

# Decision Support System for Urban Road Safety: A Comparison Between Two Different City Size

Michele Pinna[1(✉)], Gianfranco Fancello[1], Patrizia Serra[1], Sergio Useche[2], and Francisco Alonso[2]

[1] Cagliari University, Piazza D'Armi 1, 09127 Cagliari, Italy
michele.pinna@unica.it
[2] INTRAS, Valencia University, C/ Serpis 29, 3° Floor (TT), 46022 Valencia, Spain

**Abstract.** Among the objectives of the European Union in the field of road safety there is "Vision Zero", which aims to halve the number of deaths in road accidents by 2030 and reach zero deaths by 2050. The present contribution proposes a methodology for investigating and identifying preliminary indicators of road safety in urban networks for the development of a Decision Support System to assist road safety managers. The proposed approach for data research and urban road safety analysis is applied on two different urban scales: a metropolis and a city with fewer than 30,000 inhabitants. The identification of urban routes and their overlap, along with the integration of various urban traffic elements such as incidents, traffic flows, and urban attractors within a GIS environment, can enable the correlation of multiple layers related to infrastructure, safety, and accessibility, involving different actors in the decision-making process. At a practical level, this paper presents potential survey choices for identifying safety-related indicators according to the observation area. It is also highlighted how research in metropolitan cities like Madrid can benefit from a high availability of data, while smaller cities require alternative methods and data to build thematic databases. Future studies will focus on selecting the definitive KPIs (Key Performance Indicators) to be used in the creation of a DSS for Urban Road Safety.

**Keywords:** Road Safety · Cities · GIS · Urban Traffic Index · Exemplified Comparison

## 1 Introduzione

In recent years, progress has been made in the management of road safety, yet much remains to be done to further reduce crashes, particularly fatalities. Urban road safety holds a central position for municipal administrations and public agencies. Research of this kind supports the European objective known as "Vision Zero", which aims to halve road deaths by 2030 and eliminate them entirely by 2050 [1]. Most safety analyses have traditionally focused on non-urban areas, where fatality rates tend to be higher; however, urban environments though generally involving less severe outcomes–record a high frequency of incidents [2]. The significant number of crashes, injuries of varying

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severity, and deaths highlights the need to examine urban settings more closely, in order to identify ways to reduce risks. Various factors contribute to road safety, both in quantitative and qualitative terms, including the number of accidents and traffic flow levels [3]. Beyond identifying roads with higher crash rates, it is important to examine the issue from multiple urban traffic perspectives such as incident patterns, infra-structure attractiveness, traffic flow intensity, and pavement conditions. Geographic Information Systems (GIS) are useful for analyzing the spatial distribution of crashes [4] and for locating critical points within the infrastructure. In this study, we propose a method for collecting spatial data and overlapping it with the road network to derive traffic-related indicators relevant to urban safety.

Another aim of this contribution is to illustrate how data analysis methods can vary depending on the size and structure of the urban area. In large metropolitan contexts, data availability is often extensive, while in smaller municipalities, information needs to be gathered through different channels fieldwork, conventional databases, or more recent sources such as TomTom Traffic (TTT). At a practical level, identifying multidimensional urban traffic indicators can help lay the groundwork for the development of a Decision Support System (DSS) that can assist in setting priorities for road safety improvements [4]. Establishing such priorities helps decision-makers allocate available resources more effectively and supports public authorities in identifying which road segments require the most immediate attention [5]. To investigate this topic, it is necessary to define either aggregated or disaggregated safety indicators, depending on quantitative and/or qualitative criteria that reflect different aspects of the issue. Overlaying the road network with layers related to crash records, traffic flows, pavement conditions, and attractors–such as hospitals, schools, supermarkets, restaurants, and retail areas can help detect overlaps and potential conflict zones [6]. The Central Urban District (CDB), particularly during daytime hours, is subject to high traffic volumes and population density, and hosts commercial facilities, schools, and government offices [7]. Accordingly, it is expected that structuring the road network into routes made up of multiple urban streets may help providing a more realistic reflection of how decision-makers tend to address traffic management in practice [8]. In the following sections, we describe how urban elements were identified, how they were linked to the network, and how these associations were used to define the indicators.

## 2 Literature Review

In previous studies, a number of authors have moved beyond single variable analyses of crashes [9, 10], focusing instead on the development of indices aimed at identifying hotspots associated with urban attractors such as accessibility and the spatial distribution of trip generators o prioritize roads or routes that may have greater relevance for intervention and broader effects on communities [11]. Some studies have relied on different indicators relating to crash frequency, accessibility, and population density.

The relationship between urban road crashes and various factors such as infrastructure design, environmental conditions, and traffic volumes has been widely examined [5]. Traffic flow volumes have a measurable influence on crash risk, and several investigations have assessed their role in shaping safety outcomes [12].

Pavement conditions have been objectively assessed using the Pavement Condition Index (PCI), which provides a structured approach for evaluating road surface quality and preservation status [13]. For these reasons, we considered it relevant to explore the issue through an integrated and interdisciplinary approach, considering three main thematic areas and their related traffic elements. Previous research underscores the value of addressing safety from multiple perspectives and considering a range of contributing factors [14]. Some studies also point out the limitations of conventional crash prediction models, while others [15] identify segments with higher priority for action, helping decision-makers manage prevention resources through structured assessment criteria.

