Accident Analysis and Prevention 127 (2019) 110–117

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Impact of regulations to control alcohol consumption by drivers: An assessment of reduction in fatal traffic accident numbers in the Federal District, Brazil

Alam Gonçalves Guimarães, Alan Ricardo da Silva*

Programa de Pós-graduação em Transportes, Universidade de Brasília, Brazil

ARTICLE INFO

Keywords:
Traffic accidents
Control of alcohol consumption by drivers
Intervention analysis
ARIMA models

ABSTRACT

In 2008 Brazil enacted Law n° 11.705, known as the *Lei Seca* (in Portuguese) or Dry Law, altering the National Traffic Code by establishing zero tolerance for the presence of alcohol in drivers' bloodstreams and toughening punishment for offenders. In 2012 the New Dry Law, Law n° 12.760 came into force in an effort to correct for legal loopholes in the earlier version and make it feasible to produce alternative forms of proof of alcohol impediment against those drivers who refused to take the breath analysis test. Sanctions for offenders were made even more severe. Ten years after the advent of the first *Lei Seca* this study set out to make a quantitative assessment of the two laws' impacts regarding the reduction of lethal traffic accidents in the Federal District, Brazil. Intervention Analysis of Time Series was the technique used and transfer functions enabled the incorporation of the effects of dummy exogenous variables to the Box and Jenkins ARIMA model. Results showed that while Law n° 11.705 had no significant impact, Law 12.760 did have a statistically significant impact in reducing lethal accidents. Such results underscore the need for *ex post* monitoring and evaluation of Laws and confirm the premise that legislation only successfully produces its effects when compliance can be enforced.

1. Introduction

The World Health Organization has reported (WHO, 2007) that comparing data of different countries on traffic accidents involving alcohol-impaired drivers is a difficult task because few countries have sophisticated systems in place for consolidating such data and there is no uniformity among countries as to the legal limit on Blood Alcohol Concentration (BAC). It should be underscored that BAC determination is a feasible method for inferring alcohol impairment of drivers as discussed in AW (2000) and Andreuccetti et al. (2012). The same WHO (2007) report indicated that in high-income countries around 20% of fatal traffic accidents involved alcohol-impaired drivers whereas in low and middle-income countries the percentages varied from 33% to 69% (WHO, 2007).

A report of the National Highway Traffic Safety Administration, of the U.S. Department of Transportation reveals that in 2016, there were over 10 thousand fatal traffic accidents involving drivers with BACs of 0.08 g/dL or higher and that they accounted for 28% of the total number of US traffic accident deaths in that year (NHTSA, 2017).

In Brazil there are no specific statistics regarding traffic accident fatalities involving alcohol-impaired drivers. But a sample-based Ministry of Health survey (MS, 2017) of hospital service provision for external causes in municipal hospitals in the interior and capital cities of Brazilian states and the Federal District showed that around 12% of patients involved in traffic accidents declared that they had consumed alcoholic drinks, i. e., they were driving under the influence of alcohol.

Countries like South Africa, Colombia and Thailand have carried out similar surveys to the one Brazil undertook. According to WHO (2007) the results in South Africa showed that from 26% to 31% of drivers that suffered fatal injuries had BACs over the legal limit. In Thailand, a study that analyzed one hundred thousand accidents involving motorcyclists showed that 44% of the victims that were treated in public hospitals had BACs above the permitted level. A similar survey in Colombia showed that 34% of vehicle driver deaths and 23% of motorcyclist deaths were associated to excessive speed or the consumption of alcohol (WHO, 2007).

In the respective literature there are many studies analyzing the association between alcohol consumption and traffic accidents. In the 1980s, Homel (1988) discussed the effects of punishments on drivers caught in the act of driving under the influence of alcohol and its impact in reducing traffic accident rates in Australia. One of the author's main conclusions was that, in the long run, random breath-analyzing

* Corresponding author.
E-mail address: alansilva@unb.br (A.R. da Silva).

https://doi.org/10.1016/j.aap.2019.01.017
Received 10 October 2018; Received in revised form 24 December 2018; Accepted 20 January 2019
Available online 07 March 2019
0001-4575/

does have an impact in bringing about a reduction in the numbers of fatal accidents insofar as such tests heighten potential offenders' perception of the great likelihood of their being caught in the act of driving with BACs over the legal limit and consequently being subject to punishment.

According to Peek-Asa (1999) and Elder et al. (2002), imposing maximum concentration limits for alcohol levels in the blood by means of specific legislation accompanied by surveillance and inspection to ensure compliance based on setting up sobriety check points using random breath-testing can reduce the number of traffic accidents by around 20%. Social perception that the Law is being enforced and complied with is an important factor in achieving that figure. Furthermore, Shults et al. (2001) report that imposing even lower blood alcohol concentration limits on young drivers can bring about reductions ranging from 4% to 24% in accidents involving that population group.

To address that problem, in the second half of the 1990s the executive branch of the Brazilian Government issued Interim Measure n° 415 subsequently transformed into Law n° 9.503/1997 which came to be known as the National Traffic Code (*Código Nacional de Trânsito* – CNT in Portuguese). The preamble justifying the measure underscored the need to impose limits on the amount of alcohol drivers could consume in order to bring down the number of traffic accidents given that problem constituted a serious public health problem. In Article 306 the CNT sets out the sanctions to be applied in cases of drivers found to be driving their vehicles under the influence of alcohol. That Law, however, merely established the alcohol concentration that would typify a penal offence and failed to quantify limits that would constitute administrative infractions. The absence of those latter parameters made it difficult to punish offenders and hampered the effective enforcement of the law.

More than a decade had passed when on June 19, 2008 Law 11.705 was enacted, altering the CNT and establishing zero tolerance in regard to the presence of alcohol in driver's bloodstreams. It came to be known as the *Lei Seca* (in Portuguese) or 'Dry Law'. At the same time more severe penalties were introduced in the form of higher fines and suspension of the offenders driving license for a period of one year. In the cases of BACs higher than 0.06 g/dL the drivers could even be sentenced to imprisonment.

Despite the harder attitude introduced by the *Lei Seca* and the possibility it offered for inspection teams to carry out rapid breath analysis tests during the surveillance activities, in practice there were other difficulties that prevented its effective enforcement insofar as drivers were refusing to take the test alleging that there was no provision in Brazilian law that obliged them to produce proof that could be evidence against their own persons. That legal loophole made it difficult to punish offenders and it led to a perception, on the part of society at large, that the Law was not effectively being complied with.

