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Research Article

Mixed Transport Network Prioritization Based on Environmental Impact and Population Density

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Today, due to the growing importance of sustainable development in urban areas, the decision to prioritize different transportation options in an area where users have to combine different transportation modes has received much attention in the scientific community. In this research, different modes of transportation including pedestrians, taxis, buses, and bicycles are considered as a combination of two different transportation modes in Tehran's densely populated area. With the aim of prioritizing travel options in order to achieve sustainable urban development, public transport users were first asked about their travel means preferences. Next, by obtaining the opinions of urban transportation experts of Tehran Municipality regarding sustainable development of urban transportation, a set of transportation options in this area were prioritized on the basis of some criteria optimized using the analytic hierarchy process (AHP) method. The results indicate that air pollution and noise pollution, with the score of 0.33 and 0.24, respectively, were the two most important criteria for choosing a trip mode in dense population areas according to the opinion of transportation and traffic experts of Tehran. The AHP analysis indicated that the use of combined bicycle-walk mode with a score of 0.282 is the most preferred option, while bus-bicycle mixed mode with a score of 0.116 is the least preferred. Survey data indicate that there is a significant difference between people's general preferences in choosing their urban transportation options and the sustainable urban development approach.

1. Introduction

The increasing number of people living in cities has caused many problems including traffic congestion, pollution, and lack of comfort for citizens. It is estimated that, by 2050, more than two-thirds of the world's population will reside in urban areas, which will bring about many opportunities and challenges [1]. Cities are a significant consumer of energy, thereby producing high volume of greenhouse gases, pollutants, and urban waste causing many environmental problems [2–4]. The large population density of many cities not only increases the production of municipal waste, but also creates problems for the urban transportation system [5]. The population growth in an area increases transportation demand so that infrastructure may end up failing to correctly serve the citizens. This imbalance causes pollution and loss of comfort. That is one of the reasons why cities are being regarded as "drivers of sustainable development" and global environmental change [6–12].

A sustainable urban transportation system is key to promote development and increase economic conditions of citizens. Social life of citizens and urban environmental issues could be improved by policies, technologies, and other initiatives promoted by policymakers with the aim of improving urban transportation sustainability [14–18]. Not only [19] is the definition of sustainable urban system a complex issue, but is it also a challenging topic among the scholars [20–24]. Different cultures, conflicting interests of stakeholders [25], the rapid growth of transportation dynamic elements, and policies are just some of the challenges to promote sustainable urban development [26–30]. Extensive studies have been conducted so far about the abovementioned aspects [31]. However, identifying which factors are the most important ones for urban transportation sustainability is still a matter of debate among researchers [32–39]. It should be noted that such multifaceted problem needs flexible, dynamic, careful, and continuous examinations.

The expansion of roads will severely affect the travel reliability, reduce the level of comfort due to congestion, and reduce safety. Developing countries, such as Iran, are growing moderately, and many people around the country are migrating towards cites. Accommodating the increasing demand of the people is quite challenging for urban planners and transportation expert. The rapid raising of urban population upsurges the attraction of car ownership, while the travel mode is shifting towards collective and sustainable modes. Environmental considerations and population density are very key aspects in determining urban transport policies. Due to the importance of prioritizing these issues in determining urban policy, this study seeks to discuss mixed transport modes prioritization of urban transportation to improve environmental sustainability in a densely populated area.

