

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Marius JAKIMAVIČIUS

**MULTI-CRITERIA ASSESSMENT
OF URBAN AREAS TRANSPORT
SYSTEMS DEVELOPMENT
ACCORDING TO SUSTAINABILITY**

DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
CIVIL ENGINEERING (02T)

Vilnius „Technika“ 2008

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TRANSPORTO SISTEMŲ
PLĖTROS DAUGIATIKSLIS
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TECHNOLOGIJOS MOKSLAI,
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Abstract

The main goal of the current PhD thesis is urban transport system analysis according sustainability. In dissertation have been analyzed urban areas transport system using integrated decision support system methods with GIS. These methods have been adopted for urban transport system analysis, urban territories ranking according transport system level. Also the indicators system for urban transport system analysis was filled with other important indicators groups for urban sustainability (environmental, socio economic). The aim of the paper covers creation of theoretical model, which could evaluate urban transport system sustainability and perform rational planning of urban future development according decision support methods and GIS technologies. Also this model could allow executing urban transport system ranking by engineering infrastructure, socio economic and environment aspects. Model could perform comparing of urban development scenarios and to indicate the best one, which satisfies transport systems indicators. There are several main tasks under consideration: 1) to identify and to analyze urban transport systems indicators and their groups defining more efficient urban development planning; 2) to adopt multi criteria methods for urban transport systems analysis and to verify these methods integration with GIS; 3) to create model for urban development confirmation according urban transport system parameters and perform ranking urban development scenarios; 4) to verify the hypotheses of the urban transport system influence on the urban development scenarios from the point of multi criteria analysis (Vilnius case). Also to verify the hypotheses of the transport analysis zone infrastructure and socio economic data integration influence on the correct estimation of urban transport activity centers. After verification to adopt created model for urban development scenarios confirmation for Kaunas city; 5) to create, describe and check the model of urban areas transport system evaluation according development sustainability for Vilnius city. To perform transport system indicators calculation for 2015 and 2025 years according to prognosticated socio-economic data.

The results of the thesis were publicized in 5 conferences in Lithuania and Czech Republic. There were also 2 scientific papers published, including: one referred by the ISI Web of Science database and another published in reviewed scientific periodical publication. Also 2 papers were published in conferences materials (Thomson ISI Proceedings). The last 2 papers were published in conference materials.

Reziumė

Disertacijoje nagrinėjama gyvenamųjų teritorijų susisiekimo sistema darnos požiūriu. Pagal sukurta susisiekimo sistemos analizei naudojamą rodiklių sistemą, disertacijoje nagrinėjami sprendimų paramos sistemos metodai, tinkantys gyvenamųjų teritorijų susisiekimo sistemos analizės uždaviniams spręsti, tai pat analizuojamos šių metodų integracijos galimybės su geografinėmis informacinėmis sistemomis (GIS). Pagrindinis darbo tikslas – sudaryti teorinį modelį, kuris leistų daugiatiksliais sprendimų priėmimo metodais bei GIS technologijomis įvertinti gyvenamųjų teritorijų susisiekimo sistemos darną ir darniai planuoti gyvenamųjų teritorijų susisiekimo sistemos vystymąsi ateityje. Disertacijoje siūlomas modelis suteikia galimybę atlikti skirtingų gyvenamųjų teritorijų susisiekimo sistemų rangavimą, analizuoti įvairias gyvenamųjų teritorijų susisiekimo sistemos vystimosi alternatyvas, jas palyginti bei atrinkti geriausią. Modelis yra integruotas su GIS ir suteikia galimybę atlikti gyvenamųjų teritorijų plėtros tendencijų modeliavimą. Siekiant įgyvendinti užsibrėžtą tikslą, rengiant disertaciją buvo sprendžiami tokie uždaviniai: 1) nustatyti ir išanalizuoti gyvenamųjų teritorijų susisiekimo sistemą apibūdinančius rodiklius bei jų sistemas, turinčias įtaką efektyviam gyvenamųjų teritorijų planavimui; 2) išanalizuoti ir parinkti tinkančius daugiakriterinius sprendimų priėmimo metodus, tinkančius gyvenamųjų teritorijų plėtros scenarijams įvertinti susisiekimo sistemos požiūriu, atlikti šių metodų integraciją su GIS; 3) sukurti modelį urbanizuotų teritorijų plėtros scenarijų rangavimui atlikti remiantis sprendimų paramos sistemos metodais ir susisiekimo sistemos rodikliais; 4) naudojant sukurta modelį patikrinti iškeltas hipotezes, kad urbanizuotų teritorijų plėtros scenarijaus pasirinkimui turi įtakos susisiekimo sistemos rodikliai (Vilniaus miesto pavyzdžiu), kad korektiškam miesto suskaidymui į transportinius rajonus kartu įtakoja susisiekimo sistemos infrastruktūra ir demografiniai duomenys (Vilniaus ir Kauno miestų pavyzdžiais); 5) sukurti, aprašyti ir išbandyti gyvenamųjų teritorijų susisiekimo sistemos darnos įvertinimo ir vystymo planavimo teorinį modelį. Atlikti prognozuojamų susisiekimo sistemos rodiklių skaičiavimą Vilniaus miestui pagal prognozuojamus socialinius ir ekonominius duomenis 2015 ir 2025 metams.

Disertacijos tema perskaityti 5 pranešimai Lietuvos bei kitų šalių konferencijose ir paskelbti 6 moksliniai straipsniai: 2 – periodiniuose recenzuojamuose mokslo žurnaluose, kurių vienas yra įtrauktas į Thomson ISI Web of Science Database sąrašą; 2 – recenzuojamuose tarptautinių konferencijų leidiniuose (Thomson ISI Proceedings); bei 2 – kitų konferencijų medžiagoje.

Notations

Symbols

- m – number of the criteria compared
 r – number of experts
 S – sum (variance analogue)
 R_{1-16} – variables of multicriterial analysis
 W – the concordance coefficient
 ω – variable
 α – function
 χ^2 – chi square function
 v – function
 P – trip production
 A – trip attraction
 χ_k – MTA factor for each employment type
 TA – number of trips attracted
 Ag – number of agricultural jobs
 Mi – number of mining jobs
 Re – number of retail jobs
 Se – number of service jobs
 P_{ijk} – probability for a given mode k
 T_{ijk} – modal split

Abbreviations

- GIS – Geographic Information Systems
MCDM – Multi-Criteria Decision Making
EU – European Union
MODM – Multi-Objective Decision Making
MADM Multi-Attribute Decision Making
IS – Information Systems

TAZ – Traffic Analysis Zones
TAC – Transport Activity Centers
SAW – Simple Additive Weighting
TOPSIS – Technique for Order Preference by Similarity to the Ideal Solution
AHP – Analytic Hierarchy Process
OWA – Ordered Weighted Average
CP – Compromise Programming
MEW – Multiplicative Exponent Weighting
MCP – Multi-criteria Complex Proportion

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Introduction

Typically of the problem

Effectiveness of urban areas transport system development is the key factor for attaining sustainable development. Misguided urban areas development scenario gives growing travel costs, bigger energy consumption, raised travel times. In order to choose sustainable urban areas development scenario according to transport system, it is necessary to create sustainability representative indicators system and use multi-criteria methods for that evaluation.

Urban areas transport system problems are similar in many cities. Growing motorization level invokes traffic problems, raised noise level, increases driving times in peak hours. Average percentage number of Vilnius city automobiles quantity is increasing per year about 3 %. Number of personal cars in Vilnius city rose from 265 automobiles for 1000 inhabitants in 1999 till 480 in 2007 year. Sharp bounce of motorization level invokes a lot of transportation problems.

Multi criteria analysis of urban transport system is relevant in validating priority rank for transportation development projects, for identifying the projects optimal realization and financing rank. The confirmation need of urban transport system project realization increased especially Lithuania by entering to European Union and by financing urban transport projects opportunity from EU

structural funds. In that case decision support system (DSS) methods and models are popular. In order to perform urban transport system spatial analysis, DSS methods are integrating with geographic information systems (GIS). This kind of integration allows executing detailed urban transport system analysis based on spatial aspect, which could identify new associations and dependencies among urban transport system indicators.

Urban transport system multi criteria analysis using DSS methods integrated with GIS could be successfully adopted in comprehensive and strategic urban planning processes.

Relevance of the dissertation

Analysis of present urban transport system situation is very actual in planning development of transport system, in prioritizing transport infrastructure development projects even planning the main urban development directions.

Also multi criteria urban transport system analysis is used in urban territories ranking according transport system development level. In that case are popular decision support system (DSS) methods and models. In order to perform urban transport system spatial analysis, methods of DSS are integrating with geographic information systems (GIS). This kind of integration allows executing detailed urban transport system analysis based on spatial aspect, which could identify new associations and dependencies among urban transport system indicators.

Multi criteria analysis of urban transport system is relevant in validating priority rank for transportation development projects, for identifying the projects optimal realization and financing rank. The confirmation need of urban transport system project realization increased especially Lithuania by entering to European Union and by financing urban transport projects opportunity from EU structural funds.

Multi criteria analysis of urban transport system by using DSS methods integrated with GIS could be successfully adopted in comprehensive and strategic urban planning processes, in implementation of information systems for public usage. In that case would be minimized probability for not correct selection of transport system development scenario. Also created methodology and models gives possibility to perform urban development planning according transport system.

Object of the research

Research object is urban transport system analysis. In dissertation are analyzing integrated with GIS DSS methods according created indicators system. These methods are adopted for urban transport system analysis, urban territories ranking according transport system level. Also the indicators system for urban transport system analysis was filled with other important indicators groups for urban sustainability (environmental, socio economic). In narrow sense the research object could be described as indicators system identification, their analysis, urban transport system evaluation based on indicators system analysis results. Also in dissertation are presented created WEB GIS application which could perform transport system analysis tasks. It is WEB based decision support system for Vilnius and Kaunas citizens.

Aim and objective of the research

The main aim of the research is to create model, which could evaluate urban transport system sustainability and perform rational planning of urban future development according decision support methods and GIS technologies. Also this model could allow executing urban transport system ranking by engineering infrastructure, socio economic and environment aspects. Model could perform comparing of urban development scenarios and to indicate the best one, which satisfies transport systems indicators. Model also verifies the quality of urban areas division into transport analysis zones. The second stage of the research is to verify created model by performing theoretical modelling for Vilnius development scenarios for 2015 and 2025 years.

The following objectives should be accomplished while reaching the aim:

1. To identify and analyse urban transport systems indicators and their groups defining more efficient urban development planning.
2. To adopt multi criteria methods for urban transport systems analysis and to verify these methods integration with GIS.
3. To create model for urban development confirmation according urban transport system parameters and perform ranking urban development scenarios.
4. To verify the hypotheses of the urban transport system influence on the urban development scenarios from the point of multi criteria analysis (Vilnius case). Also to verify the hypotheses of the transport analysis zone infrastructure and socio economic data integration influence on the correct estimation of urban transport activity centers. After verification to adopt created model for urban development scenarios confirmation for Kaunas city.

5. To create, describe and check the model of urban areas transport system evaluation according development sustainability. To perform transport system indicators calculation for 2015 and 2025 years according to prognosticated socio-economic data.

To determine the main preconditions for more sustainable development of the city, specifically the urban transport system efficient.

Methods of the research

This study employed empirical and theoretical models of urban transport system analysis. The design of the experiment was based of decision support system methods usage. Individual analysis of empirical and theoretical studies, and projects was performed and the possible application fields for current conditions were defined.

Urban transport system analysis was performed by using decision support system multi criteria methods. For more representation and spatial analysis these methods were integrated with GIS technologies. The values of indicators were received from statistical data. The values of indicators importance were estimated by experts' questionnaire.

GIS data for the theoretical study was derived from Vilnius and Kaunas Municipalities. This database contains information about private transport (OD matrices for cars and trucks, public transport passengers flows), collected during interviews with drivers, vehicle delay functions and probe driving results. Also database contains public transport data like passengers flows, number of trips. Part of the socio-economic data was derived from Lithuanian State Department of Statistics.

Traffic Analyst modelling software and GIS database with transport indicators were employed to search for relations between the urban structure and Vilnius and transport system. A number of scenarios were performed in order to examine relations between land use and transport system development scenarios.

Scientific novelty of the research

1. For urban transport system analysis and spatial ranking were adopted decision support system methods of multi criteria analysis.

2. There was performed integration of multi criteria methods analysis with GIS technologies.

3. Created methodology allows perform urban areas development scenarios ranking according transport system sustainability.

Presented to defence

Three main hypotheses were formulated after literature overview:

1. Created indicators system for performing urban areas transport system analysis according sustainability.

2. For performing rational urban areas development scenarios evaluation decision support system methods should be integrated with GIS.

3. Urban areas zoning to transportation analysis zones should be done according to street network and socio-economical data.

4. Created model could be verified by performing modelling of urban areas development scenarios and indicators future values calculation.

Approval of the research and practical application of the results

The main issues and proposals discussed in this dissertation have been presented and discussed at international and national conferences in Lithuania and Check Republic. The material presented in the dissertation was also published in 7 editions of scientific issues and conference proceedings. Research material and developed models were applied in 1 project “Automation traffic management system in Vilnius city”.

Volume and structure of the research

The dissertation consists of five main sections: introduction, detailed evaluation of indicators and indicators groups, experiment design (multi criteria based transport system analysis), discussion of results and conclusions. Volume of the dissertation is 149 pages and its structure presented in graphic form (see Figure 1). These issues are examined in the context of sustainable urban development, and the main policies and current achievements for increasing sustainability in transport are also examined.

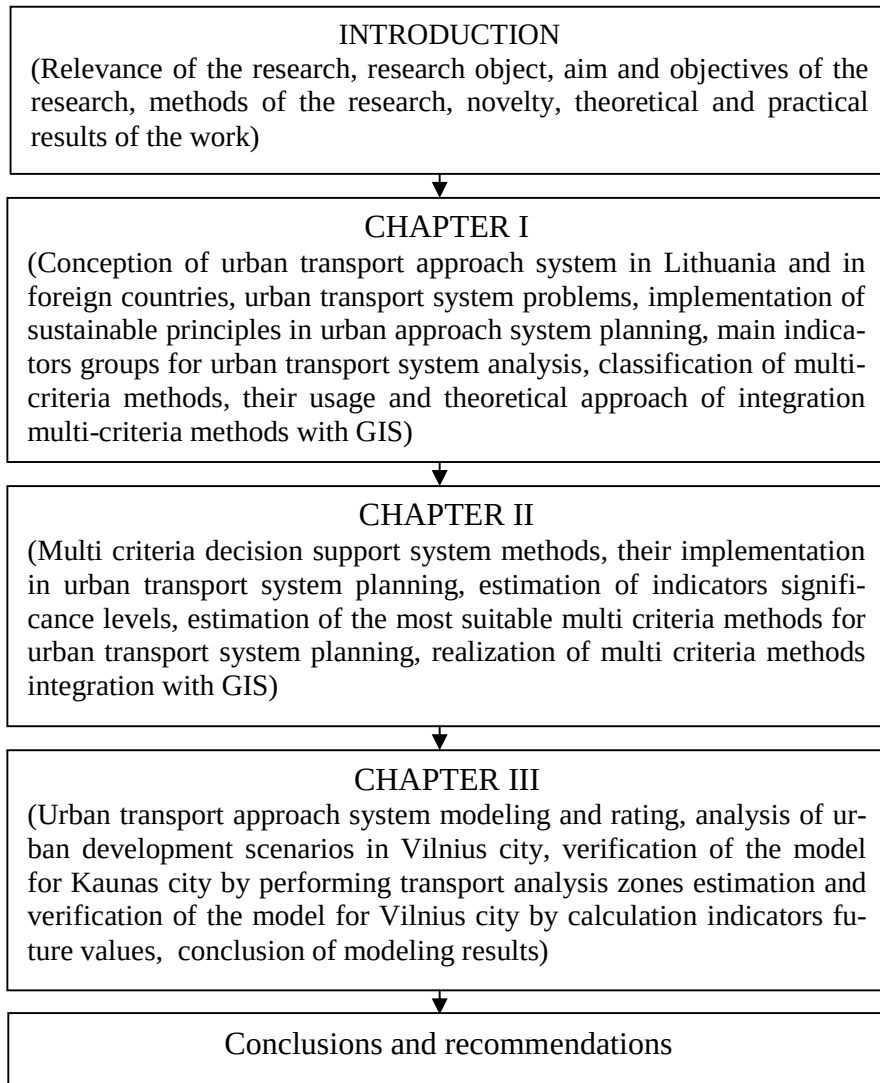


Figure 1. Structure of the dissertation

1

Conception and analysis methods of urban transport system in Lithuania and in foreign countries

1.1. Urban transport system point, principles and goals

Human history is also the history of transport evolution. Every revolution in transport technology has dramatically extended the human ability to explore and use the Earth's surface. Ground transport technologies specifically, including rail and road transport, have greatly influenced the Western urban structure since the 19th century. However, whereas the development of rail transport has been growing or slowing down since the second half of the last century, road transport has been booming, owing to advances in motor vehicles and infrastructure construction materials in conjunction with economic growth. Transport development has increased people's mobility, benefited economic growth, stimulated

changes in society, but also negatively impacted on the environment. Political debate on the value, goals and objectives of transport development has always been necessary, and transport planning has been credited as a necessary tool to assist policy making. In the Western world, the increase in motor vehicles has stimulated vast road infrastructure developments since the 1950s.

The improvement of transport infrastructures and services has made a major contribution to the suburbanization process. For several decades the major concern of transport policies has been to build more infrastructures to meet the growing demand for mobility. But up till now different transport sectors have been working in isolation, data collection has been difficult, and planning has been regarded as a blueprint rather than a process and these are just some of the problems. In Britain, the pressure on transport growth has facilitated an interest in transport planning as a distinct part of the urban and regional process (Starkie 1973). Accompanying this interest is a call for a comprehensive and systematic to transport planning, which includes a distinct concern for formulating and appraising alternative transport strategies.

While the construction of highways continued to increase in the 1970s, it was realized that travel demand would never be satisfied with new infrastructure development. The relationship between supply and demand had to be redefined, with more attention being paid to the demand side. This recognition necessitated the forecasting of travel demand under various policy alternatives, which has since evolved to become an important part of transport planning. Also, the oil crisis and economic recession in the early 1970s encouraged the improvement of public transport. Frustrated by difficulties in data collection, land use and transport models were modified to consume less data. Techniques for transport planning analysis have been improving in response to the need for demand forecasts. Land use and transport models have made use of theories on the economic base, spatial interaction and entropy. A comprehensive four-step model system has been developed to forecast aggregate flows at the strategic planning level. Although the model in its entirety has been used less in recent decades, the use of its individual step models, such as modal choice models and traffic assignment models, has increased. A call for individual analysis of travel choice was initiated from the perspective of time geography (Hagerstrand 1970). In the mean time, behavioural models have been formulated to study individual choice of travel mode and location, derived from the micro-economic theory of consumer behavior (McFadden 1973). These developments laid the foundations for the activity-based and simulation with advanced computer technologies. Zone-based transport planning has focused on the development of transport infrastructures at the strategic level. With the expansion of planning tasks from physical development to responding to more complex social, economic and environmental

policies, travel demand needs to be forecast at a more detailed level. In the mean time, it has been realized that travel demand is derived from activity demand, and that activities should be the focus of modelling. The activity-based is based on household and individual choices of mobility and lifestyle, activity and travel scheduling, and implementation and rescheduling (Bowman and Ben-Akiva 1997). Under these circumstances travel demand models have evolved from aggregated ones to disaggregated ones.

The shift from aggregate to disaggregate transport analysis indicates a reorientation of the planning profession away from engineering towards the social sciences, especially economics and psychology (Pipkin 1995). As technological and demographic changes are essentially a spatial, modern transport planning has to focus on both the spatial representation of urban systems and non-spatial aspects such as culture and political economy (Banister 2002). Accompanying this challenge is the integration of data from a wide range of sources.

With the continuous growth in mobility since the 1980s, the gap between supply and demand has become wider. Congestion, accidents and environmental impacts are the symptoms of this imbalance. Under these circumstances, transport demand management has become an important measure in transport policy to calm down traffic in congested areas. Rosenbloom (Rosenbloom 1978) proposed four basic categories of demand management:

- to reduce the number of vehicles by increasing occupancy;
- to reorient travel to off-peak periods;
- to redirect travel to alternative routes;
- to reduce the total demand for travel.

These strategies have been supplemented by various control techniques that are suitable for individual cities, such as parking control and ride sharing. Demand management belongs to a series of policy strategies. For transport demand management it is beneficial to set up a structured framework concerning the objectives and policy measures for land use and transport development (Black 1992). The ultimate goal is to balance the supply and the demand so that the social, economic and environmental benefits can be maximized while a sustainable transport system is maintained. The analysis of users' response to management measures became necessary in order to evaluate policy alternatives. Another issue is the multimodal integration of transport activities in order to respond to growing mobility and particularly to the need for efficiency. Equity is also a big problem under the new socio-economic and political requirements (Masser *et al.* 1992).

On the supply side, while the technologies for construction materials and vehicles have been under continuous improvement, the advent of information science and new detection devices has provided more efficient tools for guiding

travellers. Such techniques as advanced information provision, real time bus location and automatic congestion detection are just a few examples under the general rubric of the intelligent transport system (ITS) (Mast 1998). Advances in these technologies have expanded the capacity of highways, improved levels of service for public transport, and increased safety.

There have also been growing concerns about the negative impacts of transport on the environment and society. In general the transport industry consumes a lot of the Earth's resources. Highways are criticized as intrusions into the local landscape and way of life. The biggest problem with motor vehicles is the emission of pollutants such as carbon dioxide (CO₂) and nitrogen oxides (NO_x). Passenger cars account for more than 13 percent of the total carbon dioxide emitted from fossil fuels worldwide, which contributes directly and indirectly to global warming (Lowe 1990). Noise is another severe pollutant in urbanized areas. Reducing the impact of transport requires concerted effort at the local, national and international levels. In the United States, the 1990 Clean Air Act Amendments requires state implementation plans (SIP) to include estimates of emissions and transport control measures so that the national standard of air quality is met (Karash and Schweiger 1994). A series of emission models are available from the U.S. Environmental Protection Agency. The European Union has recognized the importance of transport impact and has outlined future development based on sustainable mobility in its new common transport policy (Haq 1997). Also European Union the directive on environmental noise requires performing noise measures for cities with more than 250 000 inhabitants and preparing strategic noise maps and an action plans to protect quiet areas against an increase in noise (Directive 2002/49/EC).

Computer and information technologies have dramatically improved the capabilities of transport forecast and evaluation models. Transport software packages are available for various scales of application, ranging from strategic trend forecasts to detailed traffic assignment. Simulation models, particularly micro-simulation models, are applicable with the availability of advanced computing methods such as object-oriented programming and parallel processing (Algers *et al.* 1998). New data capture techniques such as Global Positioning Systems (GPS) provide a revolutionary means of data collection for transport planning and operations management. Data for transport planning are best managed by and retrieved from database management systems. More advanced techniques for data manipulation are available, including data warehousing, data mining and knowledge discovery. However, as data come from a variety of sources and in varying data formats, this presents a tremendous challenge in terms of linking and integrating the transport data.

Transport challenges in the developing world appeared later than in the developed world, but developing countries generally face more serious problems, due to the lack of control on transport and especially to the failure to learn from the lessons of the developed world.

The general conditions of transport in developing countries include the shortage of infrastructure supply, highly mixed usage of vehicles, low accessibility, high traffic incident rates, and severe environmental impact (Vasconcellos 2001). In the developing countries, the need to control traffic demands is even more urgently required than in the developed countries (Tanaboriboon 1992). However, the low availability of transport related data is a serious drawback for transport planning in the developing world. These characteristics have to be taken into account when carrying out data integration studies in the developing cities.

There were formulated these goals and objectives in Vilnius city strategic plan (Vilniaus miesto 2002–2011 metų strateginis planas):

1. To ensure good international and external transport connections:

- to create favourable conditions for the transport connections of Vilnius and its suburbs;
- to ensure the permeability of international transit transport flows.

2. To ensure balanced development of the city' transportation system:

- to improve the services of urban public transport and develop the traffic of pedestrians and motor vehicles;
- to implement a subsequent strategy of urban development limiting the transportation demand;
- to form a reliable and permeable network of a transportation infrastructure.

3. To minimize the negative impact of transport traffic:

- to solve the problem of parking places;
- to minimize the negative impact of transport traffic to the environment.

The transport strategy seeks to continue the process of reshaping the transport system of Edinburgh to one that facilitates city life rather than dominates it (The city of Edinburgh council local transport strategy 2004 – 2007). In this context, the aims of Edinburgh's Local Transport Strategy are to:

1. Improve safety for all road and transport users.
2. Reduce the environmental impacts of travel.
3. Support the local economy.
4. Promote better health and fitness.
5. Reduce social exclusion.

These aims illustrate the links between transport and other policies such as land-use planning, social inclusion, economic development, the environment,

public health and safety. They also seek to ensure that urban design quality is high throughout, particularly with reference to the public realm. Meeting these aims is a challenging, long term task. It requires a broad range of actions, each of which must, nevertheless, be clearly focused.

The following objectives flow from the aims and summarize the direction of transport policy in the city:

- to reduce congestion on all modes of transport;
- to increase the proportion of journeys made on foot, by cycle, by powered two wheelers (PTW) and by public transport;
- to reduce the need to travel, especially by car;
- to reduce the adverse impacts of travel, including road accidents and environmental damage;
- to maximize the community role of streets, as places where people can meet, shop, and, in appropriate circumstances, children can play;
- to improve the ability of people with low incomes or mobility impairments to use the transport system;
- to ensure that the road, footway and cycle network are of a standard suitable for safe and comfortable movement.

In Somerset city (lies in South West England and covers an area of 3450 square kilometres. The county is home to 498,093 people, about 10% of the population of the South West region) transport system strategic plan it these aims are declared (Somerset Local Transport Plan 2006 – 2011):

Improve safety for all who travel by meeting the following objectives:

1. Reducing traffic accidents with a particular emphasis on killed and seriously injured casualties and rural main roads.
2. Reducing fear of crime in all aspects of the transport network.

Reduce social exclusion and improve access to everyday facilities by meeting the following objectives:

1. Improving access to work, learning, healthcare, food-shops and other services.
2. Improving access to the countryside and recreation.
3. Facilitating the better co-ordination of activities of other authorities to improve accessibility of services.

Reduce growth in congestion and pollution and improve health by meeting the following objectives:

1. Improving the efficiency and effectiveness of the transport network.
2. Ensuring that traffic is controlled and managed effectively.
3. Influencing travel behavior.
4. Widening travel choice.

Support sustainable economic growth in appropriate locations by meeting the following objectives:

1. Delivering transport improvements to support the Land Use Strategy.
2. Ensuring recovery of the highway network to a steady state.
3. Delivering transport improvements to support the County's Economic Development Strategy.

Protect and enhance the built and natural environment by meeting the following objectives:

1. Seeking opportunities to increase species and habitat diversity through transport scheme implementation.
2. Preserving and enhancing the character of the countryside.
3. Preserving and enhancing heritage centers and areas of historic interest.

1.2. Urban transport system problems

Cities are locations having a high level of accumulation and concentration of economic activities and are complex spatial structures that are supported by transport systems. The most important transport problems are often related to urban, when transport systems, for a variety of reasons, cannot satisfy the numerous requirements of urban mobility (Lautso *et al.* 2002). Urban productivity is highly dependent on the efficiency of its transport system to move labor, consumers and freight between multiple origins and destinations. Additionally, important transport terminals such as ports, airports, and rail yards are located within urban, contributing to a specific array of problems. Some problems are ancient, like congestion (which plagued cities such as Rome), while others are new like urban freight distribution or environmental impacts. Among the most notable urban transport problems are (Kitamura *et al.* 1997):

- **Traffic congestion and parking difficulties.** Congestion is one of the most prevalent transport problems in large urban agglomerations. It is particularly linked with motorization and the diffusion of the automobile, which has increased the demand for transport infrastructures. However, the supply of infrastructures has often not been able to keep up with the growth of mobility. Since vehicles spend the majority of the time parked, motorization has expanded the demand for parking space, which has created space consumption a problem particularly in central part of the cities;

- **Public transport inadequacy.** Many public transit systems, or parts of them, are either over or under used. During peak hours, crowdedness creates

discomfort for users, while low rider ship makes many services financially unsustainable;

- **Difficulties for pedestrians.** These difficulties are either the outcome of intense traffic, where the mobility of pedestrians and vehicles are impaired, but also because of a blatant lack of consideration for pedestrians in the physical design of facilities;

- **Loss of public space.** The majority of roads are publicly owned and free of access. Increased traffic has adverse impacts on public activities which once crowded the streets such as markets, agoras, parades and processions, games, and community interactions. These have gradually disappeared to be replaced by automobiles. In many cases, these activities have shifted to shopping malls while in other cases, they have been abandoned altogether. Traffic flows influence the life and interactions of residents and their usage of street space. More traffic impedes social interactions and street activities. People tend to walk and cycle less when traffic is high;

- **Environmental impacts and energy consumption.** Pollution, including noise, generated by circulation has become a serious impediment to the quality of life and even the health of urban populations. Further, energy consumption by urban transportation has dramatically increased and so the dependency on petroleum;

- **Accidents and safety.** Growing traffic in urban is linked with a growing number of accidents and fatalities, especially in developing countries. As traffic increases, people feel less safe to use the streets;

- **Land consumption.** The territorial imprint of transportation is significant, particularly for the automobile. Between 30% and 60% of a metropolitan area may be devoted to transportation, an outcome of the over-reliance on some forms of urban transportation.

