Identifying the Urban Development Pattern of Subway Cities Using Predictive Analysis

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Abstract: Starting from the hypothesis that there are structural differences in urban development between cities that have implemented underground transport and those that have not, the paper aims to provide a predictive analysis model to identify cities that show the pattern for the development of the subway network. In order to identify the predictive analysis model capable of classifying urban settlements, the predictive analysis part consisted of two stages. In the first stage, a Random Forest classification model will be estimated on a sample of the 27 capitals of the European Member States. Subsequently, based on this model, 9 cities in Romania will be classified from the perspective of the existence of the urban development pattern for the development of underground public transport. In order for the classification error of the predictive model to be as low as possible, variables from all areas specific to urban development (economic development, population density, circular economy, green city, digitalization, urban mobility) were used. The element of originality of the paper consists in calculating variables on the area of urban mobility, urban infrastructure and circular economy, using GIS coordinates. Thus, in addition to official international data sources, variables calculated by using geospatial technology (average distances, densities of green spaces, etc.) were included in this research. The main results of the research show that there are cities in Romania that present the same pattern of development similar to the capitals of the Member States of the European Union that have implemented underground public transport. Therefore, it can be said that for these cities it is necessary to implement this type of transport, the depreciation of the investment representing an easy process, which can be achieved in a medium or short term.

Keywords: Urban Development, Predictive Analysis, Urban Mobility, Public Transport, GIS

1. Introduction

Urban development is a particularly important aspect when the concept of "sustainability" or "sustainable development" is discussed. One of the important aspects for achieving goal 11 "Sustainable cities and communities" is the development of sustainable urban transport (Monteiro et al., 2024).

Therefore, the paper aims to identify the development patterns of sustainable urban transport among the 27 capitals of the European Union member states, but also to provide a tool for identifying the urban development patterns that require the development of the subway network. The second objective of the research, the development of a tool for the identification of urban development patterns that require the implementation of the subway network, represents the element of originality of the work. This work also offers an element of originality intended to help in the process of substantiating decisions at the level of local public administration.

2. Literature Review

The implementation of subway systems has emerged as a pivotal strategy in alleviating traffic congestion, prompting the widespread construction of subway networks in various cities. It is imperative that the dependability and resilience of these subway systems be ensured to effectively address the pressing issue of traffic congestion (Zhao and Hu, 2019). Gonzalez-Navarro and Turner (2018) examined the prevalence of subway networks in cities. Their analysis focused on a sample of 632 of the largest cities globally, with 138 of them having established subway systems. The study found that while larger cities are more inclined to have subways, the impact of these systems on urban population growth is minimal from an economic standpoint. Additionally, the research suggests that the presence of subways may lead to a degree of decentralization in cities, although the magnitude of this effect is modest. In contemporary urban transportation systems, rail transit has become a pivotal mode of passenger travel, with a particular emphasis on its operational efficiency and dependability. This is exemplified in the examination of Wuhan city, where research findings indicate that the subway network exhibits characteristics of a scale-free network (Liu and Tan, 2013). Moreover, the subway construction increases the spatial connectivity by 25%, the overall accessibility by 30.33%, and the polycentricity by 7.82%. These results demonstrate that the subway construction can significantly improve the connectivity and accessibility of Wuhan's urban spatial structure, especially the accessibility of peripheral districts, but improving polycentricity is weak (Song et al., 2023).

The integration of subway and bus networks has become an effective solution to reduce the growing congestion (Owais et al.,2021). However, Mourente and Benito (2015) state that the subway network exhibits better structural parameters than the urban bus network, with higher performance since in average a stop is reachable passing through less number of stops and carrying out less number of transfers between lines. Counterintuitively, it is found that transfer stations with large numbers of connections are not the most crucial, but the stations and lines with large betweenness centrality are essential, if subway networks are being attacked (Xiao et al., 2018).

3. Data & Methodology

The data analysis part consisted of two stages. In the first stage, using the Random Forest algorithm, a training model was developed at the level of the capitals of the European Union member states, with the classification variable being the implementation of underground transport (1- yes, 0- no). Subsequently, based on this model, a predictive model was estimated for 9 cities in Romania (Cluj-Napoca, Timisoara, Iasi, Constanta, Brasov, Craiova, Ploiesti, Galati, Oradea). These are cities that have not yet implemented urban underground transport. Therefore, the purpose of the second model is to identify the urban pattern that necessitates the implementation of urban underground transport.

