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Integration of GPS Based Floating Car Data into GIS Based Transportation Networks: Antalya Ring Road Example

Ersin AKSOY [1], Kıvanc ERTUGAY[2,*], Engin KEPENEK[2]

[1]*Republic of Turkiye, Ministry of Environment, Urbanization and Climate Change, Infrastructure and Urban Transformation Services, Antalya, Türkiye*
[2]*Akdeniz University, Faculty of Architecture, City and Regional Planning Department, Antalya, Türkiye*

Highlights

- Black box nature of GIS-GPS integration.
- Transparent process.
- More accurate accessibility modeling.

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Abstract

Although there are many studies on the use of GPS and GIS technologies in transportation planning and accessibility analyses, there is almost no research to reveal the background of the integration process in detail. To address this basic problem, we developed a free and transparent method to integrate mobile GPS data into transportation network data on GIS environment which can be used extensively in urban and regional planning research especially in transportation and accessibility analyses. Developed method was applied to a particular segment of a ring road of D400 motorway within the borders of Antalya city centre and the entire process is described in a detailed manner. The obtained results demonstrate the efficiency and usability of the proposed methodology and enable researchers and decision makers to integrate GPS-based floating data into transportation networks, to access many additional GPS provided information in GIS-based network analysis such as “starting and ending elevations of the road segments”, “the positive and negative slope of the road segments considering road direction”, “the GPS-based instantaneous speed” etc. and to reach a wide range of spatial analysis capabilities for all kind of accessibility calculation process.

1. INTRODUCTION

The concept of accessibility, which is one of the important components of land use and transportation planning can be defined as a measure that reflects the relative ease of access to/from several goods, services and activities by considering several travelling costs. Accessibility can also be defined as a crucial tool to measure the impact of land use and transportation related decisions on the city. The concept of accessibility creates direct effects on social, cultural, economic and environmental conditions [1-3].

Accessibility has a large impact area in a very wide context and constitutes an important input for almost all planning activities in cities. Since the 1960s, numerous studies have been conducted to reveal the impact of accessibility in different areas, especially in urban, transportation and land use planning, etc. [4-14]. As can be seen from Figure 1, accessibility is an important concept that interacts with many different components some of which are transportation network, land use, activity, connection, travel time, distance, cost, transportation type etc.

*Corresponding author, e-mail: kivancertugay@akdeniz.edu.tr

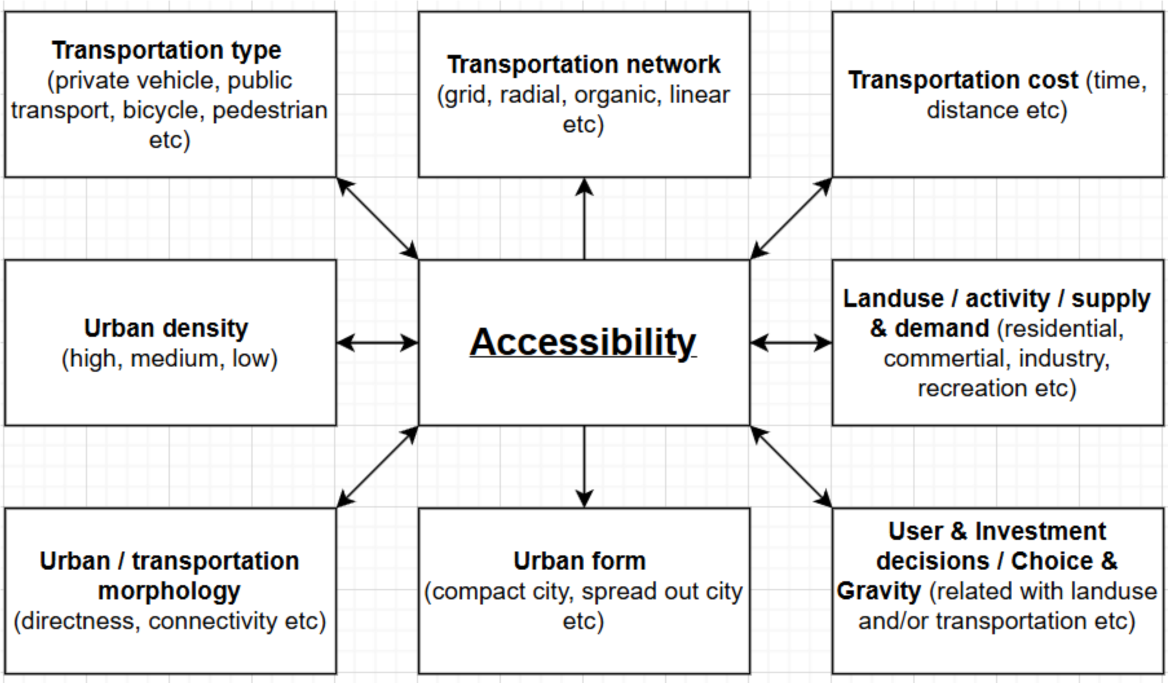


Figure 1. *The interaction of accessibility with different components [15]*

Due to the complexity of the accessibility concept, research on accessibility modelling and evaluation process is mostly conducted with Geographic Information Systems (GIS) [see many examples [16-24]. The interaction of temporal and spatial data can only be realized by using spatial information technologies. GIS can successfully provide decision support to decision makers at every stage of accessibility modelling by integrating data from different sources and spatial processing and analysis tools [4]. Most of the recent research is focused on finding patterns of how and in what way people move in urban transportation network by integrating GPS data based on real location and time with GIS. In these studies, taxi movements, mobile phones, smart card data and social media records appear as the main data sources of GPS [25-32]. Estimation of traffic speed from speed sensors has also been the subject of many studies recently [33-37]. In addition, spatial interpolation methods such as Inverse Distance Weighting (IDW) or Kriging have also been observed to be used in different types of accessibility modelling / transportation planning processes [34, 37-39]. There are also so much research that use GIS-GPS integration as a decision support tool in urban, land use and transportation planning and highlight the importance of GIS-GPS integration [40-55].

Both the increasing importance of GPS and GIS-based analyses and rapid increase in technology, opportunities and capabilities, makes GPS-GIS integration increasingly important (especially due to the great need for instant and dynamic accessibility analyses and ease of obtaining of location-based, real-time and free GIS and GPS data from many open data sources). Every day, more realistic solutions are tried to be offered for solving transportation, land use and accessibility-related problems in different areas through different software, datasets, models and/or tools.

Considering the above-mentioned literature, it can be said that although there are a wide range of studies on the integration of GPS and GIS-related technologies, there is almost no research that reveals the background of the integration process in detail, which significantly reduces and restricts many possible research opportunities and reduces the amount of research that can benefit from GIS-GPS integration. The process of integrating GPS-based floating vehicle data into transportation networks is mostly considered as a black box in the literature, otherwise it can directly help to increase the accuracy of network analyses in urban planning, or any discipline related to accessibility and transportation.

With this motivation, this study aims to develop a free and transparent method that will provide the integration of GPS data and GIS-based transportation networks that can be widely used in urban and regional planning research, especially in transportation and accessibility-related analyses. The proposed method can be widely used by researchers and experts related to accessibility modelling, as well as private, local and public urban planning-related institutions. To demonstrate the efficiency of the methodology, the proposed approach was applied to a specific ring road of the D400 highway within the borders of Antalya city centre.

2. METHODOLOGY

2.1. Freeware/Software and Data Sets

The freeware/software packages used in the method is described below:

- Geo Tracker is an Android based freeware for storing GPS-based location, time and altitude information into phone memory in ".gpx" format; alternatively, Gaia GPS freeware can also be used for iPhones. Programs similar to Geo Tracker or Gaia GPS freeware or ready-made GPS databases could also be used for accessing GPS data.

- GPS Babel is a freeware for adding speed, distance and direction information to instant GPS data and providing conversion support for different formats for PC's and mobile phones. Programs similar to GPS Babel freeware or other web-based GPS data conversion platforms (such as GPS Visualiser) could also be used in the conversion (such as gpx to txt) and improvement processes of GPS data (e.g. adding speed, distance, time, direction etc. information to instant GPS files).

