Environment, Development and Sustainability
https://doi.org/10.1007/s10668-024-04891-0

ORIGINAL PAPER

# A study on the improvement of bicycle transportation in Sivas city using hybrid multi-criteria model based network analysis

**Elif Güldü[1] · Çağdaş Kuşçu Şimşek[2] · Serdar Selim[2]**

Received: 27 October 2022 / Accepted: 3 April 2024


## Abstract

The bicycle stands out as a sustainability-friendly vehicle due to its benefits for health, the environment, and the economy. However, the deficiencies and inadequacies in the cycling infrastructure prevent a safe and comfortable riding environment, in addition to indirectly preventing the widespread use of bicycles. This study aims to integrate a few disconnected bicycle routes in a city and create a bicycle road network that will allow the efficient use of bicycles in the urban area by using a Hybrid Multi-Criteria Model-Based Network Analysis. In the study, considering the physical, social, and visual criteria that should be used when determining bicycle paths, the suitability weight of each road line for bicycle transportation was determined. In this step, the bicycle path network was created using the weighted roads between the important points of the city in terms of tourism, trade, education, health, culture, transportation, and recreation areas. The most suitable bicycle routes were generated by network analysis considering the weighted roads that were determined by a model hybridized with the analytic hierarchy process (AHP) and analytic network process (ANP) methods and minimum distances. When the eligibility checks of the obtained routes were made, it was determined that while 99.7% of the roads passed through moderately suitable, suitable, and very suitable roads, only 0.3% of the new routes passed through unsuitable roads. The findings revealed that both efficient and less costly bicycle lines can be created using the proposed method.

**Keywords** Sustainable transportation · Urban planning · Bicycle route planning · Multi-criteria analysis · GIS · Weighted network analysis

✉ Elif Güldü
elifguldu96@gmail.com

Çağdaş Kuşçu Şimşek
cksimsek@akdeniz.edu.tr

Serdar Selim
serdarselim@akdeniz.edu.tr

[1] Institute of Natural and Applied Sciences, Department of Remote Sensing and GIS, Akdeniz University, Antalya, Turkey

[2] Faculty of Science, Department of Space Sciences and Technologies - Remote Sensing and GIS, Akdeniz University, Antalya, Turkey

## 1 Introduction

The increase in the concentration of greenhouse gases, especially $CO_2$, in the atmosphere which usually arises from the combustion of fossil fuels raises concerns about future natural threats that also may affect human life (Gao et al., 2018; Solaymani, 2019). While the world's demand for fossil fuels is increasing as the day goes on (Kalair et al., 2021), many countries still do not have an effective and viable environmental policy to reduce their demand for fossil fuels (Li et al., 2011; Paterson, 2021). In this context, the transportation sector is one of the largest end consumers of total energy and sources of emissions that contribute to global emissions (Van Fan et al., 2018). Thus, 29% of the world's total energy consumption, 65% of the world's consumption of petroleum products, and approximately 14% of greenhouse gas emissions originate from transportation (IEA, 2007; IPCC, 2014; Solaymani, 2019). Therefore, the adoption of sustainable energy policies primarily depends on reducing fossil fuel consumption (Fernandez, 2021).

Transportation, which has environmental, social, and economic effects (Zhao et al., 2020), is important to ensuring sustainability from the macro scale to the micro scale. Transportation systems, which provide access to economic and social opportunities in urban areas, are some of the parameters to be considered in the planning of the sustainable development of space (Ogryzek et al., 2020). The understanding of sustainable transportation planning, which is defined as "providing current transportation and mobility needs without compromising the ability of future generations to meet these needs", has become an important issue, especially in automotive-oriented developing cities (De Gruyter et al., 2016; Rybarczyk & Wu, 2010). Unsustainable, automotive-oriented transportation systems play a significant role in both the rapid consumption of limited natural resources and the pollution of the natural environment. However, sustainable urban growth is possible with a transportation system that can provide the comfort of the residents economically, socially, and environmentally (Miller et al., 2016). At this point, especially the integration of transportation modes that coordinate the compatibility of all transportation modes such as pedestrian, bicycle, motor vehicle, bus, and rail systems is an important issue for the safety and sustainability of urban transportation systems (Saplıoğlu & Aydın, 2018).

However, unfortunately, studies revealed that the current transportation systems in many cities of the world are unsustainable, and they even pose a threat to future generations (Bamwesigye & Hlavackova, 2019). To achieve sustainability, the planning, policy, and use of technology should be analyzed, and the results should implemented as a whole within the framework of sustainability (Nilsson, 2019; Ogryzek et al., 2020). In this context, studies have shown that pro-environmental attitudes such as consuming less energy and reducing carbon emissions and air pollution encourage individuals to use bicycles (Gu et al., 2023; Sajid et al., 2023). Moreover, walking and cycling, which are the most important components of active mobility, are stated as solutions to urban transportation problems as they simultaneously promote sustainability, health, safety, and quality of life in cities (Fazio et al., 2021; Lu et al., 2018; Pucher & Buehler, 2017; Shang et al., 2021; Sun et al., 2020). Active mobility, which is economical and environmentally friendly compared to motorized transportation, indirectly supports land saving in urban areas and increases the quality of life of citizens by reducing air and noise pollution. Because of the significant benefits of walking and cycling, walkable and cyclable cities are planned in many developed and developing countries.