Because most of the trips in the investigated area are made using two modes of transportation, in this research, mixed transport refers to the choice of combining two common modes of transport to move from an origin to a destination of the city. It can be summarized that the transport costs, travel speed; frequency; prices of the tickets; and safety and comfort are the main criteria for assessment of different alternative modes of transportation that have been studied. The main types of methods that have been used can be summarized as follows: different multicriteria methods to determine the weights of defined criteria and rank the alternatives and statistical methods to investigate the clusters for the evaluation of the transport system. The experts' assessment is used to determine the weights of criteria, which leads to the increase of subjectivism in decision-making. But there is a limited study that investigated mixed mode transportation, which is addressed in this paper. The main challenge that this paper addresses is to find a suitable framework in order to aggregate information/data coming from multiple information sources with the aim of evaluating the mix transport network prioritization measure under consideration. To that end, AHP methods are used to assign weights or rate the selected options for transportation network prioritization. The objective of this paper is to define appropriate criteria for evaluating and prioritizing urban transportation strategies allowing for environmental sustainability. Considering both infrastructure facilities and services, an urban policymaker can implement a successful policy by considering mixed transportation approaches, including, roads, bus services, urban geometric design, taxies, vans, minibuses, and transportation facilities. The approach is applied to the specific situation, traffic conditions, and urban transportation features of the city of Tehran in Iran because of its high density of population and complex mobility problems.

2. Literature Review

The literature suggests that urban trip's cost, time, and distance in dense population areas should be meticulously considered for urban sustainable transportation planning [40]. On the other hand, some researchers indicate that the use of life cycle cost assessment (LCCA) should be considered to investigate the environmental impact of transport system [41]. A method called Environmental Impact Assessment (EIA) is also used to evaluate the environmental effects of pollution sources, including industries, highways, and transportation facilities [42]. Another method, Sequential Interactive Modeling for Urban Systems (SIMUS), was presented in a recent study, containing three steps, namely, defining quantitative and qualitative criteria, selection of alternatives of transportation, and ranking the variants of transportation. The research results indicated that the carriage by metro is the best transport technology for investigated route [43]. Other studies [44] provide different criteria and prioritize their importance to achieve sustainable urban development and environmental protection. Polluting emissions, resources usage, citizen comfort, speed, and accessibility are considered key criteria by some researchers [45–47]. According to the literature, the criteria should comply with a set of requirements. For example, Baker et al. indicated that criteria should be able to discriminate among the alternatives and support the comparison of their performance [48–55].

Due to the need of prioritization of different elements and approaches in multifaceted problems, researchers proposed a wide range of Multicriteria Decision Methods (MCDM) in various transportation studies. The application of MCDM techniques allows the comparison of nonhomogeneous criteria and prepare the ranking of the different alternatives. An integrated multicriteria approach is proposed in a recent study for evaluation of public transportation systems based on Delphi method, group AHP method, and PROMETHEE method. The criteria of selection of transport types that have been used are travel cost, travel time, waiting time, suitability, accessibility, and safety. Multiattribute Utility Function Theory (MAUT), Multiattribute Value Function Theory (MAVT), and Outranking methods are common MCDM methods. For example, in one study in Korea, the decision criteria for evaluating the competitiveness of each public transport mode were suggested, and a hierarchical structure for the decision-making process was developed. The relative weights of decision criteria are derived using MCDM, and the competitiveness of each public transport mode alternative is quantified in order to prioritize each mode.

One of the most commonly used MCDM methods is the Analytic Hierarchy Process (AHP), which enables policymakers to prioritize different urban transportation alternatives [56, 57]. Some researchers consider that MCDM is the most suitable method to conduct environmental impacts assessments [58, 59]. Using AHP methods, Sólnes performs a study on environmental quality indexing of large industrial development. In turn, Yedla and Shrestha investigate the Delhi transportation system alternatives regarding environmental issues using an AHP approach [60, 61]. In a literature review of sustainable energy, Wang et al. highlight the growing applicability of MCDA in socioeconomic problems. Due to their easy application and understandability, the AHP method in the rank-order weighting is pervasively considered [62, 63].

3. Methodology

3.1. Analytic Hierarchy Process (AHP). Faced with the complex problem of a multicriteria decision-making, Saaty proposed an analytic hierarchy process (AHP) decision-making model [64] consisting of 6 steps, which include the following (Table1):

(1) Defining the problem and setting the goal

(2) Structuring the hierarchy from the top to the lowest level

(3) Producing a table of preferences, like table, based on the preference of one element over another, and performing binary pairwise comparisons

(4) Making up the set of matrices of step 3, for n criteria or options $n \times (n-1)/2$ judgments

(5) Controlling for judgment consistency through the Consistency Ratio (CR) based on Saaty's model. The CR is a coefficient that shows the degree of inconsistency of the answers obtained in the questionnaire. If the value of CR is smaller than or equal to 10%, the inconsistency is acceptable.

