PRIORITIZATION OF THE BICYCLE NETWORK CLUSTERS INTEGRATED WITH THE PUBLIC TRANSPORT SYSTEM IN ISTANBUL METROPOLITAN AREA

Dilek COL YILMAZ 1 and Haluk GERCEK 2

Abstract

An ideal network design approach has to consider many details of the planning process simultaneously to yield optimal results. However, this is usually not possible due to the computational complexity. Mathematical programming approach is often limited to small networks. This study proposes a decision support model (DSM) in order to phase a citywide bicycle network plan integrated with the public transport system in Istanbul Metropolitan Area. The role of bicycle as a non-motorized transportation, and its contribution to sustainable travel goals are first presented. Secondly, layers of data produced for the GIS mapping regarding the public transport routes planned for the target year 2023, locations of transfer centers, public transport travel demand at each transfer center, and a revised citywide bicycle network are explained. The proposed bicycle network was decomposed into 14 clusters that consist of areas around the transfer centers that are accessible within 15 minutes bicycle travel time.

A survey was carried out with 42 transportation planning experts to collect data about the weights of the criteria and sub criteria considered to prioritize the clusters by using the Analytic Hierarchy Process (AHP). AHP is a multi-criteria decision-making procedure that contains both qualitative and quantitative criteria defined at several levels. The relative weights of criteria and sub criteria were calculated by pairwise comparisons. A sensitivity analysis was also included to examine the impacts of different criteria on the priorities of the network clusters. The DSM is intended to assist the municipality departments in prioritizing bicycle improvements, and help guide the implementation of the citywide bicycle network plan prepared by the municipality.

Keywords: Analytical Hierarchy Process, multicriteria decision making, bicycle network clusters, non-motorized transportation, sustainability.

1. Introduction

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Today, parallel with economic development, developing countries come across with serious issues about socio-economic differentiation, education, health and environment.

Increase in population, and collateral increase in number of motor vehicles create pressure on urban transportation systems. Besides socio-economic marginalization, air and noise pollution, traffic congestion and accidents seriously threaten the economic development and the quality of life in cities. With this process, automobile dependence becomes a characteristic of urban life; therefore automobile usage yields its place from a choice to a necessity.

Sustainable transportation has an important role in urban planning. Depending on the increase of population and private travel demand, the amount of ascending motorized travels induces greenhouse effect and climate change. In conjunction with the development of the cities, travel distances exceed the accessibility limits for pedestrians and cyclists; therefore require the use of motorized vehicles.

Beginning before the Second World War, but remarkably accelerating after it, the automobile progressively became the transportation mode that shaped the city. It became possible to develop in any direction, first filling in between train lines and then going out as far as fifty kilometres for the average half hour journey. As a result, the Auto City was born. As this process set in, the phenomenon of automobile dependence became a feature of urban life, and use of an automobile became a necessity in urban transportation. The increasing automobile dependence has created environmental, economic and social issues in cities. In order to cope with these issues, specifying mobility management strategies to encourage public transport and non-motorized transport is of vital importance. Non-motorized transportation, also known as active transportation and human powered transportation that includes walking and cycling, has an important role in mobility management.

Within the scope of this study, evaluating the factors above, the benefits of improvement and increase of non-motorized transport, providing shift from motorized to non-motorized transport are examined. The impact of the integration of non-motorized transportation and public transport on high level of mobility is evaluated; the role of bicycle on non-motorized transportation and its contribution to sustainable travel goals are discussed. The present status of non-motorized transport in Istanbul metropolitan area is evaluated, and the lack of current bicycle network is emphasized.

A decision support model is proposed in order to plan the phases of a bicycle network integrated with the public transport system within reasonable accessibility distances in Istanbul metropolitan area. By use of the planned bicycle network, it is aimed to prioritize 14 clusters that consist of impact areas within 15 minutes bicycle travel distance to transfer centres. Because of its simplicity and its ability to comply with different conditions, enabling qualitative and quantitative evaluation, Analytic Hierarchy Process (AHP) is preferred as the analysis tool. The priorities of bicycle network clusters, integrated with public transit in Istanbul metropolitan area, are
estimated, and consequently a decision support model is proposed to implement the gradual development of the projects as part of the applicable bicycle network plan.