- Microsoft Excel software could be used for editing GIS or GPS-based database files such as dbf or txt. Programs similar to Microsoft Excel could help integration of GPS data into GIS environment as they have the ability to access/change rows and columns of a database file.

- A GIS freeware/software such as QGIS, ArcGIS, MapInfo etc. could be used to handle GIS GPS integration and provide support for location-based visualization, query and network analysis.

The data sets used in the method include:

- The GPS track data obtained by "Geo Tracker" freeware

- The road network centre line open-source dataset downloaded online from OpenStreetMap website.

The proposed model describes how GPS track data is integrated into GIS-based transportation networks and helps to improve costs in transportation networks considering slope and topological direction.

2.2. Study Area

The proposed methodology is applied to a particular segment of a ring road of D400 motorway within the borders of Antalya city centre to demonstrate the efficiency and the usability of the proposed model (see Figure 2).

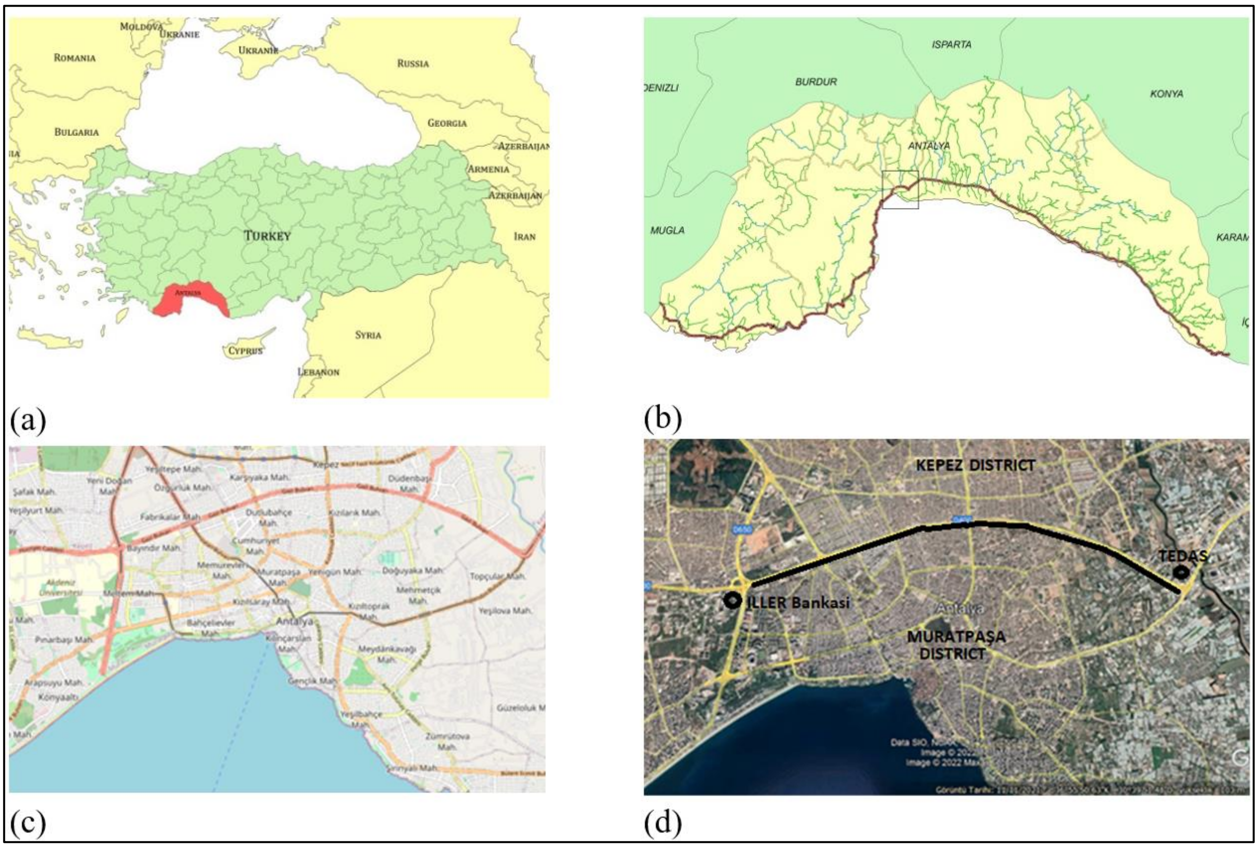


Figure 2. *Antalya Hinterland and Study Area (a) Location of Antalya in Türkiye (b) Location of D-400 Motorway in Antalya (c) Openstreet View of D-400 Motorway (d) Satellite Image of D-400 Motorway and Its Transportation Connections (black line represents district boundary between Kepez and Muratpaşa)*

Considering the population growth rate from 2013 to 2022, Antalya ranks first in population growth rate in Türkiye with an average rate of 3.52%. The swelling population leads to increased traffic volume on the D-400 motorway, which is the main distribution axis of Antalya province.

The D-400 Antalya Ring Road, examined within the scope of this study, is the most important transportation axis connecting the city to the country's transportation network. For Türkiye, the D-400 Motorway starts from the Datça District of Muğla and ends at the Esendere border gate of Yüksekova District of Hakkari. Along with its importance in the country's transport network, the D-400 motorway constitutes the most vital urban transport backbone of Antalya city centre.

The section between the two junctions of the D-400 motorway, called Iller Bankası junction in the west and TEDAŞ junction in the east, was considered as the study area route. This section, has an intensive mixed-use, enables a maximum speed of 82 km/h in both directions, is characterized by heavy traffic in all hours but especially during rush hours, forms the border between Muratpaşa and Kepez districts, the most densely populated districts of Antalya province.

In this regard, in order to demonstrate the efficiency of model; GPS-based floating car data collection on selected route as a sample dataset, started at 17:24 on Tuesday, 26.04.2022 and finished at 17:48 in both direction for 24 minutes.

As the main focus of the research is not to evaluate a specific accessibility conditions or transportation network performance in a detailed manner but to provide a methodological support about how GPS data can be integrated into GIS-based transportation networks, the research focused on a particular segment of a ring road of D400 motorway within the borders of Antalya city centre which provides different variations speed, slope and elevation data in Antalya city. As seen from the obtained outputs of the research, the collected sample dataset provided enough information flow to achieve the main purpose of the research. However, the proposed methodology could also be used by larger GPS datasets considering different research needs.

2.3. Flow Diagram

The proposed methodology is summarized under 3 main parts which are data preparation (preparation of the GPS and network data sets), integration of GPS and network datasets in GIS environment and outputs/benefits of the model (see Figure 3).