## 3 Methodology

The selected methodology outlines two different approaches for identifying itineraries and preliminary indicators, with the goal of developing a DSS in the context of urban road safety. For this study, we selected two case studies: a large city Madrid and a small municipality Iglesias, located in southwestern Sardinia, Italy. The first was chosen for the wide availability of public data, downloadable from online geoportals [16] and [17], useful for obtaining a detailed analysis with respect to the various elements of urban traffic. The other city, under 30,000 inhabitants, was taken as a second case study to highlight the fact that in small realities the detailed analysis relating to road safety can be underestimated or limited to some available traffic elements. Iglesias does not have a municipal geoportal, so data collection required more elaborate research methods and alternative sources, including the use of up-to-date traffic information provided by the TomTom Traffic database. For both cases, we also relied on open-source databases such as OpenStreetMap (OSM) and Google Earth, which were used to integrate additional data for example, identifying accommodation facilities, places of worship, various commercial activities, and infrastructure elements such as traffic lights, pedestrian crossings, and so on.

### 3.1 Itinerary

By itineraries, we refer to segments of the urban road network made up of multiple links (arcs) that belong to the same service level. Rather than analyzing single links or points, we opted for a route-based approach, as this better reflects the way policymakers usually plan and invest in road safety improvements. In urban contexts, interventions such as road resurfacing, replacement of traffic signs, or analysis of hazardous locations are typically carried out on stretches of road composed of multiple streets.

The selection of itineraries was based on a classification system that organizes roads by their level of service. By grouping links under street names, we identified those that belonged to the same route. What most clearly differentiates the two analyses is the network complexity: Madrid's network is extensive, with itineraries spanning several kilometers and clearly defined service levels, while Iglesias has a more compact network, with shorter routes about one kilometer each despite also having a service hierarchy, though with more overlap in road functions.

In Iglesias, given that the most recent available traffic data dated back to 2017, we decided to use the TTT network to define itineraries and obtain updated traffic flow data, as well as other information. TTT data are particularly useful, as they provide various types of flow reports real-time, by hour of the day, and across the entire yearwith a penetration rate of about 3%, which can be used as a conversion factor for estimating vehicles per hour on the network. These data are based on vehicles equipped with TomTom navigation systems and smartphones (e.g., iPhone and Huawei devices). Although the system does not capture the entire volume of traffic, it does offer valuable indicators such as average travel speeds and delay times across different times of the day. These indicators provide insight into traffic flow patterns in terms of travel times and delays.

In the following sections, we present the data obtained based on the observation layers, their sources, and the methods used to integrate them into the GIS project particularly focusing on how the itineraries were linked to the road network. One of the innovative aspects of this study lies in the integrated comparison of itineraries with different urban traffic elements, using geoprocessing tools within the GIS environment.

### 3.2 Fields of Analysis

**Safety**. The safety category primarily includes accident data and related indica-tors. The main difference between the two case studies is the size of their databases. In Madrid, about 4,000 injury causing crashes occur each year, whereas Iglesias has an average of around 40 per year, with a total dataset of about 400 recorded incidents from 2011 to 2022. The distribution of these incidents is illustrated in the figure.

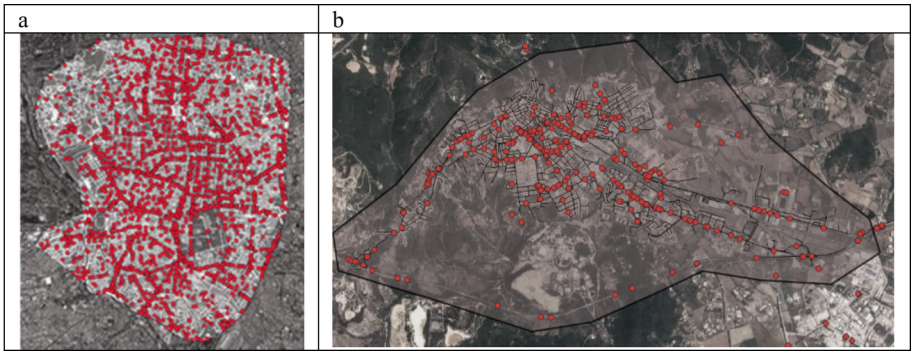



**Fig. 1.** Madrid's urban crashes 2024 (a) left, Iglesias's urban crashes 2014 - 2022(b) right.

**Accessibility.** The Accessibility Group contains data on population density and urban attractors. An attractor is a point in the urban network that attracts people and vehicles at certain times of the day such as schools, public offices, supermarkets, shops, etc. [6]. In addition to the latter, bus stops have been identified, which expose vulnerable users, such as pedestrians, to conflicts with vehicles. The data relating to traffic attractors were handled differently between the two cases, as will be described later.

**Infrastructure.** The infrastructure group includes elements related to pavement, the presence of intersections with or without traffic lights, pedestrian crossings, sidewalk

surfaces, the percentage of cycle paths per route and the number of LED street lamps. The indicators proposed for these elements vary in the two case studies according to the databases generated and the usefulness or otherwise with respect to the context of analysis.

## 4 Application Results

### 4.1 Madrid Case Study

The analysis focused on a delimited area of approximately 6 by 6 kms within the broader urban development. This area was defined using the shapefile named "area_madrid.shp," within which the relevant urban data were observed. The urban area is characterized by centres with a high residential concentration, located in different areas of the city, a Central Business District (CDB) in general a historic centre of the city with businesses such as shops, supermarkets, university, banks, offices, hotels, cinemas and theatres [18], while hospitals are widespread in the northern area (Fig. 5a). The CBD has high traffic intensity and a high population density [7]. The primary network analysed makes all these areas well connected. Once the area was established, the street network was identified in order to de-fine urban itineraries and integrate the various urban and infrastructure related elements linked to Safety, Accessibility, and Infrastructure.