(6) Weighting the criteria to form and perform the next lower level of the hierarchy

Almost all calculations related to the hierarchical analysis process are based on the initial trial choice of the decision maker, which appears in the form of a pairwise comparison matrix. Any error or inconsistency in comparing and determining the importance between options and indicators may distort the results of the calculations. The incompatibility rate is an indicator of the extent to which the priorities of the comparisons can be trusted. For example, if option A is more important than B (preferred value 5) and B is relatively more important (preferred value 3), then A should be expected to be much more important than C (preferential value of 7 or more). For this analysis, a rate of 0.1 is selected as the acceptable limit for incompatibility.

3.2. Research Process Step by Step. The steps of this research are the following ones:

(1) Asking Tehran's municipal policymakers, managers, and experts about their opinions about the most important objectives (criteria) in the field of sustainable urban transportation regarding environmental issues in densely populated areas

(2) Collecting data such as traffic volume, rush hour, speed, vehicle usage, and travel demand at different locations within the study after selecting the main transportation corridors in the dense area of Tehran

(3) Interviewing 842 transportation network users who acknowledged to often use several modes of transportation per day about those modes

(4) Compiling a data base in SPSS and Excel software from the interview results for primary evaluation and further analysis of data

(5) Determining appropriate criteria based on clustering available parameters in supply and demand data of transportation systems to clarify suitable alternatives of public transportation systems in the studied corridors. For better calculation and better visual interface, the Expert Choice prioritization platforms software was utilized

(6) Offering proper alternatives as feasible policies of public transportation for the studied corridors

4. Result and Discussion

4.1. Study Area. The location selected for this research is an area with a high population density in the center of Tehran, the capital of Iran. The city of Tehran is a large metropolis and also is the capital of the Islamic Republic of Iran. Tehran has a very high density of population, greater wealth than the rest of Iran, and many transport facilities available. Tehran is the most populous city in Iran and Western Asia, with a population of around 8.7 million in the city and 15 million in the larger metropolitan area. It is ranked 24th in the world by the population of its metropolitan area. 4.45 million cars and 7,000 buses are active in Tehran. It is estimated that Tehran's population makes 18 million daily trips within the city, out of which 7.2 million are done by taxis, individual cars, and motorcycles.

Dense traffic and pollution are two major problems, closely related to each other [65–67]. Traffic wastes millions of hours of citizens' time each year, pollutes the air, and imposes a heavy economic burden onto the society and the government. Tehran's traffic problems stem from the large use of passenger cars in the city. For that reason, location characterized by dense traffic, high population density, and large travel demand was selected. The modeling and survey area is shown in Figure 1.

Six nodes, which are the most popular origins and destinations in this area, were identified and numbered. Field observations indicate that trips in this urban area generally consist of two modes of transportation. For example, to get from Engelab Square (1) to Jahad Square (4), citizens can walk along Kargar Street to Laleh Park (2) and then continue their trip by bus, taxi, or even bicycle.

Table 1: Pair-wise comparison scale for AHP preferences.

