European Transport \ Trasporti Europei (2024) Issue 98, Paper n° 3, ISSN 1825-3997

https://doi.org/10.48295/ET.2024.98.3

Road Safety Evaluation during the COVID-19 Pandemic: An Exploratory Analysis on Brazilian Federal Highways

Eduardo Augusto de Oliveira Mendes[1], Philippe Barbosa Silva[2*]

[1]*Department of Civil Engineering, Goiano Federal Institute – Rio Verde Campus, Rio Verde 75901-970, Brazil*

[2]*Post-graduate Program in Applied Engineering and Sustainability, Goiano Federal Institute – Rio Verde Campus, Rio Verde 75901-970, Brazil*

Abstract

Because of the increase in the number of cases of COIVD-19, government authorities needed to contain the spread and implemented several measures, including restricting hours of operation and social distancing measures, such as isolation. This leads to a considerable decrease in urban mobility and, consequently, to an effect on road safety. Therefore, the problem question arises: What is the impact of the COVID-19 pandemic on road safety on Brazilian federal highways? Thus, the objective of this paper is to evaluate the safety trends during the COVID-19 pandemic in 2020. This paper used the crash database from the Brazilian Federal Highway Police (PRF), was analyzed, which enabled identifying changes in crash occurrence in 2020 when compared to the previous years (2011 - 2019). A decrease in the number of crashes on federal highways was observed, which might not have a direct relationship with the COVID-19 pandemic.

Keywords: Pandemic, Road Crash, Highway.

1. Introduction

In 2020, the world came across a new virus that negatively affected the entire world population. This resulted in a long-term pandemic that changed the lives and the routines of millions of people, which had to modify their behaviours and their daily habits to prevent the spread of the new coronavirus (Sars-CoV-2) or the COVID-19.

The COVID-19 pandemic caused several impacts. For example, social distancing measures were implemented because, to prevent infections, activities such as avoiding social gatherings and staying home are recommended. In Brazil, government authorities

Corresponding author: Philippe Barbosa Silva (philippe.silva@ifgoiano.edu.br)

established a series of changes using executive orders to implement these measures more effectively. These executive orders, which were both at the state and at the city levels, were created to ensure that citizens avoided close contact with others as much as possible. Events were canceled, commercial activities were shut down, and, in some extreme cases, highways to access other cities were closed.

Each state created its own executive orders, which composed the state plan to fight COVID-19 (CONASS, 2023). In these plans, restrictive measures were adopted to try to delay the spread of the virus. The plans lasted weeks or months, and they were divided into phases. Each phase indicated an increase in restrictions (e.g., limiting hours of operations or services) throughout the state. The restrictions established rules such as the dates and the working hours for essential services, which involved logistics, health, security, and supply. These services continued to operate with capacity restrictions and reduced hours. Therefore, this aimed not to overwhelm the Brazilian Unified Health System, and people in need could still use intensive care unit (ICU) beds.

The new coronavirus emerged differently from the previous pandemics because now the society can utilize technology in its favor, which helps in health and information access. Thus, the COVID-19 impacts provide analyses and even speculations about how humanity will deal with casual mass contamination. Given this situation, this study evaluated the impacts of the COVID-19 pandemic on road safety. Crash data from Brazilian federal highways were used, and this data was made available by the Department of Federal Highway Police (PRF, in portuguese).

Because of the mobility trends when restrictive measures were implemented, the factors that influence crash occurrence should be investigated. To determine the most important factors for road safety, this study compared the number of crashes during the last 10 years. The crash database can be then used to estimate the possible impact of these restrictive measures on road safety.

The scenario imposed by the COVID-19 pandemic led to the following research question: What is the impact of the COVID-19 pandemic on road safety, more specifically on the Brazilian federal highways? Because of this question and other associated uncertainties, evaluating road safety when restrictions were in place is necessary. In addition, it should consider drivers involved in any kind of crash in the dataset, which consists of federal highways.

The general objective of this paper is to evaluate the road safety trends during the COVID-19 pandemics on Brazilian federal highways in 2020.

