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Research Article

GEOGRAPHIC INFORMATION SYSTEM (GIS) BASED ACCESSIBILITY ANALYSIS FOR HIGHWAY TRANSPORTATION

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ABSTRACT

This manuscript presents an on-going research project, where the aim is to develop a Geographic Information System (GIS) based decision making method for supporting the sustainable transportation policies of Istanbul Electricity, Tramway and Tunnel General Management (IETT). The main approach is to design a spatio-temporal model for detecting the interaction between accessibility and land use before implementing a transport infrastructure investment and after its completion. In order to test the designed GIS-based model, a study area composed of eleven districts with high traffic density is selected at the European side of Istanbul. The designed system supports the integrated accessibility, connectivity and land use policies and aids to quantitatively measure the performance of investments that are among the priorities for transport decision makers.
Keywords: Accessibility, Geographic Information Systems, Land cover/use, Performance analysis, multi-criteria decision analyses.

1. INTRODUCTION

Due to the development of transportation systems in favor of highways, especially in cities, residential, industrial and commercial areas are intertwined and transportation of passengers and freight becomes difficult. Hence external costs, including congestion related ones, has increased significantly. Although policy makers are aware of this complex issue, there exists a gap to incorporate data and information into decision support systems for transport. This gap is larger for systems aiming sustainable transport. Hence, the purpose of this study is to quantitatively measure the interaction between transport and land-use via accessibility that will be incorporated into the Geographic Information System (GIS) based decision support methods to support sustainable transport policies. With the system; a) an integrated model for transport and land use will be achieved, where no national or local model is available and international developments which are still under development are of great interest, b) the model to be developed will suggest a new

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spatial indicator based on network a nalysis, tailored for Istanbul, c) by studying the geometrical and topological connectivity of the road network, the contribution of newly constructed highways to the network integrity and their land use effects will be determined, d) after determining the pattern of land use and transport via parameters and indicators, future forecasts and scenarios will be modeled and presented to decision makers using a multi-criteria decision making method. All developed concepts and methods are tested in a case study area.

2. CURRENT CHALLENGES AND ISSUES

Accessibility is defined as the main main product of a transport system according to the Transport Accessibility at Regional/Regional Scale and Patterns in Europe (TRACC) report published by the European Commission in 2013 [1]. It refers to the spatial superiority of a region to other regions including itself with its economic, socio-cultural, environmental and technological factors, also it defines the attraction center in a region. Definitions of accessibility have changed over time. Accessibility is influenced by a variety of factors such as transport demand, mobility, type of transport, integrated transport, passenger information and experience, affordability of transport, transport management, connectivity of transport networks, and privatization. Among these, the most important of these factors is the land use [2, 3]. The interaction is local; it varies within countries, regions and cities. Accessibility can be explained as follows through an example: Due to a highway in the region and hence reduced transportation costs, factories may find this region more suitable for investment. Affordability of transportation costs can attract other investors and could create new opportunities. This attraction center can change the land cover/use of the region by creating different economic, socio-cultural and environmental influences, also previously residential areas can be transformed into business areas. A region with higher attraction center than others can cause traffic congestions by increasing travel demand to such centers. This can increase shipping costs as well. Hence, this region will lose its attraction for investors and potential new alternatives will be on demand.

Many studies have been conducted since 1960's with the aim of revealing the systematic of transport and land use interaction [4, 5, 6, 7, 8] and the majority of the work is based on the Geographic Information System (GIS). It can be defined as databases and decision support systems in which spatial data are modelled and analyzed. The main reason for taking advantage of the GIS is to establish systematic transport and land use interaction spatially and temporally. Significant indicators for such analysis are the spatial distribution of land use and activities, transport volume and capacity, network topological integrity and accessibility measurements. Five major accessibility indicators are; distance or separation measure, cumulative opportunity measure, gravity measure, benefit-based measure and time-space measure. All these measures correspond to the main research topics of GIS and are the main reason for its frequent use in the solution of this problem.