Numerical rating	Verbal judgment of preferences
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate values between the two adjacent judgments
Reciprocals	When activity i compared to j is assigned one of the above numbers, then activity j compared to i is assigned its reciprocal

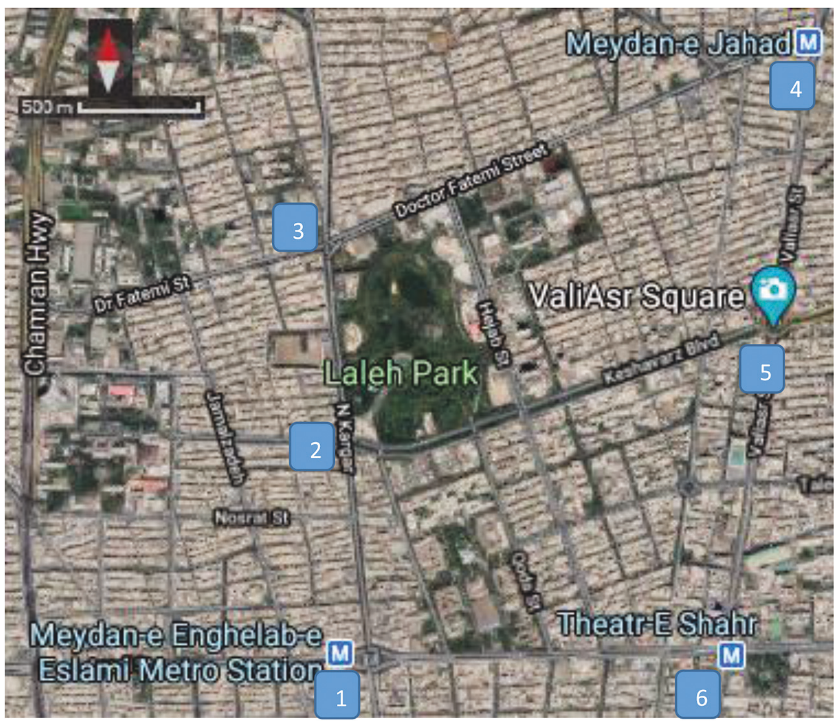

Figure 1: Study area.

4.2. Survey of Public Preferences in Choosing Urban Transportation Modes in the Study Area. The number of people using taxis, buses, bicycles, or even walking depends on a variety of factors that can play a decisive role in choosing how attractive each travel mode is. In this study, by asking the opinions of 842 people in the area, the use of those transportation modes has been examined. The results are shown in Figure 2. As can be seen in this figure, individuals are asked to report their usage of each urban transportation mode according to five categories (always, most often, half-time, sometimes, and rarely). For example, regarding walking, 6% of the people said they always use taxicab, while 36% said they rarely walk for their commute.

For example, in the case of the bus mode for long intercity trips, 12% of people reported that they always travel by bus, while 31% said that they sometimes use buses. On the other hand, according to the survey data, the use of a combination of bus and taxi has been the most common alternative. There are two reasons why this combination is the most popular one in the study area. First, because based on data from the questionnaire, most trips are business trips, where travel time is a decisive driver. And second, because the fact lack of a continuous bus route in the area obliges citizens to choose two different modes.

4.3. Surveys to City Managers and Experts. Regarding this subject, an empirical study was carried out among the members of the Municipal and Urban Transportation Officials of Tehran (MUTOT). The MUTOT expert committee on urban transport consists of 71 members representing different urban transport modes and city planning

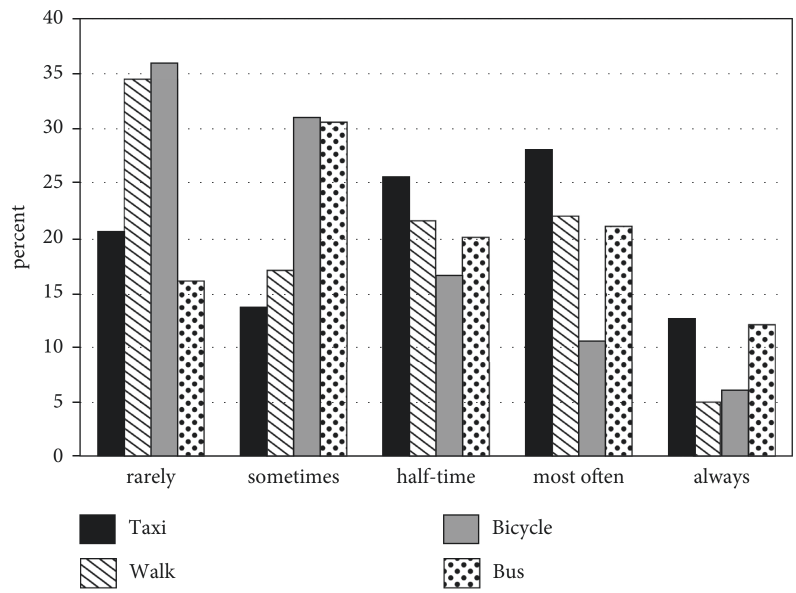

Figure 2: Different transportation modes usage.

