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Python-based evaluation of road network constraints for electric scooters and bicycles: Izmit Example

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Abstract

Means of transportation are a large part of our daily life. Along with the development of technology, we encounter different types of vehicles, but we also encounter different problems. For electric scooters, which are one of the new types of vehicles that are seen to be used in vehicle traffic, it seems that there are question marks among the public about the use of vehicles and the rules. It is seen that the legal regulations and rules in this field are not sufficiently standardized in Türkiye yet. Among these question marks, safety, comfort, and vehicle characteristics draw attention to which roads electric scooters should choose during their use. In the research, various applications and examinations were made on the parameters of the slope, road class, length of the road, and land cover, among the parameters considered in the optimal road preferences for electric scooters, where there is a starting point and an ending point. For the research, Dijkstra's Algorithm, QGIS GIS software, python programming language, and various modules were used to use the shortest path problem, cost calculations, and various data processing methods. These applications were compared within the Work titles and the effects of different parameters on the optimal route preferences were compared and discussed. The results of the research were discussed in terms of relevance, and it was determined what improvements could be added and what effects it could have on other research that could be done on this subject. As a result, it has been seen that the parameters in the research directly affect the results in the applications in different works, bringing diversity, and the expected results achieved. It has been determined that the addition of additional parameters such as the maximum distance or time that can be traveled for vehicles such as electric scooters, and the use of more sensitive and various sources will further develop this research and its importance in this type of research.

1. Introduction

The shortest path problems, which have a place in daily life and people often create their own solutions or get solutions through various applications, turn into the optimal path problems as a result of taking into account different environmental parameters. For the solution of the shortest path problem among the roads with different distances, it is a correct solution to choose the path with the shorter distance compared to the others, but this is more complicated for the optimal path problems. For example, considering the traffic density values on the road, the shortest distance road may not be the most suitable way for a vehicle to pass through the traffic. Such different parameters depend on whether the roads will be covered without vehicles or with which type of vehicles in the problem, but also the importance of the parameters in the optimal path problem may vary according to environmental factors.

With the development of technology, vehicles such as electric scooters and electric bicycles have begun to settle in people's daily lives. In times when the use of motor vehicles using the main roads is increasing day by day, people see electric scooters as an alternative that does not suffer from traffic problems or can be used as an entertainment activity. The most suitable path for a vehicle is always seen as a problem to be solved. For this reason, the necessity of conducting exemplary research and applications on this problem for these new vehicles of different types that can go into traffic has emerged.

Unfortunate accidents occur because new and technological vehicles such as electric scooters are not fully integrated into daily life and therefore citizens are not used to seeing these vehicles in traffic. Which paths are suitable for these vehicles physically and in terms of security is important for optimal path applications.

Shortest Path problems are one of the most popular problems encountered in Network analysis, which consists of nodes associated with each other through edges and used in decision-making studies, and on which algorithms have been developed. These problems are encountered in many areas such as navigation devices, network systems, and vehicle route calculations [1]. For this reason, various algorithms have been developed for the solutions to these problems, which also take into account special conditions. The most popular among these algorithms is Dijkstra's Algorithm with positively weighted edges. Dijkstra algorithm, which is used to find the shortest (costly) path between two nodes in a network consisting of nodes and edges, reaches the shortest path result by comparing the costs of all possible paths between two nodes. Dijkstra's algorithm can only work on positively weighted edges. Although it gives a fast and precise result compared to algorithms such as Bellman-Ford, which is another shortest path problem solution algorithm that can work with negatively weighted edges, it is more costly in terms of working compared to heuristic algorithms [2].

A road network consists of many nodes connected to each other via edges. Some nodes can play more important roles in the network due to their centrality [3]. Many algorithms have been developed on complex road networks from the past to the present. Reasons such as separating the application according to different types and purposes and considering the time used for problem solving can be given as the reason why there are so many algorithms [4]. Different optimization methods can be followed as a result of additional problems such as data size and branching of the data within itself.

Research and studies are carried out by using spatial information within the scope of Geographic Information Systems (GIS), which deals with spatial information, in various analyzes and models [5]. Many studies such as best fit site analysis, seasonal productivity of agricultural land, disaster risk research, spatial relations, and statistics can be given as examples of these research and studies [6]. In this research, GIS is used to solve the shortest path problems encountered in the use of road networks, road geometries, and attribute information, which are geographical data sources, in the use of electric vehicles such as electric scooters.

Any individual can contribute to the OpenStreetMap (OSM) mapping project, where volunteer-based open-source data is produced [7]. OSM data, which is available completely free of charge, is licensed under the Open Database License [8]. With the update coming in 2022, it now also includes forwarding services. Through this development, it can be seen that a topological relationship (road network) can be created between the road geometries in the OSM data. While OSM creates the node and edge relations that may be necessary for a network analysis within its own road data, it also includes important information such as the length of the road it represents, the speed and information for the vehicles, and the characteristics of the road into the related road (edge) geometry data [9].

With the development of technology day by day, GIS research and applications are becoming more widespread and their diversity is increasing. Various GIS software and programming languages are used in these studies. Among the popular examples of these software are QGIS and ArcGIS software. As they have a python programming language script, they can be written with plugins [10]. Such features also increase the use of the python programming language on GIS.

Python, an object-oriented programming language, was introduced by Guido van Rossum in 1980 [11]. Today, it is popularly used in many areas such as web applications, artificial intelligence studies, and database software programming. In addition to being easy to use thanks to its simple syntax, one of the reasons for its high usage is that it has many highly functional libraries that can be loaded into it [12]. Libraries such as Pandas, GeoPandas, NetworkX, and OSMnx can be given as examples of important python libraries to be used in the research.

The Pandas module, which allows the data to be used practically, quickly, and efficiently, is used quite frequently today, especially in the field of data science [13]. The GeoPandas module, on the other hand, includes the Pandas module and offers the opportunity to work with spatial data in addition to the capabilities of the Pandas module [14].

NetworkX module is a powerful module that can be used for network analysis and manipulation of network graphs [15]. It has various functions such as shortest path problem algorithms in itself. OSMnx is a python module that enables network analysis like the NetworkX module by using the spatial data provided by OSM. It allows for downloading OSM data, modeling road-street data, creating relationships, analyzing, visualizing, and many other spatial analyzes [16].

In the research, in which the suitability of agricultural crops for land consolidation areas was examined, multi-criteria decision analyses were made by using GIS techniques [17].

In the research where the least cost road algorithm designs for highway route selection were investigated, the effects and results of multiple costs on route calculations were analyzed [18].

In the research using geographic information systems to evaluate accessible forest areas using the Analytic hierarchy process, which is a multi-criteria decision-making method of firefighters, road network and road transportation analyses of firefighters were examined [19].

