# GIS-Based Geospatial Data Analysis: the Security of Cycle Paths in Modena

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***Abstract*—The use of fossil fuels is contributing to the global climate crisis and is threatening the sustainability of the planet. Bicycles are a vital component of the solution, as they can help mitigate the effects of climate change and improve the quality of life for all. However, cities need to be equipped with the necessary infrastructure to support their use guaranteeing safety for cyclists. Moreover, cyclists should plan their route considering the level of security associated with the different available options to reach their destination. The paper tests and presents a method that aims to integrate geographical data from various sources with different geometries and formats into a single view of the cycle paths in the province of Modena, Italy. The Geographic Information System (GIS) software functionalities have been exploited to classify paths in 5 categories: from protected bike lanes to streets with no bike infrastructure. The type of traffic that co-exists in each cycle path was analysed too. The main outcome of this research is a visualization of the cycle paths in the province of Modena highlighting the security of paths, the discontinuity of the routes, and the less covered areas. Moreover, a cycle paths graph data model was generated to perform routing based on the security level.**

***Index Terms*—GIS, sustainable mobility, cycle paths, data integration, geospatial data**

## I. Introduction

Nowadays, the world's rapidly growing cities face many challenges when it comes to sustainability and livability, especially concerning urban mobility. Due to environmental and economical concerns related to the use of cars, the value of cycling is finally gaining recognition. The use of bicycles is developing rapidly in the urban context thanks to new technologies: bike-sharing systems, electric bikes (e-bikes) that extend the radius of action, and cargo bikes that allow transporting goods. City planning will therefore benefit from a focus on promoting cycling. As reported by the European Cyclists' Federation [1], one of the primary reasons for people to avoid riding a bicycle is the perceived unsafety of sharing the roadway with motorized transport; thus, to encourage people to adopt cycling as their main transport mean it must be made as safe as possible.

The World Health Organization reported that the risk factors for cyclist-related injuries and fatalities vary according to the trip purpose, traffic mix, and type of road [2]. In mixed traffic settings, where both cyclists and other motorized vehicles travel on the same road, the speed of motorized traffic strongly influences the crash risk and the crash consequences. It is reported that the likelihood of a fatal injury for cyclists increases 11 times with vehicle speeds above 64.4 km/h and 16 times at 80.5 km/h. Analyzing bicycle collision police reports in Berkeley [3], a strong relationship between the type of streets and cyclist security emerged. Therefore, a classification of the types of cycle paths can significantly ameliorate the life of cyclists while improving the safety of their trips.

Cycle paths are usually stored and represented as geospatial data. Geospatial data identify natural or artificial elements located on the earth's surface and are characterized by: the geographical coordinates associated with a geographical reference system, and a geometry that represents their shape. There are two main ways to represent geospatial data: as vector or raster. When using vectors, the objects are represented as points, lines, or polygons with attributes that describe their characteristics. A raster, instead, is a matrix composed of several cells. The space is divided systematically as a grid, and a value is associated to each cell. Rasters are field-based and generally employed for representing continuous phenomena (e.g temperature or humidity maps). Vectors instead are object-based; thus, each element is related to a real existing object. Open geospatial data are available in municipalities' and regional's geo-portals and provided by Open Street Map[1] (OSM). The available data are often in different formats and refer to different Spatial Reference Systems (SRS). The same object can be represented with a slightly different shape or divided into several smaller objects. For this reason, successfully integrate data from various sources and identify the different representations of the same object are open research topics. Geographic Information Systems (GIS) software products allow generating, integrating, analysing, and visualizing geospatial data on digital maps. They can be employed to open and manage geospatial data in order to elaborate the available information and generate new insights.

In this paper, we present an example of the profitable usage

[1] https://www.openstreetmap.org/

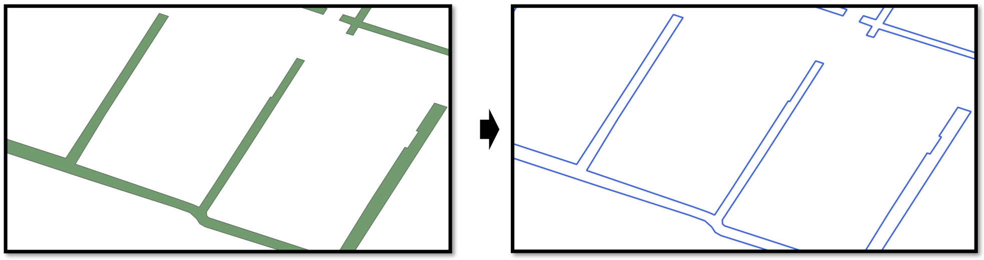

Fig. 1. Geometries obtained by applying the ‘From polygons to lines’ QGIS tool to the Geoportal layer.