authorities. The members of the commission are responsible for the strategic transport planning tasks in their cities. Such strategies need to address how to deal with current and future trends affecting the transport systems. After interviewing each member of MUTOT [68], the diagram in Figure 3 was obtained showing variable factors in terms of sustainable urban transportation systems. Experts were asked about what parameters, regardless of transportation costs, are important to achieve sustainable urban transport development [69, 70]. The experts were free to state various criteria and options regarding to environmental impact and population density of Tehran. As it can be seen in Figure 3, the criteria were determined by considering the highest frequency of individuals' responses. Then, all the dual choices of the available transportation modes in question were prioritized according to those criteria. As it was previously mentioned, this research only considers dual trips since they are the most common ones in Tehran [71].

In this study, a prioritization based on environmental sustainability was adopted, selecting the highest popular criteria prioritized by individual experts, including noise pollution, air pollution, speed, accessibility, and comfort. The effect of these 5 criteria on mixed transport network was examined based on MUTOT committee member experience. For example, as it can be seen in Figure 3, a user can select several options for traveling from Engelab Square to Jahad Square (from point 1 to 4 in Figure 1). Depending on the Tehran situation, these options can include different combinations of the available options: bicycle, walking, taxi, or bus.

In order to prevent inconsistencies in pairwise comparisons, the inconsistency index should be limited to the desired level of below 0.1. This index is calculated and reported by the Expert Choice software after the completion of each row of pairwise comparisons. In case of inconsistency greater than 0.1, it is not possible to obtain an appropriate and reliable result from the indicators. As shown in Table 2, the value of this index is 0.02, which is less than 0.1. Therefore, the validation conducted is valid. The weight of each criterion, based on experts' opinion, is shown in Figure 4. Air pollution and noise pollution, with the score of 0.33 and 0.24, respectively, were the two most important criteria for choosing a trip mode in dense population areas according to the opinion of transportation and traffic experts of Tehran. According to their point of view, reducing air pollution and noise in areas with high population density has a higher priority than other indicators in achieving sustainable urban development.

Behind vehicle pollution indicators, other parameters such as speed, accessibility, and comfort are considered to be of paramount importance. According to the survey data, the importance of accessibility is about half the importance of noise pollution. On the other hand, comfort, with the score of 0.09, has the lowest priority across the indicators. It should be noted that, in this case, comfort is associated to less physical exercise by humans, such as less walking, less waiting in standing position, and so on.

After completing the pairwise comparisons of the options, Table 2 shows the output of preferences. As shown in Figure 4, based on criteria and the survey results, it can be acknowledged that the use of a combination of pedestrian and bicycle transportation mode is the best option to achieving the goals of sustainable urban development in densely populated areas. On the other hand, according to the users' preferences in the study area, the use of a combination of bus and bicycle is the least preferred among the options.

