

Research Article

Comparison between Physical Parameters and Sensory Parameters Regarding Travel Behavior Based on Sensitivity Analysis

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Received 23 December 2021; Revised 30 May 2022; Accepted 18 August 2022; Published 10 September 2022

Academic Editor: Gabriella Mazzulla

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An effective way to optimize decision-making regarding the transport mode choice in the transportation system is improving or changing the travel cost, the travel time, or some other travel characteristics by using sensitivity analysis. This method encourages travelers to switch from private transportation to public transport, thus reducing pollution and emission. Furthermore, by searching for the most sensitive factors in travel behavior, the sensitivity analysis might highlight the directions of the improvement. However, according to previous studies, travelers will transfer from one transport mode to another only if the utility of the new choice is higher than the original transport mode. In the current paper, sensitivity analysis is applied to provide a comparison between the impacts of the physical and sensory parameters on the travel behavior and transport mode choice based on a utility function. The multinomial logit (MNL) model is used to estimate and perform the sensitivity analysis of the main variables. The sensitivity analysis demonstrates the degree of the travelers' sensitivity to changes in the travel characteristics including both physical and sensory parameters. The models are calibrated with the NLOGIT software and validated through statistical indicators; thus, the essential factors influencing the choices are obtained. The input variables selected for the models are based on the data collected in Budapest, Hungary. The sensitivity analysis is determined by the outputs of the variables based on the changes of the input variables. As the results show, the travelers have more sensitivity to the changes in the physical parameters. Furthermore, the outcomes indicate that the travel cost is an essential variable, which greatly affects the decisions related to the transport mode choice. From the sensory parameters, the comfort factor has more influence than other factors. The results of the analysis present that the travelers' sensitivity to changes in the travel utilities of the travel characteristics impacts the decisions regarding the mode choice behavior significantly.

1. Introduction

Improving the services and reducing the travel time of public transport or increasing the travel cost of private transportation (such as by increasing the petrol fees, road fees, or parking fees) are effective ways to promote sustainable modes and encourage travelers to switch from private vehicles to public transport, thus reducing the congestion and the detrimental environmental effects [1].

The decision-making theory related to the transport mode choice model is proposed by Simon [2], and

subsequent scholars, such as Mahmassani and Chang [3], Lioukas [4], Di et al. [5], Zhang et al. [6], and Mahmassani [8], have related research as well. These studies support the theory that switching from private transportation to public transport happens solely when the travel utility of a new choice is greater than the utility of the current choice. Therefore, the changes in the utility values influence the travelers' choice behavior related to mode selection. Moreover, the utility value is a factor indicating whether a transportation demand management (TDM) policy can be effectively implemented [9]. Georgescu [10] applies the

concept of the utility theory in the theory of consumer choice and suggests that consumers do not change their choices unless the utility difference exceeds a certain necessary minimum.

Current research on transportation sustainability primarily considers the connection between the impact of the changes in the travel utility and the sensitivity analysis to model travel behavior. Therefore, this study uses sensitivity analysis to measure the changes in the value of the utility related to the parameters of the transport mode choice.

Sensitivity analysis is a calculation method used to determine the impacts of changing the values of the input parameters on their outputs (i.e., outcomes) [11]. Sensitivity analyses can be divided based on the following three categories: focus, scale, and complexity. In case of focusing on the criteria, the primary purpose of the analysis is to determine the influence of the individual parameters and the order of their importance in the output. Considering the scale, partial and comprehensive sensitivity analyses can be recognized. For partial sensitivity analyses, the influence of several selected input parameters is tested. Besides, in case of comprehensive sensitivity analyses, the impact of all input parameters is assessed. In terms of complexity, one-dimensional and multidimensional analyses are distinguished. The one-dimensional sensitivity analysis constantly changes the values of one input parameter, but the other model parameters remain constant. In this way, the influence of the tested input parameter on the result can be determined unambiguously, without distortion. The multidimensional sensitivity analyses change the values of multiple input variables simultaneously and evaluate their combined effect on the calculation output [12].

Additionally, sensitivity analysis is used to determine how sensitive a model is to the changes in the value of the parameters and to the changes in the structure of the model. Sensitivity analysis is usually performed as a series of tests, where different parameter values are set to see how the changes in the parameters cause differences in the dynamic behavior of the model. By showing how the model responds to the changes in the parameter values, sensitivity analysis is a valuable tool in model building and evaluation [13]. Consequently, a systematic and thorough sensitivity analysis as a form of model assessment, parameter sensitivity testing, and validation are required [14]. Thus, the sensitivity analysis aims to identify the most significant parameters in the model and quantifies how the input uncertainty influences the output.

Thorough sensitivity analysis helps in interpreting the model, increases its credibility across a range of input scenarios, and can uncover underlying errors in the model. In general, sensitivity analysis techniques primarily consist of local and global approaches. The local approach addresses the sensitivity related to the point estimates of the parameter values, where the inputs vary once at a time around a fixed point, and the effects of the individual variation on the outputs are calculated. The local approaches include partial derivatives, one-at-a-time sensitivity measures, and a sensitivity index [15]. On the other hand, the global sensitivity analysis approach evaluates the effect of a parameter, while

all other parameters are varied. Thus, the total impact on the output and the interactions between the input parameters can be assessed [16]. Moreover, the global sensitivity method can be applied to arbitrary nonlinear functions. For instance, some typical global sensitivity analysis approaches include the regression-based approach [17], the regionalized sensitivity analysis [18], the Morris method [19], and the Sobol method [20]. In general, sensitivity analysis is used by Du [11] for the analysis of the transportation systems or by Jourquin [21] for studying the relative road costs. Moreover, Tzeng [22] applies sensitivity analysis in the multicriteria analysis of the alternative-fuel buses for public transport [21, 22].

Several researchers use sensitivity analysis to study the influence of the trip parameters on the travel behavior. For example, Chen [23] analyzes the residents' travel parameters in case of using public transport and proposes that the travel characteristics, both directly and indirectly, affect the travel behavior through some latent variables of the planned behavior theory. Based on the sensitivity theory, Jing [24] introduces the descriptive norms and latent variables of the behavioral habits and explores the impacts of the travel parameters on the travelers' behaviors and intentions to select the intercity transport modes in the metropolitan area by establishing a regression model related to the travelers' sensitivity analysis.

In the literature, a comprehensive study rarely can be found about the impact of the transport mode factors and trip factors on the travel behavior based on sensitivity analysis. Furthermore, some studies use the sensitivity analysis with a wide range of variables regarding the travelers' mode choice and consider the impact of changing variables on the travel utility and consequently, on the travelers' choices. Therefore, a comprehensive study of the changes in the travelers' sensitivity to the travel utility is conducted. The research work includes a comparison between a wide range of physical parameters and sensory parameters, and analyzes the impact on the travelers' mode choice when performing their daily activities.

In this study, the local approaches, focusing on criteria, comprehensive sensitivity analyses, and one-dimensional analyses are applied for sensitivity analysis of the transport mode choice. The main objective is to quantitatively measure the relative effect of input variables (physical and sensory variables) involved in the model of the transport mode choice. More specifically, the sensitivity analysis is used to calculate the probability of the transport mode choice by varying the selected input condition variables one after another and by keeping all other variables observed. Afterward, the effects of different parameters on the transport mode choice are measured. This research work demonstrates the utility function based on the sensitivity analysis with the travel factors (i.e., including both physical and sensory factors) to analyze the travelers' decision behavior regarding the transport mode choice based on data collected in Budapest. This sensitivity analysis reflects the degree of the travelers' sensitivity to the changes in the travel factors. The multinomial logit (MNL) model is used to estimate and perform the sensitivity analysis of the main variables.

The paper is organized into five sections. After the introduction in Section 1, the following section is the literature review. Section 3 presents the methodology and model specification, which is followed by the description of the study area. The model estimation and the results are discussed in Section 4. Finally, Section 5 is a conclusion with some suggestions for future research.

2. Literature Review

Sensitivity analysis aims to quantify the rate of change in the model outputs due to variations in the inputs. This quantification relies on the calculated utility functions (i.e., sensitivity functions), which depend on the factors of the inputs. However, the choice of the parameters can largely influence the outcomes of the sensitivity analysis, especially when the space of the inputs is considerably affected by the utility model. Different sensitivity analysis studies are characterized by various properties, computational costs, and application scopes. These research works demonstrate a thorough review of the methods used in sensitivity analysis; thus, the main approaches are briefly summarized in the following paragraphs.

One of the essential approaches in sensitivity analysis is the Monte Carlo approach used to determine the sensitivity of the demand and the valuation estimates to the choices as defined by Ronald [25]. The scholar presents an investigation of the travel-cost method of estimating a recreation demand function, which requires specifying the functional form of the first-stage demand curve and to define the width of the concentric origin zones. The results of the sensitivity analysis indicate that the estimated demand and valuation estimates are sensitive to the definition of the origin zone and the use of a semi-log versus a double-log first-stage demand curve. Additionally, Linda [26] applies the Monte Carlo approach to examine and summarize the limitations of the sensitivity analysis in a spatial model. A global sensitivity analysis considers the potential effects of the simultaneous variation of the model inputs over their finite range of uncertainties. In several studies, the sensitivity analysis is used to investigate the costs, such as travel costs or road pricing, in the transportation system. For road pricing, Jiang [27] presents a study applying a sensitivity analysis-based method proposed to solve some optimal road pricing problems. The problems can be formulated as mathematical programs with equilibrium constraints (MPECs). An essential step for solving such an MPEC problem is by the sensitivity analysis of the traffic flows by concerning the changes of the link characteristics, such as the toll prices. The objectives of the optimization can be the total travel time or the total cost incurred by all travelers. Jindřich [12] studies the issues of sensitivity analysis and its possible use for price formation in passenger road transportation. The sensitivity of the output to the input variables is determined based on a calculation demonstrating how the inputs affect the overall results. In calculating the willingness to pay (WTP), Dewi [28] uses the sensitivity analysis to identify the toll fares. The findings of the research present that the toll fare sensitivity of the Solo-Ngawi toll road is based on the WTP. The sensitivity analysis

aims to determine the sensitive parameters in the model. Furthermore, the sensitivity of the model is intended to show the changes in the probability values of the route selection (i.e., toll road or nontoll road) if a gradual attribute value change is performed. Based on the analysis, it is found that the effects of the fare change on the amount of WTP in the binomial logit model are more sensitive than those in the probit model under the same travel conditions. The range of the tariff changes the values of the WTP in the binomial logit model, which is 20% greater than the range of the values in the probit model. Additionally, to consider the issues of the travelers' sensitivity during modeling a transport mode, Baibing [29] presents an empirical study of the different alternatives linked to the sensitivity function in the transport mode choice. The research work demonstrates how sensitive a traveler is to the changes in the linear combination of travel-related attributes, such as travel time and travel expenses. Consequently, the empirical results of the study show that people might have different sensitivities to the same amount of change when using various transport modes.

