COLÓQUIO
REVISTA DO DESENVOLVIMENTO REGIONAL
FACCAT
ISSN 2318-180X

SEVERITY INDEX AND KERNEL DENSITY MAPS COMBINED TO IDENTIFY AND CHARACTERIZE TRAFFIC ACCIDENT RATIO IN SMALL CITIES

Cláudio Bellintane Júnior [1]
Thais de Cassia Martinelli Guerreiro [2]

Abstract
The unplanned growth of cities has also affected small municipalities, where mobility-related problems similar to those observed in large urban centers have emerged, albeit on a smaller scale but with comparable consequences, including numerous road traffic crashes, loss of life, and substantial social and economic costs. This study combines a traffic crash severity index with a Geographic Information System (GIS) through the development of Kernel Density Maps to identify crash hotspots in Novo Horizonte, a small municipality located in the state of São Paulo, Brazil. The adopted methodology consisted of data collection from 2018 to 2024, followed by data processing, calculation of the severity index, identification and georeferencing of critical locations within a GIS environment, and the generation of Kernel Density Maps. Motorcyclists, pedestrians, and cyclists accounted for 73.07% of all fatalities during the study period. Da Saudade Avenue exhibited the highest density hotspot, with substantial color variation along its entire length, indicating a high concentration of crashes across multiple segments and suggesting that this roadway should be prioritized for road safety interventions and improvements. Recommended measures include the closure of median openings at selected intersections, the implementation of raised pedestrian crossings, and the installation of automated speed enforcement devices. Such interventions have the potential to reduce traffic conflicts and enhance road safety for the entire population of Novo Horizonte.
Keywords: Road safety; traffic crashes; Geographic Information System (GIS); Kernel Density Mapping.

1 Introduction

The rapid growth of the urban population has led countries to seek a safe, sustainable, and efficient integration among different modes of transportation, with particular emphasis on the safety of pedestrians, cyclists, and motorcyclists, who are the most vulnerable road users (WHO, 2023).

Road traffic crashes constitute a critical public health issue that affects both transportation infrastructure and populations worldwide (Torbaghan et al., 2022). According to Vasconcellos (2005), road traffic crashes represent a significant problem in both developed and developing countries, although their characteristics vary across nations and regions.

In 2019, road traffic crashes were the leading cause of death among children and young people aged 5 to 29 years. The economically active population, comprising individuals aged 18 to 59 years, accounted for approximately two-thirds of all fatalities. Vulnerable road users (pedestrians, cyclists, and motorcyclists) represented more than half of all traffic-related deaths (WHO, 2023).

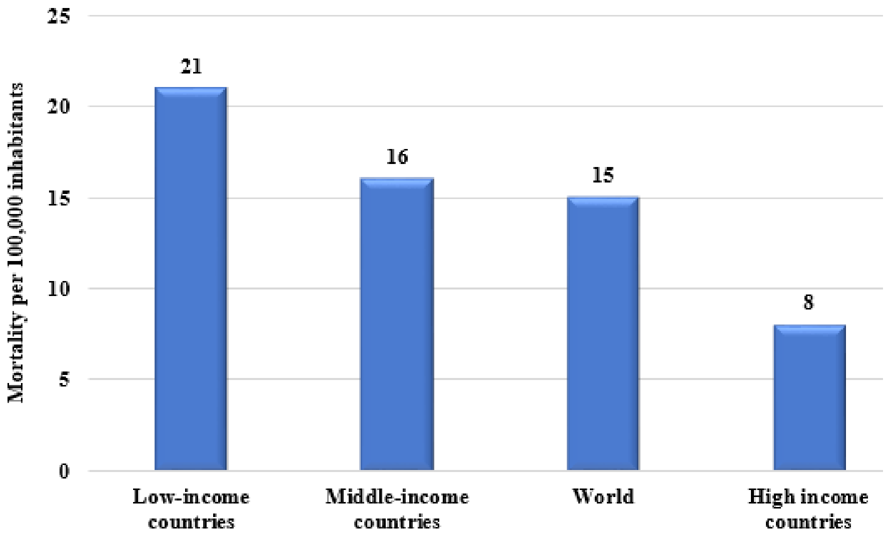
In 2021, an estimated 1.19 million people died in road traffic crashes worldwide,

[1] Mestre Master's Degree in Urban Engineering. Federal University of São Carlos (UFSCar). Chief Coordinator of the Traffic Management Unit of the Municipality of Novo Horizonte, São Paulo, Brazil. ORCID: https://orcid.org/0009-0003-1218-4302. Lattes Curriculum: http://lattes.cnpq.br/5192349156513503. E-mail: chebabejr@gmail.com
[2] Ph.D. in Science (USP/EESC). Professor in the Graduate Program in Urban Engineering at the Federal University of São Carlos (UFSCar). ORCID: https://orcid.org/0000-0001-5795-8875. Lattes Curriculum: http://lattes.cnpq.br/2650555786682535. E-mail: tcmguerreiro@ufscar.br

representing a 5% reduction compared to 2010, when approximately 1.25 million fatalities were recorded (WHO, 2023).

Considering the global scenario, in 2021 (see Figure 1), the average road traffic fatality rate was 15 deaths per 100,000 inhabitants. Low-income countries recorded a rate of 21 deaths per 100,000 inhabitants, while middle-income countries reported a rate of 16 deaths per 100,000 inhabitants. In contrast, high-income countries recorded 8 deaths per 100,000 inhabitants (WHO, 2023).

Figure 1 - Global Road Traffic Fatality Rate in 2021



Source: Prepared by the authors (2025), based on data from WHO (2023).

The disparity in road safety performance between Brazil and developed countries is significant (Carmo, 2019). According to data from DATASUS, 31,945 road traffic fatalities were recorded in Brazil in 2022. In addition, thousands of individuals suffered permanent disabilities, highlighting alarming figures that require effective mitigation measures (Brazil, 2022).

The proportion of fatalities among motorcyclists in Brazil increased substantially, rising from 8.3% in 2000 to 24.7% in 2008, and continued to increase, albeit at a slower pace, reaching 33.4% in 2017. Furthermore, the proportion of pedestrian fatalities was found to be strongly associated with municipal population size. In contrast, this relationship was not observed among automobile occupants and was even less evident among motorcyclists, whose mortality rates were considerably higher in municipalities with smaller populations (PROADESS, 2019).

In 2017, municipalities with up to 20,000 inhabitants exhibited the highest road traffic mortality rate, with 26.82 deaths per 100,000 inhabitants, whereas municipalities with more than 500,000 inhabitants recorded the lowest rate, at 12.86 deaths per 100,000 inhabitants (Prado et al., 2019). Average mortality rates also varied according to municipality size: 25 deaths per 100,000 inhabitants in small municipalities, 23 in medium-sized municipalities, and 16 in large municipalities (ONSV, 2019).

Carnevalli Fernandes (2018) emphasizes the importance of expanding theoretical and methodological discussions regarding small municipalities in Brazil, given their diversity and complexity, particularly because approximately 90% of Brazilian municipalities have populations of up to 50,000 inhabitants. According to the Brazilian Institute of Geography and Statistics (IBGE), small municipalities are defined as urban settlements with populations not exceeding 50,000 inhabitants.

Population data from the 2022 Census indicate that Brazil is composed of 5,568 municipalities. In addition, the Federal District and the State District of Fernando de Noronha are considered equivalent to municipalities according to the IBGE classification. Therefore, the total number of administrative units in the country is 5,570 (IBGE, 2023).

Of these, 3,860 municipalities, representing 69.30% of the total, have populations below 20,000 inhabitants. The population range between 20,000 and 50,000 inhabitants comprises 1,053 municipalities, corresponding to 18.90% of the total. Furthermore, 338 municipalities fall within the range of 50,000 to 100,000 inhabitants, representing 6.07% of all municipalities. Thus, 4,913 municipalities, equivalent to 88.20% of the total, have populations below 50,000 inhabitants. When considering municipalities with up to 100,000 inhabitants, the total increases to 5,251 municipalities, corresponding to 94.27% of all municipalities in Brazil (IBGE, 2023).