In the research, that determined the transportation networks that will form the basis of the most appropriate public transportation policy, it was seen that the spatial network analysis techniques of GIS were used [20].

In the research in which Dijkstra and Bellman-Ford shortest path algorithms are compared, it is seen that Dijkstra algorithm gives more precise and invariant results than Bellman-Ford algorithm [21].

In the research in which the GIS-based shortest transportation route is determined, it is seen that the stations on the shortest route are determined with the Dijkstra algorithm using the python programming language [22].

In research, it is seen that Dijkstra's Algorithm is used in the solution of the vehicle routing problem for examining the shortest paths between solid wastes. It was concluded that the Dijkstra algorithm gave a successful result in the shortest path applications made on the graph model created with the topological relations in the road networks [23].

In the research, in which optimal routes for bicycles are examined by considering different attributes other than length, attributes are used in the shortest path algorithm, taking into account different costs. In addition, it has been pointed out that the changes made in the costs with the applications with different combinations and the changes in the optimal cycling routes [24].

In this research, transportation restrictions for two-wheeled vehicles such as electric scooters and bicycles will be examined by using the Dijkstra algorithm, which is one of the most popular shortest path problem solution algorithms, taking into account different costs. Within the scope of the research, besides the python programming language and various modules it contains, GIS software such as QGIS was also used. Obtaining and manipulating the data, associating the data both within themselves and with each other, the shortest path applications on the created topological road network will be mentioned and the results will be discussed. It has been observed that there are not many studies dealings with this issue, especially today when electric vehicles are becoming more widespread day by day. It is foreseen that the analyzes and examinations to be made within the scope of the research can be handled in other more detailed and comprehensive studies and this research will be beneficial. Since there is no standard weight comparison of the cost indexes among the shortest path applications to be made, it is planned to bring richness to the research with the diversity of the applications made with different cost indices and weight values. The aim of the research is to support the applications that refer to this research with examples and detailed analysis and result comparisons rather than standardizing the cost indices and the weight coefficients of the cost indices on each other in this area. There is not enough research in the literature dealing with these topics. Plynning's research [24] has been one of the rare reference applications for the methodology of the research.

2. Material and Method

2.1. Study Area and Data

Izmit district, which is the central district of Kocaeli province, was chosen as the study area. Due to the importance of slope information in the applications to be made, the rough structure of the land in the Izmit region is taken into account. At the same time, the diversity of land use and the simplicity of road networks in the Izmit region bring convenience to different applications and research. The central coordinates of the İzmit region are known as 40° 45′ 50″ N, 29° 56′ 40″ E (Figure 1).

Path data is OSM data obtained through OSMnx. During the acquisition of this data, the necessary road network was also established through the module (Table 1). Considering the up-to-dateness and diversity of the datasets for the Izmit district, it has been seen that it can be a suitable dataset for the application.

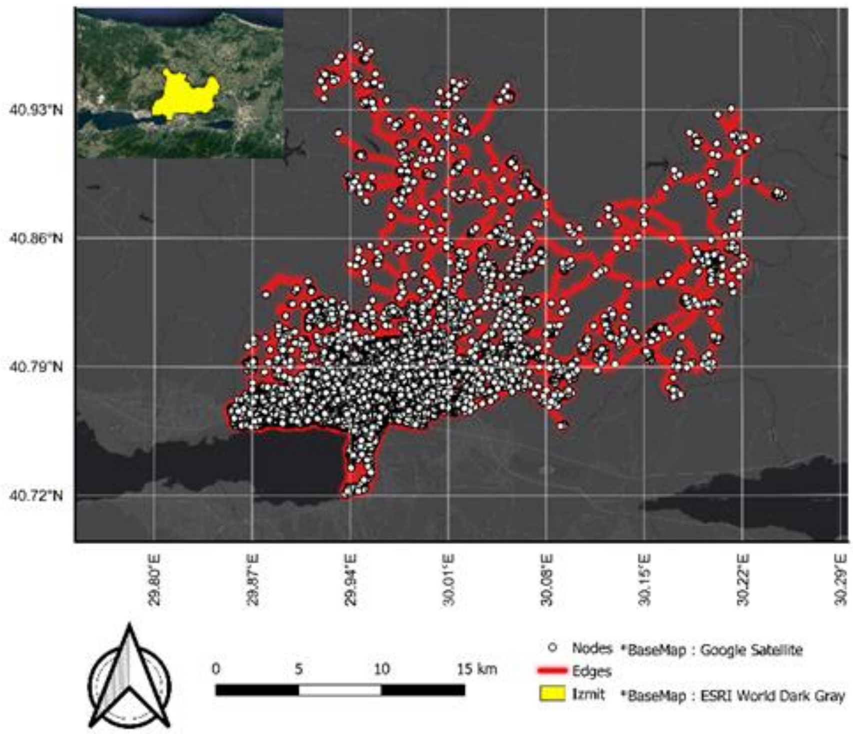

Figure 1. Study area.

Table 1. Data obtained for use in research.

Data	Format	Content	Reason For Use	Source
Road Network Data	Vector (Line)	Path geometry, lengths and classes	Use of road network, path length cost and road class cost	OSM
Elevation	Raster	Elevation values of the area	Generating road slope cost data	[25]
Land Cover	Raster	Land cover in the area	Establishment of land use cost in regions with roads	[26]

2.2. Methodology

With the Dijkstra algorithm, which is a shortest path problem algorithm selected within the scope of the research, applications that provide solutions to optimal road problems based on the shortest path and weight/cost parameters on the road will be made for electric scooter users. In these applications, the main functions for the purpose of the research will be developed with the python programming language and QGIS software will be used for some special cases. During these applications, OSMnx, NetworkX, Geopandas, and Pandas modules will be used. A topological network will be created with the road geometry data of Izmit, the central district of Kocaeli province. With the created network structure, the effects of different weight/cost parameters on the most appropriate path will be examined within applications, and statistics and reports will be created through applications where different weightings are applied to the parameters in problem solutions and various network analyses.

