2 and 3 (first four columns) present estimates of the parameters in the selected multilevel logistic regression model in each sex–age group for vulnerable and protected road users in Mexico, from 1998 to 2013. The models in the former group are rather simple, in the sense that in almost all sex–age groups, either an intercept-only model

**Table 2** Estimates of the parameters in the selected multilevel logistic regression model in each sex–age group for vulnerable road users (Mexico, 1998–2013)

| Sex–age | Parameter | Overall | | Size of municipality | | | | Residual variance |
|---|---|---|---|---|---|---|---|---|
| | | Estimate | 95 % CI | Small | Medium | Large | Big | |
| Females (years) | | | | | | | | |
| 0–11 | Intercept at 2013 | −11.64 | [−11.78, −11.49] | −0.14 | 0.22 | 0.06 | −0.13 | 0.516 |
| | Slope 1998–2013 | −0.032 | [−0.046, −0.018] | −0.002 | 0.017 | −0.005 | −0.010 | 0.002 |
| 12–15 | Intercept at 2013 | −16.82 | [−18.91, −14.73] | −0.76 | 0.61 | 0.00 | 0.14 | 40.882 |
| | Slope 2012–2013 | −4.970 | [−7.081, −2.860] | −0.840 | 0.559 | −0.020 | 0.301 | 41.748 |
| | Slope 1998–2012 | −0.033 | [−0.067, +0.001] | 0.056 | 0.008 | −0.028 | −0.037 | 0.005 |
| 16–19 | Intercept at 2013 | −11.28 | [−11.40, −11.15] | −0.31 | −0.04 | 0.18 | 0.17 | 0.336 |
| 20–23 | Intercept at 2013 | −11.40 | [−11.55, −11.26] | −0.43 | −0.04 | 0.29 | 0.18 | 0.374 |
| 24–29 | Intercept at 2013 | −11.42 | [−11.54, −11.30] | −0.28 | −0.11 | 0.22 | 0.17 | 0.308 |
| 30–39 | Intercept at 2013 | −11.33 | [−11.43, −11.24] | −0.28 | −0.07 | 0.16 | 0.19 | 0.216 |
| 40–49 | Intercept at 2013 | −11.00 | [−11.09, −10.90] | −0.27 | −0.02 | 0.15 | 0.14 | 0.206 |
| 50–59 | Intercept at 2013 | −10.88 | [−11.05, −10.70] | −0.32 | −0.00 | 0.15 | 0.30 | 0.196 |
| | Slope 1998–2013 | −0.027 | [−0.047, −0.007] | 0.039 | −0.005 | −0.031 | −0.004 | 0.001 |
| 60–74 | Intercept at 2013 | −10.14 | [−10.27, −10.01] | −0.48 | −0.12 | 0.30 | 0.30 | 0.255 |
| | Slope 1998–2013 | −0.022 | [−0.036, −0.008] | 0.003 | 0.012 | −0.001 | −0.014 | 0.002 |
| 75+ | Intercept at 2013 | −9.51 | [−9.662, −9.362] | −0.47 | −0.12 | 0.25 | 0.35 | 0.476 |
| | Slope 1998–2013 | −0.035 | [−0.051, −0.020] | 0.003 | 0.006 | −0.004 | 0.002 | 0.002 |
| Males (years) | | | | | | | | |
| 0–11 | Intercept at 2013 | −11.07 | [−11.18, −10.96] | 0.04 | 0.16 | 0.00 | −0.20 | 0.492 |
| | Slope 1998–2013 | −0.036 | [−0.046, −0.025] | 0.025 | 0.009 | −0.021 | −0.013 | 0.001 |
| 12–15 | Intercept at 2013 | −10.75 | [−10.90, −10.59] | −0.24 | 0.20 | 0.07 | −0.03 | 0.483 |
| | Slope 1998–2013 | −0.035 | [−0.051, −0.020] | −0.006 | 0.019 | −0.004 | −0.008 | 0.003 |
| 16–19 | Intercept at 2013 | −9.83 | [−9.948, −9.713] | −0.42 | 0.22 | 0.32 | −0.12 | 0.512 |
| | Slope 1998–2013 | −0.011 | [−0.023, +0.000] | −0.023 | 0.020 | 0.009 | −0.006 | 0.002 |
| 20–23 | Intercept at 2013 | −9.34 | [−9.447, −9.238] | −0.17 | 0.13 | 0.15 | −0.11 | 0.453 |
| | Slope 1998–2013 | 0.014 | [+0.003, +0.025] | 0.003 | 0.012 | −0.008 | −0.007 | 0.003 |