2. The pandemic circumstances and its effects

Pandemics have caused serious public health concerns in our society because they trigger political and socio-economic crises in the affected countries. Virus outbreaks tend to occur every century, and they have a few similarities in terms of disease propagation and containment. Therefore, the COVID-19 pandemic is comparable to other pandemics that occurred previously, and similarities are observed between this pandemic and the previous ones. The World Health Organization (WHO) defines a pandemic as a global spread of an illness. This term is utilized when an outbreak affects a region and spreads through continents in sustained transmission networks. This way, the strength of the rate of infection (e.g., the virus reproduction number) and its geographical spread measure the severity of the disease (Schueler, 2020).

2.1. The COVID-19 Pandemic.

The COVID-19 pandemic is considered the most crucial global health emergency of the 21st century and the greatest challenge humans have faced since the Second World War. The outbreak of this new coronavirus started in a fish market in Wuhan, China, in December 2019. A few months later, SARS-CoV-2 became a global health emergency.

In Latin America, the Brazilian Ministry of Health reported the first positive case on February 25th, 2020. It rapidly spread through the major urban centers. The high rate of COVID-19 transmission aroused the curiosity of the scientific community as one of the most important factors to evaluate the danger of an infectious disease epidemic is the pathogens' transmissibility (Lima et al., 2020).

The first COVID-19 death in Brazil was reported on March 16th, 2020, and it rapidly spread throughout the country in the following months. The Information Center of the National Civil Registration is responsible for reporting the number of deaths using the transparency portal, which makes information available for the general public in the country. This agency reported 196,955 confirmed deaths with a direct link to COVID-19 or with a positive COVID-19 result in the country. These deaths are related to people who had a positive diagnostic for the PCR test (polymerase chain reaction test), which can detect the SARS-CoV-2 genetic material and assure the presence of the virus (França et al., 2020).

2.2. Road Safety.

Road safety is one of the major objectives of traffic engineering, given that daily trips should be safe, comfortable, and made at a fair time. Reducing the number of crashes and the number of injuries, especially the severe injuries and the fatalities, will provide complete urban and sustainable mobility. Road safety has become a challenge for developing countries. The constant increase of individual motorized transport makes it unsustainable to provide the citizens good traffic management. This occurs because the urban infrastructure of developing countries is not good, and transit may be deficient in most cities (Carmo et al., 2019).

In 2023, the WHO report showed that approximately 1.19 million road traffic deaths were in 2021. As of 2019, road traffic crashes are the leading killer of children and youth aged 5 to 29 years. A worrying fact is 9 in 10 deaths occur in low- and middle- income countries. Because of this serious road safety problem, the 2030 Agenda for Sustainable Development established a road safety goal, which consisted of halving the number of road safety fatalities and injuries throughout the world. Road crashes are burdensome to the countries, as they represent on average 3% of their gross domestic products (GDP). In addition, more than half of the road safety fatalities and crashes occur among vulnerable road users (pedestrians, cyclists, and motorcyclists).

Several factors influence crash occurrence, including environmental conditions (e.g., weather, visibility), road characteristics, vehicle design, human errors, and traffic volume. In some cases, crashes might be due to a combination of one or more of these items. The probability of crash occurrence increases with traffic volume and with specific road characteristics, which can be worsened in situations that depend on different congestion levels. In this case, the resulting crash severity tends to be reduced when vehicles collide at lower speeds (Saladié et al., 2020).

Islam et al. (2023) indicate that the effects of the COVID-19 pandemic on road accidents varied among the analyzed administrative regions, suggesting that local characteristics partially influenced the outcomes of traffic accidents.

2.3. Urban Mobility.

The new COVID-19 pandemic made authorities adopt a series of public health measures worldwide to contain the spread and reduce the transmission. Some measures were implemented to keep the population at home, including social distancing, closures of schools and non-essential services (e.g., bars, restaurants, retail stores), prohibiting gatherings (e.g., public events, sports events, concerts), and encouraging working from home. As a result of these social distancing measures, trip demand was affected. This leads to less vehicle traffic and, consequently, less congestion during peak hours. In addition, this situation results in reducing the number of transit passengers because these road users may be considered as vectors for the virus spread. In transit, it may be difficult to avoid the interaction with other passengers (De Vos, 2020; Chakraborty and Maity, 2020).