- **Freight distribution.** Globalization and the materialization of the economy have produced growing quantities of freight moving within metropolitan. As freight traffic commonly shares infrastructures with the circulation of passengers, the mobility of freight in urban has become increasing problematic. City logistics strategies can be established to mitigate the variety of challenges faced by urban freight distribution.

There are several dimensions to the urban transport problem, most of them linked with the dominance of the automobile.

Drastic rise in travels around the world from year 1960 – an average 1820 km by car, railway or aircraft, to 4390 km in 1990 (Schafer 1998) substantiate different traffic problems in all capitals and fast growing countries.

Growing Lithuanian economy and increasing quality of the living conditions prompts population's mobility, the motorization level and increasingly

high transport flow on the countries streets and roads (Grigonis and Burinskienė 2003; Burinskienė and Paliulis 2003).

There are more than 2,448 million vehicles (where more than 1,095 million private cars) in Lithuania this year. Present level of motorization has reached 384 cars / 1000 inhabitants. With this level rapidly increasing and with the existing car fleet growth rate it is forecasted that the overall number of cars will exceed 1.5 million in the year 2005. The relative motorization indicators have also been increasing. In 1990 the motorization level (a number of vehicle per 1000 inhabitants) in Lithuania was 215; in 1993 – 245; in 1996 – 285; in 1999 – 332, in 2002 – 426; in 2004 – 476; in 2007 – 544 (Ministry of Transport and Communications). This indicator has reached and even out measured that of other European countries; for example – there are 466 vehicles per 1000 inhabitants in Germany, 421 in France, 419 in Sweden.

The growth of personal passenger cars transport in Lithuania started during the 1920's. The situation in Lithuania's transport system can be illustrated by dynamics in vehicle number growth during the period 1995–2007 (Table 1).

During the last 15 years Lithuania had experienced sudden increase in motorization level. The tendency is illustrated in Figure 2.

Table 1. Data of Lithuanian motorization level (Lithuanian Department of Statistics)

Year	1955	1960	1965	1970	1975	1980	1985	1990
Veh/1000 inhabitants	1	5	6	11	35	69	93	129
Year	1995	2000	2002	2003	2004	2005	2006	2007
Veh/. 1000 inhabita	190	315	316	336	354	395	433	429

Sharp bounce in motorization level invokes a lot of transportation problems. Many scientific researches analyze transportation system from the point of system sustainability, which influences economical, social and environmental implications (Black et al. 2002; Camagni et al. 2002; Grigonis and Burinskienė 2002). Reorganization of the transportation system is one the possibilities solving problems in transportation sphere, when existing transport flows are modelled by arranging the highway, detours, capable to unload the main traffic flow (Anderson 1999; Siewczyński 2004). Such solutions, however, necessitate in big amount of investment and strong financial capabilities.

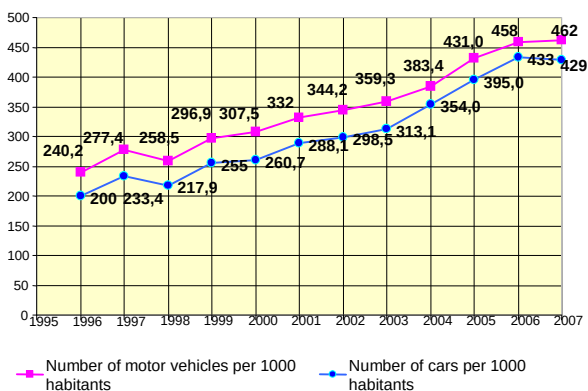


Figure 2. Dynamics of motorization level (Governmental Institution “Regitra”)

Modelling the trips is one another, no less important, part of the scientific research in decreasing the travel numbers or numbers of car users in urban transport system.

Travel demand management measures can be used to encourage car users to set car use reduction goals when experiencing impairments in travel options. In forming plans to reduce car-use contingent on such goals, car users consider a range of adaptation alternatives including more efficient car use, suppressing trips, and switching travel mode (Loukapoulos 2004). According to the analysis performed by Swedish specialists travels can be regulated generalizing them by travel behavior, infrastructure and location (Eliasson and Mattsson 2000) Travel dependence on urban structure and target accessibility is discussed in the analysis performed by Dutch National Travel Survey study in 1998 (Schwanen *et al.* 2001).

In order to reduce the idle time of cars on urban streets, the following could be one of the solutions: rational distribution of transport flows on the urban street network and rational modelling of car driving routes.

The optimal route choice is a problem thoroughly investigated in international literature, with Steenbrink’s 1978 description being a benchmark for further studies. Applying modern computer technologies, intellectual transport information systems could be created. Such type IS also covers the task of rational choice of car driving route. Geographical information system (GIS) technology offers extremely significant power in transport modelling (Arampatzis *et al.* 2004; Brown 2002). GIS could be also applied for the search for rational car routes when it is necessary to be at a specific spot of the network on the specific time. The system offers to a user a rational route, time of departure and calculated expenses depending on the set parameters. In other papers that analyze ap-

plication of GIS technologies in transport task solution, an application of multi-modal networks could be spotted. They are applied when solving route choice tasks within the overall urban transport system (cars, public transport, railway transport, and even pedestrians) (Mahmassani and Liu 1997; Abdelghany et al. 2001). The assessment of transport jams on the street network is necessary when solving the task of the choice of the fastest route. A search algorithm, the results of which depend on the time set by a system user, has been programmed as the street capacity is different depending on the time of the day (Stan and Geertman 1995). The general public might be the user of IS, which helps to choose a rational driving route. Applying ESRI technologies, a system user is given an application, which has functioned allowing to set the beginning and the end of the trip, and the interim stopping places (if necessary). IS user is given a map with the marked rational driving route.

The increasing number of population and the level of motorization cause the problem of parking the solution of which is much more complicated than that of other problems of traffic organization. Each car used in the town should have at least two parking places: near the living place, and near the working place. And each of them needs 25 square meters of the land surface (Burinskiene and Paliulis 2003).

The most urgent problem of parking is encountered in the downtown as it is really complicated to find the space for short-term parking or at least for a short stopping there. The analysis of the parking research development has revealed that at the existing level of motorization when 100 vehicles fall to 1000 inhabitants there is a shortage of the space for parking. First of all, there is the lack of the parking space on the carriageway near the sidewalk; then all the space in the parking facilities is also occupied. The problems become even more urgent when parking is forbidden on the carriageway in order to improve the capacity of the downtown streets (Burinskiene and Paliulis 2003).

Basing on the data of the research conducted in Copenhagen, the Danish scientists state that to meet the needs for parking in the downtowns of the average size towns the number of the parking places should amount to 16–18 % of the total number of the cars registered.

Valuable contribution has been made by German scientists D. Sill, G. Müller, A. Demelmayer, E. Schroder, etc. who carried out researches on the parking problems and their solutions in Hamburg, Koln, Frankfurt, Diuseldorf, Munich. The experience of these towns in the establishment of multi-storey garages in the downtown may be successfully used in the solution of transport problems in the big towns of Lithuania (Cobb 1999; Giuliano 1992; Bjorklun 1995).

Nowadays, in Lithuania designing and construction of new buildings is not allowed in the downtown unless parking facilities of proper capacity are planned.

World wide, transport produces roughly 22 % of carbon emissions and smaller shares of the other five greenhouse gases that are covered under the Kyoto protocol. Transport emissions have a clear tendency to increase and are one of the most challenging sectors because the industry and energetic sectors have decreased emissions during last decade. The number of transport units is increasing very rapidly and measurements show that pollution from mobile transport reach 25 % of the total emissions in Lithuania (State of Environment 2002). The impact and pollution share of transport is much higher in urban territories and a rough estimation indicates that 70–80 % percent in densely populated Lithuanian urban territories are affected.

A number of new vehicle technologies are emerging that may have significant market penetration over the next 20 years. The rapid motorization of transport around the world, the continued availability of low-cost liquid fossil fuels, and more powerful vehicles, all point towards a steady increase of fuel consumption in the near future. Moreover, reconstructed and well-developed transport systems generate higher demands on transportation. Global trading boosts the transportation sector's significance and it becomes the core sector that is the basis of economy in all countries. These are global challenges that must be met by the evolution of transport policies and institutions capable of managing sustainable changes in an increasingly global economy (Grigonis 2004).

1.3. Planning and implementation of urban transport system (vision, strategies, models)

There is growing interest in *sustainability* and its implications for transport planning (Litman and Burwell 2006). Sustainability reflects the fundamental human desire to improve the future world. Sustainability emphasizes the integrated nature of human activities and therefore the need to coordinate decisions among different sectors, groups and jurisdictions. Sustainability planning insures that local, short-term decisions are consistent with strategic, global, long-term goals. This contrasts with reductionism planning, in which problems are assigned to a profession or organization with narrow responsibilities and goals, which can result in solutions to one problem that exacerbate other problems facing society (Litman 2003).

There is no universally accepted definition of sustainability, sustainable development or sustainable transport planning. Below are examples:

Sustainable development “meets the needs of the present without compromising the ability of future generations to meet their own needs.” (WCED 1987)

“Sustainability is equity and harmony extended into the future, a careful journey without an endpoint, a continuous striving for the harmonious co-evolution of environmental, economic and socio-cultural goals.” (Mega and Pedersen 1998)

“...sustainability is not about threat analysis; sustainability is about systems analysis. Specifically, it is about how environmental, economic, and social systems interact to their mutual advantage or disadvantage at various space-based scales of operation.” (TRB 1997)

Sustainability is: “the capacity for continuance into the long term future. Anything that can go on being done on an indefinite basis is sustainable. Anything that cannot go on being done indefinitely is unsustainable.” (Center for Sustainability)

Environmentally Sustainable Transportation (EST) is: *Transportation that does not endanger public health or ecosystems and meets needs for access consistent with (a) use of renewable resources at below their rates of regeneration, and (b) use of non-renewable resources at below the rates of development of renewable substitutes.* (OECD 1998)

Sustainable urban transport planning requires limiting resource consumption to ecological constraints (such as limiting land use to protect habitat and fossil fuel use to minimize climate change), so sustainable development requires maximizing the efficiency with which wealth provides social welfare (happiness), as indicated in Figure 3. Sustainability is sometimes defined narrowly, focusing on a few specific problems such as resource depletion and pollution, but is increasingly defined broadly to include other issues.

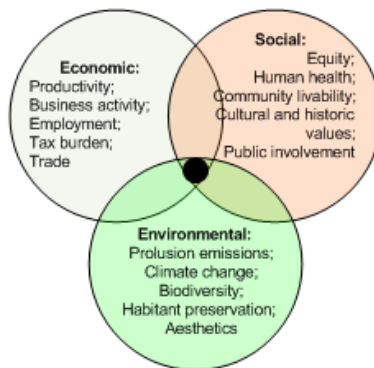


Figure 3. Illustration of various sustainability issues (Victoria Transport Policy Institute)

There are two major groups of policies influencing an individual's travel behaviour and at the same time the energy consumption:

1. Transport policies.
2. Land-use policies.

These policies have a many social, technological political and economical implications in urban areas. Daily short trips are done by walking, cycling, using a car or by public transport in urban territories and there are good opportunities to reduce the number of trips or travel in more sustainable ways, e. g. switching from personal cars to public transport or non-motorized modes. Personal cars have made every corner of the metropolitan area almost equally suitable as a place to live or work. There is no clear understanding of how the development of the transport system influences the spatial distribution of people in urban area (Newman *et al.* 1995; Newman and Kenworthy 2000).

Narrowly defined sustainability can overlook connections between issues and opportunities for integrated solutions. For example, comprehensive analysis helps identify strategies that achieve multiple planning objectives, and so are truly optimal. For example, comprehensive analysis allows planners to identify the congestion reduction strategies that also help achieve equity and environmental objectives, or at least avoid those that are socially and environmentally harmful. These integrated solutions can be considered the most sustainable. If sustainability is defined only in terms of energy consumption and air pollution emissions the best solution may be more efficient and alternative fuel vehicles. But these strategies do not help achieve other planning objectives such as congestion reduction, facility cost savings, increased safety, improved mobility for non-drivers, or more efficient land use development; in fact, by reducing vehicle operating costs, it tends to increase these problems (Litman 2004; Čiegis and Gineitienė 2008). When all impacts are considered, strategies that improve travel options, encourage reduced driving, and create more accessible land use patterns are generally more sustainable overall.

Transport planning has to reflect the requirements of a changing urban context as a result of economic development, concerns in social policy, the increase in affluence and leisure, technological advances, decentralization, and the globalization of economies. These challenges call for an improvement in planning methods, in terms of both quantitative and qualitative analysis. The workflow of planning processes which were idealized in M. Meyer and I. Pas scientific works are presented in Figure 4. A wider view of the socio-economic context implies some new directions in transport planning – for example, moves away from trend-based extrapolation to richer social analysis based on linking transport to what people do and how industries operate, and from "objective" factors in

analysis (e. g. cost and time) towards the acceptance of subjective valuation and political rationality (Banister 2002; Tanczos and Torok 2007).

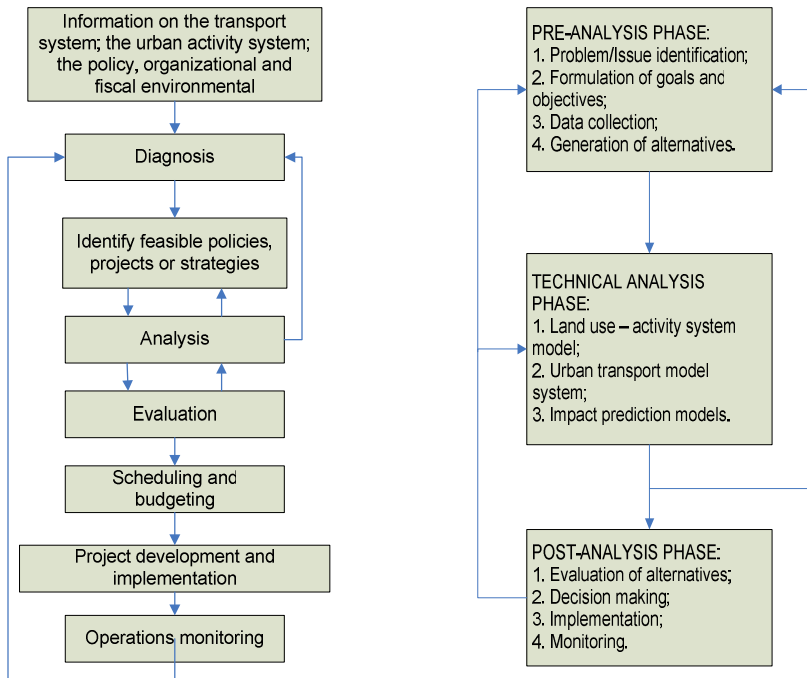


Figure 4. General urban transport system planning processes (*left*: Meyer & Miller, 1984; *right*: Pas, I. 1995)

One of the major challenges of transport planning is the evaluation of transport policies and projects. Basically, evaluation serves to identify the value of individual alternatives and to compare these alternatives with respect to their costs and benefits. The values of alternatives are expressed by measures of effectiveness (MOE), which may be specified for different socio-economic classes or for distributed geographical areas (Meyer and Miller 1984; Pas 1995). Transport policies involve a set of objectives, such as economic efficiency, environmental protection, safety, sustainability, equity, financial availability and practicability. Evaluation of these objectives requires measuring large sets of individual items, which implies a major challenge for data collection and processing. Data organization framework is presented in Figure 5.

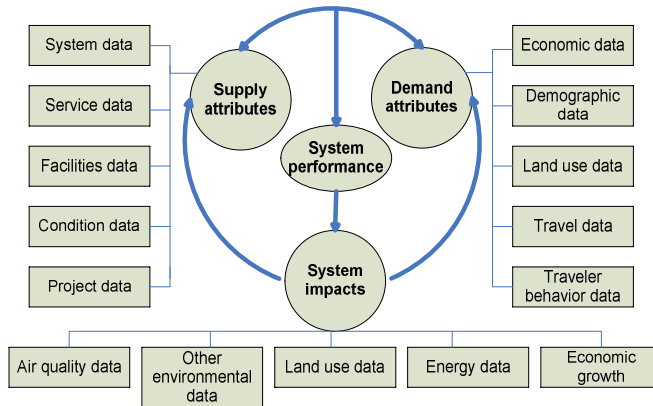


Figure 5. Data organization framework (Jack Faucett Associates, 1997)

Aggregate urban transport system planning models work on a zoned basis, typically called the Transport Analysis Zone (TAZ), in which such data as households and their economic features are aggregated or summed up according to certain criteria. Examples of such models are those used for forecasting trip productions and trip distributions in the traditional four-step Urban Transport Model System (UTMS). The transport modelling process takes advantage of aggregate data on the TAZ to estimate travel demand and makes predictions of traffic flows on the urban transport network (Figure 6). This procedure is generally referred to as a sequential model, which is composed of four distinct steps: trip generation, trip distribution, modal split and trip assignment.

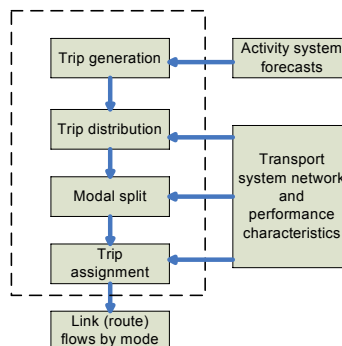


Figure 6. The four-step UTMS process (Meyer & Miller, 1984)

Trip generation estimates the total number of trips that are produced by (origin) or attracted to (destination) each TAZ. Generally, the amount of production for a zone is some function of its aggregated household and demographic characteristics, while the amount of attraction is concerned with the economic activities of the specific zone. Linear regression and category analysis (cross-classification) are the two basic es to trip generation. Linear regression analysis assumes that the number of trips is linearly related to the explanatory variables, and uses empirical data to predict the best-fit combination of those variables. The basis for category analysis is that the households or individuals are classified exclusively according to such categories as household size, age structure, car ownership and income. A trip generation rate is calculated for each category, and the total number of trips generated from a zone is estimated by summing the trips from all categories. Three broad types of information are used in trip generation models: land use type, intensity of land use, and socio-economic characteristics. These explanatory variables can be broken down according to the types of trips being modelled, and the prediction of different trip types needs different variables. Trip distribution estimates how many trips are going from each zone to all other zones. In this phase, the linkages between origins and destinations are determined, based on some measurement of the attractiveness of the destinations and the cost of getting there. By pairing the origin and destination, the overall travel patterns of the study region can be produced. The three most popular types of models for trip distribution are the gravity models, the intervening opportunity models and the entropy models (Sheppard 1995).

The gravity models assume that the number of trips from zone i to j (interaction) is positively related to the number of trips leaving zone i (origin) and to the pull attributes of zone j (destination), but is inversely related to the distance or travel time between the two zones. The measure of distance factor might be physical distance, travel time or travel cost. The intervening opportunity models are derived from the gravity models. The trip distribution calculation in these models is based on the idea that a trip maker leaving a particular origin will consider each possible opportunity sequentially, starting with the closest. The probability of stopping at the closest zone is said to be proportional to the number of opportunities there. The measure of probability depends on the number of opportunities of a zone, and on the probability that the trip maker did not stop at the previous destination. The entropy models are applied in a situation where insufficient data are available. The purpose of the models is to maximize the entropy, with some constraint functions (Webber 1984). Constraints are the information already available on such trip distribution characteristics as trip length, number of trips generated, and the number of trips at each destination.

The modal split (or mode choice) addresses the problem of how the various trips will be made. The origin-destination movements are split by travel mode, and the proportion of trips by each mode is predicted. The important factors influencing the mode selection are travel time and costs, based on which the diversion curves and choice models are utilized. Choice models estimate the probability of selecting one particular travel mode. Binomial or multinomial logic models are commonly used. The task in traffic assignment is to predict the flows along road networks, from origins to destinations, for each travelling mode. The total volume of travel for each network link is calculated based on the aggregation of routes that pass through the link, so the required capacity of the existing or planned road network can be predicted. The simplest strategy for trip assignment is to assign all trips along the shortest path between origin and destination. Two other strategies are available: the incremental assignment and the multi-path assignment. Both these strategies are based on Wardrop's first principle of network equilibrium (Sheppard 1995).

1.4. Indicators and indicators groups of urban transport system

Indicators are things that we measure in order to evaluate progress toward goals and objectives. Indicators should be carefully selected to provide useful information. In most situations, no single indicator is adequate, so a set should be selected. An indicator set should reflect various goals and objectives. For example, it is desirable that a sustainable transportation indicator set reflect the impacts listed in Table 2, and possibly more. People using indicators should understand their perspectives and limitations.

Table 2. Sustainable transportation impacts (Victoria Transport Policy Institute, 2007)

<i>Economic</i>	<i>Social</i>	<i>Environmental</i>
Traffic Congestion; Infrastructure costs; Consumer costs; Mobility barriers; Accident damages; Depletion of non-renewable resources.	Equity / Fairness; Impacts of mobility disadvantage; Human health impacts; Community cohesion; Community liveability; Aesthetics.	Air pollution; Climate change; Noise and water pollution; Habitat loss; Hydrologic impacts; Depletion of non-renewable resources.

These impacts can be defined in terms of goals, objectives, targets and thresholds. For example, a planning process may involve establishing traffic congestion *indicators* (defining how congestion will be measured), *goals* (the amount of congestion reduction desired, including factors such as whether reductions are particularly important for certain trips or vehicles, such as trucks and buses), *objectives* (shifts in travel time and mode to reduce congestion) and *targets* (specific, feasible changes in congestion impacts or travel behaviour that should be achieved), and *thresholds* (levels beyond which additional actions will be taken to reduce congestion).

Different types of indicators reflect different perspectives and assumptions. Some focus on *vehicle travel* or *mobility*, but a better perspective considers *accessibility* (the ability to reach activities and destinations), taking into account travel options and land use patterns (Litman 2003). For example, roadway level-of-service (LOS) primarily reflects automobile travel congestion. It indicates little about the quality of other modes or land use accessibility. A planning process that relies primarily on roadway LOS to evaluate transport system performance implicitly assumes that automobile travel is the most important mode and congestion is the most important problem. Two areas can have equal roadway LOS ratings but very different overall transport system performance due to differences in transport diversity and the distribution of destinations. Similarly, measuring impacts per vehicle-mile, per passenger-mile, per capita or per unit of economic activity reflect different perspectives and assumptions about what is important and desirable.

Indicators can reflect various levels, as illustrated in Table 3. For example, indicators may reflect the decision-making process (the quality of planning), responses (travel patterns), physical impacts (emission and accident rates), effects this has on people and the environment (injuries and deaths, and ecological damages), and their economic impacts (costs to society due to crashes and environmental degradation). The use of indicators is just one step in the overall planning process, which includes consulting stakeholders, defining problems, establishing goals and objectives; identifying and evaluating options, developing policies and plans, implementing programs, establishing performance targets and measuring impacts (Pas 1995). Table 3 shows how indicators can measure various levels of impacts, from the planning process to travel behaviour, impacts on people and the environment, and economic effects. Impacts identified from previous literature are placed into a framework where each can be measured.

Table 3. Level of impacts

<i>Level</i>	<i>Example</i>
External Trends ↓	Changes in population, income, economic activity, political pressures, etc.
Decision Making ↓	Planning process, pricing policies, stakeholder involvement, etc.
Options and Incentives ↓	Facility design and operations, transport services, prices, user information, etc.
Response (Physical Changes) ↓	Changes in mobility, mode choice, pollution emissions, crashes, land development patterns, etc.
Cumulative Impacts ↓	Changes in ambient pollution, traffic risk levels, overall accessibility, transportation costs, etc.
Effects on People and Environmental ↓	Changes in pollution exposure, health, traffic injuries and fatalities, ecological productivity, etc.
Economic Effects ↓	Property damages and productivity losses due to crashes and environmental degradation; increased travel costs due to reduced accessibility.
Performance Evaluation	Ability to achieve specified standards and targets.

Figure 7 is a pictorial representation of the assessment framework, which has been adapted from other sources and also includes key indicators and probable data sources. Many impacts can be included in an assessment framework and the decisions about what impacts to include will vary depending on local context. The impacts in the Vilnius and Kaunas city analysis framework do not

include all the impacts possible, but rather illustrates those that are important based on published literature and stakeholder opinion.

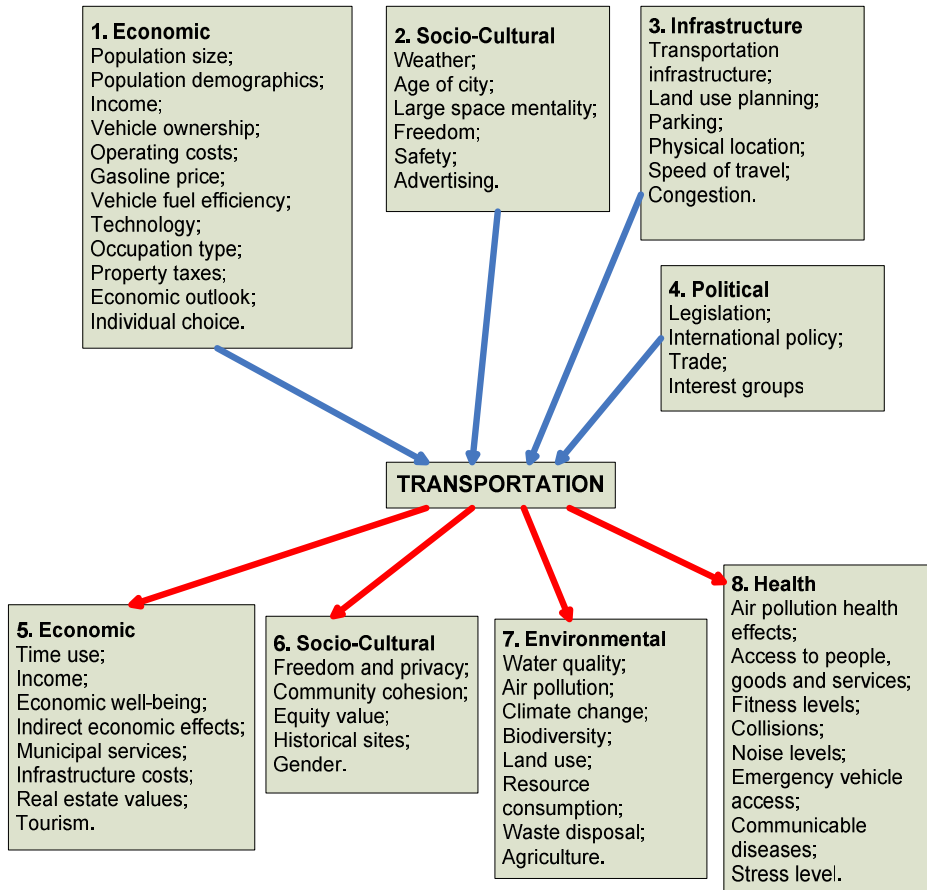


Figure 7. Transportation impact diagram (Marko, 2002)

1.4.1. Indicators by category

This section describes the selection of sustainable transportation indicators by category. There were identified economical, social and environmental groups of indicators.

Economic Indicators

Economic development refers to a community's progress toward economic objectives such as increased income, wealth, employment, productivity and so-

cial welfare. Welfare (as used by economists) refers to total human wellbeing and happiness. Economic policies are generally intended to maximize welfare, although this is difficult to measure directly. Instead, monetary income, wealth and productivity (such as Gross Domestic Product [GDP]) are often used as economic indicators. But these indicators can be criticized on several grounds (Dixon 2004; Cobb et al. 1999):

- They only measure material wealth that is traded in a market, and so overlook other factors that contribute to wellbeing such as health, self-reliance, love, community, pride, environmental resources, freedom, etc.
- These indicators give a positive value to destructive activities that reduce people's health and self-reliance, and therefore increase their use of market goods (medical services, purchased rather than home-grown or gathered foods and fuel).
- As they are typically used, these indicators do not reflect the distribution of wealth (although they can be used to compare wealth between different groups).