**Identification of Madrid Routes**

The network has been organized into hierarchical urban itineraries using OSM data, which for the moment has been preferred over the geoportal data for a better organization and wealth of information. The OSM network is hierarchical into primary, secondary, tertiary, residential and service. We focused on the primary network (Fig. 2b) identified through the selection of the arcs with the "highway" field. To define the Madrid Routes, the arches with the same name as the street were joined to form paths (Fig. 2a). As a final result, 18 itineraries of average length of 5 km each were identified.

a

| Name | descriptio | _id | highway | name_ety | surface | maxspeed |
|---|---|---|---|---|---|---|
| Acceso a Urgencias | | way/95587 | service | | | |
| Acceso galería emergencia tún | | way/32317 | service | | | |
| Antigua Carretera de la Dehesa | | way/7672( | pedestrian | | compacted | |
| Autovía de Toledo | | way/4121( | motorway | | asphalt | 50 |
| Autovía de Toledo | | way/2868( | motorway | | asphalt | 50 |
| Autovía de Toledo | | way/2436( | motorway | | asphalt | 50 |
| Autovía de Toledo | | way/3883( | motorway | | asphalt | 50 |
| Autovía de Toledo | | way/3883( | motorway | | asphalt | 50 |
| Autovía de Toledo | | way/3883( | motorway | | asphalt | 50 |
| Autovía de Toledo | | way/8878( | trunk | | asphalt | 50 |
| Autovía del Este | | way/2931( | motorway | | asphalt | 50 |
| Autovía del Este | | way/2931( | motorway | | asphalt | 60 |
| Autovía del Este | | way/1730( | motorway | | asphalt | 50 |
| Autovía del Este | | way/2419( | motorway | Q789271 | asphalt | 50 |
| Autovía del Este | | way/3203( | motorway | Q789271 | asphalt | 50 |
| Autovía del Suroeste | | way/4085( | motorway | | asphalt | 70 |
| Autovía del Suroeste | | way/4085( | motorway | | asphalt | 70 |
| Autovía del Suroeste | | way/2939( | motorway | | asphalt | 70 |

b

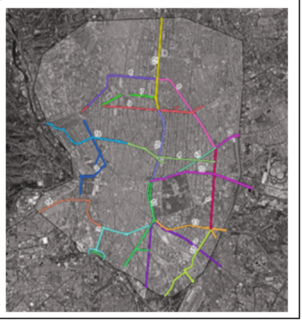


**Fig. 2.** Attribute table of OSM (a), Madrid Street and Routes choosing (b).

**Gruppo Safety of Madrid**

*Crashes.* The crash database was obtained from the municipal geoportal [16], from which we downloaded data on road crashes occurring in 2024 within the urban center (Fig. 1). For this study, we only considered crashes involving injuries. These data, formatted as CSV files, were easily geolocated thanks to the presence of X and Y coordinates. A total of 4,163 crashes were recorded within the area of analysis, with approximately 1,000 of them located along the identified itineraries (Fig. 3).

The crash attribute table includes various variables such as location and address, type of circumstance, sex, injury severity, road user type, age, and more. Among the derived indicators, we estimated severity levels by classifying injury outcomes as Minor, Serious, or Fatal, aggregated from the "lesività" field in Table 1.

For the case of Madrid, the Safety group includes three indicators:

- Accident Index of Itinerary j (I_Accj), calculated as the ratio between the sum of the accidents (Acci) characterizing each of the n arcs that make up itinerary j and the length Dj of the itinerary itself (Eq. 1);
- Average severity index of the accident in Route j (I_Sevj), calculated as the ratio between the sum of the degrees of injury (dlz) associated with each of the m accidents z occurred along route j and the total number of accidents (Accj) occurred along the same route (2);
- Pedestrian Accident Index (I_PedAccj), calculated as the ratio between the sum of accidents involving pedestrians (PedAcc) that occurred along the n arches that make up itinerary j and the total number of accidents falling within itinerary j itself (3)

$$I_Acc_j = \frac{\sum_{i=1}^{n} Acc_i}{D_j} \tag{1}$$

$$I_Sev_j = \frac{\sum_{z=1}^{m} Acc_i dl_z}{\text{Accj}} \tag{2}$$

$$I_PedAcc_j = \frac{\sum_{i=1}^{n} PedAcc_i}{\sum_{i=1}^{n} Acc_i} \tag{3}$$

where

$Acc_i$ is the number of accidents characterizing each of the n arcs that make up itinerary J

$dl_z$ is the level of severity associated with each of the m incidents z falling within route j

Accj is the total number of accidents characterizing the route j

$PedAcc_i$ is the number of accidents involving pedestrians that occurred along the n arches that make up the route j

$D_j$ is the length of the route j

**Accessibility Group Madrid.** For the Accessibility group in Madrid, we defined six indicators based on traffic flow, population density, and the location of key urban traffic attractors, namely schools, hospitals, supermarkets, and bus stops.

**Table 1.** Damage type and level.

| Code | Damage type | Damage level |
|---|---|---|
| 01 | Emergency care without subsequent admission | Low |
| 02 | Income less than or equal to 24 h | Low |
| 03 | Admission of more than 24 h | High |
| 04 | Died 24 h | Dead |
| 05 | Outpatient healthcare thereafter | Low |
| 06 | Immediate health care in a health centre or mutual insurance company | Low |
| 07 | Health care only at the scene of the accident | Low |
| 14 | No healthcare | x |
| 77 | Unknown, No health care | x |

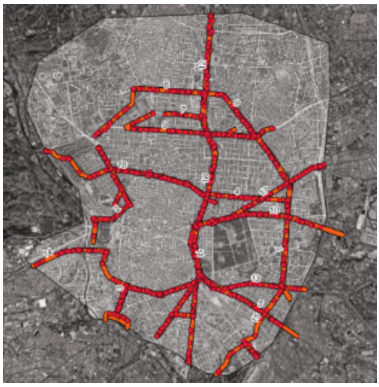


**Fig. 3.** Madrid Routes Crashes.

*Flow Intensity*. Madrid. I Traffic flow data were obtained from the municipal geoportal and were linked to the road network by merging–through the common "Id" field the CSV tables containing the geographic coordinates of traffic monitoring stations with the corresponding traffic flow data recorded during the observation period (November 2024) (Fig. 4a). The dataset included several variables, such as flow intensity (expressed in vehicles/hour), occupancy time, load, and average speed.