of the GIS software QGIS[2] for analyzing and classifying cycle paths in the urban area of the province of Modena; since cycle paths have a precise shape, we focus on linear and polygonal vector data. The main outcomes of this research are detailed maps displaying every cycle path and road segment coloured according to the security level and the mixed traffic. Moreover, the obtained cycle paths are employed to generate a graph model to enable routing based on the security level.

Section II presents the state of the art. Then, in Section III, the use case of the province of Modena is presented. Then, Section IV describes the employed data sources. Section V discussed different approaches that attempted to integrate data coming from sources with different geometries types and presents the adopted solution. Furthermore, the classification of the cycle paths based on the security level and the mixed traffic is described in Section VI. The obtained results are presented and discussed in Section VII. Section VIII presents the graph models for cycle paths. Finally, conclusions are delivered in Section IX.

## II. Related Work

There are several examples in the literature of the profitable use of GIS software to analyze geospatial information and generate new insight into the urban environment. In [4], GIS for transport (GIS-T) applications integrated with mathematical models are used to analyze the public transportation in Oradea (Romania) and its impact on urban traffic. GIS-based software is commonly employed for land-use suitability analysis [5], [6], and for road network generation and analysis [7], [8]. In the field of sustainable mobility, and particularly for bicycle transport infrastructure, the use of GIS is consolidated. In [9], the advantage of inserting new cycle paths in the urban environment is analyzed considering the combination with rail transport in the generation of new multi-modal routes that will substitute private cars. Moreover, [10] presents a routing methodology based on leisure and safety-related criteria employing the ArcGIS software. Research has been conducted to evaluate where to locate new cycle paths in a city. For example, in [11] in Zografou (Greece) a bikeability index is evaluated for each road using GIS software. The index is based on 15 aspects: 4 related to the road network (the slope, the junction density, the traffic density, and the traffic speed), 3 related to the urban environment (the presence of natural elements, buildings, and the centrality), and 3 related with the services( urban activities, public transport, bike-sharing stations). In this case, security is only one of the aspects that are taken into consideration. Besides, in [12], 4 different Bicycle Level Of Service (BLOS) methodologies are employed as routing criteria to verify if the route choices observed by empirical data are related to the BLOS indicators. As a result of this study, the authors conclude that the match rate between the optimal routes based on BLOS and the empirical routes is lower than expected ($< 30\%$); this probably depends on the fact that cyclists when planning their routes do not take into consideration the elements that mainly influence the BLOS: bicycle separation from traffic, number and type of traffic lanes, vehicular average speed, median strip, shoulder, surface quality, and width of the outside lane. For this reason, to help cyclists in choosing the safer path, we will define a safety index for each cycle path in the city of Modena.

## III. Study Area

The province of Modena is located in northern Italy and has more than 700000 inhabitants and a surface of 2688 $km^2$. The road network is composed of 1026 km of streets for vehicular circulation and more than 300 km of cycle paths. The traffic conditions and the impact on air pollution within the city have been studied in previous research activities [13]–[15], highlighting the necessity of effective measures to improve sustainable mobility. The DAS insurance institute studied the statistics of accidents that involve bikes in Italy [3]. They observed that the Emilia Romagna region has the highest number of road accidents that involve bicycles in Italy. Moreover, in 2021, the province of Modena register one accident every 1415 residents and 8 deaths. For this reason, a focus on security levels of the available cycle paths may help to recognize where to act in order to enhance cyclists’ safety.

