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Introduction

Relevance of the research

A modern town is comprised of complex interrelations between socio-political, environmental and economical subsystems. Every city is a framework directed by local inhabitant's needs and is filled with the ideas of local planners, local and global economical conditions and consequently it is crucial to find reasonable technological solutions. These solutions should shape the sustainable urban environment and the urban transport system is a substantial part of this environment. The quality and supply of transport services very closely relate to environmental aspects and are one of the main indicators showing the quality of life in cities.

Estimations show that a fleet of road vehicles consumes about half of the extracted oil in the world [1]. Moreover, the use of energy for transport is increasing while use in other sectors is relatively stable. The rise in fuel consumption causes many problems and it influences socio-political, environmental and economical subsystems. Therefore, reduction of the consumption of fossil fuels (oil, coal and gas) is a key issue in efforts made to promote sustainable development.

Transport is the most energy intensive sector of transport and is viewed as a key challenge for sustainable development. Transport causes pollution that has adverse effects on the environment at the local, regional and global levels and harms human health. Integrated approaches to transportation that include improved planning, demand management, fuel efficiency and cleaner fuels can help to meet transport's challenges.

Emissions at a global level affect the earth's climate negatively and it is a concern of the United Nations. Regional and local air pollution threatens health and much of it can be traced to the emissions of road vehicles. The rapid and uncontrollable growth of major urban centers is one of the key issues linked to energy. By taking energy issues into consideration in land use planning and in designing physical infrastructure, construction standards and transportation, systems can reduce some of the increased demand for energy that accompanies rapid urbanization and can improve the quality of the urban environment [2].

There are three main groups of tools to reduce emissions: technological, administrational, and planning [3,4]. Actually, there are no impeccable examples of integrated policies, where all tools are integrated and could be mentioned in the terms of reduced fuel consumption in transport. The growth of energy in transport use has continued its reliance on petroleum. On another hand, in most of the EU countries the formulation of the main problem could be summarized as follows: the transportation need (in kilometers) is still increasing, but the time spent on the traveling stays the same. During the last half of the 20th century it became not only possible, but also necessary for people to transport themselves considerably longer distances to reach their daily and weekly activities.

Obviously, technological measures could bring considerable reduction of the energy consumption in the transport sector but such measures do not solve the main "demand on transport" problem and Lithuania's car industry is not ready to deal with high-tech issues at the current moment. More radical tools remain in policy formations (administrative steps), i.e. increase in fuel prices, road pricing, and quotas on fuel purchasing etc. These measures could potentially change transportation patterns significantly in the course of a short time. Such rationing is both unpopular and costly: political backing and continuation of such measures are very doubtful because economic growth depends on transport.

In order to break the self-perpetuating interaction between increased mobility and transport generating land use, there will be a need for specific transport policy measures as well as a location and structuring of future development that aims at limiting the needs for transportation, or in short, a coordinated land-use and transport planning.

Global issues and the increase of fuel prices have hugely influenced national economies including Lithuanian. Lithuania is one of the new EU members with a rapid GDP growth and changes in its social and environmental subsystems. The Lithuanian transport sector is one of the main parts of Lithuania's economy, a generating considerable GDP. This sector is the one that is most integrated into the Europe market and development of other sectors depends on sustainability of the transport sector. One of the main strategic objectives of the Lithuanian transport sector is development of its infrastructure, increase of transport flows and energy efficiency. The Lithuanian policy is orientated to secured operation, traffic safety, reduction of environmental impacts,

market regulation and fiscal harmonization etc. On the other hand, the improvement of the ecological situation should take place and this is main objective of Lithuania's environmental strategy. Some possible social responses to the problem of air pollution are the introduction of energy saving measures, urban planning incentives to reduce energy consumption, and the use of more renewable fuels. Among these difficult and contradictory issues lies a technological opportunity to influence further development of the transport sector in more sustainable ways.

Research object

The investigation's object on a large scale is an urban transport system as well the relations between urban development and a transport system. The research's object in the narrow scale could be defined as: the identification and analysis of relations between urban structure elements and consumption of energy resources (energy) in a transport system, retrieval of more energy efficient Lithuanian urban structures and transport systems.

An urban structure(s) is the spatial location of activities as characterized by de/centralization, dispersion, and multiple employment centers. A transport system, as part of an urban structure, connects such centers and realizes various needs that come from the economical, political and social milieu.

Aim and objective of the research

The main objective of the research is to identify the main elements of Lithuanian urban structures that influence the energy consumption of urban transport and to evaluate weight/significance of these elements. Since the transformation of an urban structure is a long-term and complex action, it is essential to rate elements according to potentiality and the realization possibilities and to map out stepwise refinement plans for such elements.

Two models should be structured and an analysis based on such models should be performed in order to propose a more sustainable (energy efficient) urban structure. The following objectives should be accomplished while reaching the aim:

- To analyze existing conceptual frameworks of the urban system's planning, models of realization and its strengths and weaknesses;
- To identify the main indicators defining more energy efficient urban structures;

- To verify the hypotheses of the urban structure's influence on energy consumption in urban public transport from an empirical point of view;
- To verify the hypotheses of the urban structure's influence on energy consumption in private transport from a theoretical point of view;
- To determine the main preconditions for more sustainable development of the city and its transport system, specifically the energy efficient urban structure.

Methods of the research

From a methodological point of view, more detailed and concentrated problem formulation was performed after completing a survey of literature and international experiences. Analytical methods were employed to identify the main trends in the energy-planning field. The improvement of energy efficiency in the urban transport system could be achieved through land use planning whereas land use planning and development of urban areas influence accessibility to the transport system. The transport infrastructure influences the location decision in the long-term therefore various methods should be applied in order to satisfy the expectations of local inhabitants. Consequently, this study employed empirical and theoretical approaches. The design of the experiment was also based on empirical and theoretical approaches. Individual analysis of empirical and theoretical studies, and projects was performed and the possible application fields for current conditions were defined.

Data for the empirical study was collected during project "Vilnius Public Transport Research" in 2002. Interviews with passengers and on site research were the two main methods applied for data collection and analysis of the data was performed by using statistical software.

Data for the theoretical study was derived from Vilnius Municipality. VIDAS – is a Vilnius Integrated Development Assessment System and was prepared to examine different transportation and land use strategies. This database contains information about private transport (OD matrices for cars and trucks), collected during interviews with drivers, vehicle delay functions and probe driving results. Part of the data was derived from Lithuanian State Department of Statistics.

In the first case, the experiment was based on the Vilnius public transport as an example. Influences from Vilnius urban structures on energy consumption in the

Vilnius public transport were defined and rated according to their importance (weight) by the statistical means. To describe the relationship between energy consumption and predictor variables an analysis of fitting various multiple regression models was also performed.

EMME/2 modeling software and VIDAS transport database were employed to search for relations between the urban structure of Vilnius and energy consumption in the private transport. A number of scenarios were performed in order to examine relations between land use or infra-structural changes and energy consumption.

Main hypothesis

Three main hypotheses were formulated after literature overview:

1. Technological, economical, social and environmental conditions are specific in Vilnius and decisions on its transportation system should be initiated on a particular basis;
2. Mobility of inhabitants and energy consumption for transportation depends on the urban structure of Vilnius;
3. There is room for improvements in Lithuania's urban structures through use of best knowledge and then these structures could conform to sustainability indicators.

Scientific novelty of the research

A range of policy measures is available to influence energy consumption for transportation. Of these, land use can contribute, but may take a long time to take effect. On the other hand, this long-term action means that land use planning measures can set the physical pattern upon which energy consumption patterns are based for generations. The following novelty aspects could to be mentioned:

- New methods applied for the evaluation and modeling of relations between Lithuanian urban structures and energy consumption for transportation;
- The interaction between the functional structure of the city and its energy consumption in the transport system as well as its outcomes were established for the first time;

- Scientific basis for a long-term transportation energy saving policy in Lithuanian cities;
- New models evaluating energy saving in transport benefits were elaborated and refined.