Regarding the sensitivity analysis of the travel comfort factor, Xianghao [30] presents a study using the sensitivity method to examine the passengers' perception of comfort while accounting for the in-vehicle time factor and passenger load factor. The author performs a two-way analysis of variance and shows that both the in-vehicle time and the passenger load affect the passengers' comfort significantly. Moreover, Eriksson and Friberg [31] propose a study applying a sensitivity analysis method and some concepts from the design and the analysis of the experiments. The research focuses on the ride comfort of a city bus. Due to the different types of road excitations, the bus riders' responses are calculated by using an FE model of the entire bus. The design effects are calculated by using sensitivity analysis for each load case as well as compared to find the scenario variables or the combinations of those variables that considerably and effectively affect the ride comfort attributes of the bus.

On the other hand, some studies use sensitivity analysis with activity models. Arentze [32] presents an investigation to explore the sensitivity of the activity models by using the albatross model as a representative of the activity-based (and computational process-modeling) approach. The albatross model is sensitive to several variables including the population, the schedule skeletons, the opening hours, the land-use, the travel costs, and the travel times. Afterward, the impacts of the scenarios are analyzed by comparing the results of the predictions between the baseline and the scenarios. Moreover, Qiong [33] performs a sensitivity analysis on the decision trees in FEATHERS and in an activity-based microsimulation modeling framework. The relative effects of the input variables are quantitatively measured in the given decision trees on the choice variable. Both the local and global sensitivity analysis approaches are investigated. In the current study, a sensitivity analysis is applied based on the local sensitivity analysis approaches to analyze the travel demand model. Chao [34] develops a systematic framework for the quantitative uncertainty analysis of a combined travel demand model (CTDM) by

using the analytical sensitivity-based method instead of the time-consuming sampling-based methods. The CTDM overcomes the limitations of the sequential four-step procedure since it is based on a single unifying rationale. One advantage of the analytical sensitivity method is that it requires less computational effort than the sampling-based methods.

As demonstrated, the utility function of various alternatives is linked to a sensitivity function which shows how sensitive a traveler is to the changes in a linear combination of the travel-related attributes, such as the travel time or the travel expenses. Consequently, specifying a utility function supports the realization of a sensitivity analysis, and so the physical and sensory parameters related to the travel attributes can be compared. The current paper shows that travelers might have different sensitivities to the same amount of changes. Therefore, the travelers' sensitivity has to be considered during modeling.

3. Methodology

3.1. Model Framework. The sensitivity analysis is used to identify the rate of the changes in the outputs of the model as a result of variations in the input parameters [35]. The current paper uses the sensitivity analysis to determine which variables have travelers' high sensitivity when choosing transport modes for the daily activity chains. Accordingly, those changes are identified in the travel utility that enables the travelers to switch from one transport mode to another. Solely, when the travel utility of the new mode is greater than that of the current mode, the travelers move from their current transport mode to a new one.

Based on the survey data on travel behavior, the sensitivity equation of the transport mode choice is established to investigate the utility value and probability value when choosing the transport modes (i.e., car, bus/trolleybus, metro, tram, bike, or walking). The details of the survey design are presented in Subsection 4.2. Based on the utility theory, the sensitivity to a change in travel utility is an impact factor of travel behavior and constructs a theoretical model for the relationship between the essential factors and the travelers' behavior in this paper.

The analysis of the relationship between the impact factors, transport mode choice, and travel behavior is conducted by using the MNL model. The constructed model includes two main components of the parameters: finding the physical parameters, the sensory parameters, and the sensitivity to the changes in the travel utility, as well as comparing these parameters. The physical parameters consist of the travel time, the travel cost, the parking time, and the waiting time. The sensory parameters involve the comfort factors, the travel quality factors, the travel safety factors, and the environmental impact factors, where the comfort factors are related to the provided services, e.g., air conditioning makes the travel more convenient, and the travel quality factors focus on the status of the vehicle fleet (e.g., modern vehicles).

3.2. The Scenarios of the Model. Most transportation congestion management actions attempt to encourage a change

in the transport mode choice (i.e., a shift from the car mode to public transport) or to reduce trip-making during the peak period by directly or indirectly influencing the value of the variables related to the travel behavior [36, 37].

At the same time, the travelers' sensitivity is the probability of the variation in the transport mode choice due to a change in one or more of the values of those variables affecting the alternatives [29, 38]. The travelers' sensitivity for public transport is larger than that for cars indicating that the travelers using public transport are more sensitive to the changes in the value of the travel-related variables than the traveler using cars. The travelers are more sensitive to the changes in the travel time than in the travel costs in case of public transport trips [28].

Furthermore, the travelers have high sensitivity for changing the travel cost and the travel time in case of traveling by private modes during peak periods, which is the most significant effect on the probability choice of selecting a transport mode during the peak period. Therefore, the travelers' sensitivity analysis is extremely important in TDM, transportation control measures (TCMs), and in the intelligent transportation systems. Therefore, in current study, another critical motivation can be found in obtaining the results when the travel-related values of the variables change in the transportation policies as well as in using the empirical results to examine the impact of the changes in the physical or sensory parameters on the transport mode choice [39].

In the current research work, two different scenarios are simulated for the transport mode choice as well as a comparison between these scenarios is conducted, too. The two scenarios are the followings:

- (1) The first scenario of the simulations is carried out assuming that there is growth in the physical parameters related to the transport mode by increasing the values of the variables by 10%, 20%, 30%, 40%, and 50%
- (2) The second scenario of the simulations is carried out assuming that there is an increase in the sensory parameters related to the transport mode by raising the value of the variables by 10%, 20%, 30%, 40%, and 50%

The MNL model is used to calculate the choice probabilities for each traveler based on the estimated parameters. This method is beneficial to the production of the possibilities for all alternatives.

3.3. Hypotheses. Some previous research works on the transport mode choice model identify the essential elements of the transport mode choice, i.e., physical and sensory characteristics [40]. Moreover, the transport mode choice model predicts the travelers' choice of the transport mode based on the maximum utility theory [41]. The alternatives considered in the utility function are the followings: car, bus/trolleybus, metro, tram, bike, and walking. Furthermore, the independent variables examined within the utility function are divided into two types: the physical variables of the model (1) and the sensory variables of the model (2) [42].

The variables in the model with the highest accuracy are selected as the final data on the daily activity in Budapest.

Consequently, two formal hypotheses are set within the two models by using the sensitivity analysis. The two hypotheses act as the basis of establishing the role of the physical characteristics and the sensory characteristics affecting the travelers' decisions on which mode to choose when performing daily activities.

- (i) The first hypothesis is as follows: physical characteristics such as the travel time, travel cost, parking time, and waiting time influence the transport mode choice significantly, as estimated by the model.
- (ii) The second hypothesis is as follows: sensory characteristics including the comfort factor, travel quality factor, travel safety factor, and the environmental impact factor influence the transport mode choice significantly, as estimated by the model.

3.4. Utility Function (i.e., Sensitivity Function). The sensitivity analysis aims to determine and identify the sensitive parameters in the model. The sensitivity of the model is intended to understand the alteration in the probability value of the transport mode choice if a gradual parameter value change is performed. In case of those parameters categorized as sensitive, the sensitivity analysis aims to set the range of values that change the parameters and thus the optimal results [43].

The current study uses a multiple linear regression approach to determine the sensitivity function based on the utility theory of the transport mode choice. The calculation uses the MNL model to obtain the value of the regression coefficient thus estimating the model and the probability of the transport mode choice. Therefore, the following sensitivity function of each alternative can be obtained.

- (i) The sensitivity function (1) of the physical parameters (i.e., model 1):

$$S_{m1} = \beta_C^m + \beta_T^m TT_m + \beta_C^m TC_m + \beta_{PT}^m PT_m + \beta_{WT}^m WT_m, \quad (1)$$

where S_m = the value of the sensitivity function of the mode (m) (i.e., car, bus/trolleybus, metro, tram, bike, and walking) chosen by the traveler (i), TT_m = the travel time of the chosen mode (m) in minutes, TC_m = the travel cost of the mode (m) in HUF (i.e., Hungarian currency), PT_m = the parking time of the mode (car) (m) in minutes, WT_i = the waiting time of the traveler (i) in minutes, and β_k = the coefficient of the independent parameter which defines the alternatives of the mode (m) chosen by the traveler (i).

- (ii) The sensitivity function (2) of the sensory parameters (i.e., model 2):

$$S_{m2} = \beta_C^m + \beta_{CF}^m CF_m + \beta_{TQ}^m TQ_m + \beta_{TS}^m TS_m + \beta_{EI}^m EI_i. \quad (2)$$

where S_m = the value of the sensitivity function of the mode (m) (i.e., car, bus/trolleybus, metro, tram, bike, and walking) chosen by the traveler (i), CF_m = the comfort factor of the mode (m), TQ_m = the travel quality factor of the mode (m), TS_m = the travel safety factor of the mode (m), EI_i = the environmental impact factor of the traveler (i), and β_k = the coefficient of the independent parameter which defines the alternatives of the mode (m) chosen by the traveler (i).

The abovementioned equations present the linear sensitivity functions of the transport mode choice. It is used to estimate the utility values of each choice alternative, which depends on the values of the physical parameters, the sensory parameters, and the variables associated with the alternatives [39]. The travelers' choice means assigning the chosen value of the alternative with a high utility and not choosing another alternative with a less value.

3.5. The MNL Model. The MNL model is one of the most well-known statistical analysis tools used for examining the relationships between two or more variables. Additionally, it is the most widely used method to model choices among mutual alternatives, as well as it belongs to the family of random utility maximization (RUM) [44]. The model is based on the normal distribution assumption of the random error components, and it is widely applied to predict and estimate behavioral choices. The logit-based models continue to be the most common model forms of choice for travel behavior modeling because of their ease of analysis, estimation, and application [45].

The MNL model aims to estimate and predict a function that calculates the coefficients of the variables and the probability of the transport mode choice. Its simplicity represents the main advantage of the MNL model in terms of interpreting the relationships among the independent and dependent variables. The current study uses the MNL model to analyze the sensitivity of the physical and sensory parameters to the travel behavior and transport mode choice based on the utility function. Furthermore, another aim is to identify the parameter that has the highest impact on the mode choice among the variables. The variables chosen in the model are divided into the following two types: the dependent and the independent variables. The dependent variable is the transport mode. The independent variables include the travel cost, travel time, parking time, waiting time, comfort factor, travel safety factor, travel quality factor, and the environmental factor. The variables are represented following the coding system in NLOGIT. In the MNL model, the proportion by the chance accuracy rate and the model goodness of fit by using pseudo-R-square values are computed, where R^2 summarizes the proportion of the variance in the dependent variable associated with the independent variables. The goodness-of-fit measures are based on the likelihood ratio test (-2 log-likelihood).

The MNL model presents several equivalent formulations of the simple logistic regression. The probability of each category is compared to the probability of the reference independent variables [46, 47]. The MNL model equation (3) is as follows:

$$\Pr(Y_i = c) = \frac{e^{\beta_c \cdot X_i}}{\sum_{k=1}^K e^{\beta_k \cdot X_i}}, \quad (3)$$

where \Pr = the probability that an individual (i) chooses alternative (k) for variables $i = 1, 2, \dots, K$, $\beta_c = a$ vector of the estimable coefficients for alternative (k), $X_i = a$ vector of the explanatory variables for individual (I).