## IV. Data Sources

The main source of information for this study was OSM: an open crowdsourced archive of geospatial data. OSM collects data in several ways: through GPS trajectories made available by users, through satellite photos, and through the help of public administrations and common users that enrich the available data by inserting new elements in the map. Overpass

[2]https://www.qgis.org/it/site/

[3]https://www.das.it/incidenti-stradali-in-italia-i-dati-del-2021/

Turbo[4], a web service based on Overpass QL language, can be used to filter and get the OSM data regarding cycle paths in GeoJson format. We rely on the QickOSM[5] QGIS plugin which is based on Overpass API and allows querying the OSM archive through Overpass QL language and generating directly a QGIS vector layer. To select only the cycle paths, some filters have been applied to the way objects:

- **way[‘highway’ = ‘cycleway’]** allows selecting only the streets designated for bicycles;
- **way[‘bicycle’ = ‘yes’]** allows selecting all type of streets where bicycles can travel;
- **way[‘bicycle’ = ‘designated’]** allows selecting streets where cycling is legal andn at least a lane is explicitly designated for bikes.

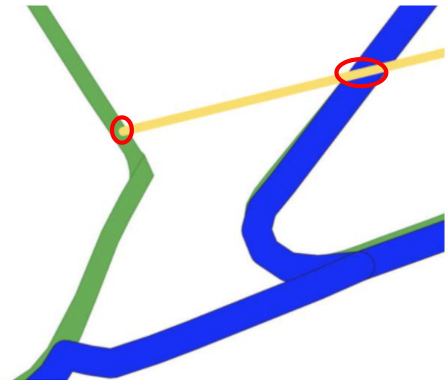

Fig. 3. An example of partially overlapping geometries; intersections are highlighted with red circles.

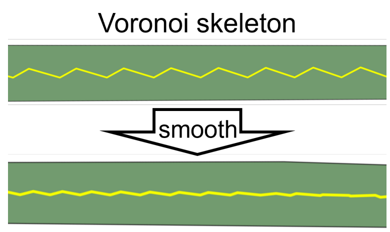


Fig. 2. The Voronoi skeleton (yellow line) of the green polygon before and after smoothing.

In OSM, each entity can be: a node (a point), a way (a collection of points), or a relation between other elements. For this reason, the best way to represent the provided geospatial data is through an object-based vector layer. The ‘merge vectors layers’ tool of QGIS was employed to generate a unique layer from the three queries. Since OSM information can be incomplete or erroneous for their crowdsourced nature, another, more reliable source of information was needed. The province of Modena is part of the Emilia Romagna region that has a geoportal where geospatial data are made openly available for citizens. In particular, the additional source of information was provided by the database[6] published by the statistic and geographical information systems service of the Emilia Romagna region that maps all the cycle paths in the region from aerial images. Data are vectors in the shapefile format.

## V. Data Integration

In the OSM data structure, cycle paths are represented as ways: a collection of points in space; thus, their geometries are represented as multi-lines. However, the data elaborated from aerial images and provided by the Emilia Romagna Geoportal are multi-polygons (ensemble of polygons). In order to integrate this data, the two different geometries should be converted into a similar format. Integrating the data, three main issues emerged:

- Managing the two different geometries: the geometry conversion,
- Studying when the two layers overlap: the overlapping analysis,
- Managing the one-to-many relationship between the Geoportal layer and the OSM layer: the one-to-many analysis.

### A. *The geometry conversion*

We followed two different approaches to reduce the two layers to the same geometrical representation. Firstly, we try to convert the Geoportal multi-polygon layer to a multi-line layer through the ‘from polygons to lines’ tool of QGIS. The obtained layer was composed of the perimeter of the polygons (Figure 1); however, the geometries of the perimeters do not correspond to the OSM line representation. Therefore, we employed the Voronoi skeleton tool that, as described in [16], partitions each polygon in a Voronoi diagram of its boundary points and then constructs the skeleton as the composition of the internal profiles of the diagram’s shapes. In this way, the central line of the polygon is extracted, but it is composed of several segments (see Figure 2); thus, we smooth the resulting line to obtain a more regular result. The generated layer is a multi-line layer that should be compared with the OSM cycle path layer. We observe that the lines obtained from the Geoportal and the OSM layer do not overlap entirely but have a small distance. Their low distance, however, does not imply that the two lines represent the same real object. We observe several cases in which the OSM layer line refers to the vehicular road while the Geoportal line refers to a cycle path parallel to that road. For this reason, the polygonal geometry of the layer appears to be influential when comparing the two layers. Therefore, we try a different approach: converting the OSM multi-line layer into a polygonal layer. In order to do that, the ‘Buffer’ QGIS tool was employed. This spatial algorithm generates a buffering area around the lines of the input layer with a given fixed width. We defined this width as the average of the sampled width of the polygons of the Geoportal layer (6.5 meters). This second solution appears to

[4]https://overpass-turbo.eu/

[5]https://plugins.qgis.org/plugins/QuickOSM/

[6]https://geoportale.regione.emilia-romagna.it/catalogo/dati-cartografici/cartografia-di-base/database-topografico-regionale/viabilita-e-trasporti/strade/layer

be more reliable than the first one because it preserves the bi-dimensionality of cycle paths.