There have been a fair number of EU studies and results into the effects of land use planning measures on urban travel pattern. The exact extent of cause and effect is inconclusive. Often, there is a complexity of local factors involved, relating to particular people and the localities that are involved. Nevertheless, the general impression of the planning policy's contribution – that denser, more compact, mixed settlements and medium-large settlements tend to exhibit a greater predilection for traveling by public transport and on foot, generates shorter journeys. While land use distribution and the design of the development do not necessarily cause shifts towards more sustainable travel behavior, it can provide a choice and stimulate more sustainable behavior. A combination of complementary land use planning measures can provide an integrated package where each element reinforces the other towards more sustainable development.

As mentioned above, there are no short term land use measures to improve energy efficiency, though best available practices, integrated measures for the sustainable development can help to achieve better quality of environment and living standards and reduce energy dependency on imported fossil fuels. Energy efficiency and land use issues have not been adjacently analyzed in Lithuania, consequently various stakeholders can benefit from the novelty of this research. The Vilnius case study is a good example and the original recommendations can be used in other Lithuanian cities.

Theoretical and practical results of the work

The main thesis validated by this dissertation is that a deeper understanding of the relations between land use and transport interaction is important for Lithuanian circumstances and leads to new practical applications of urban planning issues when striving for more sustainable urban development.

Two approaches were used for experiment's design and two separate models were developed. The first one was a pure empirical one that allowed for the determination of the pursuable goals in terms of public transport's energy efficiency. The second one was

based on theoretical considerations, though it has clear practical application. A number of scenarios and development alternatives were analyzed to explore influences of various factors on energy consumption in private transport and allowed for a comparison of investment projects. Though all alternatives have strengths and weaknesses, a cost benefit analysis should be based on money terms.

It should also be noted, that modeling results and suggestions are useful when solving urban development problems, and when preparing comprehensive plans or special transport plans for the largest cities in Lithuania.

Approval of the research work 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, Sweden, Norway, Denmark and France. The material presented in the dissertation was also published in 9 editions of scientific issues and conference proceedings.

Research material and developed models were applied in 5 international projects and 3 feasibility studies on transport infrastructure developments in Lithuanian cities. Moreover, part of the findings was used to prepare an energy efficiency action plan for the Transport sector (Lithuanian National Energy Efficiency Program).

Volume and structure of the research

The dissertation consists of five main sections: introduction, detailed problem formulation, experiment design (empirical approach and theoretical approach), discussion of results and conclusions. Volume of the dissertation is 149 pages and its structure presented in graphic form (see Illustration I).

Up-to-date urban development and energy consumption tendencies are examined in the first chapter. 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. As an outcome of such an in depth analysis adjustment and concretization of aim and objectives of the research were essential. Two main approaches are formulated, i.e. empirical and theoretical.

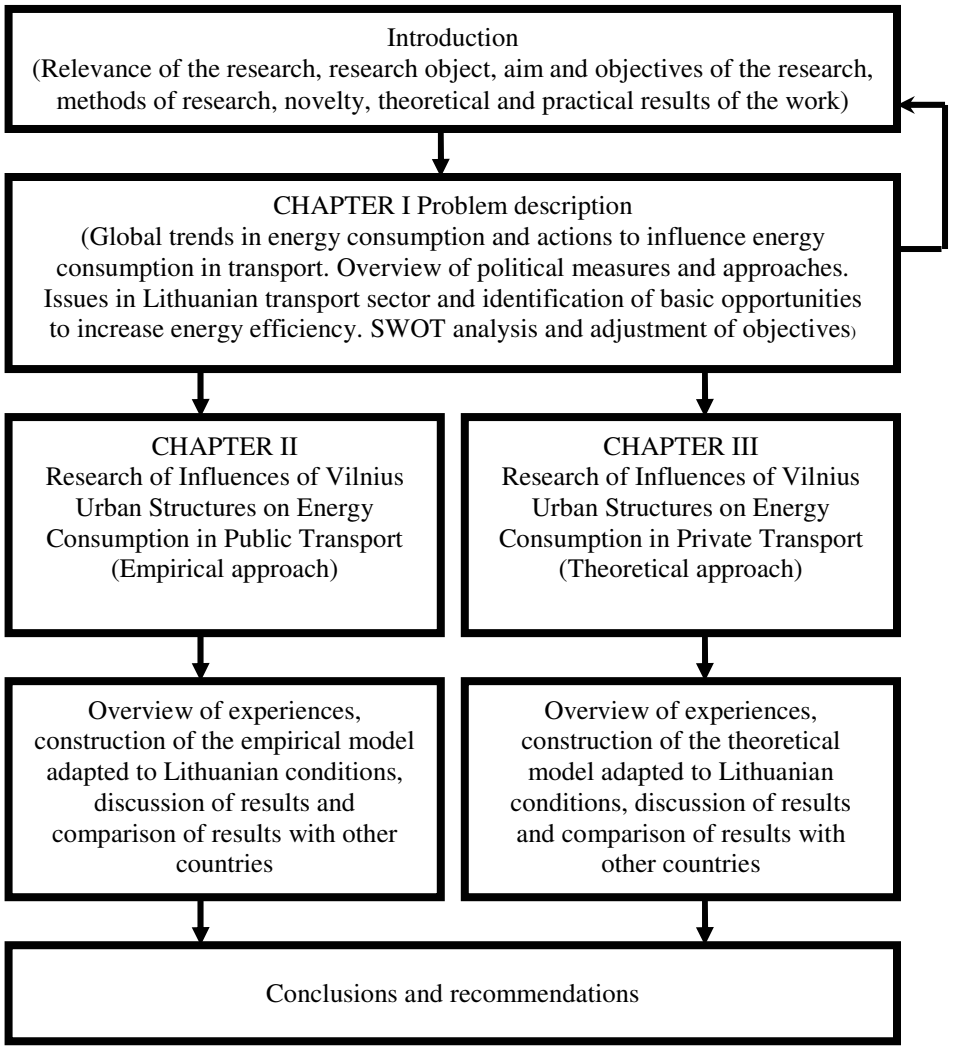


Illustration I: Structure of the dissertation

The second and third chapters cover two up-to-date trends: empirical and theoretical analysis of interactions between urban structures and the transport system. Therefore, an overview and analysis of literature are distinguished and allocated to separate chapters. The empirical study concentrates on public transport while the theoretical study is based on analysis of private transport. Relations between Urban structures and Energy consumption in transport are defined, and scenarios and proposals for the future development of Vilnius structures are compared.

At the end of the dissertation final conclusions and suggestions are presented.

1. Problem description

1.1 Global developments and ascending issues

Boundaries and interconnections between energy efficiency and land use topics should be defined in order to formulate energy efficiency aims for the transport sector. Current globalization processes have merged evident boundaries between energy transfer and consumption subsystems. That is, the transport system is an attribute of energy consumption's subsystem, because it consumes energy for goods and passenger transportation. On the other hand, transport is an attribute of energy transportation and the transformation system, because it transports and supplies a major part of the world's energy. Different economical interests define energy intensity in transport and it is much harder to link these intensities to geographical location (land-use) than to other sectors. Such an analysis is complex, because it is important to include technological, economical, environmental and social issues of sustainable transport development [5,6].

The International Energy Agency (IEA) indicates that the world's total final energy consumption was 52897.78 TWh in 1973. The share of the transport sector was 21.1 % in 1973, but the world's final energy consumption reached 81347.31 TWh and the share of transport grew to 25.8 % in 2001. This trend is explained by the rising energy consumption in the largest world's economies and the developing countries.

The transport sector consumes the biggest part of oil products. During the last decades, consumption of oil products increased twice from 10508.17 (1973) to 19953.71 (2001) TWh. On other counts, transport consumes 57% of all oil resources [7]. The share of electricity and coal decreased in the energy consumption's structure of the transport sector. It is obvious that the transport sector is vulnerable to energy prices in short-term run and current global developments force countries to search for more energy-efficient and energy-free solutions. Energy consumption is still increasing and experiences show that consumption is inelastic in the long- term.

Historically, transportation energy use and emissions have increased because reductions in energy intensities have not kept pace with increasing transport activities. The world's motor vehicle fleets increased at an average annual rate of 3-4.5 % from 1950-2000 [8].

Over the same period, light-duty vehicle fuel economy improved by 2% per year or less [9]. Increases in vehicular fuel economy have also worsened because of declining vehicle occupancy rates.