**Table 2** continued

| Sex–age | Parameter | Overall | | Size of municipality | | | | Residual variance |
|---|---|---|---|---|---|---|---|---|
| | | Estimate | 95 % CI | Small | Medium | Large | Big | |
| 24–29 | Intercept at 2013 | −9.34 | [−9.431, −9.246] | 0.03 | 0.02 | 0.08 | −0.13 | 0.412 |
| | Slope 1998–2013 | 0.007 | [−0.003, +0.016] | 0.024 | −0.001 | −0.015 | −0.008 | 0.001 |
| 30–39 | Intercept at 2013 | −9.34 | [−9.439, −9.236] | −0.08 | 0.03 | 0.08 | −0.03 | 0.388 |
| | Slope 2008–2013 | 0.031 | [+0.005, +0.056] | 0.001 | 0.020 | −0.026 | 0.005 | 0.010 |
| | Slope 1998–2008 | −0.008 | [−0.021, +0.005] | 0.024 | −0.010 | −0.002 | −0.011 | 0.004 |
| 40–49 | Intercept at 2013 | −9.31 | [−9.397, −9.229] | 0.10 | −0.02 | −0.00 | −0.09 | 0.377 |
| | Slope 1998–2013 | −0.006 | [−0.015, +0.002] | 0.027 | −0.000 | −0.020 | −0.007 | 0.002 |
| 50–59 | Intercept at 2013 | −9.16 | [−9.248, −9.067] | −0.15 | −0.00 | 0.17 | −0.02 | 0.400 |
| | Slope 1998–2013 | −0.013 | [−0.022, −0.004] | 0.015 | 0.001 | −0.011 | −0.005 | 0.002 |
| 60–74 | Intercept at 2013 | −8.82 | [−8.903, −8.727] | −0.39 | 0.04 | 0.25 | 0.10 | 0.045 |
| | Slope 1998–2013 | −0.021 | [−0.029, −0.013] | 0.011 | 0.011 | −0.009 | −0.013 | 0.001 |
| 75+ | Intercept at 2013 | −8.26 | [−8.349, −8.164] | −0.45 | −0.11 | 0.26 | 0.29 | 0.319 |
| | Slope 1998–2013 | −0.020 | [−0.029, −0.010] | 0.015 | 0.007 | −0.010 | −0.012 | 0.001 |

(i.e., no change over time, as, e.g., in the female groups between 16 and 49 years of age) or a model with an intercept and single slope (which implies a constant change over time, as, e.g., in all male age groups except the one from 30 to 39 years) was found to have an optimal fit to the data. While the intercept (whose value should be interpreted on the logit scale) is directly related to the mortality rate in the group in the year 2013 (with less negative values indicating higher mortality rates), the slope indicates the strength of a possible decrease (if negative) or increase (if positive) of the mortality rate in the associated period. For example, across sex–age groups in Table 2, males in oldest age group (75+) have the highest estimate for the intercept; hence, mortality rate in this group is highest. The negative slope for 1998–2013 in implies a relatively strong decrease of the mortality since 1998. Otherwise, in males of 20–23 years, this slope is positive, which indicates an increase over time of the mortality rate in this group.

As a technical aside, we mention that, in both tables, the results for girls between 12 and 15 years old are rather unstable, which is obvious from the wide confidence intervals and the large residual variances among municipalities (last column) and which is primarily due to the very small number of (traffic-related) deaths in this age group. As a consequence, we will not further consider these results.

Apart from the well-known differences between the sexes (with much lower traffic mortality rates in women), the most striking result in Table 2 probably is that, for males as well as females, the highest values for the intercepts are found in the age groups of 50 years and older. Given the importance of this finding, we transformed the parameter estimates for these age groups to rates over time (using the equations in the Method section) and graphically represented the model-based trends in the left panel of Fig. 2. In spite of the significant decrease over time, we observe still very high mortality rates in elder people, particularly in males over 60 years.