In view of that situation, Law 12.760 was enacted on December 20, 2012. It not only foresaw more severe punishment for offenders but it broadened the possibilities for the agents of enforcement, whenever drivers refused to take the breath analysis tests, to use other proofs of alcohol impedance such as video images, witness statements and other visible signs that the law provided for indicating alteration of the driver's psychomotor capacity. In the following month, on January 23, 2013 the Brazilian National Traffic Council (*Conselho Nacional de Trânsito* – CONTRAN, in Portuguese) published its Resolution n° 432 setting out provisions regarding inspection and surveillance procedures to enable the effective enforcement of the said law.

More recently, in December 2017, Law 13.546 introduced new regulations that came into force in April 2018 making the penalties for drivers convicted of manslaughter or causing grievous bodily harm while under the influence of alcohol or other psychoactive substances even more severe. In these last cases the police are no longer authorized to immediately set bail and free the perpetrator but the driver who committed the crime must be imprisoned *in flagrante delicto* and the Courts informed and a magistrate will be responsible for setting the bail. Furthermore, the prison sentence for causing grievous bodily harm in such cases has been increased from two years to a maximum of five years.

Thus, ten years after the enactment of the *Lei Seca* and 6 years after the enactment of the new version of it, this study intends to make a quantitative assessment of the impacts, in terms of reducing the numbers of lethal traffic accidents, stemming from those legal interventions. More specifically the objective is to answer these questions: Did the *Lei Seca* of 2008 have a significant effect in reducing the number of fatal accidents? Was the severity introduced in the legislation in 2012 sufficient to further reduce the number of fatal accidents? Were the eventual impacts on the fatal accident figures actually brought about by the restrictions that the legislation imposed or do the analyses show that those impacts have been obscured by the background noise factors that are typical of data distributed over a long time series such as seasonality, tendencies and randomness? The sections that follow will endeavor to address those questions.

2. Background

Pankratz (1991) proposes that the ability to understand the effects that certain public or private interventions produce, the nature of physical, chemical or biological phenomena, or to forecast future conditions on the basis of variables distributed over a period of time can easily be jeopardized by a failure to understand the temporal structure of the relations among them. The study of those relations is known as Time Series Analysis.

In such series it is not uncommon to observe the manifestation of phenomena capable of bringing about changes in levels or tendencies at a given instant in time. Those changes may occur because of the interference of some known event, that is, an intervention. However, it is well-known that seasonality, tendency and random error are the kind of 'noise' that can obscure the real effects of the interventions. In the autoregressive moving average (ARMA) kind of modelling proposed by Box and Jenkins those three kinds of noise can be taken into account, thereby making it possible to discern, in isolation, the real effect of the intervention on the series (Box and Jenkins, 1976).

In that context Tiao et al. (1975) used intervention analysis to assess the impacts of certain measures on pollution in Los Angeles in the period from January 1955 to December 1972. Among the said measures was the opening of the Golden State Freeway in 1960 which it was thought might have had a beneficial influence on pollution levels and another was the introduction of regulations reducing the proportions of certain hydrocarbons in the gasoline sold in Los Angeles. The model showed that the measures had managed to reduce ozone levels by 1.09 parts per 100 million.

Bhattacharyya and Layton (1979) analyzed the effect of introducing legislation on the use of seat belts in cars on the numbers of deaths caused by road accidents in the state of Queensland, Australia. Their study concluded that the intervention was successful in reducing the number of fatal accidents.

More recently Andreuccetti et al. (2012) used a time series intervention analysis to assess the effects of the reduction in BAC limits imposed by Law n° 11.705 enacted in 2008 on the numbers of traffic accidents and fatal injuries in the state of Sao Paulo, Brazil, based on monthly data covering the period 2001–2010. Their work concluded that after the reduction of the BAC limits there was a reduction in the numbers of fatalities and injuries per hundred thousand inhabitants. Furthermore, their research showed how important it was that low-income countries should conduct rigorous investigations into the effects of strategies adopted by high-income countries to control driver drinking.

Given all that has been set out above the assessment of the impacts stemming from Brazilian laws designed to control the consumption of alcohol by drivers will be done by time series analysis, adjusting the

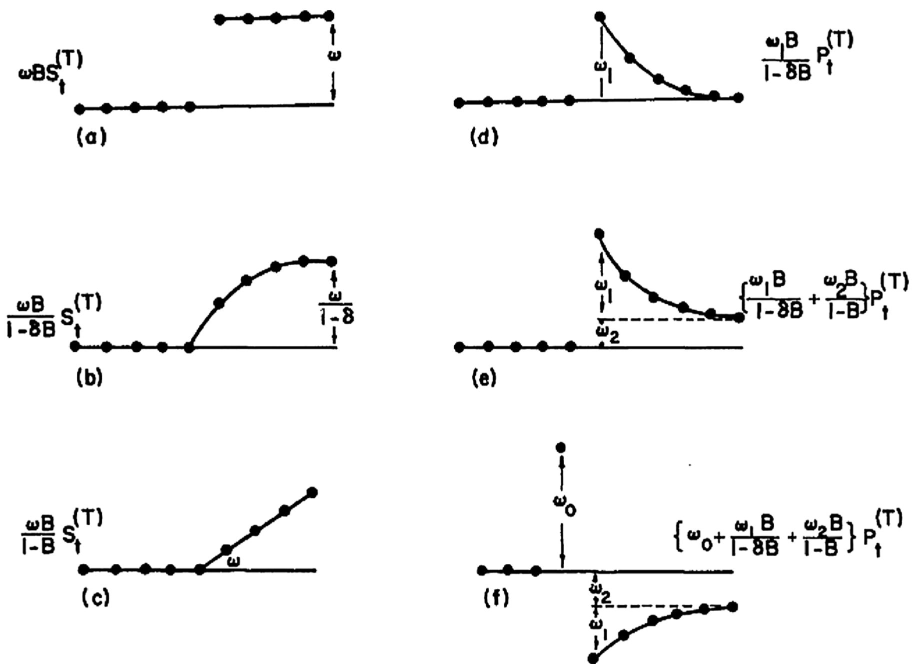

Fig. 1. Transfer Functions (adapted from Box and Tiao, 1975).

models proposed by Box and Jenkins to fatal accident statistics for the Federal District, Brazil, distributed on a monthly basis over the period from January 2000 to December 2017.