Social distancing may also influence the mode choice. The results of these choices vary: (1) people may be more willing to receive deliveries from online purchased products at home, which reduces the number of shopping trips; (2) car-owners may choose to drive more given that cars may "protect" them from other travelers; (3) reducing urban mobility may also influence the decisions of the transit operators, including reducing frequencies and capacities because of the reduced number of passengers. Therefore, several impacts can be observed (De Vos, 2020).

Several companies from the technology sector, to monitor trip changes as a result of the pandemic, engaged in helping public health authorities. They utilized several indexes (e.g., Google Maps) that may be useful for making critical decisions to fight the virus. Apple also made several reports available. These reports analyze movement trends and aim to provide information about changes that resulted from the measures to fight the COVID-19 pandemic (APPLE, 2021). In these reports, it was inferred that the overall reduction trend was concentrated on March, April, and May. These months had the most restrictions, and reopening plans were only implemented from June. This reopening was based on governmental measures that sanctioned executive orders, including authorizing non-essential services, implementing capacity restrictions, and reducing the number of working hours. Transit services had the greatest reduction in movement trends, and these indices kept reduced during the whole pandemic.

3. Method

3.1. Step 1: Defining the analysis period.

The analysis period was defined based on a literature review, which consisted of the beginning of the social distance measures and the implementations of the restrictions. Therefore, the months where these measures were in place were considered first. Consequently, the months before and after this analysis period in 2020 were also considered. In addition, the previous years (2011 to 2019) were used for comparison with the 2020 data.

3.2. Step 2: Collecting and preparing data.

The data used in this study are from the public database from the Brazilian Federal Highway Police (PRF). This data contains the crashes that occurred on Brazilian federal highways. Therefore, the data was cleaned, and inconsistencies were removed. Finally, the database was organized to meet the objectives of this research. It is important to highlight that the accident data pertain to incidents that occurred on the 75,257 kilometers of the federal highway network, excluding non-implemented highways and those under the jurisdiction of states and municipalities. This road network is crucial for the integration of cities and regions in a country with a population of 203.1 million and where the transportation matrix is highly reliant on roads.

3.3. Step 3: Data analysis.

After the procedures in the previous steps, an exploratory data analysis was conducted. The crash data were grouped by occurrence to obtain insights about the number of crashes per month, week, crash type, classification, phase of the day (e.g., daylight, night), highway type (e.g., undivided, divided), land use, and state in the country. Also, the PRF data were grouped considering the victims, i.e., it allowed the study per vehicle type, severity level, gender, and age. This is the most important step of this paper, where the analyses were systematized and presented graphically. In addition, discussions of the results were also presented.

4. Results

4.1. Defining the analysis period.

The analysis period used data from 2011 to 2020. The dates related to partial and total restrictions involve several factors, including laws, executive orders (national and at the state and city levels), and announcements from the local public health authorities. In these announcements, government officials would report the number of confirmed cases. This article shows the dates on which these restrictions were issued and lifted. Most of the states established more restrictive mobility measures at the beginning of the pandemic and, from May and mostly in June, some of these restrictions were eased. In this research, the effects of the COVID-19 pandemic on mobility were considered starting in March. In this month, the first COVID-19 deaths were registered in Brazil. Therefore, three major analysis periods were considered to compare the safety during the COVID-19 pandemic to the safety in the previous years: before the pandemic, during the restrictions, and when restrictions were eased.

4.2. Collecting and preparing data.

Some cleaning procedures were needed to use the data. For instance, crashes with missing data were excluded from the analysis. This resulted in removing 14 crashes from 2011, 19 crashes from 2012, 2 crashes from 2013, 19 crashes from 2014, and 11 crashes from 2015. No crash data was removed from 2016 to 2020.