In particular, the shared use of bicycles via smart bicycle systems that have become increasingly popular in recent years has contributed to the spread of the use of bicycles, providing an increase in the demand for them by allowing people to become independent on having a bicycle all day (Shang et al., 2021). The significant restriction of the transportation sector by the COVID-19 pandemic has further increased the importance of walking and cycling routes, especially in the city (Campisi et al., 2020). To minimize individual contact by reducing the use of public transportation and vehicles in the city, local governments have tended to establish large-scale cycling networks (Campisi et al., 2020; Nawrath et al., 2019). For example, cycling infrastructures have been strengthened in many cities of Italy (Fazio et al., 2021), and 700,000 people started cycling in Spain in 2021 (GESOP, 2021). Nevertheless, the most important factors in the widespread use of bicycles include the sufficiency of cycling infrastructures, the determination of the most suitable cycling routes, and their integration into urban transportation (Saplıoğlu & Aydın, 2018 ey are not connect). In Turkey, which is a developing country, almost no city has an extensive bicycle path infrastructure. This situation also prevents the bicycle from being an actively used means of transportation.

Various methods such as supply-based models, demand-based models, multi-criteria decision-making (MCDM) models, and GIS-based grid cell models are used in bicycle facility planning (Glavić et al., 2019; Grisé & El-Geneidy, 2018; Rybarczyk & Wu, 2010; Terh & Cao, 2018). To create this infrastructure and determine bicycle routes, many factors mentioned in the international literature should be evaluated together (Đerek et al., 2021; Zuo & Wei, 2019). The MCDM-based analysis (Manzolli et al., 2021) of alternative planning options, which allow the solution of complex problems, guides the selection of the option with the lowest environmental impact and the highest efficiency (Broniewicz & Ogrodnik, 2020).

MCDM methods, which provide effective results in solving various problems in the context of different disciplines by using numerical methods, provide the opportunity to make choices from among different alternatives and criteria (Ala et al., 2023; Triantaphyllou, 2000). The GIS-Based Fuzzy Analytic Hierarchy Process (Fuzzy AHP), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and ARAS with Fuzzy (ARAS-F) methods stand out as the most common MCDM methods in the literature (Đerek & Sikora, 2019; Guerreiro et al., 2018; Kabak et al., 2018; Lin & Wei, 2018; Saplıoğlu & Aydın, 2018; Zagorskas & Turskis, 2020). According to the results of various studies, bicycle routes aim to transform cycling into an alternative means of transportation by transforming it from a practice used solely for exercise purposes into a broader daily activity, and for this purpose, routes that can provide circulation within the city, with predetermined start and end points, are aimed to be created (Đerek & Sikora, 2019; Guerreiro et al., 2018). In the creation of these routes, it is important to identify areas where the accessibility of cycling is low or high (Lin & Wei, 2018). Scientific research shows that topography, population, traffic density, integration with transportation systems, land use, presence of green spaces, cycling infrastructures (separated bicycle lanes, bicycle parks, bicycle signage), skylines, and building facades are influential factors in bicycle use (Saplıoğlu & Aydın, 2018; Wang et al., 2023; Winters et al., 2010; Yang et al., 2019).

AHP, which is a MCDM technique, is one of the most preferred methods due to its ease of application. However, the AHP method is based on vertical independence in its application (Chang & Lin, 2023). The most important difference between the ANP and AHP techniques is the way they deal with the relationships between factors. The ANP method addresses the relationships between sub-factors in the hierarchical relationship structure between factors, allowing complex relationships between the decision levels and attributes to be addressed (Yüksel

& Dağdeviren, 2007). This feature of the method, which deals with dependency, allows for a more natural way of revealing the relationships that actually exist. Therefore, in the selection of AHP or ANP methods, factors and their interrelationships should be evaluated in detail. While the AHP method is preferred when the sub-factors to be weighted are independent from each other, the ANP method should be preferred when there are dependencies between the sub-factors (Moslem et al., 2023). In studies on bicycle route planning in the literature, it is seen that weighting with the AHP method is more prevalently preferred (Broniewicz & Ogrodnik, 2020; Carra et al., 2023; Karolemeas et al., 2022; Mosallanejad et al., 2015; Saplıoğlu & Aydın, 2018). In studies on bicycle lanes using the ANP method, it is seen that ANP is used to determine suitable routes or regions for bicycle lanes (Lin & Wei, 2018; Shin et al., 2013) and identify the criteria that are important for increasingly popular bicycle sharing operations (Liu et al., 2021). On the other hand, the hybrid use of different MCDM methods has been encountered as an effective strategy to improve the accuracy of results (Attari et al., 2023; Uhde et al., 2015). As a matter of fact, in this study, considering the characteristics of AHP and ANP models, situations where the relationships between factors and sub-factors were dependent and independent were analyzed, and a hybrid weighting model in which independent factors were weighted by AHP, and dependent factors were weighted by ANP was used. The hybrid model applied in this study allowed for more precise weighting.

Turkey is one of the countries where cycling infrastructure is in its weakest state. As a result of the automotive-oriented planning approach, both the road infrastructure and traffic operations eliminate the feasibility of a safe cycling environment and prevent the use of bicycles as an alternative means of transport (Pucher & Buehler, 2008; Pucher et al., 2010). Furthermore, the fact that cycling is not considered an alternative means of transport in Turkey's urban planning practices causes bicycle routes not to be taken into consideration at the planning stage. This necessitates the integration of bicycle routes into the existing system. The costly nature of adding safe cycling routes to the existing transport network causes decision-makers to avoid this expense. At this point, the main motivation of this study is to propose a methodology for route planning that will enable cycling to be used as a means of transport, provide a safe and pleasant riding environment, and offer a solution with the lowest cost.