The results for protected road users in Table 3 are strongly different between males and females (and also strongly differ from the results for vulnerable road users). In females, except for the age groups contained between 12 and 19 years, intercept-only models are found to be sufficient to describe the pattern over time; that is, these groups

**Table 3** Estimates of the parameters in the selected multilevel logistic regression model in each sex–age group for protected road users (Mexico, 1998–2013)

| Sex–age | Parameter | Overall | | Size of municipality | | | | Residual variance |
|---|---|---|---|---|---|---|---|---|
| | | Estimate | 95 % CI | Small | Medium | Large | Big | |
| Females (years) | | | | | | | | |
| 0–11 | Intercept at 2013 | −10.90 | [−10.97, −10.83] | 0.11 | −0.03 | −0.03 | −0.05 | 0.391 |
| 12–15 | Intercept at 2013 | −14.87 | [−16.22, −13.52] | 0.63 | −0.13 | −0.50 | −0.00 | 28.790 |
| | Slope 2012–2013 | −0.689 | [−2.192, +0.815] | 0.433 | −0.070 | −0.059 | −0.304 | 59.421 |
| | Slope 2011–2012 | −3.543 | [−4.147, −2.939] | 0.065 | −0.255 | −0.312 | 0.503 | 23.346 |
| | Slope 1998–2011 | 0.025 | [+0.003, +0.048] | −0.008 | 0.025 | −0.003 | −0.014 | <0.001 |
| 16–19 | Intercept at 2013 | −10.29 | [−10.46, −10.12] | 0.16 | 0.16 | 0.05 | −0.37 | 0.635 |
| | Slope 2006–2013 | −0.049 | [−0.081, −0.017] | 0.016 | −0.002 | 0.026 | −0.040 | 0.011 |
| | Slope 1998–2006 | 0.053 | [+0.024, +0.082] | −0.017 | 0.031 | −0.022 | 0.007 | 0.010 |
| 20–23 | Intercept at 2013 | −10.00 | [−10.07, −9.922] | 0.04 | 0.05 | −0.02 | −0.07 | 0.295 |
| 24–29 | Intercept at 2013 | −10.02 | [−10.09, −9.951] | 0.08 | 0.03 | −0.02 | −0.10 | 0.297 |
| 30–39 | Intercept at 2013 | −10.15 | [−10.21, −10.08] | 0.18 | 0.10 | −0.02 | −0.26 | 0.287 |
| 40–49 | Intercept at 2013 | −10.06 | [−10.13, −10.00] | 0.15 | 0.11 | −0.07 | −0.19 | 0.262 |
| 50–59 | Intercept at 2013 | −9.83 | [−9.894, −9.767] | 0.16 | 0.07 | −0.08 | −0.15 | 0.201 |
| 60–74 | Intercept at 2013 | −9.66 | [−9.726, −9.594] | 0.13 | 0.05 | −0.05 | −0.13 | 0.257 |
| 75+ | Intercept at 2013 | −9.55 | [−9.633, −9.459] | 0.08 | 0.00 | −0.08 | −0.01 | 0.241 |
| Males (years) | | | | | | | | |
