Road Accidents - Study of the Evolution and Mapping of Accidents Within the Municipality of Cagliari – Italy

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Abstract. In recent decades, great attention has been paid to the issue of road safety, both at the international level and on a national scale, in which individual nations have gradually put into practice both direct and indirect interventions, the effects of which have been measured by the reduction in the number of accidents over time.

However, critical issues remain, and the zero road fatalities goal advocated by the PNSS [1, 2] in its 2010 and 2020 editions has not yet been achieved; in fact, we are still quite far from the goal.

In this study, the authors analyzed accident data provided by the Cagliari Municipality for the years 2014 to 2022. The data divided by nature of accident, type of vehicles involved, accident circumstances, and severity were analyzed in order to provide an overview of their evolution. In addition, location data were mapped with GIS – *Geographic Information System* - and represented in thematic maps. These provide a powerful tool for analysts and local administrators to (i) visualize critical and conflict areas immediately and clearly and (ii) identify risk factors on which to potentially intervene in order to remove criticality.

The application to a local context through the operational use of maps, in the authors' opinion, represents the added value of the study.

Keywords: Road Accident · accident mapping · GIS

1 Introduction

Road traffic accidents currently represent a serious public health issue, comparable to cardiovascular diseases or cancer. As reported in [3], road traffic fatalities are the leading cause of death in the 5÷29 age group and the eighth for all age groups.

The report highlights that, although progress has been made in terms of legislation, vehicle safety standards, and post-accident assistance, these improvements have not occurred at a pace sufficient to offset the growth in population and the rapid global motorization. Therefore, it is crucial to strengthen regulations to mitigate risk factors and thus improve road safety.

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In countries with high levels of road safety, it is customary to apply the so-called Safe System [4], an approach based on the two assumptions that (i) human make mistakes and (ii) the human body has a limited capacity to tolerate the impacts of accidents, hence the basic principle: mistakes should never lead to death. To achieve this, it is necessary to intervene on road infrastructure, designing and managing it in such a way as to minimize the risk of errors and, when they occur, ensure that the consequences for users are mitigated. The cornerstones of safety with which the required safety conditions can be achieved are: safe road users, safe vehicles (e.g. assisted braking or electronic stability control systems), safe speeds, i.e. such as to produce impact energies below a certain threshold considered critical (e.g. in the case of accidents involving pedestrians or cyclists this threshold is set at around 30 km/h), safe roads and post-accident assistance [5, 6]. Regarding the last point, the timely transportation of the injured to hospitals for medical care, access to rehabilitation services, and generally efficient post-accident assistance is crucial and can save lives.

It is important for governments to increase their road safety efforts in order to achieve the goals set out in the 2030 Agenda for Sustainable Development, which for the 2020–2030 decade aims to reduce road deaths and serious injuries by 50% [7].

In addition, in 2020, the Commission [8], in the section on road safety, outlined a series of regulatory initiatives that concerned new guidelines on the maximum permitted blood alcohol level for drivers and the use of breathalyzer interlock devices.

At the Italian level, the reference document that transposed the communication of [9] is the National Road Safety Plan, PNSS [1, 2] which, through a normative review, data, statistical analysis on road accidents in Italy, Europe and worldwide, sets two levels of objectives and contextual strategies. The general objectives [1, 2] aim at reducing accidents by intervening on (i) infrastructure type, (ii) vehicles, (iii) emergency services. The specific ones, on the other hand, target vulnerable user categories considered at higher risk (cyclists, pedestrians, motorcyclists, children, over 65s). For each of them, the risk factors and related strategic lines of intervention are listed according to a safe system approach that covers all the components of the road safety system (user, infrastructure, vehicle).

When discussing of road safety, one cannot fail to mention the concept of risk. In fact, the achievement of safety objectives cannot be separated from a careful analysis of risk. There is no single definition of risk, but several exist, one of which is: "*The probability of reaching the potential level of damage under conditions of use or exposure to a specific factor or agent, or their combination*" [10]. According to this understanding, it can be said that risk is a probabilistic concept, i.e. it expresses the probability that a given event capable of causing harm will occur. The legislation on the subject that introduces a risk assessment and allows, in the corporate sphere, to take into consideration all the aspects that may impact on the continuity of business processes is ISO 9001 [11], while UNI ISO 31000 [12], in its Italian version then updated in 2018 is directed at the risk manager, and regulates the tools for risk management.