Fuel economy of road passenger transportation no longer appears to be improving. Air travel and truck freight activities have increased more rapidly than energy intensities have declined. Alternative energy sources have not played a significant role in the worlds' transport systems. Despite two decades of price upheavals in world oil markets, considerable research and development of alternative fuel technologies, and notable attempts to promote alternative fuels through tax subsidies and other policies, petroleum's share of transport energy use has not decreased (94.7% in 1973 and 96% in 1996). On a modal basis, road transport accounts for almost 80 % of world's transport energy use. Light-duty vehicles alone comprise of about 50%. Air transport is the second largest and the most rapidly growing mode using 12% of the current transport's energy according to the IEA estimates.

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 [10]. 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.

1.2 Policies influencing energy consumption for transportation

The spatial separation of human activities creates the need for travel and goods transport, and it is the underlying principle of transport analysis and forecasting. Following this principle, it is easily understood that the sub-urbanization of cities is connected with the increasing spatial division of labor, and hence with ever increasing mobility and energy consumption [11,12].

There are two major groups of policies influencing an individual's travel behavior 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 [13,14].

Recognition that trips and location decisions co-determine each other and that therefore transport and land-use planning needs to be coordinated led to the notion of a "land-use transport feedback cycle". The set of relationships implied by this term can be briefly summarized as follows (see Illustration 1) [15]:

- The distribution of land-uses, such as residential, industrial or commercial, over the urban area that determine the locations of human activities such as living, working, shopping, and education or leisure.
- The distribution of human activities in space requires spatial interactions, i.e. generate trips in the transport system to overcome various distances between the locations of the activities. Such spatial interactions or trips demand certain amounts of energy.

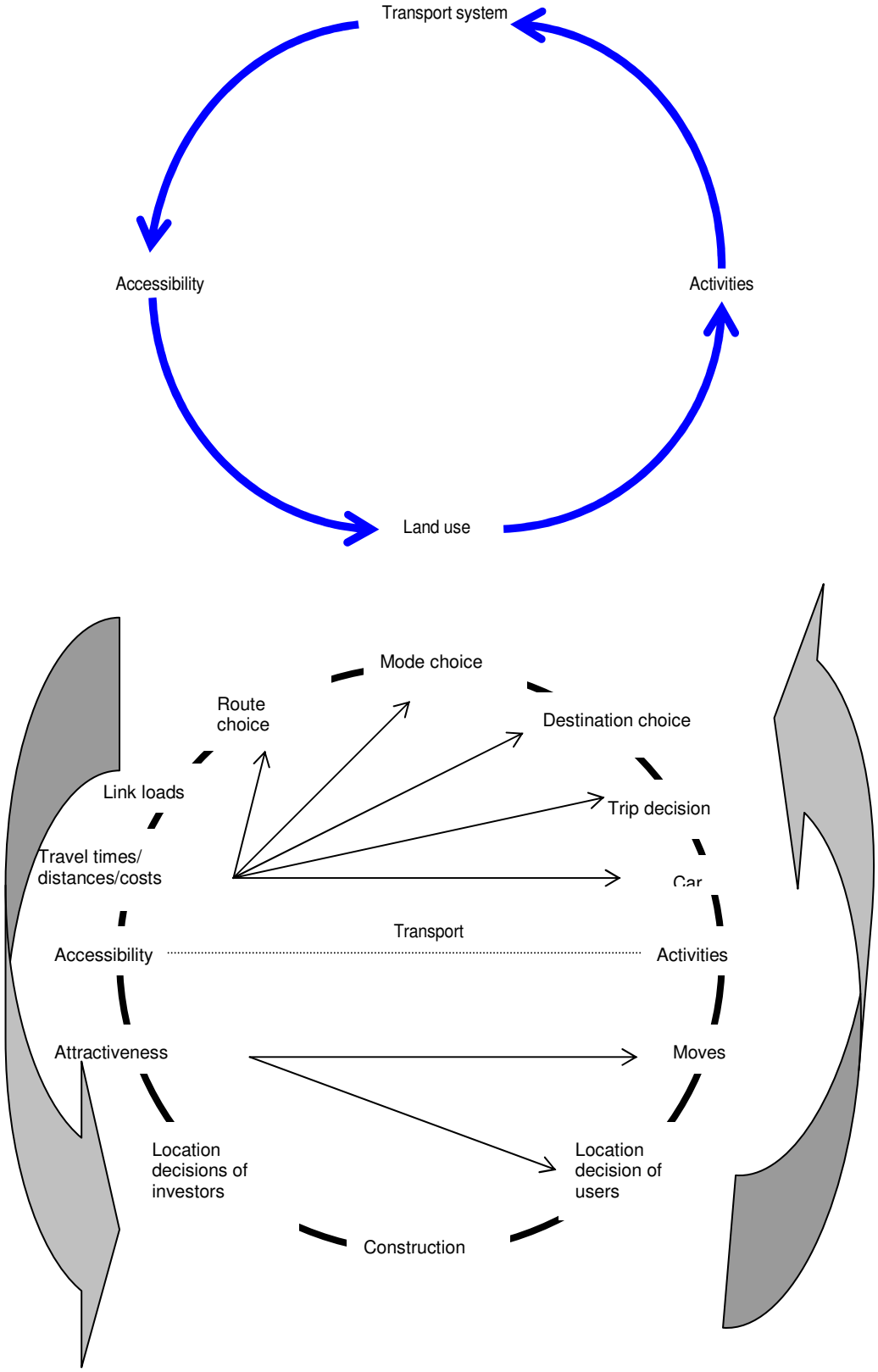


Illustration 1: The "land-use transport feedback cycle" (source: TRANSLAD, Final Report for Publication).

- The distribution of the infrastructure in the transport system creates opportunities for spatial interactions and can be measured as “accessibility”. Physical characteristics and performances of the infrastructure under different circumstances influence the energy consumption of transport means.
- The distribution of *accessibility* in space co-determines location decisions and so results in changes of the land-use system causing lower energy consumption for transportation.

Land-use and transport policies are assigned to different policy types encompassing infrastructure and services, planning, regulation, pricing and information and informal policies. The impacts of transport policies on transport patterns are clearer and stronger compared to the interplay of land-use and transport. While travel costs and travel time have a negative impact on both trip length and trip frequency, *accessibility* has a positive impact on the trip’s length and frequency. The mode choice is dependent on the relative attractiveness of a mode as compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share [16].

Policy objectives and effects are related to the primary objective of land-use and transport planning, which reduces the need for travel and makes the remaining traffic sustainable. The description of the policies shows that the objectives of land-use policies primarily relate to a reduction of the need for travel, while transport policies mainly aim at making the remaining traffic sustainable. Transport policies affect land-use as well, especially in the long-run, for example by increasing the cost of transport; and land-use policies can also affect transport, for example through compact urban structures that lead to higher efficiency in the use of public transport.

Different policy effects and emphasizes the importance of coordinating land-use and transport planning because the two policy areas are complementary in their character and the policy types reveal some overlapping of their effects. Land-use policies contribute to reducing travel distances and land take, to changing location behavior and to the efficient use of the transport’s infrastructure. Transport policies affect the modal split, travel, the location’s behavior and the efficient use of the transport’s infrastructure. Therefore, formal and material horizontal coordination is the corner stone of successful land-use transport’s integration.

Many policies, especially those that are easy to implement and effective without delay and do not presuppose complementary and additional policies can be implemented as stand-alone policies. This mainly refers to *investment*, *planning and information policies* because of their low restrictive character. However, especially in the case of *planning policies*, a higher efficiency in the implementation process can be achieved when policies are combined with *regulatory* and *pricing policies*.

The combination of policies can be differentiated by whether policies should be combined with other policies of the same policy area or with those of different policy areas. In general, combination implies sectoral, territorial and temporal integration as well as the integration of land-use and transport planning in policy packages, and different policy types should be coordinated in their time schedule and focus on a defined area to avoid side effects.

1.3 Analysis of energy consumption in Lithuania's transport sector[1]

The average annual energy consumption in Lithuania's transport sector was 13726.66 GWh during 1994-2003. The transport sector consumed 28 % of Lithuania's final energy and was second in its consumption breakdown after households (see Illustration 2). It should be noted that fuel prices are higher in Lithuania than in surrounding countries (except Poland) and most of transport companies take such differences into account. Transit transport purchases of cheaper fuel in foreign countries and is not recorded in official statistical yearbooks.