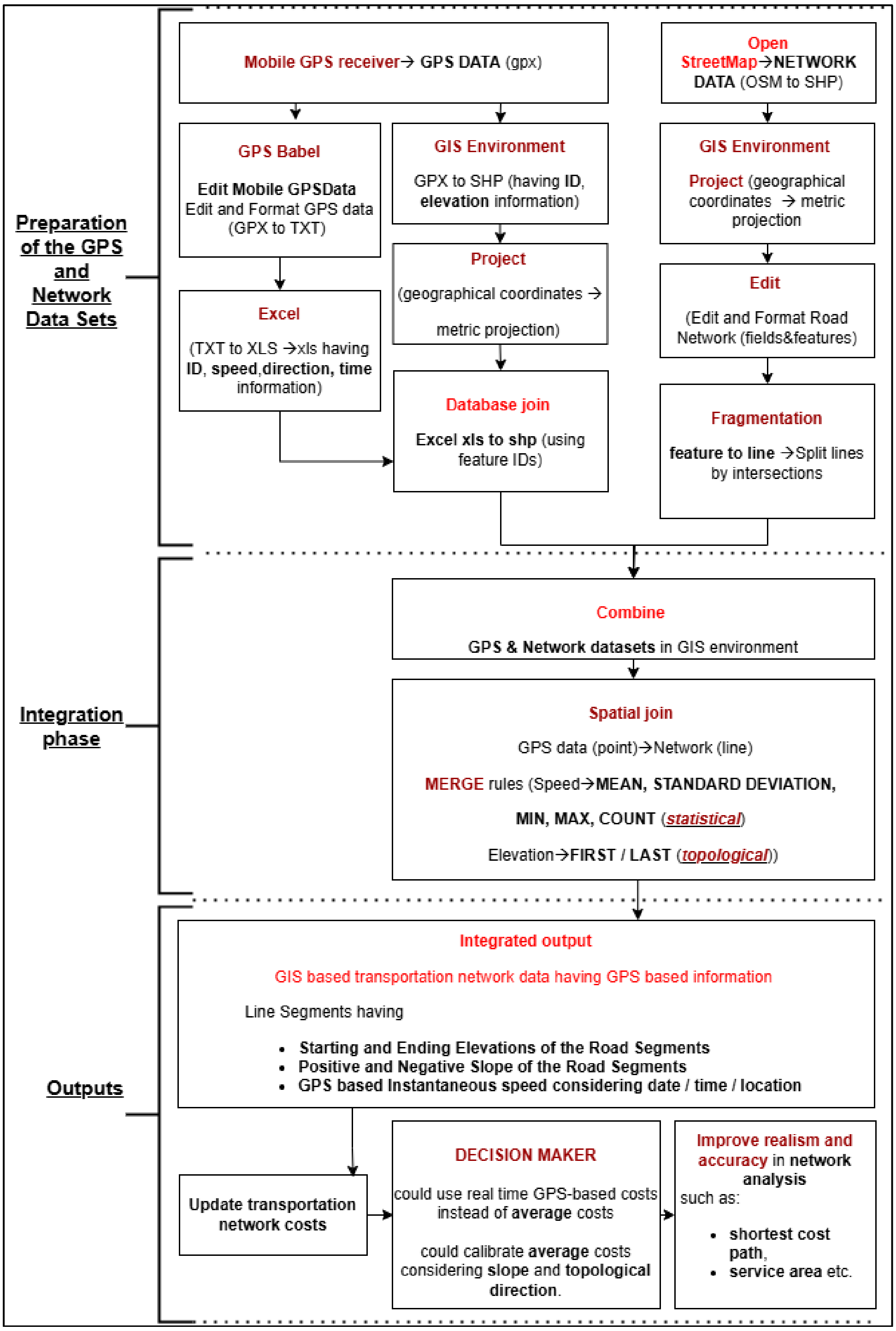


Figure 3. *Flow diagram*

2.3.1. Data preparation (Preparation of the GPS and network data sets)

Preparation of GPS Data

GPS tracker freeware's such as "GeoTracker, GaiaGPS or etc" could be used to record any kind of GPS-based track by walking, bicycle, electric vehicles or other vehicles (widely known as GPS-based floating vehicle data in the literature). The route with location information including speed, altitude, direction and time data, is possible to be saved in GPX format (or in KML/KMZ format).

Since some of the information in the GPX data such as leg speed, leg course/direction, leg length/time data could not be accessed directly by the decision maker in GIS environment, the GPX format is needed to be converted into "tab delimited txt" format by using GPS Babel or any other "GPS data conversion tool".

The conversion of the GPX format ("GPX XML") into "tab delimited txt" format ("Garmin MapSource–txt (tab delimited)") in GPS Babel freeware or in any other web-based GPS data conversion platforms (such as GPS Visualiser) help to solve this accessibility problem (see Figure 4 for the outputs).

```
Grid    Lat/Lon hddd°mm.mmm'
Datum   WGS 84


Header  Name    Start Time      Elapsed Time    Length  Average Speed   Link

Track   Antalya Ã‡evre Yolu     26/04/2022 17:24:57     0:23:01 18.7 km 49 kph

Header  Position        Time    Altitude        Depth   Temperature     Leg Length      Leg Time        Leg Speed       Leg Course

Trackpoint      N36 54.078 E30 39.993   26/04/2022 17:24:57     76 m
Trackpoint      N36 54.088 E30 40.001   26/04/2022 17:24:59     76 m                    21 m    0:00:02 39 kph  30° true
Trackpoint      N36 54.092 E30 40.006   26/04/2022 17:25:00     75 m                    11 m    0:00:01 39 kph  48° true
Trackpoint      N36 54.095 E30 40.013   26/04/2022 17:25:01     76 m                    11 m    0:00:01 40 kph  59° true
Trackpoint      N36 54.098 E30 40.019   26/04/2022 17:25:02     75 m                    11 m    0:00:01 41 kph  63° true
Trackpoint      N36 54.101 E30 40.027   26/04/2022 17:25:03     75 m                    12 m    0:00:01 43 kph  68° true
Trackpoint      N36 54.103 E30 40.035   26/04/2022 17:25:04     76 m                    13 m    0:00:01 45 kph  73° true
Trackpoint      N36 54.105 E30 40.043   26/04/2022 17:25:05     75 m                    12 m    0:00:01 45 kph  72° true
Trackpoint      N36 54.107 E30 40.051   26/04/2022 17:25:06     75 m                    13 m    0:00:01 45 kph  72° true
Trackpoint      N36 54.109 E30 40.059   26/04/2022 17:25:07     75 m                    12 m    0:00:01 44 kph  67° true
Trackpoint      N36 54.112 E30 40.067   26/04/2022 17:25:08     74 m                    13 m    0:00:01 48 kph  66° true
Trackpoint      N36 54.116 E30 40.075   26/04/2022 17:25:09     75 m                    14 m    0:00:01 49 kph  59° true
Trackpoint      N36 54.119 E30 40.082   26/04/2022 17:25:10     75 m                    12 m    0:00:01 45 kph  61° true
Trackpoint      N36 54.121 E30 40.089   26/04/2022 17:25:11     74 m                    11 m    0:00:01 41 kph  68° true
Trackpoint      N36 54.124 E30 40.097   26/04/2022 17:25:12     75 m                    13 m    0:00:01 48 kph  68° true
Trackpoint      N36 54.126 E30 40.105   26/04/2022 17:25:13     76 m                    12 m    0:00:01 42 kph  70° true
Trackpoint      N36 54.129 E30 40.112   26/04/2022 17:25:14     76 m                    11 m    0:00:01 40 kph  65° true
Trackpoint      N36 54.132 E30 40.120   26/04/2022 17:25:15     77 m                    14 m    0:00:01 49 kph  67° true
Trackpoint      N36 54.134 E30 40.128   26/04/2022 17:25:16     78 m                    13 m    0:00:01 48 kph  68° true
Trackpoint      N36 54.137 E30 40.136   26/04/2022 17:25:17     78 m                    13 m    0:00:01 46 kph  70° true
Trackpoint      N36 54.139 E30 40.145   26/04/2022 17:25:18     79 m                    13 m    0:00:01 47 kph  68° true
```

Figure 4. *Output GPS data in TXT format after conversion*

After formatting phase ("ID" column must be created and unnecessary parts that do not conform to the relational database format (RDB) should be eliminated such as unnecessary heading information, space characters, informative units etc.) by a database editing software such as Microsoft Office Excel, the final version of the GPS database looks like those in Figure 5 and ready to integrate into GPX data in GIS environment.

ID	Time	Elevation	Leg_Length	Leg_Time	Leg_Speed	Leg_Course
1	26.04.2022 17:24	76				
2	26.04.2022 17:24	76	21	00:00:02	39	30
3	26.04.2022 17:25	75	11	00:00:01	39	48
4	26.04.2022 17:25	76	11	00:00:01	40	59
5	26.04.2022 17:25	75	11	00:00:01	41	63
6	26.04.2022 17:25	75	12	00:00:01	43	68
7	26.04.2022 17:25	76	13	00:00:01	45	73
8	26.04.2022 17:25	75	12	00:00:01	45	72
9	26.04.2022 17:25	75	13	00:00:01	45	72
10	26.04.2022 17:25	75	12	00:00:01	44	67
11	26.04.2022 17:25	74	13	00:00:01	48	66
12	26.04.2022 17:25	75	14	00:00:01	49	59
13	26.04.2022 17:25	75	12	00:00:01	45	61
14	26.04.2022 17:25	74	11	00:00:01	41	68
15	26.04.2022 17:25	75	13	00:00:01	48	68
16	26.04.2022 17:25	76	12	00:00:01	42	70
17	26.04.2022 17:25	76	11	00:00:01	40	65
18	26.04.2022 17:25	77	14	00:00:01	49	67
19	26.04.2022 17:25	78	13	00:00:01	48	68
20	26.04.2022 17:25	78	13	00:00:01	46	70
21	26.04.2022 17:25	79	13	00:00:01	47	68
22	26.04.2022 17:25	80	13	00:00:01	48	70
23	26.04.2022 17:25	79	14	00:00:01	49	65
24	26.04.2022 17:25	80	12	00:00:01	43	70

Figure 5. *Formatted Data Structure in Microsoft Office Excel (relational database format (RDB)*

The "ID" column of the “GPS data” created in the MS Excel environment and the "OBJECT ID" column of the “GPX to SHP data” in GIS environment could be integrated by "Join Data" capabilities of GIS. Since the origin of both data sets are the same, their record order is the same. If an editing operation is to be made on the records (deletion, addition), this must be done for both file sets to provide data integrity. This process provides to integrate leg time, leg length, leg speed, leg course (direction) information into GPS data that were not previously included in GIS (Figure 6).