In this study, to increase the operability of the disconnected bicycle paths in the city center of the Sivas province of Turkey, potential routes that would both connect these roads and increase the practice of cycling were identified. In the first stage of this study, which consisted of two stages, the suitability weight of each road line for bicycle transportation was determined, considering physical, social, and visual criteria. After this step, the bicycle path network was created using the weighted roads at minimum distances between the important points of the city in terms of tourism, trade, education, health, culture, transportation, and recreation areas. The AHP and ANP methods were used in the study based on the parameters specified in the Urban Bicycle Routes Guide of the Ministry of Environment, Urbanization, and Climate Change. It is thought that the findings obtained from this study will set an example of urban-scale bicycle path planning in Turkey, where the practice of cycling is low due to the insufficient infrastructure. To create the sustainable and healthy cities of the future, it is important to plan transportation systems that do not depend on fossil fuels and do not produce waste.

## 2 Material and methods

### 2.1 Study area

Sivas is a city with a population of 388,079 with a settlement area of approximately 122 km$^2$ (Fig. 1). As a result of the automotive-oriented planning of the city, despite the 12% increase in population in the last 10 years, motor vehicle ownership has increased by 45%, causing the exacerbation of the parking problem in the city. Considering the topographic structure of the city, the fact that more than 55% of the population is young or middle-aged (Table 7), university students constitute 11% of the population, and the farthest neighborhood is 8.5 km from the city center indicates that bicycles can be used as an alternative means of transportation. However, there are only 5 bicycle paths in the city of Sivas, and they are not connected to each other at any point (Table 1). Therefore, rather than providing a transport environment, they serve auxiliary purposes (Fig. 7).

### 2.2 Data

In the study, road continuity, road widths, traffic density, slope, integration into transportation systems, land use, population density, and building status (floor heights and building order) were used as the criteria to be analyzed. Road data, land use data, population data, and building status data were obtained from the Sivas Municipality in vector data format. Slope data were obtained using SRTM-derived DEM data, and traffic density data were obtained using Google Maps typical traffic information.

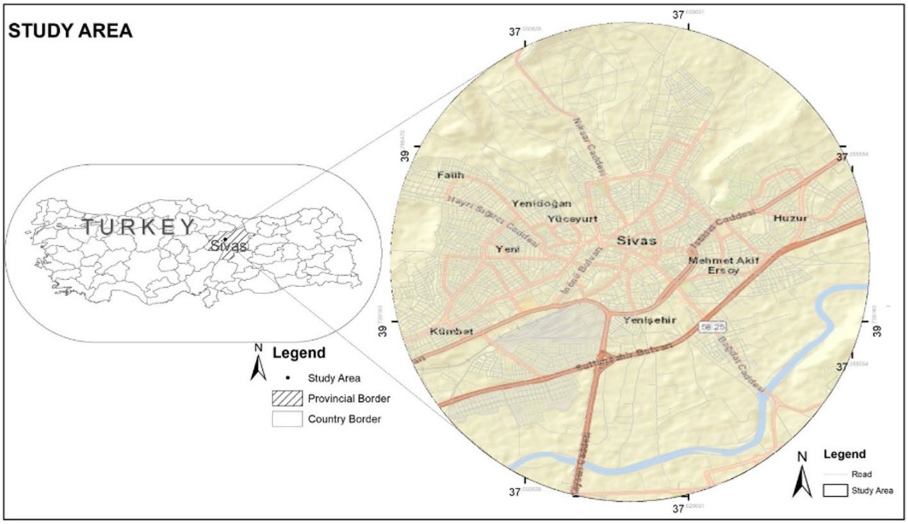


Fig. 1 Study area

**Table 1** Bicycle paths available in Sivas

| Existing bicycle paths | Length (m) |
|---|---|
| 1) Ömer Halisdemir Street (Paşafabrikası) | 3750 |
| 2) Necmettin Erbakan Street | 2000 |
| 3) Recep Tayyip Erdoğan Boulevard | 1200 |
| 4) Millet Bahçesi | 800 |
| 5) Şehit Cumhuriyet Savcısı Mehmet Selim Kiraz Park | 800 |

## 2.3 Method

To increase the integration of the disconnected bicycle paths into the city center of Sivas, the potential bicycle paths that would both connect these roads and increase the use of bicycles were determined. The flow chart of the study is given in Fig. 2. The suitability weights of the roads were calculated by using an AHP/ANP hybrid MCDM tool. AHP allows the most appropriate option to be determined in cases where there are multiple options (Selim et al., 2018). In this context, it is frequently preferred in many different areas (Ayodele et al., 2018; Kırcalı & Selim, 2021; Kuşçu Şimşek et al., 2019). ANP is a method developed by Saaty (1996) that extends AHP to dependency and feedback situations. In AHP, there is no feedback, and the main criteria are limited to the relationships between sub-criteria. On the other hand, ANP extends in all directions, is not organized in a specific order, and communicates with feedback (Saaty, 2004). However, constructing a consistent pairwise comparison matrix in ANP can be challenging (Asadabadi et al., 2019; Jorge-García & Estruch-Guitart, 2022). The difference between these relationships shows that AHP and ANP are suitable for different decision-making scenarios. In this study, ANP was used to solve the problem of the dependent relationship between traffic density and road width. AHP was used to determine the weights between other factors which were independent of each other.