2.1. Intervention analysis in time series

The literature identifies various ways of analyzing the effect of an intervention in a univariate time series among which are: *i)* application of the Student *t*-test to compare measures prior to and after the intervention; *ii)* adjusting models to pre-intervention data and post-intervention data and then applying the Chi-squared test (χ^2) to compare the estimates obtained by the pre-intervention model with the real values obtained after the intervention; and *iii)* using the procedure described by Box and Tiao (1975) to impute a dummy variable associated to a transfer function to the model at the moment of intervention.

In the case of the Student *t*-test, one of the assumptions is that the observations are independent so that makes the test unsuitable for application to any series that presents a tendency. In the case of the Chi-squared test it is important that there should be a large number of observations (Agresti, 2002). Accordingly, the present study opted to apply method (*iii)* based on the inclusion of a dummy variable associated to an ARIMA-type model as recommended by Box and Jenkins.

2.1.1. Box and Jenkins ARIMA models

Generally a time series Z_t: $z_1, z_2, \ldots, z_n$ can be decomposed into the sum of 4 components $Z_t = T_t + S_t + C_t + a_t$, where T_t is the series' tendency to increase or decrease, S_t is the seasonality, C_t the cycle and a_t is the random effect. Thus the Box and Jenkins models are based on the generation of a second-order stationary process which is used to define ARMA-type models (p, d) for stationary series, so that

$$Z_t = \frac{\theta(B)}{\Phi(B)} a_t \tag{1}$$

where $(B) = 1 - \theta_1 B^1 - \ldots - \theta_q B^q$; $\Phi(B) = 1 - \Phi_1 B^1 - \ldots - \Phi_p B^p$; and B is called the backshift operator.

The sequence a_t is considerd to be 'white noise' whenever it has constant variance and mean values and presents no serial correlation.

In practice, however most series do not present stationary characteristics (their means and variance values are not constant) and accordingly, differences Δ^d have to be applied to the original series to obtain ARIMA-type models with the form

$$Z_t = \frac{\theta(B)}{(1-B)^d\,\Phi(B)} a_t \tag{2}$$

where $\Delta^d = (1 - B)^d$.

In those cases where the presence of seasonal components in the multiple lags over a period s are detected, it is necessary to apply s differences to the original series in order to obtain a Seasonal ARIMA-type model known as SARIMA $(p, d, q)(P, D, Q)_s$, and defined as

$$Z_t = \frac{\theta(B)\Theta(B^s)}{(1-B)^d\,(1-B)^D\Phi(B)\Phi(B^s)} a_t \tag{3}$$

where $\Theta(B^s) = 1 - \Theta_1 B^s - \ldots - \Theta_1 B^{PS}$; $\Phi(B^s) = 1 - \Phi_1 B^s - \ldots - \Phi_1 B^{QS}$.

The definition of the parameters p, d and q is achieved by making graph analyses of the autocorrelation and partial autocorrelation functions (ACF and PACF) with the additional aid of the Smallest Canonical and Extended Sample Autocorrelation Function (SCAN and ESACF) tests as described by Tsay and Tiao (1984).

Spectral analysis is applied to time series to detect seasonal or cyclic patterns. In turn, Bartlett Kolmogorov-Smirnov (BKS) statistics tests the null hypothesis that the series presents no frequency peaks by comparing the accumulated distribution of the standard periodogram with the accumulated function of the uniform distribution (Miller, 1956).

2.1.2. Transfer functions

The impact of the intervention at the instant t in the series T is tested by imputing a dummy variable X_t associated to a transfer function $\omega(B)$ in the series

$$Z_t^* = \omega(B)X_t + Z_t \tag{4}$$

where X_t can take the form of a step function (5) or of a pulse function (6), that is

$$X_t = \begin{cases} 0, & t < T \\ 1, & t \geq T \end{cases} \tag{5}$$

or

$$X_t = \begin{cases} 0, & t \neq T \\ 1, & t = T \end{cases} \tag{6}$$

The step function evaluates the effect of the intervention in a continuous manner starting from the instant t whereas the pulse function evaluates the effect at the instant t alone. The transfer functions $\omega(B)$ can take the forms shown in Fig. 1, where 1(a), 1(b) and 1(c) are step functions and 1(d), 1(e) and 1(f) are pulse functions.

2.1.3. Model selection and diagnostics

When conducting analysis to determine the optimum model, it is essential to verify whether the residuals are auto-correlated. When this latter situation arises it may indicate that coefficients of the adjusted model are failing to completely capture the dynamics of the series under study. The Box-Pierce test (Davies et al., 1977) is a useful way of detecting whether the distribution of the residuals is white noise or not.

In addition, the Akaike Information Criterion – AIC (Akaike, 1974) and the Schwartz Bayesian Criterion – SBC (Schwarz, 1978) are used to select the most well-adjusted model. The smaller their values are, the more adjusted the model will be.

3. Model calibration

SAS 9.4. software was used to analyze the monthly figures registering fatal traffic accidents in the Federal District for the period January 2000 to December 2017. The figures were obtained from the Traffic Department of the Federal District. During the period in question, 6949 fatal accidents were registered for the Federal District of which, 40% involved vehicle collisions, 34% involved knocking down pedestrians, 10% involved vehicles overturning and 10%, collisions with stationary objects. The remaining 6% were associated to a variety of other kinds of fatal accidents (DETRAN, 2018). The only data the DETRAN (2018) makes available are set out in Fig. 2 in which the numbers of accidents disaggregated by month and by year are in Fig. 2 (top) and the numbers of accidents disaggregated by years and by the kind of accident are in Fig. 2 (bottom).

Given the absence of any statistics specifically pinpointing deaths involving alcohol-impeded drivers and that the data presented here refer to all fatal traffic accidents that occurred in the period in question, it must be stated that were it possible to disaggregate data specifically referring to accidents involving drivers under the influence of alcohol, then it is quite possible that the analysis would have revealed a different pattern. It should also be noted that it is not possible to use a replacement measure for the involvement of drinking drivers such as the one Heeren et al. (1985) proposed, namely the ratio of single vehicle nighttime (SVN) (6PM-6AM) crashes to multiple vehicle daytime (MVD) (6AM-6PM) crashes.