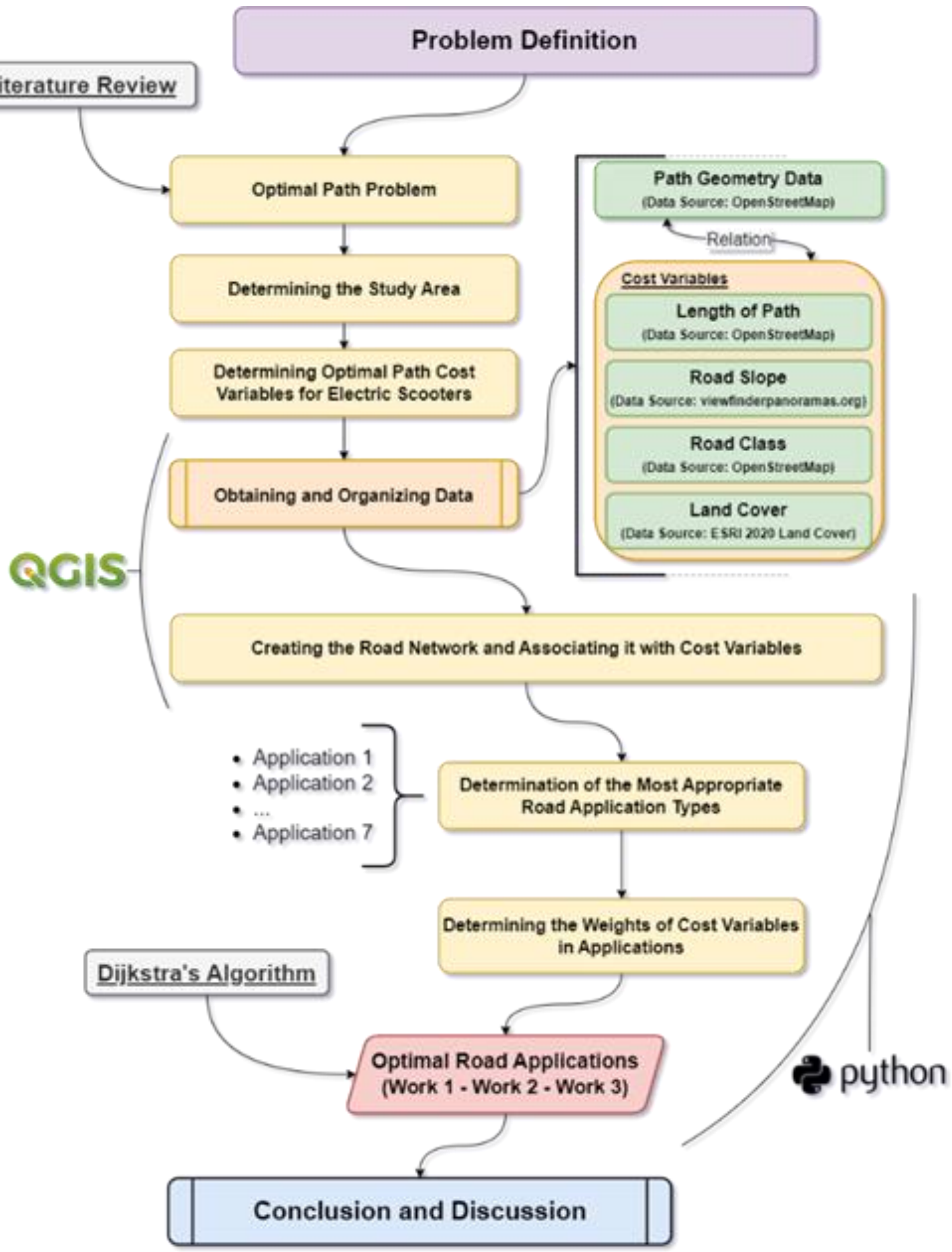

Figure 2. Methodology.

In the first stage, the road data provided by OpenStreetMap was filtered for the Izmit Region. Through the OSMnx module, data can be private with various filters such as pedestrian paths, bicycle paths, and vehicle paths. Within this path data, the necessary topological network is created and prepared in the module. In this way, there is no need to work on the stages of creating a topological network in which the roads will be related to each other. Although the filtering of bicycle paths, which have the closest features to the purpose of the research, was considered appropriate at the beginning, in the examination made on these filtered data, it was determined that some pedestrian bridges where bicycles can use together with pedestrians do not have road data. With the realization of this detail, the road data in the region were obtained without distinguishing the class, and all the information on the data was classified.

In the analyzes to be made, information such as the length of the road, the class of the road, the slope of the road, and the characteristics of the land where the road is located will be used to calculate the cost of the most suitable road for applications to be made on the road data.

The length values of the road and the road classes (categories) are available as attribute values in the road network obtained from the OSMnx module (Figure 3).

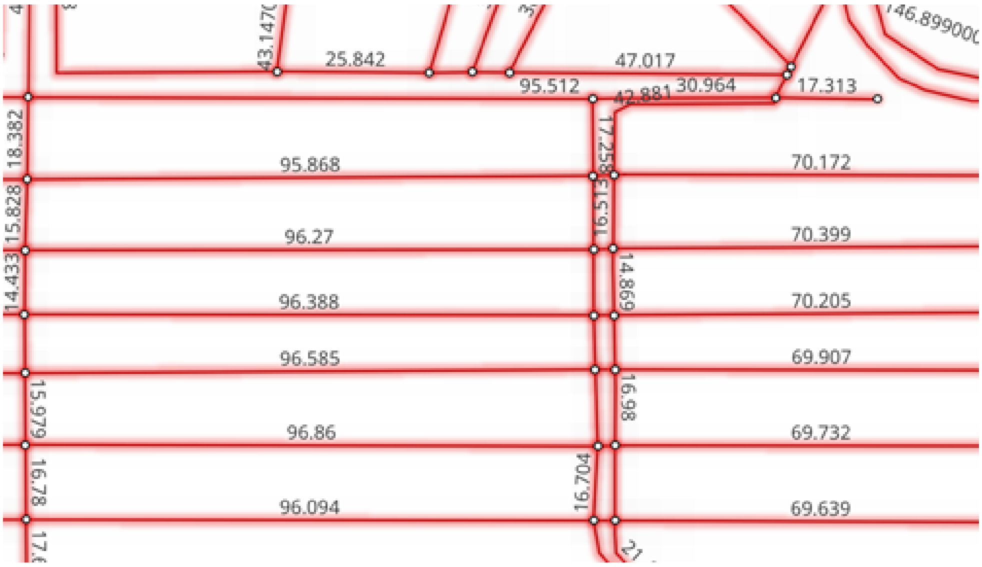

Figure 3. Example region with path length values.