In the road environment, the risk has been studied for a long time and, in the first formulations, it was represented by three components: (i) the probability of a potentially harmful event occurring, (ii) exposure relative to the risk area, and (iii) vulnerability, or the severity of the consequences [13]. Recently, new formulations have been proposed

that go beyond the old logic of using fixed and arbitrary parameters for risk components [13] instead of mathematical relations evaluated through analytical functions, as already applied in public transport [14, 15] and private [16].

For the analysis of road infrastructure safety, the European Directives [17, 18] define the Road Infrastructure Safety Management System (RISM), which is a set of procedures to support road authorities in the decision-making process for monitoring and improving road infrastructure safety. These procedures are aimed at enhancing road safety at the different stages of a road infrastructure life cycle. Some of them can be applied to existing infrastructures, thus enabling a more reactive approach (e.g. by fixing the safety issues identified on the infrastructure), while others are used in the early stages (i.e. planning and design) allowing a more proactive approach [9–20].

An initial safety assessment of the road network as a whole is designed to identify the presence of road elements which are critical in comparison with others and on which action should be taken. Subsequently, these segments can undergo further analysis, such as inspection and modeling.

One of these tools is the Road Network Screening (RNS) which represents the first stage of the RISM process and may concern: (i) the entire road system within a specific territorial area (province, region, etc.), (ii) a more limited context (municipality, section of the road network), or (iii) a particular road infrastructure (Section – road intersection). At the macro scale, a complete safety assessment can be made using socio-economic factors of the area under consideration as study data. At the micro scale, safety analyses can be performed specifically for segments, using their geometric characteristics and functional parameters as data. Typically, local decision-makers are usually more interested in making an assessment limited to their own administrative boundaries, as demonstrated by the study of Yasmin et al. [21], which highlights how most multivariate model studies have used the micro scale.

The RNS can be done in several ways, from the simple classification of road sections according to the number of accidents recorded to more advanced statistical methods based on accident prediction models. The one used by Job Safety Analysis (JSA), recommended by AASHTO [22], represents the state of the art. This method allows an analysis of a particular process starting from its general structure and then decomposing it into increasingly specific components, and aims to identify empirically the risk factors and control them by integrating the general principles of prevention. The European Road Assessment Programme (EuroRAP) [23] has also developed a form of network screening, but as it is not an official body, the risk assessment it provides does not have any official value.

Regardless of the methodology adopted, the RNS is divided into three main phases:

- Segmentation of the road network into homogeneous segments. The division can be made based on spatial functionality (homogeneity in geometry - section width, number of lanes, etc.-) or according to functional characteristics (traffic volume, etc.) or also in function of certain accident-related factors such as the relationship between expected and actual accidents;
- Development of an assessment scale through the adoption of evaluation criteria: Reactive or Proactive. The first operates downstream of the road network, i.e., on the infrastructure in use, and is based on the calculation of indices that provide a safety

assessment based on the historical series of recorded accidents (frequency, density, or severity of accidents). The second operates upstream and evaluates the potential effect of certain risk factors on road safety;
- Classification and presentation of results.

On this last point, EuroRAP has defined a colour scale of five levels, each corresponding to a level of risk ranging from low (green) to high (black). This standardization has been recognized internationally and therefore allows cross-border comparisons.

Crash Prediction Models (CPM) are essential elements of the RNS, forecasting tools that allow both quantitative and qualitative analysis to be carried out, for example on the frequency and severity aspects of accidents. These models provide an estimate of both exposure and consequences, allowing the identification of effective measures to deal with them, as well as an estimation of the improvement effects they bring in terms of accident reduction and therefore safety improvement.

AASHTO [22] presents a comprehensive set of road accident prediction models on highways, urban and suburban roads. These models are fairly versatile, based on the estimation of accident frequency as a function of flow characteristics, which is then normalized through factors related to the functional context. In 2014, a supplement to the 2010 edition [24] was issued which contains model-specific formulations for highways and interchanges.

These models have been exported outside the US and applied in international contexts. In particular, a first study addressing the transferability of the HSM model to two-lane and two-way roads was conducted by Martinelli et al. [25] on the Italian provincial road network. More recently La Torre et al. [26] with the PRACT (Predicting Road Accidents) project, has developed a European accident prediction model which, with appropriate calibration, can be applied in European road networks.

Although the majority of models focus mainly on CPMs which study accident frequency and only a few also address accident severity, over the last decade, research has been directed towards CPMs combining frequency and severity, highlighting the implications of their correlation [27]. Combined models are more suitable for use in the road infrastructure safety management process, as they allow assessments to be made of the consequences of road accidents, providing a more comprehensive analysis and a useful tool to support policymakers in choosing the most appropriate solutions to eliminate critical issues [28].