Fig. 3 (bottom) shows the distribution of the series. The red spot (on the left) and line represent the month when Law 11.705, the *Lei Seca,* was enacted, that is, June 2008; the blue spot (on the right) marks the moment of enactment of Law 12.760 in December 2012 and the complete line traced out represents the linear tendency of the series. It can be seen that there is an overall tendency to a reduction, however modest, in the number of fatal accidents.

It must be underscored that over the period in analysis there was an expressive increase in the size of the vehicle fleet in Brazil. In the Federal District in particular, data published by the National Traffic Department show that in the year 2000, the fleet consisted of a little over 400 thousand vehicles while in 2017 it consisted of about 1.7 million vehicles, a variation of 297%. Around 70% of the total fleet registered for the year 2017 corresponded to sedans, around 10% to motorcycles and other kinds of vehicle answered for around 20% (DETRAN, 2018). Against that background of vigorous growth in the vehicle fleet, it is worthwhile highlighting the automotive policy that the Brazilian government implemented in 2012 under the name of *Inovar-Auto* (Auto-innovate) which, among its other objectives has that of providing IPI-related (industrialized products tax) tax benefits in the form of presumed credit (Pascoal et al., 2015).

Furthermore, Brazil, with its continental dimension, has 26 states and one Federal District, and its 5570 municipalities occupy an area of around eight and a half million square kilometers with an estimated population in 2018 of 208 million inhabitants (IBGE, 2018). Given that background, it is important to stress here, the lack of traffic accident data unified at the national level and the further lack of urban traffic accident data disaggregated according to aspects such as the time of day

1.1 Acidentes de Trânsito com Morte, por Mês e Ano

MÊS	ANO																		
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Janeiro	30	27	27	25	22	35	33	28	31	26	40	34	24	30	32	32	21	20	31
Fevereiro	27	31	23	33	32	25	29	24	34	25	24	34	30	23	29	32	17	20	18
Março	42	38	37	34	33	34	35	26	36	41	36	36	28	24	32	27	25	13	31
Abril	38	33	39	45	26	37	27	31	47	33	30	40	40	36	30	30	39	18	36
Maio	38	30	36	33	43	36	33	35	38	33	41	37	39	31	28	29	43	17	24
Junho	43	40	36	42	33	30	24	41	36	30	39	35	29	29	38	22	27	24	20
Julho	35	38	34	43	42	46	35	35	28	30	29	31	30	27	35	22	38	35	22
Agosto	19	26	40	47	37	36	22	44	38	39	53	43	41	35	32	36	27	22	20
Setembro	21	36	37	35	31	35	28	53	34	30	42	34	37	22	33	21	35	17	14
Outubro	32	28	35	32	36	38	30	34	28	33	36	38	34	31	28	28	32	22	17
Novembro	26	30	28	37	31	25	36	34	39	29	25	32	29	31	24	18	30	17	14
Dezembro	37	29	35	64	23	33	37	37	29	34	36	24	32	43	27	34	29	16	-
Total	388	386	407	470	389	410	369	422	418	383	431	418	393	362	368	331	363	241	247

1.2 Acidentes de Trânsito com Morte, por Ano, segundo a Natureza

NATUREZA	ANO																		
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Atropelamento de Pedestre	146	163	152	155	136	152	130	131	151	112	149	130	120	120	114	105	127	79	99
Colisão	154	122	161	202	160	155	156	175	184	159	173	156	156	146	136	147	128	96	81
Capotamento/Tombamento	39	36	29	43	32	39	31	39	28	49	39	55	46	38	37	24	36	22	25
Choque com Objeto Fixo	25	43	34	40	40	32	33	39	26	32	33	52	38	40	63	34	43	24	24
Queda	15	17	20	20	14	22	16	22	26	29	32	22	26	13	11	15	27	16	15
Atropelamento de Animal	5	1	4	2	1	2	-	5	2	-	3	-	1	-	1	-	2	1	1
Demais Tipos	4	4	7	8	6	8	3	11	1	2	2	3	6	5	6	6	-	3	2
Total	388	386	407	470	389	410	369	422	418	383	431	418	393	362	368	331	363	241	247

Fig. 2. Available data for fatal traffic accidents in the Federal District, Brazil, in portuguese (DETRAN, 2018).

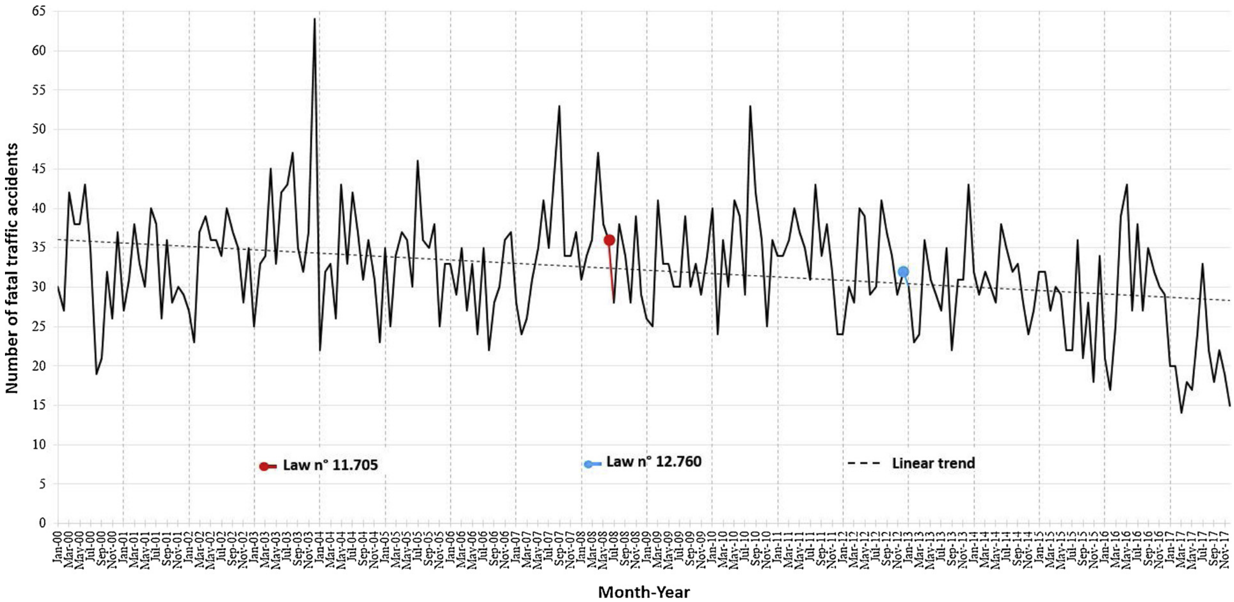

Fig. 3. Time series of fatal traffic accidents in the Federal District, Brazil (Jan./00 to Dec./17).

of accident occurrence (day or night), weather conditions at the time, roadway characteristics, as well as variables associated to the drivers' state or behavioral patterns such as speeding, failure to use the seat belt, using the cellphone while driving and, more particularly, their consumption of alcohol or other psychoactive substances to an extent that exceeds the permitted BAC levels.