Two communities can have similar economic productivity, and two people can have similar wealth, yet one has greater wellbeing overall due to differences in how the wealth is created, distributed and used. There are many possible traps by which increased wealth can fail to increase welfare, for example, if a productive process harms the environment and makes people sick, if wealth distribution is severely unequal, if wealth is spent inefficiently, and if increased material wealth disrupts community cohesion, pride, freedom or other non-market goods.

Transportation can leverage other economic impacts. Vehicle and fuel expenditures tend to provide less business activity and employment than most other consumer expenditures, since they are mostly imported and capital rather than labor intensive. Such expenditures are particularly burdensome to the economies of developing countries that import petroleum. Increased motor vehicle ownership and use increase road and parking facility costs, reduce productivity due to congestion, and harm certain industries, particularly those that require clean environments such as tourism, agriculture and fisheries.

Sustainable transportation economic indicators should reflect both the benefits and costs of motor vehicle use, and the possibility that more motorized mobility reflects a reduction in overall accessibility and transport diversity, rather than a net gain in social welfare. Increased mobility that provides little or negative net benefits to society can be considered to reduce sustainability, while policies that increase the net benefits from each unit of mobility can be considered to increase sustainability. Table 4 presents list of possible economic indicators of sustainable transportation.

Table 4. Economic indicators of sustainable transportation (Victoria Transport Policy Institute, 2007)

<i>Indicator</i>	<i>Description</i>	<i>Direction</i>
User satisfaction	Overall transport system user satisfaction ratings.	More is better
Commute time	Average door-to-door commute travel time.	Less is better
Employment accessibility	Number of job opportunities and commercial services within 30 minute travel distance of residents.	More is better
Land use mix	Average number of basic services (schools, shops and government offices) within walking distance of homes.	More is better
Electronic communication	Portion of population with Internet service.	More is better
Vehicle travel	Per capita motor vehicle-mileage, particularly in urban peak conditions.	Less is better
Transport diversity	Variety and quality of transport options available in a community.	More is better
Mode split	Portion of travel made by non automobile modes: walking, cycling, rideshare, public transit.	More is better
Congestion delay	Per capita traffic congestion delay.	Less is better
Travel costs	Portion of household expenditures devoted to transport.	Less is better
Transport costs efficiently	Transportation costs as a portion of total economic activity, and per unit of GDP.	Less is better
Facility costs	Per capita expenditures on roads, parking and traffic services.	Less is better
Cost efficiently	Portion of road and parking costs borne directly by users.	More is better
Freight efficiently	Speed and affordability of freight and commercial transport.	More is better
Delivery services	Quantity and quality of delivery services (international/intercity courier, and stores that offer delivery).	More is better
Commercial transport	Quality of transport services for commercial users (businesses, public agencies, tourists, convention attendees).	More is better

Crash costs	Per capita crash costs	Less is better
Planning quality	Comprehensiveness of the planning process: whether it considers all significant impacts and uses best current evaluation practices.	More is better
Mobility management	Implementation of mobility management programs to address problems and increase transport system efficiency.	More is better
Pricing reforms	Implementation of pricing reforms such as congestion pricing, Parking Cash Out, tax reforms, etc.	More is better
Land use planning	Applies smart growth land use planning practices, resulting in more accessible, multi-modal communities.	More is better

Social Indicators

Social impacts include equity, human health (which is also an economic impact if disease imposes financial costs or reduces productivity), community livability (the quality of the local environment as experienced by people in an area) and community cohesion (the quality of interactions among people living in a community), impacts on historic and cultural resources (such as historic sites and traditional community activities), and aesthetics. Various methods can be used to quantify these impacts (Forkenbrock et al. 2001; Litman 2004).

Transportation equity can be evaluated in Caubel works (Caubel 2004). It requires comparing differences in transport options, service quality, impacts and between different groups, particularly impacts on people who are economically, physically and socially disadvantaged.

Human health impacts of transportation include accident injuries, pollution illness, and health problems from inadequate physical activity. Policies that improve walking and cycling conditions and increase non-motorized travel improve mobility for disadvantaged people and increase fitness and so tend to support sustainable transportation. Community livability and cohesion (Litman 2006) can be measured using field surveys to see how transport facilities and activities impact the human environment, surveys of residents to determine how these impacts affects interactions among neighbors, and economic surveys to see how this affects property values and business activity. Historic and cultural resources can be evaluated using surveys which ascertain the value people place on them. Table 5 presents list of possible social indicators of sustainable transportation.

Table 5. Social indicators of sustainable transportation (Victoria Transport Policy Institute, 2007)

<i>Indicator</i>	<i>Description</i>	<i>Direction</i>
User rating	Overall satisfaction of transport system by disadvantaged users.	More is better
Safety	Per capita crash disabilities and fatalities.	Less is better
Fitness	Portion of population that walks and cycles sufficient for fitness and health (15 minutes or more daily).	More is better
Community livability	Degree to which transport activities support community livability objectives (local environmental quality).	More is better
Cultural preservation	Degree to which cultural and historic values are reflected and preserved in transport planning decisions.	More is better
Non-drivers	Quality of transport services and access for non-drivers.	More is better
Affordability	Portion of budgets spent on transport by lower income households.	Less is better
Disabilities	Quality of transport facilities and services for disabled people.	More is better
Non motorized transport	Quality of walking and cycling conditions.	More is better
Children's travel	Portion of children's travel to school and other local destinations by walking and cycling.	More is better
Inclusive planning	Substantial involvement of affected people, with special efforts to insure that disadvantaged and vulnerable groups are involved.	More is better

Environmental Indicators

Environmental impacts include various types of air pollution (including gases that contribute to climate change), noise, water pollution, depletion of non-renewable resources, landscape degradation (including pavement or damage to ecologically productive lands, habitat fragmentation, hydrologic disruptions due to pavement), heat island effects (increased ambient temperature resulting from pavement), and wildlife deaths from collisions. Various methods can be used to measure these impacts and quantify their ecological and human costs (Litman and Burwell 2006; FHWA 2004).

Of course there is considerable uncertainty about many of these costing methodologies and the resulting values. There are various ways of dealing with such uncertainty, including improved analysis methodologies, use of cost ranges rather than point values, and establishment of reference standards (such as acceptable levels of ambient air pollution and noise levels).

Many existing estimates of environmental impacts are partial analyses. For example, many monetized estimates of air pollution costs only include a portion of the types of harmful emissions produced by motor vehicles, and many only consider human health impacts, ignoring ecological, agricultural and aesthetic damages (Litman and Burwell 2006). Table 6 presents list of possible environmental indicators of sustainable transportation.

Table 6. Environmental indicators of sustainable transportation (Victoria Transport Policy Institute, 2007)

<i>Indicator</i>	<i>Description</i>	<i>Direction</i>
Climate change emissions	Per capita fossil fuel consumption, and emissions of CO ₂ and other climate change emissions.	Less is better
Other air pollution	Per capita emissions of “conventional” air pollutants (CO, VOC, NO _x , particulates, etc.)	Less is better
Air pollution	Frequency of air pollution standard violations.	Less is better
Noise pollution	Portion of population exposed to high levels of traffic noise.	Less is better
Water pollution	Per capita vehicle fluid losses.	Less is better
Land use impacts	Per capita land devoted to transportation facilities.	Less is better
Habitat protection	Preservation of high-quality wildlife habitat (wetlands, old-growth forests, etc.)	More is better
Habitat fragmentation	Average size of road less wildlife preserves.	More is better
Resource efficiency	Non-renewable resource consumption in the production and use of vehicles and transport facilities.	Less is better

In practice, it is often infeasible to apply all the indicators described above, due to data collection and analysis costs. Later in this report these indicators are

prioritized to indicate those that are most important and should usually be applied.

Accounting Indicators

Sustainable indicator systems are generally separate from conventional statistics and accounting systems commonly used by public and private organizations to evaluate the value of assets and activities, such as censuses, national accounts and corporate reports.

Yet, both systems are based on the same principles and similar data. It may be possible to integrate these systems to provide comprehensive indicators, so sustainability evaluation systems incorporate economic accounting, and economic accounting systems incorporate sustainability indicators (Federal Statistical Office Germany 2005).

Integrating these different systems requires the following:

1. Accountants and statisticians are consulted concerning the developing of sustainability indicators so that, as much as possible, indicators are consistent with standard accounting principles and practices. For example, resource consumption data, such as energy and water use, can be collected and incorporated into annual reports in order to indicate the resource efficiency of production (energy and water consumed per unit of output).
2. As much as possible, non-market impacts (such as environmental assets and human health damages) are monetized (measured in monetary units) so that they can be incorporated into standard accounts. For example, corporate accounts can include an “environmental assets” section, and the value of lost ecological services that results when land is paved can be treated as depreciation, and the value of improved environmental quality that results when a brown field site is cleaned up can be treated as asset appreciation.
3. Sustainability indicators include special analysis of long-term asset valuation and profitability. For example, strategic plans can be evaluated in terms of their impacts on corporate value a decade in the future.

There is a danger that efforts to integrate economic and sustainability indicators will end up focusing on factors that are easier to measure (such as quantified economic impacts) and overlook factors that are more difficult to measure (such as qualitative environmental and social impacts) and so perpetuate current biases.

1.4.2. Examples of sustainable transportation indicators sets

Indicators sets are different according their orientation directions. Some indicators sets are oriented to ecology and environmental aspects and they adore “green” community, other indicators sets are oriented to transport system per-

formance: sustainable mobility, safety, comfort ability, mobility for people with special needs and disadvantages. These include indicators related to roadway conditions (congestion, travel times, crashes and technical infrastructure), freight transport efficiency, pollution emissions, quality of various modes (including walking, cycling and public transit) and user satisfaction. There were analyzed four sets of indicators:

- World Business Council Sustainable Mobility Indicators;
- European Union's *Transport and Environment Reporting Mechanism* (TERM);
- European Commission sponsored project *Sustainable Mobility Measures and Assessment* (SUMMA);
- Lyons regional indicators.

The Table 7 below summarizes sustainable mobility indicators developed for the World Business Council's Sustainable Mobility project.

Table 7. Sustainable mobility indicators (Eads 2003)

<i>User concerns</i>	<i>Societal concerns</i>	<i>Business concerns</i>
Ease of access to means of mobility; Financial outlay required of user; Average door-to-door time required; Reliability, measured as variability in average door-to-door time; Safety (chance of death or serious injury befalling the user); Security (chance of the user being subjected to robbery, assault, etc.).	Impacts on the environment and on public health and safety; Greenhouse gas emissions (CO ₂ equivalent); "Conventional" emissions – NO _x , CO, SO ₂ , VOC, particulates; Safety (number of deaths and serious injuries); Security; Noise; Land use; Resource use (including recycling); Impacts on public revenues and expenditures; "Launching aid"; Publicly-provided infrastructure; Required operating subsidies; Potential for reducing public expenditures; Potential for generating government revenues; Equity impacts.	Profitability (ability to earn at least a competitive return on investment); Total market size; Conditions determining market acceptance; Required competences; Private investment required; Necessity/possibility of "launching aid" and pay-back conditions; Investment net of publicly provided infrastructure; Cash flow generation; Potential cash flow from Operations; Gap between likely actual and required cash flow, potential for public subsidies; Policy barriers/incentives.

The European Union's *Transport and Environment Reporting Mechanism* (TERM) identifies the sustainable transportation indicators summarized and presented in Table 8.

Table 8. Summarized indicators of transport sustainability in TERM project

Group	Indicators	
Transport and environmental performance		
Environmental consequences of transport	Transport final energy consumption and primary energy consumption, and share in total (fossil, nuclear, renewable) by mode	
	Transport emissions and share in total emissions for CO ₂ , NO _x , NM, VOCs, PM ₁₀ , SO _x , by mode	
	Exceedances of air quality objectives	
	Exposure to and annoyance by traffic noise	
	Infrastructure influence on ecosystems and habitats (“fragmentation”) and proximity of transport infrastructure to designated sites	
	Land take by transport infrastructures	
Transport volume and intensity	Number of transport accidents, fatalities, injured, polluting accidents (land, air and maritime)	
	Passenger transport (by mode and purpose): total passengers total passenger-kilometres passenger-kilometres per capita passenger-kilometres per GDP	Freight transport (by mode and group of goods): total tones total tone-kilometres tone-kilometres per capita tone-kilometres per GDP
Determinants of the Transport/environment System		
Spatial planning and accessibility	Average passenger journey time and length per mode, purpose (commuting, shopping, leisure) and territory (urban/rural)	
	Access to transport services e. g.: motor vehicles per household, portion of households located within 500m of public transport	
Transport supply	Capacity of transport infrastructure networks, by mode and by type of infrastructure (e. g. motorway, national road, municipal road etc.)	
	Investments in transport infrastructure/capita and by mode	
Price signals	Real passenger and freight transport price by mode	
	Fuel price	
	Taxes	
	Subsidies	
	Expenditure for personal mobility per person by income group	

	Proportion of infrastructure and environmental costs (including congestion costs) covered by price.
Technology and utilization efficiency	Energy efficiency for passenger and freight transport (per pass-km and per tone-km and by mode)
	Emissions per pass-km and emissions per tone-km for CO ₂ , NO _x , NM, VOCs, PM ₁₀ , SO _x by mode.
	Occupancy rates of passenger vehicles
	Load factors for road freight transport (LDV, HDV)
	Uptake of cleaner (unleaded petrol, electric, alternative fuels) and alternative fuelled vehicles
	Vehicle fleet size and average age
	Proportion of vehicle fleet meeting certain air and noise emission standards (by mode)
Management integration	Number of Member States that implement an integrated transport strategy
	Number of Member States with national transport and environment monitoring system
	Uptake of strategic environmental assessment in the transport sector
	Uptake of environmental management systems by transport companies
	Public awareness and behaviour

SUMMA is a European Commission sponsored project to define and to analyze sustainable mobility, develop indicators, assess the scale of sustainability problems associated with transport, and identify policy measures to promote sustainable transport. Table 9 shows the scope of its analysis.

Table 9. SUMMA outcomes of interest

<i>Economic</i>	<i>Environmental</i>	<i>Social</i>
<i>EC1: Accessibility</i> Economic accessibility has two aspects: (1) local access of goods and people to services, work, industrial plants, etc., and (2) long distance links among regions	<i>EN1: Resource use</i> The use of materials, energy and other resources by the transport sector	<i>SO1: Accessibility and affordability</i> The time and cost required to reach basic services. Lower income individuals generally have poorer accessibility to basic services than those well off
<i>EC2: Transport operating costs</i> The costs to the user of the transport system, both direct user costs (fuel, ticket	<i>EN2: Direct ecological intrusion</i> The impacts of transport on flora and fauna that are not caused by emissions or pollu-	<i>SO2: Safety and security</i> Safety implies freedom from danger. Security concerns freedom from fear (of crime or other undesired actions)

prices, transport equipment), and indirect costs, such as the costs of congestion	tion, but rather by transport infrastructure (building, using, and maintaining)	
<i>EC3: Productivity/Efficiency</i> Providing conditions for an expanding, productive and efficient economy, and therefore for more individual and public welfare. Inefficiencies increase the resources needed to produce benefits	<i>EN3: Emissions to air</i> Emissions of pollutants, etc. Into the air, which affect health and harm buildings? Also the emission of greenhouse gasses, which contributes to global warming	<i>SO3: Fitness and health</i> The trend to perform short trips by car decreases fitness and increases the threat to health (through increased pollution)
<i>EC4: Costs to economy</i> All costs of transport (except for the individual user), i.e. infrastructure investments, maintenance, public subsidies, final energy consumption and external costs of transport	<i>EN4: Emissions to soil and water</i> Emissions of pollutants to soil and water, wastewater from manufacture and maintenance, runoff from roads, discharges of oil and wastewater by ships, etc	<i>SO4: Livability and amenity</i> Transport influences our quality of life. It concerns an individual's direct surroundings and the impact transport has on it. It concerns not only measurable aspects (noise, pollution) but also perceptions and attitudes
<i>EC5: Benefits to economy</i> The gross value added generated by the transport sector, national revenues from taxes and traffic system charging, and economic growth induced by transport	<i>EN5: Noise</i> Transport is one of the most significant sources of noise in urban areas. There is evidence that noise is related to human and animal health and wellbeing	<i>SO5: Equity</i> This concerns the fair distribution of costs and benefits among different groups in society, among income classes, among regions, and among generations
	<i>EN6: Waste</i> Transport vehicles and infrastructure create large amounts of waste during their life cycle, which can partly be recycled or reused, but is otherwise disposed of by incineration and in landfills	<i>SO6: Social cohesion</i> The ongoing process of developing a community of shared values, challenges and opportunities based on trust, hope and reciprocity. It is related to <i>social capital</i> , which refers to features of social organization such as networks, norms, and social trust that facilitate cooperation for mutual benefit

Nicolas, J. P and others describe how local travel survey data and other available information are used to evaluate transport system sustainability in Lyons, France. This region has 1.2 million inhabitants with a relatively centralized, urban development pattern.

Indicators were organized to reflect economic, social and environmental impacts. Economic indicators reflect transport cost-efficiency, that is, the economic costs per unit of travel, including costs to residents, businesses, and governments. Social indicators reflect the relative mobility and transportation cost burdens for people in different income classes. Environmental indicators reflect various transport pollution emissions and land requirements. These impacts were disaggregated by mode (automobile, public transit, walking), geographic location (central, middle and outer urban areas) and household demographics. Table 10 summarizes these indicators.

Table 10. Summarized Lyons indicators of sustainable transportation

<i>Dimension</i>	<i>Indicator</i>	<i>Level of analysis</i>
<i>Mobility</i>		
Service provided	Daily number of trips; Trip purposes; Average daily travel time	Overall and by geographic location
Organization of urban mobility	Mode split; Daily average distance traveled; Average travel speed	Overall and by travel mode
<i>Economic</i>		
Cost for the community	Annual transportation costs (total, per resident and per passenger km): households; businesses; local government	Overall and per mode
<i>Social</i>		
	Household vehicle ownership; Personal travel distance; Household transportation expenditures (total or as a portion of income)	Overall by income and geographic location
<i>Environmental</i>		
Air pollution – global	Annual energy consumption and CO ₂ emissions (total and per resident)	Overall, by mode, by location of emission, and location of resident
Air pollution – local	CO, NO _x , hydrocarbons and particulates (total and per resident)	Overall, by mode, by location of emission, and location of resident
Space consumption	Daily individual consumption of public space for transport and parking; Space required for transport infrastructure	Overall, by mode and place of residence
Other	Noise; Accident risk	Overall, by mode and place of residence

The following principles should be applied when selecting transportation performance indicator (Marsden *et al.* 2006):

- *Comprehensive* – Indicators should reflect various economic, social and environmental impacts, and various transport activities (such as both personal and freight transport).
- *Data quality* – Data collection practices should reflect high standards to insure that information is accurate and consistent.
- *Comparable* – Data collection should be standardized so the results are suitable for comparison between various jurisdictions, times and groups. Indicators should be clearly defined. For example, “Number of people with good access to food shopping” should specify ‘good accesses’ and ‘food shopping.’
- *Easy to understand* – Indicators must useful to decision-makers and understandable to the general public. The more information condensed into a single index the less meaning it has for specific policy targets (for example, *Ecological Footprint* analysis incorporates many factors) and the greater the likelihood of double counting.
- *Accessible and Transparent* – Indicators (and the data they are based on) and analysis details should be available to all stakeholders.
- *Cost effective* – The suite of indicators should be cost effective to collect. The decision-making worth of the indicators must outweigh the cost of collecting them.
- *Net Effects* – Indicators should differentiate between net (total) impacts and shifts of impacts to different locations and times.
- *Performance targets* – select indicators that are suitable for establishing usable performance targets.

Analysis of different indicators groups systems showed that it is possible to divide economic, social and environmental indicators into most important and less important. Also were evaluated the main benefits of planning processes and market efficiency. Table 11 shows lists recommended indicator sets grouped into *Most Important* (should usually be used), *Less Important* (should be used if possible) and *Specialized* (should be used to reflect particular needs or objectives).

Much of the data required for these indicators may be available through existing sources, such as censuses and consumer surveys, travel surveys and other reports. Some data can be collected during regular planning activities. For example, travel surveys and traffic counts can be modified to better account for alternative modes, and to allow comparisons between different groups (e. g., surveys can include questions to categorize respondents). Some indicators require special data that may require additional resources to collect.

Some of these indicators overlap. For example, there are several indicators of transport diversity (quality and quantity of travel options, mode split, quality of non-motorized transport, amount of non-motorized transport, etc.), and cost-based pricing (the degree to which prices reflect full costs) is considered an indicator of both economic efficiency and equity/fairness. It may be most appropriate to use just one such indicator, or if several similar indicators are used, give each a smaller weight.

Table 11. Recommended indicators sets

	<i>Economic</i>	<i>Social</i>	<i>Environmental</i>
<i>Most important (should usually be used)</i>	Personal mobility (annual person kilometres and trips) and vehicle travel (annual vehicle-kilometres), by mode (non-motorized, automobile and public transport); Freight mobility (annual tone-kilometres) by mode (truck, rail, ship and air); Land use density (people and jobs per area of land); Average commute travel time and reliability. Average freight transport speed and reliability; Per capita congestion costs; Total transport expenditures (vehicles, parking, roads and transit services).	Per capita traffic crash and fatality rates; Quality of transport for disadvantaged people (disabled, low incomes, children, etc.); Affordability (portion of household budgets devoted to transport); Overall transport system satisfaction rating (based on objective user surveys); Universal design (degree to which the transport system accommodates people with disabilities and other special needs).	Per capita energy consumption, by fuel and mode; Energy consumption per freight ton-kilometre; Per capita air pollution emissions (various types), by mode; Air and noise pollution exposure and health impacts; Per capita land paved for transport facilities (roads, parking, ports and airports).
<i>Less important (should be used if possible)</i>	Quality (availability, speed, reliability, safety and prestige) of non-automobile modes (walking, cycling, ridesharing and public transit); Number of public services	Portion of residents who walk or bicycle sufficiently for health (15 minutes or more daily); Portion of children walking or cycling to school; Degree cultural re-	Community liveability ratings; Water pollution emissions; Habitat preservation in transport planning; Use of renewable fuels;

	within 10 minute walk and job opportunities within 30 minute commute of residents; Portion of households with internet access.	sources are considered in transport planning; Housing affordability in accessible locations; Transit affordability.	Transport facility resource efficiency (such as use of renewable materials and energy efficient lighting); Impacts on special habitats and environmental resources.
<i>Planning process</i>	Comprehensive (considers all significant impacts, using best current evaluation practices, and all suitable options, including alternative modes and demand management strategies); Inclusive (substantial involvement of affected people, with special efforts to insure that disadvantaged and vulnerable groups are involved); Based on <i>accessibility</i> rather than <i>mobility</i> (considers land use and other accessibility factors).		
<i>Market efficiency</i>	Portion of total transportation costs that are efficiently priced; Neutrality (public policies do not arbitrarily favour a particular mode or group) in transport pricing; taxes, planning, investment, etc. Applies <i>least cost planning</i> .		

Indicators can be disaggregated by demographic (income, employment, gender, age, physical ability, minority status, etc.) and geographic factors (urban, suburban, rural, etc.), time (peak and off-peak, day and night), and by mode (walking, cycling, transit, etc.) and trip (commercial, commuting, tourism, shopping, etc.). For equity analysis, special consideration should be given to transport service quality and cost burdens for disadvantaged people (people with disabilities, low incomes, children, etc.). For example, compare the portion of household income devoted to transport, and satisfaction with the transport system, between people with and without disabilities, the lowest and the average income quintile, and young adults with other age groups. Similarly, special consideration can be applied to the quality of “basic access” (transport with high social value, such as access to for emergency and service vehicles, medical services, education, employment, etc.), by measuring how often people are unable to make such trips.

1.5. Implementation of sustainable principles of urban transport system in comprehensive and strategic urban planning

There were identified four basic themes emerged from the public review of the principles (Banister 2002). The principles provide a framework for transportation investment over the long term. After their adoption in 1997, they have quickly had significant impacts on how transportation planning is approached and where public transportation investments are made and these principles should be taken into account when performing comprehensive and strategic planning processes.

The principles are organized under four broad themes:

- **Preserve and Manage.** Highest priority is preserving and managing existing investment in the region's transportation system. The priority for improved design and condition of major facilities should not depend upon whether the facility is owned by the state, county, city, town or village.
- **Develop the Region's Potential.** The Capital Region is a single economic unit containing a rich heritage, historic communities that cannot be replicated elsewhere, vibrant suburban areas, abundant open space and recreational opportunities, great natural resources and a highly educated work force. This region can grow into a uniquely attractive, vibrant and diverse metropolitan area. It is necessary to consider community and economic development plans as essential factors in making transportation investment decisions.
- **Link Transportation and Land Use.** Local land use decisions impact the function of the transportation system. This relationship is paramount to all transportation planning and programming decisions. Achieving the plan's goals depends as much on achieving unprecedented success in the land use area as on improving the transportation system.
- **Plan and Build for All Modes.** Transportation planning and project design need to consider and accommodate more than cars. Pedestrians, bicyclists, delivery vehicles, long-distance trucks, rail crossings and intermodal terminal access are among the modes and modal considerations elevated by the plan.

Meyer, M. D. and Miller, E. J. in their works identify four basic elements in urban transport systems strategic planning (Meyer and Miller 1984). Urban transport system strategic planning must be supply requirements of access, people and communities, environmental quality and economic viability.

1.6. Multi-attribute decision making analysis methods

Multi-attribute decision making is the most well known branch of decision making. It is a branch of a general class of Operations Research (OR) models which deal with decision problems under the presence of a number of decision criteria. This super class of models is very often called multi-criteria decision making (MCDM). According to many authors (Zimmermann 1991) MCDM is divided into Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM). MODM studies decision problems in which the decision space is continuous. A typical example is mathematical programming problems with multiple objective functions. The first reference to this problem, also known as the "*vector-maximum*" problem, is attributed to (Kuhn and Tucker 1951). On the other hand, MADM concentrates on problems with discrete decision spaces. In these problems the set of decision alternatives has been predetermined. Although MADM methods may be widely diverse, many of them have certain aspects in common (Hwang and Yoon 1981). These are the notions of alternatives, and attributes (or criteria, goals) as described next.

Researchers on regional development devote little attention to socio-economic distinctions within peripheral and core regions, rather stressing disparities between regions. To illustrate this, we may mention selected studies of developed and developing countries that examine the spatial distribution of social-welfare and development variables (Lipshitz and Raveh 1994; Nijkamp 1988; Smith 1987) studies dealing with migration and its mutual association with regional development (Brown 1988; Vining and Palone 1982), and research on spatial variations of employment and unemployment structure (Martin 1988).

This work illustrates an application of the MCDM approach to the problem of selecting a better development scenario of Vilnius city based on priority of transport system also MCDM were used for performing ranking of Vilnius city traffic analysis zones (TAZ) and Lithuanian administrative districts. Unlike traditional operations research optimization problems, which deal with a single objective function to be optimized over a set of feasible solutions, MCDM refers to making decisions in the presence of multiple, usually conflicting and non-commensurable criteria (Zanakis *et al.* 1998). Three discrete MCDM methods using a given set of a countable number of alternatives and based on the inter and intra-comparison of quantifiable attributes (criteria) of these alternatives and their implicit and explicit trading-off are chosen. These are the SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) and AHP (Analytic Hierarchy Process).

There are many MCDM methods available in the literature. Each method has its own characteristics. There are many ways one can classify MCDM

methods. One way is to classify them according to the type of the data they use. That is, we have deterministic, stochastic, or fuzzy MCDM methods. However, there may be situations which involve combinations of all the above (such as stochastic and fuzzy data) data types.

Another way of classifying MCDM methods is according to the number of decision makers involved in the decision process. Hence, there is single decision maker MCDM methods and group decision making MCDM.

Multiple-Criteria Decision-Making (MCDM) classification is often made, based on the size of the set of strategies:

- MADM – concerned with choosing from small, finite, or countable number of strategies.
- MODM – concerned with choosing from a large, infinite, or uncountable number of alternatives.

The distinction between MADM and MODM is based on the evaluation criteria which are the standards of judgments or rules on which the alternatives are ranked according to their desirability. Criterion is a general term and includes both the concepts of attributes and objectives. An attribute is a measurable quantity whose value reflects the degree to which a particular objective is achieved. An objective is a statement about the desired state of the system under consideration (Nijkamp 1988). It indicates the directions of improvement of one or more attributes. Objectives are functionality related to, or derived from a set of attributes (Smith 1987). There might be formal relationship between objectives and attributes, but usually the relationship is informal. To assign an attribute to a given objective, two properties which are comprehensiveness and measurability should be satisfied. An attribute is comprehensive if its value sufficiently indicates the degree to which the objective is met. And it is measurable if it is reasonably practical to assign a value in a relevant measurement scale. The ratio, interval, ordinal and binary scales are suitable for measurement of attributes, whereas nominal scale is not since it does not allow an ordering of the alternatives (Nijkamp 1988). MADM problems require that choices be made among alternatives described by their attributes. The set of attributes is given explicitly and multiattribute problems have a finite set of feasible alternatives. Unlike MADM, MODM problems require that means-ends relationships be specified, since they deal explicitly with the relationship of attributes of alternatives to higher level objectives. MODM involves designing the alternatives and searching for the best decisions among an infinite or very large set of feasible alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions (Malczewski 1999).

