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An integrated approach for urban road safety analysis

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Abstract

In line with the objectives of the European Union to halve the number of road deaths by 2030 compared to 2019 and to move close to zero fatalities by 2050, this work aims to contribute to these goals by proposing an investigative model based on GIS tools for defining urban and suburban blackspots (that is accident-prone locations) and thus identifying roads with higher safety risks. This study uses a small town in Sardinia (Italy) as an application case. The considered town has approximately 30,000 inhabitants and a suburban area connecting to other major cities in Southern Sardinia. Using a GIS-based methodology, both urban and sub-urban areas are analysed by constructing layers of various levels of analysis. The first level concerns the location of accidents, the second level considers traffic flows, the third level involves road maintenance while the fourth level considers accessibility aspects linked to traffic attractors present in the area (schools, hospitals, offices, residences, commercial activities, etc.). The overlay of the four layers (accidents, traffic flows, maintenance, accessibility) on a GIS map appears to be the innovative part of this contribution compared to the analysis of individual elements on road safety which is generally found in the literature. The overlay of layers will be the starting point for next studies to define new integrated KPIs (Key Performance Indicators) to create an Urban Road Safety DSS.

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1. Introduction

Road safety has become a global problem. Defined by the World Health Organization as a "public health crisis", it falls among the objectives adopted by the 2030 Agenda, with specific reference to Goal 11.2 - Sustainable cities and communities. Having accepted the UN proposals regarding road safety, the European Union implemented in 2021 the EU strategic framework for road safety 2021-2030: Next steps towards "Vision Zero". To this end, the EU has introduced new concepts such as Safe System and Sustainable System which address improved methods and behaviors regarding vehicle circulation, road infrastructure and road users' behavior (Mayorov et al., 2023). The immediate targets are to halve by 2030 the number of deaths and serious injuries caused by road accidents (European Commission, 2020).

From 2001 to today, road accident victims in Europe have more than halved, but the numbers remain still very high (European Climate, 2020). Between 2004 and 2013, more than 135,000 people died in road accidents within urban areas in the 27 countries of the European Union, representing 38% of all road accident deaths in those countries (Bauer and Machat, 2016). Although some progress has been made, few Member States are on track to reach the EU and UN target of halving the number of road deaths by 2030 compared to 2019 values.

With this publication we try to contribute to Agenda 2030 goals in line with the European objectives represented in Italy by the PNRR (National Recovery and Resilience Plan) and managed by the National Center for Sustainable Mobility (MOST) as part of the Urban Mobility Spoke 9.

The final objective is to identify a set of integrated KPIs functional to the creation of a DSS (Decision Support System) for use by local public administrations for the identification and management of urban black spots.

To this end, this paper presents a preliminary integrated analysis methodology based on GIS software and the combination of different data categories for road safety investigation: traffic flows, traffic attractors and the state of road pavements.

An Italian town just under 30,000 inhabitants has been used as an application case. As in other cities, the analyzed town is characterized by the presence of a CBD - Central Business District (Haggett, 2000). The CBD is located around the historic centre of the city, in correspondence with businesses such as shops, schools, hospitals, banks, offices, hotels, cinemas and theatres (Intini et al., 2020). The CBD has generally a high traffic intensity and a high population density during daytime hours compared to the resident population (Borruso, 2006). In the analysed CBD there are, in addition to commercial activities, several school buildings and public offices.

In addition to flow parameters and traffic attractors (Alkaabi, 2023), this study considers the state of road pavements as an additional factor that can influence road safety. Unfavourable driving behaviour is in fact recognized as one of the main causes of road accidents (Gregoriades and Mouskos, 2013). However, it is also intrinsically influenced by other parameters such as traffic and infrastructure conditions (Pinatt and Chicati, 2020). In this regard, the superposition in pairs of the different elements (accidents, road pavement conditions, traffic flows and attractors) will allow us to observe the possible presence of connections between road safety and the elements considered, in order to activate preliminary investigations for the future development of integrated KPIs. Several other authors have used GIS tools for the study of urban areas at greater risk of accidents (see, a.o., Singh and Katiyar, 2021; Choudhary et al., 2015; Le et al., 2020; Aghasi, 2019; Kundakci and Tuydes-Yaman, 2014). The superposition of the different layers turns out to be the innovative part of our contribution as different georeferenced elements that in the past were treated individually are now displayed simultaneously on a GIS map. The next step of the research will focus on the detailed analysis of the database to identify possible specific integrated KPIs for the future development of a DSS. Starting from the KPIs, the DSS will have to support the identification of any critical points and the intervention priorities for improving safety based on the cost/benefit ratio.