For the slope value of the road, with the help of the raster data obtained from the [25] source, the pixel values of the intersection of the starting and ending node points of the road edges, and the height values —increased through interpolation methods for the resolution of elevation data— were assigned to these nodes. By using these height values and the length data of the road together, the slope value of each road data was calculated. Accuracy sensitivities of the generated slope values are variable. Although the heights at the beginning and end of an edge are helpful in finding the slope between two nodes, they are not helpful in finding the height changes between these two nodes [24]. To increase the accuracy here, more than one point can be placed on a road line geometry and the slope of the road can be calculated from the height of each point. However, in the sample analyses made on the data, it was observed that the variability in the height changes between two nodes in the road geometries in the Izmit region was mostly unidirectional [26-27]. For this reason, the costs were calculated based on the slope values found only with the heights corresponding to starting points and ending points (Equation 1).

$$slope\ (\%) = \frac{elevation_2\ - elevation_1}{path\ length} * 100 \qquad (1)$$

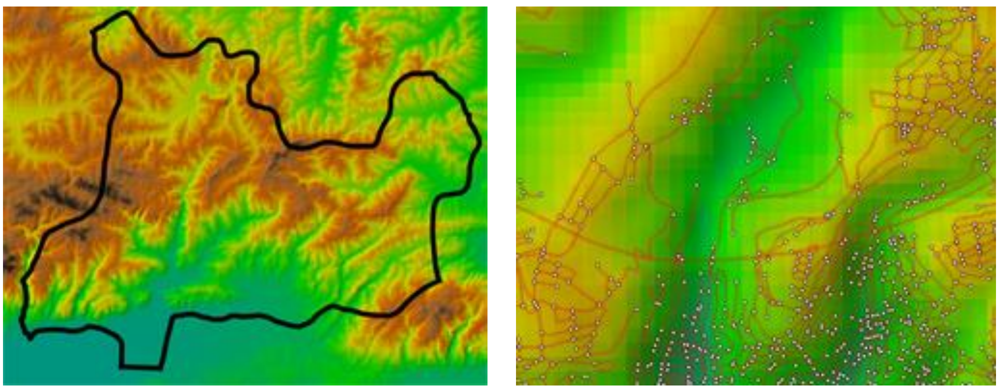

Figure 4. Dem data in Izmit District and road network nodes in a sample region.

The height values defined on the nodes and the slope values calculated on the edges can also be examined in Figure 5, which is the sample region image.

Finally, the usage information of the land where the road is located will be included in the cost calculations. Land use data is a raster data obtained from [28-33]. In order to adapt this data to the road network, 30-meter buffer zones were created for all road vector data. These buffer zones are of polygon data type. Then, with the zonal statistics method, the pixel values falling into these buffer zones were associated with the road data in the topological network over the relevant polygon [34]. For the association made, the average values of the pixels falling into the polygon were taken and assigned to the polygons. During these processes, weight values were assigned to the pixel values in the land use raster data according to the relevant land use classes (Figure 6).

The process of transferring land use data to road data with the help of buffer zones with the zonal statistics method can be examined in Figure 7.

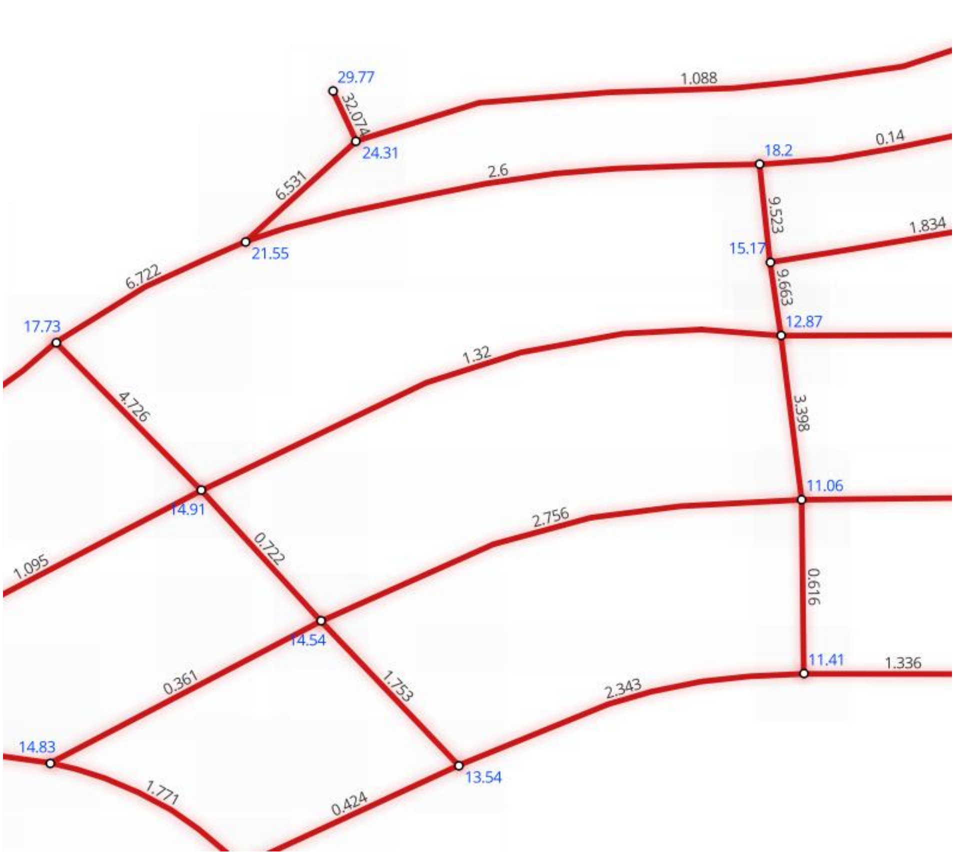

Figure 5. Example region where road height and absolute slope values appear.

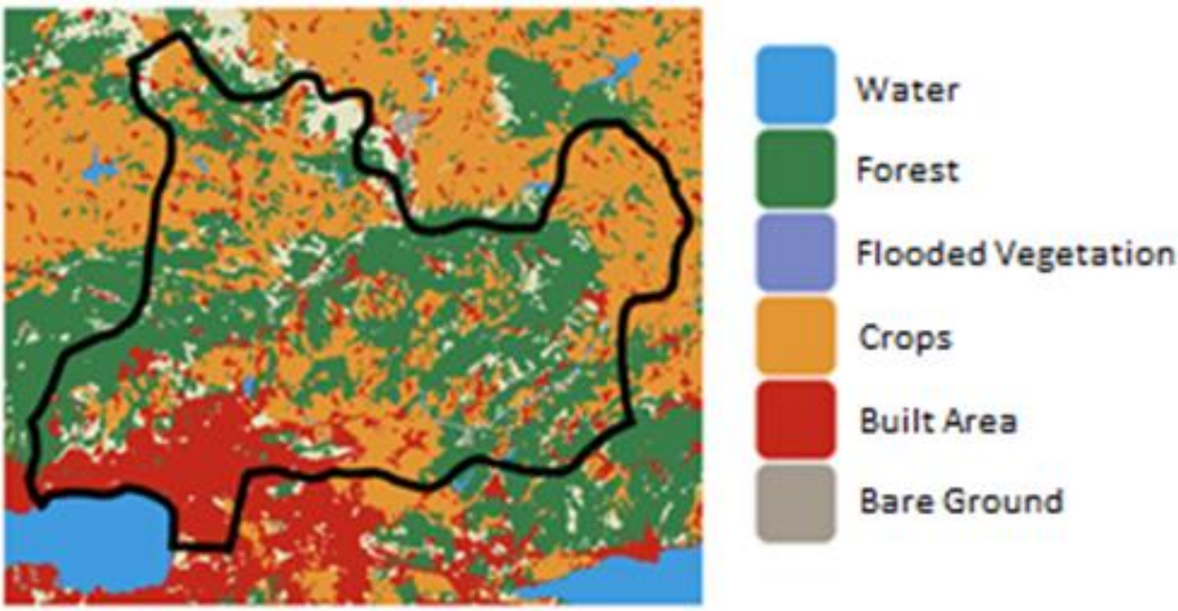

Figure 6. Land use data for Izmit District.