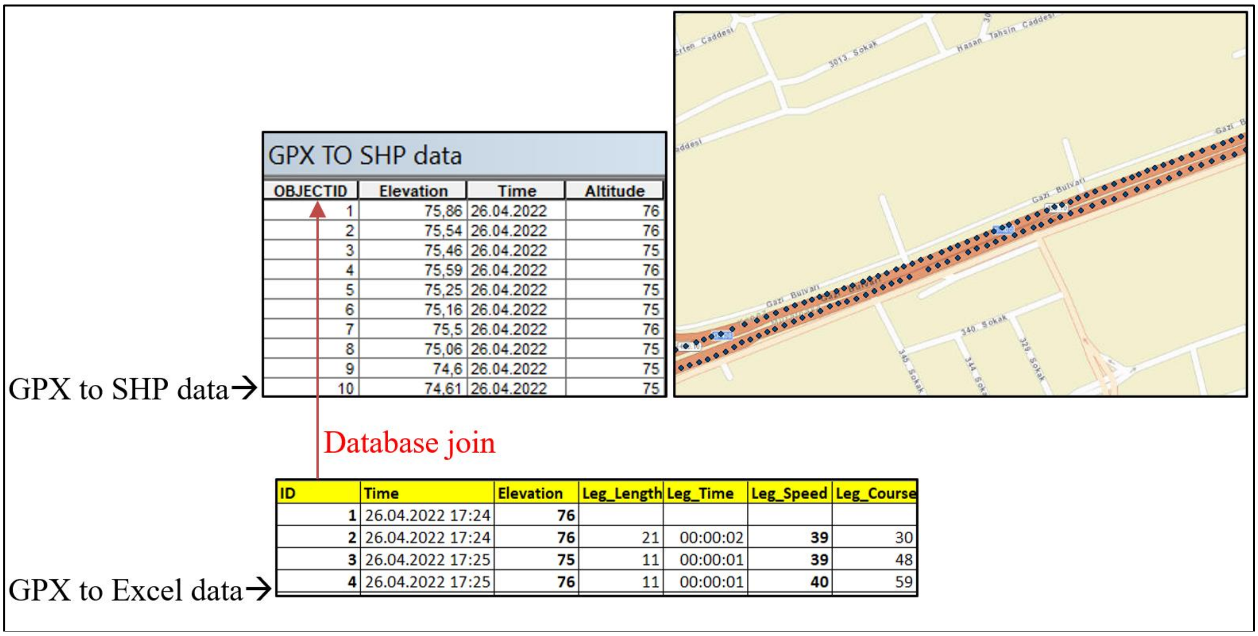


Figure 6. *Integration of GPS Data into GIS by using Join Data Function of GIS*

Preparation of Transportation Network Data

The transportation network data of the study area is obtained from OpenStreetMap environment in "map.osm" format and transferred into GIS environment (Figure 7).

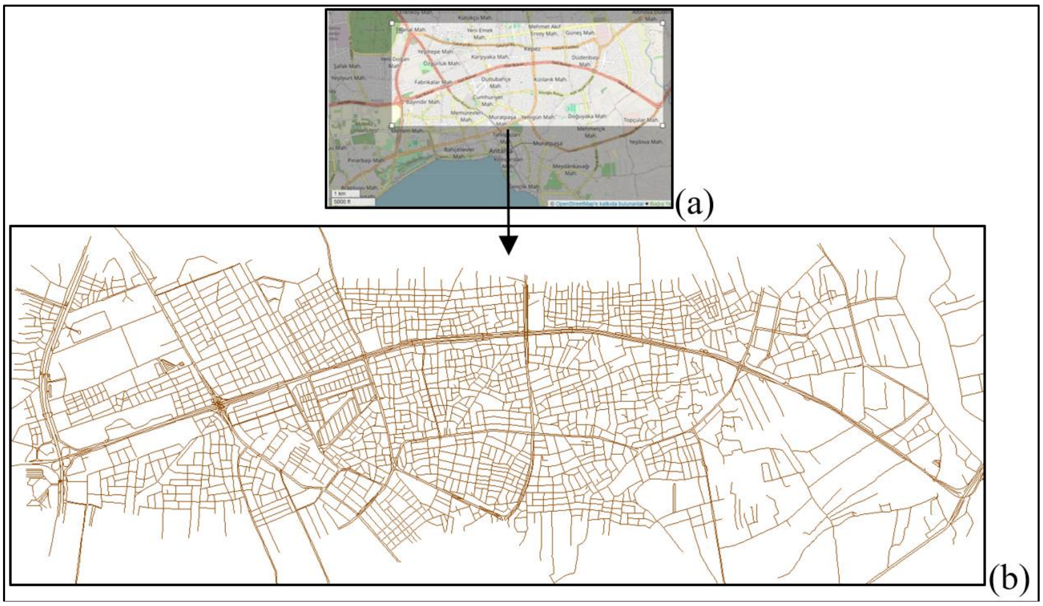


Figure 7. *(a) Obtaining Transportation Network Data for the Study Area from an Open Data Source Environment (Open Street Map), (b) Transportation Network Data Visualized in GIS Environment*

Since all data needed to be in a metric coordinate system to perform any spatial analysis in GIS environment, all data in "geographic" coordinates must be projected into "metric" coordinates such as "WGS 1984 UTM Zone 36N" or similar.

By using "feature to line" function of GIS, the polylines in the transportation network data must be separated at network intersections. The reason for this process is that a logical network analysis in GIS environment could not be possible without breaks on network intersections.

2.3.2. Integration of GPS and network datasets within GIS environment

GPS data is possible to be integrated into the transportation network polylines via the "Spatial Join" function of GIS. Since there are many GPS point data per line, statistical merge rules (MIN, MAX, MEAN, STANDARD DEVIATION, MEDIAN, COUNT etc.) or topological merge rules (FIRST, LAST) could be used for integration of leg speed and elevation. For example, topological rules could be used for determination of starting and ending elevations of road segments, and statistical rules could be used for determination of speed statistics in integration process (Figure 8).