| 0–11 | Intercept at 2013 | −10.67 | [−10.73, −10.60] | 0.18 | 0.06 | −0.08 | −0.16 | 0.356 |
| 12–15 | Intercept at 2013 | −10.10 | [−10.23, −9.971] | 0.25 | 0.21 | −0.01 | −0.45 | 0.231 |
| | Slope 2006–2013 | −0.036 | [−0.062, −0.011] | 0.004 | −0.013 | 0.032 | −0.024 | 0.003 |
| | Slope 1998–2006 | 0.042 | [+0.017, +0.067] | −0.011 | 0.020 | −0.028 | 0.018 | 0.011 |
| 16–19 | Intercept at 2013 | −8.98 | [−9.090, −8.872] | 0.18 | 0.20 | 0.00 | −0.39 | 0.526 |
| | Slope 2009–2013 | −0.091 | [−0.125, −0.057] | −0.050 | −0.022 | 0.020 | 0.052 | 0.027 |
| | Slope 2005–2009 | 0.022 | [−0.007, +0.050] | 0.043 | 0.020 | 0.010 | −0.073 | 0.023 |
| | Slope 1998–2005 | 0.043 | [+0.024, +0.061] | 0.008 | 0.009 | −0.022 | 0.005 | 0.007 |
| 20–23 | Intercept at 2013 | −8.41 | [−8.494, −8.329] | 0.28 | 0.25 | −0.05 | −0.48 | 0.310 |
| | Slope 2008–2013 | −0.035 | [−0.054, −0.016] | 0.004 | −0.001 | 0.001 | −0.004 | 0.005 |
| | Slope 1998–2008 | 0.028 | [+0.019, +0.038] | 0.013 | 0.013 | −0.008 | −0.018 | 0.001 |
| 24–29 | Intercept at 2013 | −8.38 | [−8.460, −8.301] | 0.30 | 0.20 | −0.09 | −0.41 | 0.318 |
| | Slope 2009–2013 | −0.042 | [−0.064, −0.021] | 0.013 | −0.013 | −0.005 | 0.005 | 0.006 |
| | Slope 1998–2009 | 0.017 | [+0.010, +0.024] | 0.005 | 0.018 | −0.005 | −0.019 | 0.001 |
| 30–39 | Intercept at 2013 | −8.59 | [−8.669, −8.513] | 0.23 | 0.23 | −0.03 | −0.42 | 0.305 |
| | Slope 2010–2013 | −0.078 | [−0.105, −0.052] | −0.008 | 0.003 | 0.008 | −0.003 | 0.013 |
| | Slope 1998–2010 | 0.010 | [+0.004, +0.016] | 0.000 | 0.011 | −0.000 | −0.011 | 0.001 |
| 40–49 | Intercept at 2013 | −8.60 | [−8.676, −8.529] | 0.45 | 0.12 | −0.10 | −0.48 | 0.227 |
| | Slope 2009–2013 | −0.028 | [−0.049, −0.008] | 0.037 | −0.029 | 0.005 | −0.012 | 0.005 |
| | Slope 1998–2009 | 0.002 | [−0.005, +0.010] | 0.009 | 0.019 | −0.012 | −0.016 | 0.001 |
| 50–59 | Intercept at 2013 | −8.59 | [−8.655, −8.523] | 0.34 | 0.24 | −0.14 | −0.44 | 0.265 |
| | Slope 1998–2013 | −0.004 | [−0.010, +0.002] | 0.015 | 0.010 | −0.008 | −0.017 | 0.001 |
| 60–74 | Intercept at 2013 | −8.66 | [−8.711, −8.606] | 0.22 | 0.12 | −0.06 | −0.28 | 0.231 |
| 75+ | Intercept at 2013 | −8.77 | [−8.839, −8.701] | 0.13 | 0.09 | −0.04 | −0.17 | 0.259 |