The municipality of Novo Horizonte (NH), the study area of this research, is a small-sized city located in the northwestern region of the state of São Paulo, with a population of approximately 39,000 inhabitants. Similar to large urban centers, Novo Horizonte faces challenges related to urban mobility and road safety, although on a smaller scale due to its population size. Between 2000 and 2022, the population of Novo Horizonte increased by 18.17%, while its vehicle fleet grew by an impressive 182.60% (see Table 1). However, the available road infrastructure has remained essentially unchanged. Consequently, the ratio of inhabitants per vehicle decreased from 2.83 in 2000 to 1.19 in 2022.

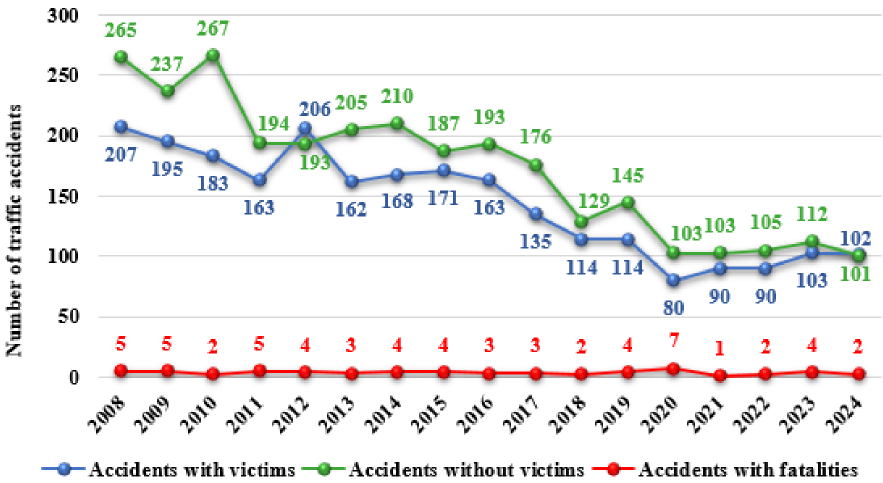
Table 1 - Population and Vehicle Fleet Growth in Novo Horizonte, São Paulo State, Brazil

	Year 2000	Year 2022	Growth (%)
Population	32,432	38,324	18.17%
Vehicle Fleet	11,443	32,338	182.60%

Source: Prepared by the authors (2025). Adapted from IBGE (2023) and SENATRAN (2023).

Despite the growth of the vehicle fleet, the municipality of Novo Horizonte, São Paulo State, Brazil, has exhibited a consistent downward trend in traffic crash occurrence. This pattern is illustrated in Figure 2, which presents the distribution of crashes by severity level from 2008 to 2024. The three crash severity categories are represented by distinct lines, allowing for a clear visualization of the trends observed throughout the study period.

Figure 2 - Traffic Crash Severity Trends (2008-2024)

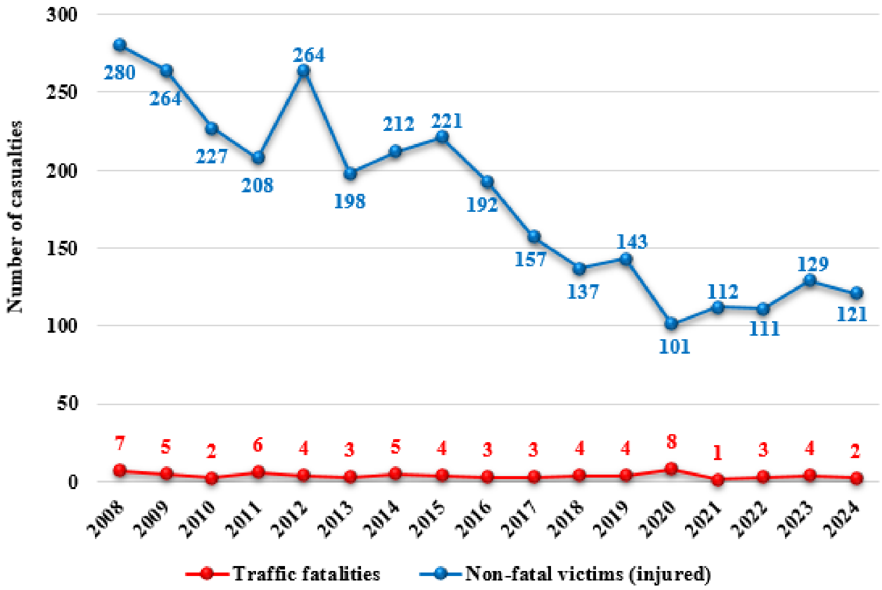


Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

A general downward trend in traffic crashes can be observed throughout the study period. Property-damage-only crashes decreased by approximately 61.89%, while injury crashes declined by 50.72%. These findings indicate a substantial reduction in the number of crash occurrences. Fatal crashes also exhibited an overall decreasing trend, despite a peak recorded in 2020. Over the analyzed period, this category experienced a reduction of 60%.

Regarding injured and fatal victims resulting from road traffic crashes, Figure 3 illustrates their evolution between 2008 and 2024. In 2008, the number of injured individuals totaled 280, and this figure gradually declined over subsequent years. Although a peak of 264 injured victims was recorded in 2012, the overall trend remained downward, with relatively minor fluctuations. By 2024, the number of injured victims had fallen to 121, representing a reduction of 56.78%. This positive trend reflects improvements in road safety conditions throughout the study period. With respect to fatalities, a peak was observed in 2020, when eight deaths were recorded. Nevertheless, over the entire period analyzed, the number of fatal victims decreased by 71.42%.

Figure 3 - Trends in Injured and Fatal Victims Resulting from Road Traffic Crashes (2008-2024)



Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

These findings reflect advances in road safety policies and increased public awareness regarding the importance of traffic safety over the years. Nevertheless, continued efforts remain essential to further reduce these figures.

Due to the limitations associated with obtaining physical crash reports for the period from 2008 to 2017, the present study was restricted to a seven-year interval covering the period from 2018 to 2024. This temporal delimitation is justified by the transition to online reporting of road traffic crashes during this period, which facilitated data accessibility and collection for the purposes of this analysis. Following data collection, processing, and systematization, a severity index expressed in Standard Severity Units (SSU) was employed to identify critical locations and roadway segments according to the severity of each road traffic crash.

The SSU is a metric used to quantify the severity of crashes at a given location, facilitating comparisons and the prioritization of road safety interventions. Severity is calculated by summing the products of the number of crashes classified by severity level and the corresponding weights assigned to each crash category, which reflect their relative severity (DENATRAN, 1987).

Following the preliminary identification of areas with the highest frequency of severe crashes, a spatial location analysis was conducted to visualize critical areas and roadway segments. This procedure aimed to enhance the analysis and direct attention toward locations requiring specific road safety interventions.

Lasmar et al. (2018) highlighted the importance of the Quantum GIS (QGIS) software for heat map analysis and the application of severity-based calculations to identify and classify critical traffic crash locations.

Therefore, the general objective of this study is to identify and characterize road traffic crashes that occurred between 2018 and 2024 within the jurisdiction of the municipality of Novo Horizonte, São Paulo State, Brazil. To achieve this objective, the following specific objectives were established:

- To characterize road traffic crashes;
- To georeference road traffic crashes in order to facilitate the identification of roadways and intersections with the highest severity incidence;
- To identify critical crash locations through the calculation of the severity index and the use of the QGIS tool known as the Kernel Density Map.

In light of the above, this study highlights the relevance of road safety research in small municipalities, which currently account for 88.20% of Brazilian cities. The importance of identifying critical crash locations and roadway segments through the calculation of severity indices and the application of Geographic Information Systems (GIS) is emphasized, as these tools can support more detailed and effective decision-making processes in road safety management.

2 Literature Review

2.1 Road Safety

Road traffic fatalities constitute a major public health problem affecting countries worldwide, particularly those with low and middle incomes. Globally, approximately 1.3 million people lose their lives and 50 million suffer injuries each year as a result of road traffic crashes (WHO, 2021).