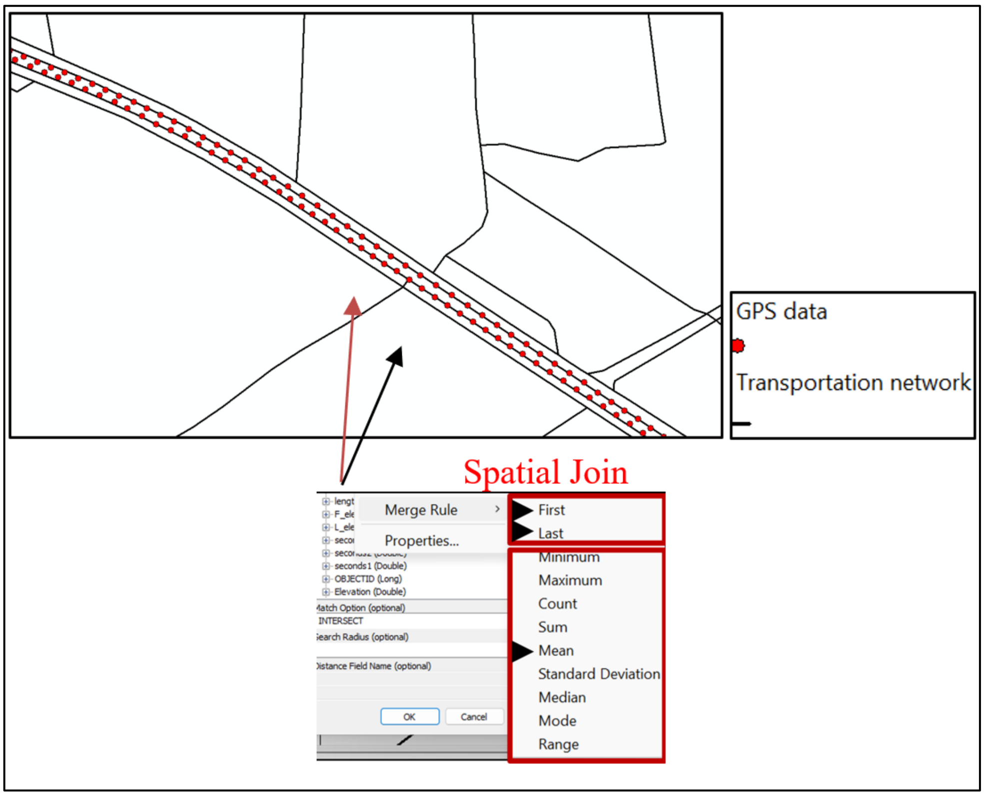


Figure 8. *Integration of GPS Data into transportation network by Spatial Join function of ArcGIS (Speed→(MEAN (statistical), Starting Elevation→ (FIRST (topological), Ending Elevation→(LAST (topological))*

As full intersection of transportation networks and GPS-based points is not possible, a logical threshold needs to be determined by the decision maker by the help of the "search radius" section of the spatial join process. In spatial join process, search radius is a critical parameter as a small threshold may cause related data not to be connected to each other, while a large threshold may cause unrelated data to be connected to each other.

All parts of the polylines in the transportation network, intersecting with a GPS data, could have an attribute of mean, min, max or standard deviation of speed. Moreover, the polylines in the transportation network could also have an attribute of starting and ending elevation, which means that "the slope information" could easily be extracted by the decision maker depending on "the direction of the road segments" (see Figure 9) as the length of each segment is already known by GIS.

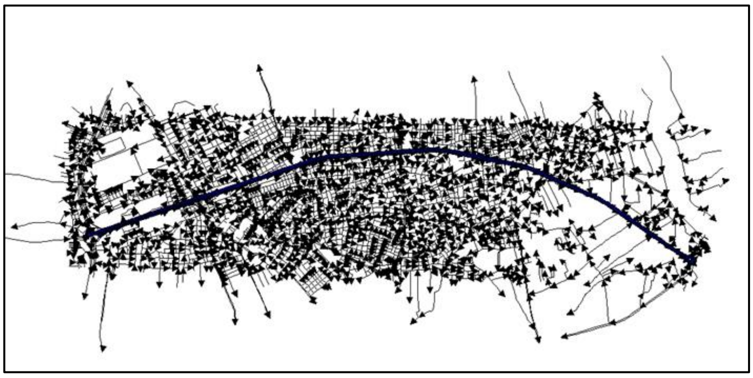


Figure 9. *Representation of Topological Direction of Road Lines (Black arrows represent the topological direction of road segments)*

Slope of road segments is a vital information for all kind of network analysis especially in accessibility modelling of bicycles, pedestrians and/or heavy vehicles such as fire trucks or garbage trucks etc. Integration of GPS-based speed and elevation statistics into road segments considering the topological direction of the road segments could trigger wide range of analysis capabilities especially for decision makers working on urban planning, transportation planning and physical accessibility. Decision maker could benefit from slope-calibrated "from-to / to-from" costs considering topological directions instead of using average costs. For example, in modelling pedestrian or bicycle accessibility etc., reduced or increased costs could be considered by the decision makers according to the direction of the slope (uphill, downhill, etc.) instead of assuming an average speed of 5 km/h, 25 km/h in all direction.

2.3.3. Outputs of the methodology

At the end of the above-mentioned process, the basic output of the model is a GIS-based transportation network having GPS-based information.

The line segments in the transportation network have

- starting and ending elevations of the road segments
- positive and negative slope of the road segments
- GPS-based instantaneous speed considering date / time / location

By the help of the above-mentioned information, decision makers a) could use real time GPS-based costs instead of average costs b) could calibrate average costs considering slope and topological direction and c) could improve cost accuracy in network analysis (decision maker could use GPS-based costs instead of average costs) such as shortest path, service area etc.

The proposed GPS / GIS integration methodology enables researchers and decision makers to be able to integrate GPS-based floating data into transportation networks, reach GPS provided information in GIS-based network analysis and opens a wide range of spatial analysis capabilities for many kinds of accessibility calculation process.

Some of the possible outputs of the proposed model are described below in a more detailed manner to demonstrate the efficiency and usability of the proposed model.

Starting and Ending Elevations of the Road Segments

Once the starting and ending elevation of the road segments in the database are created, the elevation differences of road segments depending on the topological direction of the road segments could be easily extracted by the help of the "field calculator" capabilities of GIS. There are elevation differences of +8 to -8 meters between the start point and end point of the road line considering the topological direction of the network. It is determined that the elevation differences were high since the road in case study area was a main ring road and there were overpasses at junctions, as seen in Figure 10. The negative high represents where starting elevation is higher than ending elevation, the positive high represents where starting elevation is lower than ending elevation. The road lines in grey colour represents the road segments that do not have GPS data (No Data), and black arrows represent topological direction of road segments.

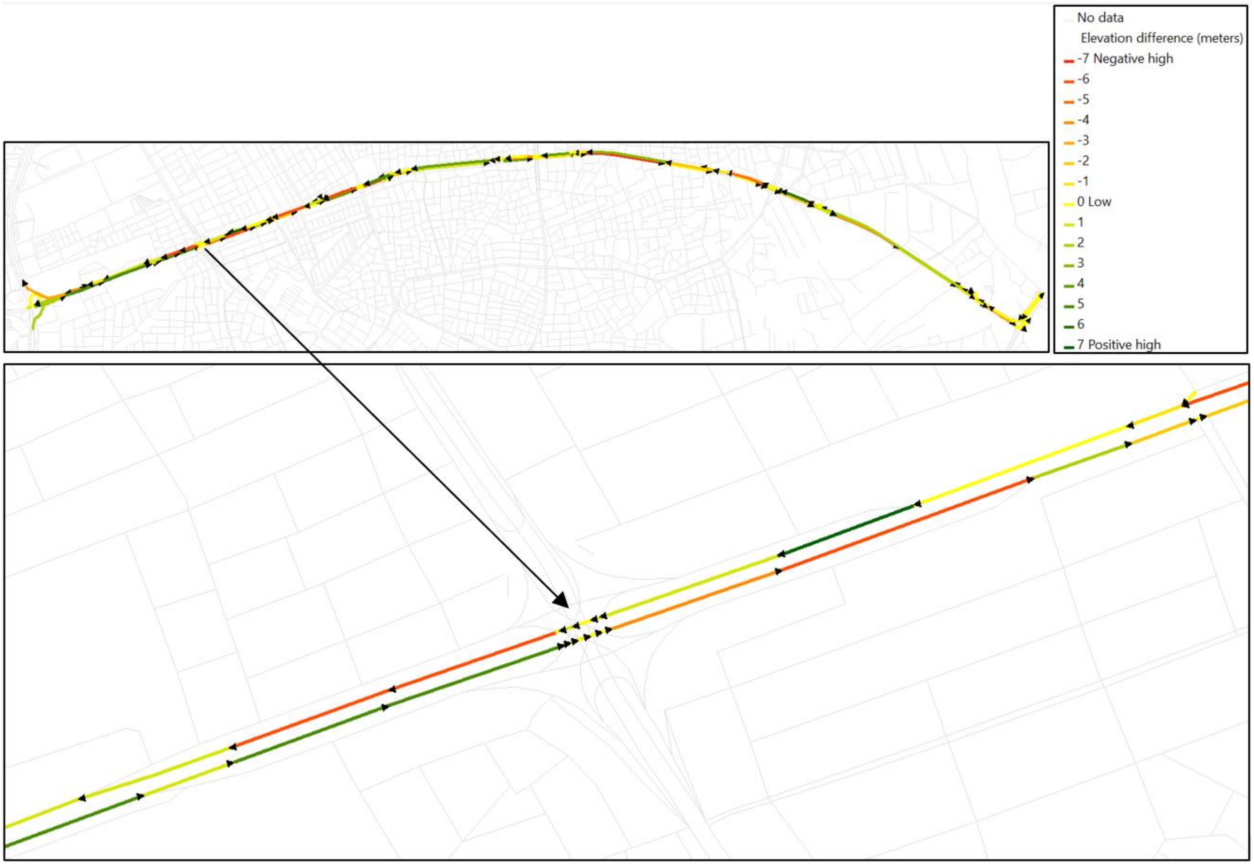


Figure 10. *Elevation Difference (Starting and Ending Difference of Elevation) (black arrows--> topological direction of road segments)*