4.3. Results and analysis.

Figure 1 shows the number of crashes that occurred between 2011 and 2020 on Brazilian federal highways. The figure shows a significant reduction in the total number of crashes in the last 10 years. For instance, there were 128,865 fewer crashes in 2020 when compared to 2011, which represents a reduction of approximately 67% in the number of crashes. Also, the last four years can be compared. From 2017 to 2018, there was a reduction of 23%; from 2018 to 2019, there was a reduction of 3%; and from 2019 to 2020, there was a reduction of 6% in the number of crashes.

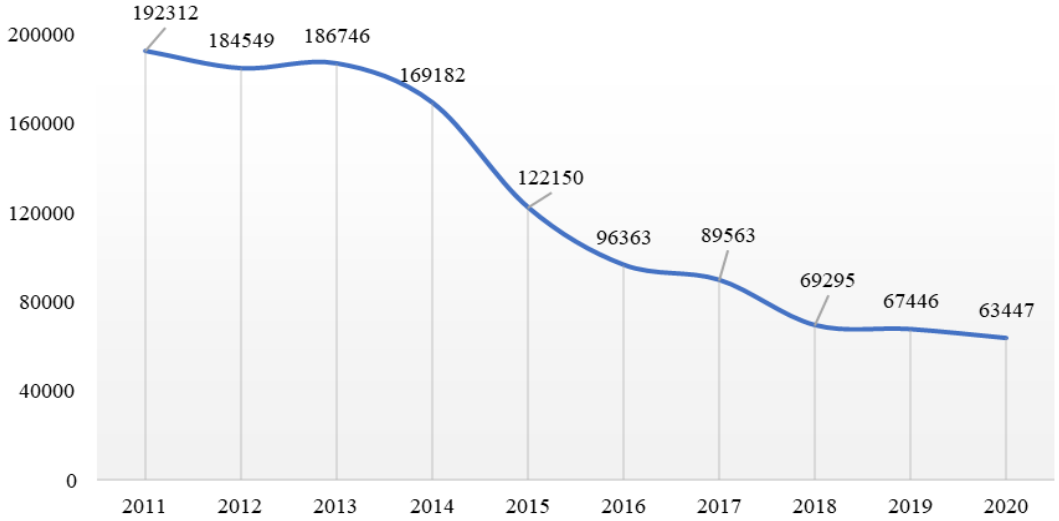


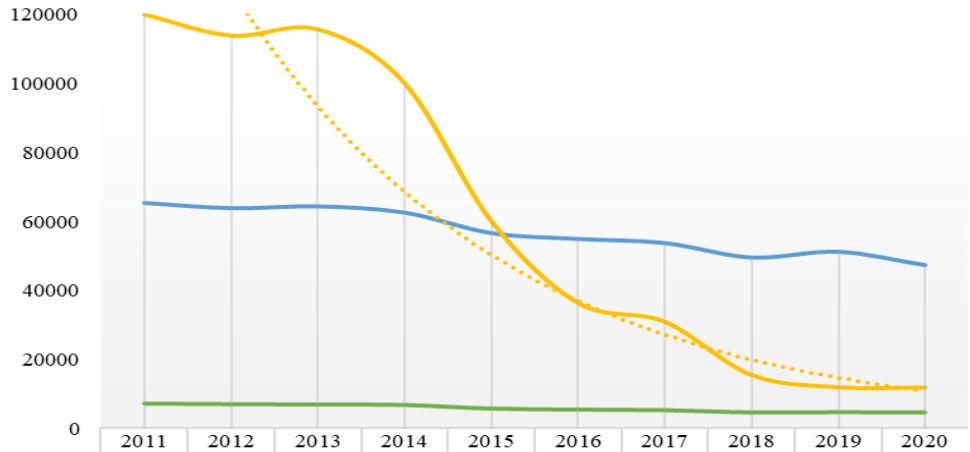
Figure 1: Number of crashes per year.
Source: (PRF, 2023).