The economic costs associated with road traffic crashes are substantial, ranging from 1% to 2% of a country's Gross Domestic Product (GDP): approximately 1% for low-income countries, 1.5% for middle-income countries, and 2% for high-income countries. These costs include property losses, hospital expenses, and expenditures related to traffic control devices and infrastructure repairs. In 2023, the global GDP was estimated at US$112.6 trillion, resulting in crash-related costs of approximately US$1.7 trillion, based on an average rate of 1.5% (Ferraz et al., 2023).

Between 2010 and 2019, road traffic crashes in Brazil generated an estimated economic impact of approximately BRL 3.8 billion, adjusted to May 2023 values using the Broad National Consumer Price Index (IPCA). This amount corresponded to approximately 1.7 million hospital admission authorizations (AIHs). These figures refer exclusively to Brazil's Unified Health System (SUS) and affiliated hospitals; therefore, costs associated with private healthcare facilities were not included (IPEA, 2023).

Ferraz et al. (2023) emphasize the importance of developing public policies based on coordinated actions in six key areas, technically known as the “Six Es,” for the effective reduction of road traffic crashes: Engineering, Education, Enforcement, Engagement, Environment, and Evaluation.

According to WHO (2023), reducing road traffic deaths and injuries requires mobility policies that protect vulnerable road users, improvements in road infrastructure, regulations that ensure safer vehicles, and standards that encourage responsible behavior, such as complying with speed limits, avoiding mobile phone use while driving, refraining from driving under the influence of alcohol, and consistently using seat belts and helmets. Speed management in areas with high concentrations of vulnerable road users is essential to reducing both the occurrence and severity of road traffic crashes. The organization also highlights the importance of civil society participation in developing solutions and emphasizes that rapid emergency response and strengthened rehabilitation services are fundamental components of post-crash care.

To reduce fatalities and the severity of injuries resulting from road traffic crashes, several countries and cities around the world have adopted the Vision Zero program, which is based on the Safe System approach. Under this framework, road safety takes precedence over mobility in terms of priority, promoting a transportation system that prioritizes people rather than vehicles (Ferrer, 2017).

Another policy increasingly adopted to reduce road traffic crashes is Traffic Calming. According to Ferrer (2017), Traffic Calming is a broad term used to describe engineering strategies aimed at reducing vehicle speeds. Gonzalo-Orden (2018) argues that Traffic Calming measures are essential for decreasing both vehicle speeds and traffic volumes, thereby reducing the risk of road traffic crashes.

In Brazil, efforts to reduce fatalities and the severity of injuries caused by road traffic crashes were reinforced in 2023 with the publication of the third edition of the National Plan for the Reduction of Traffic Deaths and Injuries (PNATRANS) by the National Secretariat for Traffic (SENATRAN). Compared with its first edition, the plan reaffirms that actions should be based on six strategic pillars: traffic safety management, safer roads, vehicle safety, traffic education, post-crash victim care, and regulation and enforcement (Brazil, 2023).

2.2 Road Traffic Crashes

The term *traffic accident* was officially replaced by *road traffic crash* according to the definition established by the Brazilian Association of Technical Standards (ABNT) through Brazilian Standard NBR 10697 (ABNT, 2020), published on November 16, 2020.

Ferraz et al. (2023) emphasize the importance of correctly understanding the different types of road traffic crashes in order to support more effective decision-making aimed at reducing crash occurrence.

The implementation of the PARE Program in 2002, an initiative of the Brazilian federal government, highlighted the importance of research for identifying crash-related factors and planning corrective interventions, with a focus on identifying vulnerable locations and assessing the severity of road traffic crashes (Brazil, 2002).

When analyzing crash occurrence across different locations, it is essential to consider the criteria used to identify and classify problematic areas, such as intersections and roadway segments. Various parameters may be employed for this purpose, including the total number of crashes, severity indices, and associated costs. It is important to note that relying solely on the total number of crashes without considering their severity may lead to misleading conclusions, as property-damage-only crashes and fatal crashes would be treated equivalently (Ferraz et al., 2023).

According to Teodoro, Alcântara, and Barbosa (2014), it is feasible to apply the methodology presented in the PARE Program manual to identify critical crash locations and roadway segments in conjunction with georeferencing tools and Kernel intensity estimators, since both approaches yielded similar results.

2.3 Geographic Information Systems (GIS)

Ouni and Belloumi (2018) explain that road traffic crashes are currently analyzed using spatial distribution techniques, which provide a more detailed understanding of crash patterns by relating geographic locations to traffic occurrences.

According to Torbaghan et al. (2022), the use of Geographic Information Systems (GIS) contributes to a better understanding of the actual crash environment and supports the adoption of more effective strategies for mitigating crash risks. This is because the primary contributing factors exhibit spatial variability associated with climate conditions, traffic volumes, and roadway characteristics. Ferreira (2017) states that GIS is a tool that enables the integration of statistical crash data with their geographic locations, allowing the creation of thematic maps that facilitate the identification of areas with high crash incidence.

Carvalho and Câmara (2004) identify Kernel Estimation as one of the main GIS applications in road traffic crash studies. This method represents and analyzes point patterns by estimating point density within a study area. Based on probability density functions, the estimator provides an effective approach for analyzing spatial point phenomena and assessing process intensity within specific regions.

Heat maps enable the visual representation of point density and are useful for identifying clusters and areas with high concentrations of a particular activity. Their construction is based on the analysis of data distribution across a given region. Consequently, more intense colors indicate a higher concentration of the phenomenon under investigation (Lasmar et al., 2018).

Kernel Density Estimation (KDE) is an effective tool for identifying crash clusters by calculating the density of events surrounding each point based on the distance between neighboring observations. This process generates a continuous surface representing risk areas through spatial interpolation (Audu et al., 2021).

According to the study conducted by Rabbani et al. (2019), the Kernel Density Estimation method for traffic crash detection analyzes the density of crash occurrences within specific areas, allowing the identification of regions with elevated risk. The fundamental principle of this technique involves calculating the density of nearby crash points while considering their distance from a reference location.

This technology assists in transforming raw data into useful information through the identification of areas with high crash incidence, commonly referred to as hotspots. Consequently, it supports the formulation of public policies and the optimization of resources dedicated to crash mitigation efforts (Bezerra, Ferreira, & Da Silva, 2020).

3 Methodology

Traffic crash data occurring within the jurisdiction of the municipality of Novo Horizonte, São Paulo State, Brazil, were collected for the period between 2018 and 2024 through the online Police Report System maintained by the Military Police of the State of São Paulo. Subsequently, a data quality assessment was conducted to identify and correct inconsistencies, particularly those related to the locations where road traffic crashes occurred.

The data were then processed using Microsoft Excel spreadsheets, and their systematization was carried out through tables, charts, and summary spreadsheets, facilitating the characterization of crash attributes such as injury and non-injury crashes, pedestrian crashes, days of the week, and times of occurrence, among others.

Following data systematization, the severity index equation established by the PARE Program (Brazil, 2002) was applied to calculate the Standard Severity Units (SSU), which were used to classify critical locations according to crash severity. This approach enables the identification of specific roadway segments or intersections that should be prioritized for safety improvements.

The SSU method is used to assess crash severity at different locations, such as roadway segments and intersections. The calculation consists of the weighted sum of crash types according to their severity level. The weights assigned are: 1 for property-damage-only crashes, 4 for injury crashes, 6 for pedestrian crashes, and 13 for fatal crashes (Brazil, 2002; DNIT, 2009), as shown in Equation 1:

$$SSU = SV.1 + CV.4 + AT.6 + VF.13 \qquad (1)$$

Where:

SSU = Standard Severity Units (severity-weighted crash index);

SV = Number of property-damage-only crashes;

CV = Number of injury crashes;

AT = Number of pedestrian crashes;

VF = Number of fatal crashes.

After data processing and systematization, the crash records were georeferenced using the latitude and longitude coordinates provided in the police reports, taking into account corrections made to the inconsistencies identified in some records. This georeferencing procedure enabled the spatial distribution analysis of road traffic crashes using the open-source software QGIS, version 3.34.8-Prizren.

The development of the Kernel Density Map based on traffic crash data required a specific methodology that incorporated crash severity. Crash records were organized into a CSV file format, which is compatible with QGIS. The dataset included information regarding latitude, longitude, and crash severity.