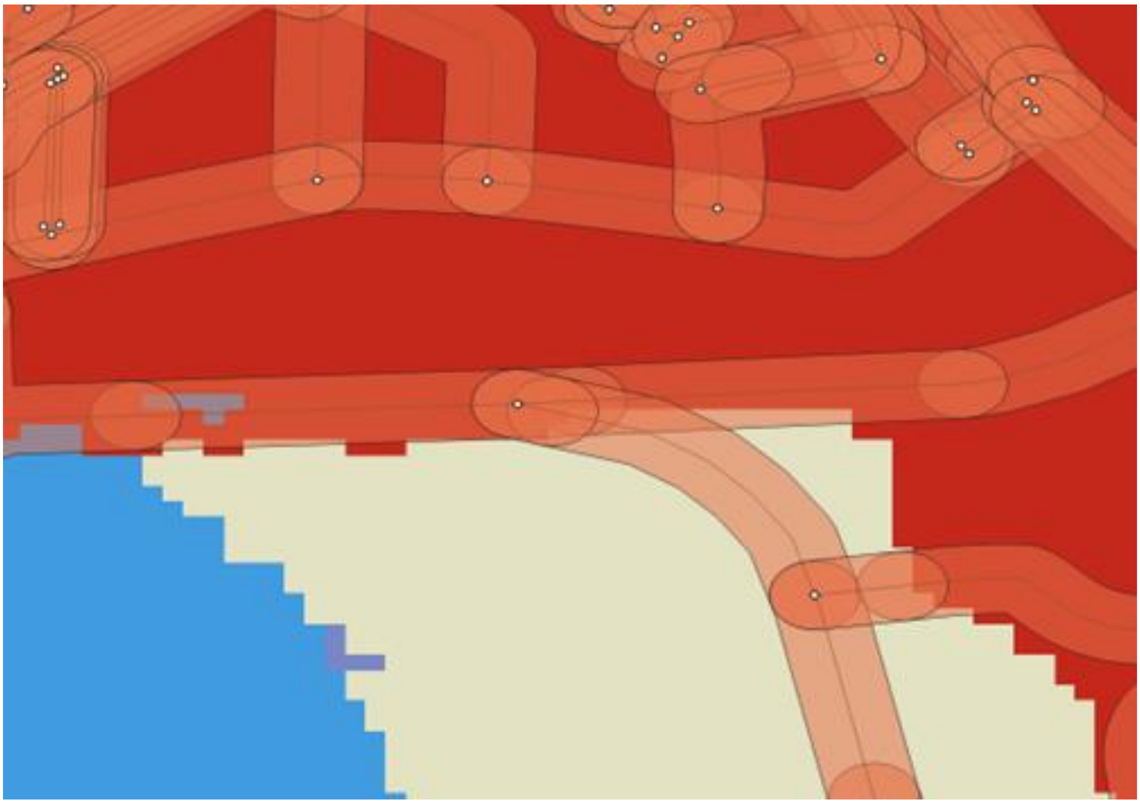

Figure 7. Example study area: Land use raster data and 30-meter buffer zones.

In order for cost indexes to be used in cost calculations, it is necessary to create indexes specific to the applications to be made. The high-cost value of a road in the shortest route application reduces the possibility of that road being preferred over other roads.

The length of the path value is the basic cost index in shortest path applications. It can be used in the application without making any changes to it.

The class of the road cost index plays a role in the drivers' preference for the roads where they can use vehicles such as electric scooters and bicycles more conveniently and safely. In this respect, the costs of road classes such as pedestrian paths and bicycle paths are low in practice. Road classes that represent more neighborhoods and streets are more expensive than pedestrian and bicycle paths. Since the unclassified data in the road data obtained for Izmit are generally similar to the data in this class, this class is also included in the same weight calculation. Main roads used by motor vehicles and considered dangerous for drivers and their derivatives are heavier than other road class weights, except for one exception class. Ladder class road data, which drivers do not have the opportunity to use and which is seen as an exception class, is taken into account as a road class that is almost impossible to be preferred by assigning an extreme value to it. The reason why this road class is not directly removed from the road network is to prevent disconnections within the network. If there is no other choice of road, the driver has to use the stairway by necessity. As a result of the application, it can be noticed whether this road class is used or not, with the extreme value given by the sum of the cost values. Although these calculations are made by considering the research [24], it is aimed to increase the diversity by making some changes to the calculations.

Table 2. Road classes cost indexes.

Road Class Group	Cost Index (NS_i)
Bicycle paths, pedestrian paths, etc.	1
Inner city roads etc.	1.25
Main roads, highway etc.	1.5
Stairs	∞

In the cost index, where the slope of the road is taken into account, the situations where vehicles such as electric scooters and electric bicycles must have a dangerous driving experience on highly inclined ramps, or rough roads or where the vehicle and the driver must rise to a height that they cannot overcome are taken into account. The fact that a road has a high slope both in the down direction and in the up direction reduces the possibility of choosing that road. For this reason, the slope of the road is taken into account by taking its absolute value into the calculation. Since absolute slope values of 10 percent and above are the roads that should not be preferred for an electric scooter/bicycle vehicle, index values are included in the cost calculations as infinity (∞). So, these routes should not be preferred. In absolute slope values of 1 percent or less, the slope difference is ignored and the index values are taken into account as 0. If the 10 percent and 1 percent slope are between the absolute slope values, a normalization is made and the slope is taken into account by taking values between 1 and 0. Although the research [24] is taken into account in this calculation, it is necessary to add an unacceptable limit for electric scooters and bicycles (Equation 2).

$$NE_i = \begin{cases} 0, & |G_i| < 1 \\ \dfrac{|G_i| - 1}{10 - 1}, & 1 \le |G_i| \le 10 \\ \infty, & |G_i| > 10 \end{cases} \tag{2}$$

The use classes of the land where the road is located, namely the land use values, are used for situations where the driver attaches more importance to the lands which are the elements of nature. For example, a forest area may be preferred more than areas where settlements are concentrated, but it may be less preferred than coastal areas. The lack of class diversity and the fact that the resolution of the existing land use data is not high enough can also prevent the application to give high precision results. The land use classes corresponding to the pixel values of the existing land use data were obtained from [35]. Table 3 guidelines were taken to be used in the research and the pixel values in the land use raster data were changed according to this guideline and score values were assigned.