1.1 Sustainable transportation and bicycle

Sustainable transport has emerged from three main sources:
1. Concerns about transportation’s burdens and the counter-productivity of much conventional highway-oriented planning began to emerge around the planet from the 1970’s onward as pollution increased and the often destructive effects of highway expansion upon cities attracted more attention (Stringer and Wenzel 1976; Gakenheimer, 1978; Newman and Kenworthy, 1999).

2. The recognition in some places that reducing traffic in cities through traffic calming (deliberately slowing personal motor vehicles, or PMVs) and pedestrianization (excluding PMVs from certain streets) had many benefits for mobility and the environment, including reductions in vehicular traffic (traffic evaporation) and traffic related injuries, especially those of pedestrians and bicyclists, and increases in the numbers of people walking, bicycling and using public transportation.

3. The growth of sustainability awareness, especially following the Brundtland Commission’s report (WCED, 1987) on sustainable development as ‘development which meets the needs of current generations without compromising the ability of future generations to meet their own needs’.

These three strands led to a lively discussion about sustainable transport and many excellent efforts to describe, characterize or define it since the 1990’s. While all efforts to define a field as complex as sustainable transport are fraught with difficulty, one of the most useful definitions is that of the University of Winnipeg’s Centre for Sustainable Transportation. A sustainable transport system is one that:

- allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- is affordable, operates efficiently, offers choice of transport mode and supports a vibrant economy;
- limits emissions and waste within the planet’s ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

The development of sustainable urban transportation systems may be characterised depending upon passenger and freight mobility, the effective use of land, effective use of renewable energy resources and low prized services (Crawford, 2002).

The transportation industry and governments will need to adopt a more systematic approach to address the growing need for mobility, integrated new stakeholders and
technologies, and allocate resources in an optimal way to deliver sustainable solutions. Tackled in the right way, these challenges can become powerful opportunities for environmental, social and economic development (WEF, 2012).

Sustainable mobility meets the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological requirements today or in the future, specifically (WEF, 2012).

1. Preserve the natural environment: The environment should not be degraded by transport-related activity
2. Meet the travel needs of the population: People need reliability and choice of modes in an integrated system
3. Support a good economy: Transport needs to support an economy that improves the well-being of all people
4. Minimize infrastructure costs: Transport systems need to be planned so that infrastructure and services can be funded in the long term, and that best use is made of investments
5. Maintain energy security: Transport can play a significant role in helping to decouple support of a good economy from increasing demand for fossil fuels
6. Ensure long-term viability of the transport system: Transport infrastructure and services must be continuously maintained work together as an integrated system

Cycling is increasingly recognised as a clean, sustainable mode of transport and an essential part of an inter-modal plan for sustainable urban travel. Cycling can have many advantages as a short-distance means of travel in urban areas: it is environment friendly without emissions and noise nuisance; provides cost-effective mobility, and offers an opportunity for health and physical fitness by regular exercise. On the other hand there are both real and perceived barriers to bicycle use that -with the exception of a few countries- keep cycling somewhat in the margins of urban travel. These barriers include vulnerability in accidents with motorised traffic, bicycle theft, increasing travel distances due to urban sprawl, perceived low social status, weather and topology (ECMT, 2004).

For short-distance travel, bicycles are often faster than other modes such as cars or trains. Cycling is often the quickest mode of transportation for travel within urban areas, particularly travel less than 5 km (EC DGXI, 1999).

On the other hand, the frequency of car use for short distances is significant. 30 % of motorised trips are shorter than 5 km in EU countries. There seems to be ample room to replace these shorter car trips with cycling travel (European Transport, 1998).

1.2 Non-motorized transport policies in big cities

As cities get larger they become more efficient. A thirty-two-city survey held by Peter Naess from Norwegian Building Research Institute showed that transport energy use per capita generally declines as city size increases. He chose twenty-two Scandinavian cities and found a very clear relationship between the size and as well as the density
of the city and its per capita transport energy use. The cities of Copenhagen, Oslo, and Stockholm were significantly lower in transport energy use per capita than were smaller provincial towns (Newman and Kenworthy, 1999).

For decades, urban economists have been pointing to the efficiency advantages of scale as well as of density. In ecological terms, it should come as no revelation that as cities grow and become more complex and diverse, they begin to create more efficiencies. Ecosystems grow from simple systems with a few pioneering species to more mature ecosystems with diversity and interconnection.