Brazil's capital, Brasilia, lies in the Federal District which along with the 26 states makes up the 27 Federative Units that compose Brazil. The Federal District is a kind of a hybrid between a state and a municipality. It is however the country's administrative capital where public policies with a national outreach are elaborated. Its population in 2018 has been estimated at around 2.9 million inhabitants, making it the third most populous capital, surpassed only by Sao Paulo and Rio de Janeiro. The DF has an area of approximately 5.8 thousand square kilometers (IBGE, 2018). Furthermore, the Census carried out in the year 2000 showed that at the time the population of the Federal District was roughly two million inhabitants, which when contrasted with the estimates of the present day population indicates an increase in terms of absolute numbers of 900 thousand inhabitants (IBGE, 2018). During that same period the fatal accident rate per 100 thousand inhabitants of the Federal District dropped from 20.8 to 8.4 (DETRAN, 2018). Fig. 4 shows the map of Brazil with the location of the Federal District in evidence.

In addition to the abovementioned population increase and the increase in the vehicle fleet, which could very well have had a direct impact on the numbers of fatal accidents, there were other factors like the technological evolution of vehicle safety equipment, educational campaigns, surveillance and inspection, and others that may well have made their respective impacts. In regard to the technological evolution of the safety equipment of vehicles observed to have taken place in the course of recent decades such as airbags, 3-point seat belts and the Anti-lock Braking System (ABS), all of them may have contributed towards achieving that reduction in the numbers of fatal accidents. Without ignoring the socio-economic and cultural differences, nevertheless it is worth mentioning that, as early as 1994, most vehicles being sold in the United States had airbags installed and that led to a reduction of 11% in the numbers of fatal traffic accidents (NHTSA, 1996).

In Brazil, it was only in 2014 that airbags and ABS became obligatory for all vehicles manufactured and traded in the country (Pascoal et al., 2015). On the other hand, despite the mandatory nature of seat belt use having been imposed ever since the publication of Law n° 9.503/1997 (WHO, 2008), the 3-point seat belt, invented as far back as 1959 and currently considered to be one of the most important innovations in vehicle safety ever (Pascoal et al., 2015), will only actually become obligatory for installation in all vehicles manufactured in Brazil from the year 2020 on according to the provisions of CONTRAN Resolution n° 29, dated January 2015.

Given the aforementioned considerations regarding the data, there now follows a presentation of the calibration of the model. First, a test was conducted for the presence of components associated to tendency ($\boldsymbol{T_t}$,), seasonality ($\boldsymbol{S_t}$) and cycle ($\boldsymbol{C_t}$) in the series. The result of the ***BKS*** test, 0.25384 (*p-value* < *0.0001*), rejected the hypothesis that the periodogram followed a uniform distribution. That result is displayed in graphic form in Fig. 5 which shows a frequency peak for period 12; an indication of the presence of the $\boldsymbol{S_t}$ component in the series and probably related to the increase in road accidents associated to the months of December. On the other hand, no frequency peaks can be seen in periods greater than 12 and that indicates the absence of $\boldsymbol{C_t}$ component in the series. Furthermore, the Chi-squared test values for lags 6 and 12 in the series were 51.38 and 72.40 respectively, resulting in *p-values* lower than 0.0001 thereby showing that the series is not white noise and indicative of the presence of the $\boldsymbol{T_t}$ component as previously detected in the graphic display in Fig. 3.

Analysis of the autocorrelation functions (ACF), the partial autocorrelation functions (PACF) and of the SCAN and ESACF tests identified the following possible models: ARIMA (1, 1, 1), ARIMA (0, 1, 1), ARIMA (1, 1, 0) and ARIMA (2, 1, 2). Table 1 shows the results obtained for each of the tested models.

In spite of the possible presence of seasonality indicated by the period 12 peak in the periodogram in Fig. 5, the model showed no significant correlation in Lag 12 or even in any of its harmonics. Furthermore, the application of seasonal difference $\boldsymbol{D} = 12$ to the series based on the SARIMA models $(\boldsymbol{p}, 1, \boldsymbol{d})(\boldsymbol{P}, 1, \boldsymbol{D})_{12}$ did not result in any gains. The results associated to the application of criteria AIC and SBC and of the application of the *t* test to the parameter estimates indicated that the choice would be the ARIMA(0,1,1) model. Fig. 6 displays the results of the residuals diagnostics for the said model.

Fig. 7 shows the results of adjusting the ARIMA (0,1,1) model. The circles represent the values corresponding to the observed accidents, the unbroken line represents the estimated values for the model and the shaded area on both sides of the line corresponds to the 95% reliability/confidence interval for the estimated values. The figure shows how well