Positive and Negative Slope of the Road Segments

The slope of the road segments can be revealed by the help of the elevation difference and road length information (see Figure 11). In this regard, a new column called "slope" in the attribute table was created and calculated by dividing the elevation difference by the road lengths in percent (%). The road lines from green to yellow colour had a negative slope between the data of 0.00 (0 %) and 15.56 (+15.6 %) and it is a downhill road, and the road line data from yellow to red colour is uphill with a positive slope between the data of -3.51 (-3.5 %) and 0.00 (0 %).

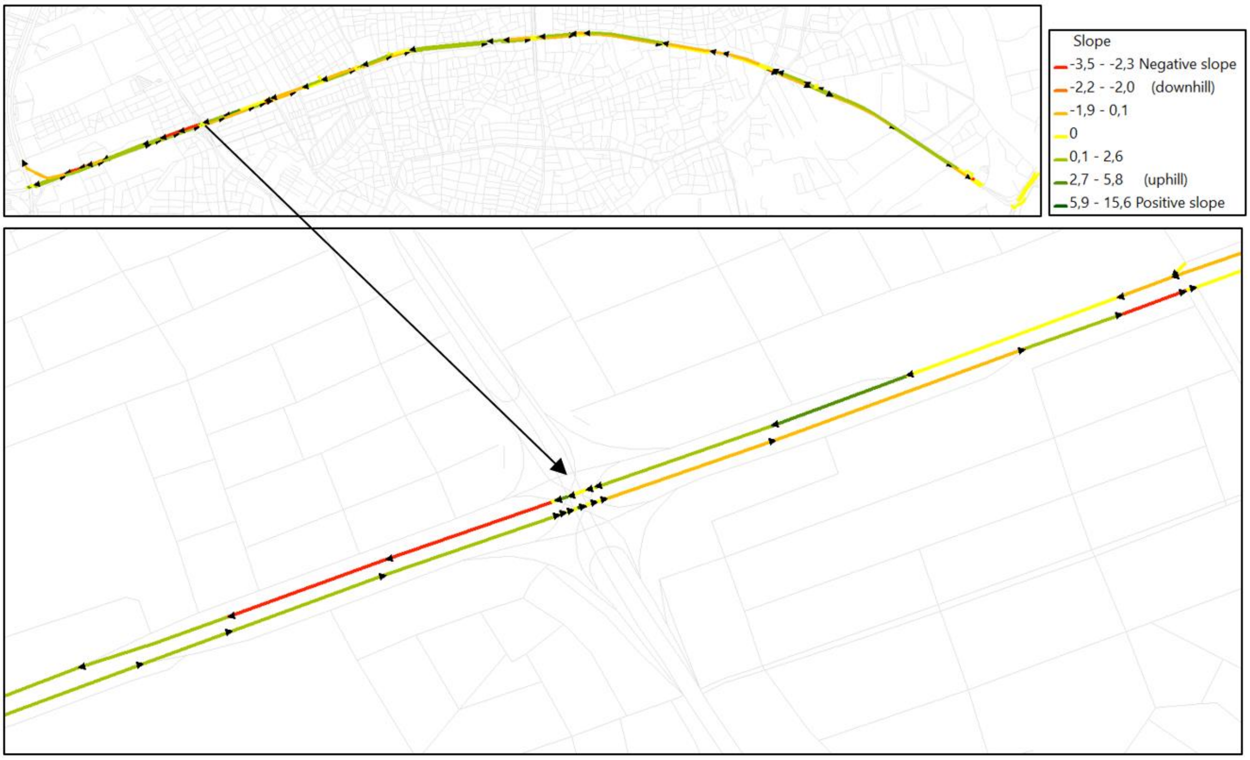


Figure 11. *Positive and Negative Slope Data Information Considering Topological Direction (black arrows--> topological direction of road segments)*

GPS-based Instantaneous Speed

By the help of the proposed model, GPS-based instantaneous speed data could also be integrated into road segments in GIS environment (see Figure 12). The observed GPS-based instantaneous speeds are between 6 km/h (minimum) and 76 km/h (maximum) on D400 motorway in which the allowed speed limit is 82 km/h. This means that the maximum speed of 82 km/h could not be reached in any segment and in any direction.

For each road segments, converting speed values into cost values in seconds is also possible. Cost in “seconds” could be calculated by the formula “time (seconds) = length (meters) / (speed (km/h) * 0.2777)” in which 0.2777 (1000/3600) converts speed unit from kilometre per hour (km/h) to meter per second (m/s). Calculated time-based cost information on transportation networks could be used by decision makers to support various types of transportation, land use and/or accessibility related scenarios considering different date, time and location conditions.

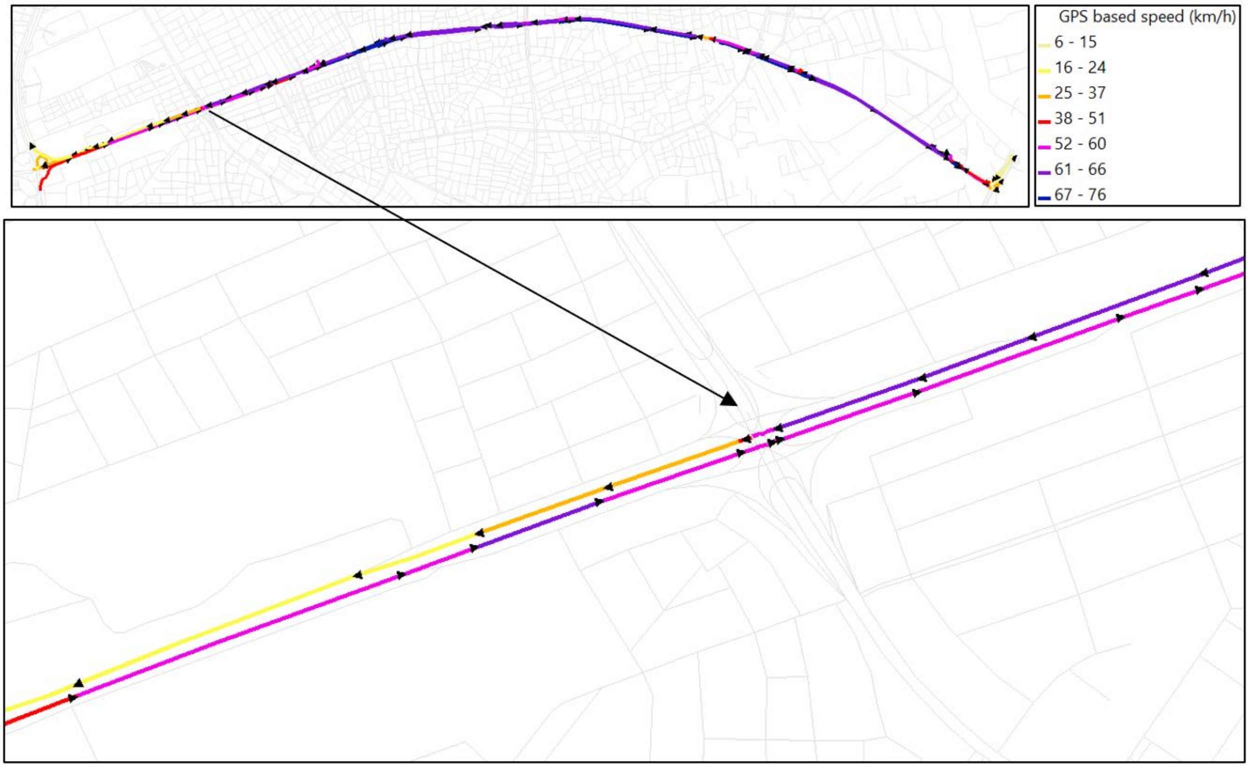


Figure 12. *Instant Speed Data Generated from GPS-based Floating Car Data (black arrows--> topological direction of road segments)*