In the first stage of the study, the cycling route criteria were determined, and a database was created (Table 2). While determining the criteria, the "Urban Bicycle Routes Guide" published by the Turkish Ministry of Environment, Urbanization, and Climate Change in 2017 was used. Additionally, bicycle path selection criteria, which have been used in the selection of bicycle paths in the literature and were not found in the Guide, were examined, and additions were made to the criteria based on this information. The criteria in the Guide are divided into three groups as physical, environmental, and visual criteria. According to this, road continuity, road width, and slope were defined as physical criteria, integration into transportation systems, land use, and population density were defined as environmental criteria, and building status (floor heights and building order) was defined as a visual criterion. The traffic density criterion (Hsu & Lin, 2011) was also used in addition to these.

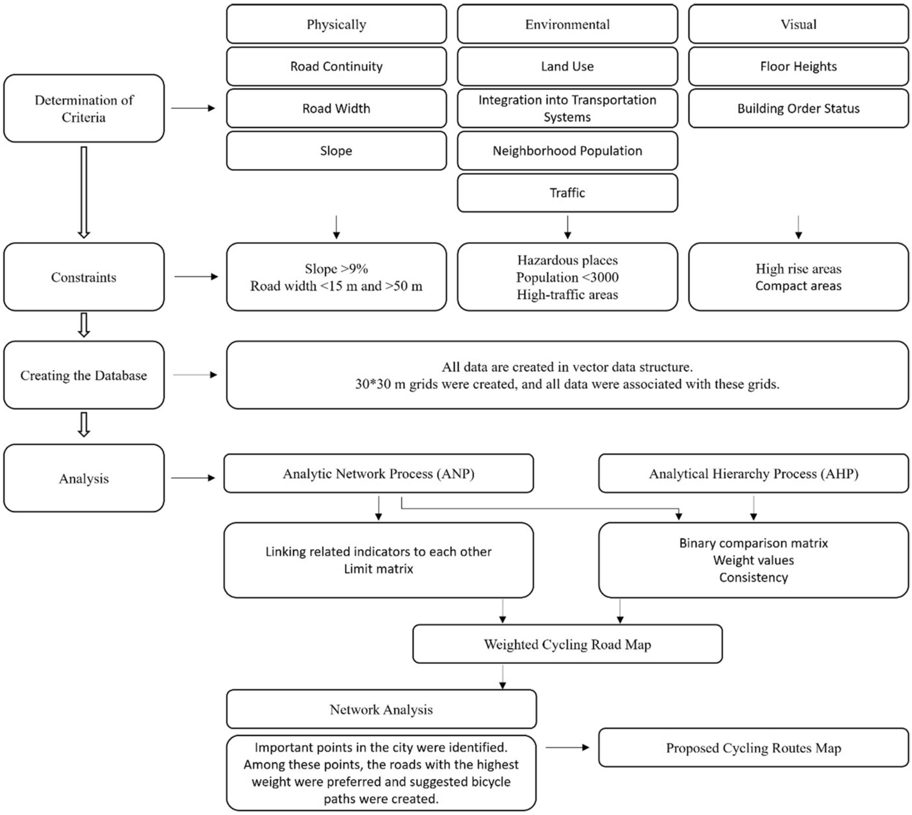


**Fig. 2** Flow chart

Then, the maps of all these parameters were prepared, and the data were made ready for the analyses.

Traffic density data were obtained using Google Maps typical traffic information. However, since the traffic data only belonged to the main streets, the traffic load of the non-street roads was determined using ANP by associating it with values of proximity to the main streets and road widths. In the application of the ANP method, as in AHP, the problem is defined, the main criteria and sub-criteria are determined, and the relationships between the criteria are identified with a pairwise comparison matrix. The weights obtained as a result of the calculations are checked by consistency analysis. In this process, if the consistency ratio (CR) is less than 0.1, the pairwise comparisons are considered to be consistent, and a super matrix is created (Saaty, 1996). The super matrix is a piecewise matrix, where each matrix cell shows the relationship between two factors within a system. The effects of the criteria on each other are determined by taking the $2n+1$th power of the super matrix, and the limit super matrix is formed. The value of "n" used when taking the power of the super matrix is a large number that is chosen randomly and the newly obtained matrix is called the "limit super matrix" (Görenler, 2009). In this context, according to the results that are obtained, the factor with the highest weight in the weight ranking gives the most

**Table 2** Bicycle path parameters

| Parameters | | |
|---|---|---|
| Criteria | Sub-Criteria | |
| Road continuity[a] | It was desired to ensure the continuity of the road. For this purpose, the slope criterion was evaluated over the sub-criteria that also took into account the distance | |
| | Maximum distance (m) | Longitudinal slope (%) |
| | 240 | 6 |
| | 120 | 7 |
| | 90 | 8 |
| | 60 | 9 |
| | 30 | 10 |
| | 15 | 11 + |
| Road width | Road width values of < 15 m and > 50 m were not preferred | |
| Traffic | Areas with heavy traffic were not preferred | |
| Slope | High slopes were not preferred (> 9%) | |
| Integration into transportation systems | Bus stops were integrated into bicycle paths | |
| Land use | Hazardous areas were not preferred (industrial areas, military areas, fuel stations, railway protection belts, storage areas, water surfaces, agricultural areas, truck parks) | |
| Neighborhood population | Regions with very low population (< 3000 people) were not preferred for safety reasons | |
| Floor heights | Low-rise areas were chosen as priority areas considering their density | |
| Building order status | Considering that they are airier and have more frequent street exits, separate residential areas were preferred over adjacent layouts | |