The reliability of output results is closely related to that of input data, the reliability and completeness of which are necessary for the accuracy of accident studies and thus for the development of effective measures to mitigate them. This highlights the importance of having access to adequate data.

Attempts have already been made over time to standardize the data collection procedure by proposing standard procedures (for example at European level with [17]). However, there are still different methods of collection and therefore, often the collected data have problems of completeness and accuracy to which usually not due attention is paid.

In this regard, the organization that collects the data plays an important role, but especially the purpose of the analysis, according to which priority is given to this or that

other data, which feeds the lack of homogeneity and inconsistency between the various databases.

The data with greater uncertainty are: (i) spatiotemporal coordinates, (ii) severity classification, (iii) inaccuracies in identifying factors that contributed to the accident, (iv) personal data of users involved and (v) difficulties in correlating with other factors (e.g., traffic flows). The reports widely used and also employed in this study are those of the law enforcement agencies, which in their recording manuals, collect a variety of data:

- Location and time of the accident, data necessary to link the accident with the environmental context in which it took place. However, despite its relevance, this data is often not reported with the accuracy it deserves, sometimes due to human error and/or equipment failure [29]. Another reason is related to the purpose of the data. For example, law enforcement agencies, with the exception of damage alone, carry out a planimetric survey of the area for legal purposes only (for possible causes/procedures) for each incident. As such, the location data is often entered in a cursory manner;
- Accident severity, defined as the maximum injury to the users involved;
- Users involved: drivers and/or passengers of vehicles or pedestrians;
- Factors contributing to the accident: It is the most difficult part to understand because of the multitude of elements involved. In general, the reports contain a fixed list of factors that may have contributed to the accident and that officers should select and prioritize.

From this brief review it is clear that the data may be lacking or imprecise and that it cannot always be remedied by additions.

In this study we propose the result of the analysis of the accidents recorded in the urban area of Cagliari (Sardinia) in the years 2014–2022 (first half of the year). In particular, on the basis of location data, where available, coordinates for each incident have been uploaded to WGS84 geographic and georeferencing results are reported on area maps.

The authors consider that cartographic reproduction of incidents is a complementary tool to descriptive analysis and that the combination of the two constitutes a more effective analytical methodology for analysts and administrations. In fact, the possibility of visualizing the area/point of occurrence in which a certain number and/or type of claims are concentrated, allows to correlate the event with the context which facilitates the identification of possible risk factors and put in place effective strategies to remove them.

The remaining paper is organized as follows. Section 2 presents the methodological framework followed for the construction of the maps. Section 3 presents the case study and related discussion. Finally, Sect. 4 concludes the study and provides research perspectives.

2 Methodological Analysis

In Italy, the main source of road accident data is a statistical survey based on the collection of the elements of road accidents. This type of survey involves the compilation, by public bodies with local jurisdiction (Traffic Police, Carabinieri, Municipal Police, etc.),

of certain forms (Istat CTT/INC model) that contain information on each accident and are then transmitted to ISTAT within 45 days of the end of the month of survey. ISTAT processes the forms and collects them in a report published annually, from 1952 to the present, in collaboration with the co-participating entities in the survey, namely ACI (Automobile Club of Italy) and some regions according to the relevant memoranda of understanding with the Ministry of Health and the Ministry of Infrastructure and Transport. The survey covers all road accidents recorded by local authorities that occurred on the national territory within a calendar year and caused injuries to people. Over the years, the survey criteria have changed: for example, since 1991, accidents that do not involve personal injury are no longer counted, while since 1999, the coding "died in road accident" covers victims who died on the spot or within the 30th day from the date of the accident while previously this time frame was limited to seven days.

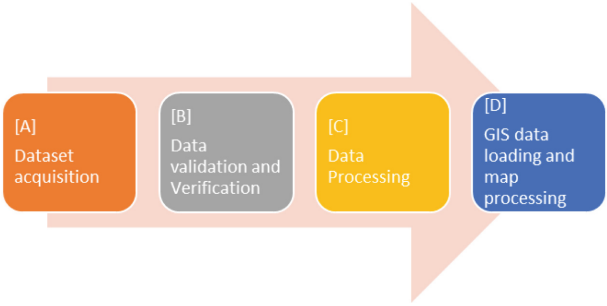

Fig. 1. Methodological framework

In the present study, accidents that occurred in a given area over a given time period were mapped. For this purpose, Fig. 1 describes the methodological scheme adopted, which consists of 4 parts:

A. **Dataset acquisition**

The dataset acquired is from law enforcement agencies and covers incidents that occurred in a given municipal area and within a given time frame. They contain data downloaded from the survey sheets and cover: Date, time and location of the accident, Survey body, Location of the accident, Type of road, Pavement, Road surface, Signs, Weather conditions, Nature of the accident, Type of vehicles involved, Circumstances of the accident, Consequences of the accident to persons, Names of the dead, injured and Institute of hospitalization.