Finally, a sensitivity analysis was conducted based on the outputs, showing how options evolve as the importance of each criterion changes (Figure5). Due to the nature of the criteria adopted in this study, it can be seen that the greater

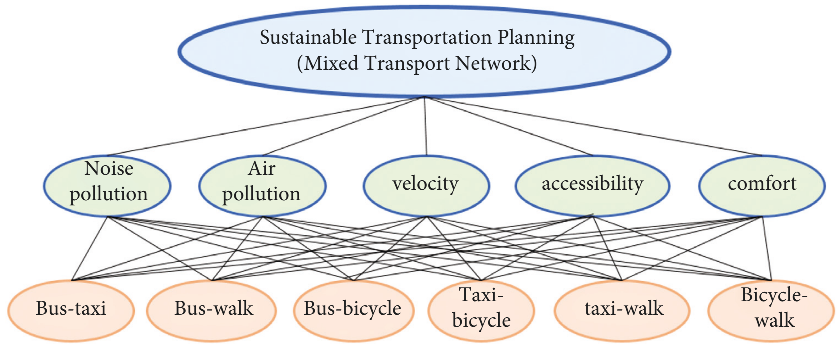

Figure 3: Hierarchical tree.

Table 2: The prioritization of options.

Priorities	Description in mixed transport	Score	Inconsistency
1	Walk-bicycle	0.282	
2	Taxi-walk	0.190	
3	Taxi-bicycle	0.167	Overall inconsistency = 0.02
4	Bus-taxi	0.127	
5	Bus-walk	0.118	
6	Bus-bicycle	0.116	

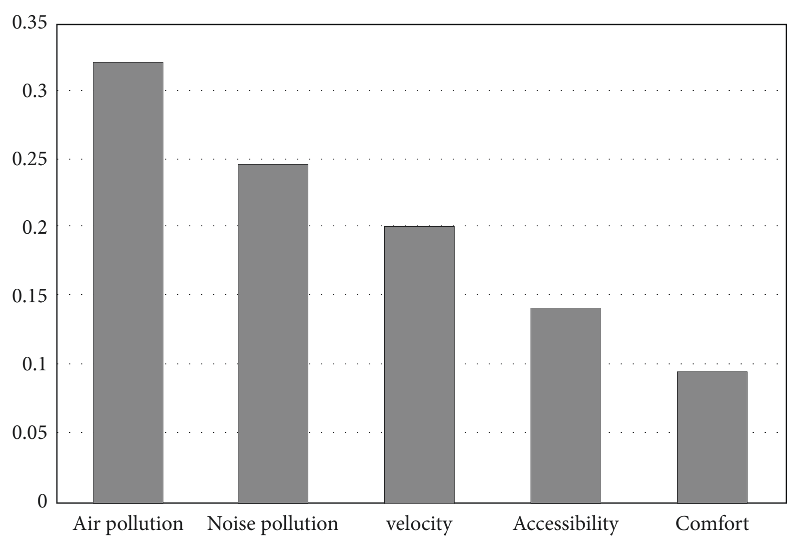

Figure 4: Prioritization of different criteria.

the importance of speed and comfort, the better the final outcome for the use of motor vehicles, such as taxis and buses. On the other hand, the larger the importance of environmental pollution, including air and noise, emphasizes the role of walking and cycling commuting. Figure 6 shows the prioritization of dual path selection options in the study area based on each of the criteria. For example, taxis-walk and bicycle-walk have the highest priority in terms of accessibility. However, if comfort is prioritized, the choice of bus and bicycle will be much more preferable. The comparison of taxi-bicycle and walk-bicycle is shown in Figure 6.

Therefore, in the study area, according to the prioritization done by AHP method, it can be acknowledged that the use of combined bicycle-walk mode with a score of 0.282 is the most preferred and bus-bicycle mixed mode with a score of 0.116 is the least preferred. After the combined mode of