[a]Maximum distance to which the longitudinal slope would be applied (AASHTO, 1999)

**Table 3** Determining the traffic density of the side streets depending on the traffic density of the streets

| Traffic jam | Traffic density of main streets | | Traffic density of side streets[a] |
|---|---|---|---|
| 4 (Most intense) | 4 | ⇒ | 3 |
| 3 (Intense) | 3 | ⇒ | 2 |
| 2 (Less intense) | 2 | ⇒ | 1 |
| 1 (No traffic) | 1 | ⇒ | 1 |

[a]Streets 200 m from the main street were included

important criterion for the decision-making process, and the set of data with the highest importance weight corresponds to the best alternative of the selection problem.

In the study, the scoring process was performed as stated in Table 3, assuming that traffic was also high in the side streets close to the main street where the traffic was high. Accordingly, a score from 1 to 5 was given according to the suitability of these points (1 is not suitable, 5 is suitable).

After all the data were prepared, 30 × 30 m grids were created, and all data were matched with these grids. To analyze only the road axes, all data without roads were removed from the database. Then, grid-based AHP was applied. The weights of the criteria, which were determined according to the opinions of eleven different experts, were calculated by taking the geometric mean to avoid the risk of unexpected ranking changes among the criteria (Krejčí & Stoklasa, 2018). Weights and consistency ratios were calculated by creating a pairwise comparison matrix. The weights given in Table 4 were obtained. Since the consistency ratio was less than 0.1, the comparison matrix was considered to be consistent. By integrating the weighted data, a map showing the suitability of the roads for bicycle transportation was created.

In the last stage of the study, first of all, the existing bicycle paths of the city had to be combined using the most suitable axes for bicycle use. Additionally, the important points of the city and the most suitable new routes to pass through these points were determined. The Historical Town Square, Meydan Mosque, Behrampaşa Inn, University, Eğri Bridge, Shopping Center, Courthouse, Sabancı High School, Train Station, Bus Station, Hospital, College, Şehitler Park, Osman Seçilmiş Park, Paşabahçe Recreation Area, Karşıyaka Recreation Area, Public Library, Millet Bahçesi, Housing Estate, Theatre, Cultural Center, Place of Worship, and Archeology Museum were chosen as the most important points in terms of tourism, business, education, health, culture, transportation, and recreation.

At this stage, the MCDM-based network analysis was performed to determine the bicycle routes by considering the highest weight. The most important feature that distinguishes this method from the classical network method is that it considers the suitability and proximity of the road simultaneously rather than choosing only the shortest route. While

**Table 4** Criterion weights (ANP)

| Criteria | Traffic | | | | |
|---|---|---|---|---|---|
| Road width | Sub-criteria | 1 | 2 | 3 | 4 |
| | < 12 m | 0.25 | 0.09 | 0.061 | 0.05 |
| | 12–15 m | 0.25 | 0.16 | 0.09 | 0.06 |
| | 17 m | 0.25 | 0.27 | 0.25 | 0.24 |
| | 20–25 m | 0.25 | 0.46 | 0.58 | 0.63 |

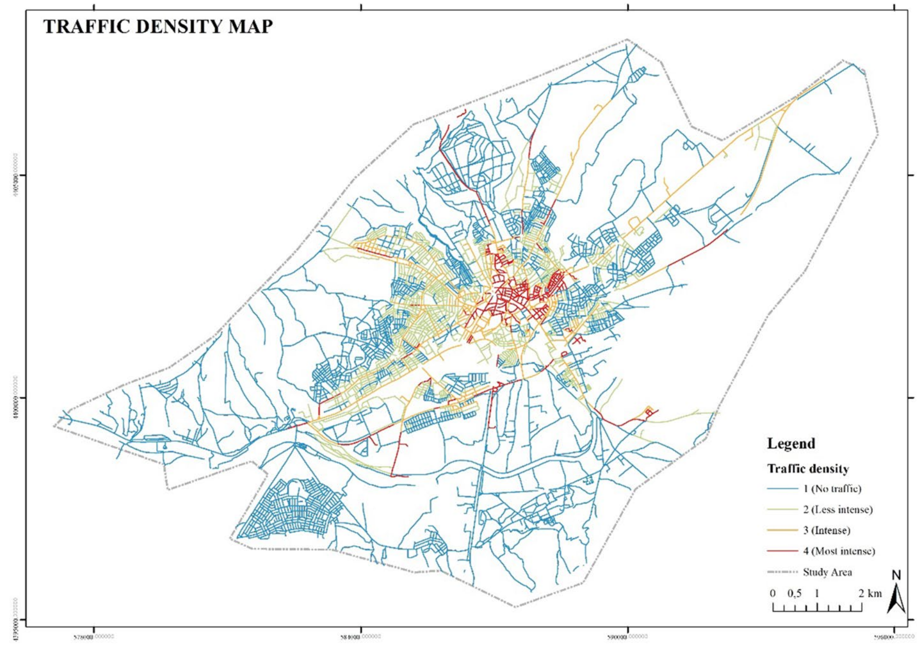


**Fig. 3** Traffic density map

performing the network analysis, not only the distance factor but also the bicycle path suitability weights obtained with the AHP method were used as parameters.