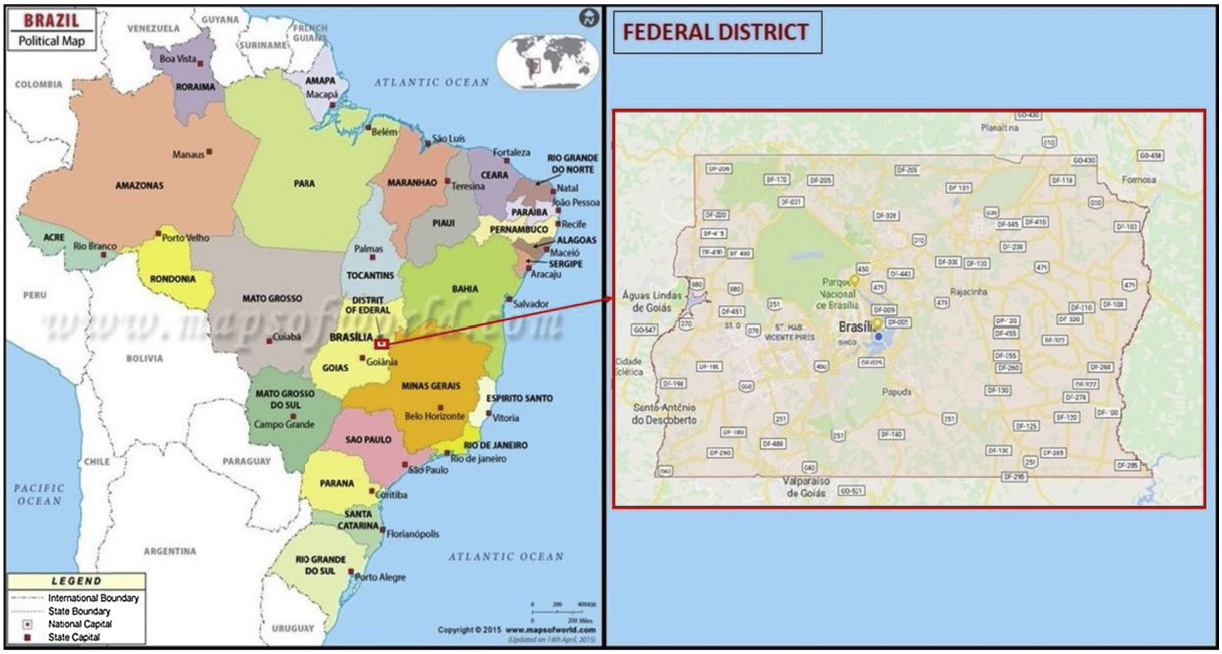

Fig. 4. Map of Brazil highlighting the location of the Federal District (adapted from MAPSOFWORLD and Googlemaps).

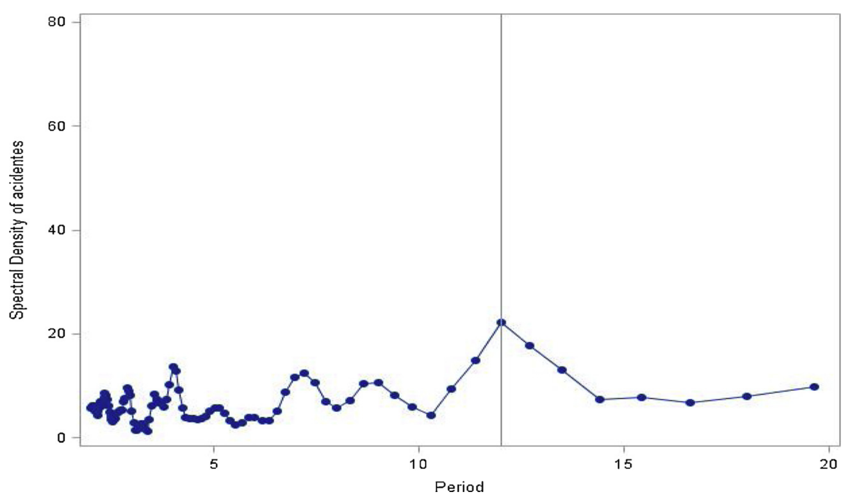

Fig. 5. Periodogram.

Table 1
Model Testing Results.

Models	Parameter	Estimate	Standard Error	*t* value	p-value	Autocorrelation Check of Residuals			Variance Estimate	AIC	SBC
						Chi-Square to Lag 6	DF	p-value			
ARIMA (1,1,1)	θ_1	0.924	0.033	27.95	< 0.0001	3.59	4	0.4630	44.36	1429.20	1435.94
	ϕ_1	0.135	0.077	1.76	0.079						
ARIMA (0,1,1)	θ_1	0.885	0.034	25.91	< 0.0001	6.83	5	0.2333	44.76	1429.96	1433.34
ARIMA (2,1,2)	θ_1	1,153	0.806	1.43	0.1541	2.06	2	0.3570	44.46	1431.68	1445.16
	θ_2	0.199	0.747	0.27	0.7901						
	ϕ_1	0.352	0.805	0.44	0.6620						
	ϕ_2	0.059	0.145	0.41	0.6815						

the model $\mathbf{Z_t} = \frac{(1-0.885\mathbf{B})}{(1-\mathbf{B})}\mathbf{a_t}$ fitted the data.

The last step was to impute the dummy variables $X_{t,j}$ representing the tested intervals to $\mathbf{Z_t}$. In that way the following combinations/interventions for the $X_{t,j}$ variable of the step function and pulse function forms were tested as displayed in Table 2. Given that the respective legislative instruments each came into force on the 20th day of the month of their respective enactments the points of intervention were considered to be the months subsequent to the months of enactment.

The model's parameter estimates are set out in Table 3.

The intervention variable in pulse function $X'_{t,j}$, was not significant to a significance level of 5% showing that none of the three interventions had an abrupt impact on the series. Similarly, the step function

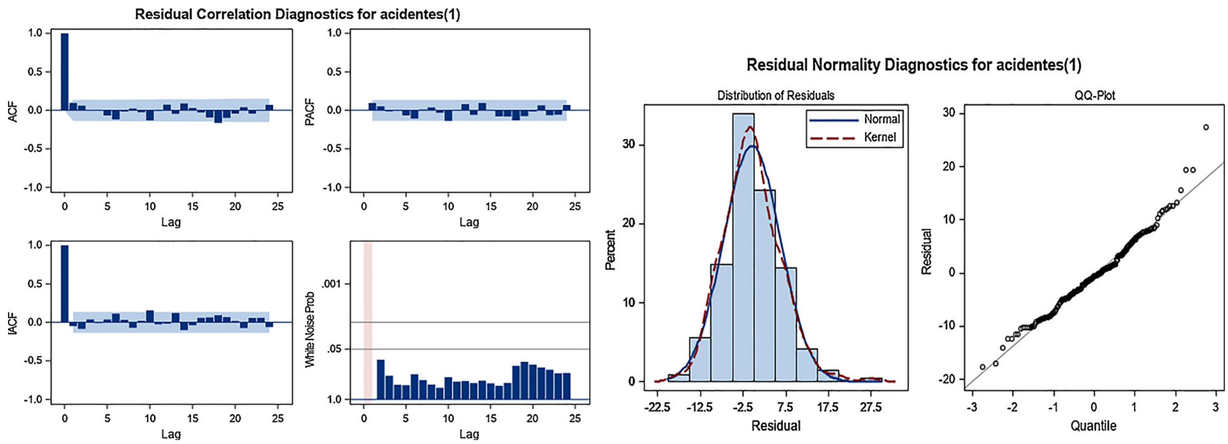

Fig. 6. Residuals Correlation Diagnostics for the ARIMA(0,1,1) model.