### *B. The overlapping analysis*

Following the second approach, two polygonal layers were produced: the original Geoportal layer and the OSM buffered layer. When comparing them, we have three possible scenarios:

- objects could be mapped in both layers,
- objects could be mapped only by the OSM buffered layer,
- objects could be mapped only by the Geoportal layer.

Identify objects that are only in the OSM, or only in the Geoportal layer, is quite easy. Applying the overlap PostGIS function to the geometries of the two layers: when the returned value is 0, we know that the geometries are not overlapping. In this case, the object will maintain only the attributes associate with its own layer. However, when the two geometries overlap, it is difficult to determine if they represent the same object in reality. For example, in Figure 3, the blue and the green geometry are overlapping, and they represent the same object; however, the yellow line is overlapping with both the green and the blue polygons (red circles), but it is clearly a different object. For this reason, the 'Overlap Analysis' tool was employed to generate a virtual layer: the 'Overlaps layer' that contains all the geometries of the Geoportal layer that overlap with the OSM buffered layer. As additional attributes, the area and the percentage of the overlapping surface between the two geometries are evaluated; then, the overlaps with an extention lower than the 60% of the object area are filtered out. In this way, we obtained the Geoportal layer's geometries also present in the OSM buffered layer. For these objects, the resulting integrated layer should contain the attributes of both layers.

### *C. The one-to-many analysis*

Since the Geoportal layer is composed of big objects, it may happen that several objects of the OSM buffered layer correspond to the same object in the Geoportal layer. Considering that the Geoportal layer is assumed to be more reliable and its geometries are the one to keep when the objects are present in both layers, the OSM buffered layer attributes of several objects should be associated to a unique entity of the Geoportal layer. Even if generally the attributes of the OSM buffered objects referring to the same Geoportal object have the same values, it may happen that these attributes are different. In this case, an approximation is needed: the more frequent value is associated with each attribute, and duplicates are removed. Finally, we obtained the integrated layer with: all attributes of both layers for the objects that are present in both layers (875 records), only the attributes associated with the OSM buffered layer when the object is only in the OSM layer (4675 records), and only the attributes associated with the Geoportal layer when no OSM information is available (541 records).

## VI. Cycle path classification

Now, that the integrated layer containing all the information regarding cycle paths has finally been generated; analysing the values of the attributes and their combination, we can define a security level and create a map for users. The final integrated layer contains several attributes that describe the type of cycle path. The list of these attributes and their description is provided in Table I. As can be observed, the Geoportal layer has only one significant attribute since the geometries contained in this layer are all designated cycle paths that can be isolated or physically protected. Although, as described in Section IV, the OSM layer contains all the roads where cyclists are allowed to travel. For this reason, the classification of the roads not present in the Geoportal layer is more complex. The combination of values of different attributes are employed to define a classification of the routes based on the security levels. Moreover, since the other vehicles allowed to travel across each path are an additional element that influence the cyclists security, an additional classification based on mixed traffic is provided.

### *A. Security levels*

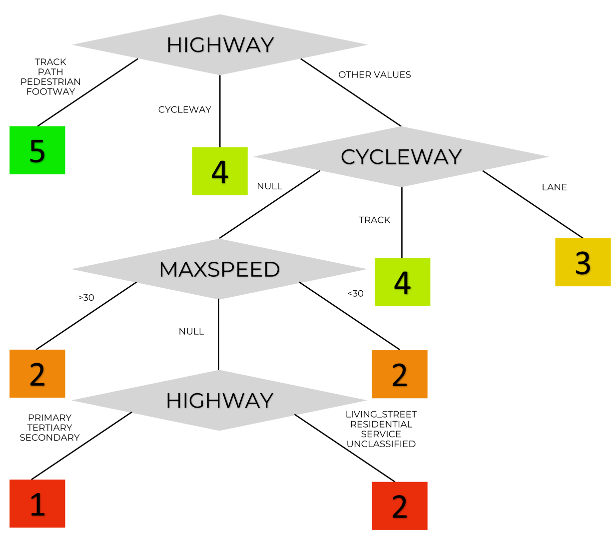


Fig. 4. Security levels decision tree.