Table 3. Land use classification.

Land use class	Score value
Water	100
Forest	*95*
Grass	*80*
Bare Ground	75
Residential area	34

After the processes in which Table 3 is taken into account, the land use index values were calculated by making normalization for the usability of the land use data in the shortest path applications and included in the cost calculations used in the applications. Normalization calculation for land use data can be examined in Equation 3.

$$NA_{\mathrm{i}} = \frac{|A_{\mathrm{i}} - max(AK)|}{max(AK) - min(AK)} \tag{3}$$

Ai =Land Use Index

Cost calculations may vary for each application to be made. Rather than establishing a standard method in this regard, it is planned to investigate the effect of different cost calculations on the diversity of applications. Calculations of cost indexes are kept constant in the applications to be made. Within the works, it is planned to make applications in which the weights of different cost indexes on the cost will vary. The application types classified according to these costs can be examined in Table 4.

Table 4. Applications and cost indices used.

Application	Length of Path index (U_i)	Road Slope Index (NE_i)	Road Class Index (NS_i)	Land Use Index (NA_i)
1	✓	*X*	*X*	*X*
2	✓	✓	*X*	*X*
3	✓	✓	✓	*X*
4	✓	✓	✓	✓
5	✓	*X*	✓	*X*
6	✓	*X*	*X*	✓
7	✓	*X*	✓	✓

Table 4 shows which cost indices will be used in which application. These cost indexes can be used in different ways in applications.

In Application 1, the path length index is taken into account as the cost value to be used in the shortest path algorithm. This application provides the shortest path to the result (Equation 4).

$$M1 = U_i \tag{4}$$

M=Cost Value

In Application 2, the road length and the slope of the road are taken into account as cost values. According to this application, if the slope index value of a road is maximum, using that road in the algorithm means that the same distance will be covered twice. Absolute slope value and cost are in a linear relationship. This application elevation gives the desired result when variable paths are not preferred (Equation 5).

$$M2 = U_i + U_i * NE_i \tag{5}$$

The length of the road, the slope of the road, and the class of the road are taken into account for the cost value in Application 3. This practice gives importance to roads where rough roads are not preferred and that the vehicle can drive more safely and healthily (Equation 6).

$$M3 = U_i * NE_i + U_i * NS_i \tag{6}$$

All cost indexes in the research, including the length of the road, the slope of the road, the class of the road, and the land use values, are taken into account in application 4. While this application supports Application 3, It gives results according to the vehicle driver's emphasis on nature excursions (Equation 7).

$$M4 = U_i * NE_i + U_i * NS_i + U_i * NA_i \tag{7}$$

In Application 5, the length of the road and the class of the road are taken into account. This app considers safer routes for the driver while finding the shortest distance to the destination. It does not prefer the roads used by motor vehicles unless it is a necessity according to weight calculations (Equation 8).

$$M5 = U_i * NS_i \tag{8}$$

In application 6, the length of the road and land use are taken into account. This application highlights the nature excursions for the driver and prefers areas such as the coastline more than areas such as the inner city (Equation 9).

$$M6 = U_i * NA_i \tag{9}$$

Compared to Application 4, the slope of the road is not taken into account in Application 7. Care has been taken to ensure that the user has a safe nature drive rather than taking into account the rough areas of the road (Equation 10).

$$M7 = U_i * NS_i + U_i * NA_i \tag{10}$$

3. Results

For the applications to be made, it is planned to make the optimal road problem works in 3 regions where it is foreseen that different and various results will be obtained. These works are also visualized on a special web map application prepared for this research, which also includes the OpenStreetMap basemap. The applications shown on the maps can be examined with the help of Table 5.

Table 5. Application representation colors on the map.

Application	Color (with Hex Code)
1	#20B2AA
2	#FFD700
3	#FF69B4
4	#0000FF
5	#A52A2A
6	#8B008B
7	#FF8C00

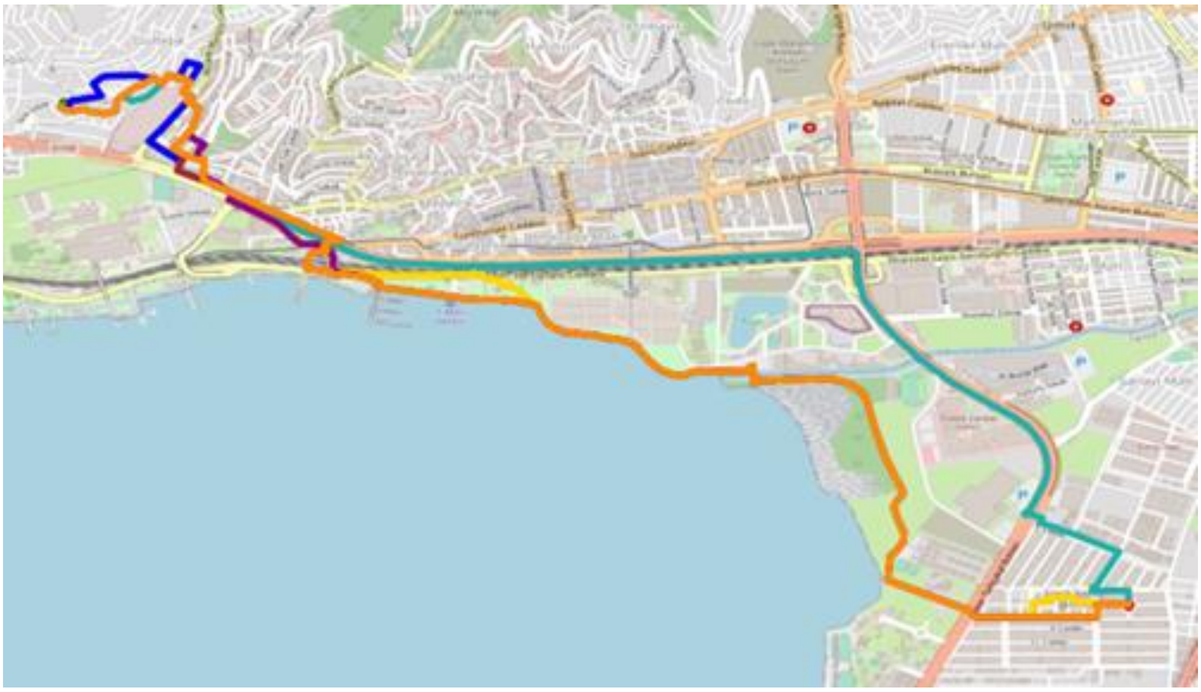

Figure 8. Work 1 map display.