To achieve the main objective of the research, the Random Forest classification algorithm was used. This classification method was chosen because its random nature provides the highest estimation accuracy. According to James et al. (2013), Random Forest trees offer an improvement in classification accuracy over "bagged trees" through a small random modification that influences the decision tree formation process. As with the "bagging" approach, it builds a series of decision trees on bootstrapped training samples (Scornet et al., 2015).

4. Results & Discussions

By using the Random Forest algorithm, the aim is to identify the factors contributing to the existence of an underground transport network in the capitals of the European Union member states. To ensure comparability between the capitals of the European Union member states and the most populated 9 cities in Romania, a common set of variables was used, with the dependent variable being the existence of a subway network in the city (1- the city has underground public transport, 0- the city does not have underground public transport).

The estimation error of the model is slightly below 20%, with slight fluctuations observed in the range of 500-600 trees. Therefore, to reduce the estimation error, the model was estimated using 700 decision trees, resulting in a prediction error of approximately 18.52%.

Analyzing the error matrix of the classification, it can be stated that the model has high accuracy for classifying cities that have implemented underground transport, with an estimation error of approximately 5.8%. On the other hand, the model does not perform with a high level of accuracy for cities that have not yet implemented urban the capitals Valletta, Riga, Dublin, and Bratislava are incorrectly classified by the model as having implemented underground public transport. Therefore, it can be argued that these cities exhibit exactly the type of urban development that necessitates the implementation of this type of public transport, but currently do not have a subway network as a mode of public transport.

For the second category of cities that have already implemented underground public transport, the only capital misclassified is Athens, the capital of Greece. This city does not exhibit the urban development pattern, in terms of infrastructure, urban mobility, and population density, of the other 16 capitals that have implemented underground public transport. In general, the subway network was implemented in densely populated cities, confirming the idea supported by Mourente and Benito (2015) that the subway is a faster means of transport than the bus. Also, analyzing the distribution of the cities that have implemented the subway network, the hypothesis supported by Gonzalez-Navaro and Turner (2018) is confirmed, which stated that large cities tend to develop the underground public transport network.

The main predictors of the predictive model are the number of buildings with 10 and 4 floors, as well as population density. So, it can be stated that subway could improve the traffic decongestion (Zhao and Hu, 2019). However, to ensure a structural decongestion of traffic, the local public administration must connect underground transport with public road transport (Owais et al., 2021). This result suggests that the urban development pattern, whether horizontal or vertical, significantly influences the implementation of an underground public transport network (Song et al, 2023).

Using the Random Forest model used at the level of the capitals of the European Union member states to classify whether they have implemented underground transport or not, a similar classification was performed for the other 9 cities in Romania. From these 10 cities, the most populous ones at the national level, Bucharest, were excluded since it is part of the training set. It is important to mention that up to this point, none of the nine municipalities have implemented underground public transport.

The model suggests that Cluj-Napoca, Constanta and Craiova are having the pattern of cities that have implemented the subway network. So, its public administrations should take into account the opportunity to develop the underground public transport system.

5. Conclusions

The random forest model resulting from the training set, at the level of the 27 European capitals, offers a good estimate for the cities that have implemented underground urban transport, with a classification error of approximately 6%, with only one capital being incorrectly classified, Athens (Greece). The main factors that influence the implementation of underground urban transport are the residential development model, horizontally or vertically, population density, as well as variables associated with urban mobility, mainly, the average distance from residential buildings to educational institutions. That is why, based on this model, there are European capitals that have not implemented the subway network, but that present the pattern of urban development that requires the development of this sustainable public transport (Valletta, Riga, Dublin, and Bratislava).

Having a classification error of up to 10% for the cities that implemented the underground public transport network, this model could also be used on the test set consisting of the 9 cities in Romania. Thus, it is found that cities such as Cluj-Napoca, Craiova and Constanta show the pattern of urban development that requires the development of underground public transport.

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