We define 5 security levels ordered from the lower to the higher security:

1) Near high-speed traffic
2) Near low-speed traffic
3) On-road cycle dedicated lane
4) Physically protected
5) Far away from traffic

The first level corresponds to the roads with a speed limit higher than 30 km/h, where the bicycle circulation is legal but without a dedicated lane. The second level corresponds to the roads with a speed limit lower or equal to 30 km/h, where the bicycle circulation is legal but without a dedicated lane. The third level, instead, is for the cycle lanes that are part of

TABLE I
ATTRIBUTES DESCRIPTION.

| | Attribute | Description | Values |
|---|---|---|---|
| Geoportal | D_TY_PZ_CC | It refers to the position of the cycle path. When 'isolated' it is far away from the street: physically separated from the vehicular traffic. | 'isolated' or 'near the street' |
| OSM | highway | It refers to the type of road. It can provide information about the type of vehicles allowed to circulate on the street and their average speed. | cycleway, path, pedestrian, footway, track, primary, secondary, tertiary, living_street, residential, service, unclassified |
| | cycleway | It refers to a designated routes for bikers. | lane, track |
| | maxspeed | It indicates the speed limit of the street. | Integer (km/h) |
| | bicycle | It indicates if a bicycle can travel on that road. | yes, no, designated |
| | foot | It indicates if pedestrians can travel on that road. | yes, no, designated |

the street near the vehicular lanes, not separated by physical elements but only with signs on the asphalt. The fourth level of security is associated with a physically protected cycle paths that can be near the street but is separated by architectural elements (e.g. flower beds, traffic islands, and sidewalks). Finally, the fifth level of security describes cycle paths inside parks or protected areas: isolated from motor vehicles derived traffic. For the objects that are contained only in the Geoportal layer, the security level is defined based on the D_TY_PZ_CC attribute; when its value is 'isolated', the cycle paths are classified in the $5^{th}$ level, although they are classified in the $4^{th}$. For all the other objects, the attributes associated with

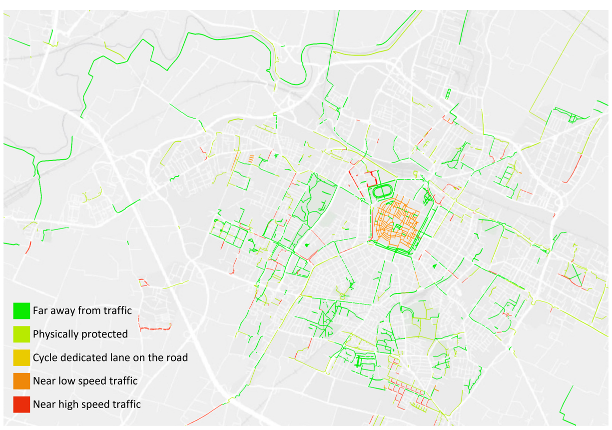


Fig. 5. Security level map for the city of Modena.

the OSM layer are exploited to perform the classification. To identify the $5^{th}$, $4^{th}$ and the $3^{th}$ classes the type of road is taken into consideration ('highway' attribute) together with the 'cycleway' tag value when available. The decision tree is shown in Figure 4. As can be observed, the distinction between the $1^{st}$ and the $2^{nd}$ class is based on the speed limit ('maxspeed' attribute) or, when this information is not available, the type of street ('highway' attribute). The classification is implemented through a PostGIS query performed on the integrated layer.

### B. Mixed Traffic

Cyclists might need to change their behavior when their route is shared with pedestrians or motorized traffic; thus, they should plan their trip considering this aspect. We can easily distinguish the cycle paths shared with motor vehicles by exploiting the security level classification. The cycle paths that belong to $1^{st}$ and $2^{nd}$ class are shared with motor vehicles. For the other security levels, instead, the attributes 'bicycle' and 'foot' are taken into consideration to distinguish between a cycling area and a pedestrian/cycle path. These attributes indicate if cyclists and pedestrians are legally allowed to travel on the road. When the road is a cycle path or is bicycle designated then it is identified as a cycling area; however, if it is a footway and cycling is allowed, then it is classified as a pedestrian/cycle path.