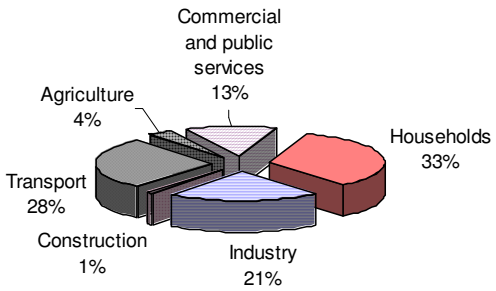


Illustration 2: Lithuania's energy balance during 1994-2003 (%, final consumption)

[1] Statistical information collected from statistical yearbooks "Environment and energy" and "Transport and communications" (2002) issued by the Lithuanian Department of Statistics.

Energy consumption dynamics during 1994-2003 show that the numerical share of transport does not fluctuate greatly and reflects the economical situation in Lithuania. The percentage share increases very rapidly because of decreasing energy consumption in other sectors (see Illustration 3). The share of the transport sector increased in Lithuania's energy balance from 24.7 % (1994) to 29.1 % (2003).

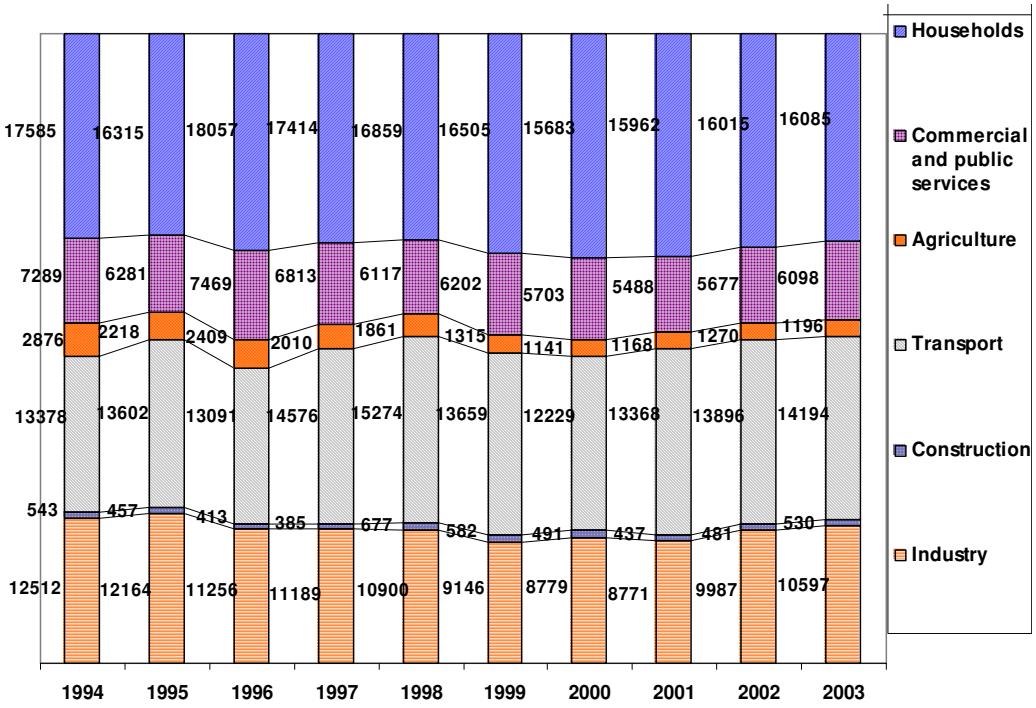


Illustration 3: Dynamics of Lithuania's energy balance during 1994-2003 (final energy consumption, GWh)

1.4 Energy sources and types in Lithuania

The vast majority of transport vehicles in Lithuania are run on fossil fuels. Lithuanian geological surveys show huge increase in oil extraction, i.e. 12 thousand tones in 1990 up to 316.5 thousand tones in 2000 [17]. As for the Lithuanian geological survey's estimations it was found that Lithuania has 4.47 million tones of explored oil resources and this is sufficient for 20 years under current extraction trends. Various stakeholders assess unexplored oil resources differently, but the geological survey forecasts 64 million tones in overland and 23 million tones in Baltic Sea oil fields.

Lithuania imports most of its crude oil from Russia and local oil extraction covers only 7 % of the total crude oil consumption. The biggest part of Lithuanian oil is exported to Poland. Consequently, the Lithuanian transport sector depends on imported crude oil

and oil products. The share of bio-fuels is still very low and it is not included in official statistical yearbooks.

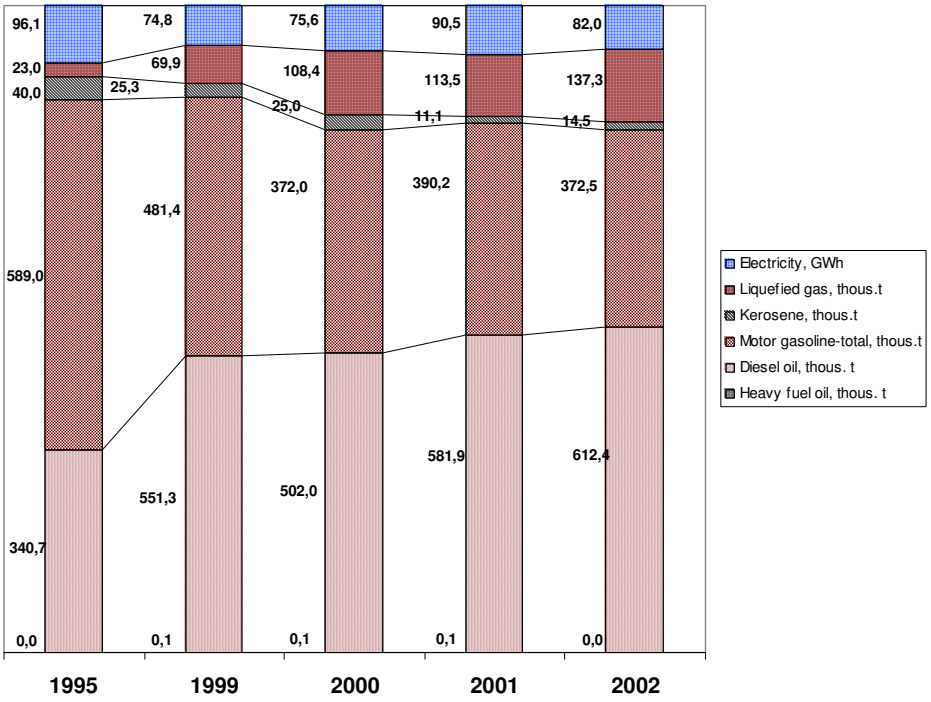


Illustration 4: Consumption of fuel and energy in Lithuanian transport, 1995-2002[2]

Energy and fuel consumption dynamics are shown in the fourth illustration. Consumption of diesel and liquefied gas has increased permanently, but consumption of gasoline has decreased. Conductive Lithuanian tax policy on more economical and more environmentally friendly fuels promoted these energy types, but increased consumption of such fuels in EU markets returns with higher prices for diesel and liquefied gas in Lithuania.

1.5 Main energy consumers in Lithuania's transport sector

The biggest share of imported and locally produced fuels is consumed by road transport (Illustration 5). The average annual energy consumption for passengers and cargo transportation was 12384.6 GWh during 1996-2002 (Illustration 6). Diesel and gasoline predominated in the pattern of road transports' energy consumption.

[2] Illustration 3 shows consumption trends of certain energy or fuel, however energy values cannot be compared in this case.