do not show a significant change in mortality rates during the study period. Males, on the other hand, particularly those between 12 and 49 years old, show more complex patterns involving two or three different slopes. These patterns, which are graphically depicted in the right panel of Fig. 2, consistently show the same evolution: First, rates steadily increase until 2009 ± 1, and subsequently show a strong decrease.

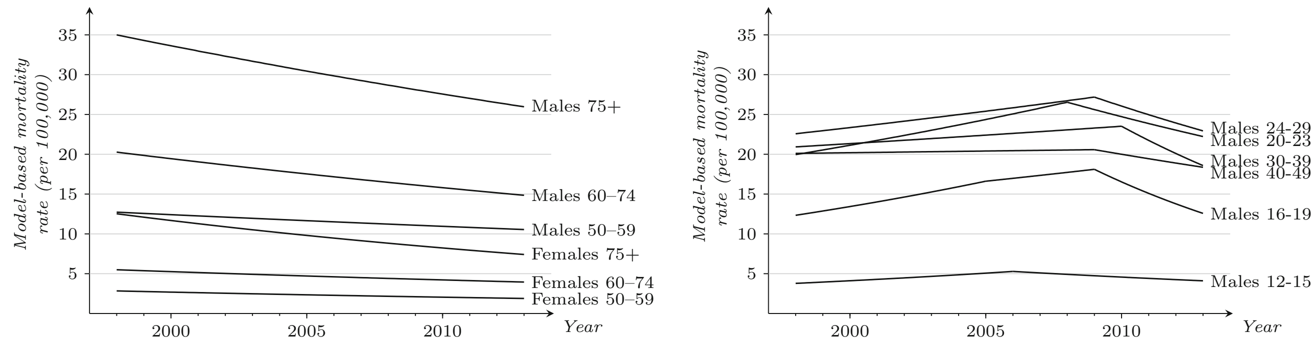


**Fig. 2** Graphical representation of the overall evolution over time of the mortality rate (per 100,000 inhabitants) in vulnerable road users of over 50 years of age (*left panel*) and male protected road users between 12 and 50 years of age. The mortality rates are based upon the selected statistical model and the parameters estimates presented in Tables 2 and 3. The order of the labels on the right follows the same order as the corresponding mortality rates in 2013 (Mexico, 1998–2013)

Geographical distribution

The columns in Tables 2 and 3, labeled Size of municipality, indicate possible differences in the associated parameter among municipalities of different population size. As a general tendency (with some minor exceptions, though), it is observed in Table 2 that the intercepts for the small and medium municipalities are lower than for large and big municipalities. This implies that the mortality rates for vulnerable road users are relatively larger in the more populated areas. On the other hand, for the models that include a slope (for the full 1998—2013 period), the estimate is often higher in smaller municipalities as compared to the larger ones. This means that the general decrease (as shown in the left graph of Fig. 2, for example), is less pronounced in the less populated areas.

For the protected road users, we observe an inverse pattern, with higher values for the intercepts in the smaller municipalities: Mortality rates for this type of road users generally are relatively smaller in the more populated areas. With respect to the slopes (in the models for young males), differences among municipalities are small and no general pattern emerges.

Combining the just described fixed effects with the random effects in the model, we examined differences among municipalities with respect to each parameter.

The upper left map of Fig. 3 shows differences among municipalities. Interestingly, in the latter graph, a clear division between the northern and southern part of the country emerges, with higher mortality rates in the north, whereas the distribution of the mortality rates in the former map (among vulnerable road users) is more balanced across the country. The maps on the right display the distribution of the slopes: for the vulnerable population in the age groups of 50 years and above (upper right) and for the protected male road users of between 12 and 49 years (lower right), we observe generally higher values (darker areas) for the municipalities in the south, which means that the decrease between 2009 and 2013 in the mortality rates is stronger in the northern part of the country.

## Discussion

This study adds important information to the Global Burden of Disease study of trends in road fatality by road user type for each country of the world, in that it looks at a subnational (municipal) geographical level of disaggregation, not addressed in GBD́s and includes contextual information regarding national level road safety preventive interventions. In contrast to other nations which began systemic road safety national approaches in the early 1970s and 1980s (Elvik et al. 2009), Mexico was a late comer on the international road safety movement. The first national road safety program of action dates to 2007, and was directed by the Ministry of Health and its National Council of Injury Prevention (Secretaría de Salud 2008; Cervantes-Trejo and Frausto-Bermúdez 2011). During the first 3 years of the DARS Mexico has attained significant progress, in line with the 50 % reduction targets set by the National Road Safety Strategy 2011–2020.

Given that the number and rates of deaths increased by 29 and 15 %, respectively, between 1998 and 2008, and that 2009 marks a major turning point, it is likely that the latter outcome relates to the IMESEVI intervention and the different components of its implementation; in particular, the launching of the national drink driving program, which began in 2008 and targeted high risk youth, by including not only sobriety checkpoints but also mass media campaigns and social mobilization efforts. It is worthwhile to note that among the young age groups of male protected road users death rates decreased 22 %, whereas these rates in the vulnerable groups stay approximately the same. Sobriety checkpoints, a core strategy undertaken by IMESEVI, became accepted nationally and also became