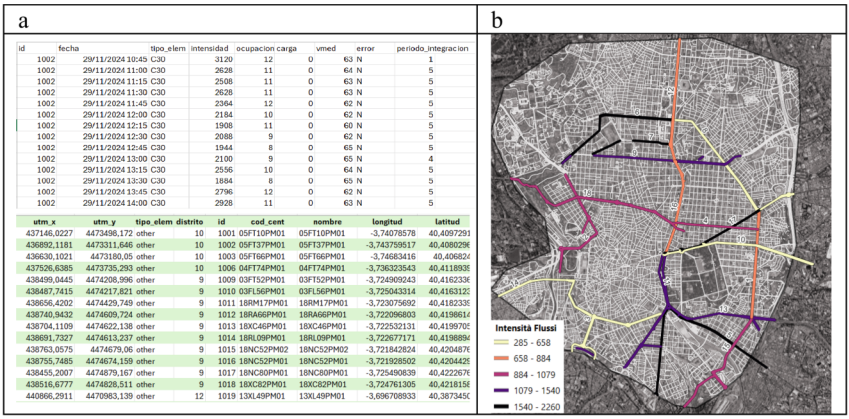
Using a "spatial join" between traffic monitoring stations and the urban itineraries, we assigned traffic intensity values to each itinerary. Traffic flow intensity was considered a suitable indicator to capture differences in vehicular volumes across itineraries in absolute terms (Fig. 4b).

To obtain a single intensity index for each itinerary j, which might intersect segments with different traffic intensities, we assigned the maximum intensity value recorded along the itinerary. This approach was chosen as a conservative estimate, assuming the worst case traffic conditions across the entire segment.

$$Flow\ Intensity_j = MaxIi \tag{4}$$

where:

$MaxI_i$ is the maximum intensity recorded along one of the arcs i that make up itinerary j




| id | fecha | tipo_elem | intensidad | ocupacion | carga | vmed | error | periodo_integracion |
|---|---|---|---|---|---|---|---|---|
| 1002 | 29/11/2024 10:45 | C30 | 3120 | 12 | 0 | 63 | N | 1 |
| 1002 | 29/11/2024 11:00 | C30 | 2628 | 11 | 0 | 64 | N | 5 |
| 1002 | 29/11/2024 11:15 | C30 | 2508 | 11 | 0 | 63 | N | 5 |
| 1002 | 29/11/2024 11:30 | C30 | 2628 | 11 | 0 | 63 | N | 5 |
| 1002 | 29/11/2024 11:45 | C30 | 2364 | 12 | 0 | 62 | N | 5 |
| 1002 | 29/11/2024 12:00 | C30 | 2184 | 10 | 0 | 62 | N | 5 |
| 1002 | 29/11/2024 12:15 | C30 | 1908 | 11 | 0 | 60 | N | 5 |
| 1002 | 29/11/2024 12:30 | C30 | 2088 | 9 | 0 | 62 | N | 5 |
| 1002 | 29/11/2024 12:45 | C30 | 1944 | 8 | 0 | 65 | N | 5 |
| 1002 | 29/11/2024 13:00 | C30 | 2100 | 9 | 0 | 65 | N | 4 |
| 1002 | 29/11/2024 13:15 | C30 | 2556 | 10 | 0 | 64 | N | 5 |
| 1002 | 29/11/2024 13:30 | C30 | 1884 | 8 | 0 | 65 | N | 5 |
| 1002 | 29/11/2024 13:45 | C30 | 2796 | 12 | 0 | 62 | N | 5 |
| 1002 | 29/11/2024 14:00 | C30 | 2928 | 11 | 0 | 63 | N | 5 |

| utm_x | utm_y | tipo_elem | distrito | id | cod_cent | nombre | longitud | latitud |
|---|---|---|---|---|---|---|---|---|
| 437146,0227 | 4473498,172 | other | 10 | 1001 | 05FT10PM01 | 05FT10PM01 | -3,74078578 | 40,4097291 |
| 436892,1181 | 4473311,646 | other | 10 | 1002 | 05FT37PM01 | 05FT37PM01 | -3,743759517 | 40,4080296 |
| 436630,1021 | 4473180,05 | other | 10 | 1003 | 05FT66PM01 | 05FT66PM01 | -3,74683416 | 40,406824 |
| 437526,6385 | 4473735,293 | other | 10 | 1006 | 04FT74PM01 | 04FT74PM01 | -3,736323543 | 40,411893 |
| 438499,0445 | 4474208,996 | other | 9 | 1009 | 03FT52PM01 | 03FT52PM01 | -3,724909243 | 40,416233 |
| 438487,7415 | 4474217,821 | other | 9 | 1010 | 03FL56PM01 | 03FL56PM01 | -3,725043314 | 40,416312 |
| 438656,4202 | 4474429,749 | other | 9 | 1011 | 18RM17PM01 | 18RM17PM01 | -3,723075692 | 40,418233 |
| 438740,9432 | 4474609,724 | other | 9 | 1012 | 18RA66PM01 | 18RA66PM01 | -3,722096803 | 40,419861 |
| 438704,1109 | 4474622,138 | other | 9 | 1013 | 18XC46PM01 | 18XC46PM01 | -3,722532131 | 40,419970 |
| 438691,7327 | 4474613,237 | other | 9 | 1014 | 18RL09PM01 | 18RL09PM01 | -3,722677171 | 40,419888 |
| 438763,0575 | 4474679,06 | other | 9 | 1015 | 18NC52PM02 | 18NC52PM02 | -3,721842824 | 40,420487 |
| 438755,7485 | 4474674,159 | other | 9 | 1016 | 18NC52PM01 | 18NC52PM01 | -3,721928502 | 40,420442 |
| 438455,2007 | 4474879,167 | other | 9 | 1017 | 18NC80PM01 | 18NC80PM01 | -3,725490839 | 40,422267 |
| 438516,6777 | 4474828,511 | other | 9 | 1018 | 18XC82PM01 | 18XC82PM01 | -3,724761305 | 40,421815 |
| 440866,2911 | 4470983,139 | other | 12 | 1019 | 13XL49PM01 | 13XL49PM01 | -3,696708933 | 40,387345 |