Prior to importing the data into QGIS, it was necessary to replicate crash points according to their severity level. Under the adopted methodology, the coordinates of property-damage-only crashes were replicated once, resulting in a single point. Injury crashes were replicated four times, generating four points. Pedestrian crashes were replicated six times, while fatal crashes were replicated thirteen times. This replication procedure was performed in Microsoft Excel by creating additional rows corresponding to each replication, ensuring that the dataset was properly prepared for subsequent analysis within QGIS.

Following data preparation, the resulting file was imported into QGIS, where the heat map was generated using the Kernel Density Estimation (KDE) tool.

The coordinate reference system adopted was SIRGAS 2000 / UTM Zone 22S. To aggregate road traffic crashes within the KDE analysis, a quartic kernel function was selected due to its ability to model continuous surfaces from discrete datasets, such as point locations representing crash occurrences. To represent crash incidence, a search radius of 100 meters was applied, while the X and Y cell sizes were set to 1 meter in order to achieve a higher-resolution visualization. The resulting data were subsequently classified into categories. Additional parameters required for heat map generation were automatically configured by QGIS, as detailed below.

I. Band Rendering:

i. Rendering Type: A singleband pseudocolor rendering technique was applied.

ii. Selected Band: Band 1 (Gray).

iii. Threshold Values:

- Minimum Value: 0
- Maximum Value: 55

II. Minimum and Maximum Value Settings:

i. Interpolation Method: The discrete interpolation method was employed for data classification.

ii. Label Precision: 0.

iii. Color Gradient: Spectral color ramp with inverted colors.

- Range from 0 to 11: Blue
- Range from 11 to 22: Green
- Range from 22 to 33: Yellow
- Range from 33 to 44: Orange
- Values above 44: Red

The adoption of this standardization enabled the critical transition zone for the seven-year study period to be highlighted in red whenever the severity index reached at least 44 SSU. The label precision was set to 0 (zero) because decimal places are unnecessary, given that road traffic crash records are represented by whole numbers.

Band 1 (Gray) displays the first raster band using a grayscale palette. This feature supports analyses that require simplified data visualization, such as identifying areas with varying intensities of a given phenomenon. The X pixel size refers to the width of each pixel along the horizontal axis (X-axis), whereas the Y pixel size refers to the height of each pixel along the vertical axis (Y-axis) (QGIS, 2024).

Singleband pseudocolor rendering with an inverted spectral color ramp is a raster visualization technique in QGIS that applies a color scale to a single data band. This visualization method includes a color transition ranging from blue to red, passing through green, yellow, and orange, thereby representing numerical values through an intuitive visual scale. The inverted color ramp means that the color palette is applied in reverse order, emphasizing areas with higher intensity values through warmer colors (QGIS, 2024).

Accordingly, the color sequence was organized as follows: blue, green, yellow, orange,

COLÓQUIO
REVISTA DO DESENVOLVIMENTO REGIONAL
FACCAT
ISSN 2318-180X

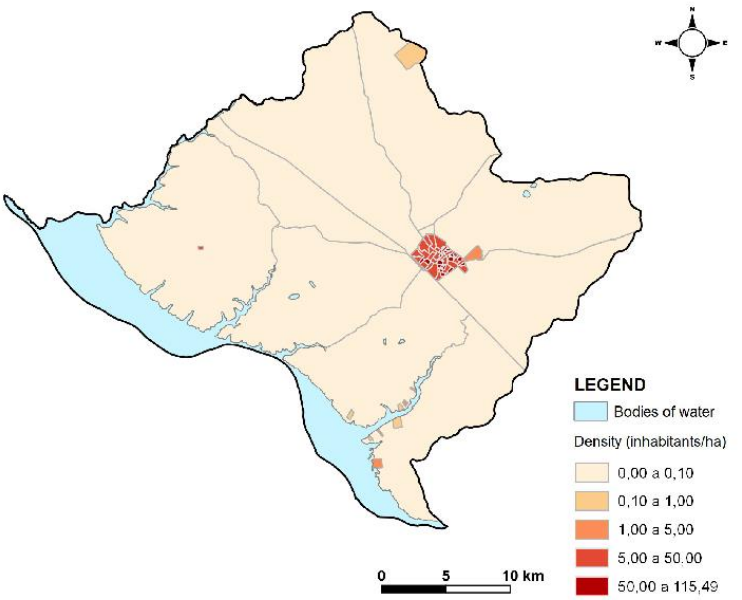
and red. The heat map color progression was defined from blue to red, with red representing the highest concentration of road traffic crashes. The choice of the discrete interpolation method was based on its ability to provide a clearer visualization of crash severity levels. This approach facilitates the identification of areas classified as severe, moderate, or low severity, enabling a more intuitive and effective interpretation of the data. The simplified representation of different severity levels contributes to a better understanding of the results.

3.1 Study Area Characterization

The municipality of Novo Horizonte, located in the northwestern region of the State of São Paulo, Brazil, is situated at latitude 21°28′05″ South and longitude 49°13′15″ West, at an elevation of 447 meters above sea level. The municipality belongs to the administrative region of Catanduva and has a population of 38,324 inhabitants, with a population density of 41.13 inhabitants per square kilometer (IBGE, 2023).

Novo Horizonte covers a territorial area of 931.74 km², ranking 48th among municipalities in the State of São Paulo and 1,522nd among Brazilian municipalities. Its urbanized area corresponds to 8.98 km², representing 0.96% of the municipality's total land area (IBGE, 2023). Figure 4 illustrates the municipality of Novo Horizonte, São Paulo State, Brazil.

Figure 4 - Population Density and Land Use Occupation

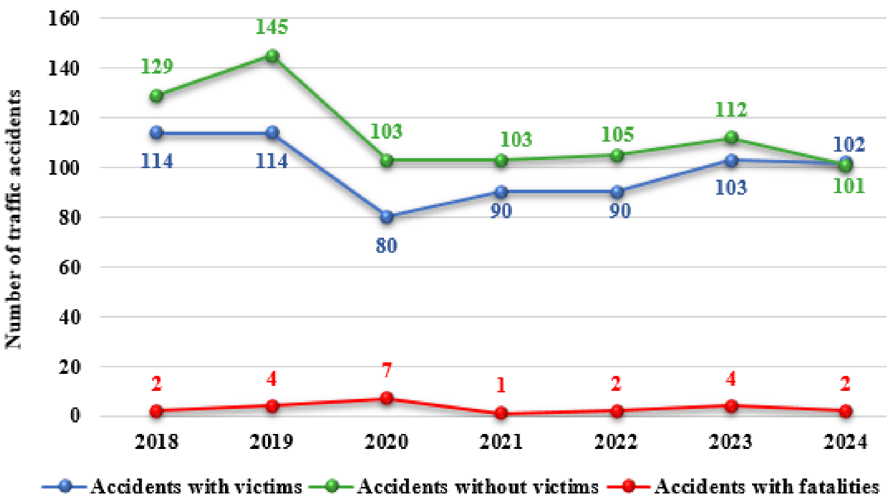


Source: IBGE (2023).

4 Data Analysis

Between 2018 and 2024, a total of 1,513 road traffic crashes were recorded within the jurisdiction of the municipality of Novo Horizonte, São Paulo State, Brazil. Of these, 798 were property-damage-only crashes, 693 were injury crashes, and 22 were fatal crashes. Figure 5 presents the evolution of road traffic crashes by severity category during the seven-year study period.