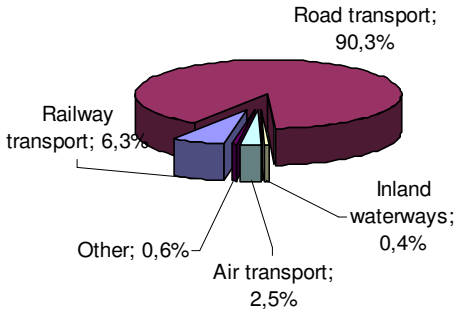


Illustration 5: Consumption of fuel and energy in Lithuanian transport modes, 1996-2002 (%)

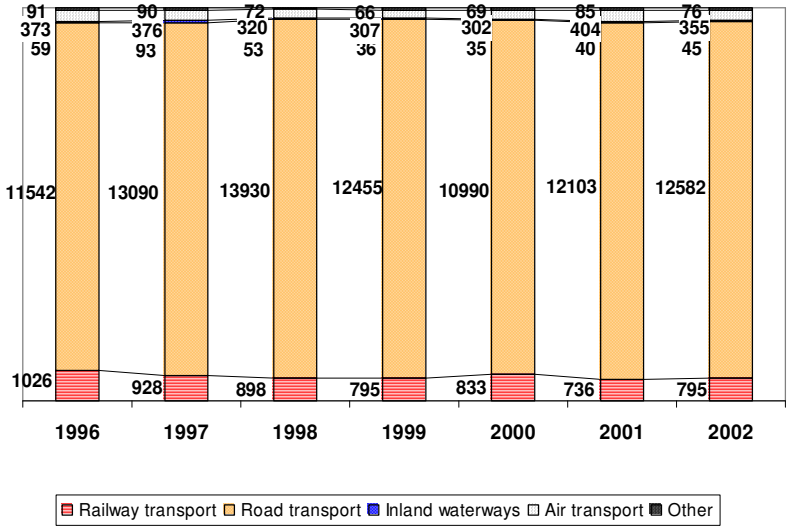


Illustration 6: Consumption of fuel and energy in Lithuanian transport modes, 1995-2002 (GWh)

1.6 Main energy issues in Lithuania's transport sector

Energy efficiency of Lithuania's transport sector is mainly dependent on imported technologies such as oil extraction, fuel transportation and production, and energy transformation (motor in vehicles). These technologies originated in Western countries and oil comes from Eastern countries. Most of imported cars from Western countries are very old and depreciated, and consequently consume more energy and maintenance is more costly.

Road transport prevails in the transportation market, e.g. it transported 36 % cargo in 1995 and 42 % in 2002. A long-term analysis (1995-2002) shows that railway transport has the biggest market share (Illustration 7). Data provided by the State Department of Statistics shows that Lithuanian fleets comprised of 83 % of personal cars, 5.7 % of trucks and 11.3 of transporters, buses, motorbikes and house trailers in 2001.

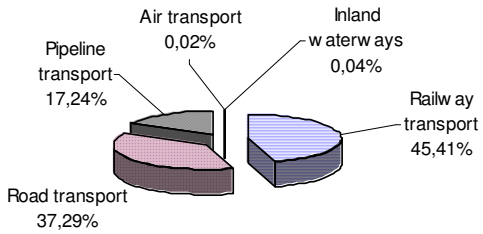


Illustration 7: Goods transportation, 1995-2002 (%)

Rail and pipeline are the most energy efficient means of land transport. For instance, the German institute for applied knowledge compared energy efficiency in various transport types and found the following results. Rail transport is 1.5-3 times more efficient than road transport. Air transport is 2-5 times less efficient than road transport. Travel by car is two or three and more times less energy efficient than travel by bus [9,18]. Illustration 8 and Table 1 show the energy consumption of different means of transportation (depending on the measurement unit: distance or travel time).

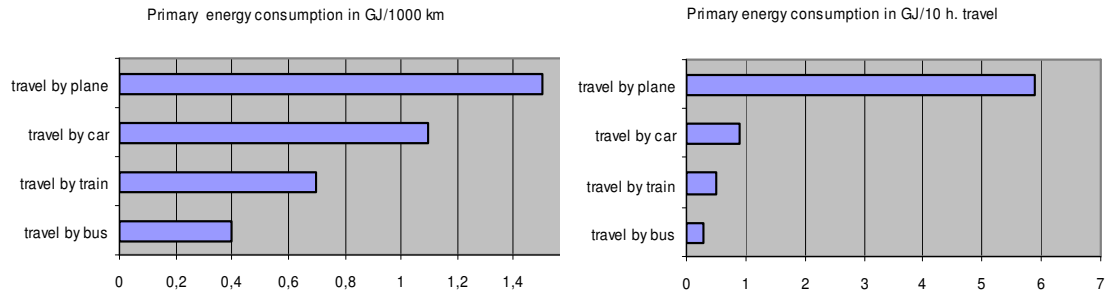


Illustration 8: Energy consumption of different transportation means

Energy efficiency and emission improvements in road transport have slowed down over the past 10-15 years. The average energy used per passenger-kilometer in Europe and Japan has actually increased from 1973-1993, but declined by almost 20 % in the USA during the same period. Because of the slowing down of energy efficiency gains, world transportation energy use is now increasing just slightly less than the rate of growth in transportation activities.

Given the relatively close correlation between economic growth and the demand for transport, it is reasonable to expect continued strong growth of transport energy use and carbon emissions, unless significant and new policy initiatives such as land-use planning are undertaken. However, very little specific information could be found on the interaction between the urban structure and the provisions of the transport system in

Lithuania. Energy efficiency and consequently air pollution from urban transport is not included in the current Lithuanian urban planning practice.

Table 1: Modal energy intensities, 1973 and 1994 (MJ per passenger-km)

	Europe (1973)	**Europe (1993)**	**USA (1973)**	**USA (1993)**	**Japan (1973)**	**Japan (1993)**
Average, all modes	1.46	1.56	3.10	2.52	1.22	1.67
Car	1.65	1.73	3.10	2.59	2.20	2.46
Bus	0.58	0.71	0.79	1.03	0.54	0.73
Rail	0.58	0.48	1.81	2.15	0.17	0.19
Air	4.55	2.78	4.92	2.46	3.49	2.13

Air transport is the fastest means of transportation and reaches almost all places on the earth, and it does not directly compete with land transport. As a result, Lithuania's air transport permanently increases its share in the cargo and passenger transportation market (see Illustration 9 and 11). It is likely that air transport will increase its market share because of its attractiveness (decreasing ticket prices and speed).

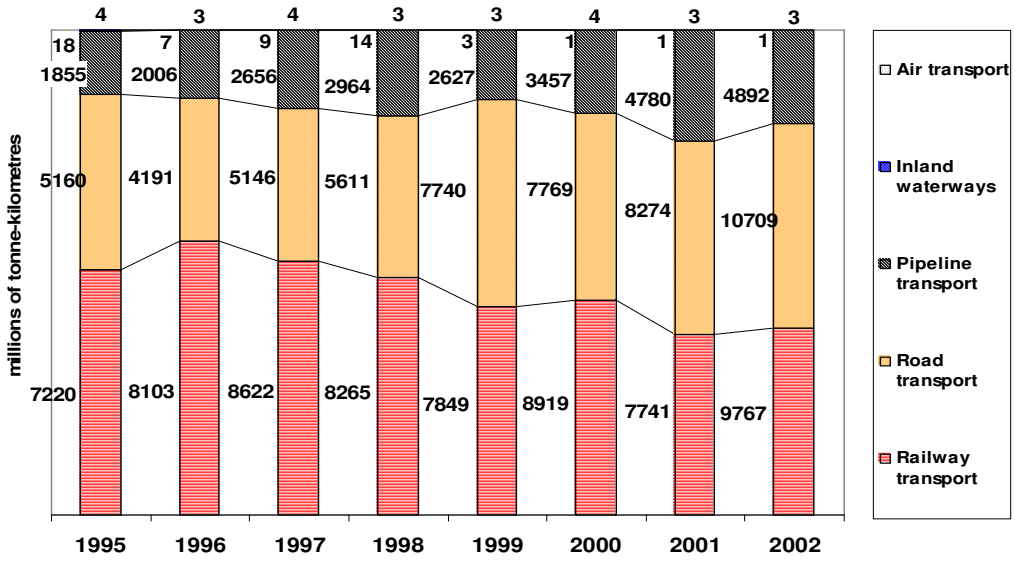


Illustration 9: Modal split for goods transport during 1995-2002 (million tonne-kilometers)

The number of passengers decreased dramatically in public transport during past 7 years. This has negatively influenced energy efficiency in transport, because the switch from public services to personal cars has lead to 3 times more energy consumption.