3. STUDY AREA

For the testing and development of the designed system, a case study area is selected. The area is at the European side of Istanbul Metropolitan Municipality that contains districts of Esenler, Bağcılar, Güngören, Zeytinburnu, Bakırköy, Bahçelievler, Küçükçekmece, Avcılar, Esenyurt, Beylikdüzü and Büyükçekmece. The study area is approximately 405 km^2 and the population is about 4,864,766. The population growth of the study area is below the average of Istanbul between years 2007 and 2014, where according to the Turkish Statistical Institute Istanbul grew by 12% within aforementioned years. Only two districts namely; Büyükçekmece and Avcılar, are exceptions, where the population has increased 80% and by 20% respectively. There are about 40 shopping centers, many factories, universities and residential areas in the region. One of the major investments for the IETT, the metrobus line, exists within the study area, where it has been opened and operated by IETT since 2007. The highways passing through the case study area are E-5, TEM and connection routes. The length of the highways (E-5, TEM and connecting roads) in the region is approximately 112 km, where these are illustrated in Figure 1. The region is the main artery for passenger and freight transport in national and international terms and faces many problems such as congestion, uncontrolled land use and environmental pollution.

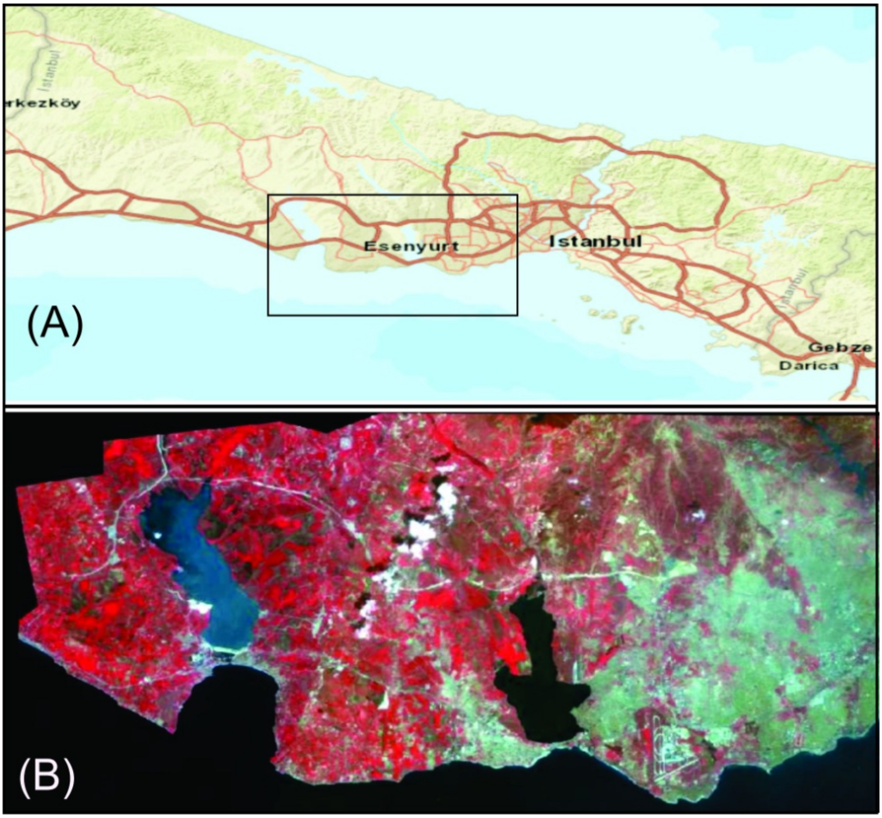

Figure 1. Study area (A) and transportation infrastructures (B) to be analyzed

4. THE METHODOLOGY

In order to detect the interaction between transport and land cover/use, accessibility and connectivity measures are going to be modelled in a GIS-based model. The designed model detects the pattern of interaction before the planning phase of transportation infrastructure, during construction and put into service. Hence the performance is quantified. The methodology is as follows: a) temporal land cover/usage data, demographic data and traffic related data is processed and prepared, b) the interaction for the study area is measured and modelled via accessibility and network integrity indicators in a GIS-based decision support system, c) with the help of advanced simulation techniques, the future distribution of land cover/use and their change is compared with the previous periods of the study area, where accessibility and connectivity is used to measure and rank possible alternatives via spatial multi-criteria decision analysis. The process steps are presented in Figure 2. Satellite images and spatial analysis are used to determine time-dependent land cover/use. Impact area buffers of different widths (1km, 2km and 3km) along the roadway are created for periods of approximately 10 years to detail the change in land cover/use that could be associated with transport. The satellite images to be used having various spatial resolutions.