2. Methodology

The location of the road accident alone is not sufficient to carry out a detailed analysis of safety in an urban environment. Analysing traffic flows, the state of the pavement and the positioning of attractive elements such as schools, supermarkets, churches, restaurants, shops can instead give an idea of the presence of interferences and possible black spots depending on the flows and distribution of the traffic attractors and the state of road maintenance.

The research is based on the direct observation of GIS overlay maps of the following georeferenced layers:

- elements of attractiveness, local and supra-local traffic attractors related to public and private services
- traffic flows, detected and processed with Visum software
- road pavement conditions (at the points where accidents occurred)
- road accidents.

Figure 1 depicts the methodology flowchart and its three main phases: data collection, transposition of the data into GIS layers, creation of overlay maps.

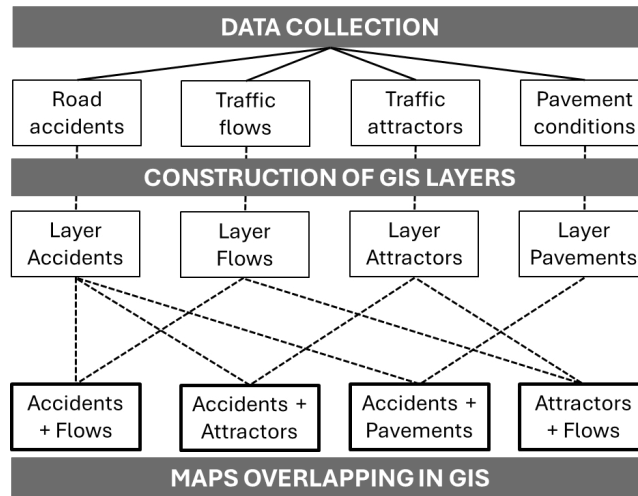


Fig. 1. Methodology flowchart

3. Application

The described methodology has been applied to the urban area of Iglesias, a municipality of just under 30,000 inhabitants in southern Sardinia (Italy). The analysis was based on the development of a GIS project onto which the various layers were loaded:

- traffic attractors, data collected from Google Earth
- traffic flows, data in possession of the research team and relating to the time slot 08:00-09:00 A.M.
- state of the road pavement, data reworked starting from Google Street View images
- accidents, data collected through the Istat Contact Center.

The territorial elements that theme the project map were downloaded from the Geoportal of Sardinia website, specifically: the WMS Ortofoto Satellitare Sardegna 2019 raster, the shape file of the buildings, the shape file of the municipal road network of Iglesias extracted from the regional network and the file form of urban zoning of the city of Iglesias carried out by the department colleges. The map was observed at a scale of 1:10,000.

The following subparagraphs are dedicated to the description of the individual layers.

3.1. Elements of Attractiveness

As defined by Loret et al. (2012), an attractive element is a point placed in the urban network that attracts traffic flows and people at certain times of the day. The identification of the attractive elements and their positioning on the GIS map was made using the search engine of Google Earth and the map of Google Maps Road to have about 760 elements extracted in KML format, which were then reworked for the GIS project. For each element, an Attractiveness Index (I_a) was defined by observing the urban context and considering the weight values defined by Gullotta et al. (2020). Differently from their work, which also considers the hours of congestion produced by each attractor, in this application the values were chosen based on the type of service offered by the attractor (primary or secondary), the type of building (commercial, residential, hospital, school, etc.) and its location (urban or peripheral). In future studies, surface or employee/customer variables will be introduced to give more strength to the choice of weights. Bus stops

have also been included as a point of attraction for users and as a point of conflict risk. Bus stops of extra urban lines were rated as strong attractors (weight 10) while those of urban lines took a lower weight (value 2). The choice of weights depends on the type of service (primary or secondary) and the type of building on which it falls (commercial or residential). For residential buildings, the weight has been reduced by 50% assuming smaller surfaces and sights accesses. For specific elements such as schools it has been differentiated according to the grade of the school. The weights range from 8 to 10 for middle and high schools, and from 4 and 6 for kindergartens and elementary schools. Table 1 shows the different attractiveness values (I_a) while Figure 2 their positioning in the map.