## VII. RESULTS AND DISCUSSION

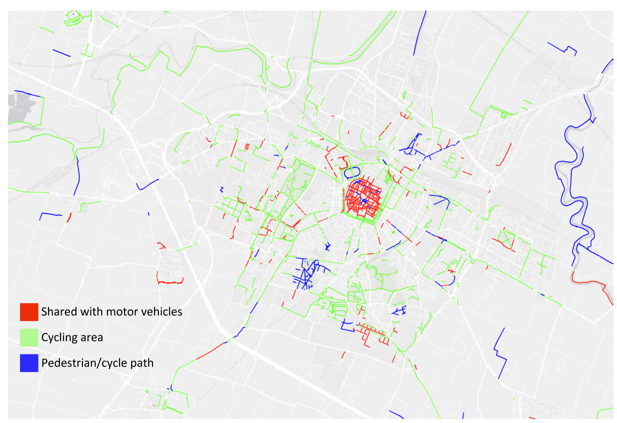


Fig. 6. Mixed traffic map for the city of Modena.

Analyzing the distribution of security levels in the province of Modena, we discover that the 58% (3445 records) of the total kilometers of cycle paths are far away from traffic, and the 30% (1745 records) are physically protected. A small percentage (the 5%, 484 records) is near low-speed traffic and (the 7%, 418 records) near high-speed traffic. Moreover, in the city of Modena, some on-road cycle dedicated lanes have been introduced recently (2021) but they have not been mapped yet.

For this reason, the percentage of elements in the $3^{rd}$ class is zero. As described in Section IV, the data collected from OSM concerns the streets where bicycles can travel. However, we observed several cases where this attribute is not present due to mapping errors; this explains the very low percentages of both the $1^{st}$ and the $2^{nd}$ class. To overcome this issue, a better solution could be to exclude only the streets where the 'bicycle' attribute indicates that cyclist traffic is forbidden (bicycle = 'no'). Since OSM data are crowdsourced, there could be some errors in the values of the attributes and some latency in the insertion of new elements. The analysis based on the mixed traffic reveals that 44% of the cycle paths is a cycle area (2477 records), and 39% is a pedestrian/cycle path (2190 records). Moreover, only the 16% of the cycle paths share traffic with motor vehicles (902 records). As a result, we generated a map for the province of Modena with colors representing security levels. The green is associated with a higher security level and the red with the lowest. In Figure 5, the map obtained for the urban area of the city of Modena is displayed. Also, similarly, a map for the mixed traffic was generated (see Figure 6). The map data are openly available in the shapefile format and as QGIS layers ('.qlr' format) in the Github directory [7]. Observing the maps, the majority of cycle paths appear to have a high security level and are classified as cycle areas. Although, the city center has a low security level since the traffic is shared by motor vehicles. Hopefully, the majority of roads in the city center can be accessed only by residents and allowed vehicles; thus, the traffic is limited.

## VIII. The Cycle Paths Graph Model

In order to perform the shortest path finding based on the security level, a Cycle Paths Graph Model (CPGM) was generated. We employ the ACID compliant Neo4j[8] database with the Neo4j Spatial library that allows storing different types of geometries as single properties of nodes in Well known Binary (WKB) format: the same geographic geometry format employed by PostgreSQL. Neo4j Spatial facilitates the enabling of spatial operations on data. In particular, you can add spatial indexes, and perform spatial operations on the data: like searching for data within specified regions or a specified distance from a given point. To exploit the Neo4j Spatial functions the nodes in the graph should be located in a 'Spatial Layer' that enables spatial indexing with space-filling curves in 2D or 3D over an underlying generalized B+Tree. A network of cycle paths is composed of cycle paths sections connected by street crossings or crosswalks. In the resulting graph, the nodes will be the sections of continuous cycle paths with their polygonal geometry labeled as 'BicycleLane'. Neo4j spatial functionalities allow finding the 'BicycleLane' nodes that are intersecting. When there is an intersection between two cycle paths, the cyclist can travel directly from the first to the second and vice versa; therefore, in the graph model the cycle paths are linked with the `'CONTINUE_ON_BYCICLE_LANE'` relationship. The resulting path is 'BicycleLane'-'BicycleLane'-'BicycleLane'. It may happen that cycle phats' sections are not continuous but divided by crossings; in this case, the cyclist needs to cross the street to complete its path from the first to the second section. Information about the crossings' locations has been fetched from OSM through the Overpass API. Crossings are mapped in OSM as nodes or as ways objects: depending on the choice of the user that mapped them; thus, as can be seen in Figure 7.A, their geometry can be a point or a line. We inserted the crossings in the graph model as nodes labeled as 'Crossing'. However, to manage the difference between the geometry, we inserted an additional label to distinguish between 'CrossNode' and 'CrossWay'. Finally, we search for the cycle paths in a distance equal to or lower than 9 meters from a 'CrossNode' or intersecting a 'CrossWay' and generate the `'CROSS_THE_ROAD'` bidirectional relationship between the resulting cycle paths and the crossing. The resulting path is a 'BicycleLane'-'Crossing'-'BicycleLane'. Moreover, cycle paths are connected with the Point Of Interests (POI) located nearby (considering a maximum distance ray of 100 meters) with a `'NEAR_TO'` relationship. As a result, a path finding algorithm can easily find the cycle route between a POI source and a POI destination. In 7, we can observe the graph model derived from a real map and the schema of the graph database. The model can be automatically generated through the Python-based open-source code available in our repository [9]. This model enables the generation of optimal paths based on different approaches: (e.g, the security level, the number of crossings, and the length). Moreover, as described in [17], we are working on the integration of different transport networks' graph models combining cycling, footing, public transport, and road transport to generate multi-modal routes that couple different transport means.