B. **Data validation and Verification**

Checking and verification are two actions that are necessary and instrumental to the next stage of processing. At this stage, the format of the data (e.g., date, time, coordinates etc.) and the presence of any typographical errors and/or duplicates are checked. Any distortions are corrected at this stage, resulting in a database that is homogeneous in format and consistent in the information it contains.

C. **Data processing**

Since the objective of the study is the mapping of accidents in a cartographic support, the main processing of the data involves the input of geographic coordinates for each record. In fact, authority reports usually in the location field contain the street call sign with additional fields designed to identify the area of occurrence such as: the house number, a landmark, a mileage progress and in the case of an intersection, the call sign of another street. Through an address geolocator, one can convert the location data into the corresponding WGS84 geographic coordinates.

D. **GIS data loading and map processing**

A valuable tool for producing maps in digital format is the GIS (Geographic Information System), a computerized information system that primarily enables the acquisition, visualization and analysis of geographic data, that is, associating them with their geographic location on the earth's surface and processing them to derive information. GIS makes it possible to combine different types of data with each other, united by the same geographical reference, and thus develop new information according to the user's needs. In a geographic information system, data can be associated with their geographic location as (i) vector data, i.e., formed by points, lines, and polygons which are suitable for representing data that vary discretely, or (ii) as raster data, which allow surfaces to be represented by means of arrays of cells, called pixels, with each of which certain information about the area represented is associated, and these are more suitable for representing data that vary continuously. In GIS there are three types of information:

- Geometric: concern the cartographic representation of the objects represented (shape, size, geographical location);
- Topological: concern the connections between objects;
- Informational: concern the data associated with each object represented.

The database in CSV format containing accident data are imported into the GIS, which can be queried by creating thematic maps of the nature and quantity of accidents on the map base.

3 Case Study

The objective of the study is to map accidents within an urban area so as to have a true distribution both in terms of concentration and in terms of the nature of the event. The study area is the Cagliari Municipality. Specifically, through GIS, the detected accidents were mapped over the area and then discretized according to their characteristics.

The data source is the traffic accident reports collected by the Cagliari Municipal Police Department, containing the list of accidents recorded between 2014 and the first half of 2022, totaling 9,648 accidents. The reports contain the following information (Table 1).

Table 1. Data report details

Data	Example
Temporal Data	Date, hour
Spatial data	Street, House Number, Kilometer Progression, Additional Notes
Nature of accident	Damage, with/without injuries, fatalities
Accident Description	Right of way, rear-end collision, side impact, etc.
Involved Vehicles	Number and type (passenger cars, two-wheeled vehicles, heavy vehicles, bicycles, pedestrians))
Involved Persons	Number and age divided by gender
Injured Persons	Number and divided into seriously injured and deceased

An initial data processing involved formatting the temporal fields in date and time format to make the data processable through pivot table extraction. At the same time, text fields were corrected for typographical errors, primarily in the street names. For the nature and description of the accident, homogenization was carried out by removing duplicates (e.g., "With/without injuries"—"Yes/No injuries" was standardized as "With/without injuries").

The second processing step involved adding geographic coordinates (longitude and latitude). This was done using both the address geolocator from the "Sardegna Geoportale" website [30] and "Google Maps" [31], through which coordinates in the WGS84 geographic format were obtained by entering the location data contained in the reports.

However, in some cases, due to the absence of the house number or kilometer progression, it was not possible to identify the geographic coordinates. This occurred for about 24% of the accidents, or 2361 cases, while the remaining 7287 incidents were geolocated using the specified method. However, even for these, there were issues with determining the exact incident location. This was particularly true in situations such as road/square adjacency, wide carriageway roads, and roundabouts, especially those with a large radius.

Once the geographic coordinates were loaded, the mapping of road accidents was carried out using QGIS software. The data database, stored in an Excel CSV file format, was imported as a text file into QGIS. This was overlaid onto the street map layer of the urban area of Cagliari, loaded from the WMS service of the Sardegna Geoportale, and onto the boundaries layer of the urban areas of municipalities in the metropolitan area, also available on the Geoportale. In this way, the urban area of Cagliari, the focus of the study, was isolated.