For many years, planning and policy decisions regarding surface transportation in large central cities took place within a framework in which the roadway and transit were central, with pedestrians and bicyclists just two more components that had to be worked in where possible. However, the Intermodal Surface Transportation Efficiency Act (ISTEA) began to change this way of thinking beginning in 1991 when it provided new sources of funding for bicycle and pedestrian facilities; these provisions were extended under the 1998 Transportation Equity Act for the 21st Century (TEA-21). Nevertheless, some fifteen years later, promoting walking and bicycling while ensuring safety and mobility for the overall transportation system, continues to present a challenge, especially for large central cities, which must balance multiple and competing interests while facing limited space and funding. Further, they must address such issues with limited data in a number of areas, including safety, design, and usage.

Large central cities have several unique features relative to other locales. First and foremost is the sheer difference in size, geographically as well as overall population and density. In these cities, having more pedestrians than motor vehicles in their downtowns at certain times of the day is commonplace. Diversity is a second complicating factor in large central cities. Multiple languages and customs make encouraging stakeholder involvement, improving safety through education, and communicating policies and regulations more difficult. A third factor unique to large central cities is the degree to which transportation must function within a built urban environment. A fourth distinguishing factor of large central cities is the use of multiple modes by travellers. It is common for people to walk to and from transit or to use an automobile to park at a station, get on commuter rail, and then walk or use transit within the city. Finally, unlike their smaller urban counterparts, large central cities are more likely to have large recreational facilities utilized by bicyclists and pedestrians. Such facilities often difficult to access and tend to fall under different jurisdictional authority than the rest of the transportation system, making it difficult to fully integrate them and ensure easy and safe access (Cerreno, Novotny, 2006).

2. Material and method

2.1 Structure of AHP

The problem is built hierarchically in AHP. The prioritization process follows the configuration phase (Saaty, 1990).
Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements’ relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations (Saaty, 2008).

2.2 Definition of decision making problem and determination of the relations

This level includes identifying the decision nodes and the factors affecting them. AHP allows decision makers to model the problem in a hierarchic structure that shows the relations between the mail goal of the problem, main criteria, sub criteria, and alternatives. This form of AHP is seen in Figure 1. The number of criteria may be more than 1, and there may be sub criteria of criteria. The determined criteria should be understandable and clear. The number of levels in decision hierarchy gets changed based on the complexity of the problem (Kuruüzüm, 2001).

![Figure 1. A Simple AHP hierarchy](image)

2.3 Pairwise comparisons and relative importance vector

Comparison process begins after defining criteria, sub criteria and alternatives that constitute the problem. Comparative judgements and pairwise comparisons form the second main and most important step of AHP.
In multi-criteria decision problems, the experts of the subject are interviewed and their opinions and judgements about the subject are found out. Because the results directly depend on the judgements of surveyed people in AHP, they must be expert or well informed about the study, in order to get consistent results. According to the given judgements preference, judgement or pairwise comparison matrices are generated. The matrix is formed by converting the judgements into quantitative values (Saaty, 2000).

Table 1 reports the pairwise comparison scale used in the AHP developed by Saaty (1977). It allows converting the qualitative judgements into numerical values, also with intangible attributes.

<table>
<thead>
<tr>
<th>Criterion 1</th>
<th>Criterion 2</th>
<th>...</th>
<th>Criterion n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
<td>$w_1/w_1$</td>
<td>$w_1/w_2$</td>
<td>...</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>$w_2/w_1$</td>
<td>$w_2/w_2$</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Criterion i</td>
<td>$w_i/w_1$</td>
<td>$w_i/w_2$</td>
<td>...</td>
</tr>
</tbody>
</table>

For computing the priorities of the elements, a judgmental matrix is assumed as follows:

$$A = \begin{bmatrix}
    a_{11} & a_{12} & \cdots & a_{1n} \\
    a_{21} & a_{22} & \cdots & a_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    a_{ni} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}$$

where $a_{ij}$ represents the pairwise comparison rating between the element $i$ and element $j$ of a level with respect to the upper level. The entries $a_{ij}$ are governed by the following rules $a_{ij} > 0; a_{ij} = 1/a_{ji}, a_{ii} = 1$