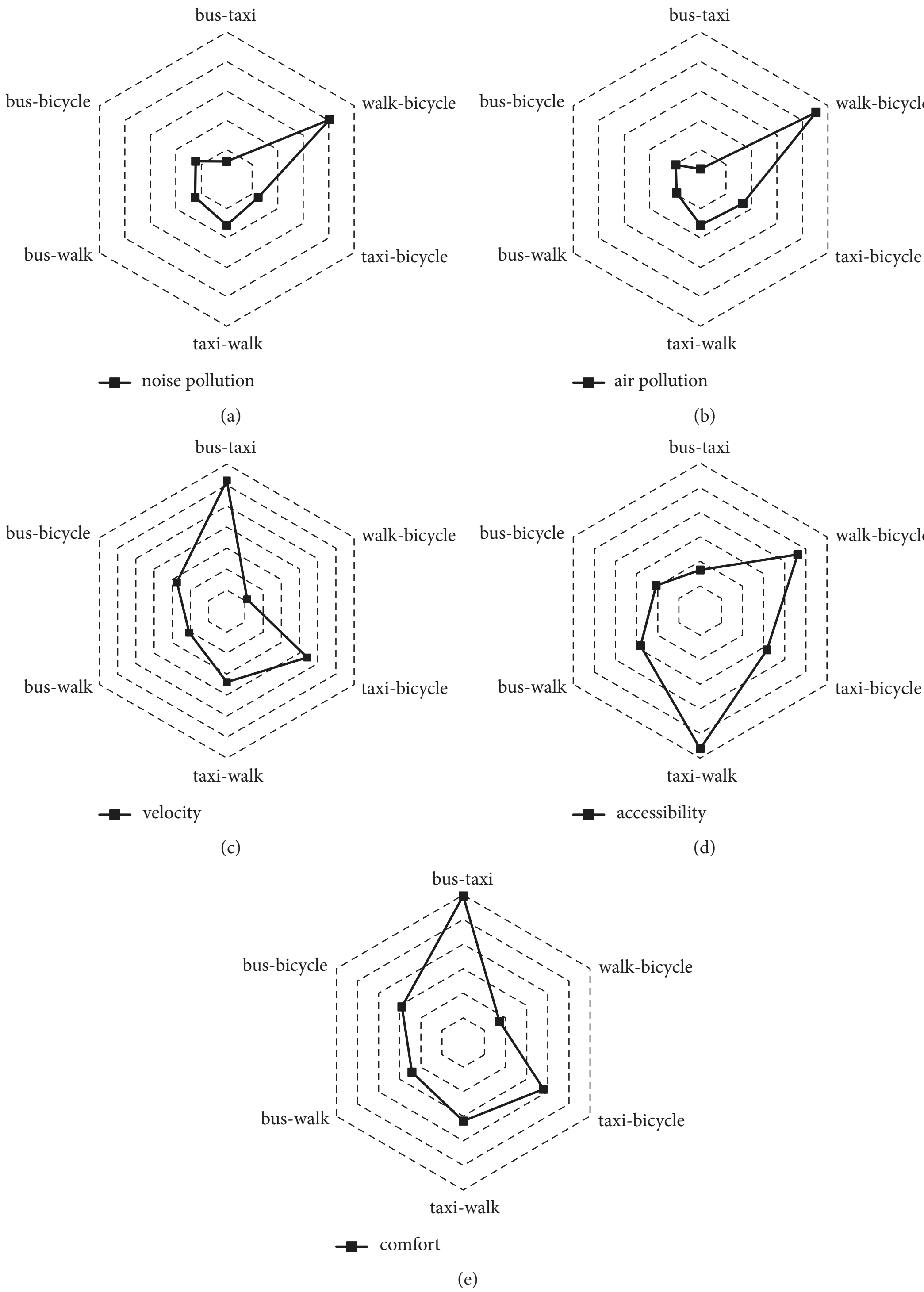

Figure 5: Prioritization of options regarding different criteria.