The crashes might also be analyzed per month of the year. In general, there is little variation in the number of crashes per month. In 2011, there were between 15,000 and 18,000 crashes per month, whereas, in 2020, there were between 4,000 and 6,000 crashes per month. In 2011, July and December presented the greatest number of crashes and, in 2020, October and December were the months with the highest number of crashes. More crashes were observed on Fridays, Saturdays, and Sundays, which is expected because of the greater number of trips during weekends. Tuesdays, Wednesdays, and Thursdays presented the lowest number of crashes.

Figure 2 shows the crash classifications, which corresponds to the severity condition of the victims that were involved in the crash (i.e., fatalities, injuries, no injuries). The number of crashes shown in the figure might indicate crash types (in terms of severity level) that were effectively modified during the analysis period, and these modifications might have relationships with the COVID-19 pandemic.

Figure 2 provides several insights into the crash data. For example, Figure 2 shows a sharp decrease in the number of crashes after 2014. This is related to a reduction in the number of crashes with no injuries and, from data exploration, it seems to be corroborated by the implementation of the RC (Reporting Crashes) system. This system, which has been active since 2015, is an official government platform for registering crash occurrences with no injuries. In this system, users themselves register their involvement in crashes online. These users, who have been directly or indirectly involved in crashes, have up to 180 days after the crash to register it in the system.

The 2030 Agenda might also explain this reduction in the number of crashes because the number of crashes with no injuries reduced by 90%. For the crashes with fatalities, there was a reduction of 37% and, for the crashes with injuries, there was a reduction of 27%. These numbers can be considered promising given that the 2030 Agenda aims for a 50% reduction in these cases. These reductions correspond to an average reduction of 5% per year in crashes with fatalities and of 3% per year in crashes with injuries from 2011 to 2020. These reductions can also be observed for a more specific time frame (2016 to 2020). From 2016 to 2020, the number of crashes with fatalities reduced by 16%, the number of crashes with injuries reduced by 14%, and the number of crashes with no injuries reduced by 68%. For this time frame, the average crash reductions per year were kept constant.



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
with fatalities	7157	7002	6887	6741	5648	5355	5183	4505	4592	4520
with injuries	65252	63762	64268	62473	56570	54873	53699	49543	51183	47345
with no injuries	119903	113785	115591	99968	59932	36135	30681	15247	11671	11582

Figure 2: Number of crashes by classification (levels of severity).
Source: (PRF, 2023).

The number of crashes can also be analyzed considering how injured the victims were. The victims with no injuries represented the greatest share of the crash reduction. Between 2016 and 2020, there were average reductions of 5% for serious injuries, 4% for slight injuries, 14% for no injuries, and 4% for fatalities. Considering the gender of the victims, there was some masculine predominance in the number of crashes, whereas the number of female victims kept almost constant, but with a small reduction. In 2011, the number of crashes with at least one male represented approximately 80% of the total number of crashes, which is very different for the crashes with only females (16%). This trend was slightly modified through the years: the percentage of crashes with males decreased and the percentage of crashes with females increased. For example, in 2020, 72% of the total number of crashes involved males, and 21% involved females. These values were kept constant since 2016. Considering age, most of the victims are between 21 and 60 years old, which is expected as this is the age group of economically active people in the country. The other ages did not show reasonable levels of the number of crashes per year, i.e., they showed a slight trend of reduction.

In terms of crash types, collisions also represent the greatest share of crashes: the number of collisions is greater than the sum of all other types of crashes. In 2020, 6% of crashes involved pedestrians, 12% were rollover crashes, 57% were collisions, and 17% were run-off-road crashes. In 2019, 7% involved pedestrians, 11% were rollover crashes, 58% were collisions, and 15% were run-off-road crashes. These numbers are similar to 2018 and 2017, and there were no significant improvements. The crashes can also be analyzed considering vehicle types. Automobiles represented the greatest share of crashes, followed by motorcycles and buses, which represent a smaller share of the vehicle fleet in the country.