Equation (3) expresses the logit as a linear function of the independent variables (x_i). Therefore, the equation allows the interpretation of the logit weights for the variables in the same way as in the linear regressions [48].

4. Descriptive Analysis

4.1. Model Specification. According to previous theoretical and empirical works on the transport mode choice models, the variables related to the model specification are identified by taking the conditions of the datasets and the study area into account [39, 49–51]. The data are used as a set of variables for model generation, which is related to the transport mode choice. Afterward, the final specification of the variables is identified based on the statistical testing performed on the dataset.

The variables included in the model are divided into two groups: the first group consists of the physical variables: travel time, travel cost, parking time, and waiting time (i.e., based on the transport modes). The second group involves the comfort factors, travel quality factors, travel safety factors, and the environmental impact factors. Table 1 provides a list and description of those variables used in the model. These variables are calculated from the available data in the survey for inclusion in the utility functions. The essential variables are included in the analysis that could help in describing the relationship between the transport mode choice and the travel behavior.

4.2. Study Area. The travelers' travel demand in Budapest is constantly increasing as the legislative assembly, the government departments, tourist places, parks, and other business centers are located in the city. The significant sources of transportation problems in Budapest are congestion, the lack of parking spaces, and the increasing use of private modes [52–54]. Budapest is selected as the study area for conducting the individual survey.

The data used in this paper are based on a survey conducted on individual travel during 2019 in the Budapest metropolitan area with the aim of evaluating the travel behavior and the mode choice model. The data are collected from randomly selected individuals, which correspond to the simple random sampling method. Data collection is conducted both personally and online, where first, the travelers answer a paper-based survey, which is transferred to an online form afterward. Each individual completes a travel diary that documents the individual members' activities on an assigned day. As with most individual travel surveys, each person's detailed sociodemographic and trip information are collected, as well.

The questionnaire presented to the travelers consists of the following three sections. The first section is about socio-economic and personal information. Afterward, the transport mode evaluation and the weighting of the parameters are to be conducted. The third section consists of the trip characteristics based on the activity types. The personal information and socio-economic data include traveler's age, gender, marital status, household size, income, educational level, occupation, car availability, bike availability, and public transport ticket availability. The transport mode evaluation parameters of each mode demonstrate the comfort factor, travel quality factor, travel safety factor, environmental impact factor, health impact factor, and the weather impact factor. Moreover, the trip parameters of each activity include the activity purpose, trip distance, origin-destination location, origin-destination travel time, waiting time, and parking time.

The travel time consists of the walking and bicycle-access times, the in-vehicle time, and the egress time. The transportation fare is calculated as the sum of the boarding fare and any transfer fares of the transportation network. The travel cost by car primarily includes the operation cost and the parking cost. The operation cost is computed as the monetary costs associated with the fuel consumption, maintenance, insurance, registration, road toll, and tire. The parking cost for each zone provides the parking cost.

In the current research work, to use the sensitivity analysis, the focus is on two groups of parameters. The first group is related to the physical parameters. The study concentrates on four questions from the survey to identify which parameters have high sensitivity to the travelers' mode choice. The questions are as follows:

- (i) What is the average in-vehicle travel time to your work/university? (minutes)
- (ii) What is the average travel cost to your work/university? (HUF)
- (iii) What is the average time you spend on finding a parking place? (In case car is used; minutes)
- (vi) What is the average time you spend on transferring and waiting? (In case public transport is used; minutes)

The second group includes the sensory parameters. The study concentrates on four questions of the survey to identify which parameters from the second group have a high sensitivity to the transport mode choice. The questions are as follows:

- (i) How do you evaluate the modes of transportation based on the travel comfort while choosing the mode of transportation?
- (ii) How do you evaluate the modes of transportation based on the travel quality while choosing the mode of transportation?
- (iii) How do you evaluate the modes of transportation based on the travel safety while choosing the mode of transportation?

TABLE 1: The description of the variables.

Shortened form of the variable	Variable	Description	Measure
<i>Transport mode variable</i>			
TM	Transport mode	Transport mode 1: car; transport mode 2: bus/trolleybus Transport mode 3: metro; transport mode 4: tram Transport mode 5: bike; transport mode 6: walking	Nominal
<i>Physical variable</i>			
TT	Travel time	Travel time in minutes	Scale
TC	Travel cost	Travel cost in Hungary forint (HUF)	Scale
PT	Parking time	Parking time in minutes	Scale
WT	Waiting time	Waiting time in minutes	Scale
<i>Sensory variable</i>			
CF	Comfort factor	Comfort factor 1: very bad; comfort factor 2: fairly bad Comfort factor 3: bad; comfort factor 4: neither good nor bad Comfort factor 5: good; comfort factor 6: fairly good Comfort factor 7: very good	Ordinal
TQ	Travel quality factor	Travel quality 1: very bad; travel quality 2: fairly bad Travel quality 3: bad; travel quality 4: neither good nor bad Travel quality 5: good; travel quality 6: fairly good Travel quality 7: very good	Ordinal
TS	Travel safety factor	Travel safety 1: very bad; travel safety 2: fairly bad Travel safety 3: bad; travel safety 4: neither good nor bad Travel safety 5: good; travel safety 6: fairly good Travel safety 7: very good	Ordinal
EI	Environmental impact factor	Environmental impact 1: very bad; environmental impact 2: fairly bad Environmental impact 3: bad; environmental impact 4: neither good nor bad Environmental impact 5: good; environmental impact 6: fairly good Environmental impact 7: very good	Ordinal

- (vi) How do you evaluate the modes of transportation based on the environmental impact caused by the travel while choosing the mode of transportation?

A significant effort is made to clean the data and identify the nested tree of the transport mode choice. The mode choice is determined as car, bus/trolleybus, metro, tram, bike, and walking.

4.3. The Characteristics of the Transport Modes. According to the information collected from the respondents, the essential variables found in the analysis and any variables that could help in describing the sensitivity analysis of the transport mode choice and travel behavior are collected. From the available data, the variables are calculated for inclusion in the sensitivity functions. The descriptive analysis of the variables included in current study is given in Table 2, which summarizes the statistics of the dataset, as well. Table 3 presents the percentages of the travelers' transport mode choice, comfort factors, travel quality factors, travel safety factors, and environmental impact factors.

The analysis of the questionnaires shows that 63.5% of the travelers use public transport, while 18.3% prefer to walk or travel by bike. Furthermore, the questionnaires reveal that 18.2% of the travelers use cars to perform their daily activities. The sample is not fully representative, but some parameters are close to the real values. For example, in the

sample, 63% use public transport, 18% travel by car, and 18% walk or bike. These modal share values are similar to the general modal share of Budapest, where the values are 45% for public transport, 35% for the car mode, and 20% for walking or using a bike, as collected by the European Platform on Mobility Management (EPOMM) in 2014. The difference in the values for public transport might be caused by the data collection method because at the main transfer points of the city, typically more public transport users than car users are approached during the data collection. The survey is used to measure the travelers' sensitivity to the changes in the travel utility from two dimensions: the physical and sensory parameters.

5. The Model Estimation and Results

5.1. The Computing of the Model Accuracy. The proportion of the model accuracy rate can be computed by calculating the proportion of the cases for each set based on the number of the cases in each dependent variable set. This method is measured by squaring and summing the proportion of the cases of the various mode choice (i.e., car, bus/trolleybus, metro, tram, bike, and walking) in each model. For models 1 and 2, it is $((0.182)^2 + (0.14)^2 + (0.137)^2 + (0.358)^2 + (0.095)^2 + (0.088)^2) = 0.216 = 21.6\%$. The benchmark used to characterize the MNL model has a 25% improvement over the rate of the accuracy achievable by the model alone; thus, the

TABLE 2: The descriptive statistics of the sample data.

Variable	The descriptive statistics of the physical variables			The descriptive statistics of the sensory variables					
	Statistic	Mean	Std. error	Statistic	Mean	Std. error	Statistic	Std. deviation	Variance
Travel time	32.423	1.877	Mode choice (car)	183.190	13.535	Mode choice (car)	6.404	0.127	0.834
Travel cost	1628.846	106.548		590328.054	768.328	Travel comfort	6.269	0.132	0.906
Parking time	5.289	0.466		11.307	3.363	Travel quality	6.096	0.158	1.304
Waiting time	0.0	0.0		0.0	0.0	Travel safety	5.173	0.224	2.617
			Environmental impact			Environmental impact			
Travel time	31.650	2.465	Mode choice (bus/trolleybus)	243.054	15.590	Travel comfort	5.125	0.187	1.394
Travel cost	498.750	27.705		30703.526	175.224	Travel quality	4.825	0.212	1.789
Parking time	0.0	0.0		0.0	0.0	Travel safety	5.300	0.176	1.241
Waiting time	7.575	0.599		14.353	3.789	Environmental impact	4.875	0.249	2.471
			Environmental impact			Environmental impact			
Travel time	32.897	2.890	Mode choice (metro)	325.831	18.051	Travel comfort	5.385	0.219	1.874
Travel cost	475.641	27.236		28930.499	170.089	Travel quality	5.692	0.169	1.113
Parking time	0.0	0.0		0.0	0.0	Travel safety	5.692	0.198	1.534
Waiting time	6.000	0.436		7.421	2.724	Environmental impact	5.410	0.291	3.301
			Environmental impact			Environmental impact			
Travel time	26.088	1.196	Mode choice (tram)	145.863	12.077	Travel comfort	5.275	0.142	2.043
Travel cost	418.628	13.827		19501.068	139.646	Travel quality	5.128	0.136	1.894
Parking time	0.0	0.0		0.0	0.0	Travel safety	5.294	0.131	1.754
Waiting time	5.745	0.281		8.033	2.834	Environmental impact	5.177	0.143	2.087
			Environmental impact			Environmental impact			
Travel time	21.296	1.798	Mode choice (bike)	87.293	9.343	Travel comfort	5.370	0.321	2.781
Travel cost	0.0	0.0		0.0	0.0	Travel quality	5.222	0.304	2.487
Parking time	1.556	0.134		0.487	0.698	Travel safety	4.741	0.394	4.199
Waiting time	2.519	0.172		0.798	0.893	Environmental impact	5.259	0.265	1.892
			Environmental impact			Environmental impact			
Travel time	18.760	1.328	Mode choice (walking)	44.107	6.641	Travel comfort	5.240	0.328	2.690
Travel cost	0.0	0.0		0.0	0.0	Travel quality	5.320	0.325	2.643
Parking time	0.0	0.0		0.0	0.0	Travel safety	5.120	0.376	3.527
Waiting time	0.0	0.0		0.0	0.0	Environmental impact	5.120	0.338	2.860
			Environmental impact			Environmental impact			

TABLE 3: The description of the analysis to the proportion of the variables.