3.1 Data Analysis

Considering only the data from the complete years, i.e., 2014 ÷ 2021, the time series is shown in the graph in Fig. 2.

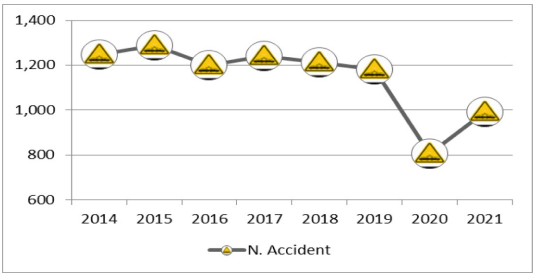

Fig. 2. Trend of accidents over the years

Disregarding the last two years affected by lockdown measures due to the pandemic and stopping the analysis at 2019, i.e., before COVID, the number of accidents decreased by approximately 64 units, recording an average annual decrease of −1.1%.

Considering the nature of the accidents, 51.9% were accidents with no injuries, 42.8% involved injuries, 4.7% were property damage, and 0.6% were fatal. Figure 3 shows the accident data by category expressed as index numbers with 2014 as the baseline. Comparing 2019/2014, accidents with property damage and fatalities saw the most significant increases, with a total growth of 137% and 40%, respectively, and average annual increases of 19% and 7%. These types of accidents remained stable during the years affected by the pandemic, while property damage incidents, after a decline of −24%, reversed the trend with a +29%, matching the 2019 figure. On the other hand, accidents with and without injuries experienced a total reduction of −14% and −6%, respectively, with average annual decreases of −3% and −1%. The physiological contraction in 2020 (−43% with injuries and −24% without) was followed by a stronger recovery for accidents with injuries (+46%) compared to those without injuries (+9%).

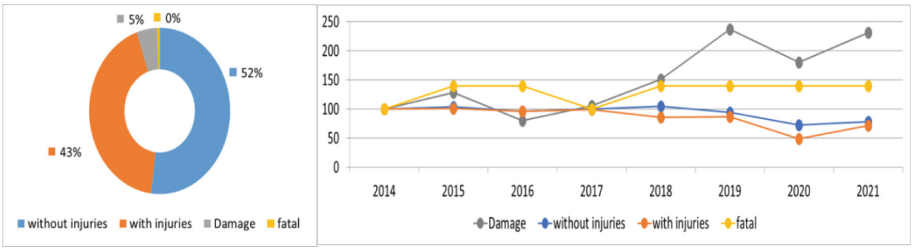

Fig. 3. Nature of accidents and evolution over the years (data expressed as index number as of 2014)

Figure 4 shows the weekly trend and for each day the distribution by time slot. It is noticeable that the majority of accidents occur during weekdays, which is related to the intensity of physiological traffic volumes on these days. The peak hours for accidents are from 2 p.m. to 6 p.m. (average 39 percent) and from 9 a.m. to noon (average value 35 percent). In contrast, during the weekend, there is a decrease in the number of accidents, although they tend to concentrate in the 24 - 7 range on Sundays (23%) and Saturdays 21%.

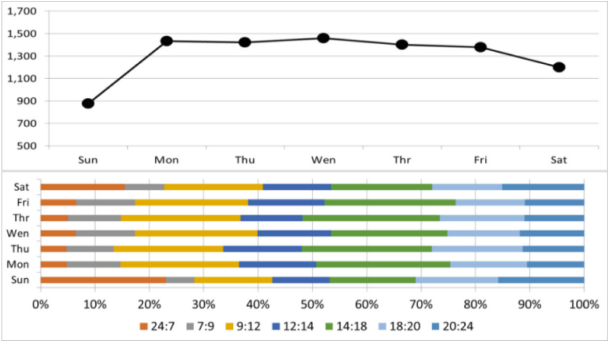

Fig. 4. Total Accidents – Weekly Trend and Time Slot Distribution

Among the confirmed causes, the first place goes to rear-end collision and pedestrian hit-and-run (21%) followed in order by skidding (11%), front/side and side impacts (9% and 7%), failure to yield right of way (6%), collision with parked vehicle (5%), and a mix of other causes (Fig. 5).