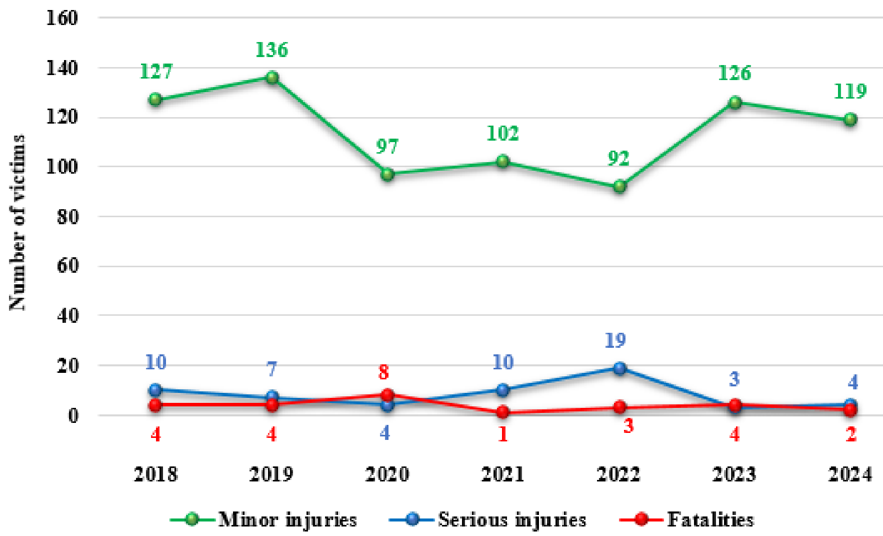
Figure 5 - Traffic Crash Severity by Category (2018-2024)



Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

The average number of road traffic crashes per day was 0.59. Considering that 2020 and 2024 were leap years, the study period comprised a total of 2,557 days. Overall, 882 victims were involved in road traffic crashes, distributed according to the following severity levels: 2.95% fatalities, 6.46% serious injuries, and 90.59% minor injuries. Figure 6 presents the historical trend in the number of injured and fatal victims from 2018 to 2024.

Figure 6 - Trends in Injured and Fatal Victims Resulting from Road Traffic Crashes (2018-2024)



Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

A discrepancy can be observed between the number of fatalities presented in Figures 5 and 6. This difference arises because Figure 5 includes only the number of fatal crashes, whereas Figure 6 presents the number of individuals who died either at the crash scene or within 30 days following the occurrence. It should also be noted that a single fatal crash may result in more than one fatality.

Considering the period from 2018 to 2024, Table 2 shows that motorcyclists accounted for 38.46% of all fatalities, followed by pedestrians (26.92%) and passengers (23.08%). Vulnerable road users (motorcyclists, pedestrians, and cyclists) represented 73.07% of all traffic-related deaths recorded during the study period.

Table 2 - Distribution of Fatal Victims by Road User Category (2018-2024)

Fatal Victim Category	Year 2018	Year 2019	Year 2020	Year 2021	Year 2022	Year 2023	Year 2024	Total
Driver	0	0	1	0	0	0	0	1 (3,85%)
Passenger	3	0	1	0	2	0	0	6 (23,08%)
Cyclist	0	0	2	0	0	0	0	2 (7,69%)
Pedestrian	0	0	3	1	0	2	1	7 (26,92%)
Motorcyclist	1	4	1	0	1	2	1	10 (38,46%)
Total	4	4	8	1	3	4	2	26

Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

Table 3 presents the distribution of fatalities by age group. The 18-29 age group accounted for the highest proportion of deaths during the seven-year study period, representing 38.46% of all fatalities. This was followed by the 30-39 age group, which accounted for 23.07% of the total fatalities.

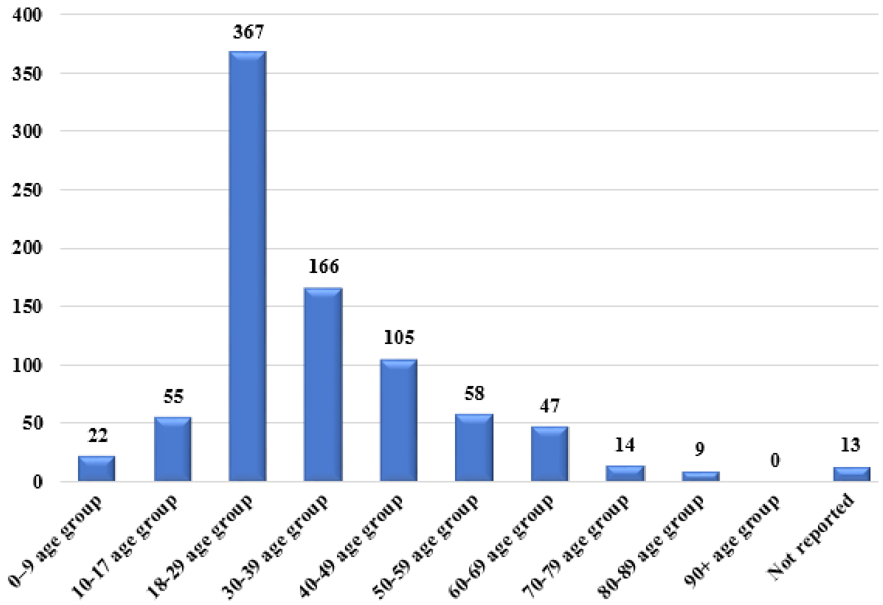
Table 3 - Age Distribution of Fatal Victims (2018-2024)

Age Group	Number of Fatalities	Percentage
0-9 years	1	3,85%
10-17 years	3	11,54%
18-29 years	10	38,46%
30-39 years	6	23,07%
40-49 years	2	7,69%
50-59 years	1	3,85%
60-69 years	1	3,85%
70-79 years	2	7,69%
80-89 years	0	0,00%
90 years or older	0	0,00%
Not reported	0	0,00%
Total	26	100%

Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

Non-fatal victims were also predominantly concentrated in the 18-29 age group, as illustrated by the column chart shown in Figure 7.

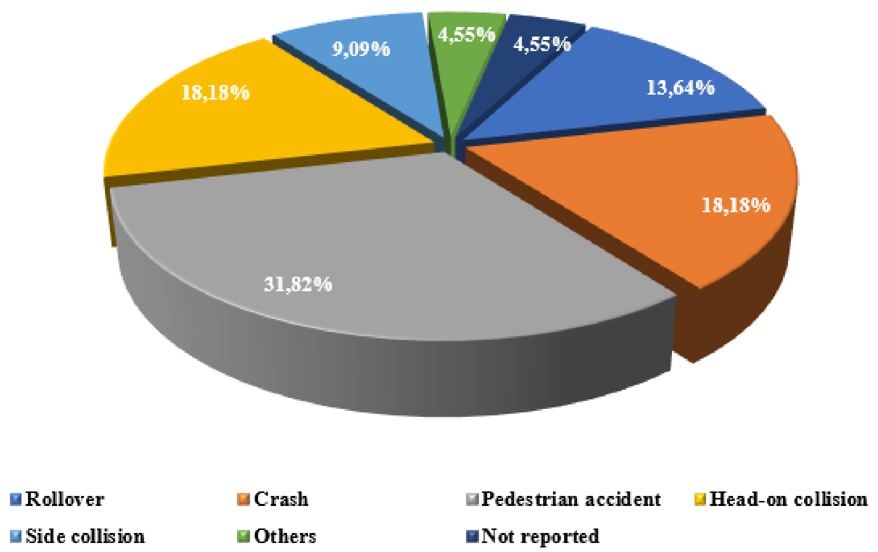
Figure 7 - Age Distribution of Injured Victims (2018-2024)



Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

Figure 8 illustrates the types of road traffic crashes that resulted in fatalities between 2018 and 2024, providing a clear visual representation of the proportion associated with each crash type.

Figure 8 - Distribution of Crash Types Resulting in Fatalities (2018-2024)



Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

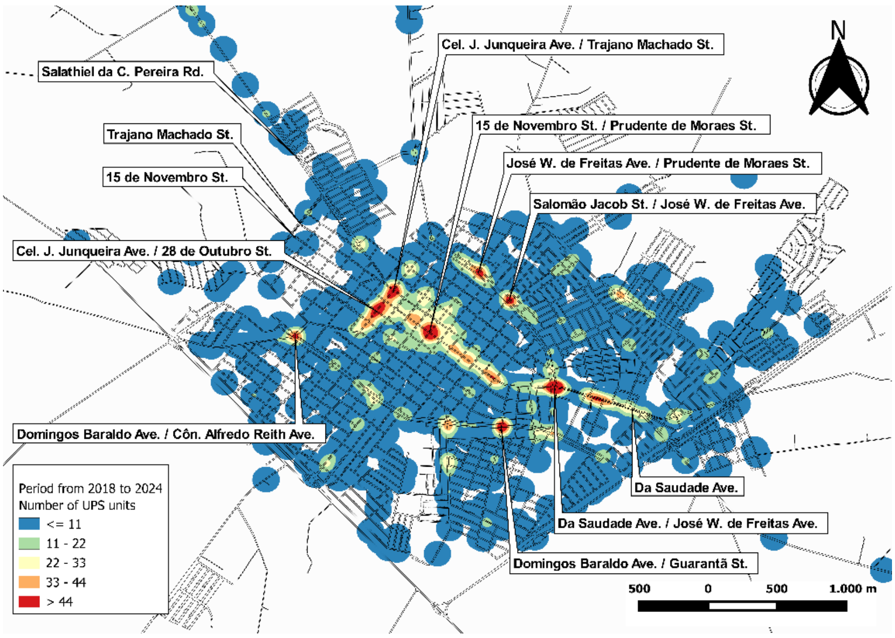
To better understand the spatial distribution of road traffic crashes across the entire road network of Novo Horizonte, São Paulo State, Brazil, the QGIS software was employed. Using the Kernel Density Estimation (KDE) tool, a heat map of traffic crashes was generated.