First of all, starting and target points were selected in the coastal areas where pedestrian/bicycle and main roads are dense and the land use class value is the highest, and 7 different applications work were carried out for these points.

Although it is seen that the same roads are preferred in some regions in different applications in the work shown in Figure 8 after the detailed examination made from the work result table in Table 6, road length differences and total cost values emerge more clearly.

When the application results are examined, it can be seen that the applications in which the cost variables are taken into account give results as expected. Especially in applications where road class and land use are taken into account, it is noteworthy that walking/bike paths on the coast side are preferred instead of the main road. In addition, the total weights of the roads preferred in applications in other applications can be examined in Table 7.

Table 6. Work 1 application results.

Application	Total Path Length	Total Cost Value
1	6194.9	6194.90
2	6541.58	8013.16
3	6676.91	8956.72
4	6676.91	14308.35
5	6447.37	7007.86
6	6268.72	4946.02
7	6432.50	12142.12

Table 7. Work 1 application results comparison.

Application	Cost1	Cost 2	Cost 3	Cost 4	Cost 5	Cost 6	Cost 7
1	6194.90	∞	∞	∞	∞	5913.56	∞
2	6541.58	8013.16	∞	∞	∞	5464.25	∞
3	6676.91	8279.26	8956.72	14308.35	7354.37	5351.63	12706.00
4	6676.91	8279.26	8956.72	14308.35	7354.37	5351.63	12706.00
5	6447.37	∞	∞	∞	7007.86	5151.79	12159.66
6	6268.72	∞	∞	∞	∞	4946.02	∞
7	6432.50	∞	∞	∞	7011.95	5130.17	12142.12

With the examinations made in Table 7, it is noteworthy that the road weights in cases where the cost variable conditions that are not accepted for the most appropriate road in different applications are ignored, the result directly converts the most appropriate road weight to an infinite value in applications where these conditions are considered important.

Additional information such as maximum slope, average slope, and average land use index values encountered in these applications can be examined in Table 8.

According to the examinations made in Table 8, a direct proportion can be established between the cost variables taken into account by the applications with additional information and the application results. Figure 9 can be examined as an example of regions that are mostly preferred due to land use data in Work 1.

For Work 2, care was taken to select two points where the slope cost variable differed greatly. For the starting point, a central point can be seen almost as sea level, and for the target point, a peak around which the heights vary at different rates was chosen (Figure 10).

Work 2 application results can be examined in Table 9.

Table 8. Work 1 Applications Results Additional Information.

Applications	Maximum Slope Encountered (%)	Average Slope Encountered (%)	Average Land Use Index
1	12.59	4.94	0.4805
2	5.25	2.84	0.4536
3	5.45	2.88	0.4268
4	5.45	2.88	0.4268
5	12.59	4.69	0.4157
6	12.59	4.58	0.3870
7	12.59	4.38	0.4111

Figure 9. Work 1 sample google street view image.

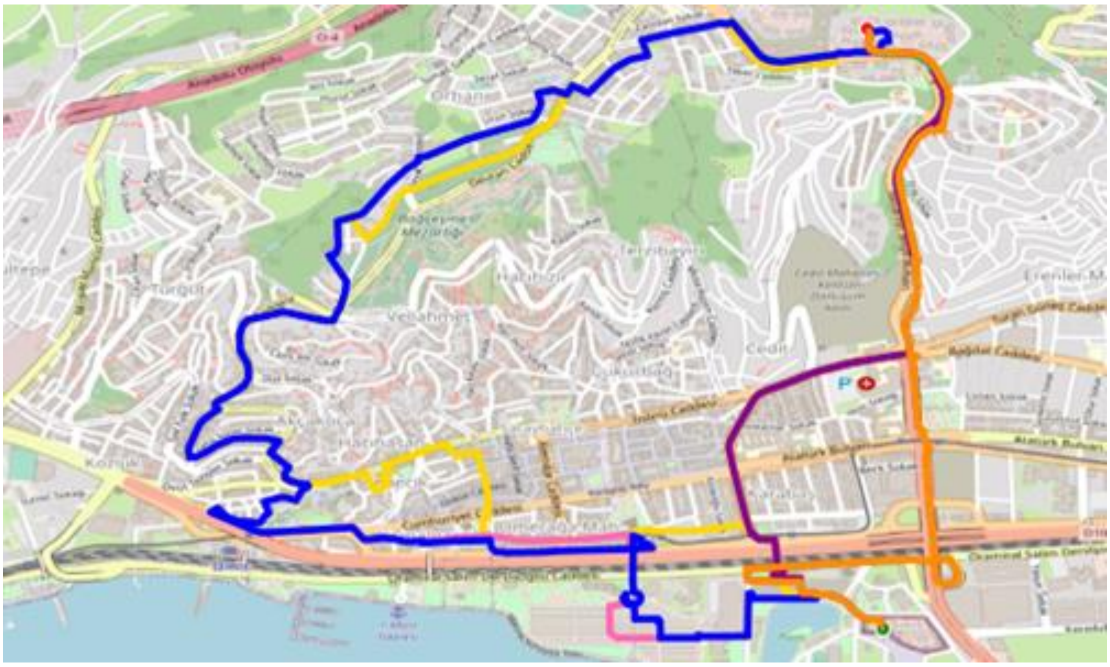

Figure 10. Work 2 map display.

Table 9. Work 2 application results.

Application	Total Path Length	Total Cost Value
1	3064.16	3064.16
2	6510.83	∞
3	7298.74	∞
4	7214.96	∞
5	3593.76	4464.90
6	3073.73	2951.72
7	3593.76	7971.49

As seen in Table 9, it is seen that the slope between these two points necessarily exceeds the unacceptable limits, and therefore the total cost values of application 2, application 3 and application 4 reach infinite values. It is seen that the roads with less total infinite cost are preferred in the applications where the slope is taken into account, due to the desire to reach a result regardless of the map application. Although the result is a road directly on the map in the map application, it is not possible to use this direction under the conditions specified in the applications. Comparisons of application results within Work 2 can be examined in Table 10.

Table 10. Work 2 application results comparison.

Application	Cost1	Cost 2	Cost 3	Cost 4	Cost 5	Cost 6	Cost 7
1	3064.16	∞	∞	∞	∞	2959.66	∞
2	6510.83	∞	∞	∞	∞	6281.32	∞
3	7298.74	∞	∞	∞	∞	7016.53	∞
4	7214.96	∞	∞	∞	∞	6930.40	∞
5	3593.76	∞	∞	∞	4464.90	3506.59	7971.49
6	3073.73	∞	∞	∞	∞	2951.72	∞
7	3593.76	∞	∞	∞	4464.90	3506.59	7971.49

As it can be understood from Table 10, the cost values reach infinite values in all applications where the slope cost variable is included. The reason for this is that the slope values are not below the accepted values in any of the most suitable road preferences in applications. Additional information can be examined in Table 11.