Variable summary	N	Marginal percentage (%)		
Transport mode choice	Car	18.2		
	Bus/Trolleybus	14.0		
	Metro	13.7		
	Tram	35.8		
	Bike	9.5		
	Walking	8.8		
Valid	285	100.0		
<i>Sensory variable (marginal percentage)</i>				
Category	Comfort factor (%)	Travel quality factor (%)	Travel safety factor (%)	Environmental impact factor (%)
Very bad	0	0.4	0	2.8
Fairly bad	7.4	5.6	8.1	7.0
Bad	1.1	1.4	0.7	3.9
Neither good nor bad	11.2	14.4	10.2	10.9
Good	25.3	30.5	32.6	29.1
Fairly good	26.7	20.4	18.2	24.9
Very good	28.4	27.4	30.2%	21.4

proportional chance accuracy criteria is $1.25 * 0.216 = 0.27 = 27\%$.

The overall classification of the model accuracy percentage of the dependent variable computed by model 1 is 75.8%, and for model 2, it is 42.8%, which is greater than the proportional model accuracy criterion (27%). The results show that model 1 has a bigger accuracy rate than model 2. The criterion for the classification accuracy of the model is satisfied, as shown in Table 4.

5.2. Pseudo R-Square. To assess the goodness of fit of the models, the pseudo R^2 is examined. The pseudo R -square values can be calculated as shown in Table 5. According to the measures, the model with the largest pseudo R -square statistic is the best [55]. The findings indicate that model 1 has a better goodness of fit compared to model 2.

5.3. The Goodness-of-Fit Measures. The likelihood-ratio test assesses the goodness of fit of two competing statistical models based on the ratio of their likelihoods. More precisely, one of the values is found by maximization over the entire parameter space, and the other is found after imposing some constraints [55]. Table 6 shows the goodness of fit of the models, while Table 7 demonstrates the model fitting data. The significance of the difference between the likelihood ratio tests and the $-2 \log$ likelihood of the reduced model for the selected model is provided in Table 8.

The chi-square statistic presents the difference in the $-2 \log$ -likelihoods between the final and the reduced models. The reduced model is formed by omitting an effect from the final model. If the chi-square is significant, the effect of the interaction contributes significantly to the whole model and should be retained. The presence of a relationship between the dependent variable and a combination of the independent variables is based on the statistical significance.

In current model, the values of the travel cost variables are the following: the p value is 5, the $-2 \log$ -likelihood is 285.678, the chi-square is 128.818, and the Sig. is 0.000, which is less than the level of the significance 0.05. On the

other hand, the values of the environmental impact variable are the followings: the p value is 5, the $-2 \log$ likelihood is 602.898, the chi-square of the model is 2.635, and the Sig. is 0.046, which is less than 0.05. The results show that the travel cost variable affects the transport mode choice significantly, while the environmental impact variable is less significant than the other variables. Therefore, the null hypothesis, which states that there is no difference between the model without the independent variables and the model with the independent variables, is rejected [56]. The results demonstrate a statistically significant relationship between the combination of the independent variables and the dependent variable.

5.4. Parameter Estimates. The sensitivity analysis is performed by changing the selected input variables one after the other while keeping all other variables observed. Afterward, the relative impact of the input variables (i.e., physical and sensory variables) involved in the model of the transport mode choice on the outcomes is measured quantitatively. As a next step, the probability value of the mode selection is determined from the utility function based on the input variables. Sensitivity analysis is performed on the travel cost, travel time, parking time, waiting time, comfort factor, travel quality factor, travel safety factor, and the environmental impact factor.

The MNL model is used to estimate and identify the influence of different trip parameters in the sensitivity analysis of the transport mode choice. The results of the MNL model coefficients and the probability of the variables obtained from the analysis are shown in Tables 9.

The software NLOGIT and SPSS are used to estimate the coefficients of the model parameters through the maximum likelihood method. Finally, the significance of the variables is checked based on the analysis. Thus, the nonsignificant variables are eliminated based on the significant value, the t -statistic, and the likelihood ratio test. Therefore, the parking time and the waiting time are eliminated. The reference category is the walking mode.

TABLE 4: The classification of the dependent variable.

Observed	Predicted						Percent correct (%)
	Car	Bus/Trolleybus	Metro	Tram	Bike	Walking	
<i>The classification of model 1 (i.e., physical variables)</i>							
Car	52	0	0	0	0	0	100.0
Bus/trolleybus	0	11	4	25	0	0	27.5
Metro	0	1	10	28	0	0	25.6
Tram	0	6	4	92	0	0	90.2
Bike	0	0	0	0	26	1	96.3
Walking	0	0	0	0	0	25	100.0
Overall percentage (%)	18.2	6.3	6.3	50.9	9.1	9.1	75.8
<i>The classification of model 2 (i.e., sensory variables)</i>							
Car	31	0	0	21	0	0	59.6
Bus/Trolleybus	2	1	0	37	0	0	2.5
Metro	9	0	4	26	0	0	10.3
Tram	17	1	2	82	0	0	80.4
Bike	5	0	1	18	3	0	11.1
Walking	8	0	1	16	0	0	0.0
Overall percentage (%)	25.3	0.7	2.8	70.2	1.1	0.0	42.5

TABLE 5: Pseudo R-square.

<i>The pseudo R-square of model 1 (i.e., physical variables)</i>	
Cox and Snell	0.881
Nagelkerke	0.913
McFadden	0.639
<i>The pseudo R-square of model 2 (i.e., sensory variables)</i>	
Cox and Snell	0.202
Nagelkerke	0.209
McFadden	0.068

The model estimation is found statistically significant (i.e., sig. = $p = 0.005$) except for the parking time and the waiting time (sig. = $p > 0.005$), and the regression coefficients (β) have values of no more than 4. On the other hand, the regression coefficients of the independent variables are measured by calculating the change in the logit for a one-unit change in the predictor variable. In this study, the dependent variable is the transport mode such as car, bus/trolleybus, metro, tram, bike, and walking.

From Table 9, the value of β to the travelers' travel time on the transport mode tram is -2.60 , and on the transport mode public transport is -2.557 . The value of β to the travelers' travel cost on the transport mode car is -1.949 . These results indicate that the travel time and the travel cost are the two most influential variables for the variation of the predicted mode choice. Such a result is self-evident to some extent, which justifies the effectiveness of the sensitivity analyses.

To analyze the model, the focus is on the independent variables related to the dependent variable which have a statistical significance less than 0.05, as shown in Tables 9. The MNL model of the estimation coefficients, the statistically significant level, and the t-test of the variables obtained from the analysis are shown in Table 9.

- (i) The parameter estimates of the physical parameters are as follows:
 - (a) The travel time is a significant parameter in defining the choice of the transport mode. The

TABLE 6: The goodness of fit.

<i>The goodness of fit of model 1 (i.e., physical variables)</i>			
	Chi-square	df	Sig.
Pearson	90.221	395	0.000
Deviance	87.741	395	0.000
<i>The goodness of fit of model 2 (i.e., sensory variables)</i>			
	Chi-square	df	Sig.
Pearson	676.584	640	0.153
Deviance	493.572	640	0.000

TABLE 7: The model fitting information.

Model	Model fitting criteria		Likelihood ratio tests	
	-2 log likelihood	Chi-square	df	Sig.
<i>The model fitting information of model 1 (i.e., physical variables)</i>				
Intercept only	762.437			
Final	156.860	605.577	20	0.000
<i>The model fitting information of model 2 (i.e., sensory variables)</i>				
Intercept only	664.496			
Final	600.262	64.233	20	0.000

travel time is considered as a primary parameter when the travelers select their transport modes. The results demonstrate that those travelers who use the modes of the public transport (i.e., bus/trolleybus, metro, and tram) have a higher sensitivity regarding the travel time than those who usually travel by car to perform their daily activities. Additionally, the travel time has more impact on travelers using the tram than the other modes. This result is consistent with the findings of the studies by [29, 57].

- (b) In estimating the travel cost parameters of the transport modes, the travel cost has negative signs as it is expected. The travelers seem to be more sensitive to the travel cost. An increase in the travel cost creates a higher dissatisfaction

TABLE 8: The likelihood ratio tests of the selected model.

Effect	Model fitting criteria		Likelihood ratio tests		
	-2 log likelihood of the reduced model		Chi-square	df	Sig.
<i>The likelihood ratio tests of model 1 (i.e., physical variables)</i>					
Intercept	179.718		22.858	5	0.000
Travel time	166.078		9.218	5	0.001
Travel cost	285.678		128.818	5	0.000
Parking time	169.034 ^a		12.174	5	0.032
Waiting time	226.739 ^a		69.879	5	0.000
<i>The likelihood ratio tests of model 2 (i.e., sensory variables)</i>					
Intercept	632.285		32.022	5	0.000
Travel comfort	613.596		13.334	5	0.020
Travel quality	614.391		14.129	5	0.015
Travel safety	609.441		9.178	5	0.002
Environmental impact	602.898		2.635	5	0.046

TABLE 9: The estimation coefficients of the variables.

The mode of transportation		Coefficient	t-test	Sig.	The mode of transportation		Coefficient	t-test	Sig.
Car	Intercept	4.597	5.469	0.008	Car	Intercept	-4.793	-5.589	0.003
	Travel time	-0.675	-2.418	0.024		Travel comfort	0.794	2.331	0.016
	Travel cost	-1.13	-4.598	0.014		Travel quality	0.211	1.951	0.054
	Parking time	0.906	3.436	0.057		Travel safety	0.122	1.245	0.019
	Waiting time	—	7.607	0.061		Environmental impact	-0.098	-1.164	0.052
Bus/trolleybus	Intercept	16.348	6.009	0.051	Bus/trolleybus	Intercept	1.090	2.308	0.025
	Travel time	-1.057	-3.118	0.023		Travel comfort	0.505	1.772	0.014
	Travel cost	-1.15	-4.103	0.010		Travel quality	0.137	1.313	0.045
	Parking time	—	2.922	0.087		Travel safety	0.297	2.229	0.044
	Waiting time	—	2.559	0.061		Environmental impact	-0.069	-1.163	0.049
Metro	Intercept	18.542	6.009	0.060	Metro	Intercept	-1.649	-4.437	0.055
	Travel time	-0.93	-2.008	0.034		Travel comfort	0.531	1.270	0.021
	Travel cost	-1.144	-3.004	0.000		Travel quality	0.2	2.340	0.056
	Parking time	—	8.250	0.083		Travel safety	0.257	2.543	0.038
	Waiting time	—	5.559	0.061		Environmental impact	0.112	1.171	0.042
Tram	Intercept	19.715	6.009	0.049	Tram	Intercept	1.297	3.158	0.033
	Travel time	-1.007	-4.982	0.033		Travel comfort	0.487	1.239	0.046
	Travel cost	-1.145	-5.270	0.002		Travel quality	0.168	1.285	0.056
	Parking time	—	1.471	0.091		Travel safety	0.244	2.200	0.023
	Waiting time	—	5.559	0.081		Environmental impact	0.087	0.945	0.043
Bike	Intercept	16.489	6.548	0.021	Bike	Intercept	0.067	1.447	0.063
	Travel time	-0.784	-3.769	0.016		Travel comfort	0.241	2.302	0.036
	Travel cost	-1.012	-5.313	0.000		Travel quality	-0.096	-1.357	0.047
	Parking time	0.262	1.873	0.099		Travel safety	-0.131	-1.835	0.026
	Waiting time	—	9.143	0.077		Environmental impact	0.091	2.183	0.051

amongst the travelers, primarily when they use the private mode (i.e., car). The travel cost of a car has a higher effect than in case of the other modes and has less impact on the bike and walking mode as it is expected. In comparison, the travel cost has the same impact on all public transport modes because the fees are the same. This result is consistent with the outcomes found by [29, 57, 58].