The accessibility indicators calculated and compared for each period. For the comparison, two accessibility criteria (potential and daily) are used. Once the accessibility analysis is complete, topological analyses will be performed to determine the geometric integrity of the network, and how new paths participating in the network effecting network integrity. Some of the indicators that can be used are network density, attraction center, shortest paths between node points (betweenness), geodetic distance and detour measurements. By testing the geometric integrity indicators for the years 1975-1987-1997-2007-2014, the influence of the new roads on the network integrity will be tested and a new edge-based indicator will be proposed.

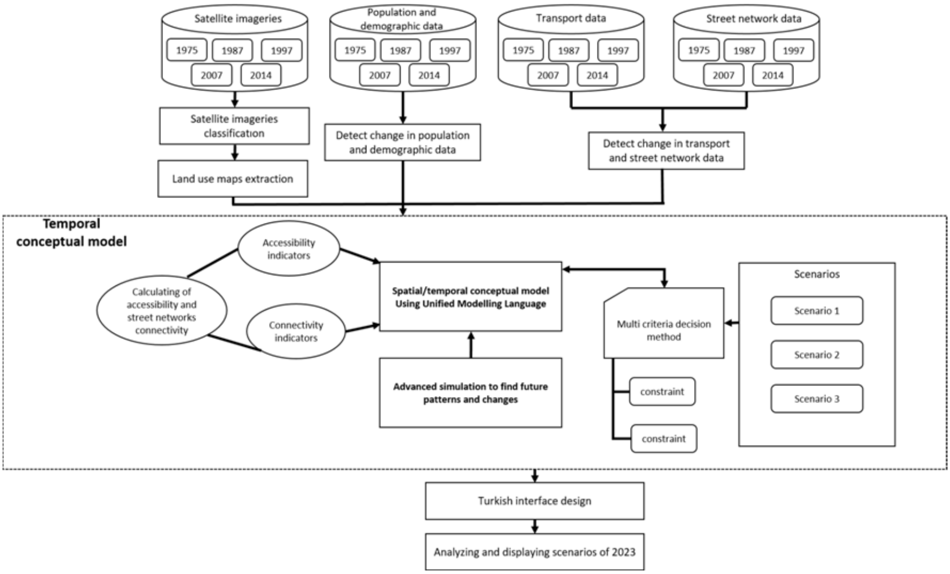

Figure 2. The framework of the project

The designed time-based spatial data model is a relational-object based model. In the conceptual data model, the European Community spatial data infrastructure "Infrastructure for Spatial Information in the European Community (INSPIRE)" basic geometric data model will be used for geometric data. GIS and agent-based methods will be integrated and the land cover/use pattern will be modelled for the future. The results obtained will be compared using linear regression. In this way, it will be possible to test the reliability of the predictions. The platform to develop simulations is open source. Using multi-criteria decision analysis, another function of the data model, the effect of the selected scenario on accessibility and land use will be analyzed. The designed system will be passed through various tests and will be presented to the decision makers to support sustainable transport policies.

5. PRELIMINARY RESULTS AND FURTHER STEPS

The first stage of the project is completed. For the selected years 1975-1987-1997-2007 and 2014, land cover/use were extracted. The classification of satellite images has been carried out in accordance with the European Union established standard, Coordination of Information on the

Environment (CORINE). The CORINE land cover classification system is a hierarchical structure consisting of three levels under five main groups. These groups are artificial areas, agricultural areas, forests and natural areas, wetlands and water structures. The group that needs to be classified in detail within the scope of the project is the artificial regions, where classification is performed up to the third level. At the third level, some classes are "continuous city structure", “industrial and commercial units”, "highways", "railways and related areas", "ports" and "airports" (subgroup of industry, commerce and transport units), "sports and entertainment sites" (artificial, non-agricultural green areas). However, more detailed classification is needed to determine the interaction at a higher resolution. Subgroups called the fourth level are determined at the national level according to the CORINE project. Work at the national level has just begun and has not been concluded. For this reason, some details required within the scope of the project will be classified and named as the fourth level. These classes are adapted from the Danish national classification system. The subgroups to be classified are public buildings, work places, parking lots, high-rise buildings, satellite cities, hospitals, universities, campuses and theatre, cinema, museums. The project does not require detailed classes for agricultural areas, forests and semi-natural areas, wetlands and water structures.