**Fig. 4.** Flows Table (a), Route Intensity Flows(b).

*Traffic Attractors.* The processing of the traffic attractors database required more time because, although several elements such as markets, hospitals, and schools were widely available on the geoportal, they needed to be reorganized into unique fields and further integrated with external databases like OSM. For this reason, the OSM database was ultimately preferred due to its homogeneity and data richness.

After gathering numerous elements of various typologies and levels of attractivity, we decided to focus only on indicators related to the number of hospitals, schools, and supermarkets. These were considered priorities due to their potential to generate intense traffic flows, thereby increasing users' exposure to crash risks particularly for vulnerable users, such as in the case of schools. These indicators were associated with the primary road network using a 1-km buffer, based on the assumption that the primary network exerts a wider spatial influence, connecting with attractors that are not necessarily adjacent. By counting, for each itinerary, the number of hospitals, schools, and supermarkets within this 1 km buffer, we estimated an attractiveness index of the itinerary (I_Attractivenessj) as the ratio between the total number of attractors (TotAttractorsj) and the length Dj of the itinerary itself (5).

$$I_Attractiveness_j = \frac{TotAttractorsj}{D_j} \tag{5}$$

where:

T *otAttractorsj* is the total of the Attractiveness elements belongs to itinerary j.

*Bus stop.* Bus stops are directly connected to the flow of pedestrians and therefore to their accessibility to the attractors, but they also represent a parameter relating to exposure to the risk of being run over by vehicles in transit near the stops. To associate the bus stops (Fig. 5b) a buffer of 30 m of the stops was considered in order to intersect the adjacent routes and count the number of stops per route. The index is calculated as the ratio between the number of stops and the length of the route (6).

$$I_Bus_j = \frac{TotBusj}{D_j} \tag{6}$$

where:

$TotBus_j$ is the total of the bus stop belongs to itinerary j

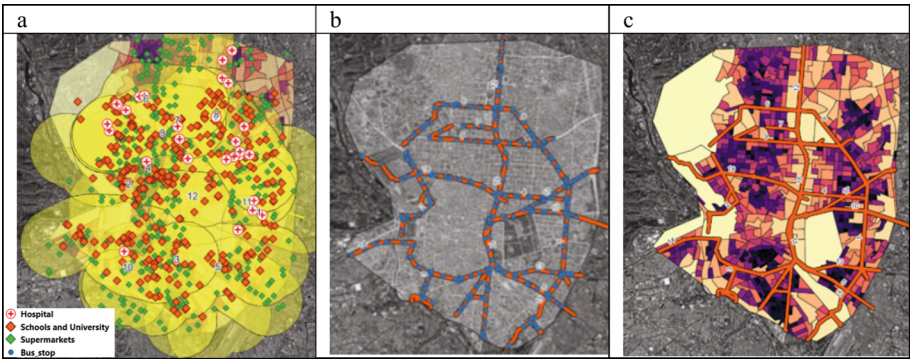



**Fig. 5.** Route buffer in attractors (a), Route's bus stop (b) Population density (c).

*Population density.* To estimate an index of population density, the shape of the routes was superimposed on the shape of the density (Fig. 5c), downloaded from the geoportal. The figure represents the population per square kilometer within the neighborhood section under 10,000 inhabitants. The intersection generates an array that for each row shows the route j and the intersecting density value. To obtain a unit density index for the route, an average value per kilometre is derived by dividing the sum of the intersecting densities and the length of the route (7).

$$Index\ Density_j = \frac{Tot\ Density_j}{D_j} \tag{7}$$

where:

$Density_j$ is the density belongs to itinerary j

**Infrastructure Madrid Group.** As far as the infrastructure group is concerned, the main element falls on the condition of the pavement, subsequently the number of traffic lights, intersections without traffic lights, the surfaces of the sidewalks, the number of LED Lampposts, the pedestrian crossings and the lengths of the cycle paths were estimated.

*Pavement*. As far as asphalt is concerned, its status has been defined according to the shape file relating to the asphalting interventions carried out, attributing a PCI value of 100 to the sections of the route intersected with it, for the sections not intersected, we have assumed a PCI equal to 70. In fact, this choice derives from sample observations of the roads made through Street View (SW), it was found that most of the asphalt was of sufficient quality. In order to estimate the lengths of the two types of asphalt, for each itinerary, an intersection procedure was first performed between asphalt shapes, with PCI 100 and shapes itineraries, then with the "Symmetrical difference" function the sections for which PCI 70 is assumed were extracted, copying the latter in the first intersection we can a table of the Itineraries with PCI 100 and 70 (Fig. 6a). In order to provide a unit value of PCI, for each Itinerary, the weighted average of the lengths of the sections has been made by their value of PCI (8).

*Numbers of Traffic Light.* For the identification and localization of the traffic lights, the data of the geoportal were integrated with those of OSM obtaining a shape file of the traffic lights present in the study area. In order to be able to associate the traffic lights to the network and therefore to each route, we intersected the points with the network after creating a buffer of 5 m, and then counted them for each route, the index is given by the ratio with the length of the intercepted route (Fig. 6b).