After the examinations made in Table 11, it will be noticed that the average slope value in application 3 is lower than the average slope value in application 2. With the total path length value in Table 9, it will be noticed that the effect of the path length cost variable in the applications should not be ignored even if the slope is taken into account in the work. Figure 11 can be examined as an example of high slope regions in Work 2.

Table 11. Work 2 applications results additional information.

Applications	Maximum Slope Encountered (%)	Average Slope Encountered (%)	Average Land Use Index
1	29.09	5.83	0.542169
2	17.39	3.45	0.500000
3	17.39	3.25	0.536424
4	17.39	3.43	0.510345
5	31.05	6.76	0.542169
6	29.09	5.60	0.506024
7	31.05	6.76	0.542169

Figure 11. Work 2 sample google street view image.

For Work 3, two different points were selected at random in the city where the construction was intense, and it was planned to examine the cost variables of the road class within the applications. It has been taken into account that there are equivalent access roads to different categories such as pedestrian bridges, main roads, avenues, and walking paths between these two selected points. Work 3 application results can be examined in Table 12.

In the examination made in Table 12, it was seen that the conditions that were not accepted in the applications were not encountered. With the result comparison in Table 13, the differences between the applications can be examined in more detail.

Table 13 shows the effects of different road routes on the cost values of the applications in Work 3. It is seen that the values of Application 3, Application 4, Application 5, and Application 7, in which the road classes are examined, have relatively close values on different roads. With the examinations made in Table 12 and Table 13, it can be interpreted that the roads used in Work 3 are generally the intervals where the road class is suitable for electric scooters and bicycles. Table 14 with additional information for Work 3 can be viewed as an appendix.

Figure 13 can be examined as an example of the most preferred regions due to road class indices in Work 3.

Table 12. Work 3 application results.

Application	Total Path Length	Total Cost Value
1	2175.30	2175.30
2	2273.89	2754.50
3	2244.45	2877.10
4	2225.00	5038.83
5	2227.98	2281.63
6	2202.23	2039.60
7	2231.35	4432.06

Figure 12. Work 3 map display.

Table 13. Work 3 application results comparison.

Application	Cost1	Cost 2	Cost 3	Cost 4	Cost 5	Cost 6	Cost 7
1	2175.3	∞	∞	∞	2884.07	2091.31	4975.38
2	2273.89	2754.5	3188.04	5408.84	2707.44	2220.8	4928.23
3	2244.45	2812.73	2877.1	5054.15	2308.82	2177.04	4485.86
4	2225	2819.61	2883.98	5038.83	2289.37	2154.85	4444.22
5	2227.98	2834.3	2887.95	5044	2281.63	2156.05	4437.68
6	2202.23	∞	∞	∞	3199.5	2039.6	5239.1
7	2231.35	2894.11	2947.76	5094.83	2285	2147.06	4432.06

Table 14. Work 3 applications results additional information.

Applications	Maximum Slope Encountered (%)	Average Slope Encountered (%)	Average Land Use Index
1	11.13	3.50	0.543478
2	5.25	2.61	0.565217
3	6.34	2.98	0.480769
4	5.25	3.13	0.458333
5	6.34	3.19	0.446809
6	12.59	4.39	0.347826
7	6.34	2.96	0.480000

4. Discussion

The results were partially as expected for all three studies, which were planned to yield different results. It can be said that it is positive in terms of the preferred ways and results against the cost variables that the applications have paid attention to in the studies, and partially sufficient in terms of accuracy.

Although the shortest route preferences are close to the city center areas in Work 1 applications, it has been observed that coastal areas are preferred in applications where land use is taken into account. It has been seen that walking and cycling paths are preferred in applications where the road class is taken into account. The applications in Work 1 give the expected results.

Figure 13. Work 3 sample google street view image.

As can be seen in Figure 11, the elevation differences between the two selected points in Work 2 applications are quite large. For this reason, it is seen that in applications where road slopes are taken into account, infinite values and roads that are not preferred for application are encountered. It is planned to examine how road preferences in applications can yield results in different applications. For this reason, an algorithm is designed in which, if there is no path to be preferred in applications, the shortest paths with total infinite cost value will be preferred. Thus, the results of different road preferences in different applications could also be examined.

For Work 3, it is planned to examine the options in the city center. As expected, in applications where road class values are taken into account, it is seen that pedestrian and bicycle paths are preferred.

With the help of results comparison and additional information tables in works, it is possible to observe and discuss whether the application results are reasonable or not. The average and maximum values encountered in applications that consider only the slope may have a lower value in applications that also consider other cost variables other than the slope. It is seen that this situation arises from the fact that the length values of the roads also have an effect on the result. This situation can also be seen in applications where other cost variables are taken into account.

According to the inferences made from the research results, it is seen that both the land use and elevation data resolution are not sensitive enough and diverse data for the study. The height values that vary greatly in the region are vectorially in the same direction. In addition, important conditions such as speed limits on vehicle roads, and battery times for electric scooters/bicycles were not used. Such situations reduce the accuracy of the results of the research and the effect of the inferences to be made from this research. On the other hand, the usability of the GIS software and software libraries used, the working speed of the Dijkstra algorithm and the effects of the conditions accepted in the study on the result provided a positive impression for this study.

5. Conclusion

In the research, it was examined how different cost variables for electric scooters and bicycles affect the results in applications with various combinations. It was seen that the research gave successful results, but the accuracy of the results was not sensitive enough and the variety in cost variables should be further increased. It has been examined that the results of the research are logical results with the examinations and comparisons made on the results. Thus, it has been concluded that GIS, Dijkstra's Algorithm, used GIS software, programming language, and libraries can be used in research in this area. The materials that can be obtained from open sources for the research can be used in such studies, but these materials should be examined in detail before the research.

The effects of the cost variables found in the research on the weight give positive results. It has been seen that more appropriate and healthy results can be encountered with the optimizations that can be made on the index values of the cost variables in the application and that these applications can also lead to other research.

It is thought that if applications such as bicycle parking points offered by local municipalities are used for electric scooters/bicycles, different results can be seen with different applications and works. Although there are some legal rules for electric scooters/bicycles in various countries today, it is noteworthy that there are no rules in Izmit district (and other nearby districts/provinces) in this study, which examines the most suitable roads. If some mandatory rules are introduced for electric scooter/bicycle riders, a preliminary research material may be created for such studies.

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Author contributions

Ahmet Şirin: Idea, Design, Literature Review, Data Collection and Processing, Data curation, Visualization, Software, Methodology, Analysis and Interpretation, Writing. **Arzu Erener:** Idea, Design, Writing-Reviewing, Data Collection, Methodology, Thesis and Article Review, Supervision.

Conflicts of interest

The authors declare no conflicts of interest.

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