- (c) Furthermore, the coefficient of the parking time is expected to have a negative utility, but it provides a statistically insignificant positive value. The most likely explanation for this

unexpected result is the strong correlations between the parking time, travel time, and waiting time. This problem occurs when the models are estimated with not enough independent variations in the variables for the estimation process to separate the effect of one from the others. The results show that the parking time (i.e., in case of the car mode) affects the transport mode choice more than those in the case of other modes (e.g., bike). At the same time, the parking time is not important in case of other modes (i.e., bus/trolleybus, metro, tram, and walking). The most likely explanation for these expected results is

TABLE 10: Comparisons between the parameters of the mode choice based on various scenarios.

Sensitivity rate %	Car (%)	Bus/trolleybus (%)	Metro (%)	Tram (%)	Bike (%)
<i>Physical parameters</i>					
Travel cost (scenario between 0 and 5)	41.3	33.6	36.3	34.2	4.2
Travel time (scenario between 0 and 5)	20.3	22.7	23.3	21	3.1
<i>Sensory parameters</i>					
Comfort factor (scenario between 0 and 5)	38.7	30.3	31.6	35.9	14.9
Travel quality factor (scenario between 0 and 5)	27.5	24.8	26	19.6	10.4
Travel safety factor (scenario between 0 and 5)	24.6	30.9	28.8	31.9	15.3
Environmental impact factor (scenario between 0 and 5)	20.4	23.1	33.9	29.9	32.9

that there is no dataset of public transport or walking related to the parking time.

- (d) According to the results, after performing several trials with the MNL model specifications based on the sensitivity function of the waiting time variable within the transport mode, the coefficients are found insignificant in the transport mode; therefore, the coefficients of the waiting time are omitted from Table 9. This is an interesting result since the waiting time is usually valued more once compared to the in-vehicle travel time. Moreover, the reliability of the public transport is considered important by most public transport users. The passengers are adversely affected by the consequences of unreliability, such as additional waiting time, late or early arrival at the destinations, and missed connections, which increases their anxiety and discomfort. This needs further analysis with a more specific survey considering these parameters.
- (ii) The parameter estimates of the sensory parameters:
- (a) In current study, the comfort factor is tested as a crucial variable of the utility function within the sensory parameters. Most of the variables highlight this behavioral trend of the comfort factor explicitly. The findings show that the coefficients of the comfort factor are positive and highly significant indicating a preference for car use. Additionally, the coefficient of the comfort factor affects the metro mode to a great extent. The results demonstrate that some travelers need the vehicle to pick up the children from day-care or school as well as to perform other daily activities, where using a car means more comfort. This result is consistent with the findings of the research work conducted by [30].
- (b) The outcomes present that the travel quality significantly affects the transport mode choice in the sensitivity analysis. The travel quality positively impacts the mode choice except for the bike mode. Additionally, the results show that the travel quality has a higher impact on metro than on the other modes. According to the findings, the travelers prefer to travel by metro when they are looking for more travel quality.
- (c) The travelers' travel safety factor is tested regarding its role in the transport mode choice based on the sensitivity function. The coefficient of the travel safety influences the transport mode choice in case of car, bus/trolleybus, metro, and tram positively, while it impacts the bike mode negatively. The travelers consider public transport safer than traveling by car. According to the result, the bus mode is safer than the other modes. Therefore, the travelers prefer to travel by public transport more than using a car when performing their daily activities. The results match the outcomes of [33].
- (d) The findings show that the environmental impact factor affects the mode choice solely slightly. The environmental impact factor has a negative effect on the car and bus modes, but it influences the metro, the tram, and the bike modes positively. It is not considered a primary factor when the travelers select the transport mode (i.e., car, bus/trolleybus, metro, and tram). On the other hand, the environmental impact factor is essential when the travelers use bikes for traveling [59].

The paper uses the MNL model to analyze the travelers' sensitivity to various scenarios, to explain all the parameters affecting the travelers' mode choice, and to compare the physical and sensory parameters [29, 59]. The probability of the first scenario is related to the changes in the travel cost of a car or the travel time of the public transport. Afterward, the comfort factor of the modes (i.e., bus/trolleybus, metro, tram, and bike), the travel quality factor, the travel safety factor, and the environmental impact factor of the modes are changed, as presented in Table 10.

Table 10 shows the probability of the two scenarios, which influence the physical or sensory parameters on the transportation choice probabilities. When the travel cost is altered, the changes in the likelihood of using a car are larger than that for the other modes indicating that the travelers are more sensitive to the attributes related to the travel cost. The travelers are more susceptible to the changes in the physical parameters than in the sensory parameters in case of traveling by car, bus/trolleybus, metro, tram, or bike [37].

The effects of the travel cost, travel time, comfort factor, travel quality, travel safety, and environmental impact on the transport mode choice based on the two scenarios are demonstrated in Figures 1–6. The horizontal axis shows the

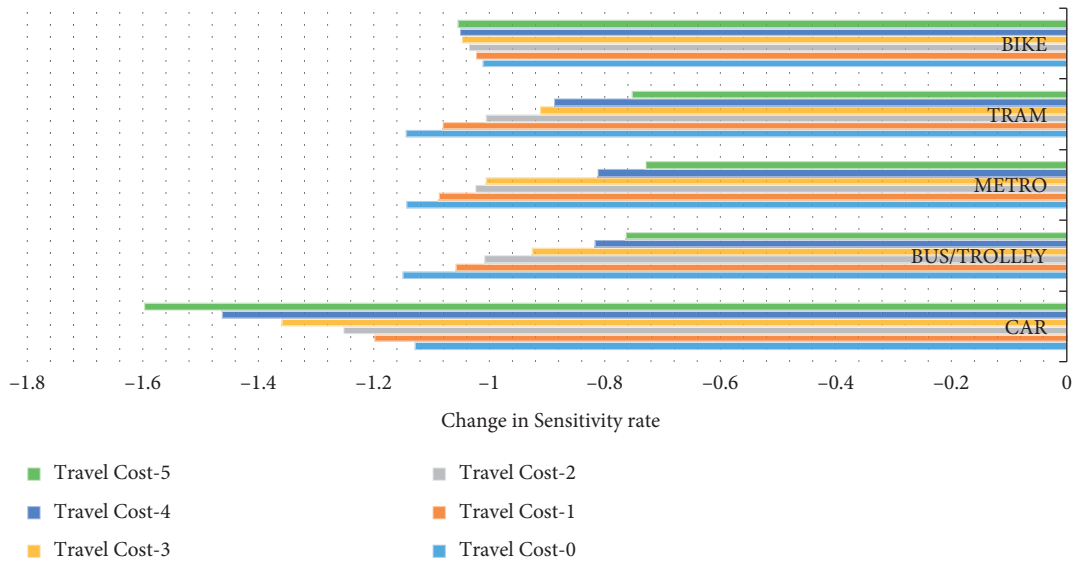


FIGURE 1: The values of the coefficients based on the changes in the travel cost.

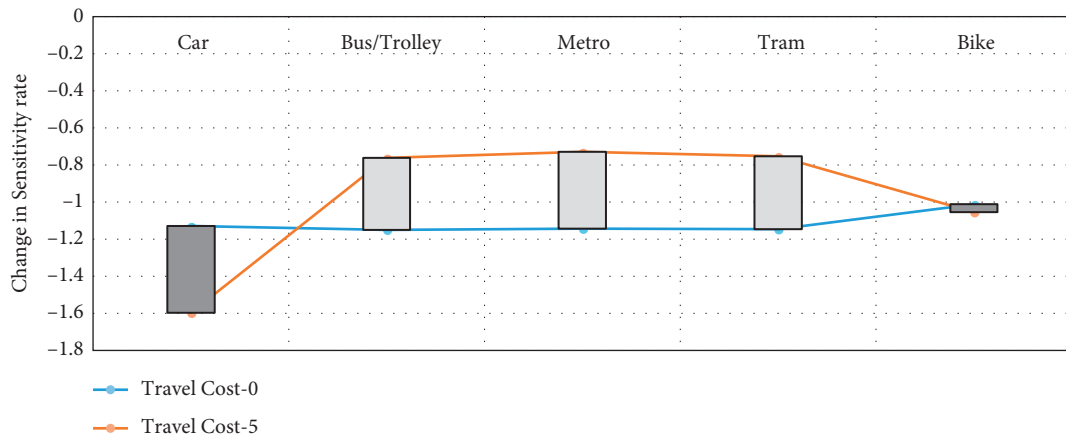


FIGURE 2: A comparison between the coefficients of the mode choice based on changing the travel cost.

values of the coefficients. According to the results of the scenarios, a shift occurs primarily from the car to other modes in case of changing the travel cost, travel time, and comfort factors. A slight shift from the car to the different modes occurs as a result of altering the environmental impact factors. The higher travel costs during peak hours attract more people to use public transport instead of the car mode, and the increased travel costs encourage people to change their transport modes.

5.5. The Parameter Estimates of the Physical Parameters.

The first scenario shows an increase of the physical parameters (i.e., travel cost and travel time) by a different rate (i.e., 10%, 20%, 30%, 40%, and 50%) [11]. As expected, the results of the scenario demonstrate that the choice probability of using a car decrease by a rate of 41.3% in case of increasing the travel cost by 50%. On the other hand, the choice probability of the bus/trolleybus, metro, and tram modes increases by 33.6%, 36.3%, and 34.2%, respectively, as shown in Table 10.