Table 1. Attractiveness Indices (I_a)

| Category | I_a | Simbol |
|---|--------|--------|
| Primary / Commercial (1): hospitals, care homes, superior/middle schools, supermarkets, public offices, extra-urban bus stops, train stations, cinemas | 8 - 10 | ▲ |
| Primary / Residential (1): markets, pharmacies, primary schools, kindergartens | 4 - 5 | ▲ |
| Secondary / Commercial (2): hotels, restaurants, churches, medical offices, sport facilities, fuel stations | 3 - 4 | ▲ |
| Secondary / Residential (2): restaurants, churches, medical offices, sport facilities, fuel stations, libraries, bars, police stations, private offices, B&Bs, hotels, shops, urban bus stops, bakeries, car repair, etc. | 1 - 2 | ▲ |



Fig. 2. Elements of Attractiveness

3.2. Traffic Flows

The data relating to traffic flows was derived from an hourly matrix previously calibrated by the research team. The considered traffic flows refer to the winter peak hour in the morning (8:00 - 9:00). Each road arc i was characterized in terms of capacity (vehicles/h) and flow (vehicles/h). For each arc i , a saturation index (I_{sat}) was calculated as the ratio between flow and hourly capacity (equation 1). Figure 3 shows the traffic flow map (a) and the I_{sat} chart of values (b).

$$I_{sat}_i = \frac{Flow_i}{Capacity_i} \quad (1)$$

3.3. Road pavement conditions

Having no official data provided by the city administration of Iglesias, the state of the pavement was qualitatively assessed based on Google Street View images. The assessment was made only for the arcs where accidents have occurred and considering from time to time the image of the flooring relating to the specific year or the nearest available year. Through direct observation of the Google images (Figure 4 b), a value was given on the maintenance status of the pavement (I_{pav}) of arc i using the International Pavement Condition Index (PCI) ASTM D6433 – 20. ASTM identifies seven PCI classes as represented in Figure 4 (a).

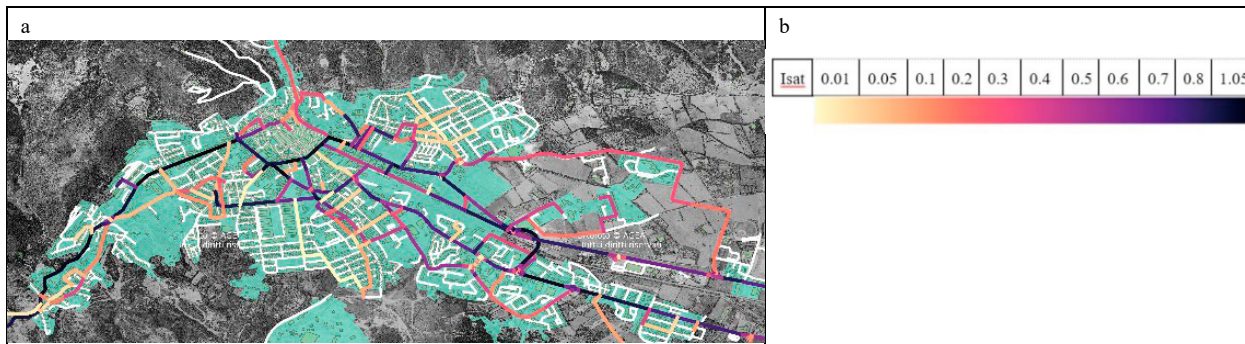


Fig. 3. (a) Traffic Flows; (b) I_{sat} chart's values

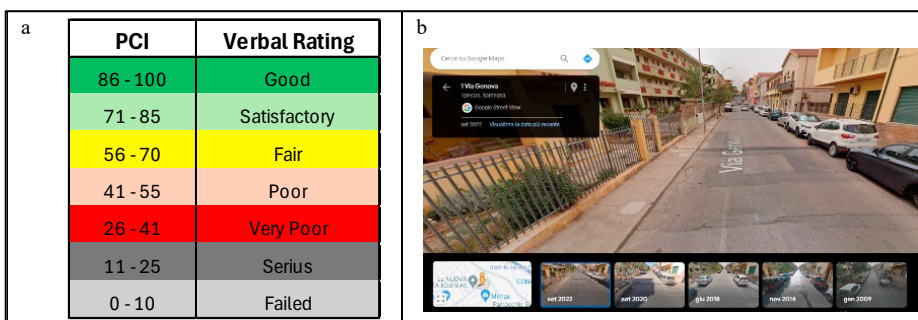


Fig. 4. (a) PCI Index values, (b) Google Street View observation

3.4. Accidents

The accident database includes the accidents occurred in the decade from 2013 to 2022. For years 2013-2021, it was received by the National Statistical Institute ISTAT while the accidents of 2022 were derived from the reports of the local police. For each arc i of the network, an Accident Index I_{acc} was calculated (equation 2) as the mean of the accidents that occurred in arc i during the n years considered, in our case $n=10$ (from 2013 to 2022). Figure 5 shows the I_{acc} values on the GIS map (a) and the related chart values (b).