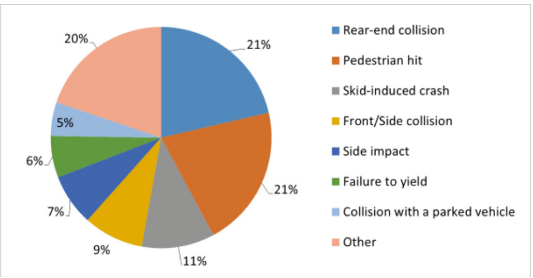

Fig. 5. Main Caeses of accidents

The main causes have also been examined over the years. Figure 6 shows the trend in the years 2014–2019 of rear-end collisions and skidding exit.

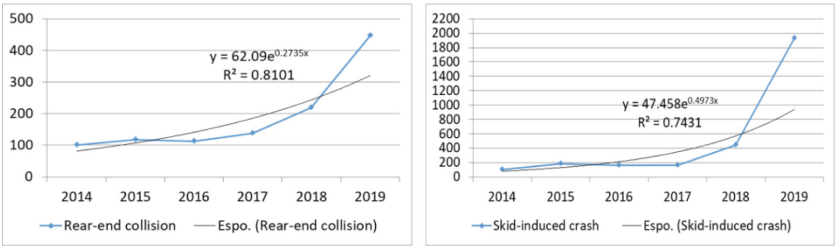

Fig. 6. Trend 2014 – 2019 Rear-End collision and Skidding Exit

In both cases, a relevant peak is observed in 2019. Such a trend was observed in the first 6 causes with the exception of pedestrian investment. This increase was immediately found to be abnormal, i.e., not justifiable in any way by either exogenous causes or traffic flows. A detailed analysis of the data revealed that the reason for the spike is due to increased accuracy in filling out the field: cause of accident. In fact, it was found that in previous years the field in question did not report the cause of the accident, leaving the cells blank. The graph in Fig. 7 shows the distribution, for each year, of whether the cause was found or not. As can be seen, until 2018, the ascertainment of the cause of the accident was transcribed for a limited number of accidents, ranging from a low of 13% (2014) up to 34% in 2018, after which, just in 2019, there is a reversal of the trend witnessed by a transcription coverage of 81%, a trend that is maintained in the following years. This is the reason for the 2019 spike: an increase in accuracy when filling out the field and, consequently, in the reporting of the incident.

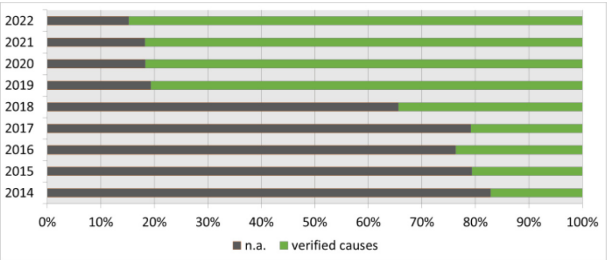

Fig. 7. Confirmed Causes vs Unconfirmed Causes

3.2 Construction of the Maps

For the purpose of the study, this section will present the digital maps of the urban area of Cagliari with georeferenced accidents, that is, those for which latitude and longitude coordinates were obtained in WGS84, as described in Sect. 2 (D) (Fig. 8).

Upon initial analysis, critical intersections were identified based on the placement of the points on the map. Criticality is not in quantitative terms i.e., by number of accidents as much as by complexity and multitude of maneuvers allowed, which results in placement of points in irregular areas due to irregular trajectories resulting in increased conflict points. Figure 9 shows those assessed as most critical according to the logic just described: (1) Via Roma – Piazza Giacomo Matteotti - Largo Carlo Felice, (2) Viale Marconi – Asse Mediano di Scorrimento, (3) Viale Poetto – Via Tramontana – Viale Campioni d'Italia 1969/1970 e (4) Via Diego Cadello – Via Santa Maria Chiara.

Moving on to the quantitative analysis, Fig. 10 shows the location of accidents in the main access/exit routes and throughways of the urban area and in which the highest number of accidents were detected. They in order are: Asse Mediano di Scorrimento and Viale Marconi (in blue) in which 10% of the total number of accidents occurred; Viale Trieste, Viale Sant'Avendrace and Viale Monastir (in green) with 5% of the accidents; Via Roma, Viale Armando Diaz and Viale Campioni d'Italia 1969/1970 (in yellow) 4.3%; Viale Poetto, Viale Lungo Mare Poetto and Via Lungo Saline (in purple) account for about 3.6%.