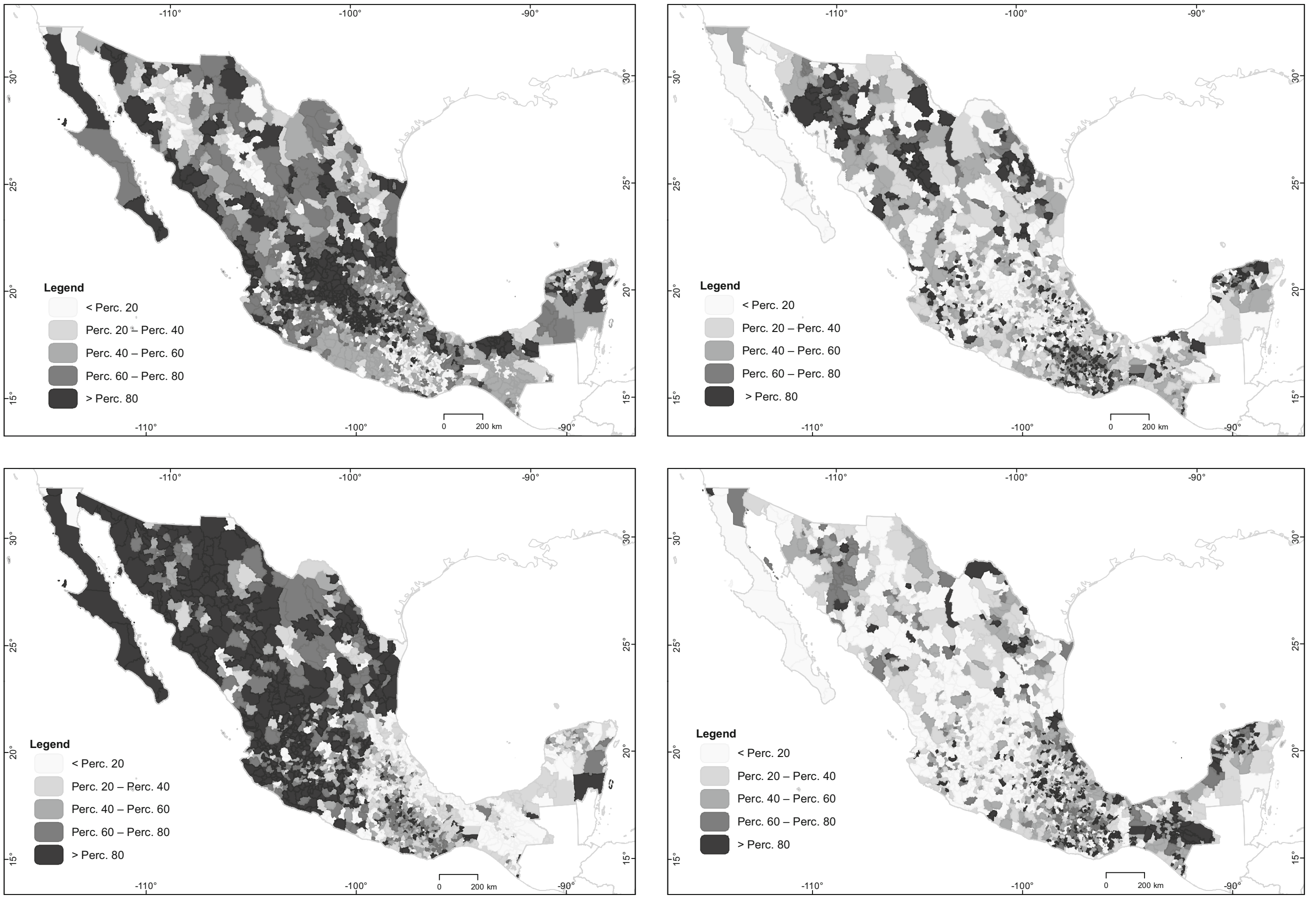


**Fig. 3** Geographic distribution of the 2013 overall mortality rate in vulnerable road users (*upper left*), in protected road users (*lower left*), of the change in mortality rate during the 1998–2013 period in vulnerable road users of over 50 years of age (*upper right*), and the change in mortality rate during the 2009–2013 period in male protected road users between 12 and 49 years (*lower right*). The gray levels are based on a division by quintiles, with darker areas indicating larger values (Mexico, 1998–2013)

widespread. These finding suggests that strategies aimed at reducing risk behavior among young drivers producing desired results and should be enhanced to further reduce death rates.