3. DEMONSTRATION OF REALISM AND ACCURACY OF THE PROPOSED METHODOLOGY

After introducing the possible outputs of the proposed model in the previous section ("starting and ending elevations of the road segments (elevation differences), the positive and negative slope of the road segments", the GPS-based instantaneous speed"), this section demonstrates the realism and accuracy of the proposed methodology by giving some basic statistics and usage examples about how the outputs of the proposed model could improve accessibility modelling in GIS environment such as; shortest path analysis, service area analysis and/or cost improvement process in a comparable manner.

The purpose of this section is to demonstrate the usability of the proposed methodology by performing some main and probably the most widely used examples of network analysis in GIS environment rather than to perform a detailed accessibility modelling for user defined locations and/or thresholds. Therefore, the location and threshold parameters used in this section are for visualization/illustration purposes only.

In shortest path example, accessibility costs (time in seconds) between origin and destination locations on D400 motorway are calculated both with GPS-based and with average based costs. While GPS-based costs take "GPS-based speed" into account, average based costs take "82 km/h constant speed" into account on D400 motorway sections. There is nearly 640 seconds (10,60 minutes) time difference between average and GPS-based costs in seconds which demonstrates the importance of GPS and GIS integration in accessibility analysis (Total route is 23.54 km, Total GPS-based cost between origin 1 and destination 3 is 1751 seconds, Total average based cost between origin 1 and destination 3 is 1113 seconds) (see Figure 13).

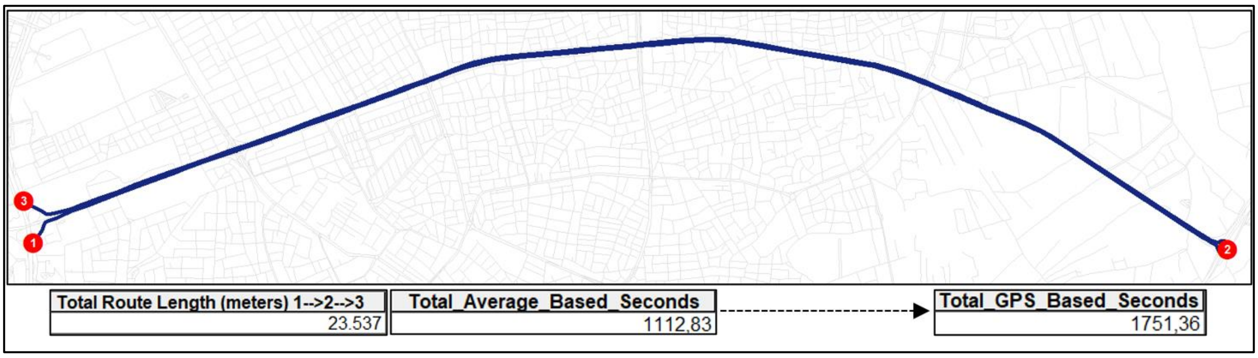


Figure 13. *Demonstration of Usability of the Proposed Methodology: Shortest Path Analysis (Considering Time) Between Points on Network*

In service area example, accessibility costs (time in seconds) are calculated in a structure that starts from origin 1 and spreads along the D400 motorway representing accessibility scores for every 300 seconds (5 minutes) time interval. While the GPS-based costs take "GPS-based speed" into account, average based costs take "82 km/h constant speed" into account on D400 motorway sections. When the accessibility scores are compared, differences of up to 1,5-2 km were observed, especially in the direction of the D400 motorway where GPS data is collected (see Figure 14).

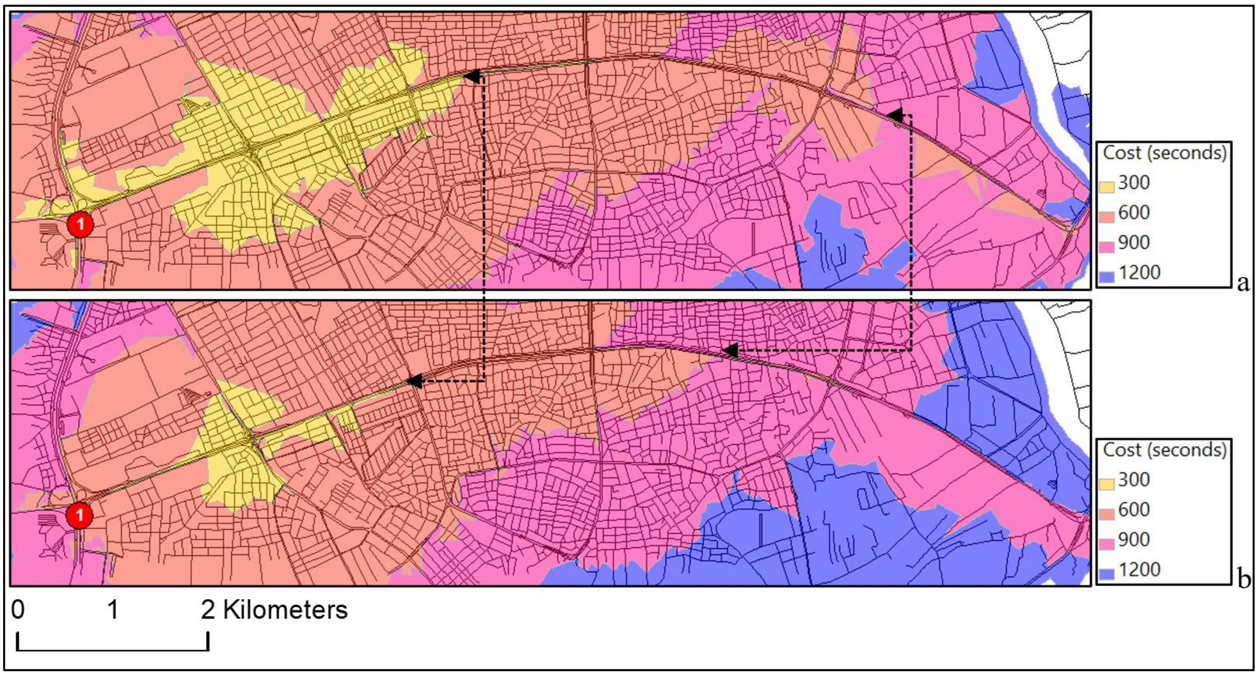
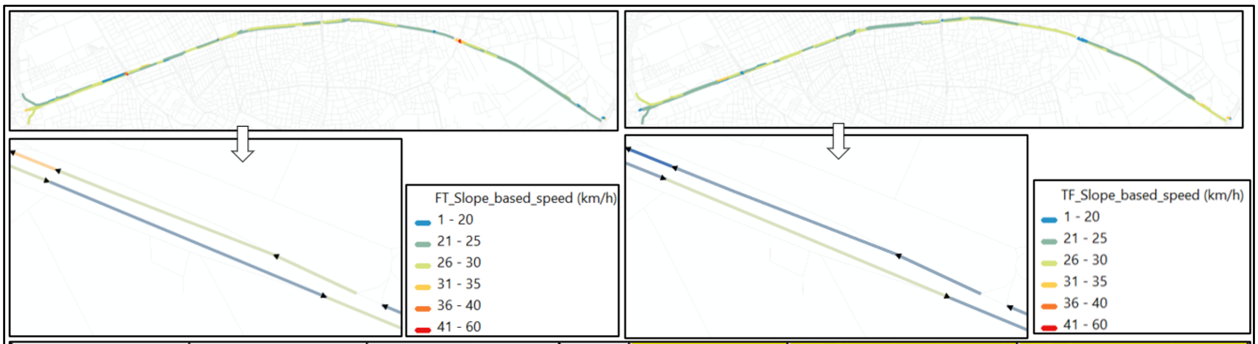


Figure 14. *Demonstration of Usability of the Proposed Methodology: Service Area by Time a) Average cost-based accessibility scores (without using GPS-based costs) b) GPS cost-based accessibility scores*

Cost improvement example demonstrates that the average speed information in transportation networks could be calibrated by the decision makers considering "starting elevation", "ending elevation", "elevation difference" and "slope" information, especially in accessibility research considering pedestrians, bicycles and/or heavy vehicles (fire trucks etc.) which are highly affected by the slope.