Fig. 8. Georeferenced Accident Mapping - 2014 – 2022 (Jen-Jun)



Fig. 9. Critical intersections

The maps were then discretized according to the nature of the accidents (Fig. 11): with injuries (3,174), without injuries (3,756), fatal (37) and with damage (320). Accidents involving pedestrians (999), velocipedes (65) and both (4) were then mapped (Fig. 12).

Finally, concentration maps were created that identify the areas of highest risk in terms of accident occurrence. First, a representation of all accidents in the reference time frame was made (Fig. 13). Next, the municipal territory was divided into (250 × 250) m cells obtaining 2,537 cells divided into 43 rows and 59 columns. For each of them, the number of accidents occurring within it was estimated. Further processing involved the creation of concentration maps during the hours within the peak hours (Figs. 14 and 15).



Fig. 10. Mapping on the main access/exit routes and throughways of the urban area

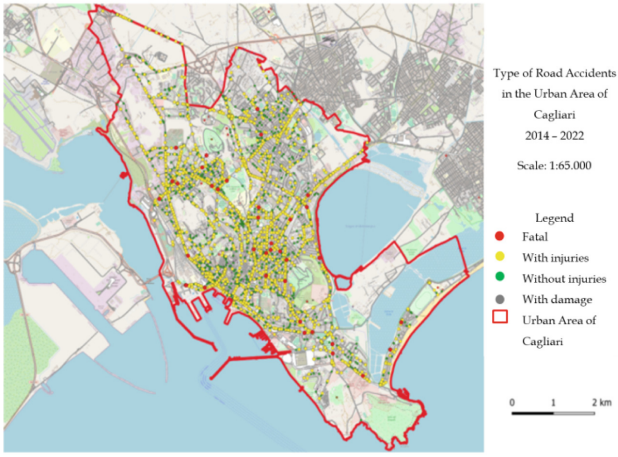

Fig. 11. Cagliari - Accident Map by Type - 2014 – 2022 (Jen-Jun)

Regarding the analysis by time slot, the day was divided into 4 time intervals, each lasting 6 hours. For each of these intervals, the time range with the highest concentration was calculated, and these were mapped. Three critical time intervals were identified:

- 7 am - 9 am belonging to Band 2 (06:00 am ÷ 12:00 pm) where a total of 900 incidents were recorded, corresponding to about 30% of the band and about 9% of the overall total (Fig. 14);
- 12 pm - 2 pm belonging to Band 3 (12:00 pm ÷ 6:00 pm) 1,279 accidents were

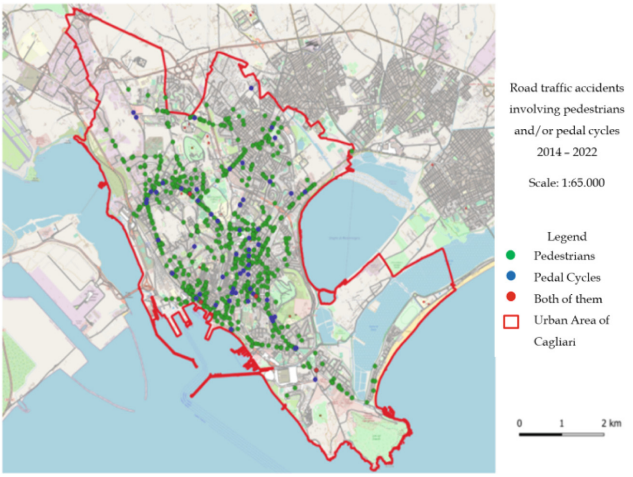

Fig. 12. Cagliari - Accident Map by Pedestrians/Pedal cycles/Both - 2014 – 2022 (Jen-Jun)



Fig. 13. Cagliari - Concentration Map - 2014 – 2022 (Jen-Jun)

recorded, about 37% of the band and about 13% of the overall total (Fig. 15);

- 6 pm - 8 pm belonging to band 4 (6:00 pm ÷ 12:00 am) 1,379 incidents were recorded, or about 54% of the band and about 14% of the overall total (Fig. 16).