Following Saaty (1980, 2000), the priorities of the elements can be estimated by finding the principal eigenvector $w$ of the matrix $A$, that is:

$$AW = \lambda_{\text{max}} \cdot W$$

When the vector $W$ is normalized, it becomes the vector of priorities of elements of one level with respect to the upper level. $\lambda_{\text{max}}$ is the largest eigenvalue of the matrix $A$. 
In cases where the pairwise comparison matrix satisfies transitivity for all pairwise comparisons it is said to be consistent and it verifies the following relation:

\[ a_{ij} = a_{ik}.a_{kj} \]

Saaty (1980) has shown that to maintain consistency when deriving priorities from paired comparisons, the number of factors being considered must be less or equal to nine. AHP allows inconsistency, but provides a measure of the inconsistency of the judgmental matrix can be determined by a measure called the consistency ratio (CR), defined as:

\[ CR = \frac{CI}{RI} \]

Where \( CI \) is called the consistency index and \( RI \) is the Random Index.

Furthermore, Saaty (1980, 2000) provided average consistencies (RI values) of randomly generated matrices. CI for a matrix of order \( n \) is defined as:

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]

Saaty offers a AHP measurement scale that includes numbers from 1 to 9. Table 2 shows the measurement scale.

In accordance with the numbers in the measurement scale table, pairwise comparisons are executed by the experts. For example if the value is 7, then it is understood that criteria i is very strongly important over criteria n. In this case similarly the importance of criteria n over criteria i is \( 1/7 \) (Gungor, Isler, 2005).

The intermediate values mean the value between two main values in comparisons. The method of Saaty gives the best results for \( n<10 \) criteria, especially for 7 criteria. In other words, solving the multi criteria decision problems with AHP when the number of criteria exceeds 9, inconsistencies may occur.

<table>
<thead>
<tr>
<th>Numerical Values</th>
<th>Verbal Scale</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance of both elements</td>
<td>Two elements contributes equally</td>
</tr>
</tbody>
</table>
2.4 AHP in transportation planning

AHP is a method that is independent from the type of the problem. Therefore, it is easily applicable to any planning of transportation mode such as highway, railway, airway, seaway, postal services, communication, and freight transportation. The method can be applied to establishments with different scale and different problems with different complexity. In other words, it can be applied for the organizations making freight transport, and middle scaled organizations as well as a national railway company. It is possible to separate the problem into goal, criteria, and alternatives.

AHP can be used in transportation planning (Saaty, 1995), traffic planning (Pogarcic et al, 2008), prioritization of urban transportation alternatives (Yedla, Shresta, 2007), corridor and route selection of light rail transit lines, selection of transit mode (Akad, Gedizlioglu, 2007), (Banai, 2006), planning of the most feasible railway network (Gercek et al, 2004), specifying the railway system routes with geographical information systems (Ludin, Latip, 2006), selection of the most cost efficient highway route (Piantanakulchai, Saengkhao, 2003), the classification of sustainability of transportation investments (Sadasivuni et al, 2009), evaluation of public transit fare system (Nassi, Costa, 2012), analysis of public transit service quality [40], the prioritization of public transit companies (Khasnabis, Chaudhury, 1994), the analysis of urban transportation demand with discrete choice models (Banai, 1989).

Multi-criteria approach in planning of bikeways (Chan, Suja, 2003), bikeway planning with geographical information systems, and multi-criteria decision-making analysis (Rybarczyk, 2006), studies include small scaled area case studies about bicycle planning with multi-criteria decision making methods. However, study of bicycle transportation planning in a metropolitan area using AHP has not been encountered in literature.

3. Implementation

3.1 Building the baseline for the study
In the extent of the study, the present situation for non-motorized transportation in Istanbul Metropolitan area is reviewed, the inadequacy of present bikeways is revealed. Furthermore, the disconnection in present and planned bikeway projects is specified while finding out the lack of an integrated bicycle network with public transport system in the city.

Building up the ‘bicycle impact areas’, public transport transfer centers that planned by Istanbul Metropolitan Municipality (IMM) for the whole city, are taken as the centre nodes for bicycle clusters. The proposed bicycle network is decomposed into 14 clusters that consist of areas around the transfer centres that are accessible within 15-minute bicycle travel time. Encircling these centres, impacts areas that show similar characteristics, are combined forming 14 bicycle clusters. Thereafter, these 14 bicycle clusters are evaluated qualitatively and quantitatively in terms of the data and criteria from hierarchy table.