## IX. Conclusion

In our use case, we exploited the data provided by the Emilia Romagna region, and we elaborate a procedure for geospatial data integration through QGIS to integrate them with OSM data. A similar approach can be repeated in other cities or with different data. We define security levels mainly based on OSM attributes to allow the replication of this project in any urban environment, even where public administrations are not providing any data regarding cycle paths. Moreover, despite the availability of other more reliable data, we encourage researchers and planners to consider crowdsourced data to fill data gaps and integrate new information. Finally, We employ the resulting data to automatically generate a graph model for cycle paths for analysis and routing purposes. As future work, a navigation system for cyclists will be produced based on the security levels and the mixed traffic. Moreover, we will collect data about perceived security from citizens and evaluate its relationship with the security levels and the

[7]https://github.com/ChiaraBachechi/CyclePathSecurityLevels
[8]https://neo4j.com/
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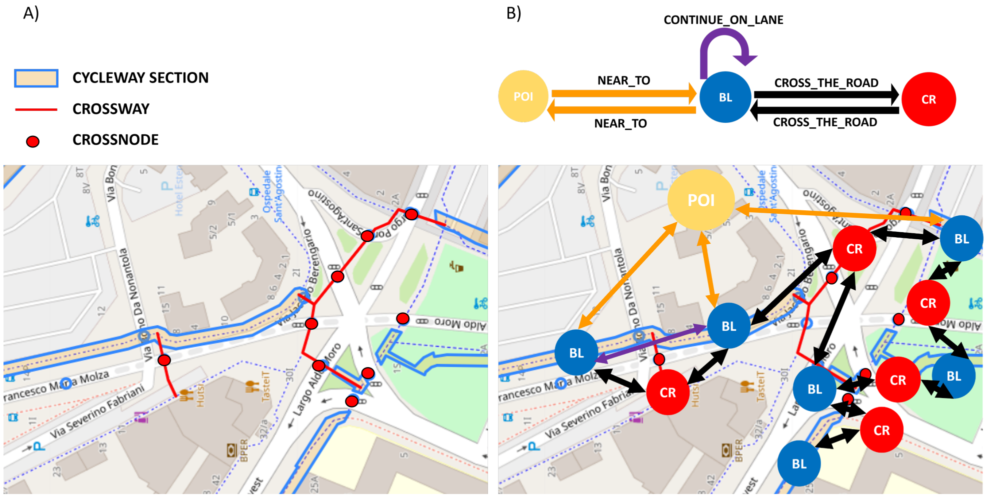


Fig. 7. Physical elements on map and the derived graph model.

mixed traffic. Additionally, road traffic data can be considered when evaluating the security level of the cycle paths. In our region, data regarding bicycle accidents are not openly available. Crowdsourced resources of bicycle accidents data, like Bikemaps.org, have very few information for the province of Modena. However, it could be interesting to analyze the relationship between the accidents' location and the security levels. In order to do that, the same classification should be performed in an area where bike accident data are available.

## ACKNOWLEDGEMENTS

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