*Intersections without traffic lights.* To identify the intersections without traffic holes, we first located them, through the intersection of the lines of the total network of Madrid with the lines of the identified routes. By intersecting the traffic light buffer with the identified intersections, the intersections without difference traffic lights were obtained (Fig. 6c).

*Sidewalk Surfaces.* To identify the sidewalk surfaces of each Route, we buffered 30 m of the Routes to overlap them with the polygon of the adjacent sidewalks. To count the surfaces, we intersected the sidewalks with the route buffer and then added up the areas identified for each one. The index is given by the ratio between the sum of the areas of the j-th Route and the length of the j-th Route (Fig. 7a).

*Bike Lines.* Madrid's bike lane network was downloaded from the geoportal and intersected with the itineraries. This allowed us to calculate the percentage of bike lane length relative to the total length of each itinerary (Fig. 7b).

*Pedestrian Crossings.* Pedestrian crossings were identified exclusively using OSM. Their integration with the itineraries followed the same method used for bus stops (Fig. 8a).

*LED Lampposts.* We considered the number of LED lampposts along the itineraries relevant. The dataset includes lampposts with LED lights, mixed lighting, and traditional lighting types. The indicator represents the number of LED lampposts out of the total number of lampposts in each itinerary (Fig. 8b).

Below, we present the main infrastructure-related indices considered. The indices for traffic lights, unsignalized intersections, bike lanes, and lampposts (8) were all calculated

as the ratio of the number of elements within itinerary j to the length of itinerary j (6):

$$Index_PCI_j = \frac{\sum_{r=1}^{n} PCI_{rj} * length_{rj}}{D_j} \tag{8}$$

The various indices relating to the different traffic elements such as the number of traffic lights, intersections without traffic lights, pedestrian crossings, cycle paths and street lamps, have all been calculated as the ratio of the sum of the elements falling within route j divided by the length of route j (9):

$$Index\ \mathrm{E}_j = \frac{TotElementsj}{D_j} \tag{9}$$

where:

$PCI_{rj} * length_{rj}$ is the product of the PCI r times the length r belonging to route j
$D_j$ is the length of the route j
$E_j$ is the element of the estimated index that belongs to route j

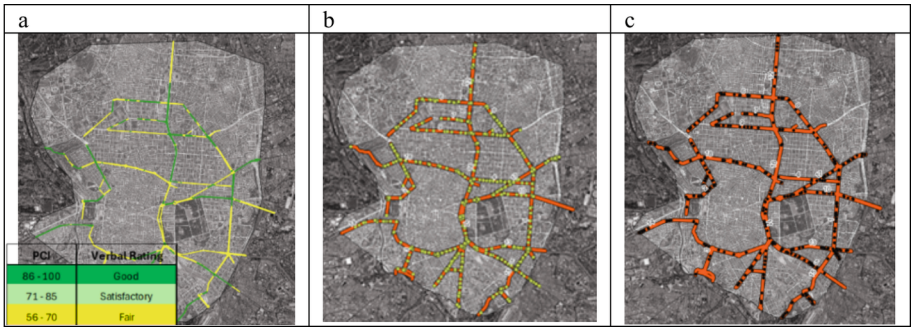



**Fig. 6.** PCI Pavement (a), Traffic lights(b), Intersections without Traffic lights (c).

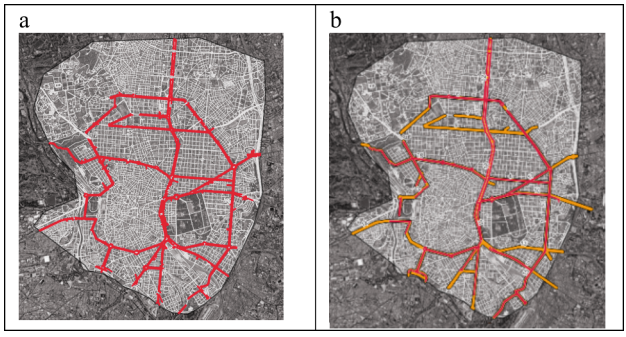



**Fig. 7.** Sidewalk (a), Cicle line(b).

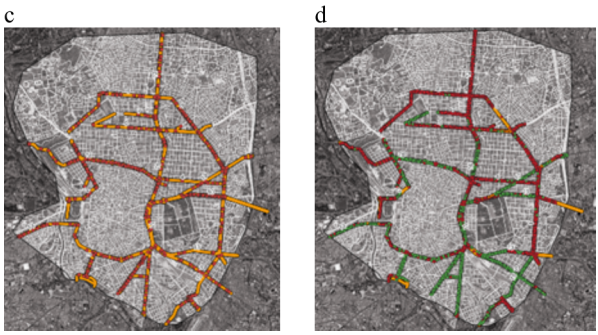



**Fig. 8.** Crossway (a), Led Illumination in green (b).

**Case Study Iglesias.** The town of Iglesias, located in the south of Sardinia (Italy), is an example of a small town with less than 30,000 inhabitants consisting of a central urban core, with a historic center characterized by the presence of a CDB with various commercial activities, schools, hospital and public offices, residential nuclei located in various areas of the city and peripheral areas with larger commercial activities such as supermarkets, cinemas and sports facilities.Also in this case we have divided the research into two parts, identification of the itineraries and elements of the three destination areas (Infrastructure, Safety and Accessibility) highlighting the similarities and differences compared to the case of Madrid in terms of databases and survey methodologies. For the elements of safety, we used the accident database, obtained through authorization at the Contact Center of the Institute of Statistics (Istat), for the years 2011 and 2021, while in 2022 for the moment we entered the partial data provided by the local police. For this case study, we considered all the urban attributes present, both high and low, with respect to the generation of traffic flows. This choice is due to the fact that in a small urban center, the main network allows you to reach almost all urban attractions. In particular, in the case of Iglesias, the main network passing adjacent to the historic urban center, takes charge of flows due to the presence of different commercial activities and city meeting places. The methodology we describe has been applied to the entire urban and sub-urban area of about 6 x 2 km.