Road transport is very flexible and a time-efficient means of transportation for short distances. The road transport sector is most liberalized and privatized among all the transport sectors. Therefore, an increasing number of cars will raise the energy consumption in the transport sector.

The distribution of private cars according to age and origin of country (Illustration 10) is essential for an evaluation of fuel consumption. The biggest part of Russian cars consumes more fuel than do western cars and the average age of the western cars' fleet is 14-15 years. Such ages determine the low efficiency of engines and the comparatively very high emissions.

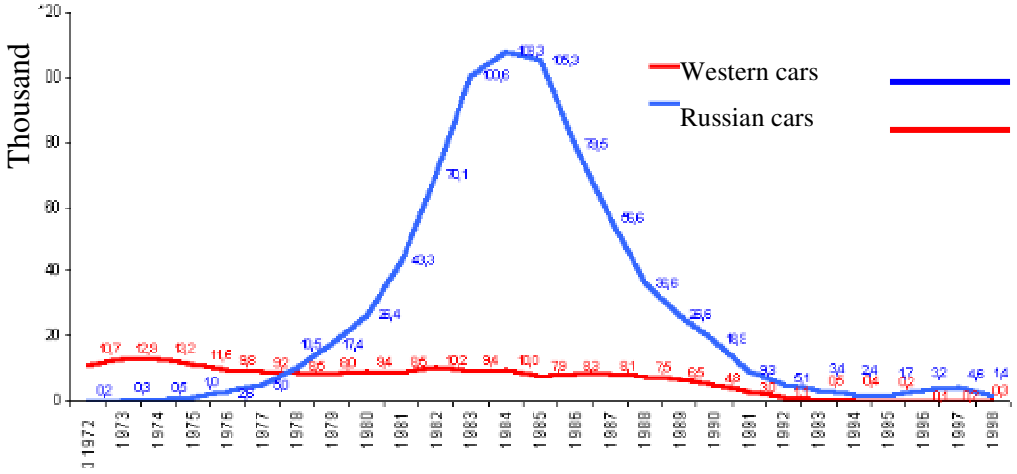


Illustration 10: Distribution of private cars according to age and origin (1999)

The increasing number of personal cars causes various problems in urban territories, particularly in transport's infrastructure. Development of the transport's infrastructure is not adequate and cannot evolve at such speedy rates and traffic jams cause higher energy intensity and time expenditures.

These developments negatively affect public transport. During 1995-2002, the number of passengers in Lithuania's public rail and road transport decreased more than two times and only the number of air travelers has increased (see illustration 11). During the same time, the number of personal cars per 1,000 residents increased from 185 cars in 1995 to 316 cars in 2002. This is not only the outcome of Lithuania's improved

economic situation, but also a result of the necessity to use a personal car as a means of transport because there are no other alternatives.

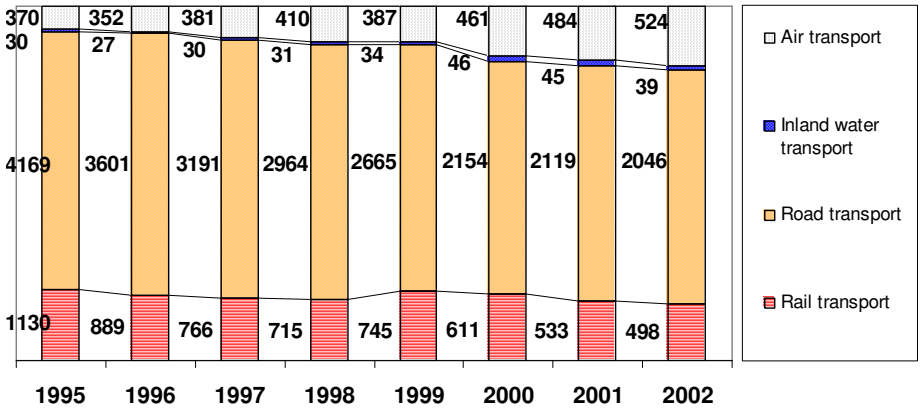


Illustration 11: Transportation of passengers during 1995-2002 in millions passenger-km)

The increase of traffic flows directly depends on car numbers in Lithuania. Illustration 12 shows this relationship and was derived from two sets of data. *Dynamics of car ownership* and *traffic intensity* [19] were translated into percentages and changed as an index in 1993 (1993=100%). The linear model defines the relationship between the *dynamics of car ownership* and *traffic intensity* in the best way. The illustration shows results of fitting a linear model to describe the relationship between the *dynamics of car ownership* and *traffic intensity*.

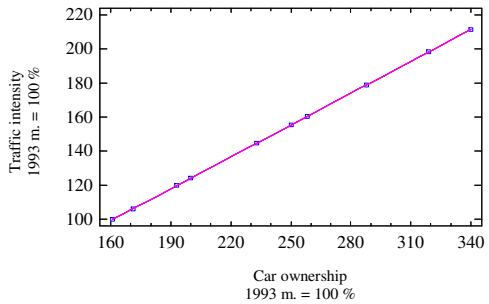


Illustration 12: Relationship between car ownership and traffic intensity

The equation of the fitted model is:

*Change in traffic intensity = -0.00133 + 0.621*dynamics of car ownership.*

Since the *P-value* is 0 and it is less than 0.01, there is a statistically significant relationship between the *dynamics of car ownership* and *traffic intensity* at the 99% confidence level. The *R-Squared* statistic indicates that the linear model as fitted explains 100.0% of the variability in traffic intensity and it is the best result from the set of alternative models. Further, the correlation coefficient equals *r=1.0* indicating a relatively strong relationship between the variables. These results can be used to forecast traffic intensity at national and local levels, because these findings are based on large and representative samples. Moreover, a higher mobility of inhabitants will determine higher energy consumption and air pollution in the long-term by causing various health problems.

The resident's mobility analysis showed [20,21] that the main factor in Lithuania's communication policy enables it to predetermine its structure and needs, i.e. land-use. All in all, it could be foreseen that both residents and workplaces are going to be placed farther and farther from the city center, and result in an urban sprawl. This trend can cause further problems to public transport because the network and social services will need to serve a greater area as travel between residences and workplaces will increase. It is possible to state that the construction of low-storied houses prevailing in Lithuania as well as the predetermined increase of communication needs and more opportunities for personal cars also influences the present situation. This has further created unfavorable conditions for public transport.

1.7 International actions to increase energy efficiency in transport

The challenge to the EU in this area is to reduce emissions and the energy consumption due to transport activities, in order to avoid or to reduce the related environmental impacts (mainly of air pollution in urban areas, with consequent effects on human health and on local and regional environments, and the production of greenhouse gases), without affecting the economic growth. In other terms the challenge is one of sustainable developments of transport.

The European Commission prepared an Action Plan to Improve Energy Efficiency in the European Community [22] and all the best practice and policies, research and

development results are included in this document. Policy priorities of a non-technological nature include incentives for optimal occupancy of public and private vehicles, the promotion of a new and alternative infrastructure and subsequently modal shifting and modal integration, management alternatives to air transport, completion of the internal market in rail transport and changing behavior regarding mobility. Transport energy efficiency policies of a technological nature are more widely described in other documents and papers (for more information see also Transport policies).

Transport energy efficiency issues are very relevant in most countries around the world. Such issues are included in various sector strategies: territory planning, development of infrastructure, pricing and fiscal policy and etc. A short summary of policies from different countries reflect the main tendencies.

Denmark

Transportation is one of the sectors where policies aim at reducing energy use and greenhouse gas emissions and are most controversial. The Danish government approved a Transport action plan in 1990 and intended to stabilize CO_2 emissions from transportation at the 1988 level by 2005. It was also intended to reduce CO_2emissions by 25 % by 2030 (compare to 1988 level). These objectives have been abandoned and even a new action plan to reduce CO_2 emissions in the transport sector in 1996 did not succeed. Therefore, a set of additional documents to reduce CO_2 emissions in transport sector was issued in 2000. The main instruments to reach these objectives are as follows [23]:

1. Increase of engine energy efficiency,
2. Increased fuel prices,
3. Other instruments:

- Physical planning,
- Active participation of private individuals and business;
- Public private partnerships,
- Direct measures increasing energy efficiency in vehicle Research and Development,

- Development of public transport,
- Promotion of bicycle transport,
- Traffic management in larger cities;
- Freight transport and logistics, modal integration,
- Development of seaboard transport,
- External costs of transport (social costs should be included in pricing).