## 2.4 Results

Assessing traffic density throughout a city is a challenging and time-consuming endeavour (Chung & Sohn, 2017), and the use of the ANP method has proven to be highly beneficial in this regard. In this study, the ANP method was used to correlate traffic density with road width, and weights were assigned to traffic density based on road width (Table 4). The

**Table 5** Criterion weights (AHP)

| Criteria | | Weight |
|---|---|---|
| Road continuity | | 0.28 |
| Road width | | 0.18 |
| Traffic | | 0.18 |
| Slope | | 0.11 |
| Integration into transportation systems | | 0.11 |
| Land use | | 0.07 |
| Neighborhood population | | 0.04 |
| Building status | | 0.03 |
| CI = 0.019 | Ri = 1.41 | CR = 0.014[a] |

[a] *CI* Consistency index, *Ri* Random consistency index, *CR* Consistency ratio (Saaty, 1987, 1990)

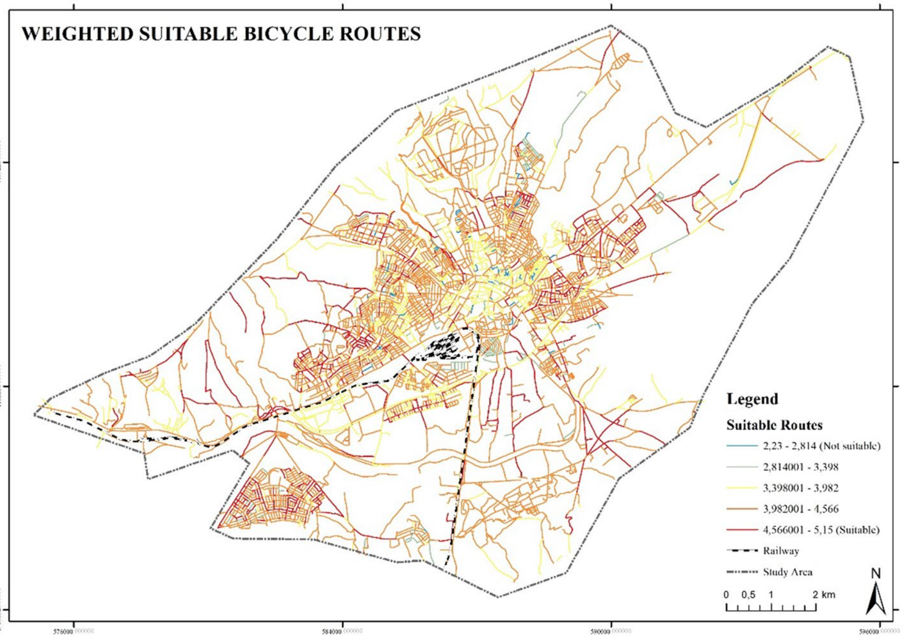


**Fig. 4** Weighted road suitability map

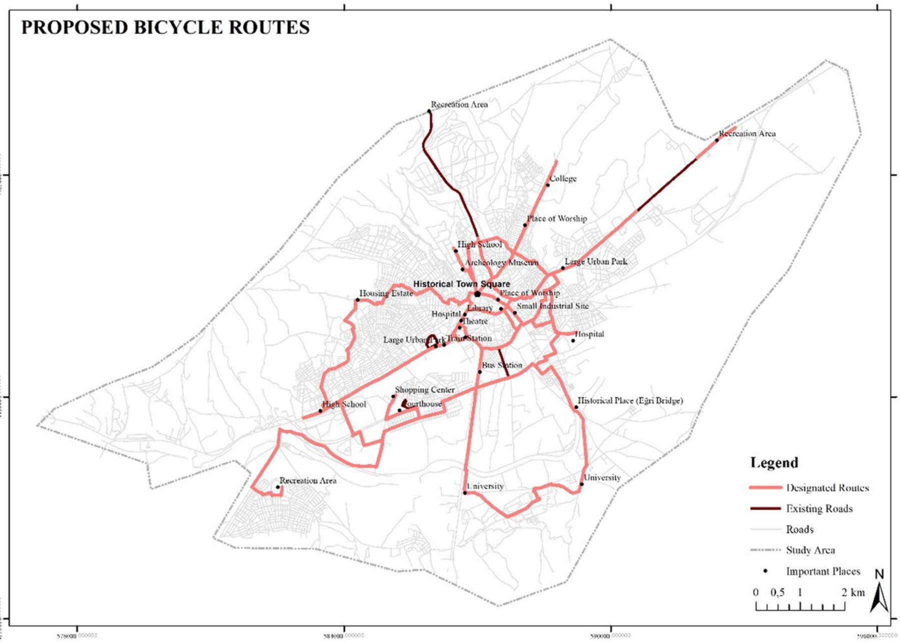


**Fig. 5** Locations of proposed new bicycle routes in the study area

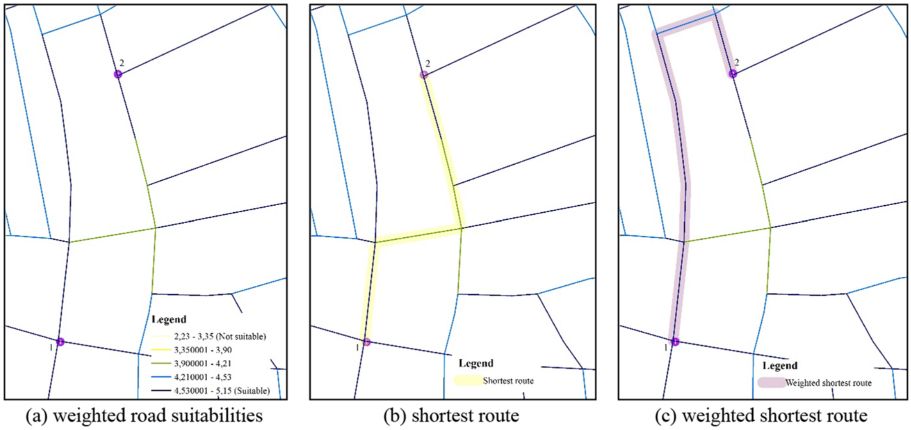


**Fig. 6** Selecting the sample of "weighted shortest route" between "1" to "2"

resulting map (Fig. 3) was generated by multiplying the derived weights by the respective scores.

The factor weights of the parameters calculated with the AHP analysis used in cycle path planning were determined (Table 5), and then, the weighted cycle path suitability map was obtained by combining the data of all parameters over these weights in GIS (Fig. 4).

When creating new bicycle routes, existing bicycle routes (Table 1) have been combined by passing through important points of the city (Fig. 5). At this stage, according to the weight distribution that was obtained, roads with weight values greater than a threshold value determined according to the weight distribution were considered suitable for the construction of bicycle roads, and the places with weight values greater than this value were prioritized in the MCDM-based network analysis. The main goal in using this method was to choose the road lines where the conditions were the most suitable while creating the route between two points and keep the unsuitable road lines, which must be used compulsorily, at a minimum level when there was no alternative (Fig. 6). This way, the cost of restoring roads that were not suitable for cycling would be minimized.

The most important point to be considered at this stage, where it was aimed to connect the important points of the city, was that while creating a bicycle transportation axis for the desired region, it was needed to choose low-weight roads in the absence of any alternatives. However, it was ensured that the number of low-weight roads remained at a minimum level in the new routes created with the weighted shortest road selection process that was carried out (Table 6). As a matter of fact, it was seen that only 0.29% of the new routes passed through less suitable roads, 99.7% of them passed through suitable (moderate and above) roads, and 83% passed through suitable and very suitable roads.

## 3 Discussion and conclusion

### 3.1 Discussion

In this study, first of all, existing bicycle paths in the city of Sivas, which were located in the city but were not connected to each other due to the fragmented planning approach,