As the GIS GPS integration could provide additional information about the network and movement characteristics, it could be possible for the decision maker to calibrate cost in network segments considering downhill or uphill information of the transportation network segments (slope), topological direction of the road segments and movement direction of the vehicle or passenger. The below example demonstrates how the average speed of 25 km/h for a bicycle could be decreased or increased by the decision maker according to different positive and negative slope scores in different road segments. Single costs can be specialized as "from-to cost" (cost of moving in the same direction of the topological direction of the road segment) and "to-from cost" (cost of moving in the reverse direction of the topological direction of the road segment) considering the size and the direction of the slope (see Figure 15).



starting_elevation	ending_elevation	elevation_difference	slope	Average_speed	FT_Slope_based_speed	TF_Slope_based_speed
101	102	1	8,39	25	42	8
95	96	1	5,85	25	37	13
85	86	1	5,06	25	35	15
78	79	1	4,48	25	34	16
85	92	7	3,75	25	32	18
93	94	1	3,6	25	32	18
85	87	2	3,08	25	31	19
84	85	1	3,02	25	31	19
82	83	1	2,94	25	31	19
87	88	1	2,59	25	30	20
90	95	5	2,36	25	30	20
89	90	1	2,32	25	30	20
96	101	5	2,1	25	29	21
86	84	-2	-2,19	25	21	29
82	81	-1	-2,26	25	20	30
92	90	-2	-2,27	25	20	30
84	80	-4	-2,43	25	20	30
96	90	-6	-2,64	25	20	30
90	84	-6	-2,76	25	19	31
76	75	-1	-2,79	25	19	31
81	80	-1	-3,27	25	18	32
85	84	-1	-3,43	25	18	32
94	93	-1	-3,52	25	18	32

Figure 15. *Demonstration of Usability of the Proposed Methodology: An example of cost calibration process for accessibility modelling considering different slope and topological direction (ft speed→from-to speed and tf speed→to-from speed)*

4. CONCLUSIONS

The benefits / usage areas / advantages and future research capabilities that this research could provide for readers, researchers and /or decision makers working on accessibility are summarized below in detail both in local and broader scale.

Local Scale:

- The outputs of the proposed model (starting and ending elevations of road segments, positive and negative slopes of road segments, GPS-based instantaneous speeds of different modes) can be used on urban, land use and/or transportation planning research, considering different transportation modes such as pedestrians, bicycles, electric bicycles, public transportation, automobiles, etc.

- The proposed methodology could easily be improved for specific needs of decision makers or researchers. Free and practical integration of GPS-based data, including departure and arrival time, waiting time, leg distance and direction etc. (in addition to speed and altitude) into GIS-based transportation networks could enable many further spatial analyses to be conducted in urban, transportation and land use planning area.

- More detailed GIS-based accessibility analyses can be performed by using more comprehensive and larger GPS databases (considering hourly, daily, weekly, monthly, annual and/or seasonal variations on transportation network costs).

- GPS-GIS integration can significantly increase the realism and accuracy of network analyses. Instead of "using average speeds" in calculating transportation costs (e.g. 90 km/h on main roads for cars, 25 km/h for bicycles or 5 km/h for pedestrians etc.), "instant speeds considering different traffic conditions" or "calibrated speeds considering the direction and size of the slope" could be used. By this way, basic statistics of transportation network costs such as average speed, minimum speed, maximum speed, standard deviation of speed etc. for different road stages and sections, considering different dates and time periods (peak hour, normal hour, weekend etc.) could be accessed by the decision makers.

- Additional GPS-based information integrated into GIS (Starting and Ending Elevations of the Road Segments, The Positive and Negative Slope of the Road Segments, The GPS-based Instantaneous speed considering date / time / location) could be used to improve the outputs of different types of network analysis such as "least cost path", "least cost facility", "route optimization", "service area", "location allocation", "origin destination" "cost matrix" which are frequently used in the GIS environment.

- Knowing the elevation difference and slope information of the starting and ending points of transportation network segments could contribute more realistic and accurate modelling of accessibility, especially in accessibility research on pedestrians, bicycles and/or heavy tonnage vehicles.

- Providing the ability to calculate detailed cost statistics (average speed, minimum speed, maximum speed, standard deviation of speed, etc.) for each transportation segment with GPS support may enable probabilistic modelling of accessibility, which is mostly modelled deterministically in the literature. With the help of improved datasets and models, better visualization, analysis and/or modelling of accessibility and transportation systems could be possible.

- Integrating GPS-based space-time information (e.g., waiting times of pedestrians, cyclists, cars at traffic lights/crosswalks, waiting times of public transport vehicles (buses, trams, etc.) at stops, etc.) into GIS-based transportation networks can support many new research areas specific to accessibility and transportation planning (e.g., understanding traffic patterns, measuring congestion, evaluating pedestrian, cyclist, and/or public transport efficiency, identifying traffic bottlenecks, and/or proposing solutions for better traffic signal timing, etc.).

- Analysis of GPS-based space-time information in a GIS environment can support many research areas especially in the field of urban design (interactions of pedestrians, bicycles, micromobility vehicles, public transportation vehicles, cars with land use, streets, spaces, how sidewalks, squares, bicycle paths, and/or vehicle roads are used by different users etc.).

Broader Scale:

Integration of GIS and GPS plays a crucial role in urban, land use and transportation planning research by providing a powerful platform for data collection, analysis, and decision-making.

More accurate, precise and real-time (live) data about transportation and infrastructure networks, land use, buildings etc. could be collected /gathered by the help of the GPS-enabled devices and GIS technologies for many different purposes like mapping urban and regional environments, understanding urban and regional dynamics, identifying opportunities for growth and development, understanding urban and regional impacts and/or supporting accessibility, location/allocation type of decisions etc.

The GIS-GPS integration could provide a strong synergy for researchers and decision makers to make better decisions in many research areas related to accessibility, land use and transportation:

- transportation planning (regarding how live GPS-based traffic data (from buses, trains, or micro mobility services) and GIS models could enable better research),
- route optimization (e.g. simulating optimal transportation routes),
- urban mobility (e.g. understanding the movement of different transportation types (pedestrian, bike, public transport, car) in urban area),
- traffic management (e.g. understanding traffic track patterns, flow patterns, incident patterns and congestion),
- land-use planning (e.g. assessing the current urban footprint and identify interactions among different land-use types (residential, commercial, green areas) for future development),
- impact analysis (e.g. forecasting the effects of "zoning changes, pedestrian movements, urban sprawl and/or land-use changes" on traffic patterns and accessibility, help understanding urban expansion, or shifts in population size and density),
- emergency services (e.g. more efficient fire truck / ambulance routes and service areas, best routes for evacuation or emergency/disaster response and risk assessment, accessibility),
- accessibility modelling (e.g. more efficient public transportation routes, schedules, and stop locations based on real-time demand and traffic conditions, public transportation accessibility),
- environmental impact assessment (e.g. GPS data on environmental factors like air quality, flood zones, noise, or pollution can be integrated into GIS to analyse the environmental impact of urban development and transportation systems),
- participatory planning (e.g. GPS-enabled devices allow citizens to contribute data on urban infrastructure, such as road conditions, traffic congestion areas or problematic locations which help decision makers to create comprehensive interactive maps of urban issues).

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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