However, much progress remains to be achieved. Mexico has not yet implemented the core recommendation of the officially approved National Road Safety Strategy (Secretaría de Comunicaciones y Transporte 2011) nor of the United Nations Global Road Safety Strategy, which calls for the creation of a lead agency in charge of road safety at national level. Mexico continues to have an incomplete and fragmented legislative framework, with a large diversity in its 32 states. Furthermore, the current political agenda does not address, in any way, the need to develop an articulated legal and institutional framework for improving road safety. A comprehensive national road safety approach requires national leadership from agencies such as the ones established in most OCDE member countries such as Spain, United States, United Kingdom and most other, as well as in Argentina and Colombia, which are shown to be key for implementing radical road safety and safe mobility initiatives at national levels (Elvick et al. 2009; Hyder and Bishai 2012). Progress is possible, as it is evidenced by the encouraging results presented in this work, however, if the DARS objectives of 50 % reduction in fatalities (starting with the 2010 baseline), are to be met by 2020, it is imperative for Mexico to work on a comprehensive road safety agenda.

Among the limitations of our study, we note that our results depend on the quality of available records of vital statistics and classification of deaths in the country. National reporting systems are complex and under-registration is possible (see, e.g., the dip in the mortality statistics in 2007 in the left panel of Fig. 1, which is probably related to a variation in the recording procedures). A second limitation is that the grouping of all vulnerable road users into one category may obscure differential patterns among pedestrians, cyclists, and motorcyclists. For example, deaths among motorcyclists, although small in absolute number (as compared to pedestrians) are steadily increasing, especially among young males, whereas the trend in the overall group of vulnerable road users is decreasing. Further research on the topic of vulnerable road users is forthcoming from our group. Sustained improvement in data collection for mortality and disease classification in Mexico, and particularly the registration of additional valuable information (on vehicles or details of occupants and victims) is relevant as this information could support research and provide light on this subject area. In this respect, Mexico should adopt International Road Traffic Accident Database Standards.

## Conclusions

The turning point of 2009 in the traffic death rates (after a steadily climbing trend to 17 per 100,000) coincides with the time of implementation of the first national Specific Program of Action for Road Safety 2007–2012, and it is undoubtedly related to the Mexican Initiative for Road Safety (IMESEVI), whose stated objective was to reduce deaths from road traffic injuries, specifically among children and male youth applying the evidence-based approach of public health and epidemiology (see Cervantes-Trejo and Frausto-Bermúdez 2011). From 2009, there is a prominent decreasing trend in the subsequent years, leading to an overall traffic death rate of 13.8, which is the lowest value across the study period. The latter is accomplished in spite of an 18 % increase in population (from 97 million in 1998 to 115 million in 2013) and an almost threefold increase in vehicle fleet (from 13 million vehicles in 1998 to 38 million in 2014; INEGI 2015).

A particularly interesting finding relates to vulnerable road users of 50 years and older, with males of over 75 years of age showing the highest rates of mortality. Although overall rates in these groups tend to be decreasing for the entire 16-year period, their vulnerability merits special attention, specifically in densely populated areas. Programs for safer mobility are needed in these urban settings. Although woman exhibit much lower traffic mortality rates than men, the highest values observed are also in those 50 years and older. Programs aimed at safe mobility and safe transportation for the elderly in cities are warranted.

Geographic findings are relevant because they sustain the well documented observation that mortality rates for vulnerable road users are larger in more densely populated areas, where the growth in vehicle fleet is most evident (Elvik et al. 2009). These large (>100,000 persons) and very large (>500,000 persons) municipalities present the highest risk for vulnerable road users (motorcyclists, pedestrians and cyclists). For protected road users the spatial dispersion of risk shows a difference between the northern municipalities and the southern municipalities of the country, with higher mortality rates observed in the north. Overall, the decreases in traffic-related death rates in the country, from 2009 through 2013, is steeper in the northern and central parts of the country, which coincide with more industrialized commerce and socially developed parts of the country. Road safety and mobility efforts should be strengthened in these urban areas and lessons learned should be transferred to smaller southern state neighboring cities which lag behind in road safety efforts.