**Table 6** Distribution of new bike routes determined by network analysis according to their weights

| 2.23–2.814 Unsuitable | 2.814–3.398 Less suitable | 3.398–3.982 Moderately suitable | 3.982–4.566 Suitable | 4.566–5.15 Very suitable |
|---|---|---|---|---|
| 0% | 0.29% | 16.65% | 58.72% | 24.33% |

were integrated with the city by connecting them to each other. Additionally, the most important points of the city in terms of tourism, business, education, health, culture, transportation, and recreation were marked, and access between these points was ensured. This way, a route planning process was conducted, where bicycles could be used as an important means of transportation in the city rather than being exercise tools, and the results of the analysis showed that the roads to be created based on this planning process were highly suitable.

In the literature, it was seen that different analysis methods have been used for cycle route planning (Lin et al., 2020; Liu et al., 2019; Rybarczyk & Wu, 2010). However, considering analyzing studies on route planning between specific destinations in the literature that are similar to this study, it is seen that the use of different methods and techniques along with the shortest distance criterion provides more realistic results. For example, Guerreiro et al. (2018) found that route planning provides more realistic results not only by using physical data but also by taking into account the preferences and locations of real users, potential users based on population data, and origin–destination points. Similarly, Akbarzadeh et al. (2018) created routes between specific origins and destinations by considering the number of passengers, total travel cost (distance-time), and route length. Ospina et al. (2022) revealed a methodology that balances network coverage and cost-effectiveness, diverging from the sole focus on cost minimization in most research. Indeed, in this study too, the finding that 83.07% of the routes were created by selecting 'suitable' and 'highly suitable' roads highlights a route planning method that can be effective in making efficient use of resources.

On the other hand, it is seen that while the bicycle is accepted by society and used as a transportation vehicle in many countries, it is still not accepted as a means of transportation in Turkey (Pucher & Buehler, 2008; Saplıoğlu & Aydın, 2018). The most important reasons for this include the lack of safe bicycle paths and the automobile-oriented urban development approach. As a matter of fact, the existing bicycle paths of the city of Sivas, which were planned in a manner that did not consider connecting them to each other, are important examples of this understanding. It is known that there are similar examples in many cities of Turkey (Mansuroğlu & Dağ, 2021). The first regulation on bicycle paths in Turkey was enacted in 2015, and it was updated in 2019 by making it mandatory to have bicycle paths in areas to be newly built (MEU, 2015, 2019). However, the absence of this obligation in the old city areas with existing buildings breaks the continuity of bicycle routes (Ağaoğlu et al., 2021). Although there are cities such as Konya, Sakarya, and Eskişehir that give importance to bicycle transportation and make investments, in Turkey, there are serious shortcomings in terms of raising public awareness and providing an effective and efficient infrastructure (Cabiroğlu & Özden, 2021).