The crashes can be divided by phases of the day. Crashes during daylight reduced, whereas small variations were observed during the night, in the sunrise, and in the sunshine. In 2011, the difference between daylight and night consisted of approximately 50,000 crashes. This difference in 2020 was of 10,000 crashes. In terms of crashes per highway type, most of the crashes occur on undivided (i.e., two-lane two-way highways) and multilane highways. Multilane highways with more than three lanes in each direction presented the lowest number of crashes. Also, most of the crashes occur on urban roads, and this represents a difference of approximately 10,000 in comparison to crashes on rural roads.

To evaluate the impact of the COVID-19 pandemic on the safety of Brazilian multilane highways, several considerations were taken to segregate the data. Figure 3 represents the number of crashes in three different phases of 2020. The months in green represent no social restrictions, i.e., there were no confirmed COVID-19 cases in the country. The months in red show an increase in COVID-19 cases, and they are also associated with the first COVID-19 deaths and with the first restrictive measures (e.g., social distancing, quarantine, lockdown). Finally, the months in yellow represent the months when restrictions were eased. During this time, there were fewer restrictions for businesses and, in some cities, even total reopening.

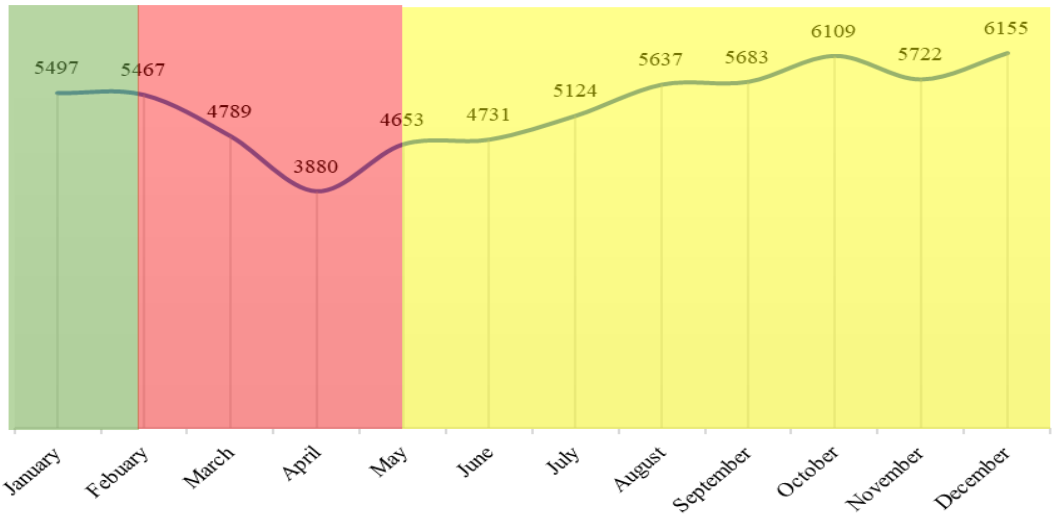
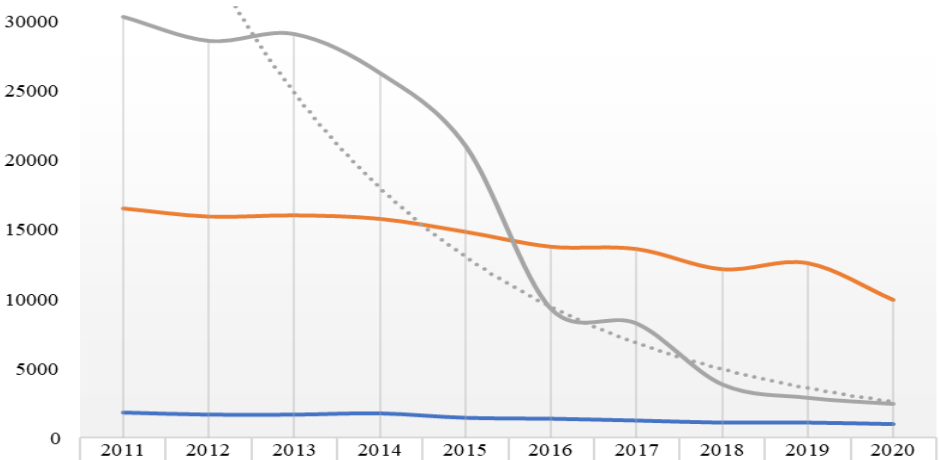


Figure 3: Number of crashes per month in 2020. The different colors indicate three periods: pre-COVID, during restrictions, and with eased restrictions.
Source: (CRC, 2020 and PRF, 2023).