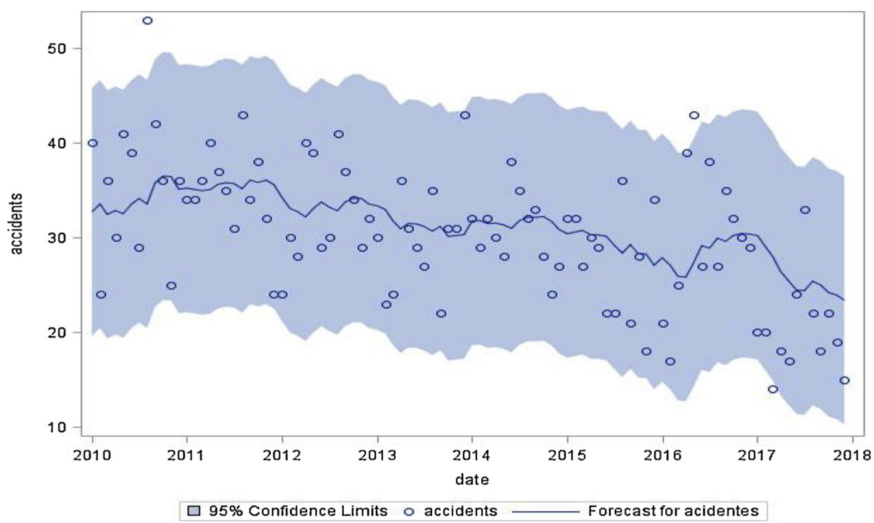

Fig. 7. Adjusted Model.

Table 2
The tested intervention variables.

Intervention	T_j	$X_{t,j}$ step function	pulse function
Law n° 11.705	T_1: July-08	$X_{t,1} = \begin{cases} 0, & t < T_1 \text{ and } t > T_2 \\ 1, & T_1 \le t \le T_2 \end{cases}$	$X'_{t,1} = \begin{cases} 0, & t \ne T_1 \\ 1, & t = T_1 \end{cases}$
Law n° 12.760	T_2: January-13	$X_{t,2} = \begin{cases} 0, & t < T_2 \\ 1, & t \ge T_2 \end{cases}$	$X'_{t,2} = \begin{cases} 0, & t \ne T_2 \\ 1, & t = T_2 \end{cases}$
CONTRAN Resolution n° 430	T_3: February-13	$X_{t,3} = \begin{cases} 0, & t < T_3 \\ 1, & t \ge T_3 \end{cases}$	$X'_{t,3} = \begin{cases} 0, & t \ne T_3 \\ 1, & t = T_3 \end{cases}$

variable $X_{t,1}$ was not statistically significant showing that Law 11.705, enacted in June 2008 did not result in any significant reduction in lethal accidents. On the other hand, the variables $X_{t,2}$ and $X_{t,3}$ were statistically significant for any level of significance (p-value < 0.0001), showing that both Law 12.760, enacted in December 2012, and CONTRAN Resolution n° 430, issued in January 2013, resulted in a significant, continuous reduction in the numbers of lethal traffic accidents.

It must be underscored that even though the reductions in $X_{t,2}$ and $X_{t,3}$ proved to be statistically significant, they were of a relatively low intensity. As mentioned above, that fact can be explained by another, namely that the analysis is being applied to the overall numbers of fatal traffic accidents in general so it is quite possible that future analyses using the same method but applying it to a time series made up only of those lethal accidents involving alcohol-impeded drivers could reveal

Table 3
Results obtained for the models.

Parameter	Estimate	Standard Error	t value	p-value	Variance Estimate	AIC	Models
θ_1	0.879	0.035	24.97	< 0.0001	44.90	1431.60	$Z_t^* = -0.068X_{t,1} + \frac{(1-0.879B)}{(1-B)}a_t$
$X_{t,1}$	−0.068	0.118	−0.58	0.565			
θ_1	0.999	5.743	0.17	0.8618	42.45	1423.43	$Z_t^* = -0.184X_{t,2} + \frac{(1-0.999B)}{(1-B)}a_t$
$X_{t,2}$	−0.184	0.029	−6.90	< 0.0001			
θ_1	0.999	12.62	0.08	0.9369	42.49	1423.60	$Z_t^* = -0.187X_{t,3} + \frac{(1-0.999B)}{(1-B)}a_t$
3	−0.187	0.027	−6.86	< 0.0001			

far more significant reductions with greater intensities. Again, as previously mentioned, the unavailability of disaggregated data distinguishing the data referring specifically to lethal accidents involving alcohol-impeded drivers strongly hampers any efforts to monitor and assess the impacts of Laws designed to control it.

4. Concluding remarks

The descriptive analysis of lethal traffic accidents in the Federal District, Brazil in the period from 2000 to 2017 made it possible to detect a tendency to a linear reduction in the time series showing that, in spite of the considerable increase in the vehicle fleet and a significant increase in the population size during the same period there is an apparent tendency in the contrary direction towards a reduction in the number of fatal traffic accidents. Furthermore there was observable 12-month seasonality in the figures.

The estimated parameters for the $X_{t,j}$ variable imputed to the ARIMA (0,1,1) model, considering pulse functions, did not prove to be statistically significant for any level of significance, showing that the three interventions analyzed did not lead to any abrupt changes in the series. That could be related to the fact that legislation of that kind calls for the implementation of associated policies such as educational and publicity campaigns as well as an increasing perception, on the part of society at large, that offenders are being duly punished. Only then can their overall goals can be achieved.

Similarly, the estimated parameters for the $X_{t,1}$, variable in the step function form, that is, analyzing the continuous effect starting from the month subsequent to the enactment of the Law, also failed to show any significance at the 5% level, showing that the enactment of Law 11.705, in 2008 had no significant effect in reducing the numbers of lethal traffic accidents in the Federal District. In this latter case, the results of the model showed, in quantitative terms, that the difficulty encountered in effectively enforcing the Law rendered it innocuous, with due allowance for the eventual fidelity of the data and for the use of a series referring to traffic deaths as a whole instead of a series restricted to lethal accidents involving alcohol-impeded drivers as discussed above.