In this study, while carrying out the cycle path suitability analysis, in addition to the factors described above, bicycle path standards, urban transportation features, existing bicycle paths of the city, and important points of the city selected to encourage the use of bicycles as a means of transportation were used. The hybrid MCDM based network analysis method proposed in the study for the selection of the most suitable routes enabled the selection of the shortest route by taking into account physical, environmental, and social conditions. The findings obtained here showed that while providing a safe riding environment in use, cycling can also be advantageous in terms of time and cost in practice. The results of the analyses revealed that most of the city was suitable for medium- and high-weight bicycle transportation. On the suitability map, it is seen that the historical city center with narrow roads and heavy traffic was found to be the least suitable area for cycling. This is actually an advantage for Sivas because it is difficult and costly to create bicycle paths with the road widening method (Zuo & Wei, 2019). Therefore, it is foreseen that there is no need for substantial expenses to make the whole city suitable for bicycle transportation, and most of the work could be done for the city center. However, on the other hand, the old city center, where narrow roads and heavy traffic are seen, is not suitable for widening the roads and opening bicycle paths. The most suitable method for this area is to reduce the number of automobile lanes or designate bicycle lanes by converting two-way roads to one-way ones. In this context, the results of this study suggest feasible ways for central-local governments and practitioners.

### 3.2 Conclusion

This study aimed to create the most suitable bicycle routes at the city scale to expand the use of cycling, which has various social, economic, and ecological benefits within the scope of sustainable urbanization. For this purpose, a hybrid (AHP-ANP) MCDM based network analysis method was used to create the most suitable bicycle routes by considering physical, environmental, and social conditions to guide spatial planning in the Sivas province of Turkey where urbanization and population growth are accelerating. Furthermore, this study presents a crucial solution plan that can be utilized to implement the policies and measures outlined in the Sivas Municipality, 2020–2024 Strategic Plan, titled 'Policies and Measures'. The plan includes the implementation of legal and financial support mechanisms to promote the use of bicycles (703(3)), as well as the preparation of a bicycle road master plan and implementation plan, with the construction of new bicycle roads in mind (703(4)) (Sivas Municipality, 2020).

Ensuring the applicability of the results obtained in this study will be an example for implementations to be made in different cities. In Turkey, where the dependency on the automotive infrastructure as a means of transport is high, and bicycle usage rates are low, it is important to change transportation habits to develop the sustainable cities of the future. In particular, the lack of a safe and pleasant riding environment for cyclists on existing road networks is one of the most important factors in this matter. Providing a safe and pleasant riding environment is a complex problem that depends on many factors. The ANP-AHP based network model used in the solution of this problem created additional shortcut networks that could provide a comfortable and safe cycling environment rather than reaching the target based on the shortest distance. In this respect, the paper offers a new suggestion to the literature. The findings should be put into practice, and urban transformation efforts regarding transport networks in urban areas should be carried out.

It is necessary in terms of sustainable urban development for the bicycle to be used as a transportation vehicle that we use in our daily routines rather than being an exercise tool. Therefore, the strategies to be developed should also aim to change people's habits. In this context, the routes planned by integrating with the city's transportation flow and the important points of the city will allow the bicycle to be positioned as an alternative transportation vehicle, and this will support urban health by contributing to the reduction of vehicle density. The use of bicycles and the popularization of bicycle use are encouraged in Turkey, as well as in the rest of the world. However, the bicycle route infrastructure is not sufficient in Turkish cities, and relevant municipalities are working to develop this infrastructure. For the development and sustainability of the bicycle route infrastructure, it is necessary to consider, integrate, and plan the existing bicycle paths, highways, and centers of attraction together. For this purpose, in this study, a comprehensive bicycle route plan was created to integrate the insufficient existing bicycle paths into the city of Sivas, which is very suitable for cycling in terms of its topography, climate, population, and land use characteristics. The route created here would serve the whole city along the east–west and north–south axes of the city, and it would connect the peripherals and the center of city to each other. The results of this study showed that unsuitable routes could be made suitable by making structural changes to the existing infrastructure. It is also predicted that new bicycle routes that serve the whole city will become widespread as an alternative means of transportation against the increasing vehicle traffic.

## Appendix

See Table 7 and Fig. 7

**Table 7** Sivas city center population distribution

| Population by ages | 0–20 | 20–40 | 40–60 | 60–80 | 80+ |
|---|---|---|---|---|---|
| Ratio (%) | 30 | 33.24 | 23.84 | 11.27 | 1.45 |

**Fig. 7** **a** Ömer Halisdemir Street **b** Necmettin Erbakan Street **c** Recep Tayyip Erdoğan Boulevard **d** Millet Bahçesi **e** Şehit Cumhuriyet Savcısı Mehmet Selim Kiraz Park

**Author Contributions** Conceptualization: Elif Güldü, Çağdaş Kuşçu Şimşek, Serdar Selim; Methodology: Elif Güldü, Çağdaş Kuşçu Şimşek, Serdar Selim; Formal analysis: Elif Güldü, Çağdaş Kuşçu Şimşek; Data Curation: Elif Güldü; Writing & Editing—Original Draft: Elif Güldü; Writing—Original Draft—Review & Editing: Çağdaş Kuşçu Şimşek, Serdar Selim.

**Funding** Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

**Data availability** The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

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