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APPLICATION OF NEURAL NETWORKS IN ASSESSING THE IMPACT OF MICROMOBILITY ON ENVIRONMENTAL POLLUTION

Keywords
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Abstract

Constant increase of passenger cars usage in urban area has numerous negative social and economic effects. More and more often, road traffic is the leading source of negative impacts on the environment. In order to solve the problems of environmental pollution caused by road traffic, without imposing mobility restrictions, alternatives to vehicles with combustion engines are often proposed. The results of numerous studies indicate that micromobility vehicles can have a significant impact on reducing environmental pollution, if, in addition to emissions of pollutants and noise, the source of electricity and the process of their production are taken into account. Bearing in mind the above, the aim of this paper is to analyze the influence of micromobility vehicles on environmental pollution, as well as to analyze the acceptability of the use of this type of mobility by the public. In addition to the descriptive statistical analysis, the methods of artificial neural networks and Naive Bayes were applied in order to evaluate the impact of micromobility vehicles on environmental pollution. The obtained results indicate that in addition to the fact that micromobility vehicles can have a significant impact on environmental pollution, they can also contribute to changing modal shift. A comprehensive analysis can be a useful basis for decision-making when defining strategies for reducing environmental pollution.

1. INTRODUCTION

The increased use of internal combustion passenger cars and their growing number contribute to dependence on fossil fuels and exhaust gas emissions [1,2]. The majority of greenhouse gas emissions from transportation are carbon dioxide (CO_2) emissions that result from the combustion of petroleum-based fuels, such as gasoline and diesel fuel, in internal combustion engines [3].

For decades, various strategies have been proposed to reduce the emission of polluting substances, among which are the redistribution of surface uses, the promotion of more energy-efficient and environmentally sustainable vehicles [4]. In this regard, the use of electric microvehicles is often proposed as one of the possible solutions for reducing environmental pollution, taking into account their characteristics and the possibility of solving the first and last kilometer problem [5,6].

Microvehicles, such as e-scooters, e-bikes, and e-mopeds, do not emit or have limited direct CO_2 emissions into the air, making them sustainable and more environmentally friendly than other forms of transport. Namely, zero emissions of pollutants from vehicle exhaust pipes, such as carbon dioxide, can be achieved by using electricity from renewable sources [7,8]. Also, as an important impact on the environment, the production process of microvehicles can be highlighted, including the material from which both the vehicle and its battery are made. In this regard, many conducted studies indicate that the production process can contribute to a much greater extent to environmental pollution (over 50% of the total emissions), especially in the case of the use of materials such as extracted raw materials (steel, aluminum, etc.) [9]. However, this is not the case if recycled materials are used for the production of vehicles and batteries, which can reduce the negative impact on the environment.

In addition to the above, the use of microvehicles, which has experienced expansion in the past few years, has replaced movements that were previously realized by some other type [10]. Bearing in mind that in most cases walking is the type of movement that is most replaced by the use of microvehicles, it is evident that pollutant emissions will increase in that case. For this reason, during the implementation of such a transport subsystem, it is necessary to motivate as many users as possible to replace the movement with a passenger car, for some of the types of microvehicles with electric drive. Bearing in mind the above, the goal of this paper is to analyze the impact on the acceptability of the use of this form of mobility by the residents of Belgrade. The paper will present the analysis of the data obtained from the research, as well as the accuracy and precision of the machine learning model in predicting the acceptability of microvehicles. The obtained results of the artificial neural networks (Multilayer Perceptron) and Naive Bayes models can represent a useful basis for decision-making when defining strategies for reducing environmental pollution.

2. APPLIED METHODOLOGY

2.1. Data Description

Data on users' attitudes were collected through an online survey in the period from April 2023 to May 2023. The questionnaire combined questions about revealed preferences, related to existing habits in daily movement and attitudes about environmental pollution by road vehicles. In addition, we asked about the stated preference, to analyze the attitude of the respondents on the acceptability of using microvehicles from an ecological aspect. The survey was sent to residents and users of the territory of Belgrade, 20 km from the roundabout on Square Slavija. After incomplete questionnaires with illogical answers were removed from the total sample, the valid sample used in the further analysis consisted of 302 respondents.

Survey data were analyzed using IBM SPSS 22 and Weka software. In this paper, using IBM SPSS 22 software, data analysis was performed using the standard method of descriptive statistics. The specialized software tool Weka (Waikato Environment for Knowledge Analysis) was used to predict the output data and evaluate the most influential factors on the acceptability of the use of microvehicles. For this work, after entering the collected data from the survey, the Multilayer Perceptron and Naive Bayes algorithms were used for training.