**Definition of Iglesias Itineraries.** For the road network of Iglesias we could count on several alternatives, the road network of the regional geoportal, the network developed by our research department and the network obtained from the purchase of the TTT database. We used the latter as it had all the information necessary for identifying the itineraries, i.e. the hierarchy with the name of the streets and the values of traffic flows updated to the last two years (Fig. 2). Another advantage of this database is that it divides the network into two directions of travel. The TTT network hierarchizes the network through the "FRC" field, an acronym for Functional Road Class, a field used to merge partial arcs together with the street name field. We have carried out a further hierarchization, defining it as "primary" by introducing a network of Itineraries obtained as the sum of partial arcs characterized by FRC values ranging from 2 to 5. As a final

result, 16 itineraries of average length of 1 km each were identified, two of which of about 2.5 km, as we can see in Fig. 9.



**Fig. 9.** Iglesias's Routes.

**Safety Group Iglesias.** The safety group includes indicators derived from the accident database, built using data obtained from ISTAT. As with the ISTAT data for Madrid, we have access to detailed information regarding the type of event, its severity, and details about the users involved. To simplify data interpretation, we organized the database so that each accident record includes the total number of injuries, pedestrian victims, and fatalities involved in each incident. This approach allows for indices comparable to those used for Madrid, with the difference that the Severity Index in this case lacks a parameter differentiating the se-verity levels of the injuries.

**Accessibility Group Iglesias.** For the accessibility group, we propose different indices due to both the lower availability and variety of data, and the lesser necessity for such detailed indicators.

*Traffic flows.* Using TTT databases, we estimated a traffic intensity value expressed in vehicles per hour, based on the Hits field corresponding to the morning peak hour (8 a.m.). To obtain these values, we generated a 54-day report from the TomTom Move platform, aiming to compute average values that best represent network behavior over a three-month work period.

The Hits field indicates the number of cars detected in the ith segment of the j-th itinerary. This number does not reflect the actual volume of vehicles using the network per hour, since, as stated by TomTom, it represents approximately 3% of the total. To estimate the actual number of circulating vehicles, we adjusted the data using a 3% penetration rate and divided it by the 54 days of observation. We also validated these values through on-site field measurements. From an operational standpoint, by merging the values from the CSV file with the itinerary network using the "Id" field, we obtained a representation of the maximum average intensity values for each itinerary (Fig. 10).

*Traffic attractors***.** Unlike in Madrid, urban attractors were considered in their entirety and are often located adjacent to the primary network, which shows no major differences



**Fig. 10.** Flow intensity.

in levels of attractiveness. The itineraries reach various attractors directly, particularly as the primary road network runs alongside the historic city center, where there are many commercial activities such as shops, private offices, and more, which we assigned lower attractiveness values.

The attractiveness index refers to the overall attractiveness of each itinerary, calculated as the sum of all attractors located nearby. The work involved geolocating these activities within the GIS project and assigning different weights based on activity type [19], with maximum values (10) for schools, hospitals, and supermarkets, and lower values (1–2) for small businesses and shops. To obtain the data, we used multiple databases including Google Earth, OpenStreetMap (OSM), and a highly useful list provided by the Municipality of Iglesias used for the waste tax (TARI). This list includes a key parameter surface area which we used to estimate differentiated weights based on the size of each establishment.

To spatially distribute point-based attractiveness values across the urban network, we applied a Kernel Density analysis (Fig. 11a) using a dedicated plugin, defining each element's attractiveness value based on the Val1 parameter [19]. The density map was generated using a 100-m search radius weighted by Val1.

This parameter was calculated as follows: $\text{Val1} = \sqrt{(\text{P} \times \text{T} \times \text{S})}$, where: P is the weight of the activity type, T is the exposure or operating time (ranging from 3 to 8), and S is a sensitivity value (ranging from 10 to 1), introduced to reflect the risk to vulnerable users in the case of an accident–particularly near schools and bus stops.

The Val1 parameter was then used to generate the Kernel Density map, which was subsequently vectorized. By intersecting the itineraries with this vector layer, we produced a matrix with rows representing each itinerary and its corresponding attractiveness. The unique attractiveness value for each itinerary was derived from the sum of all intersected values (Fig. 11b).

*Population density.* Population density data was obtained from the ISTAT web site and integrated into the Itinerary network using the same calculation methodology as for Madrid.

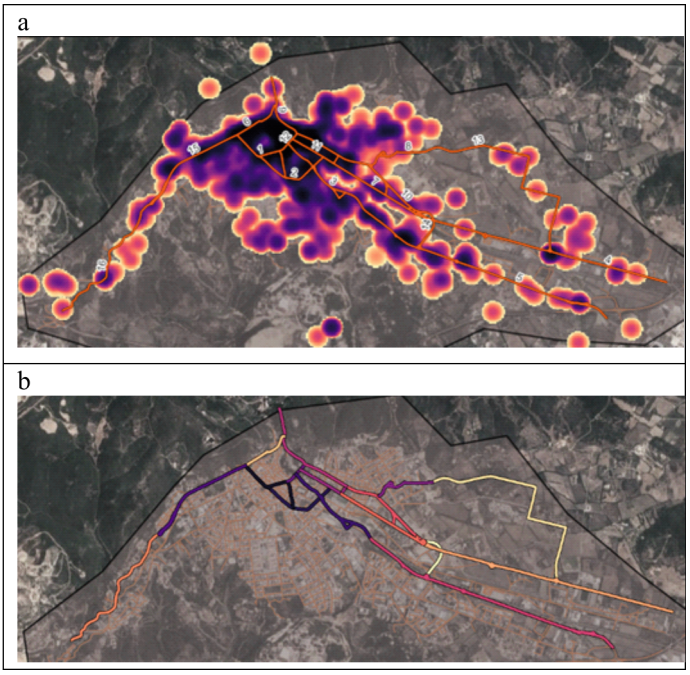



**Fig. 11.** Kernel density of attractiveness(a), Route's attractiveness(b).

*Bus stops.* Bus stop locations for this case study were identified using Google Earth and verified using Google Maps. Integration into the itineraries and calculation of the related indices followed the same method used for Madrid.