United Kingdom

The main objective of the energy efficiency plan is to reduce emissions by 10 MtC by 2020. The transport sector is included as part of the plan and there are the following instruments involved [24]:

1. Improvement of fuel efficiency in the cars,
2. Economical instruments (Taxes),
3. Travel awareness and information,
4. Promotion of new technologies and alternative fuels (pilot projects),
5. Integrated transport and land-use planning.

New Zealand

A project for National Energy Efficiency and Conservation Strategy was prepared in 2001. The transport action plan is included among other sectors as a very important part of the whole strategy. The transport sector consumes about 41% (2001) of the energy and the policy concentrates on the following instruments [25]:

1. Reduction of demand on transport (mobility and demand management),
2. Introduction of eco-efficient vehicles,
3. Vehicle efficiency standards and related measures,
4. Vehicle fuel consumption information,
5. Transport system pricing and related policy measures,
6. Alternatives to road transport,
7. Promotion of energy efficient modes,

8. Energy efficient road networks and traffic management,
9. Speed management (Reduce open road speeds to conserve energy);
10. Fleet management (change fleet management perceptions, purchase decisions and management practices),
11. Personal energy efficient behavior.

Institutions responsible for the implementation of this program are EECA (Energy Efficiency and Conservation Authority), Ministry of transport and local authorities. A leading institution is assigned to every instrument and all instruments have implementation indicators such as actions, criteria and links to strategy goals.

Hungary

Hungary, like Lithuania, is a country with a transition economy. The transportation sector is developing and huge logistic centers have been established or are under consideration. Hungary's energy efficiency transport plan encompasses more administrative instruments and includes [26]:

1. Import restrictions for vehicles more than six years old,
2. Mandatory vehicle inspections (stricter emissions standards),
3. Development of transport systems (building and integration of major highways, city rings, bypasses, reconstruction of existing infrastructure),
4. Urban transport (new tram, metro and bus infrastructure and reconstruction of old infrastructure, park and ride, new bridges and pricing),
5. Development of Rail Transport (restructuring and renewal of railway organization and infrastructure, new European corridors),
6. Buses with compressed natural gas-fuelled engines (RABA/IKARUS project).

Czech Republic

The main objective of the Czech Republic's national energy agency is to save energy and to decrease the negative impact of energy production and consumption on the environment. The government supports the following instruments [27]:

1. Support and promotion of public transport (integrated PT systems),

2. Implementation of the Highway Development Program, i.e. ring roads and city bypasses as well as access roads to highways,
3. Support for the development of combined transport, through a wide range of measures such as favorable taxation, adequate infrastructure, special railways, etc,
4. Speed limitations,
5. Taxation on Lorries,
6. Progressive charges on engine capacity.

1.8 Energy saving potential in Lithuania's transport sector

The main energy saving policies for transport sector has already been defined. However, best results would be achieved in the case of integrated and coordinated land use and transport policies. Mobility of inhabitants and energy consumption depends on many subsystems such as social economic, spatial environment (geographical indicators) and the transport's infrastructure. These subsystems are interconnected and there are various instruments to influence its equilibrium. Instruments may be grouped into technological, planning and administrative sets.

Lithuania is not participating actively in the creation of new and advanced energy efficient technologies for the transport sector. These technologies are still very expensive and used only by the world's strongest countries in collaboration with multinational companies and leading institutes searching for sustainable technological solutions [28]. There are some Lithuanian scientific works on energy efficient transport issues, and they mainly concentrate on the same technological solutions and improvements [29,30]. Therefore, administrative and sustainable planning issues might be a new opportunity for a more sustainable Lithuanian transport system. This arguably encompasses investments in new transport fleets, infrastructure and bio-fuels as these issues are included in the common EU transport policy, the long-term development strategy of the Lithuanian transport system, and the long-term development strategy of Lithuania [31-33]. A more detailed description and analysis of land use and transport policies will be conducted in order to formulate objectives for Lithuania's transport sector. Policy objectives defined during the EU Transland project are listed in Table 2.

Table 2: Overview of policy objectives (source: TRANSLAND, Final Report for Publication)

Policy area	Policy type	Policy objectives	Primary objective
Land-use	Investment and services	Dense, mixed-use structures Co-ordination of urban development with transport infrastructure	Reduce the need for travel
	Planning	Dense, mixed-use structures Coordination of urban development with transport infrastructure	
	Regulation	Dense, mixed-use structures Accessibility by public transport	
	Pricing	*Restricting pricing*: Dense, mixed-use structure *Subsidies*: Coordination of urban development with transport infrastructure	
	Information	Dense, mixed-use structures Coordination of urban development with transport infrastructure	
Transport	Investment and services	Co-ordination of transport modes Extension and densification of (public) transport network	Make the remaining traffic sustainable
	Planning	Coordination of transport modes Extension and densification of (public) transport network Coordination of transport network with urban development	
	Regulation	Restriction in car use Restriction in parking	
	Pricing	*Subsidies*: Coordination of transport modes; Extension and dense (public) transport network; Coordination of transport network with urban development *Restrictive Pricing*: Restriction in car use; Restriction of parking	
	Information	Restriction in car use	

Land use policies

Land-use policies contribute to reducing travel distances and land take, to changing "localization behavior" and to the efficient use of the transport's infrastructure. Energy saving potential and the application of land use policies are quite ambiguous under Lithuanian conditions. There are a lot of uncertainties concerning causes and effects of such strategies in different countries [34,35]. There are two proved aspects concerning land-use policies: new infrastructure generates traffic flows and integrated public transport and restrictive measures that ensure good results. Some Australian, European and American cities are trying new strategies and are preparing special transportation plans in order to minimize transportation and particularly private car needs, promote non-motorized modes and public transport. The outcomes of other combinations are quite different as interests of various groups influence the implementation of strategies and environmental issues that are often abandoned during long term realizations. Realization of such issues takes a long time and effects might be only evaluated after 20-30 years (appropriate monitoring is also needed).

Similar principles such as integrated land use and public transport planning, and management of urban development were applied in Lithuania during the Soviet period. Public transport lines served densely populated residential and industrial areas, very strict planning procedures and regulations supported the quite optimal interaction between transport and land use.

Densification policy

A set of instruments for the densification of residential zones, recovery of non-viable urban zones located close to public transport lines is necessary. Investments and provision of services would accelerate changes in such areas. The theory of a compact city states that mixed activities (residential, leisure, industry etc) arranged in certain spatial ways influence the mobility of inhabitants and the modal split.

Integrated land use and public transport planning policy

Concentrating high-density residential development near stations along public transport corridors is one of the options to decrease the mobility of inhabitants. Developers of new urban territories ought to prepare detailed plans for the development of its public infrastructure. The infrastructure has to satisfy the needs of local inhabitants and to form a healthy environment. In this instance, new territories could be reclaimed only if land

for new public transport corridors and nodes are reserved. It is also possible to manipulate downtown development and attractiveness for investors through pricing so as to enable or disable trip-generating activities in downtown through pricing and taxation mechanisms.

Development of new urban centers

New urban centers with a variety of activities prevent part of the trips and increase the quality of life. Urban territories with a high density of inhabitants and lower quality of life could be converted to more attractive zones, e.g. pedestrian zones or streets with entertainment, shopping and other services. Car traffic and parking do not necessarily restrict movements, but parking limitations are optional and good public transportation should be provided.

Management of urban development

Nowadays, mixed land use development may be encouraged with the intention of allowing homes, shops and workplaces to be mixed in together and this can promote choice and minimize travel distances. Management of urban development could also be implemented by using planning measures such as green belts. Authorities are trying to prevent the establishment of new shopping centers and business-parks far away from public transport infrastructureThe argument for establishing new jobs in such centers sometimes outweighs car usage threats and restrictions. Provision of information to inhabitants about restrictions and discussions of master plan solutions are the main instruments for deal with car dependency.