On the other hand the estimated parameters for the $X_{t,2}$ and $X_{t,3}$ variables, both with a continuous effect, showed themselves to be statistically significant for any level of significance starting from the month following the enactment of Law 12.760, in December 2012, and the month following the publication of CONTRAN Resolution n° 432, in January 2013. Thus the restrictions which those two norms imposed did indeed have an impact in reducing the numbers of lethal traffic accidents in the Federal District, Brazil.

Lastly, now that 10 years have gone by since the enactment of the *Lei Seca* and 6 years since that of the new version of it, this analysis shows that the *Lei Seca* of 2008 did not prove to be efficient but that the perfecting of it that came with the New *Lei Seca* in 2012, contributed towards reducing the numbers of traffic-related deaths in the Federal District. It is quite likely that future analyses based on the recent advent of more severe sanctions contemplated by Law 13.546/2017 will reveal even more significant reductions in the figures.

In addition, it is important to underscore the need to obtain and make available to society more reliable disaggregated and detailed data on traffic accidents, which will make specific separate analyses of the presence of alcohol-impeded drivers in the accident figures possible. It is believed that such a situation will make *ex post* monitoring and evaluation of the regulations designed to control alcohol consumption by drivers more efficacious thereby contributing towards improving those regulations and their effect in the sense of reducing the number of traffic accident deaths due to the mixture of drinking and driving.

Finally, as has been shown, the data available for this study did not include any information on the numbers of vehicles involved in the accidents or the time the accidents occurred. If such data should become available in the future, then it will be possible to make use of the measurements that Heeren et al. (1985) proposed and Voas et al. (2009) updated in order to find out whether the accidents had been caused by alcohol-impaired drivers and determine the single vehicle nighttime (SVN) (6PM-6AM) to multiple vehicle daytime (MVD) (6AM-6PM) ratio.

References

Agresti, A., 2002. Categorical Data Analysis. University of Florida. Wiley-Interscience, Gainesville, Florida.

Akaike, H., 1974. A New Look at the Statistical Model Identification. IEEE Transaction on Automatic Control. AC-19. pp. 716–723.

AW, J., 2000. Medicolegal alcohol determinations — blood- or breath-alcohol concentration? Forensic Sci. Rev. 12, 23–47.

Bhattacharyya, M.N., Layton, A.P., 1979. Effectiveness of seat belt legislation on the Queensland road toll: an Australian case study in intervention analysis. J. Stat. Assoc. 74 (367), 596–603 Alexandria.

Box, G.P., Jenkins, G.M., 1976. Time Series Analysis: Forecasting and Control. Holden Day, New York, pp. 575.

Box, G.E.P., Tiao, G.C., 1975. Intervention analysis with applications to economic and environmental problems. JASA 70, 70–79.

Davies, N., Triggs, C.M., Newbold, P., 1977. Significance levels of the box-pierce portmanteau statistic in finite samples. Biometrika 64, 517–522.

DETRAN, 2018. Departamento Nacional de Trânsito. Estatísticas de Trânsito. Available at http://www.detran.df.gov.br/wp-content/uploads/2018/06/df_serie_historica_fatal_2000_2018_novembro.pdf Consulted on May 01, 2018. .

Elder, R.W., Shults, R.A., Sleet, D.A., Nichols, J.L., Zaza, S., Thompson, R.S., 2002. Effectiveness of sobriety checkpoints for reducing alcohol-involved crashes. Traffic Inj. Prev. 3, 266–274.

Heeren, T., Smith, R.A., Morelock, S., Hingson, R.W., 1985. Surrogate measures of alcohol involvement in fatal crashes: are conventional indicators adequate? J. Safety Res. 16 (3), 127–134.

Homel, R.J., 1988. Policing and Punishing the Drinking Driver. A Study of General and Specific Deterrence. Springer-Verlag, New York.

IBGE, 2018. Brasil em síntese. Available at https://cidades.ibge.gov.br/brasil/df/brasilia/panorama Consulted on December 12, 2018. .

Miller, L.H., 1956. Tables of percentage points of kolmogorov statistics. J. Am. Stat. Assoc. 51, 111.

MS, 2017. Viva: Vigilância de Violências e Acidentes. Ministério da Saúde. Secretaria de Vigilância em Saúde, Brasília/DF.

NHTSA, 1996. Fatality Reduction by Air Bags: Analyses of Accident Data through Early 1996. National Highway Traffic Safety Administration. U.S. Departament of Transportation, Washington, DC. Available athttps://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/808470&gtConsulted on December 12, 2018.

Pankratz, A., 1991. Forecasting With Dynamic Regression Models. Wiley-Interscience.

Pascoal, E.T., da Silva, A.L.N., Ferreira Filho, V.S., 2015. The new Brazilian automotive policy challenges in the technological advancement of vehicle security in Brazil. J. Mech. Eng. Autom. Available at http://www.davidpublisher.org/Public/uploads/Contribute/55af445f0f5f0.pdf Consulted on December 12, 2018.

Peek-Asa, C., 1999. The effect of random alcohol screening in reducing motor vehicle crash injuries. Am. J. Prevent. Med. 16 (Suppl. 1), 57–67.

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

Shults, R., et al., 2001. Reviews of evidence regarding interventions to reduce alcohol-impaired driving. Am. J. Prev. Med. 21 (Suppl 4), 66–88.

Tiao, G.C., 1975. Analysis of Los Angeles photochemical smog data: a statistical overview. J. Air Pollut. Control Assoc. 25 (3), 260–268 [S.I.].

Tsay, R.S., Tiao, G.C., 1984. Consistent estimates of autoregressive parameters and extended sample autocorrelation function for stationary and nonstationary. JASA 79 (385), 84–96.

Voas, R.B., Romano, E., Peck, R., 2009. Validity of surrogate measures of alcohol involvement when applied to nonfatal crashes. Accid. Anal. Prev. 41 (3), 522–530.

WHO, 2007. Drinking and Driving: a Road Safety Manual for Decision-makers and Practitioners. Geneva, Global Road Safety Partnership. Available at https://www.grsproadsafety.org/wp-content/uploads/DrinkingDriving_English.pdf Consulted on December 12, 2018. .

WHO, 2008. Brazil Seat-Belt Legislation. Available at https://www.who.int/violence_injury_prevention/road_safety_status/2009/laws/seat_belt_brazil_en.pdf Consulted on December 12, 2018. .