- (i) Figure 1 demonstrates the scenarios (i.e., 1– 5) of the travelers’ sensitivity to the transport mode choice (i.e., car, bus/trolleybus, metro, tram, and bike) based on the changes in the travel cost (in case of the car mode), which belongs to the physical parameters. In the first scenario, the travel cost of a car is raised from 10% to 50% of the value of the travel cost while all the other variables are kept at the same value. As a result, from scenario 1 to scenario 5, the probability of using a car decreases. However, the likelihood of traveling by public transport (i.e., bus/ trolleybus, metro, and tram) increases. To conclude, the travelers have the highest sensitivity to the changes in the expense-cost, which might trigger a modal shift from the car to the public transport mode. The travelers are more sensitive to the changes in the cost, they have stronger intentions and more inclined to choose public transport.
- (ii) Figure 2 presents the scenarios (i.e., 0–5) of the travelers’ sensitivity to choose a transport mode based on the change in the travel cost (in case of the

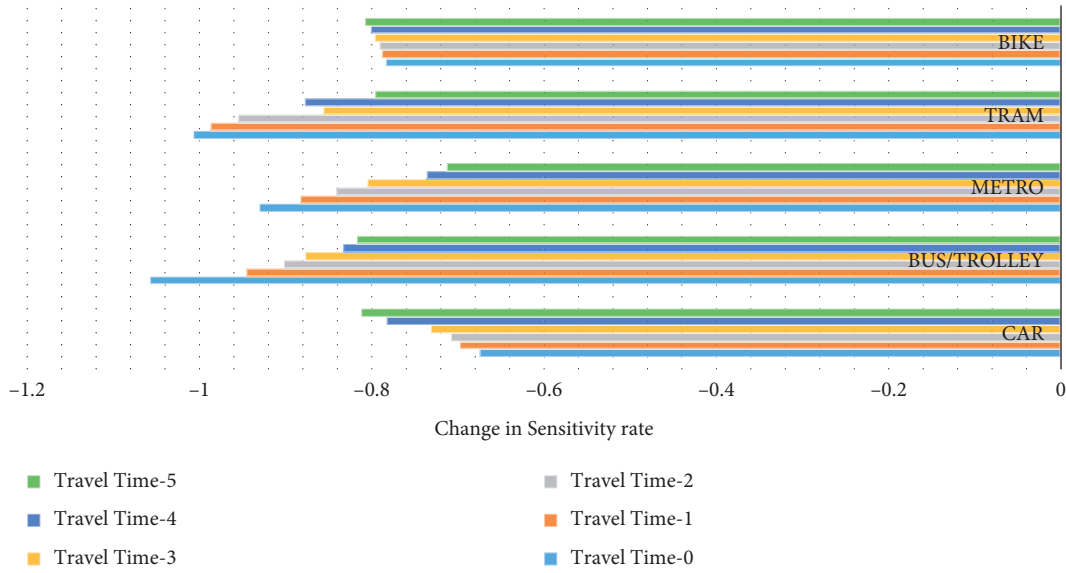


FIGURE 3: The coefficients values based on the changes in the physical parameter of the travel time.

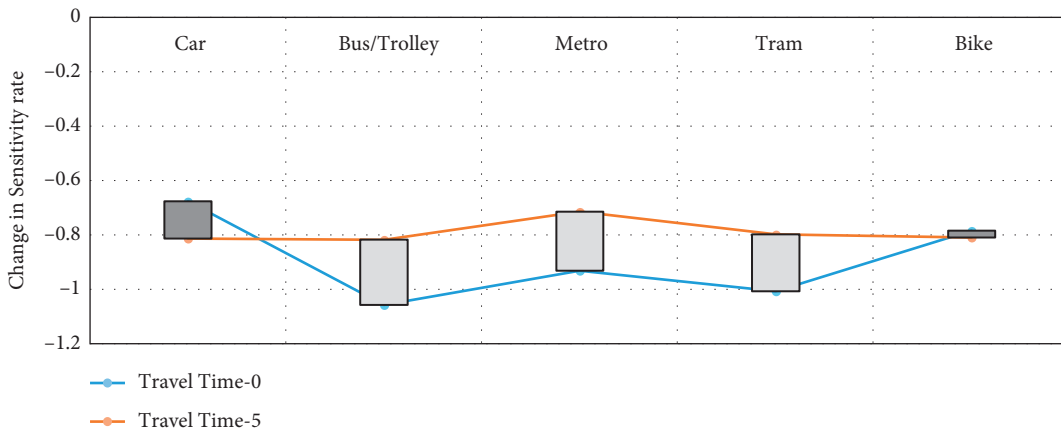


FIGURE 4: A comparison of the coefficients of the mode choice based on changing the travel time.

car mode), which belongs to the physical parameters. The results show that when the travel cost of a car increases, the probability of using a car decreases. On the other hand, the likelihood of traveling by public transport (i.e., bus/trolleybus, metro, or tram) increases.

(iii) Figure 3 shows the results of the sensitivity analysis based on the changes in the travel time of the different scenarios in case of the car, bus/trolleybus, metro, tram, and bike modes. The study uses various scenarios (i.e., from 1 to 5) of the travelers' sensitivity based on the changes in the travel time, which is a physical parameter. In the second scenario, the travel time of the public transport is raised from 10% to 50% of the value of the travel time while all other variables have the same values. The outcomes demonstrate that from scenario 1 to scenario 5, the likelihood of traveling by public transport (i.e., bus/trolleybus, metro, or tram) decreases but with a median value. On the other hand, the probability of driving a car rises at a medium rate. The conclusion is

that the travelers have low sensitivity to the changes in the travel time. Moreover, the travelers have a low sensitivity to the changes in the travel time once compared to the alteration of the travel cost. A decreased usage of public transport means that a lot of travelers are not encouraged to move from the car mode.

(vi) Figure 4 indicates the scenarios (i.e., 0 and 5) of the travelers' sensitivity to the transport mode choice based on the changes in the travel time (i.e., in case of public transport), which belongs to the physical parameters. The findings show that when the travel time of the public transport (i.e., bus/trolleybus, metro, and tram) decreases, the likelihood of traveling by public transport rises. On the other hand, the probability of using a car is less.

5.6. *The Parameter Estimates of the Sensory Parameters.* The second scenario shows an increase in the sensory parameters (i.e., comfort factor, travel safety, travel quality, and

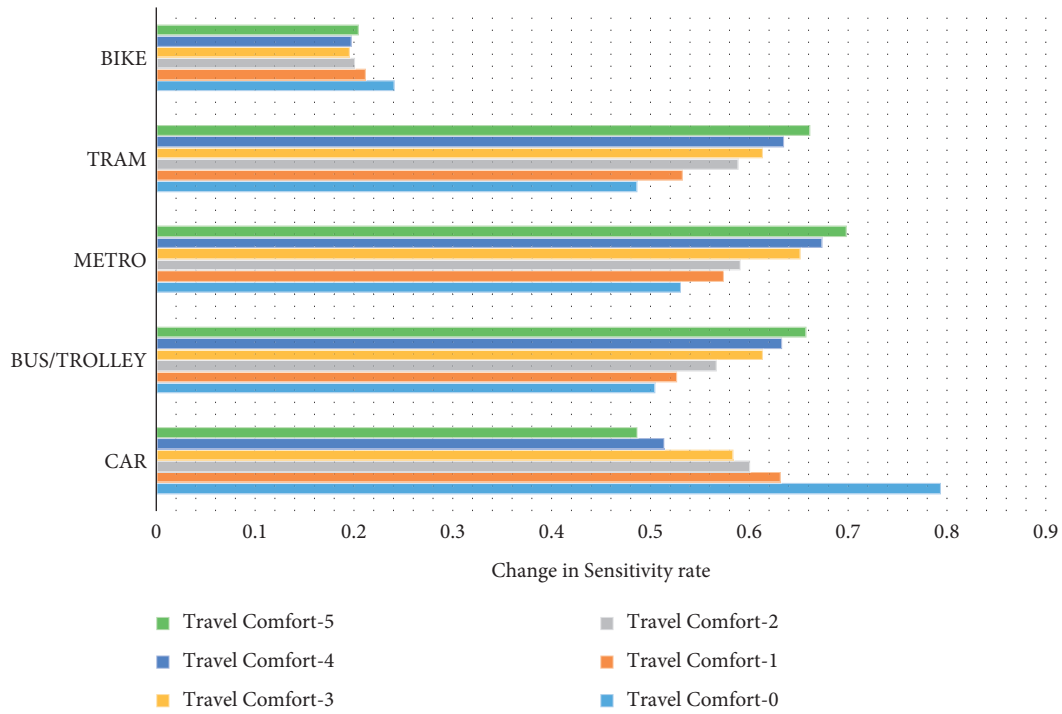


FIGURE 5: The values of the coefficients based on changing travel comfort.

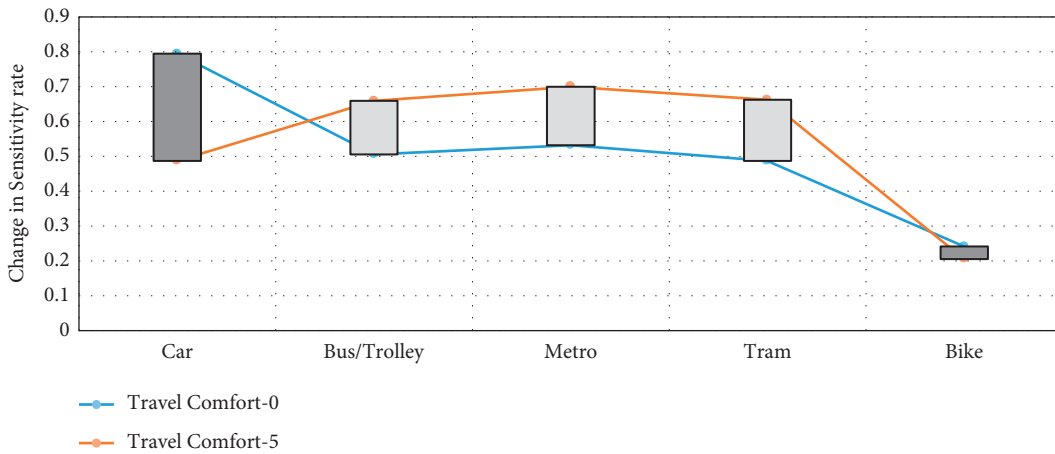


FIGURE 6: A comparison between the coefficients of the mode choice based on changing the comfort factor.

environmental impact factor) of the bus/trolleybus, metro, tram, and bike modes by various rates (i.e., 10%, 20%, 30%, 40%, and 50%). As expected, in Table 10, the scenario results demonstrate that the choice probability of a car decreases as there is an increase in the sensory parameters. It is especially true with the comfort factor, which has a high effect on the transport mode choice compared to the other modes.

- (i) The results in Figure 5 demonstrate the outcomes of the sensitivity analysis when changes in the comfort factor appear. Different scenarios are used to reveal the transport mode choice. The study examines various scenarios (i.e., from 1 to 5) of the analysis based on the changes in the comfort factor, which is a sensory parameter of public transport. In the

second scenario, the comfort factor of the public transport is raised from 10% to 50%. The other variables keep the same values. As the results indicate, from scenario 1 to scenario 5, the likelihood of choosing public transport (i.e., bus/trolleybus, metro, or tram) increases but with a median value. On the other hand, the probability of using a car decreases at a medium rate. It is concluded that the travelers have sensitivity to the changes in the comfort factor to a lower extent once compared to the cases of the travel cost or travel time. Moreover, the travelers have medium sensitivity to the changes in the comfort factor. With increasing the comfort factor in the public transport, a medium rate of travelers moves from the car to the public transport mode.