**Infrastructure Group Iglesias**

*Pavement conditions.* Unlike Madrid, due to the lack of a dedicated asphalt data base, we opted for an objective assessment of pavement conditions. Condition ratings were assigned using PCI (Pavement Condition Index) values derived from visual inspection by Street View and attributed to each road segment (Fig. 12) To assign a single PCI value to each itinerary, we computed a weighted average based on segment lengths, divided by the total length of the itinerary as described in Eq. 9.

*Pedestrian crossings.* The list of pedestrian crossings was compiled through OSM data and supplemented with manual additions identified by satellite imagery (2022) provided by the Sardinia Geoportal. This analysis allowed us to distinguish between flat crossings and raised ones. The proposed index is the percentage of crossings per itinerary length, weighted by the proportion of raised crossings.

*Number of intersections.* In this regard, we calculated the number of intersections for each itinerary by intersecting the identified itinerary network with the overall road network.

*Bicycle Lanes and Traffic Lights.* Indices for bicycle lanes and traffic lights were not included in the analysis, as they were not considered relevant. Only one signalized intersection and one improperly constructed bicycle lane were identified.

a

| PCI | Verbal Rating |
|---|---|
| 86 - 100 | Good |
| 71 - 85 | Satisfactory |
| 56 - 70 | Fair |
| 41 - 55 | Poor |
| 26 - 41 | Very Poor |
| 11 - 25 | Serius |
| 0 - 10 | Failed |

b

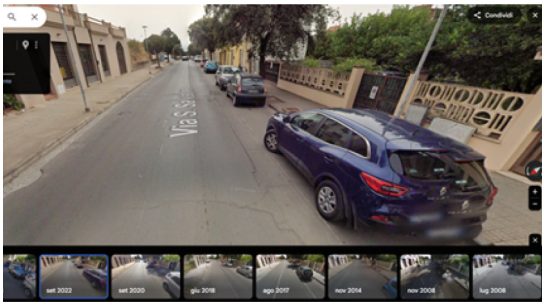


**Fig. 12.** Street View osservation(a), PCI values (b).

## 5 Comparison and Differences

Looking at the two figures below, we see a summary of the identified indicators for the two case studies, along with the main data sources. For the Safety and Accessibility groups, we used the same types of indicators, while for the Infra-structure group there are differences due to the lack of available data and the negligible relevance of certain indicators to the context of the study.

Regarding Accessibility, the main difference in the case of Iglesias lies in the approach used to calculate the attractiveness index. In this case, all attractors were considered, not just those with high attractiveness, as was done for Madrid. The infrastructure group includes fewer indicators because the number of traffic lights and the length of bicycle lanes were not deemed numerically relevant. Other indicators, such as the number of LED Lampposts and sidewalks, were not included due to the unavailability of georeferenced datasets and the inability to assess their numerical relevance.

The lack of available data highlights how analyzing road safety can be more time-consuming in areas albeit not large in size that lack georeferenced data, compared to metropolises or large cities with well-structured geoportals. Moreover, for cities without a geoportal, data collection times increase with the size of the city and the number of inhabitants (Fig. 13).

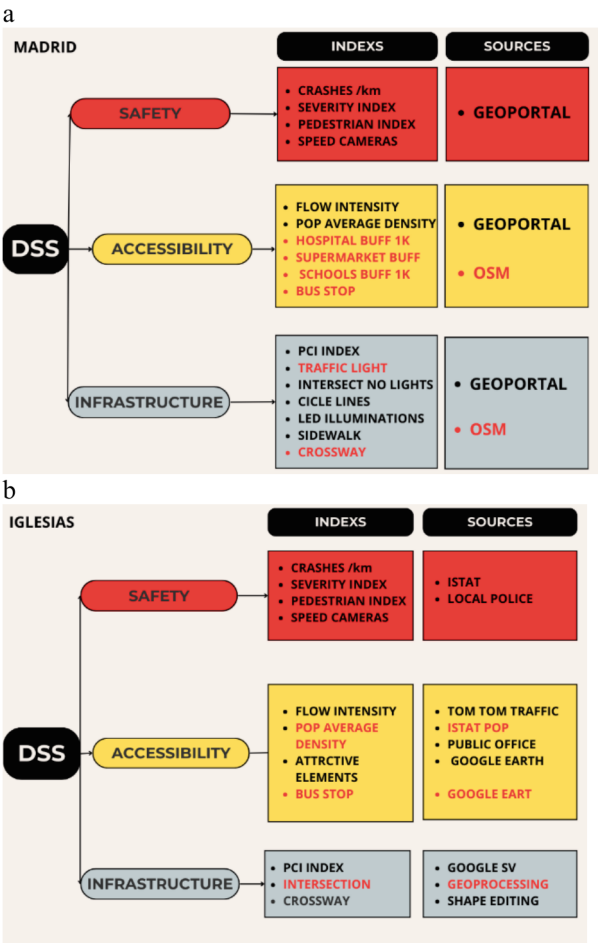



**Fig. 13.** DSS Flow Chart Madrid (a), DSS Flow Chart Iglesias (b).

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