Table 12. Comparison of MODM and MADM Approaches (Hwang and Yoon, 1981; Starr and Zeleny, 1977)

PARAMETER	MODM	MADM
Criteria defined by:	Objectives	Attributes
Objectives defined:	Explicitly	Implicitly
Attributes defined:	Implicitly	Explicitly
Constraints defined:	Explicitly	Implicitly
Alternatives defined:	Implicitly	Explicitly
Number of alternatives	Infinite (large)	Finite (small)
Decision maker's control	Significant	Limited
Decision modelling paradigm	Process-oriented	Outcome-oriented
Relevant to:	Design/search	Evaluation/choice
Relevance of geographical data structure	Vector-based GIS	Raster-based GIS

Both MADM and MODM problems can be further classified as individual and group decision making depending on the goal-preference structure. If there is a single goal preference, the problems is considered as individual decision making regardless of the number of decision makers involved in the process. However, if the individual or interest groups are characterized by different goal preferences, the problem becomes the group decision making (Malczewski 1999).

The other classification depends on the certainty of the decision. If the decision maker has perfect knowledge of the decision environment and the amount of knowledge available is enough, then the decision is considered as decision under certainty. However, most of the real world decisions involve some aspects that are unknown and difficult to predict. This type of decisions is referred as decisions under uncertainty. The decisions under uncertainty can be further subdivided into fuzzy and probabilistic decision making. The probabilistic decisions are handled by probability theory and statistics. And the outcome of a stochastic event is either true or false. However, if the situation is ambiguous, the problem is structured as the degree of how much an event belongs to a class. This type of problems is handled by fuzzy set theory (Zadeh 1978).

In many decision rules it is assumed that complete information is available so that the criterion outcomes of each alternative are precisely known. However, in real world situations, this is not the case and analysis should be made to investigate whether the preliminary conclusions are robust or not. Sensitivity analysis aims to identify the effects of changes in the inputs which are geographical data

and the decision maker's preferences on the outputs, in other words, on the ranking of alternatives. If the changes do not significantly affect the outputs, then the ranking is assumed as robust and satisfactory. If the result is unsatisfactory, it should be return to the problem formulation step (Malczewski 1999).

Table 13 shows a summary of the most often used MODM.

Table 13. A summary of the most often used MODM (Ríos Insua 1990)

MODM Method	Input	Output	Types of Decisions	DM Interaction	Assumptions
Value/utility models	Value/utility functions, weights	Best alternative	Individual DM, deterministic, probabilistic	Moderate/high	Very restrictive
Goal programming	Aspiration levels, priorities, weights	Best alternative	Individual DM, deterministic, fuzzy	High	Very restrictive
Interactive programming	Aspiration, reservation	Satisfying alternative	Individual DM, deterministic, fuzzy	Moderate increases with problem size	Moderately, restrictive
Compromise programming	Ideal point, weights	Compromise alternative, cardinal ranking	Individual and group DMs, probabilistic, fuzzy	Moderate	Moderately, restrictive
Data envelopment analysis	Set of evaluation inputs and outputs	Cardinal ranking	Individual and group DMs, deterministic, probabilistic, fuzzy	Low	Moderately, restrictive

Because of its wide scope, many mathematical methodologies have been developed over the years to solve MADM problems. Naturally, some methods are more suitable and efficient than others in the solution of each particular decision problem. However, such knowledge is not readily available and this has deterred many potential users from utilizing these methods. From research, it was found that several methods were used for solving a decision problem throughout the entire process. Hence, the system should preferably contain suffi-

cient number of methods for the decision makers' use during the decision making process.

To harness the potential of these methods effectively, the system must possess two important characteristics. Firstly, it should possess the flexibility to be modified so that new or revised methods could be introduced when the need arises. Secondly, it should be capable of guiding users possessing various levels of expertise on the usage of these MADM methods. In this research analysis of urban transport system were performed by using several MADM methods. Table 14 shows a summary of the most often used MADM.

Table 14. A summary of the most often used MADM (Malczewski 1999)

MADM method	Input	Output	Decision types
Scoring (SAW)	Attribute scores, weights	Ordinal ranking	Individual DM, deterministic
Multi-attribute value	Value functions, weights	Cardinal ranking	Individual and group DMs, deterministic, fuzzy
Multi-attribute utility	Utility functions, weights	Cardinal ranking	Individual and group DMs, probabilistic, fuzzy
Analytic hierarchy process (AHP)	Attribute scores, pair wise comparisons	Cardinal ranking (ratio scale)	Individual and group DMs, deterministic, probabilistic, fuzzy
Ideal point (TOPSIS)	Attribute scores, weights, ideal point	Cardinal ranking	Individual and group DMs, deterministic, probabilistic, fuzzy
Concordance	Attribute scores, weights	Partial or ordinal ranking	Individual and group DMs, deterministic, probabilistic, fuzzy
Ordered weighted averaging	Fuzzy attribute, weights, order weights	Cardinal or ordinal ranking	Individual and group DMs, fuzzy

1.7. Practice of multi criteria decision support system methods usage in Lithuania and in foreign countries

Many scientists were performing analysis of multi criteria methods. Scientists like Mahmoud M. R. and Garcia L. A. (Mahmoud and Garcia 2000) in their works have been comparing five multi criteria methods: ordered weighted average (OWA), PROMETHEE II, Compromise programming (CP), ELECTRE II, Analytic hierarchy process (AHP). These scientists have been analyzing stability of the results, evidence of the methods and necessary demand of additional information. The main conclusion in this research was that the most suitable method in order to solve formulated task is OWA.

Other scientists Zanakis S. H., Solomon A. (Zanakis *et al.* 1998) have been chosen eight methods of multi criteria analysis for mathematical experiment: ELECTRE, TOPSIS, Multiplicative Exponent Weighting (MEW), simple additive weighting (SAW) and four versions of analytical hierarchical process (AHP). The best variant according experiment condition was SAW, MEW, TOPSIS after these methods are four versions of AHP and at least ELECTRE methods. Other scientists Opricovic S. and Tzeng G. H (Opricovic and Tzeng 2004) have performed comparison of multi criteria methods like VIKOR and TOPSIS, alternatives have been valuated according distance to ideal solution. It was noticed that when calculations of the shortest distance to ideal positive solution and the longest distance to ideal negative solution were made by method TOPSIS it is not enough have been valuated proportional importance of these distances. These methods could be successfully adopted for evaluation urban areas transport system development scenarios, especially then sustainability components are described by quantitative criterions.

Olson D. L. (Olson 2001) adopted SMART, PROMETHEE and CENTROID multi criteria methods for games theory result prognosis. The conclusions of this research were that the most suitable for that task is PROMETHEE II, which uses Gaussian priority function and SMART method. CENTROID method which uses ordinal data is less suitable.

The analysis of a large amount of data processing operations performed by human beings has shown that the psychologically correct operations are as follows:

- comparison of two assessments in verbal scale by two criteria;
- assignment of multi criteria alternatives to decision classes;
- comparative verbal assessment of alternatives according to separate criteria.

The operations mentioned above were used in the verbal methods of decision

analysis such as ZAPROS, ZAPROS III, ORCLASS, PARK, SAC (CLARA), CYCLE, ZAPROS Method (Closed Procedures for Supporting Situations) (Larichev et al. 2002). The common features of decision problems are as follows (Ustinovičius and Jakučionis 2000):

1. Formalized and numerically expressed (for example, prestige of organization, attitude towards reforms, etc.); very often the coefficients (factors) are described in the language well – known to the decision maker.
2. Problem analysis is also subjective: major principles of revision and comparison of the main qualitative data are set by the decision maker.

Advantages of ZAPROS method:

1. All questions are simple and comprehensible by the decision maker, in addition they are formulated by means of criteria assessment.
2. The decision maker should answer the questions consistently, and the computer verifies the compatibility of the answers.
3. Any comparisons of qualitative alternatives should be explained in the same language.

Nevertheless, the method has some essential drawbacks:

1. It is designed for the problems which are assessed by three-five indices.
2. The amount of comparable variants is also limited.
3. The scale of indices is based on verbal assessments.

ZAPROS III method (Larichev 2000). This method belongs to a group of ZAPROS methods based on more efficient tools of problem solution. In ZAPROS III, a procedure shown in the first version for preference ranking is applied (Larichev 2000). However, this procedure is modified to make the method more efficient and rigorous. One of the most important features of ZAPROS methods is the use of psychologically grounded procedures for setting the preferences. This method evaluates personal abilities and limitations of human information processing system. Verbal Analysis decision making methods are suitable for urban transport system development scenario analysis then sustainability is described with conceptual indicators system.

Lithuanian scientists Zavadskas E. K. (Zavadskas *et al.* 1999) in his researches have analyzed and adopted many multi criteria methods: games theory (Valdo, Savidge); generalized indicators (distance to ideal point, combined, utility functions); methods of sequential optimization (decisions compatibility, determination of priorities, selection of non dominative variants). Synthesis methods have been analyzed by Lithuanian scientist Ustinovičius L. (Ustinovičius 2003). This scientist analyzed verbal methods of decision analysis for estimating investments projects effectiveness; he estimated advantages of these methods. Also he have created complex of verbal methods SNOD

(Scale of Normalized and Ordered Differences), this method was successfully adopted for estimation of new construction and old building reconstruction projects effectiveness. Also Ustinovicus L. suggested multi criteria penalty points' methodology for buildings projects effectiveness estimation (Ustinovičius and Jakučionis 1998; Ustinovičius and Jakučionis 1998). This scientist methodology validated ELECTRE III and ELECTRE IV methods by solving practical tasks and created synthesis method for rational constructional, technological and organizational variants selection.

1.8. Methods of multi criteria decision support system integration with GIS

Spatial multi-criteria decision problems typically involve a set of geographically-defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Malczewski, J. 1999). Spatial multi-criteria analysis is vastly different from conventional MCDM techniques due to inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, spatial multi-criteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria. This means analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two considerations are of paramount importance for spatial multi-criteria decision analysis:

- the GIS component (data acquisition, storage, retrieval, manipulation, and analysis capability);
- the MCDM analysis component (aggregation of spatial data and decision makers' preferences into discrete decision alternatives) (Carver 1991; Carver 1996).

The major elements involved in spatial multi-criteria analysis are shown in Figure 8 (Malczewski 1999). Figure 9 presents a three-stage hierarchy of intelligence, design, and choice to represent the decision making process (Simon 1960). In the intelligence phase, data are acquired, processed, and exploratory data analysis is performed. The design phase usually involves formal modeling/GIS interaction in order to develop solution set of spatial decision alternatives. The integration of decision analytical techniques and GIS functions is critical for supporting the design phase. The choice phase involves selecting a particular alternative from those available. In this phase, specific decision rules are used to evaluate and rank alternatives. The three stages of decision making

do not necessarily follow a linear path from intelligence, to design, and to choice.

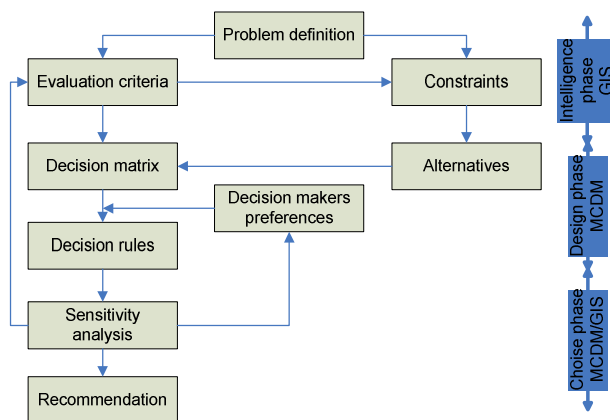


Figure 8. Decision flowchart for spatial multi criteria analysis (Malczewski 1999)

There has been a considerable discussion in the literature of the different methods of integrating external software packages with GIS, and a number of different viewpoints exist. The most widely accepted classification is based on the architectural characteristics of the method of integration according to the degree and form of data exchange or sharing between GIS and the external package(s) (Fedra 1993; Goodchild *et al.* 1993; Heywood *et al.* 1995; Anselin *et al.* 1993). In this classification a basic distinction is made between loose coupling and close coupling.

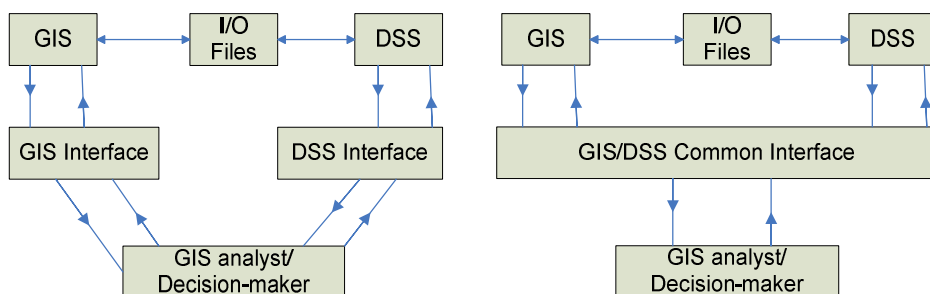


Figure 9. System integration – loose and close coupling (Fedra 1993)

In loose coupling, the two software systems exchange input and output files by means of an efficient interchange of data between the two packages. At this

level of integration, no system modification or programming is required and the two systems run independently. Close coupling, on the other hand, involves writing some form of program to automate or facilitate the integration process. The systems share both the communication files and the common user interface. Close coupling normally involves modifying the operation of the GIS software itself and a variety of mechanisms are available in most GIS packages to assist with this.

Another approach to classification is that based on the direction of integration between systems which recognizes the difference between one directional, two directional, and dynamic integration (Anselin *et al.* 1993; Pereira and Duckstein 1993). In one directional integration, there is a single, one way flow of information between the GIS and the decision support system and the flow may originate from either. In the system developed here, the data generated in GIS serves as the input data to the decision support system. In the case of two directional integration, the systems are linked through a two way flow of information. In most research employing this approach, the GIS generates data that is input to the decision support system for processing, the results of which are subsequently transferred back to the GIS and added to the existing attribute data base as new data

which may then be further analyzed or displayed. Dynamic integration is a more advanced form of two directional integration that enables data to move back and forth between the two software modules in a more flexible way determined by the user's needs. This type of integration is especially useful when the decision maker wants to revise the data or the decision scenarios after examining the results obtained from an intermediate iteration.

The aim of integrating GIS with MCDM models in this research is to develop a tool that meets the requirements for advanced GIS application in identifying best transport system development scenarios in urban areas also created application could perform urban areas ranking according urban transport system sustainability indicators. The integration approach significantly contributes to the embedding of multi criteria problem handling methods within a spatial information system and to fuse capabilities available in the individual systems to provide some desired level of usability. Several factors favor the choice of the loose coupling approach for developing the spatial decision support environmental (SDSS) in this research.

Firstly, both MCDM and GIS are well established tools but essentially separate fields of research. The state of art software now available may be used directly when loosely coupled and this integration technique is the basis of most approaches that involves the integration of systems (Parks 1993).

Secondly, GIS and MCDM software packages are typically proprietary systems and as such they are developed and maintained externally with limited opportunities for local modification. It is not necessary to start from scratch to develop a closely coupled integrated system. At a technical level, MCDM packages are of comparable size and complexity to a GIS, consequently re-implementation of a MCDM package within GIS would be a daunting and costly task.

Finally, an important feature of more recent GIS software development is that it is now much easier to customize them or loosely integrate them with other software packages for specific GIS based applications. There is some value in determining the limits of integration possible using existing systems and in identifying the additional facilities which would facilitate the task of integration. An alternative form of the integration problem is that of coupling GIS and other systems to deliver the capabilities needed to satisfy the requirements of an application.

The above considerations have suggested that the loose coupling approach is appropriate for the task addressed here. Following the argument of Abel (Abel 1994), the approach to the problem of systems integration adopted in this research is to loosely couple preexisting systems to fuse a desired set of capabilities with some targeted degree of usability of the integrated system. A similar approach has been used in developing integrated systems for land use applications based on raster data (Janssen and Rievelt 1990; Jankowski and Richard 1994). While the pre existing software packages themselves are not actually modified, their integration typically involves the design of specialist linkage components to facilitate coupling. In this context, identifying the types of linkage components needed is one of the core issues of the systems integration problem.

1.9. Conclusions of the first chapter

1. Recent research and developments indicate the importance of sustainability between the quality of the environmental, social equality and economical development. Sustainable development of such areas and research of such issues will have huge applied implications on major part of people is living in urban areas.

2. For comprehensive and sustainable transportation planning it is usually best to choose a balanced set of indicators reflecting a combination of economic, social and environmental objectives. An indicator set that focuses too much on one type of impact or overlooks others can result in decisions that are not overall

optimal. It is important that users understand the perspectives, assumptions and limitations of each indicator.

3. There are currently no standardized indicator sets for comprehensive and sustainable transport planning. Each jurisdiction or organization must develop its own set based on needs and abilities. It would be useful for major planning and professional organizations to establish recommended sustainable transportation indicator sets, data collection standards, and evaluation best practices in order to improve sustainability planning and facilitate comparisons between jurisdictions, organizations and time periods.

4. The convectional understanding of urban areas transport system development covers economical, social and environmental subsystems as well technological, socio-economical and natural interactions. Transport system development processes in urban areas are hard to describe by unified and weighted indicators as all cities are rather special and have specific features. Consequently, identification of main group of indicators for urban transport system evaluation should be analyzed by geographical aspect (zoning urban area into small transport activity zones) and perform calculations for each zone in Vilnius and Kaunas cities.

5. Two stages of the approach can be employed to model evaluation for urban areas transport systems. The first stage of an approach is to estimate necessary indicators and methods of decision support system and the second to evaluate urban areas development scenarios and perform calculations and data integration with GIS.

6. For development for urban transport system scenarios could be used multi criteria decision making methods which operates quantitative criterions information.

7. Analyzed criterions weights estimation method and decided that the best methods for criterions weights estimation should be with statistical data analysis and performing calculations with input data from questionnaire.

8. When urban areas transport system indicators is expressed by qualitative criterions for urban transport system scenarios ranking could be used verbal multi criteria decision making methods like ZAPROS, ORCLASS, PARK and CLARA.

Multi-criteria decision making methods, their analysis and selection, integration with GIS

2.1. Practical analysis and selection of multi criteria decision making methods for urban transport system analysis tasks

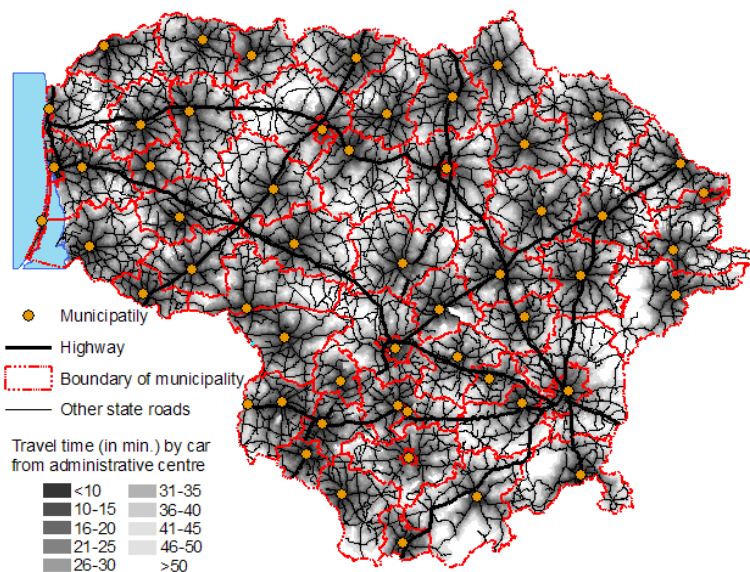
For comparing and selection multi criteria decision making methods there used these criterions:

1. Stability of calculation results.
2. Time spend of performing calculations.
3. Simplicity of the method.

Calculations have been performed using 6 methods: SAW, MCDM-23, AHP, TOPSIS, ELECTRE III and MCP. All detailed calculations are presented in ANNEX A) In order to perform MCDM methods analysis there were created simplified decision support system matrix (see Table 15). and results are commented using the data from this matrix. This matrix presents Lithuanian transport system criterions in five municipalities: Utena, Jonava, Zarasai, Plunge, Skuodas. Regional statistical data is taken from Lithuanian Department of Statistics in 2006 year.

Table 15. Decision support system matrix

N°	Criterion name	Units	*	Municipality				
				Utena	Jonava	Zarasai	Plunge	Skuodas
R1	Road network density in regions (in each municipality)	km/km ²	+	1,36	0,99	1,15	0,95	1,01
R2	Density of local roads in regions (in each municipality)	km/km ²	+	1,21	0,95	1,02	0,84	0,78
R3	Length of roads for 1000 inhabitants in administrative regions (municipalities)	km	+	26,6	17,6	58,2	23,8	37,2
R4	Length of local roads for 1000 rural inhabitants in administrative regions (municipalities)	km	+	95,8	51,0	104,8	45,0	41,2
R5	Percentage coverage of territorial accessibility from the administrative unit going 30 minutes by car from local community (municipality)	%	+	68,0	72,0	64,0	77,0	69,0
R6	Number of traffic accidents	accident	-	81,0	119,0	34,0	68,0	32,0

**Figure 10.** Results of accessibility by car calculations

Percentage coverage of territorial accessibility from the administrative unit going 30 minutes by car from local community (municipality) was estimated ArcGIS 9.2 software and Lithuanian rod and street network GIS database which contains traffic information (Loukopoulos et al. 2004; Jakimavičius and Burinskienė 2007): one way directions, speed, two-level crossings, turn restrictions. Figure 10 presents results of accessibility by car calculations in Lithuanian municipalities.

2.2. Estimation of urban transport system indicators weights

A weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration. Assigning weights of importance to evaluation criteria accounts for (i) the changes in the range of variation for each evaluation criterion, and (ii) the different degrees of importance being attached to these ranges of variation (Kirkwood 1997). There are four different techniques when assigning the weights: Ranking, Pairwise Comparison.

2.2.1. Ranking method

This is the simplest method for evaluating the importance of weights which includes that every criterion under consideration is ranked in the order of decision maker's preferences. Due to its simplicity, the method is very attractive. However, the larger the number of criteria used, the less appropriate is the method. Another disadvantage is lack of theoretical foundation.

According ranking method criterions importance is estimating by proximate method. There are using discrete (1, 2, ...) or real (20/100, 40/100, ...) type numbers scales. For example importance of criterions it is possible to describe in 10 mark scale. The most important criterion gets 10 marks (it is possible that there are a few most important criterions). All other criterions are comparing with most important ones. For example if a criterion is less important than the most important it gets 8 marks. Ranking scale and estimation of criterions importance looks similar like that: 10 marks the most important criterions, 9, 8 - little bit less importance, 7, 6, 5 - patently less importance, 4 - criterion is not important (MCDM-23 User Manual).

It is possible to use such 10 mark scale. For example criterions importance it is possible to describe with numbers from 1 to 10 marks. In this case marks are the following: 1, 2 - not important criterions; 3, 4 - few important criterions; 5,

6 – average important criterions; 7, 8 – important criterions; 9, 10 – very important criterions. By using scale for criterions importance estimation from 4 to 10 we can see in advance that very important from less important criterion differs in 2,5 times. In case when used scale is 10 marks, difference is in 10 times. Using this scale expert's opinion will disperse wider and opportunity that will be reached experts opinions incompatibility is less.

Results performing experts' questionnaire t_{jk} are processing statistically. Criterions importance average value is calculating according this formula (Завадскас 1987; Zavadskas and Kaklauskas 1996):

$$\bar{t}_j = \frac{\sum_{k=1}^r t_{jk}}{r}, \quad (1)$$

here: t_{jk} – k experts performed criterion's j rating; r – number of experts.

Each criterion importance is calculating by this formula (Завадскас 1987; Zavadskas and Kaklauskas 1996):

$$q_j = \frac{\bar{t}_j}{\sum_{j=1}^n \bar{t}_j}, \quad (2)$$

Reliability of experts' valuation it is possible to describe according coefficient of concordation. This coefficient describes the level of experts' opinion incompatibility:

$$W = \frac{12 \times S}{r^2(n^3 - n) - r \sum_{k=1}^r T_k}, \quad (3)$$

$$S = \sum_{j=1}^n \left(\sum_{k=1}^r t_{jk} - \frac{1}{n} \times \sum_{j=1}^n \sum_{k=1}^r t_{jk} \right)^2, \quad (4)$$

$$T_k = \sum_{l=1}^{H_l} (h_l^3 - h_l). \quad (5)$$

here: S – results of criterions valuation deviation of sum-square; T_k – indicator of associated ranks in range k; H_l – number of equal rank groups in range k; h_l – number of equal ranks in associated group of ranks l, by expert k valuating, t_{jk} –

experts k valuating rank for criterion j ; r – number of experts; n – number of indicators in indicators set.

If there are no associated ranks then coefficient of concordation it is possible estimate according this formula:

$$W = \frac{12 \times S}{r^2(n^3 - n)}. \quad (6)$$

If coefficient of concordation is equal 1, it means that all experts' rankings are equal; if this coefficient is 0, it means that experts ranking very vary.

Value of concordation coefficient is calculating according this formula:

$$\chi^2 = \frac{12 \times S}{r \times n \times (n+1) - \frac{1}{n-1} \sum_{k=1}^r T_k}. \quad (7)$$

If value of χ^2 is greater that value χ^2_{table} (value from the table. This value is dependant from degree of freedom and initiated importance level) then hypothesis of experts opinions compatibility is accepted. If $\chi^2 < \chi^2_{table}$, then experts opinions are not compatible.

Ranking method advantages: simplicity, clearness, experts' expenditure for valuation of criterions importance is not big. For example, when we have indicator system with 20 criterions and performing criterions importance estimation by pair wise comparison method it would be necessary to make 190 comparison actions, by using ranking method it would be necessary to perform 20 actions.

2.2.2. Pairwise comparison method

The method involves pairwise comparisons to create a ratio matrix. It takes pairwise comparisons as input and produced relative weights as output. The pairwise comparison method involves three steps:

The 1st step:

Development of a pairwise comparison matrix: The method uses a scale with values range from 1 to 9. The possible values are presented in Table 16. Calculations and experts valuations are performed in matrix form. Table 17 presents the sum of all experts pairwise comparison matrix where each expert in aech row and column intersection marks is value x_{ij} . This value could be 1, 0 or 0,5 according indicator i is priority to indicator j or if indicators priority is equal.

Table 16. Scale for pairwise comparison (Satty, 1977)

Intensity of importance	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Table 17. Pairwise comparison matrix

Criterion <i>i</i>	Criterion <i>j</i>					
	1	2	...	<i>j</i>	...	<i>n</i>
1	-	x_{12}	...	x_{1j}	...	x_{1n}
2	x_{21}	-	...	x_{2j}	...	x_{2n}
...	...	...	-	...	...	...
<i>i</i>	x_{i1}	x_{i2}	...	-	...	x_{in}
...	...	...	...	...	-	...
<i>n</i>	x_{n1}	x_{n2}	...	x_{nj}	...	-

Table 18 presents pairwise comparison matrix of percentage proportion when criterion *i* is more important than criterion *j* according total criterion valuation number. The results in this matrix more practically is represented in the following expression $p_{ij} = \frac{x_{ij}}{k}$ (here: *k* – number of experts).

The 2nd step:

Calculation of the weights. Table 19 presents reformed pairwise comparison matrix. If experts *k* gave *n* valuation R_i , $i = 1, 2, 3, \dots, n$ for indications C_j , $j = 1, 2, 3, \dots, n$ in numbers form according having *X* indication, then C_j are numbers of R_i indications valuation according scale. Subtraction is described by scale model (Zavadskas *et al.* 1999; Ustinovičius and Jakučionis 1998).