These crashes segregated per month show that, in March, April, and May, there was a considerable decrease in the number of crashes. The same critical period was evaluated in the previous years. There was a reduction in crashes: between February and March, there was a reduction of 12%, between March and April, there was a reduction of 19%; and between April and May, there was an increase of 20%. These reductions and increases are not expected given that, in the previous years, the variations were around 3%.

Finally, the last graphical analysis shows the crashes per classification (i.e., fatalities, injuries, no injuries) in March, April, and May. Figure 4 shows a sharp decrease in the number of no injury crashes between 2011 and 2020, and a stabilization trend is observed. This is confirmed by the table on the bottom, which represents the crashes per classification in these months. Between 2016 and 2020, the number of fatalities reduced by 8%, the number of injured victims reduced by 7%, and the number of cases with no injuries reduced by 26%.



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
with fatalities	1824	1672	1675	1766	1445	1379	1248	1095	1099	987
with injuries	16462	15882	15969	15720	14790	13726	13563	12116	12549	9919
with no injuries	30256	28533	29022	26217	20979	9253	8201	3821	2854	2416

Figure 3: Number of crashes by classification (levels of severity) during the critical period.

Source: (PRF, 2023).

5. Final Remarks

Data from January 2011 to December 2020 was used in this study. Restrictive measures were expected to lead to a possible crash reduction on the federal highways. However, based on the analysis in this paper, this decrease was probably expected given the decreasing trend in the number of crashes. Some changes in the crash characteristics were also expected. These changes could eventually help to adopt more effective measures to reduce the number of crashes. However, it did not occur, and significant changes were not observed. These findings do not fully converge with what was observed by Shaik and Ahmed (2022) and Gong, Lu, and Yang (2023), and Islam et al. (2023), who found a consistent reduction in accidents when compared to the pre-pandemic phase.

In summary, it is assumed that road accidents resulting in minor injuries or no injuries may be affected by social lockdown policies, while road accidents resulting in serious or fatal injuries are not. It was found that, in recent years, there has been a reduction in traffic accidents in relation to the number of victims without injuries, which may be due to the mandatory safety items such as ABS brakes and airbags in vehicles. The reason behind the lack of reduction in crashes that resulted in fatalities or serious injuries, both before and during the mandatory social lockdown, is unclear. Reasons may include other factors such as a possible increase in traffic speeds due to reduced congestion, as this may increase the number of serious or fatal road accidents and therefore nullify the effect of reduced traffic. Other factors that may also have been contributors are a possible increase in the number of drivers under the influence of alcohol and drugs, economic pressures that force drivers to save time, changes in road safety advertising campaigns, the lower level of policing and enforcement of fines, in addition to the increase in the speed of heavy vehicle traffic, since this segment did not have a significant downward trend, that is, without any change in the volume of traffic.

Regarding the other analyses, most of them served as an informative method that sought to visualize possible factors that correlated to cause an impact on road accidents. So, as seen in the graphs, there was indeed a reduction in the fleet, not necessarily having a direct connection with the new coronavirus pandemic. This may represent that this reduction was already expected due to new implementations of laws such as containment measures at high speeds, even more evident signaling or even improvements in the conditions of federal roads and highways, being necessary here a greater understanding or more specific studies to specify the interference of COVID-19 in these data.