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**Compliance with ethical standards**

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## References

Bhalla K (2013) The costs of road injuries in Latin America 2013 (IDB Technical Note 597). Inter-American Development Bank, New York

Cervantes-Trejo A, Frausto-Bermúdez I (2011) Esto no es un accidente: La memoria de la Iniciativa Mexicana de Seguridad Vial. Secretaría de Salud, Mexico

Cervantes-Trejo A, Leenen I (2014a) Helmet use by motorcyclists in four metropolitan areas of Mexico. Gac Med Mex 150(S1):11–20

Cervantes-Trejo A, Leenen I (2014b) If you drink, don't drive: drunk drivers in Guadalajara and León, Mexico. Gac Med Mex 150:552–562

Cervantes-Trejo A, Leenen I (2015) The use of seatbelts and child seats in drivers and passengers of motor vehicles in four metropolitan areas in Mexico. Gac Med Mex 151:54–65

Cervantes-Trejo A, Camarota-Costas F, Rojas-Vargas R, López-Hernández P (2011a) IMESEVI Manual de orientaciones básicas. Secretaría de Salud, Mexico

Cervantes-Trejo A, Rojas-Vargas R, Rosas-Osuna R, Barrera-Muciño H, Ruelas-Valdés DA, Davidson K, Pérez-Barba JU (2011b) Programa nacional de alcoholometría: manual para la implementación de operativos. Secretaría de Salud, Mexico

Elvik R, Høye A, Vaa AT, Sørensen M (2009) The handbook of road safety measures, 2nd edn. Emerald, Bingley

Global Road Safety Facility, World Bank; Institute for Health Metrics and Evaluation (2014) Transport and health: the global burden of disease for motorized road transport. IHME Washington DC, The World Bank, Seattle

Hyder AA, Bishai D (2012) Road safety in 10 countries: a global opportunity. Traffic Inj Prev 13(S1):1–2

Instituto Nacional de Estadística y Geografía (2015) Interactive data query. http://www.inegi.org.mx/est/contenidos/proyectos/cubos. Accessed 4 Dec 2015

Leenen I, Cervantes-Trejo A (2014) Temporal and geographic trends in homicide and suicide rates in Mexico, from 1998 through 2012. Agress Violent Behav 19:699–707. doi:10.1016/j.avb.2014.09.004

Pan American Health Organization (2013) Datos sobre la seguridad vial en la Región de las Américas. Washington **(Author)**

Peden M, Scurfield R, Sleet D, Mohan D, Hyder AA, Jarawan E, Mathers C (2004) World report on road traffic injury prevention. World Health Organization, Geneva

SAS Institute (2013) SAS/STAT® 13.1 user's guide. Cary **(Author)**

Schwarz G (1978) Estimating the dimension of a model. Ann Stat 6(2):461–464

Secretaría de Comunicaciones y Transporte (2011) Acuerdo por el que se da a conocer la Estrategia Nacional de Seguridad Vial 2011–2020. Diario Oficial, México. http://dof.gob.mx/nota_detalle.php?codigo=5193284&fecha=06/06/2011. Accessed Dec 2015

Secretaría de Salud (2008) Programa de acción específico 2007–2012: Seguridad vial. México **(Author)**

Snijders TAB, Bosker RJ (2012) Multilevel analysis: an introduction to basic and advanced multilevel modeling, 2nd edn. Sage, London

STCONAPRA (2014) Informe sobre la situación de la seguridad vial, México 2014. Secretaría de Salud, México

United Nations (2004) Resolution adopted by the General Assembly, A/RES/58/289, http://www.who.int/violence_injury_prevention/media/news/en/unga_58_289_en.pdf. Accessed Dec 2015

Wong GY, Mason WM (1985) The hierarchical logistic regression model for multilevel analysis. J Am Stat Assoc 80:513–524

World Health Organization (2009) Global status report on road safety: time for action. Geneva. http://www.un.org/ar/roadsafety/pdf/roadsafetyreport.pdf. Accessed 4 Dec 2015 **(Author)**

World Health Organization (2011) International statistical classification of diseases and related health problems (10th revision). Geneva **(Author)**

World Health Organization (2015) Global status report on road safety 2015. Geneva www.who.int/violence_injury_prevention/road_safety_status/2015. Accessed 4 Dec 2015 **(Author)**

Zucchini W (2000) An introduction to model selection. J Math Psychol 44:41–61. doi:10.1006/jmps.1999.1276