2.2. Model development

Weka software was used to develop the two models. Based on the set of data collected from the questionnaire, the development of the Multilayer Perceptron (MLP) and Naive Bayesian (NB) models are approached. The MLP algorithm consists of a perceptron that computes a single output (y) from multiple inputs (x_i), creating a linear combination based on their input weights (w_i). Adding noise (b) affects the increase of the weighted sum of the input, which is shown by formula (1).

$$y = f\left(\sum_{i=1}^{n} x_i w_i + b\right) \quad (1)$$

On the other hand, the Naive Bayes model represents a simple probabilistic classification model that relies on Bayes' theorem. In this regard, the model implies that the attributes are conditionally independent of each other and that each attribute contributes equally to the final decision. Taking into account the above, the output value of the algorithm v_{NB} is obtained by formula (2), where V represents the final set of input values, and its individual members are marked with v_j. Based on the definition, it is possible to calculate the product of individual attributes $P\left(a_i \middle| v_j\right)$.

$$v_{NB} = argmax_{v_j \epsilon V} P(v_j) \prod_i P\left(a_i \middle| v_j\right) \quad (2)$$

In this regard, in this paper, supervised (MLP) and unsupervised (NB) machine learning was applied to the available data set, with the aim of obtaining a prediction of the target variable, i.e., acceptance of the use of microvehicles from an environmental point of view. The datasets within the MLP and NB models are randomly divided into two subsets, for training and testing. The training dataset made up 70%, while the testing set made up the remaining 30% of the data, in the case of both models. The parameters related to the learning speed are assumed values and amount to "Learning Rate = 0.3" and "momentum = 0.2". Data are normalized based on its properties and classes. Also, when it comes to the number of epochs intended for training and the training process, it is 500, as assumed in the Weka software.

During the development of the model, 27 attributes were defined, which are considered to be important in terms of assessing the respondents' attitudes when accepting the use of microvehicles. The first 5 attributes refer to the sociodemographic characteristics of the respondents, then the next 16 refer to the characteristics of movement, while the last group of attributes includes reasons that influence the attitude of the respondents towards not using microvehicles. All attributes represented artificial neurons within the input layer of the MLP model, as well as the input attributes of the NB model. Also, the output layer of the MLP model, which was related to the question of the acceptability of the use of microvehicles, consisted of two neurons, which represented the answers "Yes" and "No", while the hidden layers were automatically defined by the Weka software. On the other hand, within the NB model, the mentioned answers represented classes during the process of classifying the output values of the algorithm. After the learning or training process is performed, the resulting data can be predicted within a data set in which there is no output data. Namely, in the data set for testing (30%), instead of the output data ("Yes" and "No"), the sign "?" was defined, with the aim of predicting the acceptability of the use of microvehicles.

3. RESULTS

3.1. Sample characteristics

The study included 302 participants. Of the total number of participants, 51.99% were men, and 48.01% were women. When it comes to the age category, the most represented category was respondents aged 18 to 25 (49.3%). They are followed by those aged 46-55 (15.6%) and those aged 26-35 (14.6%). Of the total number of respondents who believe that measures should be taken to reduce environmental pollution (257), 10.5% use one of the offered types of microvehicles (electric bicycle (17), electric scooter (12), and electric moped (1). The remaining 89.5% do not use these vehicles for their movement and they were considered in further analysis to predict acceptability. Of the 89.5% of respondents, 72.8% would change their attitude and accept the use of microvehicles, while the other 16,7% would not. Respondents who would agree to use microvehicles from an environmental point of view, most often move by motorized means and on foot. Observing daily movements with the purpose of going to work and for other purposes, respondents mostly use passenger cars (26.6% and 30.3% respectively), public transport (34.0% and 29.2% respectively) and walking (30.5% and 32.8% respectively). By replacing passenger cars with some types of microvehicles, it would significantly affect both the reduction of environmental pollution and the problem of traffic congestion.

3.2. Experimental results

Before displaying the results, the Weka software indicates the time required to build and test the model on the training data. In this regard, the MLP model requires more time, i.e. 14.12s for the creation and 0.02s for testing the model, compared to the NB model (0.00s and 0.01s respectively).

By comparing the performance of the algorithms regarding the accuracy of classification of instances during data training, it can be seen that the MLP algorithm gives better results (98.76%) compared to the NB algorithm (88.2%) (Table 1). Comparing other statistical parameters, it can be concluded that the values of the Kappa statistic indicate that the MLP algorithm has an almost perfect agreement with the existing data. The error results (MAE, RAE, and RRSE) indicate that the MLP algorithm has better prediction accuracy results compared to the NB algorithm. Nevertheless, the NB algorithm shows relatively good prediction accuracy results, especially in terms of the RMSE error, in which it is the only one better than the MLP algorithm.