The layers that will be a baseline for the study, include highway network, public transport network, planned transfer centers, household origin-destination (O-D) travel survey data of 2006, Istanbul Metropolitan Area Urban Integrated Transportation Master Plan (IBB, 2006a) traffic analysis zones data (population, employment, number of students, household income, and car ownership), bikeways data from the study of ‘The Research, Planning and Projects of Bikeways and Pedestrian Ways, and Regional Transportation and Traffic Study’ (IBB, 2006b) as well as the data of 5 m. contour lines from slope analysis. The transportation planning software of TransCAD, and Geographical Information Systems (GIS) software of ArcMap are used in the study.

The quantitative data of zones includes: Population, employment (the number of employee), workers (number of working people), number of students (at home), number of students (at school), income, car ownership, the length of the bikeways, park&ride capacity, on-road parking capacity, the number of signalized intersections, the percentage of heavy road vehicles in traffic, and volume/capacity ratios.

The visual data of zones includes: Bikeways (separated bikeways, non-separated bikeways, shared bike pedestrian path, shared bike vehicle way, pedestrian walking path with bikes), bicycle parking areas, public transport transfer centers, and number of daily passengers in these centers. The map including the data for bicycle network clusters according to the criteria is presented in Figure 2.
3.2 Building up the hierarchy

AHP, a decision support system is applied for prioritization of bicycle network clusters developing around particular focus points within accessible distances, integrated with public transport network in the city. Criteria and sub-criteria are defined in order to build the map that will be the basis for the evaluation and to apply AHP. Criteria are separated into two groups: main criteria, and sub-criteria. 6 main criteria include user characteristics, road characteristics, traffic characteristics, bikeway service and operation characteristics, public transport and transfer facilities, and land-use characteristics.

26 sub-criteria are defined in such a manner that all of them will be in relation with their own main criteria. User characteristics include socio-economic status (income, and car ownership), and employment characteristics. Road characteristics include road functional class, slope, surface type, surface condition, bicycle lane existence, number of signalized intersections, continuousness and directness. Traffic characteristics include motor vehicle traffic volume, heavy (long) vehicle traffic volume, speed limits, traffic calming enforcement, on-road parking availability, and security. Bikeway
service and operation characteristics include travel time, travel cost, construction time, and construction cost. Public transport and transfer facilities include daily public transport demand, bicycle-parking facilities, and bikes on public transport vehicles. Land-use characteristics include land-use, compliance with historic pattern of the city, and compliance with urban and transportation plans.

After combining the ’15-minute bicycle travel time zones’, 14 clusters are evaluated with a survey conducted with 42 transportation planning experts to collect data about the weights of the criteria and sub criteria considered to prioritize the clusters by using Analytic Hierarchy Process (AHP). The hierarchy of problem is presented in Figure 3. The hierarchy consists of goal, main criteria, sub-criteria, and alternatives.

![Figure 3. 'Prioritization of integrated bicycle network clusters' hierarchy](image)

### 3.3 Pairwise comparisons

A survey was conducted among 42 transportation-planning experts. In the first part of the survey, the pairwise comparisons of main criteria in the sense of goal are made in order to find out the weights of criteria with respect to each other. Each expert is asked for choosing one of the scales 1, 3, 5, 7, 9 (1:equal, 3:moderate importance, 5:strong importance, 7:very strong importance, 9:extreme importance) for each criterion in order to define their degree of importance.
In the second part of the survey, the experts are asked to make pairwise comparisons of sub-criteria in the sense of main criteria. The scales of 1, 3, 5, 7, 9 are also given for the sub-criteria, and the importance of sub-criteria are calculated.

The calculations including pairwise comparisons are performed by ‘Super Decisions’ package software. The table of pairwise comparisons between main criteria is given in Figure 4. Figure 5 shows the hierarchy that built by the software. The super matrix is weighted by the eigenvectors that are obtained by the software.