$$I_{acc_i} = \frac{\sum_{j=1}^n Acci_{ij}}{n_j} \tag{2}$$

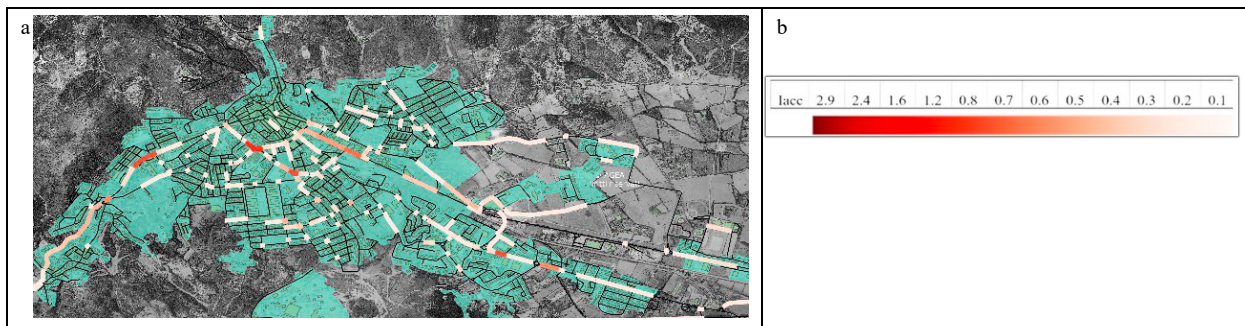


Fig.5. (a) I_{acc} on the GIS map; (b) I_{acc} chart's values

4. Integrated Maps

To start searching for integrated road safety related KPIs, the following overlappings were made:

- Accident Index / Flow Saturation Index
- Accident Index / Attractiveness Index
- Accident Index / Pavement Condition Index
- Attractiveness Index / Flow Saturation Index

4.1. Overlay map of Accident Index and Saturation Index

The overlap of the Saturation Index with the Accident Index shows a good correspondence between the increase in traffic flows, represented with lines of variable blue thickness and the number of accidents, represented in intensity of red and white (Figure 6). Analyzing the numerical data, it is highlighted that 71% of saturated arcs have at least two or more incidents (up to a maximum of 13). We consider as saturated arcs those with a Saturation Index greater than or equal to 57% (considering as a proxied reference the lower limit of the LoS D of two-lane extra-urban roads) As a future development, we will try to understand what the correlations between flows and accidents may be by investigating the nature and circumstances of accidents on the basis of which proposals for intervention relating to the improvement of safety conditions will be made.

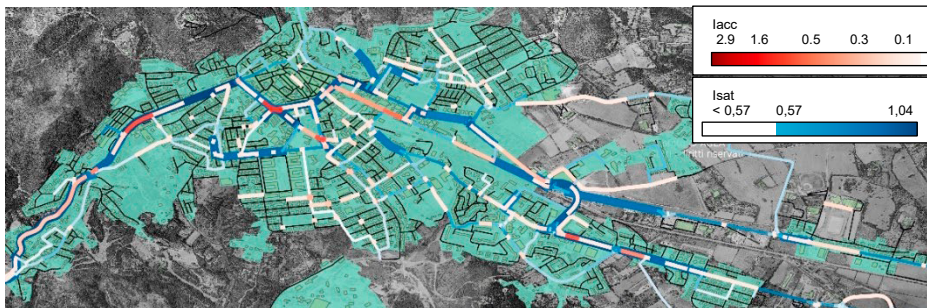


Fig. 6. Overlay map - Accidents Index and Saturation Index

4.2. Overlay map of Accident Index and Attractiveness Index

The overlap of the Accident Index with the Attractiveness Index shows a good link between high accident rates and the presence of attractors with a high I_a . The map (Figure 7) was created by joining the accident arcs with the attractor points. All the attractors that are not involved in accidents have been represented in white, while for the others a diversification has been made by intensity of red and different size according to the index of attractiveness.