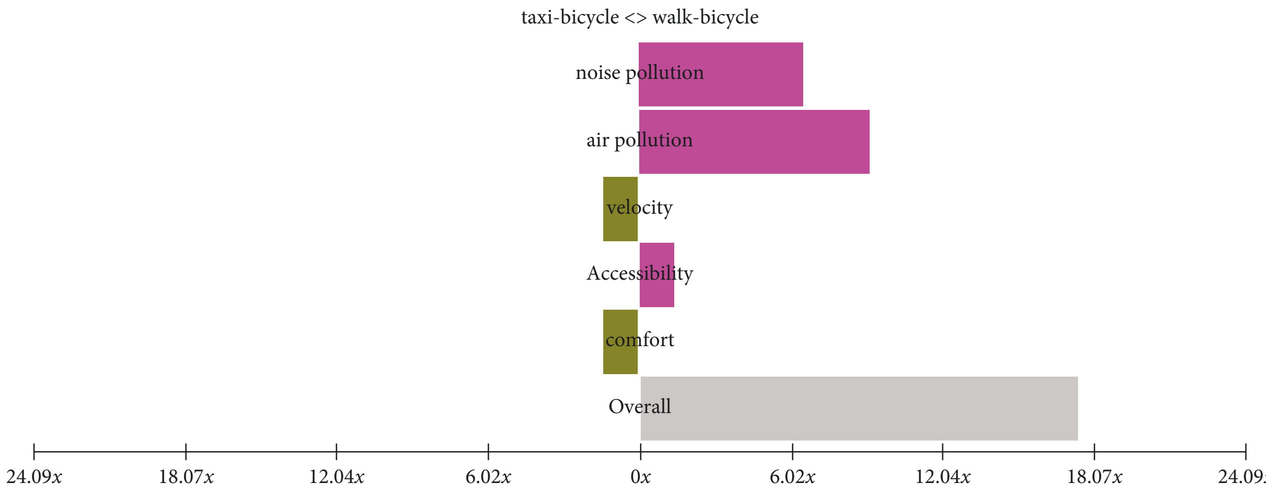

Figure 6: Comparison of two mixed modes with different items.

pedestrian-bicycle, the combined mode of taxi-pedestrian and taxi-bicycle with a score of 0.190 and 0.167, respectively, are in the second and third ranks of importance.

5. Conclusions

Due to the great importance of environmental and social aspects in areas with high population density, this research studies the impact on sustainability of combining two transportation modes for the central region of Tehran. For this purpose, users were first asked about their modal preferences, which were subsequently classified. In addition, the opinions of urban transportation experts from Tehran Municipality about key drivers for sustainable development of urban transportation were collected. Finally, a selection model using the AHP method was used to prioritize options.

The most important conclusions of this research are the following ones:

(i) According to the survey data of public preferences in choosing urban transportation modes in the study area, the use of bus and taxi was the most common combination of modes. This indicates people's tendency in this area towards using nonactive pollutant modes, which can be caused by lack of consciousness, lack of availability to other modes, and lack of measures to incentivize other modes.

(ii) Municipal experts acknowledge that reducing air pollution is the most determining factor for sustainable urban development, followed by reducing noise pollution, improving accessibility, and increasing comfort and speed, respectively. In fact, air pollution and noise pollution, with the score of 0.33 and 0.24, respectively, were the two most important criteria for choosing a trip mode in dense population areas according to the opinion of transportation and traffic experts of Tehran.

(iii) According to the results of the AHP modeling based upon the priorities set by Tehran's experts, the use of the combined pedestrian-bicycle transportation mode is the most suitable one to ensure sustainable development of urban transportation, while the use of bicycle-bus transportation mode has the lowest priority from the user preferences' point of view. In fact, the use of combined bicycle-walk mode with a score of 0.282 is the most preferred and bus-bicycle mixed mode with a score of 0.116 is the least preferred.

(iv) While overall people's preference is to use motor transportation vehicles, such as buses and taxis, according to the experts' opinion, sustainable urban development requires encouraging the pedestrian and bicycle modes. It is concluded that urban transport experts and decision makers should take actions to increase the attractiveness of bicycle or pedestrian modes. Promoting laws aimed at incentivizing people to use nonmotorized transport modes will be crucial to improve environmental metrics in urban areas, such as Teheran.

(v) In order to increase the attractiveness of pedestrian mode or bicycle, some actions could be proposed by the government, such as upgrading and updating urban furniture, developing a bicycle sharing system, increasing the visual appeal of the environment, and making pedestrian and bicycle passages safer and more beautiful.

Data Availability

There are no available data for this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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