Table 1. Statistical analysis of classification algorithm models

Statistical parameter	Classification algorithm	
	Multilayer Perceptron	Naïve Bayes
Correctly Classified Instances	98.76 %	88.199%
Incorrectly Classified Instances	1.24 %	11.80%
Kappa statistic (KS)	0.954	0.512
Mean absolute error (MAE)	0.015	0.1596
Root mean squared error (RMSE)	0.112	0.301
Relative absolute error (RAE)	5.34%	56.62%
Root relative squared error (RRSE)	29.86%	80.68%

In addition to the above, as another type of model performance analysis, the accuracy of the classification of output values is checked. The obtained values in Table 2 indicate that the values of the MLP algorithm are close to "perfect" class prediction. While the parameter values of the NB algorithm lie on the borderline between very poor and perfect prediction. As the ROC Area value is one of the most important for defining the quality of the classification algorithm, it is required that its value be as close as possible to 1. In this regard, the MLP and NB models have very good ROC Area values (0.94 and 0.91 respectively), which indicates the significant quality of their classification.

Table 2. Classification parameters of MLP and NB models

Alg.	TP	FP	Precision	Recall	F1	MCC	ROC	PRC	Class
MLP	1.00	0.07	0.99	1.00	0.99	0.96	0.94	0.97	Yes
NB	0.96	0.52	0.90	0.96	0.93	0.52	0.91	0.98	No
MLP	0.93	0.00	1.00	0.93	0.96	0.96	0.94	0.94	Yes
NB	0.48	0.04	0.72	0.48	0.58	0.52	0.91	0.64	No
MLP	0.99	0.06	0.99	0.99	0.99	0.96	0.94	0.97	**Weigh. Avg.**
NB	0.88	0.44	0.87	0.88	0.87	0.53	0.91	0.92	

In addition to the above, a confusion matrix is used as another way of checking the performance of the algorithms regarding their classification of instances into the "Yes" and "No" classes. Table 3 presents a 2x2 confusion matrix, the dimension of which depends on the number of responses. The gray fields indicate the correctly classified answers of the respondents, while the white fields indicate the incorrect ones.

Table 3. Confusion matrices of MLP and NB algorithms

		Multilayer Perceptron		Naïve Bayes	
		Existing values			
Sample	**Estimated values**	Yes	No	Yes	No
Training data	Yes	134	0	129	5
	No	2	25	14	13

The obtained results indicate that both models have a greater number of correctly classified values, so it can be concluded that they are properly trained and therefore function correctly. Also, it is evident that the MLP model performs a more accurate classification compared to the NB.

After the analysis of the results obtained after the training of the data, the analysis of the prediction of the data concerning the acceptability of the use of the microvehicle is approached. The prediction result from both algorithms indicates that they almost equally accurately predicted and classified "Yes" and "No" responses for the observed cases. Namely, out of 69 instances, the MLP algorithm correctly predicted the values for 51 instances, while the NB algorithm correctly predicted the values for 50 instances.

At the very end, within the framework of the MLP algorithm, an analysis of the weight coefficients of the model can be performed. During the training of the network itself, the weights of the branches are constantly recalculated, so that at the end of the training process, the weights of the branches converge to certain values. In this regard, the acceptability was significantly influenced by the respondents for whom a significant reason for not using a microvehicle (No) is safety (0,49), then also those who never move on foot for other purposes (entertainment/recreation/shopping)

(0,48). On the other hand, respondents aged 46-55 (-0,62), as well as those who walk every day with the aim of going to work (-0,46), had the least impact on output values.

4. CONCLUSION

The increasing use of vehicles with an internal combustion engine, results in increasing environmental pollution, with the emission of polluting particles and noise. In this regard, the use of microvehicles is often proposed as one of the possible solutions for reducing environmental pollution. Having that in mind, the focus of this paper was on the analysis and prediction of the acceptability of the use of microvehicles in order to reduce environmental pollution. The research results indicate that the residents of Belgrade have a positive attitude towards the use of these vehicles, which was successfully predicted by the MLP and NB model developed in this paper. It is important to point out that the MLP model has higher sensitivity, specificity and prediction accuracy than the NB model. In addition, using the MLP model it was possible to determine which attributes have the most influence on the acceptability of microvehicles, such as movement characteristics and reasons for not using them.

Future research directions should be aimed at increasing the number of research participants, with the application of both proposed models, in order to help decision makers when implementing a system of one of the types of microvehicles from an ecological aspect.

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