The interpretation of the heat map reveals different levels of crash severity represented by a color scale ranging from blue, associated with the lowest severity levels, to red, corresponding to the most severe crash occurrences. The adopted color progression follows the sequence blue, green, yellow, orange, and red, indicating increasing levels of severity and concentration of crash events within the 100-meter search radius used in the analysis.

Areas highlighted in red represent locations with the highest concentration and severity of road traffic crashes, characterizing critical hotspots that require priority road safety interventions. In contrast, orange and yellow areas indicate intermediate levels of severity, requiring monitoring and preventive actions. Green areas exhibit lower crash intensity, while blue zones correspond to locations with relatively low crash incidence and severity. This color-based classification facilitates the identification of critical areas and supports the prioritization of urban planning and road safety measures.

Figure 9 presents the spatial distribution of road traffic crash severity throughout the seven-year study period.

Figure 9 - Heat Map of Road Traffic Crash Severity in Novo Horizonte, São Paulo State, Brazil (2018-2024)



Source: Prepared by the authors (2025).

Based on these findings, the relevant authorities can develop strategic plans aimed at improving road safety, with a particular focus on reducing crash severity along the critical roadways and locations identified in this study.

COLÓQUIO
REVISTA DO DESENVOLVIMENTO REGIONAL
FACCAT
ISSN 2318-180X

5 Discussion of Results

Considering the year 2022, the total of 31,945 fatalities recorded nationwide highlights the severity of the road safety crisis in Brazil. At the state level, 4,847 deaths were reported, while at the municipal level, three fatalities were recorded in Novo Horizonte. Particular attention should be given to the high number of deaths among motorcyclists (Table 4). This road user group faces significant risks due to its greater exposure to traffic environments and increased physical vulnerability in the event of a road traffic crash.

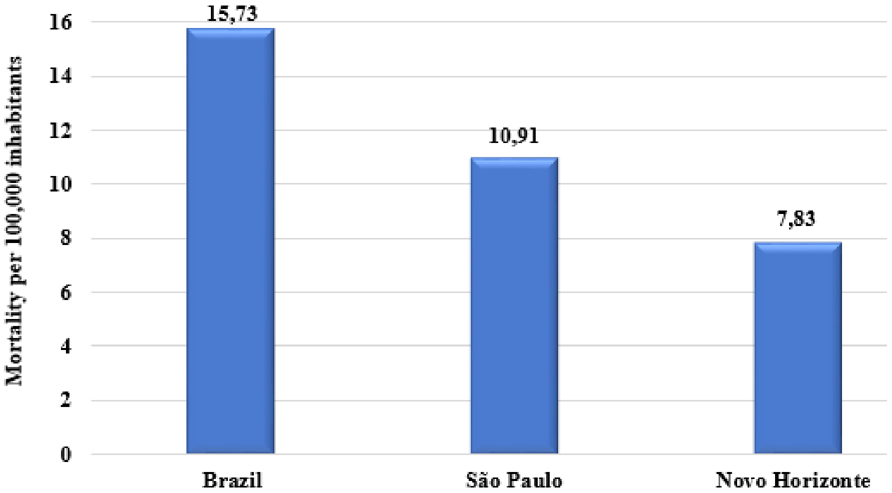
Table 4 - Traffic Fatalities by Administrative Level in 2022

ICD-10 Group	National Level - Brazil	State Level - São Paulo	Municipal Level - Novo Horizonte
Pedestrian injured in a transport crash	5.715	1.113	0
Cyclist injured in a transport crash	1.358	278	0
Motorcyclist injured in a transport crash	11.182	1.532	1
Occupant of a motorized tricycle injured in a transport crash	33	4	0
Car occupant injured in a transport crash	6.899	924	2
Pickup truck occupant injured in a transport crash	328	32	0
Occupant of a heavy transport vehicle injured in a transport crash	819	111	0
Bus occupant injured in a transport crash	138	11	0
Other land transport crashes	5.473	842	0
Total Fatalities	31.945	4.847	3

Source: Prepared by the authors (2025). Adapted from Brazil (2022) and Novo Horizonte/SP (2023).

The average road traffic fatality rate per 100,000 inhabitants is a fundamental indicator for assessing road safety performance across different territorial scales, as illustrated in Figure 10.

Figure 10 - Road Traffic Fatality Rate per 100,000 Inhabitants in 2022



Source: Prepared by the authors (2025), based on data from DATASUS and Novo Horizonte/SP (2023).

The national average fatality rate of 15.73 deaths per 100,000 inhabitants is a matter of concern and highlights the need for urgent road safety interventions. The rate of 10.91 recorded for the State of São Paulo, although lower than the national average, still indicates the necessity for effective safety strategies. In contrast, the rate of 7.83 observed in the municipality of Novo Horizonte suggests a relatively safer environment; however, it also underscores the importance of maintaining and further improving current road safety conditions.

Table 5 presents the roadways with the highest traffic crash severity indices between 2018 and 2024. The table provides a comprehensive overview of crash severity across different roadways and contributes to the identification of critical locations requiring immediate and effective road safety interventions.

Table 5 - Locations with the Highest Traffic Crash Severity Indices (2018-2024)

Location	Fatal Crashes (VF)	Injury Crashes (CV)	Property -Damage-Only Crashes (SV)	Pedestrian Crashes (AT)	Total Crashes	Total SSU
Da Saudade Avenue	1	45	43	1	90	242
Salathiel da Costa Pereira Municipal Road	5	16	14	0	35	143
15 de Novembro Street	1	11	30	5	47	117
José Wilibaldo de Freitas Avenue	0	22	21	1	44	115
Domingos Baraldo Avenue	0	19	30	1	50	112
Coronel Joaquim Junqueira Avenue	0	14	21	1	36	83
Professor Miguel Brabo Municipal Road	1	13	9	0	23	74
Trajano Machado Street	0	8	29	2	39	73
Jorge Ismael de Biasi Avenue	2	5	3	1	11	55
Guido Della Togna Avenue	1	4	13	2	20	54
José Wilibaldo de Freitas Ave. / Da Saudade Ave. Intersection	0	8	16	1	25	54
Ângela Blaso Segreto Avenue	0	11	9	0	20	53

Source: Prepared by the authors (2025), based on data obtained from Military Police crash reports.

Da Saudade Avenue is the roadway with the highest traffic volume in the municipality, due to the concentration of businesses, educational institutions, and its function as the primary gateway for entering and leaving the city. The avenue features adequate horizontal and vertical traffic signage, a posted speed limit of 40 km/h, and a high volume of both light and heavy vehicles throughout the day.

15 de Novembro Street and Trajano Machado Street constitute the main traffic corridors within the downtown area. These roadways are characterized by a high concentration of commercial activities, intense pedestrian movement, and access to important urban facilities. Both

streets have a posted speed limit of 30 km/h, extensive traffic signage, and several pedestrian crossings, consistent with the high levels of urban and commercial activity.

José Wilibaldo de Freitas Avenue and Domingos Baraldo Avenue, commonly referred to as the municipality's riverside avenues, play an important role in urban traffic distribution and accommodate numerous businesses and commercial establishments. Both avenues experience heavy traffic volumes and are separated by a stream, forming a major circulation corridor that provides access between different areas of the city.