Table 18. Pairwise comparison matrix with percentage proportion

Criterion i	Criterion j						Sum of row
	1	2	...	j	...	n	
1	-	p_{12}	...	p_{1j}	...	p_{1n}	p_1
2	p_{21}	-	...	p_{2j}	...	p_{2n}	p_2
...	...	...	-	...	...	...	...
i	p_{i1}	p_{i2}	...	-	...	p_{in}	p_i
...	...	...	...	...	-	...	...
n	p_{n1}	p_{n2}	...	p_{nj}	...	-	p_n

Table 19. Reformed pairwise comparison matrix

Criterion i	Criterion j						Total	Average
	1	2	...	j	...	n		
1	-	z_{12}	...	z_{1j}	...	z_{1n}	z_1	$\overline{z_1}$
2	z_{21}	-	...	z_{2j}	...	z_{2n}	z_2	$\overline{z_2}$
...	...	...	-	...	...	...	...	...
i	z_{i1}	z_{i2}	...	-	...	z_{in}	z_i	$\overline{z_i}$
...	...	...	...	...	-	...	...	...
n	z_{n1}	z_{n2}	...	z_{nj}	...	-	z_n	$\overline{z_n}$

$$C_i - C_j = Z_{ij} \times \sigma_{ij}, \quad (8)$$

here: C_i, C_j – criterions valuation according scale; Z_{ij} – normal deviation, which presents how indicator i is more priority to indicator j ; σ_{ij} – mean square deviation of subtraction of C_i and C_j :

$$G(Z_{ij}) = p_{ij} = \int_{-\infty}^{Z_{ij}} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt. \quad (9)$$

In order to simplify it is possible to accept that according (8) $\sigma_{ij} = 1$, then:

$$C_i - C_j = Z_{ij}. \quad (10)$$

Suppose that area under the curve of normal distribution (in interval from -3σ to $+3\sigma$) is equal to 1. Then formula (9) could be written with expanded mode:

$$G(Z_{ij}) = p_{ij} = \int_{-\infty}^0 \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt + \int_0^{Z_{ij}} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt. \quad (11)$$

As interval from $-\infty$ to 0 is equal 0,5, it is possible to use:

$$G(Z_{ij}) = p_{ij} = 0,5 + \int_0^{Z_{ij}} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt. \quad (12)$$

In following calculations are using this expression.

Are known that real valuation differs from Z_{ij} and it is necessary to find a set of valuations where this difference is smaller. In that case the procedure of valuating according scale it is possible to describe by the following. It is necessary pairwise comparison matrix with percentage proportion (see Table 19) reverse to expecting Z_{ij} . This reversion could be done by (11) formula and by using normalized normal distribution from the table. These Z_{ij} values compiles reformed pairwise comparison matrix (see Table 19). In this matrix each Z_{ij} is subtraction between i and j criterions in their standard deviations, $Z_{ij} = \sum_{i=1}^n Z_i -$ sum of values. Average of these values:

$$\bar{Z} = \frac{\sum_{i=1}^n Z_i}{k}, \quad (13)$$

here: k – number of experts.

p_{ij} is analyzing like area under the curve of normalized normal distribution in interval from $-\infty$ to Z .

Group ranking is correct when experts' opinions are matched. In order to know it, it is necessary to perform valuation of experts' opinions matching. Concordation coefficient could be estimated by this formula:

$$W = \frac{Q}{Q_{\max}}, \quad (14)$$

$$Q = \sum_{i=1}^n C_{p_{ij}}^2,$$

$$Q_{\max} = \frac{k(k-1)n(n-1)}{4},$$

from this:

$$W = \frac{4}{k(k-1)} \sum_{i=1}^n \frac{C_{p_{ij}}^2}{n(n-1)}.$$

The smaller possible value of concordation coefficient is calculating according this formula:

$$W = \frac{k-2}{2(k-1)}. \quad (15)$$

Pairwise comparison method is good because it is explicit mathematically. The main disadvantages are:

- It is necessary to perform a lot of comparisons. Number of comparisons it is possible to calculate according formula $\frac{n \cdot n - n}{2}$, n – number of criterions.
- By performing criterions valuations is a big mistakes possibility.

Performing urban transport system scenarios analysis requires a big number of sustainable urban development indicators. According these conditions it is very difficult to use pairwise comparison method for estimating indicators weights.

2.2.3. Estimation of criterions importance (weights)

Importance was estimated by executing 28 experts of transportation system questioning. Table 20 presents results of experts questioning. The lowest value means that criterion is the most important and the highest value means that criterion is less important.

1) Calculation of rang sum:

$$t_{\text{sum},i} = \sum_{j=1}^l t_{ij}; i=1,2..n, j=1,2..l, n=6, l=28;$$

$$t_{\text{sum}1}=128; t_{\text{sum}2}=114; t_{\text{sum}3}=114; t_{\text{sum}4}=91; t_{\text{sum}5}=81; t_{\text{sum}6}=60$$

2) Calculation of rang average:

$$t_{avg,i}=t_{sum,i}/l$$

$$t_{avg1}=128/28=4,57; \quad t_{avg2}=114/28=4,07; \quad t_{avg3}=114/28=4,07; \quad t_{avg4}=91/28=3,25; \\ t_{avg5}=81/28=2,83; \quad t_{avg6}=60/28=2,14.$$

3) Calculation of subjective criterions importance formula (2) :

$$qs_1=4,57/21=0,218; \quad qs_2=4,07/21=0,194; \quad qs_3=4,07/21=0,194; \quad qs_4=3,25/21=0,155; \\ qs_5=2,83/21=0,135; \quad qs_6=2,14/21=0,102.$$

Table 20. Results of experts questioning

N ^o	1	2	3	4	5	6
Experts	Criterions					
	R1	R2	R3	R4	R5	R6
E1	5	4	3	1	2	6
E2	4	5	6	2	3	1
E3	5	3	6	1	4	2
E4	5	4	6	2	1	3
E5	5	4	6	1	3	2
E6	5	4	3	6	2	1
E7	3	4	6	5	1	2
E8	5	4	3	6	1	2
E9	4	5	3	6	2	1
E10	4	5	2	1	6	3
E11	5	4	6	2	1	3
E12	5	4	3	6	1	2
E13	4	5	1	6	3	2
E14	5	4	6	1	2	3
E15	5	4	3	2	6	1
E16	3	6	1	4	5	2
E17	5	4	6	2	1	3
E18	5	4	3	6	1	2
E19	5	2	6	3	4	1
E20	4	5	3	1	6	2
E21	5	4	3	2	6	1
E22	5	4	3	2	6	1
E23	3	4	2	5	6	1
E24	5	1	6	3	2	4
E25	4	5	6	1	2	3
E26	5	4	6	2	1	3
E27	5	4	3	6	1	2
E28	5	4	3	6	2	1
t_{sum}	128	114	114	91	81	60
t_{avg}	4,57	4,07	4,07	3,25	2,83	2,14

$$\sum t_{sum}=588; \quad \sum t_{avg}=21$$

$$q_i = 1 - q_i; \quad (16)$$

$$q_1 = 1 - 0,218 = 0,782; \quad q_2 = 1 - 0,194 = 0,806; \quad q_3 = 1 - 0,194 = 0,806; \quad q_4 = 1 - 0,155 = 0,845; \\ q_5 = 1 - 0,135 = 0,865; \quad q_6 = 1 - 0,102 = 0,898.$$

$$\sum_{i=1}^n q_i = 0,782 + 0,806 + 0,806 + 0,845 + 0,865 + 0,898 = 5.$$

$$q_i = \frac{q_i}{\sum_{i=1}^n q_i}.$$

$$q_1 = 0,782/5 = 0,156; \quad q_2 = 0,806/5 = 0,161; \quad q_3 = 0,806/5 = 0,161; \quad q_4 = 0,845/5 = 0,169; \\ q_5 = 0,865/5 = 0,173; \quad q_6 = 0,898/5 = 0,180.$$

4) Calculation of criterions valuation deviation set of sum-square formula (4):

$$\frac{1}{6} \sum_{i=1}^6 \sum_{j=1}^{28} t_{ij} = 98,$$

$$S = \sum_{i=1}^6 \left(\sum_{j=1}^{28} t_{ij} - 98 \right)^2 = (128 - 98)^2 + (114 - 98)^2 + (114 - 98)^2 + (91 - 98)^2 + (81 - 98)^2 + (60 - 98)^2 = 3194.$$

5) Estimation of concordation coefficient formula (3):

$$W = \frac{12 \times 3194}{28^2 \times (6^3 - 6)} = 0,2328.$$

6) Estimation of variance formula (7):

$$v = n - 1 = 6 - 1 = 5, \quad \chi^2_{\text{TABLE}} = 15,086,$$

$$\chi^2 = \frac{12 \times 3194}{28 \times 6(6 + 1)} = 32,59.$$

7) Validation results of experts questioning:

$W > 0$, $W = 0,2328 > 0$; $\chi^2 > \chi^2_{\text{TABLE}}$, $32,59 > 15,086$.

$\chi^2_{\text{TABLE}} = 15,086$, when variance is $v = n - 1 = 6 - 1 = 5$ and significance level 1%.

Table 21. Decision support system matrix with criterions importance

N ^o	Criterion name	Units	Importance	*	Municipality				
					Utena	Jonava	Zarasai	Plunge	Skuodas
R1	Road network density in regions (in each municipality)	km/km ²	0,156	+	1,36	0,99	1,15	0,95	1,01
R2	Density of local roads in regions (in each municipality)	km/km ²	0,161	+	1,21	0,95	1,02	0,84	0,78
R3	Length of roads for 1000 inhabitants in administrative regions (municipalities)	km	0,161	+	26,6	17,6	58,2	23,8	37,2
R4	Length of local roads for 1000 rural inhabitants in administrative regions (municipalities)	km	0,169	+	95,8	51,0	104,8	45,0	41,2
R5	Percentage coverage of territorial accessibility from the administrative unit going 30 minutes by car from local community (municipality)	%	0,173	+	68,0	72,0	64,0	77,0	69,0
R6	Number of traffic accidents	accident	0,180	-	81,0	119,0	34,0	68,0	32,0

Table 21 presents weights of transport system analysis in five Lithuanian municipalities.

2.3. Analysis of used multi criteria methods

Simple analysis of transport system in municipalities was performed according six multi criteria methods. The stability of the results is presented in Table 22.

Table 22. Calculation results of used MCDM methods

Alternatives	Method					
	SAW	MCDM-23	AHP	TOPSIS	ELECTRE III	MCP
Utena (A1)	2	2	2	3	2	2
Jonava (A2)	5	5	5	1	4	4
Zarasai (A3)	1	1	1	5	1	1
Plunge (A4)	4	4	4	2	3	3
Skuodas (A5)	3	3	3	4	5	5

Comparisons of multi criteria methods are presented in Table 23.

Table 23. Caomparisons of calculation methods

Method	Evaluation criterions			Other features
	Results stability	Expenditures of calculations performing non automate calculations	Comprehensibility	
SAW	Stabile	Minor	Easy comprehensibility	
MCDM-23	Stabile	Minor	Easy comprehensibility	Formulating of ideal alternative
AHP	Not stabile	Minor	Easy comprehensibility	
TOPSIS	Not stabile	Minor	Easy comprehensibility	
ELECTRE III	Not stabile	Major	Hard comprehensibility	Evaluate of criterions weights
MCP	Not stabile	Minor	Easy comprehensibility	

Results shows that calculations by SAW, MCDM-23 and AHP methods are the same. Calculations by TOPSIS method differs from calculations by other methods, because TOPSIS method shows best alternative A2 and the methods for the best alternative gives A3. Results of calculations by ELECTRE III and MCP methods are the same. These calculations differs from SAW, MCDM-23 and AHP by one alternative position, rank of A2 is the fourth and the first tree method for alternative A2 give the fifth rank.

2.4. Traffic modelling

A transportation model can be described as being a mathematical model of a certain geographical area and the transportation system in this area, focusing on how traffic is generated in each geographical area, how it is distributed between origins and destinations of trips, and how it is assigned to the various transportation networks within the area.

The size of the model area, the level of detail of the model, and the complexity of the mathematics involved can all vary substantially, depending on the purpose of the specific transport model.

A detailed definition of a transport model is beyond the scope of this documentation. Interested users are therefore referred to the literature of the field, and a particularly good summary is contained in the book by Ortuzar and Willumsen (2001) *Modelling Transport*.

Typical uses of transport models

In general, transport models are used to support planning and decision making in the field of transport. Good examples of their use and application are:

1. Evaluating the short-term impact of a relatively simple infrastructure change (e. g., adding lanes to a highway or expanding an intersection).
2. Producing long-term prognoses of travel demand and passenger flows, using a set of scenarios which describe varying assumptions regarding economic development, land use, demographic developments, changes to the transport system, etc.
3. Using the detailed data produced by a transport model in other models (e. g., a land-use model or an environmental impact model).
4. Using the output of a transport model as the basis of an environmental impact study (e. g., using modeled traffic flows as input to a noise propagation model).
5. As an aid helping to evaluate the impact of proposed policy changes (e. g., the consequences of introducing road pricing).

Transport models from most of these applications are developed at many different scales from cities of 20,000 inhabitants, say, to major metropolitan areas of millions. In general, transport models have a wide range of uses and therefore, also vary greatly in complexity and data requirements. For Vilnius city transportation model was created using Traffic Analyst software.

Traffic Analyst consists of a collection of geoprocessing tools, supported by an underlying data model and some specialized editing tools. The Traffic Analyst geoprocessing tools implement all calculation functions commonly used in transportation models. Using ArcGIS Geoprocessing to combine these tools allows the users to build exactly the modelling functionality needed, making it possible to build models ranging from simple to very complex transportation models.

The use of the ArcGIS Geoprocessing framework also makes it possible to freely blend Traffic Analyst tools with ESRI Geoprocessing tools, user-made scripts and tools, and other 3rd party Geoprocessing tools, thus allowing a very large degree of flexibility.

Trip generation

Underpinning the Traffic Analyst tools is an implicit data model for the data necessary for a transportation model. These can roughly be divided into:

- socio-economic data – associated with the zones usually used to subdivide the area being modeled;
- travel patterns (Trip Matrices) and descriptions of travelers' preferences;
- infrastructure networks – Road, Rail, Light Rail etc.
- the transit network – the public transport lines and timetables (bus, rail, light rail etc.).

Calculations by Traffic Analyst software:

Calculates trip production, P and trip attraction, A for each unique combination of zone, i and category, k :

$$P_{ik} = f_{1k} \cdot P_{1k} + f_{2k} \cdot P_{2k} + \dots \quad (17)$$

$$A_{ik} = g_{1k} \cdot A_{1k} + g_{2k} \cdot A_{2k} + \dots \quad (18)$$

where f and g are generation parameters. These are combined with zone specific socio-economic data such as population or number of workplaces in order to perform the calculation.

Trip balancing

Performs balancing calculation of generated trips. This is done to ensure that the total number produced trips equals the total number of attracted trips. The calculation can be performed as:

$$P_i = fP_{oi} + (1-f)P_{oi} \frac{\sum A_0}{\sum P_0}, \quad (19)$$

$$A_i = (1-f)A + fA_{oi} + \frac{\sum P_0}{\sum A_0}. \quad (20)$$

where f is the balancing factor

Trip distribution

Calculation of a deterrence matrix on the basis of a CostMatrix and gravity model parameters. The deterrence value for traffic from zone i to zone j for category k is calculated as:

$$fC_{ijk} = C_{ijk}^{-\alpha} e^{-\beta C_{ijk}}. \quad (21)$$

This tool typical use of this tool is to transform a 24 hour matrix (symmetric) into e. g. a morning rush hour traffic matrix (asymmetric). This can be done either by the use direction distribution parameters or by using an existing or estimated OD matrix. In the first case the calculation is performed as:

$$OD_{ij} = \alpha_1 PA_{ij} + (1-\alpha_2) PA_{ji}, \quad (22)$$

$$OD_{ji} = (1-\alpha_1) PA_{ji} + \alpha_2 PA_{ij}. \quad (23)$$

And in the second case the calculation is performed as:

$$OD_{ij}^{NEW} = \frac{OD_{ij}^{OLD}}{OD_{ij}^{OLD} + OD_{ji}^{OLD}} (PA_{ij} + PA_{ji}). \quad (24)$$

Modal split

Performs modal split calculation on an OD matrix with traffic for all modes. The matrix is split up into an OD matrix for each mode using a logit model with non-correlated alternatives. The probability for a given mode k , can be calculated as:

$$P_{ijk} = \frac{e^{-\beta C_{ijk}}}{\sum_m e^{-\beta C_{ijm}}}, \quad (25)$$

$$T_{ijk} = T_{ij} P_{ijk} . \quad (26)$$

Car assignment

An important part of most transportation models is the ability to simulate the flow of car traffic, and to calculate the related effects (such as resulting speeds of the traffics flows and the resulting average travel lengths and –times between zones).

The Car Assignment tool is used to perform these calculations. In overall terms, the approach is the following:

The area being modeled is described using the following model data:

1. The area is described by dividing it into a number of zones.
2. Travel patterns are described as trip matrices, describing the number of trips between each pair of zones.
3. The road network in the area being modeled is described using a network of links and nodes. This network is connected to the model zones.
4. Various parameters describe the car travelers' preferences regarding choice of route.

The figure below shows an overview of input and output data for the Car Assignment tool.

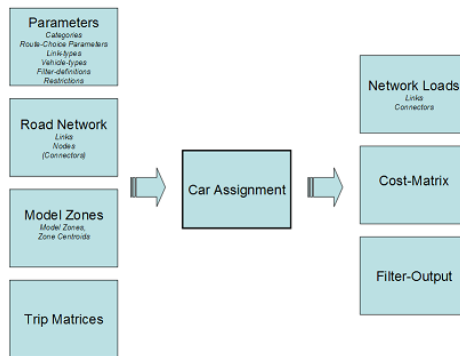


Figure 11. Input and output data of car assignment tool

Using these data the following calculations are carried out:

- For each pair of model-zones, the best travel route through the network is calculated (how the 'best' route is defined, is described in more detail below).

- The amount of traffic between the pair of zones (described in the trip matrices) is added to each link in the travel route.
- Optionally, if road capacity data was included in the network data, the travel time for each link is updated, as a function of the amount of traffic on the link.

Depending on how the Car Assignment tool is used, these steps can be repeated a number of times. When the calculations are done, the main outputs are:

- Traffic flows, in the form of an amount of traffic per road link.
- Travel Costs, described in the form of average travel costs (length and distance) between each pair of zones.

The Traffic Analyst Car Assignment tool is a static assignment tool. That is, the calculation output represents a static average of the period being modeled. This is the most widely used traffic assignment modelling approach.

2.5. Realization of multi-criteria methods integration with GIS

2.5.1. Dynamic Data Exchange (DDE)

DDE is a Microsoft Windows protocol that lets two or more programs running under Windows simultaneously exchange data - a form of inter-process communication that uses shared memory to exchange data between applications. Applications can use DDE for one-time data transfers and for ongoing exchanges and updating of data.

DDE enables applications to be set up to pass both data and commands from one software package to the other. Normally one application requests the transfer and the other responds. The application that does the requesting is called the *client* application, and the application that responds is called the *server*. The information passing between client and server is called the *conversation*. A client application can use DDE to establish a link to an item in a server application. After such a link is established, the server sends periodic updates of the linked item to the client, typically whenever the value of the item changes. Thus, permanent data stream is established between the two applications which remain in place until it is explicitly disconnected. This mechanism enables two applications to continuously and automatically exchange data and creates a relationship between data stored in one application with data stored in another. Both applications must support DDE to be able to participate in this data exchange, and all applications must be at the same computer.

Basically, DDE allows the automation of cut and paste actions, the export of files, calculation of statistics for specific locations. From an end user standpoint, automation via DDE creates an easy to use, seamless application.

2.5.2. The framework of the GIS and MCDM system integration

The SDSS developed in this research is designed around the integration of MCDM with ESRI ArcGIS 9.2 using Dynamic Data Exchange (DDE) in the Microsoft Windows environment (Figure 12). Following the arguments by Jankowski P. (Jankowski and Richard 1994) the loose coupling architecture is used for linking together the two software packages by means of a bi-directional data transfer in which ArcGIS is the visualization engine and MCDM the criteria data analysis engine. Its main objective is to provide an efficient way to gather spatial criteria, evaluate branch alternatives, and display the results of spatial and multi-criteria analyses.

In this system, GIS database management functions are used for managing data derived from different sources and formats, and integrating data based on spatial relations. The analytical functions facilitate spatial manipulation and generate data based on spatial analysis, and the visual display functions are used for displaying the results of spatial analysis and the decision scores from the MCDM models.

The multiple criteria evaluation process is realized using ArcGIS software, the functions of which include the enumeration of criteria preferences, selection of aggregation functions, and the generation of decision scores.

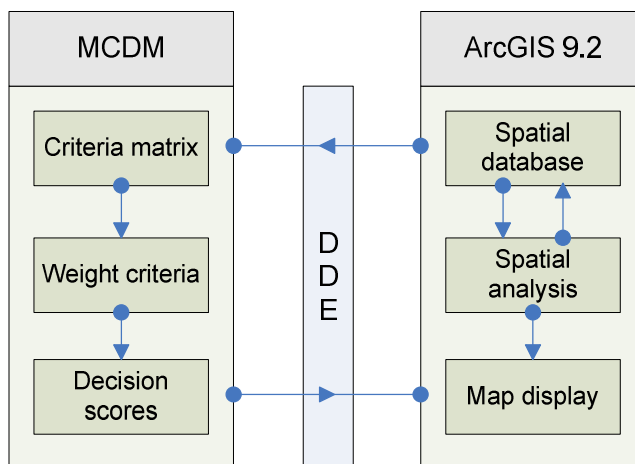


Figure 12. MCDM and GIS system integration

2.5.3. Data conversation in DDE

Two basic concepts are essential to the understanding of how a DDE conversation works:

- Definition.
- Data exchange methods.

There are two components that define a conversation in DDE: the application name and the topic. Each application has a unique name; generally this is the name of the application without its extension (e. g. ArcGIS, EXCEL or ACCESS). A topic refers to the subject of the conversation. The subject could be a file name or a more general topic (e. g. system). Together, the application name and topic uniquely define each conversation. Once the conversation is initiated, specific methods are available in DDE for exchanging information. These methods are application specific. ArcGIS supports three basic data exchange methods: Execute Request and Poke. Execute sends a command string from the client to the server application. Here ArcGIS acts as the client application and sends commands to MCDM application. Request instructs ArcGIS to get data from MCDM for processing (a flow from server to client) and Poke activates a reverse flow enabling ArcView to send data to MCDM (a flow from client to server). The application in this research demonstrates the use of all three DDE methods of exchanging data.

2.6. Algorithms of tasks of setting rational driving routes and their solutions

Algorithm of setting rational driving routes was used to find criterion of territorial allocation from administrative centers.

The optimal route choice is a problem thoroughly investigated in international literature, with Steenbrink's 1978 description being a benchmark for further studies. Applying modern computer technologies, intellectual transport information systems could be created. Such type IS also covers the task of rational choice of car driving route. Geographical information system (GIS) technology offers extremely significant power in transport modelling (Arampatzis et al. 2004; Brown 2002). GIS could be also applied for the search for rational car routes when it is necessary to be at a specific spot of the network on the specific time. The system offers to a user a rational route, time of departure and calculated expenses depending on the set parameters. In other papers that analyze application of GIS technologies in transport task solution, an application of multi-modal networks could be spotted. They are applied when solving route choice

tasks within the overall urban transport system (cars, public transport, railway transport, and even pedestrians) (Mahmassani and Liu 1997; Abdelghany et al. 2001). The assessment of transport jams on the street network is necessary when solving the task of the choice of the fastest route. A search algorithm, the results of which depend on the time set by a system user, has been programmed as the street capacity is different depending on the time of the day (Stan and Geertman 1995). The general public might be the user of IS, which helps to choose a rational driving route. Applying ESRI technologies, a system user is given an application, which has functioned allowing to set the beginning and the end of the trip, and the interim stopping places (if necessary). IS user is given a map with the marked rational driving route.

Standard Network Analyst extension of ArcGIS software allows GIS users to find the shortest path through line segments according their geometric length. Created data model allows users to assign weights to line (street) segments. It is possible to assign driving time and traffic flow data to street segments. In that reason we can calculate the quickest and the least loaded route. An optimization criterion depends on user's choice.

2.6.1. The performance principle of the mechanism of the search for a rational route

The created data model structure and ArcGIS software enable solution of the tasks of setting routes on the street network and calculation of those routes. The software module *Utility Network Analyst* is used for calculations. This tool has been chosen, as the rational driving route calculation uses the *Deijkstra* method (Eliasson and Mattsson 2000; Jakimavičius and Macerinskiene 2006) and weights could be attached to the street line sections. Three-type route setting tasks are being analysed:

- finding of the shortest driving route;
- finding of the fastest driving route;
- setting the driving routes according to the alternatives by using the calculated flow of transport means on one traffic line.

Calculation of the rational route is used when the amount of the weight (numeral value, for example, section length) given to each street section is minimized. After setting the search for the optimal route from point 6 to point 5, the route is chosen, where the sum of section weights is the lowest. There are two alternatives in the given example:

- 1) The route passing sections s61, s12, s24, s45.
- 2) The route passing sections s61, s13, s34, s45.

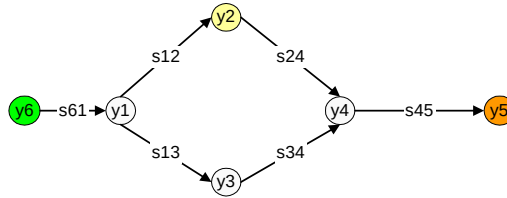


Figure 13. The scheme of the street network with weights

The optimal route will be the one where the sum of section weights is lowest: $\min \sum S_{ij}$.

The group of these tasks belongs to the group of network optimisation, or, to be more specific, to the type of the task of the shortest route optimisation. The essence of the task of the shortest route lays in the fact that a shortest uninterrupted route should be found on the network of streets from the initial to the final point. All the given tasks of rational route modelling have the following features (Kalanta 2003):

- a section of the street corresponds to the edge of the graph, and the junction corresponds to the peak;
- the network of streets consists of m nodes (junctions) on Figure 14 and knowing the weights between nodes S_{ij} we can find rational routes between the initial node $i=1$ and the final node $i=m$;
- by the weight S_{ij} the distance between the nodes i and j , and the driving time from the node i to the node j , the load of the section between the nodes i and j with the transport flows and other conditions that are of interest might be expressed;
- we accept variables X_{ij} , the value of which may be equal to 0 or 1. If the shortest, fastest or the least loaded route passes the nodes (junctions) i and j , then $X_{ij} = 1$, on the contrary $X_{ij} = 0$;
- N_i^- is the set j of streets coming from i node (junction), and N_i^+ is the set j of streets coming to i node (junction);

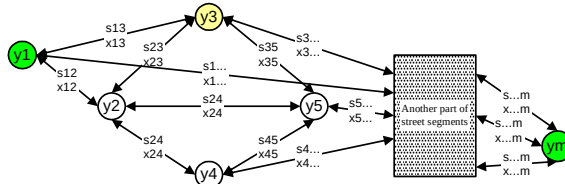


Figure 14. The street network scheme with the weights attributed to sections

Then the task of the shortest or the fastest route or the lowest load on the road will be described according to the following mathematical model:

$$\text{Min } f(x) = \sum_{i=1}^{m-1} \sum_{j \in N_i} s_{ij} x_{ij} \quad - \text{goal function} \quad (27)$$

$$\text{when: } \sum_{k \in N_i^-} x_{1j} = 1, \quad i=1;$$

$$\sum_{k \in N_i^-} x_{ij} - \sum_{k \in N_i^+} x_{ij} = 0, \quad x_{ij}=0;$$

$$x_{ij} \geq 0; \quad i=1,2,3,\dots,m; \quad j=2,3,\dots,m.$$

Here the goal function means that we perform the minimization of a certain route, depending on the weight S_{ij} . The weight is a numeral value, which is kept in the field of the created database. It could be used to set the length of the street section, the time of covering a specific section of the street or the load of the specific section of the street with transport flows. If the weight S_{ij} is used for setting the street section length, then the task solution would be the shortest driving route, when the driving speed is set as a specific section, then the solution will be the finding the route of the fastest driving, and if the weight S_{ij} is used to set the load of the street section with the transport flows, then the result will be the least loaded driving route.

The equation of restrictions (1) is used to set the balance equation of the first node, which describes the requirement that a certain single direction should be taken from the first node (chosen on the beginning of our route within the network of streets). The equation (2) sets the condition of balance, so that if a certain section is taken to come to the node, then another section is taken to leave the node.

2.6.2. Finding of the shortest driving route; its mathematical model and solution

In order to find the shortest driving route between the two specific points within the network of streets, the weights s_{ij} , the numeral values of which are equal to the section lengths, should be attributed to the street sections. Let's suppose that we have the network of the following sections:

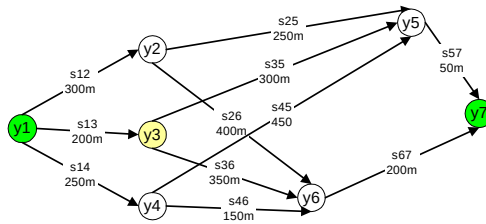


Figure 15. Scheme of street section network with section weights

The shortest route of driving should be found when the lengths of street sections and the driving directions are known. A mathematical model of this task would be the following:

$$f(x)_{\min} = s_{12} \cdot x_{12} + s_{13} \cdot x_{13} + s_{14} \cdot x_{14} + s_{25} \cdot x_{25} + s_{35} \cdot x_{35} + s_{45} \cdot x_{45} + s_{26} \cdot x_{26} + s_{36} \cdot x_{36} + s_{46} \cdot x_{46} + s_{57} \cdot x_{57} + s_{67} \cdot x_{67}.$$

Here: s_{ij} – distance of street network section;

x_{ij} – route coefficient, possible values (0 or 1).