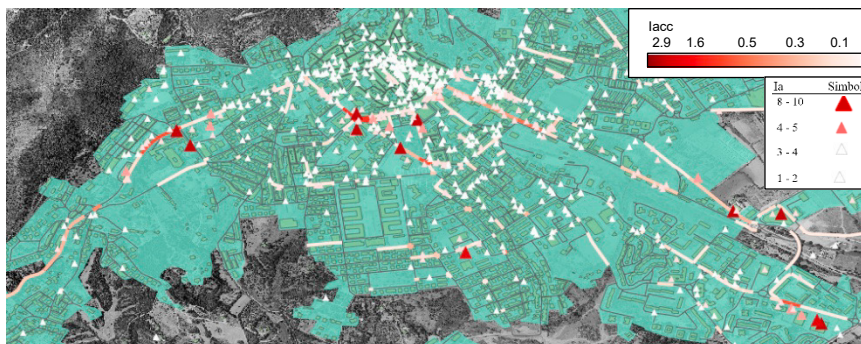


Fig. 7. Overlay map - Accident Index and Attractiveness Index

High average accident rates can be seen in correspondence with hospitals, schools and supermarkets. A good correspondence is confirmed between the elements with both a high I_a and I_{acc} , although elements with a low I_a and an I_{acc} other than zero also emerged. Further investigations are needed to evaluate to what extent the weight of an attractor can impact urban safety.

4.3. Overlay map of Accident Index and Pavement Condition Index

Figure 8 shows the overlap between the PCI shape file related to 2017 (i.e. the year characterized by the lowest /average PCI - value 69) with the accidents that occurred in the same year. The interesting fact is that 72% of the accidents occurred on arcs with PCI lower than 71 (23 out of 32). While for the year 2019, the year with the highest number of accidents and an average PCI of 77, 56% of accidents occurred on arcs with PCI from 71 to 100 (sufficient - good) and 44% occurred on arcs with PCI from 65 to 69. In future studies we will try to delve deeper into the phenomenon to interpret the PCI parameter in more detail with respect to the accident rate.



Fig. 8. Overlay map - Accidents Index and PCI Index (year 2017)

4.4. Overlay map of Attractiveness Index and Saturation Index

The overlay map shown in Figure 9 highlights the possible connections between the degree of attractiveness of a road and related traffic flows. A certain dependence between the elements seem to emerge, however there are also areas in which this phenomenon is less evident or absent. Attractiveness and flows will be used as indicators of users' behavior in the urban area to preliminarily identify the areas at greatest risk of conflicts and accidents.

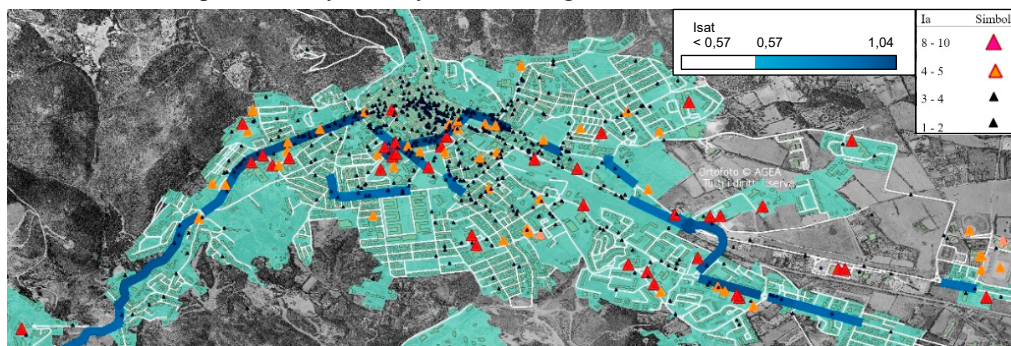


Fig.9. Overlay map - Attractiveness Index and Saturation Index

Conclusions

The study proposed represents a first attempt to investigate road safety in urban areas based on the direct visual observation of the road safety phenomenon. From a first observation of the GIS maps generated with the pairwise

superposition of the various layers representing accidents, traffic flows, traffic attractors and pavement conditions, it seems that a certain degree of correspondence emerged between the location of accidents and the presence of attractors, traffic flows and the state of the roads. This initial evidence will have to be further verified and analysed in order to confirm or deny any connections on the basis of integrated KPIs to be defined. The superposition of the Attractiveness Index with the Saturation Index allows us to know and preliminarily identify the areas at greatest risk of accidents and the probable road safety problems that these factors entail.

This contribution represents the first step towards the identification and analysis of black points with the aim of creating a DSS that allows the issue of road safety in urban areas to be better managed.

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