Coronel Joaquim Junqueira Avenue stands out as the municipality's primary gastronomic corridor and is also home to important urban facilities, including the ETEC School, the municipal hospital, a fuel station, and various commercial establishments. The avenue features a physical central median, adequate traffic signage, and substantial vehicular and pedestrian traffic along its entire length.

Jorge Ismael de Biasi Avenue is located in the most populous neighborhood of the municipality and serves an important local connectivity function. The avenue contains a physical central median along part of its length, while other sections are separated only by raised pavement markers and horizontal road markings. The roadway accommodates commercial establishments and also serves students and guardians traveling to José Luis Tomazi Municipal School. Although the avenue has adequate traffic signage and a posted speed limit of 40 km/h, the pavement is deteriorated and requires resurfacing.

Guido Della Togna Avenue provides important access to SP-304 Highway and concentrates large companies, educational institutions, and public agencies, including the Department of Water and Electric Energy (DAEE) and the Rural Electrification and Development Cooperative of the Novo Horizonte Region (CERNHE). The avenue features a physical central median, adequate horizontal and vertical signage, and a posted speed limit of 40 km/h.

Ângela Blaso Segreto Avenue has become one of the municipality's principal urban roadways in recent years due to the urban expansion occurring in its surrounding areas. The avenue currently accommodates businesses, services, and recreational facilities for the local population. A physical central median is present along most of its length, although some segments remain separated only by raised pavement markers and horizontal road markings due to the ongoing roadway duplication project. The posted speed limit is 40 km/h.

The intersection between José Wilibaldo de Freitas Avenue and Da Saudade Avenue exhibits the highest crash rate among the municipality's major intersections. This condition is associated with the substantial traffic volume generated by the convergence of two important urban arterials. The intersection is controlled by a traffic signal system.

Regarding the municipal roads, Salathiel da Costa Pereira Municipal Road connects Novo Horizonte to the municipality of Urupês and is widely used by passenger vehicles and trucks, particularly as an alternative route to avoid tolls. Although the road has adequate horizontal and vertical signage, it presents significant structural limitations, including the absence of paved shoulders and the presence of sharp curves, factors that increase crash risk. An automated speed enforcement camera has been installed at one location identified as critical.

Similarly, Professor Miguel Brabo Municipal Road, which provides access to Vila Cardoso and the municipality of Itajobi, also has adequate traffic signage and is frequently used by drivers traveling to Catanduva for work, leisure, and specialized medical services. However, like Salathiel da Costa Pereira Municipal Road, it lacks paved shoulders and includes winding sections, requiring increased driver attention.

During the study period, the municipality did not have bicycle lanes or cycle tracks installed along the roadways listed in Table 5, which presented the highest severity indices. It is important to note that no traffic volume counts were conducted during this period, nor were official data available to accurately quantify traffic flows on the analyzed roadways. Consequently, the roadway characterizations presented herein were based on field observations, land-use patterns, and the functional importance of each roadway within the municipal urban mobility system.

By analyzing a seven-year time series covering the period from 2018 to 2024, this study provides robust evidence to support decision-making aimed at mitigating traffic crashes on urban roads and municipal roads within Novo Horizonte. The results identified the locations with the highest crash occurrence rates and provided detailed information regarding crash victims, highlighting that vulnerable road users require priority consideration in road safety policies and interventions. The findings emphasize the need to prioritize vulnerable road users—motorcyclists, pedestrians, and cyclists—who accounted for 73.07% of all fatalities recorded during the study period.

6 Final Considerations

Road traffic crashes represent a significant phenomenon that affects public health worldwide, particularly in low- and middle-income countries. This issue is not restricted to large urban centers but also affects small municipalities. According to data from the 2022 Brazilian Census conducted by the Brazilian Institute of Geography and Statistics (IBGE), 4,913 of the 5,570 Brazilian municipalities have fewer than 50,000 inhabitants, highlighting the extent of the problem in locations that are often overlooked in the literature, as noted by Carnevalli Fernandes (2018). Accordingly, the objective of this study was to identify and characterize the road traffic crashes that occurred between 2018 and 2024 within the jurisdiction of the municipality of Novo

Horizonte, São Paulo State, Brazil.

This research was developed based on official traffic crash records obtained from police reports. Therefore, the analysis was limited to formally reported crashes and did not account for potential underreporting. Furthermore, the causes of crashes were not the primary focus of this study, which concentrated instead on the spatial characterization and severity of crashes within the municipality.

The methodology proved suitable for achieving the proposed objectives, as it enabled the characterization of road traffic crashes and the identification of critical locations and roadway segments through the calculation of the Severity Index. In addition, crash occurrences were georeferenced to facilitate the visualization of areas with higher crash severity using Kernel Density Estimation (KDE) mapping techniques.

The data analysis and discussion of results identified the principal roadways and critical locations requiring intervention. Based on the collected data, motorcyclists accounted for the highest number of fatalities, followed by pedestrians, passengers, cyclists, and drivers. These findings indicate that motorcyclists are substantially more vulnerable to fatal crashes. The results corroborate the findings reported by PROADESS (2019), which identified higher mortality rates among motorcyclists in small municipalities. Furthermore, motorcyclists, pedestrians, and cyclists accounted for 73.07% of all fatalities recorded during the study period, supporting the findings of the WHO (2023), which identifies pedestrians, cyclists, and motorcyclists as vulnerable road users responsible for more than half of all traffic-related deaths worldwide. This scenario highlights the need for effective public policies addressing road safety, particularly in small municipalities, where adequate infrastructure and public awareness of traffic risks are equally essential.

Regarding the critical roadways identified, the study revealed several opportunities for improvement from the perspectives of urban planning and traffic engineering, prioritizing interventions capable of enhancing road safety and reducing crash severity, particularly for pedestrians and cyclists. Recommended measures include the implementation of vertical deflection devices, such as raised pedestrian crossings and speed humps; horizontal deflection measures, including curb extensions, reduced turning radii, and mini-roundabouts; as well as the development of cycling infrastructure, roadway narrowing treatments, closure of median openings, installation of pedestrian traffic signals, and fixed automated speed enforcement cameras.

For Da Saudade Avenue, which exhibited the highest severity index, recommended interventions include closing selected median openings at intersections, implementing raised pedestrian crossings, and installing automated speed enforcement devices. These measures have the potential to reduce traffic conflicts and improve safety conditions. For 15 de Novembro Street and Trajano Machado Street, roadway narrowing is recommended within the area exhibiting the highest pedestrian activity, combined with curb extensions that would restrict vehicle circulation to a single traffic lane. Such measures are expected to reduce operating speeds and increase the area available for safe pedestrian movement. Along the remaining segments of these streets, curb extensions at intersections are recommended as a minimum intervention.

For José Wilibaldo de Freitas Avenue and Domingos Baraldo Avenue, the implementation of bicycle lanes and raised pedestrian crossings should be prioritized to improve cyclist protection and pedestrian safety. On Coronel Joaquim Junqueira Avenue, raised pedestrian crossings and the installation of a traffic signal at the intersection with 28 de Outubro Street are recommended due to the intense flow of vehicles and pedestrians associated with access to the municipal hospital. For Jorge Ismael de Biasi Avenue, the completion of the central median, reduction of turning radii, and installation of speed humps are recommended to promote traffic calming and reduce vehicle speeds. On Guido Della Togna Avenue, the implementation of bicycle lanes and speed humps is recommended, particularly near the school and at critical locations along the avenue, to improve the safety of vulnerable road users. For Ângela Blaso Segreto Avenue, roadway duplication along its entire length is suggested, combined with bicycle lanes, mini-roundabouts at high-volume intersections, and fixed speed enforcement cameras. At the intersection of José Wilibaldo de Freitas Avenue and Da Saudade Avenue, the installation of a pedestrian signal integrated with the existing traffic signal system is recommended, as well as enforcement cameras to monitor red-light violations, a behavior frequently associated with crashes at this location.

Finally, for Salathiel da Costa Pereira Municipal Road and Professor Miguel Brabo Municipal Road, the implementation of paved shoulders and fixed speed enforcement cameras at critical locations is recommended to enhance safety for daily users of these roadways.