There was a reduction in the total number of crashes, as observed by Shaik and Ahmed (2022) and Gong, Lu and Yang (2023); however, these reductions were not so strong when compared to the previous three years. This shows that the COVID-19 pandemic has not significantly impacted road safety. In addition, between 2018 and 2019, the number of crashes with injuries increased by 5%, and the number of crashes with no injuries decreased by 5%. Between 2019 and 2020, the number of crashes with injuries reduced by 2%, and the number of crashes with no injuries increased by 1%. Although important COVID-19 effects on road safety in Brazilian federal highways were not identified within the scope of this study, it is advisable that future studies be conducted to assess medium and long-term effects.

The research evaluated road accident data to identify potential impacts of COVID-19, serving as an exploratory study to indicate trends or variations. However, limitations such as the lack of traffic data and georeferenced accident data conditioned the results and depth of the analyses.

References

Carmo, C. L., Raia Junior, A. A. (2019) “Segurança em rodovias inseridas em áreas urbanas na região sul do Brasil”, *Urbe: Revista Brasileira de Gestão Urbana* 3 (1), pp. 1-15.

Chakraborty, I., & Maity, P. (2020) “COVID-19 outbreak: Migration, effects on society, global environment and prevention”, *Science of The Total Environment* 728 (13882), pp. 1-7.

CRC - Central de Informações do Registro Civil Nacional. (2020) "Portal da Transparência do Governo Federal, Convênios por Estado/Município: banco de dados". Brasil. disponível em: <https://transparencia.registrocivil.org.br/especial-COVID#prazos>.

CONASS – Conselho Nacional de Secretários de Saúde. (2023) "COVID-19 – Normas estaduais". Brasil. disponível em: <https://www.conass.org.br/coronavirus/>.

De Vos, J. (2020) "The effect of COVID-19 and subsequent social distancing on travel behavior", *Transportation Research Interdisciplinary Perspectives* 5 (100121), pp. 1-3.

França, E. B., Ishitani, L. H., Teixeira, R. A., Abreu, D. M. X., Corrêa, P. R. L., Marinho, F., Vasconcelos, A. M. N. (2020) "Óbitos por COVID-19 no Brasil: quantos e quais estamos identificando?", *Revista Brasileira de Epidemiologia*, 23(1), pp. 1-7.

Islam, S.; Huq, A. S.; Iqra, S. H.; Tomal, R. S. (2023) Impacts of COVID-19 Pandemic Lockdown on Road Safety in Bangladesh. Sustainability, 15, 2675. https://doi.org/10.3390/su15032675.

Lima, D. L. F., Dias, A. A., Rabelo, R. S., Cruz, I. D., Costa, S. C., Nigri, F. M. N., & Neri, J. R. (2020) "Covid-19 in the State of Ceará: behaviors and beliefs in the arrival of the pandemic", *Ciência & Saúde Coletiva* 25 (5), pp. 1575-1586.

Apple. (2021)."Relatórios de tendências de movimentação". Disponível em: https://covid19.apple.com/mobility.

PRF – Polícia Rodoviária Federal. (2023) "Dados de Abertos da PRF". Brasil. disponível em: <https://www.gov.br/prf/pt-br/acesso-a-informacao/dados-abertos/dados-abertos-da-prf>.

Saladié, Ò., Bustamante, E., Gutiérrez, A. (2020) "COVID-19 lockdown and reduction of traffic accidents in Tarragona province, Spain", *Transportation Research Interdisciplinary Perspectives*, 8 (100218), pp. 1-10.

Schueler, P. (2020) "O que é uma pandemia", Fundação Oswaldo Cruz, Rio de Janeiro – RJ. Disponível em: <https://www.bio.fiocruz.br/index.php/br/noticias/1763-o-que-e-uma-pandemia>.

Shaik, M. E.; Ahmed, S. (2022) An overview of the impact of COVID-19 on road traffic safety and travel behavior. Transportation Engineering, 9. https://doi.org/10.1016/j.treng.2022.100119.

Gong, Y.; Lu, P.; Yang, X. T. (2023) Impact of COVID-19 on traffic safety from the "Lockdown" to the "New Normal": A case study of Utah. Accident Analysis and Prevention, 184. https://doi.org/10.1016/j.aap.2023.106995.

Acknowledgements

The authors thank the support of the Goiano Federal Institute to develop this work.