Limitation of equation:

$$x_{12} + x_{13} + x_{14} = 1;$$

$$-x_{12} + x_{25} + x_{26} = 0;$$

$$-x_{13} + x_{35} + x_{36} = 0;$$

$$-x_{14} + x_{45} + x_{46} = 0;$$

$$-x_{25} - x_{35} - x_{46} + x_{57} = 0;$$

$$-x_{26} - x_{36} - x_{46} + x_{67} = 0;$$

$$x_{ij} \geq 0.$$

The 7th node does not need restrictions to be put down, as then the equation would have linear dependence. The following task is being solved using Deijkstra algorithm:

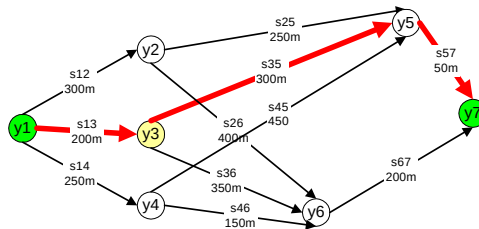


Figure 16. The scheme with the shortest route

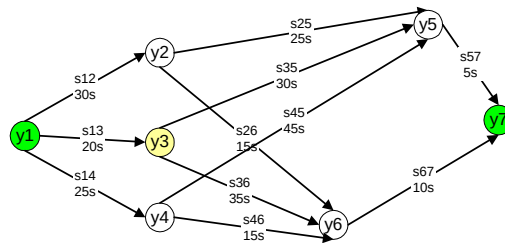
Table 24. Solution of the shortest driving route

1) iteration	$y_1=0.$
2) iteration	$y_2=300;$
	$y_3=200;$
	$y_4=250.$
3) iteration	$y_5=\min(y_2+s_{25}, y_3+s_{35}, y_4+s_{45})=\min(300+250, 200+300, 250+450)=500;$
	$y_6=\min(y_2+s_{26}, y_3+s_{36}, y_4+s_{46})=\min(300+400, 200+350, 250+150)=400;$
4) iteration	$y_7=\min(y_5+s_{57}, y_6+s_{67}) = \min(500+50, 400+200)=550 \text{ m.}$

The shortest route between the points 1 and 7 passes through the nodes (junctions) 1, 3, 5, 7 and its length is 550 m.

2.6.3. The task of the fastest driving route; its mathematical model and solution

In order to find the shortest driving route between the two specific points within the network of streets, the weights s_{ij} , the numeral values of which are equal to the section lengths, should be attributed to the street sections. The possible traffic directions along the sections are known. Let's suppose that we have the network of the following sections:

**Figure 17.** Scheme of street section network with section weights

The fastest driving route should be found when the driving time and the traffic directions on street sections are known. A mathematical model of this task would be the following:

$$f(x)\min = s_{12} \cdot x_{12} + s_{13} \cdot x_{13} + s_{14} \cdot x_{14} + s_{25} \cdot x_{25} + s_{35} \cdot x_{35} + s_{45} \cdot x_{45} + s_{26} \cdot x_{26} + s_{36} \cdot x_{36} + s_{46} \cdot x_{46} + s_{57} \cdot x_{57} + s_{67} \cdot x_{67}.$$

Here: s_{ij} – driving time in street network section;

x_{ij} – route coefficient, possible values (0 or 1).

Limitation of equation:

$$x_{12} + x_{13} + x_{14} = 1;$$

$$\begin{aligned}
& -x_{12} + x_{25} + x_{26} = 0; \\
& -x_{13} + x_{35} + x_{36} = 0; \\
& -x_{14} + x_{45} + x_{46} = 0; \\
& -x_{25} - x_{35} - x_{46} + x_{57} = 0; \\
& -x_{26} - x_{36} - x_{46} + x_{67} = 0; \\
& x_{ij} \geq 0.
\end{aligned}$$

The 7th node does not need restrictions to be put down, as then the equation would have linear dependence. The following task is being solved using Dijkstra algorithm:

Table 25. Solution of the fastest driving route

1) iteration	$y_1=0$.
2) iteration	$y_2=s_{12}=30$;
	$y_3=s_{13}=20$;
	$y_4=s_{14}=25$.
3) iteration	$y_5=\min(y_2+s_{25}, y_3+s_{35}, y_4+s_{45}) = \min(30+25, 20+30, 25+45)=50s$;
	$y_6=\min(y_2+s_{26}, y_3+s_{36}, y_4+s_{46}) = \min(30+15, 20+35, 25+15)=40s$.
4) iteration	$y_7=\min(y_5+s_{57}, y_6+s_{67}) = \min(50+5, 40+10)=50 s$.

The route that is covered in the fastest way from point 1 to point 7 passes the nodes (junctions) 1, 4, 6, 7 and the duration of such driving is 50 s:

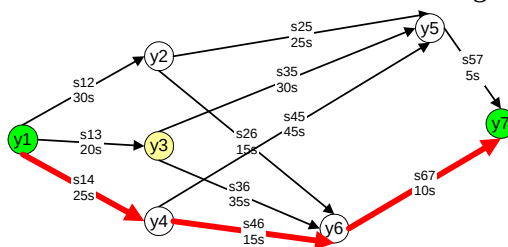


Figure 18. The scheme with the fastest route

2.6.4. The task of the route the least loaded with transport flows: its mathematical model and solution

In order to find the least loaded driving route between the two specific points within the network of streets, the weights s_{ij} , the numeral values of which are equal to the section lengths, should be attributed to the street sections. Let's suppose that we have the network of the following sections:

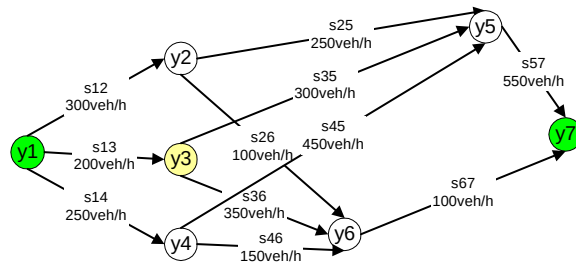


Figure 19. Scheme of street section network with section weights

The route that is the least loaded with transport flows should be found, when the hourly flow of transport means is known on each street section. The driving direction is also known. A mathematical model of this task would be the following:

$$f(x)_{\min} = s_{12} \cdot x_{12} + s_{13} \cdot x_{13} + s_{14} \cdot x_{14} + s_{25} \cdot x_{25} + s_{35} \cdot x_{35} + s_{45} \cdot x_{45} + s_{26} \cdot x_{26} + s_{36} \cdot x_{36} + s_{46} \cdot x_{46} + s_{57} \cdot x_{57} + s_{67} \cdot x_{67}$$

Where: s_{ij} – traffic flows in street network section;

x_{ij} – route coefficient, possible values (0 or 1).

Limitation of equation:

$$x_{12} + x_{13} + x_{14} = 1;$$

$$-x_{12} + x_{25} + x_{26} = 0;$$

$$-x_{13} + x_{35} + x_{36} = 0;$$

$$-x_{14} + x_{45} + x_{46} = 0;$$

$$-x_{25} - x_{35} - x_{46} + x_{57} = 0;$$

$$-x_{26} - x_{36} - x_{46} + x_{67} = 0;$$

$$x_{ij} \geq 0.$$

Table 26. Solution of the least loaded driving route

1) iteration	$y_1=0$.
2) iteration	$y_2=300$;
	$y_3=200$;
	$y_4=250$.
3) iteration	$y_5 = \min(y_2 + s_{25}, y_3 + s_{35}, y_4 + s_{45}) = \min(300 + 250, 200 + 300, 250 + 450) = 500m$;
	$y_6 = \min(y_2 + s_{26}, y_3 + s_{36}, y_4 + s_{46}) = \min(300 + 100, 200 + 350, 250 + 150) = 400m$.
4) iteration	$y_7 = \min(y_5 + s_{57}, y_6 + s_{67}) = \min(500 + 550, 400 + 100) = 500 \text{ veh./h.}$

The 7th node does not need restrictions to be put down, as then the equation would have linear dependence. The following task is being solved using Dijkstra algorithm (see Table 26).

The route that is the least loaded with transport flows is between points 1 and 7 and passes the nodes (junctions) 1, 2, 6, 7 and the overall loading of this route is 500 veh./h:

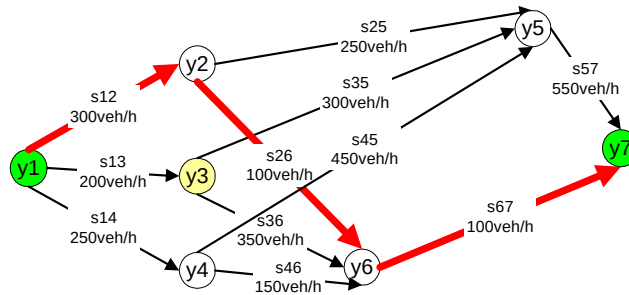


Figure 20. The scheme with the marked least loaded route

2.6.5 Example of optimal route calculation

Developed model was adapted in modelling the Vilnius city transportation network. Three possible routes between two chosen points y1 and y2 with the different optimization criteria have been calculated.

A route may be found on which the minimal transport intensity is seen and the weights of the street section are used along the vectorisation direction and counter the vectorisation direction, which characterise an average hourly flow per day or the overall traffic flow irrespective of the number of lines: on the section of one direction traffic or street, the problem of complete prohibition of transport is being solved by applying the maximum values of the flow weight that could be entered into the database. For example, if the traffic on a street section is prohibited along the vectorisation direction, then the weight given to the section along the vectorisation direction is 32000, which is a maximum value that could be entered into the database field the type of which is *Short Integer*.

Within the urban street network, such numeral value of the weight is sufficient for the route analysis. If the traffic is fully prohibited on the section, then we have to apply maximum weights of street section along the vectorisation direction and counter it. The values of such weights must be 32000; and such values are sufficient for the tool *Network Analyst* not to include the section, traffic on which is prohibited, into the route of route formation.

The way from point 1 to point 2 was found taking into consideration the minimal load of the street:

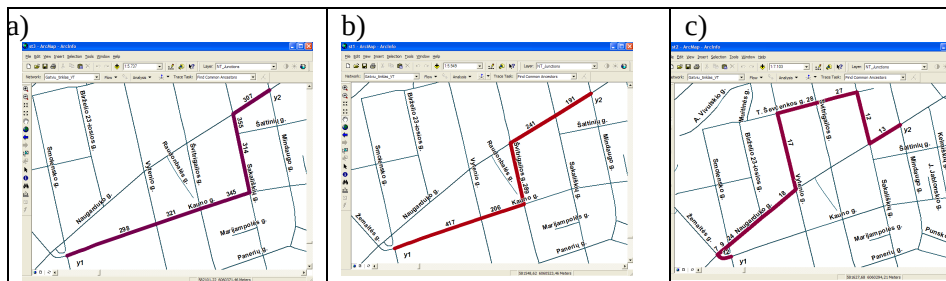


Figure 21. An example of different type of routes: a) The least loaded route; b) The route, when transport flow weights are not attributed to the sections; c) The quickest route

After weights characterizing the load are taken away we get a route which is shortest in geometrical terms and possible driving directions but it is not the one that is the least loaded.

Created data model allows using a weight for street segment. A weight could be a time period when transport vehicle goes through a street segment. System allows using two weights for one street segment; one along vectorisation direction and other in opposite direction.

In Table 27 calculation results between the same two points but different optimization criteria can be compared.

Table 27. Solution of the least loaded driving route

Optimization criteria	Route length, m	Driving time, s	Average traffic flow, veh/h
The shortest route	1344	188	678
The quickest route	1965	167	648
The least loaded route	1387	179	612

2.7. Conclusions of the second chapter

1. For criteria weights estimation decided to use experts ranking method, precision of this method is not very high but calculations performance is big and it is easy to process data from questionnaires.

2. According analysis of MCDM methods by performing one task calculation was estimated that the best methods for urban areas transport scenarios ranking most suitable is SAW, MCDM-23, AHP, ELECTRE III and MCP.

TOPSIS method gives different results than other methods. TOPSIS method could not be used for urban transport system scenarios ranking.

3. Selected methods for urban areas transport system ranking could give different calculations results according formulated task. In that case the selection of multi-criteria methods it is necessary to verify with reference to formulated task.

4.MCDM integration with GIS technologies enables visualizations of calculations data; this allows uses to easier find optimal decisions of urban areas transport system development scenarios. Integrations could be made. The best integration GIS with DSS when software has common interface.

5.A created mechanism of finding the rational driving route can help a user to find a route depending on the optimality criterion chosen by him: the shortest route, the route that is covered in the shortest time and the route that has the lowest load of transport flows.

6.Deijkstra algorithm has been applied in calculations of finding the rational driving route depending on the optimality criterion of the choice of the route, the street sections are given weights, i.e. attribute fields kept in the database: a street section length, time that is needed to pass the section, and traffic intensity.

Urban transport system modelling and rating

3.1. Assessment and rating of traffic analysis zones

Accessibility from the centre of traffic analysis zone to the central part of Vilnius was taken as the main factor for transport system analysis in Vilnius city. Also have been included other factors like population density in traffic analysis zone (TAZ), number of working places in TAZ, street network density in traffic zone, public transport density, average number of daily trips in each analysis zone. By comparing the georeferenced data like street network, the territorial allocation and statistical data for each traffic analysis zone in Vilnius can argue about the equity of investments distribution for each TAZ. Also created GIS application could be used for transport analysis zones ranking by various aspects and problematic zones identification.

3.1.1. Transport system situation in Vilnius city

Average percentage number of Vilnius city automobiles quantity is increasing per year about 3%. Number of personal cars in Vilnius city rose from 265 automobiles for 1000 inhabitants in 1999 till 480 in 2007 year. Sharp bounce of

motorization level invokes a lot of transportation problems. The main Vilnius city transport system indicators are presented in Table 28.

Table 28. Transport system indicators in Vilnius city, 1999 and 2005

Indicator	1999	2005	2007
Street network density (km/km ²)	1,9	2,4	2,8
Public transport network density (km/km ²)	0,55	0,62	0,69
Bicycle paths network density (km/km ²)	0,10	0,16	0,18
Average traffic flow in peak hours (aut./h)	1275	1521	1510
Percentage number of trucks in average flow	3,4	2,4	2,1
Average speed in peak traffic flow (km/h)	37,5	29,3	33,4
Modal split			
- pedestrian trips in %	31,3	34,8	31,4
- trips by bicycles in %	0,3	0,3	0,3
- trip by public transport in %	45,4	34,2	34,9
- trips by car in %	23,0	30,7	33,4
Maximum number of public transport passengers in peak hours	5300	3600	3900
Transit of trucks in peak hours in %	21,3	13,2	10,1
Number of traffic accidents for 1000 inhabitants	1,83	2,22	1,63

Vilnius city is divided into 51 traffic analysis zones. TAZ and population density (inhabitants in hectare) in each traffic analysis zone of Vilnius city are shown in Figure 22.

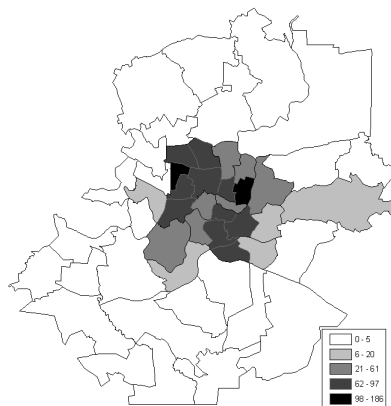


Figure 22. Traffic analysis zones and population density in Vilnius city

Analysis of modal split of Vilnius city transportation system showed that trips by public transport decreases (see Figure 23) and trips by private transport are increasing.

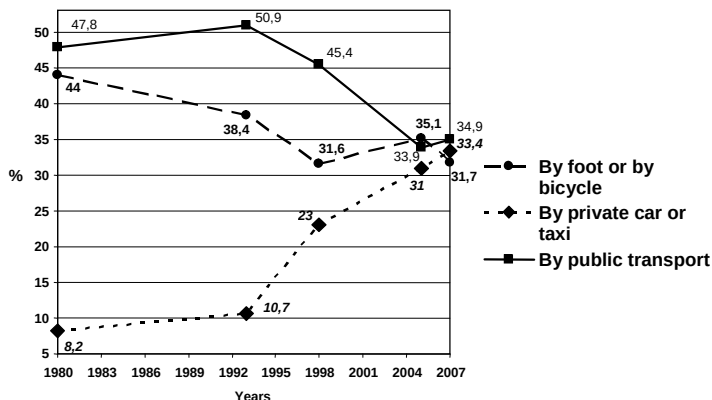


Figure 23. Trips modal split tendencies in Vilnius city

The most concentration of working places is in the central part of Vilnius city (see Figure 24). Largest density of working places in the central part of Vilnius involves parking and traffic flow problems.

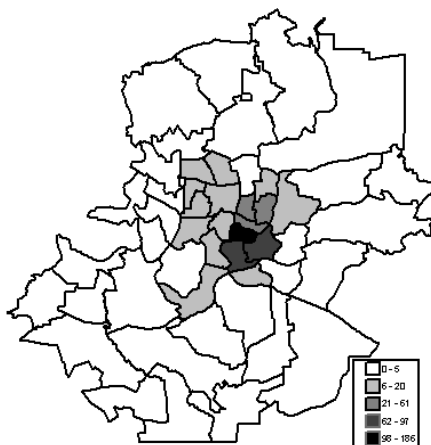


Figure 24. Working places density in Vilnius city

3.1.2. Methodology of calculations

For this research, several changes to the Bogart and Ferry (Bogart and Ferry 1999) model are implemented. First, three “levels” of activity centers are defined: major urban centers of large cities, secondary urban centers of smaller cities and suburban centers. Decreasing employment and employment density thresholds are utilized in each case. Establishing differing thresholds for inclusion ensures that the method will identify those TAZ’s with higher than adjacent employment characteristics, the essence of an activity center. A second set of modifications involves formation of activity center clusters. Recall that in the Bogart and Ferry method, those zones which by themselves do not meet the activity center employment thresholds may be clustered with adjacent zones and so meet the criteria to form larger areas. Bogart and Ferry added zones until the whole cluster density fell below the threshold. The author have adopted this method, but only for suburban activity centers, to avoid the case where a single ultrahigh density zone in an urban center dominates such that all adjacent zones would be included to form a “superzone.” Further, we require that individual zones being added meet a minimum employment density threshold. This requirement avoids the case where open space adjacent to a high density employment center is considered part of a suburban activity center. Finally, we relax the adjacency requirement such that any two zones are considered adjacent if they share a common border of any length. The most significant change we propose is motivated by the following observation. A hypothetical TAZ with 100 mining jobs attracts far fewer trips than a TAZ with sufficient retail development to employ 100 persons. Furthermore, Targa (Targa 1990) has shown that different employment types tend to respond to agglomerative location forces more readily than others, with retail among the most responsive. Transportation models specifically for retail activity have been developed by Hamed and Easa (Hamed and Easa 1998). Generally, retail activities produce more trips, are more likely to agglomerate, and therefore are likely to have stronger impacts on regional transportation patterns. For transportation analysis, then, the method to identify transportation activity centers TACs should not be based solely on employment density, but rather on the trip-attracting strength of the disaggregate employment types present in a TAZ. To incorporate trip attraction strength into the TAC definition, one could compute the product of employment and trip attraction rate per job for each disaggregate employment type. Those zones that exceeded a threshold value of trips and trip density trips per unit of area would then be considered part of a TAC. The decision statistic, however, would then no longer be the well established gross employment and employment density thresholds frequently used in the literature. The approach advanced here is to define a hypothetical “mean trip-attracting” (MTA) job. Suppose that there is a TAZ with ex-

actly one job in each of the 11 standard disaggregate employment types: agriculture, mining, construction, manufacturing, transportation, whole sale, retail, fire, service, government, and military employment. In this case, a total number of daily trips would be attracted to this zone, and an average number of trips per job could be computed. The relative strength of each employment type can be calculated as the ratio of each employment type's attraction rate to the mean attraction rate. This ratio can be used to express each *actual* job in terms of *equivalent* MTA jobs. A zone that exceeds the gross employment and employment density levels in terms of MTA jobs would then be considered for inclusion in a TAC.

Trip attraction to TAZs in their metropolitan region equals:

$$TA = 1,2Mi + 2,6Re + 2,2Se. \quad (28)$$

Where:

TA – number of trips attracted;
 Mi – number of mining jobs;
 Re – number of retail jobs; and
 Se – number of service jobs.

If a TAZ had only four jobs, one in of the above categories, the zone would attract six trips, or two trips per job. Thus, an MTA job would attract two trips. Retail, in contrast, attracts 2,6 trips per job; thus, a retail job can be considered 2,6/2 or 1,3 MTA jobs. The example is generalized as follows. If α_k is defined as the trip attraction rate for employment type k then:

$$\chi_k = \frac{\alpha_k n}{\sum_{k=1}^n \alpha_k} \forall k. \quad (29)$$

Where χ_k = MTA factor for each employment type, k ; and n total number of employment types. A TAZ would be considered as a TAC if:

$$\sum_k E_k \chi_k \geq \xi \quad (30)$$

and:

$$\frac{\sum_k E_k \chi_k}{A} \geq \varphi. \quad (31)$$

Where E_k – actual employment of type k ; ξ – gross employment threshold (MTA jobs); A – area of the TAZ (hectares) and φ – employment density threshold (MTA jobs per hectare). Thus, TAZs that meet or exceed the employment and employment density thresholds using MTA jobs are considered TACs. The creation of TAC clusters is done by adding adjacent candidate zones (those with MTA employment density greater than 3,0 MTA jobs per hectare) such that the total cluster remains above the threshold level. For our research, we utilized MTA employment and MTA employment density thresholds equal to gross employment thresholds typically used in the literature.

The following sections demonstrate the analysis of the Vilnius city using standard activity center definitions and the TAC method presented here.

The map of traffic analysis zones of Vilnius city (see Figure 25) presents the areas where traffic analysis zones could be considered like transport activity centers (these zones are presented in black color).



Figure 25. Traffic activity centers in Vilnius city

This analysis showed TAZ could not be consider like TAC that in central part and old town of Vilnius, also in areas of Vilnius city which are in a distant of central part of Vilnius city. The main reason is that in the central part of Vilnius is big concentration of working places and in areas around Vilnius city are dominating residential houses and less working places.

Second stage is to perform estimated traffic analysis zones ranking using various transportation indicators. For TAZ ranking were used two methods of

decision support system – SAW GIS based application computes the ranks of transport analysis zones.

SAW (Simple Additive Weighting) method in GIS application

For a fragment of input from Vilnius traffic analysis zones socio-economic data for GIS application (see Figure 26).

X_{ij}	Criteria for analysis of automobiles transport system in Lithuania 1, 2 ... i							
	Attributes of vilnius lks							
1	RAJ. PAVAI.	PLOTA	2999 GYV.	2005 GYV.	2015 GYV.	2999 DARB.	2005 DARB.	2015 DARB.
2	Senaamiestis	389,8	26495	25000	23000	45037	43000	41000
.	Centras I	104,4	9485	9000	8000	39148	38000	37500
.	Naugamiestis	346,9	27657	30000	32000	32878	35000	37000
.	Ž. Paneriai	740,7	14547	12000	11500	17038	16500	16000
.	Antakalnis	837,3	30301	28000	27000	12856	13000	13500
.	Snipiskės	185,7	14142	15500	16500	8488	10000	13000
.	Santarišės	2010	10301	11500	12700	10554	11000	12100
.	Centras I	156,7	6049	7000	7500	7745	8650	11000
.	Žirmūnai I	262,7	40979	38500	38000	14925	11000	10500
.	Žirmūnai II	284,8	16111	18000	15500	6328	7500	8700
.	Kirtimai	1477,6	4599	4000	3500	9596	9000	8700
.	Žvėrynas	280,8	13519	14000	14000	7573	8000	8000
.	Karoliškės	398	38407	34500	32000	7405	7700	7900
.	Naugė Vilnia	2389,4	29338	31600	37500	5314	6000	7800
.	Vilkipėdė	335	12656	13000	13500	6129	7000	7500
.	Garūnai	2026,2	1887	2000	2000	6427	7000	7500
.	Naugininkai	311,4	26626	24000	23000	6725	7100	7300

Figure 26. Socio-economic Vilnius TAZ data

Input data for calculation is the criteria and their values of importance; criteria matrix is normalized according to these conditions:

If criterion is maximized:

$$X_{ij} = \frac{X_{ij}}{X_{j}^{\max}} \quad (32)$$

If criterion is minimized:

$$X_{ij} = \frac{X_{j}^{\min}}{X_{ij}} \quad (33)$$

Normalized matrix for each criterion of concrete municipality is multiplied with its importance. Multiplied criteria are summed for each row (for each

Indicators of Vilnius city transport system analysis for each traffic analysis zone are presented in Table 29.

Table 29. Transport system indicators for Vilnius TAZ analysis

Indicator description	Function	Importance, %
Street network density (km/km ²) in each TAZ	maximize	19
Public transport network density (km/km ²) in each TAZ	maximize	15
Length of streets for 1000 inhabitants in each TAZ	maximize	16
Disproportion for population and employees densities	minimize	22
Density of parking places (parking places/ hectare)	maximize	10
Accessibility from the central part from each transport activity centre to Vilnius city central part	maximize	9
Average number of daily trips in each analysis zone	maximize	9

Importance for each indicator was estimated by performing transport specialists questionnaire.



Figure 27. Results of ranking Vilnius TAZ's

In order to estimate which TAZ could be consider like TAC Kaunas city

was divided into 166 traffic analysis zones. The geometry form of these traffic analysis zones was rectangular type and size is 1x1 kilometer (see Figure 28).

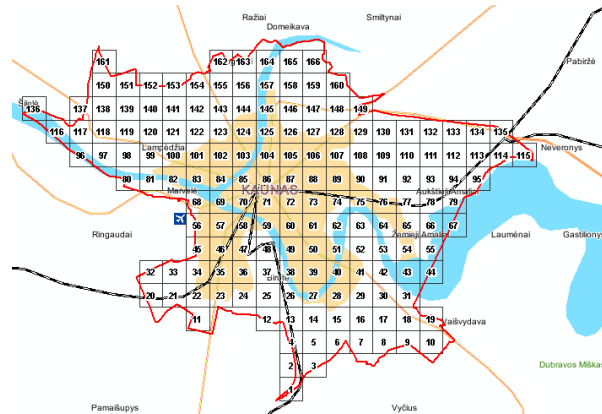


Figure 28. Division Kaunas city area to TAZ's

Table 30 presents socio statistical data for Kaunas city districts. Using GIS software proportional by territory statistical data was calculated to rectangular TAZ's

Table 30. Statistical data for Kaunas city TAZ analysis (Municipality of Kaunas city, 2007)

District name	Area, km ²	Population density, inhabitants /ha	Density of working places, inhabitants /ha
Senamiestis	1,44	59,58	38,19
Naujamiestis	3,14	56,69	208,33
Žemieji Šančiai	4,32	29,05	38,19
Aukštieji Šančiai	3,09	47,54	13,19
Žaliakalnis	4,78	55,23	68,06
Kalniečiai	2,58	46,74	47,22
Eiguliai	5,34	115,35	45,83
Dainava	5,28	164,02	56,25
VI fortas	3,81	105,38	34,03
Naujasodis	9,02	0,56	243,06
Palemonas	7,73	4,85	56,94
Amaliai	2,55	4,31	0,00
Petrašiūnai	9,16	10,92	67,36
Vičiūnai	4,66	2,15	3,00

Panemunė	2,80	28,21	6,94
Rokai	8,74	4,79	6,94
Vaišvydava	8,58	3,32	6,94
Birutė	5,28	13,92	15,28
Freda	4,16	6,49	38,19
Aleksotas	4,38	14,61	35,42
Kazliškės	8,18	7,85	48,61
Marvelė	2,27	5,29	12,50
Lampėdžiai	6,12	4	5,56
Vakarinė Vilijampolė	3,73	19,3	72,92
Senoji Vilijampolė	2,56	55,39	38,19
Paneriai	1,97	64,16	14,58
Smėliai	2,56	50,94	31,25
Milikoniai	1,75	129,14	31,25
Šilainiai	7,20	1,11	20,83
Romainiai	5,73	3,66	3,47
Sargėnai	4,63	9,91	27,78
Kleboniškis	6,86	0,74	5,00

According formulas (49–52) was performed calculation for Kaunas city traffic analysis zones. Results of Kaunas city TAZ analysis (see Figure 29) indicated that just 3 rectangular traffic analysis zones (in grey color) it is possible consider like transportation activity centers.