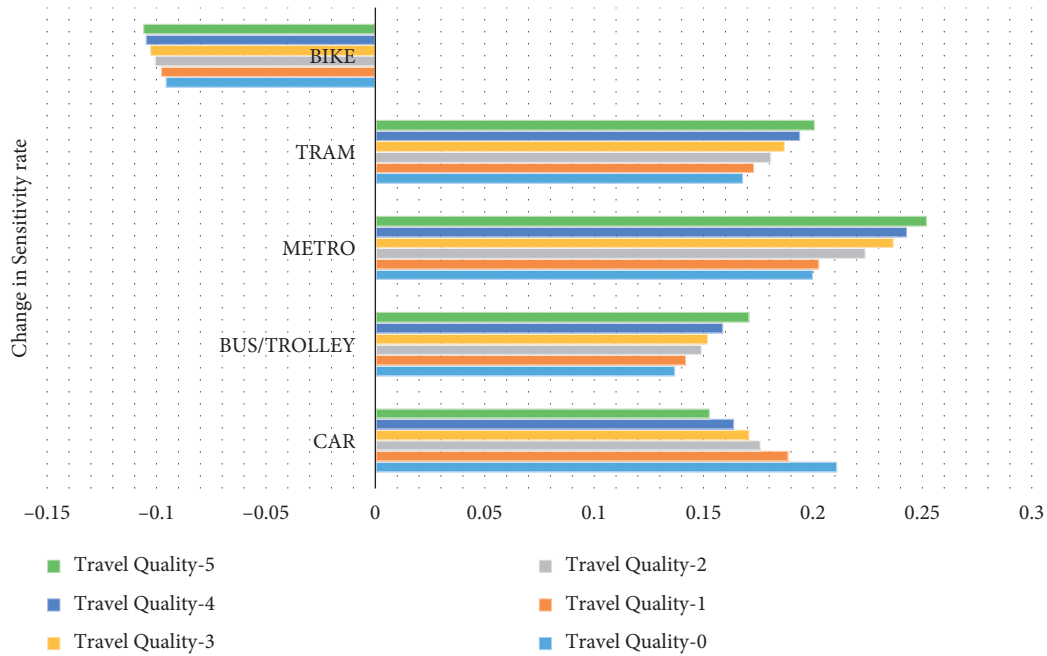


FIGURE 7: The values of the coefficients based on the changes in travel quality.

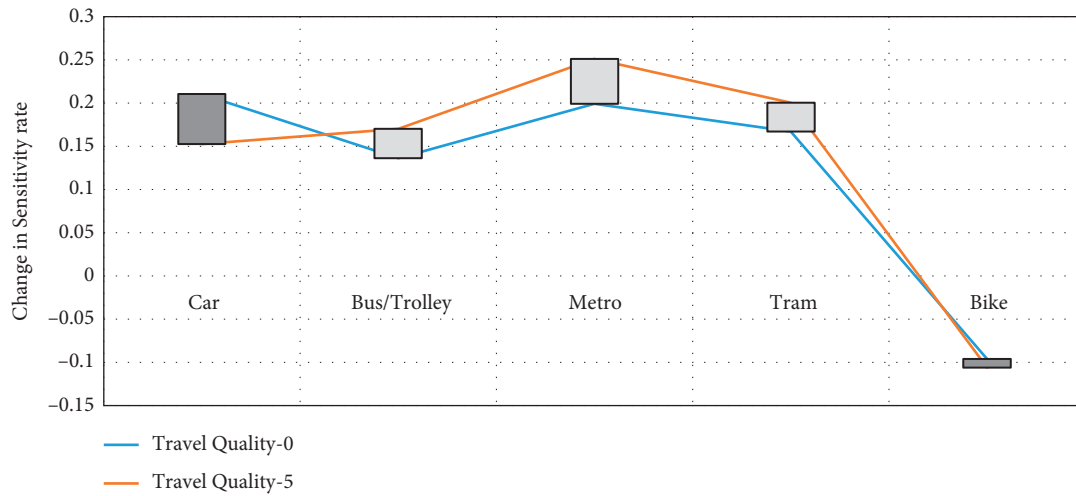


FIGURE 8: A comparison between the coefficients of the mode choice based on changing travel quality.

- (ii) Figure 6 shows a comparison between scenarios 0 and 5 demonstrating the travelers' sensitivity to the transport mode choice based on the changes in the comfort factor (i.e., in case of public transport), which belongs to the sensory parameters. The outcomes present that when the comfort factor of the public transport mode (i.e., bus/trolleybus, metro, and tram) increases, the likelihood of traveling by public transport increases, as well. This result is confirmed as a higher level of comfort factor on the public transport vehicles pushes more people to travel by bus/trolleybus, metro, or tram. Moreover, the probability of using a car decreases.
- (iii) The results of Figure 7 present the findings of the sensitivity analysis when changes in the travel

quality appear. The outcomes of the scenarios 1–5 indicate that the probability of traveling by public transport (i.e., bus/trolleybus, metro, or tram) shows an increasing tendency but with a low value, except for the case of the metro which rises with a medium rate. The probability of driving a car decreases at a low rate. The conclusion is that the travelers have low sensitivity to the alteration in the travel quality compared to the changes in the travel cost or travel time. As a result, the travel quality has a low effect on the decision-making regarding the transport mode.

- (iv) Figure 8 shows a comparison between scenarios 0 and 5 presenting the sensitivity analysis regarding the transport mode choice based on the changes in

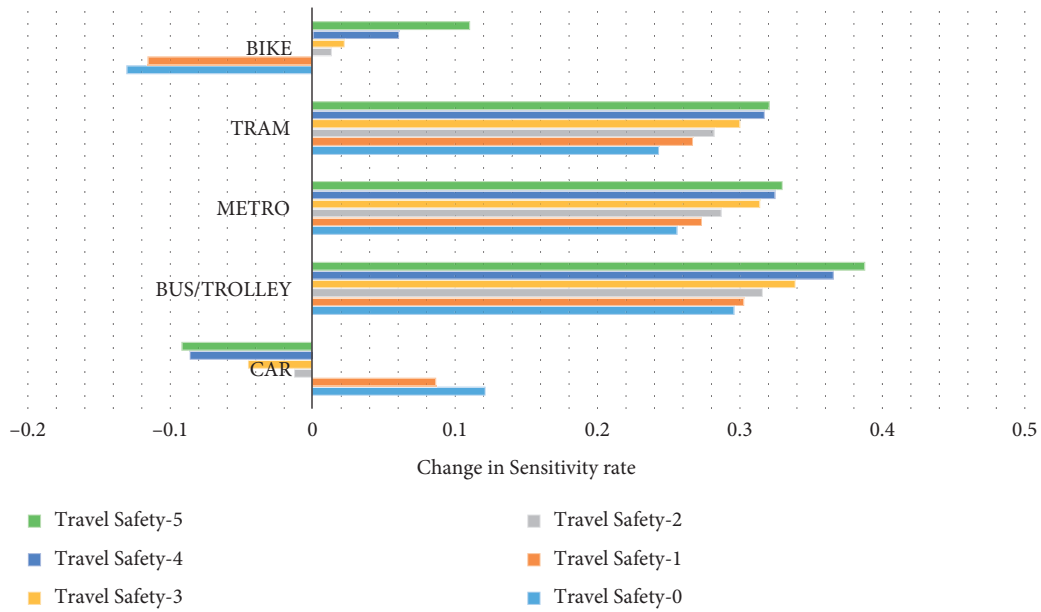


FIGURE 9: The values of the coefficients based on the changes in travel safety.

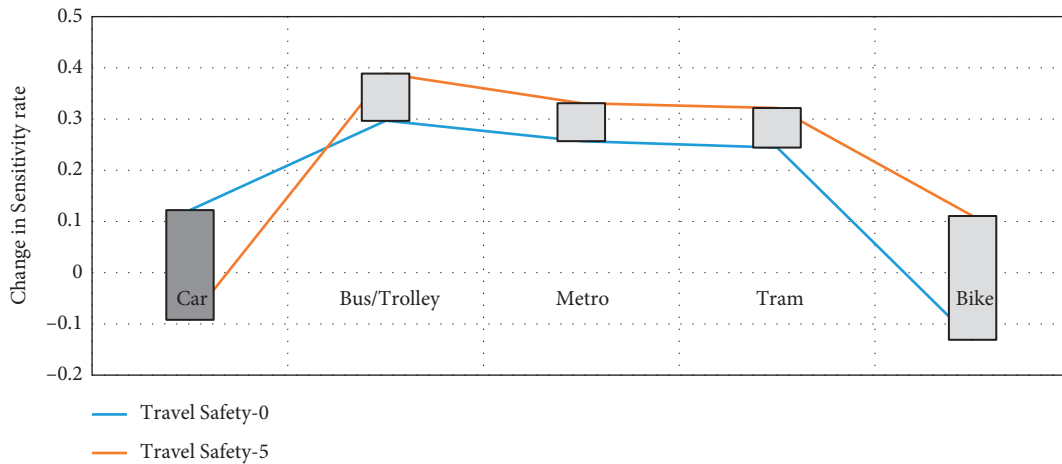


FIGURE 10: The comparison between the coefficients of the mode choice based on changing travel safety.

the travel quality of the public transport, which is a sensory parameter. As the findings reveal, when the travel quality of the public transport (i.e., bus/trolleybus, metro, and tram) increases, the likelihood of traveling by public transport rises as well. This result is confirmed as the increase of the travel quality on public transport vehicles encourages more people to use the bus/trolleybus, metro, or tram modes. It is especially true for the metro. On the other hand, the probability of using a car decreases.

- (v) As seen in Figure 9, for the car, bus/trolleybus, metro, tram, and bike modes, the scenarios (i.e., 1–5) of the sensitivity analysis on the transport mode choice are based on the changes in the travel safety factor of the public transport (i.e., bus/trolleybus, metro, and tram), which belongs to the sensory parameters. In this scenario, the travel safety factor of each mode (i.e., bus/trolleybus,

metro, tram, and bike) is raised by 10%, 20%, 30%, 40%, and 50%, and all other variables are kept with the same values. As the results show, the probability of choosing the public transport when the travel safety factor is increased rises but with low value. On the other hand, the probability of using a car decreases. In conclusion, the travelers have less sensitivity to the changes in the travel safety factors. The increase in the travel safety factor does not trigger more people to use public transport, but it improves the satisfaction with the public transport services.