![Figure 4. Matrix of pairwise comparisons between main criteria](image)

### 3.4 The synthesis of the priorities

In the third part of the survey, the ‘rating’ method is used by asking experts to give points according to the preference of alternatives in sense of sub-criteria. Each sub-criterion is given points between 1 and 5 (1:bad, 2:poor, 3:fair, 4:good, 5:excellent). In Table 3, the calculated local and global weights of criteria and sub-criteria are presented.

According to the weights of the criteria “bikeway service and operation characteristics” has the highest weight. The criteria of “public transport and transfer facilities” and “traffic characteristics” rank among second and third place. Travel time sub criterion has the highest weight as a result of pairwise comparisons according to “bikeway service and operation characteristics” criteria.

The score results of alternatives are given in Table 4. Alternatives that include the clusters of 11, 12, and 5 share the first three in grading. The development of bicycle network in metropolitan area will systematically take place with respect to these ranking.
Table 3. The weights of criteria and sub criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Local Weights</th>
<th>Sub Criteria</th>
<th>Local Weights</th>
<th>Global Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 USER CHRCT.</td>
<td>0.0768</td>
<td>11 SOCIO-ECONOMIC STATUS</td>
<td>0.607</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 EMPLOYMENT CHARACTERISTICS</td>
<td>0.393</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 ROAD FUNCTIONAL CLASS</td>
<td>0.083</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22 SLOPE</td>
<td>0.181</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23 SURFACE TYPE</td>
<td>0.045</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 SURFACE CONDITION</td>
<td>0.068</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 BICYCLE LANE EXISTENCE</td>
<td>0.285</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26 NUMBER OF SIGNALIZED INTERSECTIONS</td>
<td>0.072</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27 CONTINUOUSNESS</td>
<td>0.192</td>
<td>0.035</td>
</tr>
<tr>
<td>2 ROAD CHRCT.</td>
<td>0.1843</td>
<td>28 DIRECTNESS</td>
<td>0.075</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31 MOTOR VEHICLE TRAFFIC VOLUME</td>
<td>0.231</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32 LONG VEHICLE TRAFFIC VOLUME</td>
<td>0.147</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33 SPEED LIMIT FOR VEHICLES</td>
<td>0.098</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34 TRAFFIC CALMING ENFORCEMENT</td>
<td>0.098</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35 ON-Road PARKING AVAILABILITY</td>
<td>0.167</td>
<td>0.027</td>
</tr>
<tr>
<td>3 TRAFFIC CHRCT.</td>
<td>0.1634</td>
<td>36 SECURITY</td>
<td>0.260</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41 TRAVEL TIME</td>
<td>0.373</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td></td>
<td>42 TRAVEL COST</td>
<td>0.179</td>
<td>0.039</td>
</tr>
<tr>
<td>4 BCY SRV CHRCT.</td>
<td>0.2177</td>
<td>43 CONSTRUCTION TIME</td>
<td>0.243</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44 CONSTRUCTION COST</td>
<td>0.205</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51 DAILY PUBLIC TRANSIT DEMAND</td>
<td>0.318</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52 BICYCLE PARKING FACILITIES</td>
<td>0.318</td>
<td>0.063</td>
</tr>
<tr>
<td>5 PT TRNS FAC.</td>
<td>0.1978</td>
<td>53 BIKES ON PUBLIC TRANSIT VEHICLES</td>
<td>0.365</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61 LAND USE</td>
<td>0.448</td>
<td>0.072</td>
</tr>
<tr>
<td>6 LAND USE CHRCT.</td>
<td>0.1601</td>
<td>62 COMPLIANCE WITH HISTORIC PATTERN</td>
<td>0.172</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td></td>
<td>63 COMPLIANCE WITH URBAN AND TR. PLANS</td>
<td>0.380</td>
<td>0.061</td>
</tr>
</tbody>
</table>
Table 4. Scores of alternatives

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTERNATIVE 11</td>
<td>3.4085</td>
</tr>
<tr>
<td>ALTERNATIVE 12</td>
<td>3.4033</td>
</tr>
<tr>
<td>ALTERNATIVE 5</td>
<td>3.3590</td>
</tr>
<tr>
<td>ALTERNATIVE 13</td>
<td>3.2861</td>
</tr>
<tr>
<td>ALTERNATIVE 6</td>
<td>3.2835</td>
</tr>
<tr>
<td>ALTERNATIVE 1</td>
<td>3.2382</td>
</tr>
<tr>
<td>ALTERNATIVE 9</td>
<td>3.1760</td>
</tr>
<tr>
<td>ALTERNATIVE 14</td>
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</tr>
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</table>

3.5 Sensitivity analyses

Sensitivity analysis is made to determine how “sensitive” a model is to changes in the value of the parameters of the model and to changes in the structure of the model. Sensitivity analysis helps build confidence in the model by studying the uncertainties that are often associated with parameters in models. The analysis allows the modeller to determine what level of accuracy is necessary for a parameter to make the model sufficiently useful and valid.