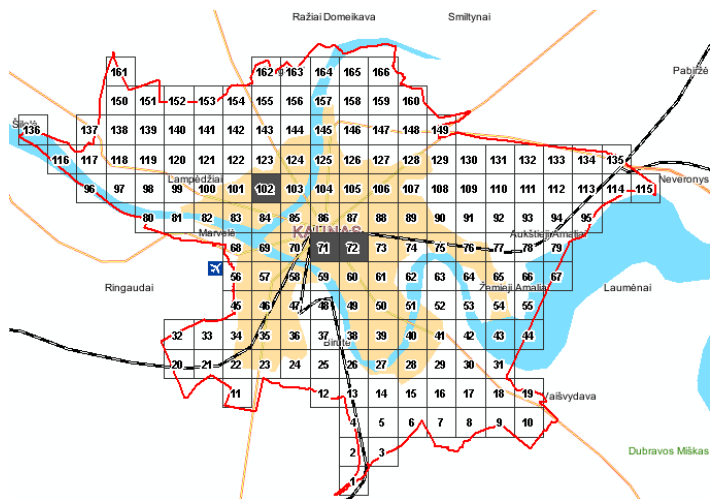


Figure 29. Results of TAZ matching to TAC analysis in Kaunas city

Analysis traffic analysis zones of Kaunas city showed that urban area zoning by rectangular is not so precise for urban areas transport system analysis. Better way is to perform transport system modelling in urban areas which has boundaries with main streets and are divided according different zones of residential areas.

3.2. Assessment of three Vilnius city development concepts

It was performed analysis of Vilnius city development scenarios to 2025 year according transport system sustainability. For multi-criteria analysis was used MCDM method SAW and criterions weights were estimated by ranking method. It was performed 20 experts from Vilnius municipality and municipalities' company "Vilniaus planas" questionnaire. Decision support system matrix is presented in Table 31.

Table 31. Decision support system matrix of Vilnius development scenarios evaluation

No	Criterion name	Units	*	Development scenario		
				Extensive development	Concentrated development	Decentralized concentrated development
Quantitative criterions						
R1	Budget for urban area transport system development	mln. Lt.	-	4802	4432	4535
R2	Necessary land use for building new streets	ha	-	902	115	300
R3	Fuel consumption for one automobile kilometer	1 aut. km /l	-	0.1115	0.1119	0.1109
R4	Total driven distance per morning peak hours	km	-	1468700	1280251	1368911
R5	Total trip by	h	-	20655	32180	21451

	car downtime per morning peak hours					
R6	Total driving time per morning peak hours	h	-	47225	48125	45125
<i>Qualitative criterions</i>						
R7	Possibilities of internal trip realization	score	+	3	4	4
R8	Possibilities of trip realiza- tion in out of city area	score	+	3	4	3
R9	Possibilities of trip realiza- tion by public transport	score	+	2	4	3
R10	Possibilities of transport mobility re- duction, in- fluence to traffic flows speed, envi- ronmental impact	score	+	2	3	3
R11	Complicity of urban trans- port system network de- velopment	score	-	4	2	3
R12	Loaded traffic flows in cen- tral part of the city	score	-	3	4	2
R13	Increasing of citizens mo- bility	score	-	4	3	4
R14	Noise and air pollution in central part of the city	score	-	3	4	3

R15	Motivation of city bypass need through: Rudamina, N. Vilnia, Balsiai, Riese, Grigiskes and Lentvaris	score	+	4	2	3
R16	Motivation of rail transport usability	score	+	2	1	4

3.2.1. Vilnius city development scenarios ranking by SAW

Calculation of indicators weights for Vilnius city development scenarios ranking have been performed using ranking method, the input data have been collected by performing 28 experts questionnaire. Experts from Vilnius city municipality from municipality organization “Susisiekimo Paslaugos” and VGTU have filled questionnaires for evaluating criterions importance. The results of ranking method are presented in Table 32.

Table 32. Decision support system matrix with criterions importance of Vilnius development scenarios evaluation

Nº	Criterion name	Units	Importance	*	Development scenario		
					Extensive development	Concentrated development	Decentralized concentrated development
Quantitative criterions							
R1	Budget for urban area transport system development	mln. Lt.	0,078	-	4802	4432	4535
R2	Necessary land use for building new streets	ha	0,061	-	902	115	300
R3	Fuel consumption for one automobile kilometer	1 aut. km /l	0,071	-	0,1115	0,1119	0,1109
R4	Total driven distance per morning	km	0,086	-	1468700	1280251	1368911

	peak hours						
R5	Total trip by car down-time per morning peak hours	h	0,086	-	20655	32180	21451
R6	Total driving time per morning peak hours	h	0,089	-	47225	48125	45125
<i>Qualitative criterions</i>							
R7	Possibilities of internal trip realization	score	0,052	+	3	4	4
R8	Possibilities of trip realization in out of city area	score	0,061	+	3	4	3
R9	Possibilities of trip realization by public transport	score	0,072	+	2	4	3
R10	Possibilities of transport mobility reduction, influence to traffic flows speed, environmental impact	score	0,069	+	2	3	3
R11	Complicity of urban transport system network development	score	0,031	-	4	2	3
R12	Loaded traffic flows in central part of the city	score	0,044	-	3	4	2
R13	Increasing of citizens mobility	score	0,051	-	4	3	4
R14	Noise and air pollution in central part of the city	score	0,064	-	3	4	3
R15	Motivation	score	0,056	+	4	2	3

	of city bypass need through: Rudamina, N. Vilnia, Balsiai, Riese, Grig- iskes and Lentvaris						
R16	Motivation of rail transport usability	score	0,029	+	2	1	4

Calculations in order to find rational variant of Vilnius city transport system development have been performed by computer program WinDetermination. The program's interface with prepared data for calculations is presented in Figure 30.

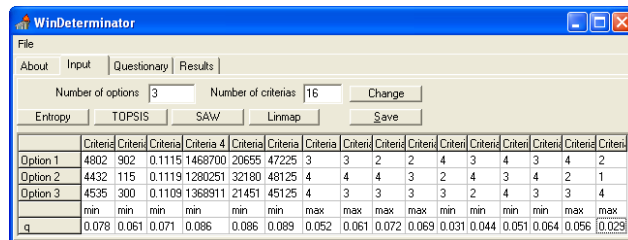


Figure 30. Input data for calculations in computer program interface

Variants priority row by SAW method:

Decentralized concentrated development > Concentrated development > Extensive development = 0,882 > 0,875 > 0,871.

3.3. Vilnius city urban areas development scenarios theoretic modelling

3.3.1. Input data for the modelling

The system was created on the Traffic Analyst modelling software. With the help of the transportation analysis system, it is possible to calculate current and future traffic flows, speeds and the consequent pollution along the roads. However, in order to find out the efficiency of individual new transport infrastructure

objects – new streets, intersections, bridges, viaducts, tunnels and other transport structures or newly implemented projects of traffic control systems – calculations of the economical efficiency of the projects had to be carried out; as well as transport and passenger time losses and accident-related losses, such calculations include the evaluation of fuel consumption.

One of the essential parts in modelling was to create a matrix that describes that amount of vehicle movements between different areas in Vilnius. For that purpose, the studied area was divided into zones (see Figure 31). The road system and public transport system were also described in the model.

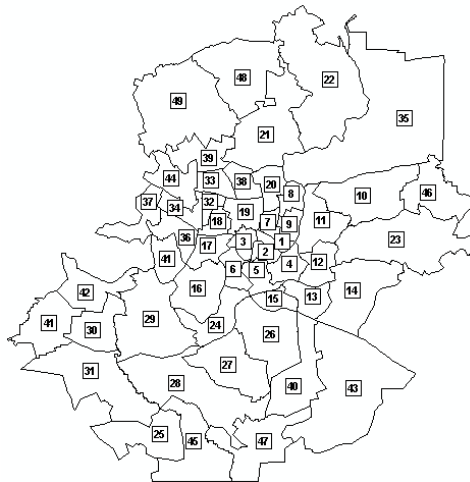


Figure 31. Transport analysis zones of Vilnius city

The aim of the model was to represent travel times and traffic flows during the morning rush hour in Vilnius under different assumptions of the transport system, distribution of the population, employment and car ownership. Therefore, the study area of the model includes the whole of Vilnius. The used zone system consists of 51 zones.

For each zone in the study area, it was necessary to obtain information about the population, the number of working places and the travel pattern to and from other zones. Model calibration was based on actual traffic volumes (morning peak hour 2004). The population of each zone was calculated from a register of voters and an address table. Information about the number of employees in each zone was obtained from Vilnius comprehensive plan GIS database.

Attribute data was related to zones, streets and public transport network GIS objects. This united attribute and geographic data is stored in the GIS database

which structure is suitable for performing modelling with Traffic Analyst software. Stored GIS databank contains the following data for the base year:

- population and employment by zones;
- number of trips by car and by truck and by public transport between the zones;
- travel time by car between zones;
- number of registered cars per resident.

3.3.2. Structure of the modelling

The model calculates and forecasts the number of car and truck trips. A truck is a vehicle with a maximal allowed weight of over 3.5 tons, and cars mean all other vehicles with four wheels including light cars, vans, minibuses and small trucks, including regular buses and trolleybuses.

A common way to produce a transport forecast is to divide the calculations in the following modelling steps: Trip Generation, Trip Distribution, Mode Split and Network Assignments.

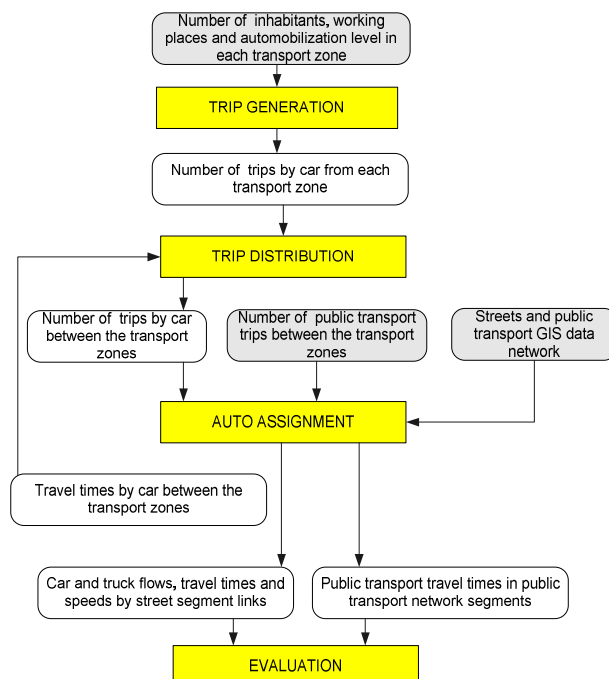


Figure 32. Transport modelling steps

The Traffic Analyst model includes the following steps:

1. Trip Generation.
2. Trip Distribution.
3. Auto Assignment.
4. Evaluation (Fuel Consumption Calculation).

In a Trip Generation step, the number of car and truck trips that start in each zone and the number of trips that end in each zone are calculated. In the Trip Distribution step, the geographical trip pattern is calculated, which is determined by the number of car and truck trips between each pair of the zones. In Auto Assignment step, the car and truck trips between different zone pairs are simultaneously allocated to the network and travel times by car between the zones that are calculated. Trips by public transport are allocated to the public transport network and travel times by public transport between zones are calculated. In the last step, fuel consumption is calculated for the whole network. The different steps and data flows in the model are shown in the Figure 32.

In the Auto Assignment Step, the car and truck trips between zones are allocated (assigned) to the road network according to the equilibrium traffic assignment. Also are assigned public transport trips to a public transport network segments. The behaviour assumption of the traffic assignment is that each driver tries to choose the route that takes him/her to the destination as fast as possible. The route travel time is calculated as the sum of link's travel times along the route. The link travel times are calculated by using increasing volume delay functions where the travel time along a route increases with the number of users. The consequence is that, between each origin/destination pair, only the routes that have minimal travel time are used. In the Traffic Analyst Model, the distribution of trips by routes is performed as a multi-class traffic assignment with generalized travel cost that is a modification of the traffic assignment based on plain travel times.

3.3.3. Modelling scenarios and variables

Different Vilnius city transport system scenarios have been modelled to 2015 and 2025 years. Also have been modelled present situation according present transport and socio-economic data and present Vilnius city streets network.

Land-use is possible to be modified through changes in the size of the population and the number of workplaces in each zone. There are possibilities to analyze different levels of expansions, the growth of new suburbs, relocation of working places and other land-use strategies (see Figure 33 and Figure 34).

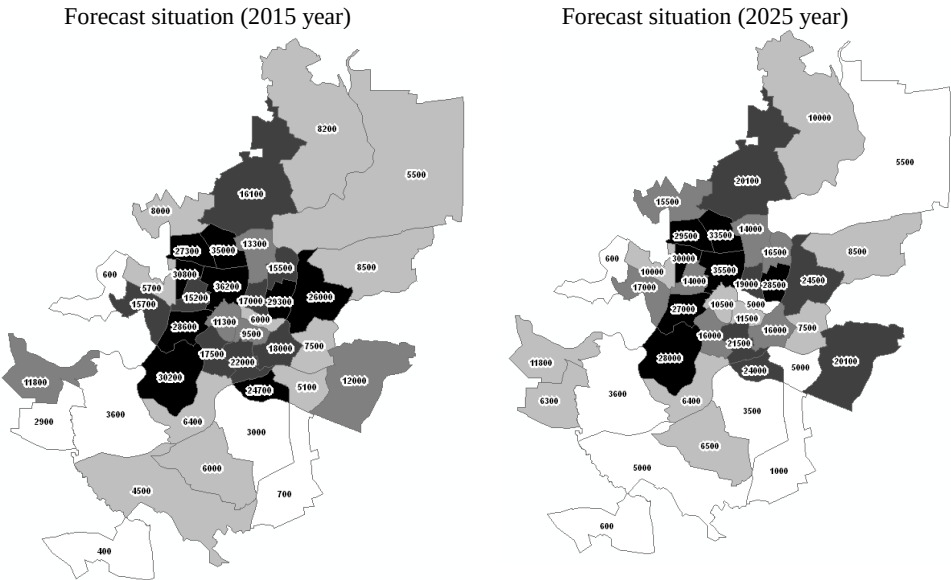


Figure 33. Inhabitants in Vilnius transportation zones: 2015 and 2025 year

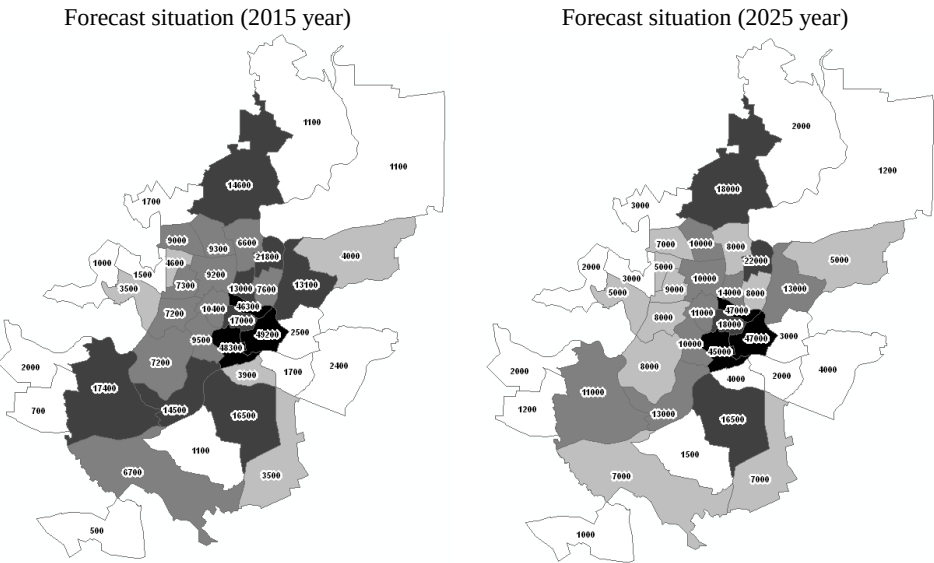


Figure 34. Working places in Vilnius transportation zones: 2015 and 2025 year

Forecasting of changes in land-use across the city is quite complicated as many factors are involved: policy packages, private initiatives, infrastructure development and changes in global economics. Consequently, it was decided to operate with developments that are targeted and hypothesized in the Vilnius Comprehensive Plan (Comprehensive plan of Vilnius city 2007).

Hence, other forecast factors were development within Vilnius's transport infrastructure according to the Comprehensive Plan and its influence on traffic flows. Also have been modelled transport system scenarios according infrastructure of the street network.

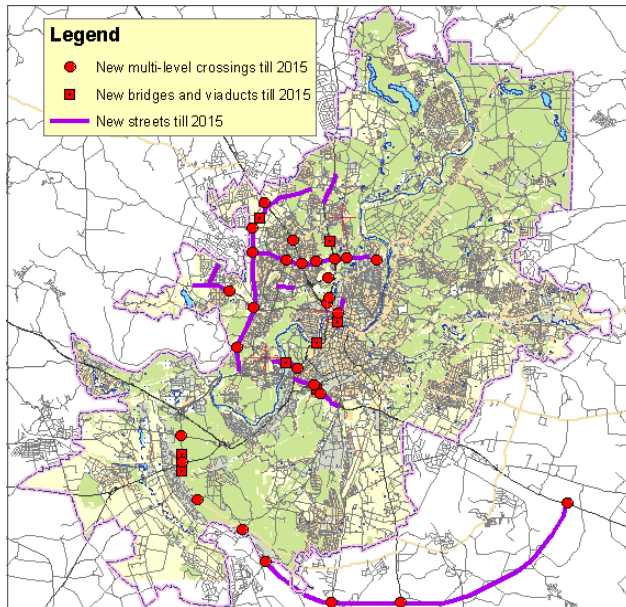


Figure 35. Development of Vilnius bypasses and two level crossing according Vilnius Comprehensive Plan till 2015

Vilnius city transport system development scenarios have been modelled also that these main new projects of Vilnius city transport infrastructure would be developed till 2015:

- Equipment of the South Vilnius city bypass.
- Equipment of the West Vilnius city bypass.
- New segment of G. Vilko street from Mokyklos street to A14 road.
- New two-level crossing at Zalgirio st. and Gelezinio Vilko st.
- New two-level crossing at Ukmerges st. – Ateities st. – Laisves st.

- Equipmnet of Siaurine st. from new West bypass to Zirmunu st.
- Equipment of Pilaites street follow-up.
- New connection from Ozo st. at Buivydiskiu st. to Laisves st.
- New two level crossing at Kernaves st. – Ozo st. intersection.
- New connection through Bajorai village from Mokslininku st.
- New connection from Kernaves st. to Tumo-Vaizganto st. through new bridge.

It is possible to modify car ownership by changing the number of cars per person. The forecasted car ownership in 2015 is 570 cars per 1,000 inhabitants and ownership in 2025 is 590 cars per 1,000 inhabitants. The total number of car trips in the region is calculated as a function of changes in the total population and the car ownership as compared to the base year situation. The consequence is that if the population and car ownership is unchanged as compared to the base year situation but the total number of workplaces increased, then the total number of car trips will be the same as for the base year situation. If the workplaces are relocated, for example to more central areas, it will have an effect on the trip's pattern for cars but not on the total number of trips.

The trip frequencies in the Trip Generation model are estimated and based on the travel behaviour in 2007. Hence, it is the level of car use for the base year situation that is included in the model. If there is reason to believe that the cars will be used to a higher extent in the future then the way to implement that in the Model is to increase the car ownership a slightly in addition to the increase of the number of registered cars per capita.

3.3.4. Description of Vilnius city development scenarios modelling

Construction of scenarios should reflect expected and desired aspects of developments. There are many factors that could be changed in the model, consequently the number of scenarios will strongly and unreasonably increase. Scenarios were chosen for the comparison they are presented in Table 33. Factors that were used in the scenarios are explained later.

Table 33. Chosen scenarios for Vilnius transport system modelling

	Present situation	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4
Street Network	2007	2007	2015	2007	2015	2007	2015	2007	2015	2007	2015	2007	2015
Social data	2007	2015	2015	2025	2025	2015	2015	2025	2025	2015	2015	2025	2025
Car ownership	2007	2015	2015	2025	2025	2015	2015	2025	2025	2015	2015	2025	2025

- C – Concentrated development;
- D – Decentralized concentrated development;
- E – Extensive development.

Street Network 2007 – means the current street network and other infrastructure, i.e. length of the streets, number of lanes, modes allowed, and volume-delay function index.

Street Network 2015 – means the development of bypasses and two-level crossings according to the Comprehensive Plan of Vilnius (see previous chapter).

Social Data 2007 – current situation, i.e. total number of inhabitants is 554000 and the rough number of workplaces is 310000.

Social Data 2015 – number of inhabitants that increased to 576000 and the rough number of workplaces will be 409,000. The ratio between workplace and number of resident's are more balanced, as were population and employment moves to suburban areas, especially in the Northern direction. The number of inhabitants decreased in the central part of the city, and most of the residents will have to travel towards center.

Social Data 2025 – number of inhabitants that increased to 600000 and the rough number of workplaces will be 426000.

Car ownership in 2007 – car ownership initially used in model. Such a car ownership rate was used in the model's calibration, and therefore it does not fully correspond to the real figures (official statistics could be questioned).

Car ownership 2015 – due to economical growth car ownership will increase rapidly to 570 cars per 1000 inhabitants and car ownership in 2025 will be 590 cars per 1000 inhabitants.

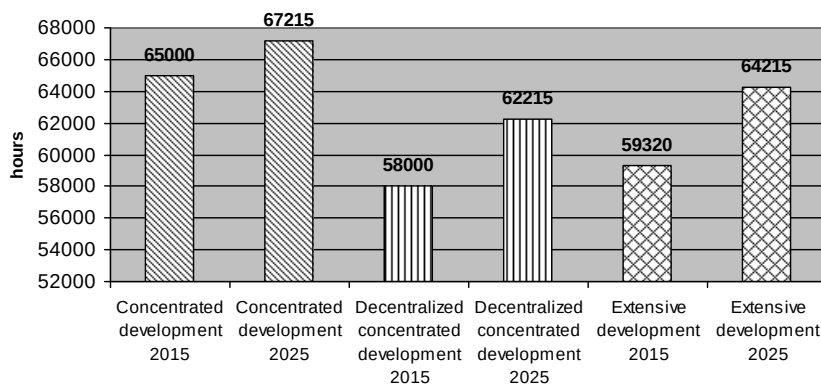
4.3.5. Discussion results of Vilnius city transport system modelling scenarios

All scenarios were evaluated by combining different factors and planning horizons according to Vilnius city urban areas development strategies. The model produced rational results for a peak-hour and is presented in the Table 34. In order to see an effect of new transport system infrastructure development according Vilnius city Comprehensive Plan it is necessary to perform a comparison of developments with base scenario and future scenarios with "the worst future" scenario is essential. The "worst future" scenario means that there are no changes in the infrastructure, but car ownership increased and land use pattern changes and so will influence more trips from suburbs to the city center (in 2015 and 2025).

Table 34. Results of Vilnius city development scenarios calculations

Indicator	2007	Concentrated development				Decentralized concentrated development				Extensive development			
		C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4
Length of street network, km	1710	1710	1790	1710	1790	1710	1790	1710	1790	1710	1790	1710	1790
Driving time, h.	18250	65000	45320	67215	48125	58000	43421	62215	45125	59320	48901	64215	47225
Driving down-time, h.	9925	38000	24135	43512	32180	25451	18214	29451	21451	23451	17254	27861	20655
Driven distance, km	850230	1151250	1100251	1371250	1280251	1291780	1210631	1459560	1368911	1367780	1270631	1589840	1468700
Fuel consumption 1 aut-km, litr.	0,0854	0,1077	0,1069	0,1131	0,1119	0,1051	0,1042	0,1122	0,1109	0,1059	0,1048	0,1129	0,1115

Travel time by car of “the worst future” scenario is presented in Figure 36. This figure presents travel time by car in morning peak-hours of the three Vilnius city development scenarios in 2015 and 2025 years, when new transport system infrastructure (two-level crossings and new bypasses) would not be developed.

**Figure 36.** Driven time by car according different Vilnius city development scenarios for 2015 and 2025 years

The next charts shows an average modelled driven distance for one Vilnius inhabitant and an average fuel consumption in litres for one driven kilometre in 2015 and 2025 years according different Vilnius city transport system development scenario (see Figure 37 and Figure 38). For modelling of fuel consumption and average driven distance have been taken into account that new projects of

Vilnius city transport infrastructure according Vilnius Comprehensive Plan would be developed till 2015 year.

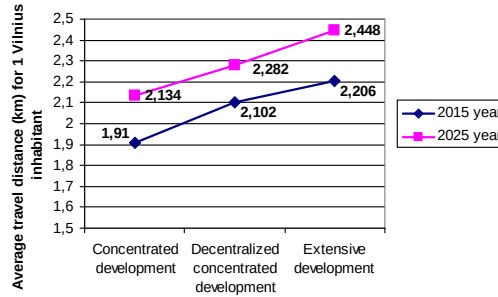


Figure 37. Average driven distance according different Vilnius city development scenarios for 2015 and 2025 years

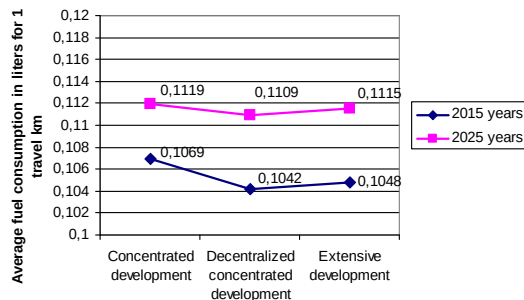


Figure 38. Fuel consumption according development scenarios for 2015 and 2025 years of Vilnius city

Driving pattern is a complex phenomenon, which is influenced by several variables as the driver behaviour, the street environment, the traffic flow and the car type, and the driving patterns may vary strongly. A large number of the measures must be employed in order to capture all these sources of variation (Loukopoulos *et al.* 2004). In this part of the dissertation, the aim was to prepare model that would describe a way how to choose the correct city development scenario according urban transport system conditions. Also was presented methodology for estimation correct traffic analysis zones in the urban area, have been compared to different types for TAZ zones evaluation. Further have been performed modelling of three Vilnius city development scenarios according traffic conditions in Vilnius. The aim was to employ decision support system calcula-

tion methods and GIS technologies for urban areas transport system analysis according sustainability and investigate the effect of GIS and DSS methods integration.

Modelling results clearly show that all infrastructure developments and changes in land use influence the driven distance and fuel consumption.

Generally, the exact extent of cause and effect between urban areas development scenarios and transport system indicators in transport is not conclusive. Often there are a number of local factors involved, relating to particular people behaviours and the involved localities. A combination of complementary land use planning measures and infrastructure development can provide an integrated package where each element reinforces the other towards a more sustainable development.

The current situation (social data 2007, i.e. total number of inhabitants is 554000 and the rough number of workplaces is 310000 and the street network data for 2007 situation) initially shows that average driven distance for one Vilnius inhabitant is 1,56 km. The “worst future” scenario for 2015 and 2025 year, when street network infrastructure would not be developed according Vilnius Comprehensive Plan, indicates the huge increase of time spend in traffic jams. Modelling results shows that average time for one Vilnius inhabitant spends in traffic jams without any movement in 2015 would be about 5 minutes and in 2025 – 7 minutes for Vilnius city concentrated development scenario. If would be taken into account prognosis of Vilnius city automobilization level the average time spend in traffic jams for Vilnius inhabitants who have automobiles would be 7 and 9 minutes in 2015 and 2025 years. In order to calculate the effectiveness of fuel consumption in morning peak hours for each Vilnius city development scenario according streets infrastructure projects which are in Comprehensive Plan it is possible to compare modelling scenarios with the urban areas development scenarios with 2007 year street network (see Figure 39 and Figure 40).