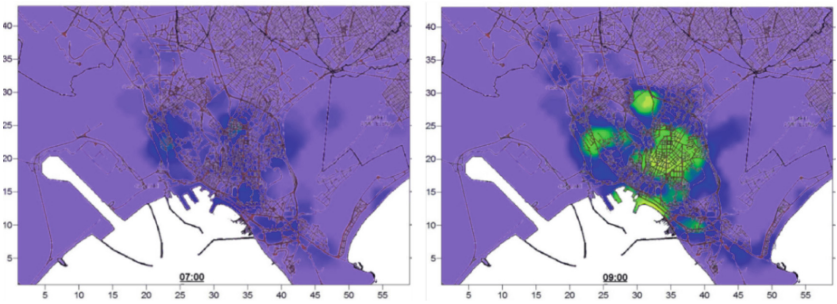

Fig. 14. Cagliari - Concentration Map for Hours: 7am÷9am –2014 – 2022 (Jen-Jun)

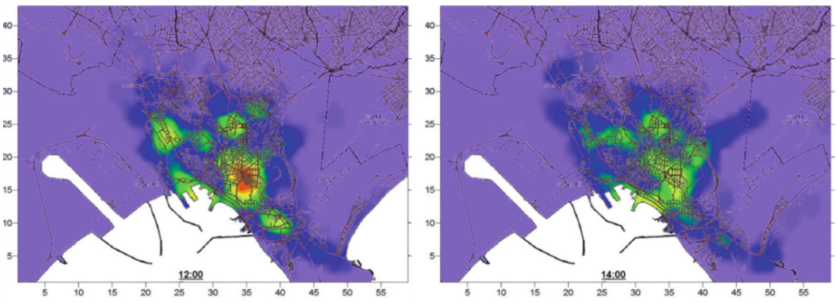

Fig. 15. Cagliari - Concentration Map for Hours:12pm÷2pm – 2014 – 2022 (Jen-Jun)

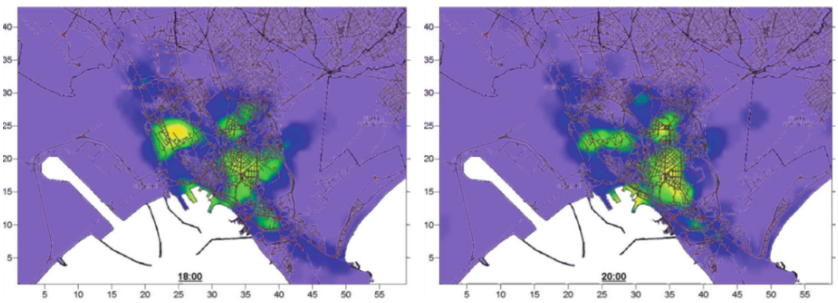

Fig. 16. Cagliari - Concentration Map for Hours:6pm÷8pm – 2014 – 2022 (Jen-Jun)

4 Conclusions

In recent years, the issue of road safety has received much global and national attention, with various countries implementing interventions whose results have led to a gradual reduction in the number of accidents. However, problems still persist, suffice it to say that the goal promoted by the [1, 2] of zero deaths on the roads is far from being achieved.

This study analyzed the accidents recorded in the urban area of Cagliari (Sardinia), in the years 2014 ÷ 2022 (first half of the year), for a total of 9,648 accidents. Of these, 76% or 7,287 accidents were geolocated using the methodology given in Sect. 2 (D).

The inclusion of geographic coordinates made it possible to represent the phenomenon on the cartography of the urban area and thus produce thematic maps: (i) overall, i.e., representative of the number of accidents regardless of the nature and elements involved (Fig. 8), (ii) by nature i.e., according to the extent of the severity of the damage (Fig. 11), (iii) by vulnerable users, specifically pedestrians and cyclists (Fig. 12), and (iv) concentration maps in which the areas of highest frequency of accident occurrence are clearly identifiable (Fig. 13 ÷ Fig. 16).

Thematic maps, according to the authors, are a powerful tool to aid in the descriptive analysis of the phenomenon. In fact, by discretizing the parameters, individually or in cross-tabulated form, they make it possible to make an immediate and direct examination of the accident situation in the area: (i) identifying the most critical areas or points in a timely and effective manner, (ii) correlating them with the geometric and functional characteristics of the road, (iii) thus identifying the underlying risk factors, and (iv) implementing effective interventions. This is of great help, to analysts and local authorities.

For the authors, the present study represents a starting point for future research that has the Cagliari metropolitan area as a case study. The next steps will involve, (1) updating the data to 2024, (2) a detailed analysis on accidents involving pedestrians. In this regard, it should be noted that in the current year, following serious events that resulted in the death by investment of some young people, and which rightly drew the attention of local governments, raised crosswalks were planned and implemented in some specific areas. Following this, it would be interesting to conduct a pre- and post-analysis to evaluate the effectiveness of the intervention and, in the most recent scenario, to estimate the risk components. Furthermore, a series of investigations can be conducted on sensitive areas such as zones near schools, hospitals, etc.

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