The changes in alternatives and the changes in the whole result are observed in case of a change in the weight of a particular sub-criterion. In the extent of the sensitivity analyses, certain highest value sub-criteria are taken into consideration, and their weights are changed to find out how other sub-criteria and alternatives are affected. Microsoft Office Excel package software is used for sensitivity analyses.

Considering the results of expert opinions, the weight of “travel time” sub-criterion with a weight of % 8.1, is tested for the cases of % 0 and % 100. When the weight is accepted as % 0, no change in the ranking of the alternatives is observed. When the weight is accepted as % 100, Alternative-1 changes its place from 6th rank to 2nd.
As the weight of “bikes on public transit vehicles” gets % 0, the ranks of first two alternatives are changed, as it gets % 100, Alternative-1 gets on 1st, Alternative-13 gets on 3rd rank.

4. Results and discussion

In this study, an important sustainable transportation mode, bicycle transportation has been examined in terms of policies and planning. The study proposes a decision support model (DSM) in order to phase a citywide bicycle network plan integrated with the public transport system in Istanbul Metropolitan Area.

As a result of several analyses and interpretation of these analyses, a solution is generated which shows the levels of developing the bicycle network around specified transfer centers. It has been seen that “bikeway service and operation characteristics” criteria, and “travel time” sub-criteria have more importance over other criteria.

As a result of the calculations, observing the weights of criteria, the local weight of bikeway service and operation characteristics criterion with the value of 0.2177 ranks first while public transport and transfer facilities criterion comes next with the value of 0.1978, and road characteristics criterion follows with the value of 0.1843.

After prioritizing the bicycle network clusters, the proposed bicycle network should be implemented starting from the clusters 11 and 12 in Asian side, following the cluster 5 in European side, and getting along with the cluster 13 on the same axis.

The network development is estimated to occur along Uskudar, Kadikoy, Maltepe, and Kartal axis in Asian side, and along Zeytinburnu, Bakırköy ve Avcilar axis in European side. The Sariyer axis and other independent network clusters in both sides follow these clusters.

Considering the ranking, the bicycle network extending along the coast on an axis in both sides of the city is prioritized in clusters where there exists a relatively more regular road hierarchy, lower slopes, more opportunities of using seaway transportation, and easier intermodal transportation integration.

The clusters that take place on the last ranks show the characteristics of more irregular land-use pattern including high-density residential areas with commercial use, warehouse and industry. The clusters also encloses areas where inadequate public transport system, narrow roads, and high slopes are observed with the intersections on main arterial roads and highways such as D-100 and TEM, having low capacities with bottlenecks, and uncontrolled level junctions. These clusters include the districts of Bayrampasa, Esenler, Gungoren, Gaziosmanpasa, and Sultangazi.

After the determination of alternatives’ ranking, the sensitivity analysis is performed in order to find out how the alternatives are affected when the weights of the sub-criteria change. As a result of series of analysis, the differentiation in the rankings of alternatives, according to different weights of sub-criteria, is calculated.
The study has a flexible characteristic that provides a makeover entering new/updated data and adding new alternatives. With regards to provide prospective foresights, the data can be revised and updated regularly, in parallel with changes in housing and population, socio-economic development, and transportation system.

For further studies, the process of weighting the criteria and rating can be extended by taking the opinions of different stakeholders such as decision makers, executors, and civil authorities.

5 Acknowledgements

This study is part of the PhD thesis “Prioritization of Integrated Bicycle Network Clusters in Istanbul Metropolitan Area Using Analytic Hierarchy Process” in the programme of Transportation Engineering in Istanbul Technical University, Institute of Science and Technology.

6 References


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