- (vi) Figure 10 demonstrates a comparison between scenarios 0 and 5 of the sensitivity analysis regarding the transport mode choice based on the changes in the travel safety factor of the public transport. As the findings show, when the travel safety of the public transport (i.e., bus/trolleybus, metro, and tram) increases, the likelihood of

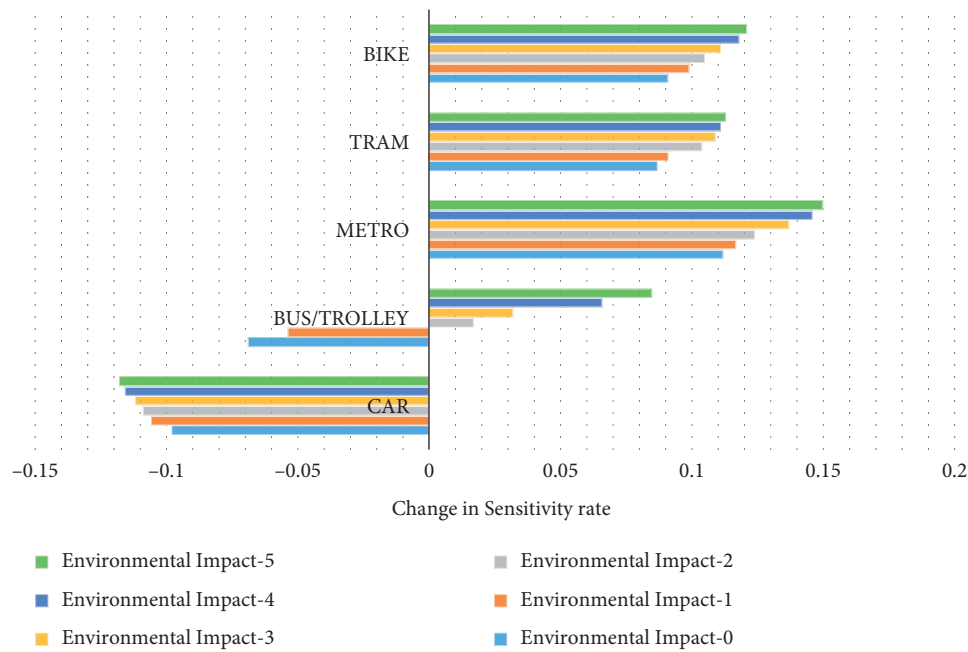


FIGURE 11: The values of the coefficients based on the changes in the environmental impact.

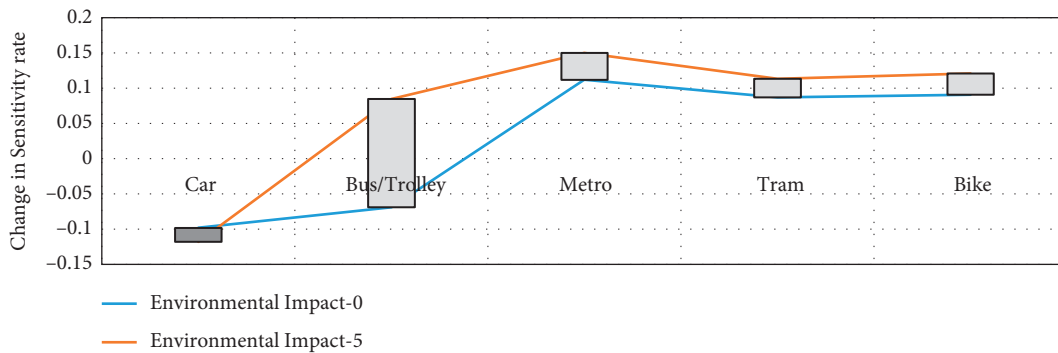


FIGURE 12: The comparison between the coefficients of the mode choice based on the changes in the environmental impact.

traveling by public transport rises, too. Additionally, for the bike mode, when the travel safety improves, such as by establishing more bike paths, more people choose the mode. On the other hand, the probability of using a car clearly decreases.

(vii) As presented in Figure 11, the scenarios (i.e., 1–5) of the sensitivity analysis regarding the transport mode choice are based on the changes in the environmental impact factor. In this scenario, the environmental impact factor of each mode (i.e., bus/trolleybus, metro, tram, and bike) is raised by 10%, 20%, 30%, 40%, and 50% of the value of the environmental impact factor, while the other variables are kept with the same values. According to the findings, based on the rise of the environmental impact factor of the public transport (i.e., bus/trolleybus, metro, and tram), the probability of using the mode increases but with a low value, except for the metro which grows with a medium rate. On the other hand, the probability to use a car

decreases. To conclude, the travelers have less sensitivity to the changes in the environmental impact factor. The results indicate that many people do not consider the environmental impact factor when choosing the mode of travel.

Figure 12 shows a comparison between scenarios 0 and 5 of the sensitivity analysis with the changes in the travel environmental impact factor of public transport. As the findings demonstrate, when the environmental impact is increased, the likelihood of traveling by public transport (i.e., bus/trolleybus, metro, and tram) rises. It is especially true for the bus/trolleybus mode.

In Figure 13, the results of using the sensitivity analysis to estimate the value of the coefficients of the parameters regarding the transport mode choice (i.e., car, bus/trolleybus, metro, tram, and bike) are presented. The findings compare the scenarios (i.e., 0 and 5) and compare the physical and sensory parameters based on the changes in the parameters. The outcomes show that the physical parameters affect the transport mode choice more significantly than the

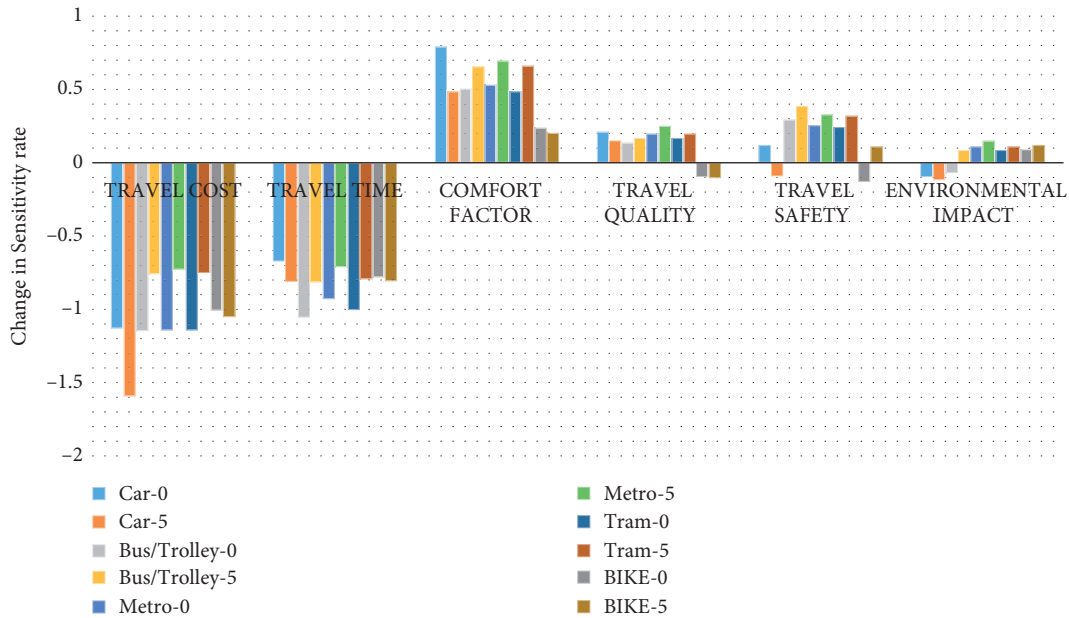


FIGURE 13: Comparisons between the physical and sensory parameters of the mode choice based on the first and the fifth scenarios.

sensory parameters. Additionally, the results indicate that the travel cost, travel time, and comfort factors have an impact on the parameters more than others.

The results of the scenarios lead to the improvement of the public transport services. The research aims to encourage travelers to use public transport during peak periods. Transportation planners should increase the travel cost for using cars, decrease the travel time of public transport, and improve public transport services. Additionally, the study aims at reducing car use and the traffic congestion during the peak periods. As estimated, the results of Table 10 and Figure 13 show that the physical parameters play an important role in deciding on the transport modes.

For example, a policy allowing increased travel costs, which decreases the travel time of the public transport, reduces the peak demand for cars. Additionally, to improve the environment, converting some existing parking areas to bicycle and pedestrian facility areas is likely to encourage more travelers to make walking and cycling trips. This is especially true for those travelers whose residential locations are not far away from their workplaces. At the same time, most transportation congestion management actions attempt to encourage a change in the transport mode choice away from cars to reduce the number of trips during the peak periods by directly or indirectly influencing the level-of-service variables.

6. Conclusion

The paper aims to investigate the trip parameters regarding the transport mode choice by using a sensitivity analysis. The current research work shows that sensitivity analysis plays an essential role in transportation planning measuring the travelers' sensitivity regarding the travel parameters. Changing the value of a specific trip parameter alters the structure of the transportation system due to the impacts on

the travelers' behavior. However, significant changes in the behavior do not occur for all parameters. According to the results, travelers present different sensitivities regarding the trip parameters and the various transport modes. At the same time, the sensitivity analysis indicates that the travelers' reaction to the trip parameters does not change proportionately.

In this paper, the travelers' sensitivity to the changes in the travel utility of the trip parameters are considered as an essential factor influencing travel behavior. A utility function is established based on the sensitivity analysis by using the travel behavior survey data. To explore the heterogeneity of the travelers' mode choice behavior, the trip parameters are grouped into two types: physical and sensory parameters. These parameters include the travel time, travel cost, parking time, waiting time, comfort factor, travel quality factor, travel safety factor, and the environmental impact factor. A comparison is made between the parameters. Finally, various transportation management policies are proposed for the different types of travelers by making scenarios. The results show the followings:

- (1) The travelers' sensitivity to the changes in the travel utility related to the alteration of the values of the trip parameters make a significant impact on the mode choice intention and mode choice behavior.
- (2) The effects of the travel cost and comfort factors on the transport mode choice is major regarding the travelers' sensitivity to the utility difference between the modes.
- (3) The influence of the environmental impact factor in choosing the transport mode is secondary in the travelers' sensitivity to the utility difference between the modes.
- (4) Reducing the travel time has an advantageous effect on the travelers' intention to use public transport.

The outcomes of the presented hypotheses are evaluated.

Based on the results, it can be stated that the travel time and the travel cost are the most significant physical parameters which influence the transport mode choice, while the parking time and the waiting time do not show such significant effects. Furthermore, the comfort, travel quality, and the travel safety factors are the most significant sensory parameters affecting the transport mode choice, while the environmental impact factor do not show such a significance.

The results demonstrate the followings:

- (i) The travelers' decision-making should be the main object of the priority development strategies for public transport and economic leveraging.
- (ii) The travelers focus on the travel cost, comfort, and travel time; thus, improvements regarding these parameters should be the main targets of the development strategies and the travel strategies.
- (iii) For cost-sensitive travelers who often use public transport, a priority development strategy of public transport could be adopted to stabilize this type of transportation by increasing the accessibility and by establishing new lines to reduce the travel time and cost, which triggers the private vehicle users to switch to public transport.
- (iv) To move to more sustainable transport modes, travelers can be guided in two ways: by controlling the private transportation and by prioritizing the development of the public transport.

In conclusion, the sensitivity analysis is an essential tool in the model-building process, which shows that the transportation system reacts significantly to the changes in the parameter values. Moreover, it allows a better understanding of the travelers' behavior, as well. Future research can focus on the evolution of the travelers' mode choice behavior by using such advanced models as the Monte Carlo model or the probit models. At the same time, the influence of other various variables can be studied. Finally, the current study leads to the development of a micro-simulation-based prototype of the mode demand model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The research reported in this paper is part of the project no. BME-NVA-02 implemented with the support provided by the Ministry of Innovation and Technology of Hungary from the National Research Development and Innovation Fund, financed under the TKP2021 funding scheme. This paper was supported by the János Bolyai Research Scholarship of

the Hungarian Academy of Sciences (BO/00090/21/6). The linguistic revision of the current paper is prepared by Eszter Tóth.

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