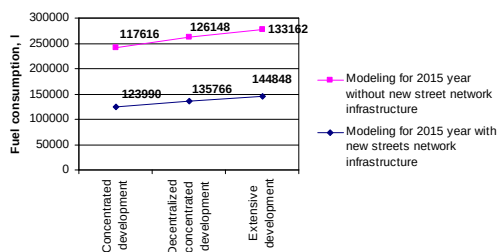


Figure 39. Fuel consumption according Vilnius development scenario for 2015 year and street network infrastructure

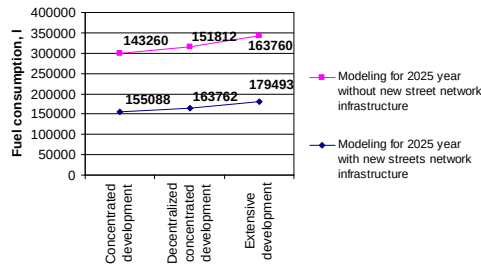


Figure 40. Fuel consumption according Vilnius development scenario for 2025 year and street network infrastructure

The biggest difference in fuel consumption in morning peak hours according new transport network infrastructure has extensive development scenario. Difference in fuel consumption is 11686 litres and 15733 litres according modelling scenarios for 2015 and 2025 years. Other Vilnius city development scenarios are not so sensitive for the need of new infrastructure development and the results differs in 1%. Decentralized concentrated development scenario for 2015 year and without new street network infrastructure has 135766 litres and 163762 litres for 2025 year and respectively concentrated development has 123990 litres for 2015 year and 155088 litres for 2025 year. Development of Vilnius city new street network infrastructure according Vilnius city Comprehensive Plan till 2015 gives 6374 litres economy of fuel consumption according concentrated development and 9618 litres according decentralized concentrated development. The best variant of Vilnius city development scenario according travel time is scenario of decentralized concentrated development. The modelling results of total travel time by car with evaluated new street network infrastructure are 43421 hours duration in morning peak hours in 2015 year and 45125 hours in 2025.

3.4. Conclusions of the third chapter

1. Research of traffic analysis zones in Vilnius city showed that not all traffic analysis zones could be possible to consider like transport activity centers. Such kind of problematic situation is in the central part of Vilnius and in the TAZ which are in a distant area of the central part of Vilnius. The main reason is a large disproportion of population and working places density in these areas. In central part of Vilnius city working places density is 2,4 times bigger than living

places density; otherwise there are some zones in a distant area from central part where living places density is 4 times bigger than density of working places.

2. The problems of correct selection of urban areas transport system development could be solved by using decision support system methods and created indicators group of urban transport system. Created indicators system could be used for evaluating urban areas development scenarios according sustainability of transport system.

3. Urban transport system analysis model was developed for Vilnius conditions, which estimates the fuel consumption, average travel distance and driven time by car in morning peak hours depending on urban areas development scenario and socio-economic data. This model should be used when calculating new projects of the transport's infrastructure (by-passes, new bridges) and when evaluating the economic efficiency of traffic organization projects.

4. Application of model solved several practical problems. Analysis of three different Vilnius' city development scenarios would determine that decentralized concentrated development scenario has the lowest fuel consumption per one passenger per kilometre, but it would also lead to longer (but faster) trips and consequently higher total fuel consumption than concentrated development scenario. Meanwhile, reconstruction of current critical intersections will reduce fuel consumption and reduce pollution in highly populated areas. More concentrated and mixed land use is definitely an advantage to lowering total fuel consumption, but it is not advantage for sustainable transport system. Concentrated land use increases travel time and time spend in traffic jams.

5. For evaluating urban areas land use scenarios according transport system sustainability successfully could be used integrated multi criteria decision support system methods with GIS software, also for urban areas transport system detailed analysis in order to calculate traffic indicators could be used traffic modelling software.

6. Hence, various developments have strengths and weaknesses. Reducing dependency of fuel consumption in urban areas it is necessary to promote concentrated development in urban areas however; concentrated development has enormous positive spin-offs in the overall transportation sustainability and liveability of the Vilnius.

Conclusions and recommendations

The chapter examines the practical solutions to the issues raised by the previous chapters. The methodological insights (a model) have been presented and concluding remarks given within.

1. Urban areas transport system sustainability comprises of complex interrelations between social, environmental and economical subsystems. Sustainable development finds no sense then indicators represent only one subsystem. Indicators sets must be taken into an account from all groups for urban areas development scenarios assessment according to transport system sustainability.

2. Analysis of 6 multi criteria analysis methods presented that the most suitable methods for urban areas transport system assessment are SAW, MCDM-23, AHP and multi criteria proportional method. Calculation results by TOPSIS method are not so stable. According to integration opportunities with GIS, were integrated SAW and multi criteria complex proportional methods and created mechanism for urban areas development scenarios assessment.

3. In order to perform transport system assessment, urban areas must be divided into smaller subdivisions – traffic analysis zones. According to calculations for Vilnius and Kaunas cities, the author estimated that urban area division into traffic analysis zones with natural boundaries is better and more effective

than rectangular zones division. The effectiveness of traffic analysis zones consideration like transport activity centers is 37 %.

4. Using integrated with GIS decision support system methods have been performed modelling of three Vilnius city urban areas development scenarios (decentralized concentrated development, concentrated development and extensive development). Results showed that the best variant of Vilnius city development scenario according to transport system sustainability is decentralized concentrated development.

5. Assessment of Vilnius city development scenarios for 2015 and 2025 years according to theoretical transportation model indicated that the best scenario is decentralized concentrated development. This scenario minimizes travel time in morning peak hours. According to travel time this development scenario is 4 % more effective than concentrated development and even 12 % more effective than extensive development.

6. Decentralized concentrated development scenario has the least fuel consumption for 1 kilometres in morning peak hours, but concentrated development scenario has 8500 litres less total fuel consumption. Evaluating in the model new transport infrastructure, according to Comprehensive Vilnius Plan to 2015 year, gives 5 % economic effect of decentralized concentrated development scenario in total fuel consumption.

7. Created model for urban areas transport system present situation and future development scenarios assessment could be successfully used with theoretical models like TrafficAnalyst and Vissum.

8. Analysis of particular planning problems has shown that multi-criteria methods are suitable for assessment of present urban areas transport system situation, for evaluation of urban areas development scenarios. Multi-criteria methods are compatible with GIS. This enables to improve analysis of spatial characteristics.

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List of author's publications on the topic of dissertation

Articles in the reviewed scientific periodical publications

- Jakimavičius, M., Burinskienė, M. (2007). Automobile Transport system analysis and ranking in Lithuanian administrative regions. *Transport*. ISSN 1648-4142. Vilnius : Technika. Vol. 22, no. 3, p. 214–220. (Thomson ISI Web of Science).
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- Jakimavičius, M., Mačerinskienė, (2006). A. Accessibility based automobile transport system analysis in Lithuanian regions and forecasting potential in residential areas. *Urban Transport XII: Urban Transport and the Environment in the 21st Century / Wessex Institute of Technology (UK)*, Technical University Pardubice (Czech Republic). ISBN 1-84564-179-5. Southampton : WIT Press, p. 141–149. (Thomson ISI Proceedings).
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ANNEX

1. Calculation with simple additive weighting method (SAW)

Simple additive weighting (SAW) method allows valuating indicators having different dimensions. Sum of all criterions importance values must be equal to one ($\sum_{i=1}^n q_i = 1$). According this method it is necessary to to these steps:

1st step: Normalization of decision support system matrix.

If criterion is maximized:

$$X_{ij} = \frac{X_{ij}}{X_j^{\max}}. \quad (1A)$$

If criterion is minimized:

$$X_{ij} = \frac{X_j^{\min}}{X_{ij}}. \quad (2A)$$

Table 1A shows normalized criterions matrix, which was calculated according (1A) and (2A) formulas.

Table 1A. Normalized criterions matrix

No	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	1,0000	0,7279	0,8456	0,6985	0,7426
R2	1,0000	0,7851	0,8430	0,6942	0,6446
R3	0,4570	0,3024	1,0000	0,4089	0,6392
R4	0,9141	0,4866	1,0000	0,4294	0,3931
R5	0,8831	0,9351	0,8312	1,0000	0,8961
R6	0,3951	0,2689	0,9412	0,4706	1,0000

2nd step: When we have normalized matrix each criterion of concrete municipality is multiplied with its importance. Multiplied criterions are summed for each row (for each municipality).

$$S_{SAW} = \max_j \sum_{i=1}^n X_{ij} \times q_i . \quad (3A)$$

Table 2A. Criterion multiplicity matrix

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	0,1560	0,1136	0,1319	0,1090	0,1159
R2	0,1610	0,1264	0,1357	0,1118	0,1038
R3	0,0736	0,0487	0,1610	0,0658	0,1029
R4	0,1545	0,0822	0,1690	0,0726	0,0664
R5	0,1528	0,1618	0,1438	0,1730	0,1550
R6	0,0711	0,0484	0,1694	0,0847	0,1800

3rd step: According formula (3A) have been estimated the best alternatives.

$$S_1 = 0,1560 + 0,1610 + 0,0736 + 0,1545 + 0,1528 + 0,0711 = 0,7690;$$

$$S_2 = 0,5811; S_3 = 0,9108; S_4 = 0,6169; S_5 = 0,7240.$$

Variants priority row by SAW method: Zarasai > Utena > Skuodas > Plunge > Jonava.

2. Calculation with multi criteria decision making method MCDM-23

This method was created in USA in National Laboratory of Alternative Energy (Balcomb and Curtner 2000, p. 219–221). For the best alternative selection is using formula (3A). In order to normalize criterions values it is necessary to create scales of marks, which allows different type of indicators values recalculate to marks.

In MCDM-23, the 1-to-10 scale is truncated at the bottom resulting in a 4-to-10 scale. The reason is a common theorem in decision-making theory that holds that a scale with seven items is about as fine a scale as people can easily deal with. Description of MCDM-23 method scale is presented in Table 3A.

Table 3A. MCDM-24 scale for indicators values recalculation

Score	Description
10	Excellent
9	Good to excellent
8	Good
7	Fair to good
6	Fair
5	Borderline fair
4	Marginally acceptable

1st step: Design of measure scales for indicators values.

Table 4A. Measure scales for indicators values

Nº	Criterion name	Units	The best value	Score for the best value	The worst value	Score for the worst value
R1	Road network density in regions (in each municipality)	km/km ²	1,4	10	0,9	4
R2	Density of local roads in regions (in each municipality)	km/km ²	1,3	10	0,7	4
R3	Length of roads for 1000 inhabitants in administrative regions (municipalities)	km	60	10	15	4
R4	Length of local roads for 1000 rural inhabitants in administrative regions	km	105	10	40	4

	(municipalities)					
R5	Percentage coverage of territorial accessibility from the administrative unit going 30 minutes by car from local community (municipality)	%	80	10	60	4
R6	Number of traffic accidents	accident	30	10	120	4

2nd step: Calculation the scores for each indicator according measure scale.

In order to perform these calculations are using (4A) and (5A) formulas subject to indicators function (minimizing or maximizing).

$$B_n = B_{n,\min} + (R_{n,\max} - R_n) \times tg\alpha, \quad (4A)$$

$$B_n = B_{n,\min} + (R_n - R_{n,\min}) \times tg\alpha, \quad (5A)$$

here: B_n - the score of n indicator, $B_{n,\min}$ - minimal value of n indicator in scale range, $B_{n,\max}$ - maximal value of n indicator in scale range, R_n - n indicators value, $R_{n,\max}$ - maximal indicators n value in a range, $R_{n,\min}$ - minimal indicators

n value in a range, $tg\alpha = \frac{B_{n,\max} - B_{n,\min}}{R_{n,\max} - R_{n,\min}}$.

$$a_{11} = 4 + (1,36 - 0,9) \times \frac{(10 - 4)}{(1,4 - 0,9)} = 9,52 \text{ score.}$$

All other indicators transformation to scores are performed analogical. The results are presented in Table 5A.

Table 5A. Normalized criterions matrix

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	9,52	5,08	7,00	4,60	5,32
R2	9,10	6,50	7,20	5,40	4,80
R3	5,55	4,35	9,76	5,17	6,96
R4	9,13	5,01	9,96	4,46	4,11
R5	6,40	7,60	5,20	9,10	6,70
R6	6,03	4,05	8,47	6,70	8,58

3rd step: Calculation the best alternative

At the beginning it is necessary to calculate criterions multiplicity matrix according formula (3A). And after that to sum criterions values for each municipality, the highest value is the best.

Table 6A. Criterions multiplicity with importance matrix

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	1,49	0,79	1,09	0,72	0,83
R2	1,47	1,05	1,16	0,87	0,77
R3	0,89	0,70	1,57	0,83	1,12
R4	1,54	0,85	1,68	0,75	0,69
R5	1,11	1,31	0,90	1,57	1,16
R6	1,09	0,73	1,52	1,21	1,54

$S_1 = 1,49 + 1,47 + 0,89 + 1,54 + 1,11 + 1,09 = 7,58$ score; $S_2 = 5,43$ score;
 $S_3 = 7,93$ score; $S_4 = 5,95$ score; $S_5 = 6,12$ score.

Variants priority row by MCDM-23 method: Zarasai > Utena > Skuodas > Plunge > Jonava.

3. Calculation with analytic hierarchy process (AHP) method

The AHP developed by Saaty T. L. (1980) is a technique for analyzing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles: decomposition, comparative judgment and synthesis of priorities. AHP method operates with $m \times n$ matrix, where m is number of alternatives and n is number of indicators. This method requires that each indicator a_{ij} must be normalized by supplying this condition:

$$\sum_{j=1}^n a_{ij} = 1. \quad (6A)$$

The best alternative by calculating with AHP method is that one, which satisfy this condition:

$$S_{SAHP} = \max_j \sum_{i=1}^n a_{ij} \times q_i, j=1, 2, 3, \dots, m. \quad (7A)$$

AHP method uses proportional values therefore it is possible to use when indicators have different dimensions. If there are indicators with minimizing function then all indicators values are transformed to maximizing function values:

$$a_{ij}^* = \frac{1}{a_{ij}}. \quad (8A)$$

Then $a_{61} = \frac{1}{81} = 0,012$, all minimized indicators values transformation to maximize is presented in Table 7A.

Table 7A. Summary of minimized criterions transformation to maximized

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R6	0,012	0,008	0,029	0,015	0,031

Table 8A. Normalized criterions matrix according (6A) condition

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	0,2491	0,1813	0,2106	0,1740	0,1850
R2	0,2521	0,1979	0,2125	0,1750	0,1625
R3	0,1628	0,1077	0,3562	0,1457	0,2277
R4	0,2836	0,1510	0,3102	0,1332	0,1220
R5	0,1943	0,2057	0,1829	0,2200	0,1971
R6	0,1284	0,0874	0,3060	0,1530	0,3251

Table 9A. Matrix of criterions multiplicity with importance

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	0,0389	0,0283	0,0329	0,0271	0,0289
R2	0,0406	0,0319	0,0342	0,0282	0,0262
R3	0,0262	0,0173	0,0573	0,0235	0,0367
R4	0,0479	0,0255	0,0524	0,0225	0,0206
R5	0,0336	0,0356	0,0316	0,0381	0,0341
R6	0,0231	0,0157	0,0551	0,0275	0,0585

$S_{1,AHP} = 0,0389 + 0,0406 + 0,0262 + 0,0479 + 0,0336 + 0,0231 = 0,2103$;
 $S_{2,AHP} = 0,1443$; $S_{3,AHP} = 0,2636$; $S_{4,AHP} = 0,1669$; $S_{5,AHP} = 0,2049$.

Variants priority row by MCDM-23 method: Zarasai > Utena > Skuodas > Plunge > Jonava.

4. Calculation with technique for order preference by similarity to an ideal solution (TOPSIS) method

Technique for order preference by similarity to an ideal solution based upon the concept that a chosen alternative should have the shortest distance from an ideal solution and the farthest one from a negative-ideal solution (Hwang and Yoon 1981).

1st step: Construct the normalized matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^m x_{kj}^2}} \quad (9A)$$

$r_{11} = \frac{1,36}{\sqrt{1,36^2 + 0,99^2 + 1,15^2 + 0,95^2 + 1,01^2}} = 0,552$. Other values of criteria normalization are presented in Table 10A.

Table 10A. Normalized matrix

N°	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	0,552	0,402	0,467	0,385	0,410
R2	0,557	0,437	0,469	0,387	0,359
R3	0,334	0,221	0,730	0,299	0,467
R4	0,589	0,313	0,644	0,277	0,253
R5	0,434	0,459	0,408	0,491	0,440
R6	0,488	0,717	0,205	0,410	0,193

2nd step: Construct the normalized weighted matrix. Each element from criteria matrix is multiplied with matrix of importance values:

$$P^* = [R] \times [q], \quad (10A)$$

$$P^* = \begin{bmatrix} 0,552 & 0,402 & 0,467 & 0,385 & 0,410 \\ 0,557 & 0,437 & 0,469 & 0,387 & 0,359 \\ 0,334 & 0,221 & 0,730 & 0,299 & 0,467 \\ 0,589 & 0,313 & 0,644 & 0,277 & 0,253 \\ 0,434 & 0,459 & 0,408 & 0,491 & 0,440 \\ 0,488 & 0,717 & 0,205 & 0,410 & 0,193 \end{bmatrix} \times \begin{bmatrix} 0,156 \\ 0,161 \\ 0,161 \\ 0,169 \\ 0,173 \\ 0,180 \end{bmatrix} = \begin{bmatrix} 0,086 & 0,063 & 0,073 & 0,060 & 0,064 \\ 0,090 & 0,070 & 0,076 & 0,062 & 0,058 \\ 0,054 & 0,036 & 0,118 & 0,048 & 0,075 \\ 0,099 & 0,053 & 0,109 & 0,047 & 0,043 \\ 0,075 & 0,079 & 0,071 & 0,085 & 0,076 \\ 0,088 & 0,129 & 0,037 & 0,074 & 0,035 \end{bmatrix}$$

3rd step: Determine ideal positive (A^+) and ideal negative (A^-) solutions:

$$A^+ = \left\{ \left(\max_j v_{ij} \mid i \in I \right) \left(\min_j v_{ij} \mid i \in I' \right) \mid j=1, 2, 3, \dots, m \right\} = \{v_1^+, v_2^+, \dots, v_n^+\}, \quad (11A)$$

$$A^- = \left\{ \left(\min_j v_{ij} \mid i \in I \right) \left(\max_j v_{ij} \mid i \in I' \right) \mid j=1, 2, 3, \dots, m \right\} = \{v_1^-, v_2^-, \dots, v_n^-\}, \quad (12A)$$

here: $I = \{i=1, 2, 3, \dots, n\}$ and $I' = \{i=1, 2, 3, \dots, n\}$.

If criterion is minimized then it is necessary to take from each row minimal value. If criterion is maximized then from each row to take maximal value in order to calculate ideal positive solution:

$$A^+ = \{0,086; 0,090; 0,118; 0,109; 0,085; 0,035\}.$$

If criterion is minimized then it is necessary to take from each row maximal value. If criterion is maximized then from each row to take minimal value in order to calculate ideal negative solution:

$$A^- = \{0,060; 0,058; 0,036; 0,043; 0,071; 0,129\}.$$

4th step: Calculate relative closeness to an ideal positive and negative solution:

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_i^+)^2}, \quad j = 1, 2, 3, \dots, m; \quad (13A)$$

here: S_i^+ – relative cosines of concrete alternative to ideal positive solution.

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_i^-)^2}, \quad j = 1, 2, 3, \dots, m; \quad (14A)$$

here: S_i^- – relative cosines of concrete alternative to ideal negative solution.

$$S_1^+ = \sqrt{\frac{(0,086 - 0,086)^2 + (0,090 - 0,090)^2 + (0,054 - 0,118)^2 + (0,099 - 0,109)^2}{(0,075 - 0,085)^2 + (0,088 - 0,035)^2}} = 0,084$$

$$S_1^- = \sqrt{\frac{(0,086 - 0,060)^2 + (0,090 - 0,058)^2 + (0,054 - 0,036)^2 + (0,099 - 0,043)^2}{(0,075 - 0,071)^2 + (0,088 - 0,129)^2}} = 0,083$$

All other alternatives relative distances to ideal positive and negative solution is presented in Table 11A.

Table 11A. Relative distances to ideal positive and negative solution

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
S^+	0,084	0,140	0,022	0,108	0,088
S^-	0,083	0,020	0,141	0,060	0,103

5th step: Calculate relative closeness to an ideal solution (K_{BIT}). Alternative A_j relative distance to ideal solution:

$$C_j^+ = \frac{S_j^+}{S_j^+ + S_j^-}. \quad (15A)$$

$1 \geq C_j^+ \geq 0$, $j = 1, 2, 3, \dots, m$. $A_j = A^+$ then $C_i^+ = 1$ and $A_j = A^-$ then $C_i^+ = 0$.

$$C_1 = \frac{0,084}{0,083 + 0,084} = 0,503; C_2 = 0,875; C_3 = 0,135; C_4 = 0,643; C_5 = 0,461.$$

Variants priority row by TOPSIS method: Jonava > Plunge > Utena > Skuodas > Zarasai.

5. Calculation with Elimination et Choice Translating Reality (ELECTRE III) method

Assuming that there exist defined criteria, g_j , $j = 1, 2, \dots, n$ and a set of alternatives A , the ELECTRE methods introduce the concept of an indifference threshold, q , and preference threshold. The preference relations are defined as follows:

APb (a is strongly preferred to b) $\Leftrightarrow g(a) - g(b) > p$;

AQb (a is weakly preferred to b) $\Leftrightarrow q < g(a) - g(b) \leq p$;

alb (a is indifferent to b ; and b to a) $\Leftrightarrow g(a) - g(b) \leq p$.

The ELECTRE method seeks to build an outranking relation S . aSb means that according to the global model of DM' preferences, there are good reasons to consider that " a " is at least as good as " b " or " a " is not worse than " b ". Each pair of alternatives a and b is then tested in order to check if the assertion aSb is valid or not. The test to accept the assertion aSb is implemented using two principles:

1. A concordance principle which requires that a majority of criteria, after considering their relative importance, is in favor of the assertion – the majority principle.

2. A non-discordance principle, which requires that within the minority of criteria, which do not support the assertion, none of them is strongly against the assertion – the respect of minorities' principle.

The operational implementation of these two principles is now discussed, assuming that all criteria are to be maximized. We first consider the outranking relation defined for each of the n criteria; that is, aS_jb means that " a is at least as good as b with respect to the j^{th} criterion," $j = 1, 2, \dots, n$.

The j^{th} criterion is in concordance with the assertion aSb if and only if aS_jb . That is, if $g_j(a) \geq g_j(b) - q_j$. Thus, even if $g_j(a)$ is less than $g_j(b)$ by an amount up to q_j , it does not contravene the assertion aS_jb and therefore is in concordance. The j^{th} criterion is in discordance with the assertion aSb if and only if bP_ja . That is, if $g_j(b) \geq g_j(a) + p_j$. That is, if b is strictly preferred to a for criterion j , then it is clearly not in concordance with the assertion that aSb . With these concepts it is now possible to measure the strength of the assertion aSb . The first step is to develop a measure of concordance; as contained in the concordance index $C(a, b)$, for every pair of alternatives $(a, b) \in A$. Let k_j be the importance coefficient or weight for criterion j . We define a fuzzy outranking relation as follows:

$$C(a, b) = \frac{1}{k} \sum_{j=1}^n k_j c_j(a, b), \quad \text{where} \quad k = \sum_{j=1}^n k_j \quad (16A)$$

$$c_j(a,b) = \begin{cases} 1, & \text{if } g_j(a) + q_j \geq g_j(b) \\ 0, & \text{if } g_j(a) + p_j \leq g_j(b), \quad j = 1, 2, \dots, n. \\ \frac{p_j + g_j(a) - g_j(b)}{p_j - q_j} & \text{otherwise} \end{cases}$$

To calculate discordance, a further threshold called the veto threshold is defined. The veto threshold v_j , allows for the possibility of aSb to be refused totally if, for any one criterion j , $g_j(b) > g_j(a) + v_j$. The discordance index for each criterion j , $d_j(a,b)$ is calculated as:

$$d_j(a,b) = \begin{cases} 0, & \text{if } g_j(a) + p_j \geq g_j(b) \\ 1, & \text{if } g_j(a) + v_j \leq g_j(b), \quad j = 1, 2, \dots, n. \\ \frac{g_j + g_j(a) - p_j}{v_j - p_j} & \text{otherwise} \end{cases} \quad (17A)$$

The final step in the model building phase is to combine these two measures to produce a measure of the degree of outranking; that is, a credibility index which assesses the strength of the assertion that “a is at least as good as b.” The credibility degree for each pair $(a,b) \in A$ is defined as:

$$S(a,b) = \begin{cases} C(a,b), & \text{if } d_j(a,b) \leq C(a,b) \quad \forall j \\ \frac{1 - d_j(a,b)}{1 - C(a,b)} & \text{where } J(a,b) \text{ is the set of criteria} \\ C(a,b) \cdot \prod_{j \in J(a,b)} & \text{such that } -d_j(a,b) > C(a,b) \end{cases} \quad (18A)$$

This concludes the construction of the outranking model. The next step in the outranking approach is to exploit the model and produce a ranking of alternatives from the fuzzy outranking relation.

For the calculations priority of alternatives was used ELECTRE III-IV software (ELECTRE III-IV):

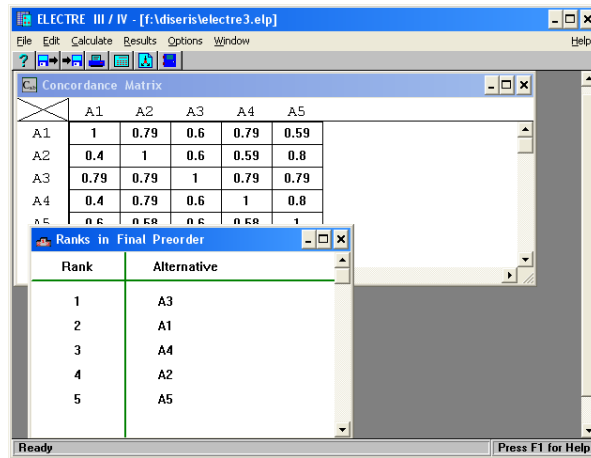


Figure 1A. Results of ELECTRE III software calculations

Variants priority row by ELECTRE III method: Zarasai > Utena > Plunge > Jonava > Skuodas.

6. Calculation with multicriteria complex proportion method (MCP)

This method was created by Lithuanian scientists Zavadskas E. K. and Kaklauskas A. (Zavadskas and Kaklauskas 1996). This method declare that variants importance level directly and proportionally dependence from criterions values and criterions weights.

1st step: Determinations of normalized criterions matrix:

$$d_{ij} = \frac{x_{ij} \times q_{ij}}{\sum_{j=1}^m x_{ij}}, i = 1, 2, 3, \dots, n; j = 1, 2, 3, \dots, m. \quad (19A)$$

$$d_{11} = \frac{1,36 \times 0,156}{1,36 + 0,99 + 1,15 + 0,95 + 1,01} = 0,0389.$$

Table 12A. Normalized criterions matrix for complex proportional method calculation

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
R1	0,0389	0,0283	0,0329	0,0271	0,0289
R2	0,0406	0,0319	0,0342	0,0282	0,0262
R3	0,0262	0,0173	0,0573	0,0235	0,0367
R4	0,0479	0,0255	0,0524	0,0225	0,0206
R5	0,0336	0,0356	0,0316	0,0381	0,0341
R6	0,0437	0,0641	0,0183	0,0366	0,0172

2nd step: Calculation of minimizing (S_{-j}) and maximizing (S_{+j}) normalized criterions sums for alternative j :

$$S_{-j} = \sum_{i=1}^n d_{-ij}; S_{+j} = \sum_{i=1}^n d_{+ij}; i = 1, 2, 3, \dots, n; j = 1, 2, 3, \dots, m. \quad (20A)$$

$$S_{+1} = 0,0389 + 0,0406 + 0,0262 + 0,0479 + 0,0336 = 0,1872; S_{-1} = 0,0437.$$

Table 13A. Results of minimized and maximized normalized criterions sums calculations

N ^o	Municipality				
	Utena	Jonava	Zarasai	Plunge	Skuodas
S_{+j}	0,1872	0,1386	0,2085	0,1393	0,1464
S_{-j}	0,0437	0,0641	0,0183	0,0366	0,0172

3rd step: Calculation of variant's a_j importance Q_j :

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^m S_{-j}}{S_{-j} \cdot \sum_{j=1}^m \frac{S_{-\min}}{S_{-j}}}, j = 1, 2, 3, \dots, m. \quad (21A)$$

$$Q_1 = 0,1872 + \frac{0,0172 \cdot (0,0437 + 0,0641 + 0,0183 + 0,0366 + 0,0172)}{0,0437 \cdot \left(\frac{0,0172}{0,0437} + \frac{0,0172}{0,0641} + \frac{0,0172}{0,0183} + \frac{0,0172}{0,0366} + \frac{0,0172}{0,0172} \right)} =$$

$$0,406; Q_2 = 0,287; Q_3 = 0,730; Q_4 = 0,400; Q_5 = 0,700.$$

4th step: Calculation of variant's a_j importance level in percentage N_j :

$$N_j = \frac{Q_j}{Q_{\max}} \times 100. \quad (22A)$$

$$N_1 = \frac{0,406}{0,700} \times 100 = 58,1\%; \quad N_2 = 39,4\%; \quad N_3 = 100; \quad N_4 = 54,8; \quad N_5 = 95,9.$$

Variants priority row by complex proportional method: Zarasai > Skuodas > Utena > Plunge > Jonava.

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Doctoral dissertation

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