After the different satellite images of the study area were geometrically corrected with the help of ground control points, images are processed. At the end of the geometric correction process, an average of 0.4 meter root mean square error was calculated using approximately 48 ground control points for all images. Part of the geometric correction step for imagery of 1997 is presented in Figure 3. After completing this phase, accessibility and road network integrity values and their changes for the selected years will be analyzed according to the designed model.

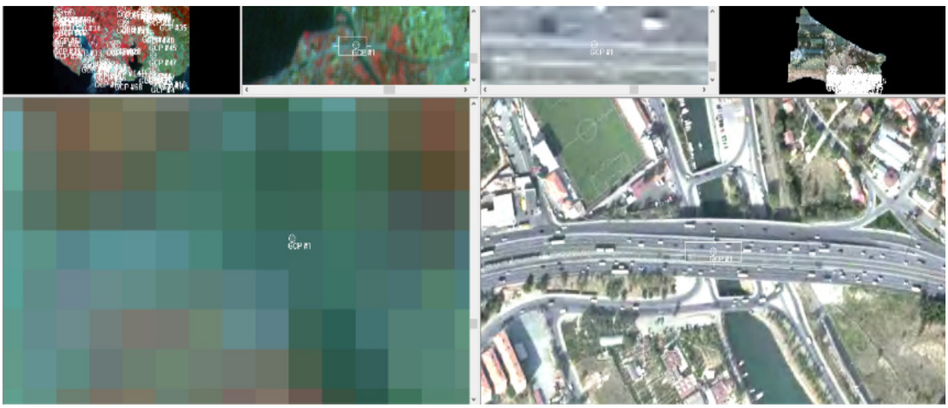

Figure 3. Geometric correction for a sample of 1997 satellite imagery

According to the results of the analyze, as illustrated in Figure 4, the relationship between accessibility and land use may vary depending on the spatial distribution of the attraction center. In 1987, the agricultural areas within the study area were transformed into settlements in order to react the supply and demand requirements in the region. The roads inside the area increased over time. As a result, economic, cultural and social factors related to the region have been visibly changed. Compared to the year 1987, changes are prominent in years 2007 and 2014. The urban areas within the selected test area have increased twice, where industrial areas increased three times. Since the metrobus line passes through the selected test area, a detailed analyses was conducted. With the 3 kilometer band buffering the metrobus line, land cover/use change was enormous. The urban areas increased 17 times, where industrial areas increase 7 times. The potential accessibility of the test area increased as well. The potential accessibility increased 49.09%, where daily accessibility increased 47.73%. The increase in potential and daily accessibility within the 3km band of metrobus line are almost doubled compared to the whole test area reaching 98% and 95% respectively.

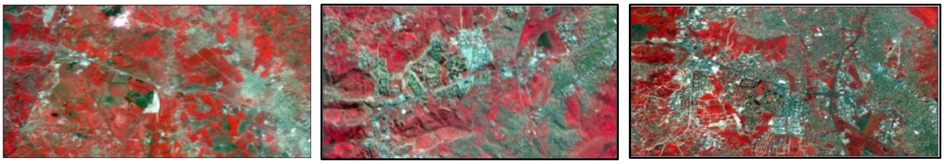

Figure 4. A section from the study area of 1987, 1997, 2007 respectively.

6. CONCLUSION AND FURTHER STEPS

This project is designed to support decision makers to develop common policies and increase transport service performance and quality. By the end of this project several outputs will be provided as follows: a) Decision-makers will be supported by a system that can jointly evaluate accessibility and land use in the project, b) The management of sustainable transport systems and many new parameters and variables for newly planned transport infrastructures will be identified and reliable information will be generated, c) Accessibility and land use can be monitored and the impact of decisions taken can be analyzed. d) A verified and tested system to plan and manage sustainable transport at the forefront of the pre-determined issues in the European Union accession process (EU Negotiations Chapter: 14, Transport Policies), e) The designed system will provide support for decisions based on quantitative results that could lead to an efficient transportation system.

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