Based on the results obtained, it was possible to characterize, georeference, and identify critical crash locations and roadway segments within the municipality, as well as to propose interventions and improvement opportunities for public authorities aimed at reducing crash severity and enhancing road safety. The findings reinforce the importance of integrating urban planning with mobility and traffic engineering policies, particularly regarding the protection of vulnerable road users.

One limitation encountered during the study involved inconsistencies identified in a small number of Military Police crash reports. Examples included crashes occurring on state highways and incidents taking place within private rural properties or private company facilities, locations that fall outside the jurisdiction of municipal authorities.

This study contributes to future research, particularly in small municipalities, by providing a methodology for identifying critical crash locations and offering robust evidence to support decision-making processes aimed at reducing road traffic crashes and improving road safety.

References

ABNT - Associação Brasileira de Normas Técnicas. *NBR 10697: Pesquisa de sinistros de trânsito - Terminologia* [Road Traffic Crash Investigation - Terminology]. 3rd ed. Rio de Janeiro: ABNT, 2020.

Audu, A. A., Iyiola, O. F., Popopola, A. A., Adeleye, B. M., Medayese, S., Mosima, C., & Blamah, N. (2021). The application of geographic information system as an intelligent system towards emergency responses in road traffic accident in Ibadan. *Journal of Transport and Supply Chain Management*, 15, 1-17, a546. https://doi.org/10.4102/jtscm.v15i0.546

Bezerra, A. L. F., Ferreira, E. A., & Da Silva, P. C. M. (2020). Aplicação do princípio de Pareto e mapa de calor na análise de acidentes de trânsito [Application of the Pareto Principle and Heat Maps in Traffic Accident Analysis]. In *Proceedings of the 8th International Symposium on Project Management, Innovation and Sustainability (SINGEP VIII)* (pp. 1-17). São Paulo, Brazil.

Brasil. Ministério dos Transportes. (2002). *Programa PARE: Procedimentos para o Tratamento de Locais Críticos de Acidentes de Trânsito* [PARE Program: Procedures for the Treatment of Critical Traffic Accident Locations]. Brasília, DF, Brazil.

Brasil. Ministério da Saúde. (2022). *DATASUS - Tabnet*. Brasília, DF, Brazil.

Brasil. Ministério da Infraestrutura. Secretaria Nacional de Trânsito. (2023). *PNATRANS - Plano Nacional de Redução de Mortes e Lesões no Trânsito* [National Plan for the Reduction of Traffic Deaths and Injuries]. Brasília, DF, Brazil.

Carnevalli Fernandes, P. H. (2018). O urbano brasileiro a partir das pequenas cidades [The Brazilian urban context from small cities]. *Revista Geoaraguaia*, 8(1), 13-31.

Carmo, C. L. (2019). *Segurança viária em trechos urbanos de rodovias federais* [Road Safety on Urban Sections of Federal Highways] (Doctoral dissertation). Federal University of São Carlos, São Carlos, Brazil.

Carvalho, M. S., & Câmara, G. (2004). Análise espacial de eventos [Spatial analysis of events]. In S. Druck, M. S. Carvalho, G. Câmara, & A. M. V. Monteiro (Eds.), *Análise Espacial de Dados Geográficos* [Spatial Analysis of Geographic Data] (Chapter 2). Brasília: INPE.

DENATRAN - Departamento Nacional de Trânsito. (1987). *Manual de identificação, análise e tratamento de pontos negros* [Manual for Identification, Analysis and Treatment of Black Spots]. Brasília, DF, Brazil.

DNIT - Departamento Nacional de Infraestrutura de Transportes. (2009). *Metodologia para identificação de segmentos críticos: Identificação e proposição de melhorias em segmentos críticos da malha rodoviária federal do DNIT* [Methodology for Identifying Critical Road Segments]. São Paulo, Brazil.

Ferraz, A. C. P., et al. (2023). *Segurança no Trânsito* [Traffic Safety] (3rd ed.). Curitiba, Brazil: Authors' Edition.

Ferreira, P. C. P. (2017). *Uma proposta de tratamento dos dados sobre acidentes nas rodovias federais brasileiras com vistas a atuar preventivamente na redução de sua ocorrência* [A Proposal for Processing Crash Data on Brazilian Federal Highways to Support Preventive Actions] (Doctoral dissertation). Federal University of Rio de Janeiro, COPPE, Rio de Janeiro, Brazil.

Ferrer, A. (2017). Movilidad urbana segura. *Revista dos Transportes Públicos - ANTP*, 145, 7-18.

Gonzalo-Orden, H., Perez-Acebo, H., Unamunzaga, A. L., & Arce, M. R. (2018). Effects of traffic calming measures in different urban areas. *Transportation Research Procedia*, 33, 83-90. https://doi.org/10.1016/j.trpro.2018.10.079

IBGE - Instituto Brasileiro de Geografia e Estatística. (2023). *IBGE Cidades: Novo Horizonte - Panorama*. Rio de Janeiro, Brazil.

IPEA - Instituto de Pesquisa Econômica Aplicada. (2023). *Balanço da primeira década de ação pela segurança no trânsito no Brasil e perspectivas para a segunda década* [Assessment of the First Decade of Action for Road Safety in Brazil and Perspectives for the Second Decade]. Brasília, DF, Brazil.

Lasmar, M. T., Moraes, B. M., Inouye, T. I., Bacaltchuck, P. B., & Pamboukian, S. V. D. (2018). Identificação e classificação de pontos críticos de acidentes de trânsito [Identification and Classification of Critical Traffic Crash Locations]. *Revista Mackenzie de Engenharia e Computação*, 17(1).

Novo Horizonte/SP. Prefeitura Municipal. Unidade Gestora de Trânsito. (2023). *Dados estatísticos de sinistros de trânsito* [Traffic Crash Statistics]. Novo Horizonte, Brazil.

ONSV - Observatório Nacional de Segurança Viária. (2019). *Acidentes por porte de município* [Traffic Crashes by Municipality Size].

Ouni, F., & Belloumi, M. (2018). Spatio-temporal pattern of vulnerable road users' collision hotspots and related risk factors for injury severity in Tunisia. *Transportation Research Part F: Traffic Psychology and Behaviour*, 56, 477-495. https://doi.org/10.1016/j.trf.2018.05.003

PROADESS - Projeto Avaliação do Desempenho do Sistema de Saúde. (2019). *Acidentes de transporte terrestre no Brasil: aspectos da morbimortalidade (2000-2017)* [Land Transport Crashes in Brazil: Morbidity and Mortality Aspects (2000-2017)]. *PROADESS Informative Bulletin*, 5.

QGIS Development Team. (2024). *QGIS User Guide*. QGIS Documentation.

Rabbani, M. B. A., Khan, S. A., Iqbal, Q., & Zaman, E. Q. (2019). Analysis of vehicle accidents using spatio-temporal tools in ArcGIS: A case study of Hayatabad, Peshawar. *International Journal of Engineering Works*, 6(12), 439-444.

SENATRAN - Secretaria Nacional de Trânsito. (2023). *Frota de Veículos* [Vehicle Fleet Statistics].

Teodoro, A. B., Alcântara, F. A., & Barbosa, H. M. (2014). Comparação entre dois métodos para identificação de locais críticos de acidentes de trânsito [Comparison Between Two Methods for Identifying Critical Traffic Crash Locations]. In *Proceedings of the 28th National Congress on Transport Research*. Curitiba, Brazil.

Torbaghan, M. E., Sasidharan, M. S., Reardon, L., & Muchanga-Hvelplund, L. C. W. (2022). Understanding the potential of emerging digital technologies for improving road safety. *Accident Analysis & Prevention*, 166, 106543. https://doi.org/10.1016/j.aap.2021.106543

Vasconcellos, E. A. (2005). *A cidade, o transporte e o trânsito* [The City, Transport and Traffic]. São Paulo, Brazil: Prolivros.

World Health Organization (WHO). (2021). *Global Plan for the Decade of Action for Road Safety 2021-2030*. Geneva, Switzerland: WHO.

World Health Organization (WHO). (2023). *Global Status Report on Road Safety 2023*. Geneva, Switzerland: World Health Organization.