Transport policies

Transport policies affect modal split and travel and location behavior and the efficient use of the transport infrastructure. Objectives of a transport's strategy can also be divided into 5 main groups (see table 2). Transport planners have a wide range of instruments of transport policy available, and the main instruments will be described. These are the means by which the policy objectives can be achieved, and the energy efficiency problems identified and overcome.

Investments into public transport's infrastructure

The increase of public transport's quality and attractiveness leads to more passengers and better energy efficiency. Consequently investments in the new infrastructure,

vehicles and an increase in frequencies, subsidies for public transport and new ticketing systems are the best instruments for efficiency.

Development of cycling and walking infrastructure

Many cities, especially in Europe (the Netherlands, Denmark, Sweden) have provided for easy access/use of bicycles in city-centers and residential areas. The potential for using a bicycle would be substantial in Lithuania if necessary attention and support of authorities will be paid. The majority of trips in smaller towns are short (2-3 km) and there are great opportunities for developing walking and bicycle infrastructure.

Cities across the EU are working on the reconstruction and building of new sidewalks and paths, providing good maintenance during the winter-time, and installing safe places to keep bicycles. Better results are achieved if cycling and walking campaigns are combined with infrastructure development.

Traffic restrains and restrictions

Measures are usually related to a polluter-pay principle, and limitations on car parking places or car access to inner cities. The state could also introduce a taxation policy for cars, e.g. by promoting the one family car idea (see taxation). The best "toll collecting" cities and examples are Oslo and Singapore. Traffic intensity decreased by 6-8 percent after the introduction of a toll system in Oslo. Parking fees are short-term measures and "fee size -free parking place" balance should be permanently maintained. A general lack of parking space may mean people will have to drive around looking for a place to park. It is also proved by research that free parking places close to the workplace are the main reason to use car.

Restricting access to city centers for cars has been tried in many cities (Milan, Zurich, Rome, Seoul, Munich, and London). So far very little evaluation material seems to be available that shows the effects from such measures on cars in the urban area at large.

Traffic management

Traffic management, in general: means trying to increase the capacity of the existing road network. Improvements can be obtained in two ways: road traffic telematics (RTI) and car-sharing or car pooling. Telematics – management of traffic with the help of new informational technologies. Huge savings can be achieved if the current Lithuanian traffic management system would be interconnected and work in a coordinated network.

Car-sharing or car pooling means either picking up others while driving to work or joining in a system where participants take turn at driving. A Combination of such measures with HOV (high occupancy vehicles) lines gives much better results.

Development of new transport infrastructure

Development of new transport infrastructure generates larger traffic flows, but it does not mean that road building is not productive. New transport infrastructure should be combined with other traffic management or restrictive measures. The main problem is the lack of the bypasses and high speed streets in major Lithuanian cities. Energy intensity is much higher in traffic jams than on car-free streets.

Water and rail transport are the most energy efficient means of transportation. EU transport policies support development and integration of such means, particularly the establishment of new logistic and multi-modal centers. Multi-modal centers are increasing the load of transport units (and energy efficiency) but at the same time minimizing the idle run.

Taxation

Countries around the world are imposing lower or higher taxes on fuels (or cars) and roads. These are two main measures that are widely used to decrease energy consumption. There are more examples of diverse taxes such as the CO_2 tax that was introduced in Sweden (1990). According to IEA estimations, the increase in fuel prices does not influence global fuel consumption in the long-term perspective (see chapter 1.1 for details). There is a strong relationship between fuel prices and the energy efficiency of the car (see table 1) and Europeans drive more energy efficient cars than do the USA citizens.

Fuel prices in Lithuania more or less depend on the situation in the world's oil market and the existing taxes as set by the Parliament. The excise tax will gradually increase up to the minimum requirements of EU Commission (target date is 2010) [36]. Instability on world's oil market could change existing taxation and new EU directives which will decrease fuel taxes will come on agenda. There are not any intentions to increase fuel taxes higher than the minimum EU requirements according to the Lithuanian energy strategy [37]. Therefore, it is most likely that fuel taxes will not increase for political and economical reasons as well.

Taxes on cars promoting more energy efficient vehicles (e.g. EURO 3 or 4, hybrid cars) could have fair effect on energy consumption. Implementation of such measures depends on the political willingness because new "engine volume" (power) or "second car" taxes will lead to disaffection.

Direct technological measures

A number of new vehicle technologies are emerging that may have a significant market share over the next 20 years. Within the EU MEET project [38], a study was carried out to assess the technologies most likely be in use by 2020 and to provide estimates of the emissions that they will produce. The following technologies were assessed in detail:

- Electric vehicles,
- Hybrid electric vehicles,
- Fuel cell electric vehicles.

Developments of conventional engines and emission control systems, such as direct injection for gasoline engines, were considered to be evolutionary. Unfortunately such technologies originated in western countries and the Lithuanian policy should perform advantageous tax policy towards energy efficient vehicles.

Alternative fuels

This short survey focuses on those fuels that may have significant market penetration over the next 20 years. These include natural gas, methanol, ethanol, bio-diesel and dimethyl ether. Lithuania has great potential to produce bio-fuels from renewable recourses (agricultural). Bio-fuels are less polluting (than fossil fuels) and raw materials are more sustainable.

1.9 Approaches defining energy-efficient structures

Energy-efficient spatial structures are those in which useful energy requirements are minimized or those where energy needs can be met in ways which minimize the ratios along the chain of primary, secondary, delivered and useful energy [39]. Current knowledge of what constitutes energy-efficient spatial structure comes from a wide variety of sources. Originally these sources were divided in two main categories: theoretical and empirical.

Empirical and theoretical studies are the two main and broad categories, though there is an overlap between them and it results in various combinations of studies and models. There is an empirical comparison of energy consumption in different geographical areas. To extend that difference in energy consumption, patterns can be correlated with structural variables, and some conclusions may be drawn about the energy implications of different spatial structures. There are problems of defining and quantifying the various dimensions of urban forms in existing areas, which are only the current stage of a long process of evolution: Such dimensions may not reflect any specific urban form and will not represent all urban forms at all. Then, considerable variation in energy demands patterns due to climatic, socioeconomic and many other factors tend to obscure any variation which might be attributed to spatial structure.

Empirical work has mainly been concerned with transport energy requirements, although some studies have also included residential energy consumption. Results have tended to be inconclusive with significant relationships not always emerging clearly and with many contradictions between the different studies.

Another approach is theoretical, i.e. to estimate the energy requirements associated with alternative hypothetical spatial patterns and to evaluate the alternatives in terms of energy efficiency. The theoretical approach has an advantage over empirical work in that alternatives can be investigated in *laboratory* conditions, with variables other than those of direct interest being held constant. This method invariably involves urban modeling and is open to criticism that can be leveled at this technique, especially the need to oversimplify the real world often to such a degree that it is difficult to see how the results could have any genuine policy application. Another problem relates to the fact that alternative spatial configurations for evaluation are selected with varying degrees of subjectivity. Investigators mostly use gravity type models to predict travel and energy demands associated with alternative arrangements of land uses.

Lastly, there is much to be learnt from combinations and extension of the above methodologies for normative planning and the evaluation of specific ideas.

1.10 SWOT analysis

Priorities were concretized by applying a SWOT analysis. The SWOT analysis was carried out on the basis of the preliminary analysis and findings. The SWOT analysis is

a good tool for describing a large number of internal and external factors influencing research object. It is also right way to conclude and to prepare priority list of the most central challenges.

The idea of concretizing a few, but central challenges is to point out what aspects should be paid the highest attention in the future in order to improve current/unsustainable situation. As can be seen from the following, this is also the case in this study where the list of strengths, weaknesses, opportunities and threats ends up with a short description of a few critical problems and/or central challenges. The evaluation has been carried out as a SWOT analysis where the SWOT-elements are in Table 3:

Strengths: In the form of actual factors, that may positively affect the future opportunities for an energy-efficient and sustainable transport system in Lithuania. "More energy efficient" means lower energy consumption to produce a certain amount of work or lower the need for fossil energy (switch to alternative fuels, new hybrid technologies or consumption avoidance e.g. non-motorized transport).

Weaknesses: Actual factors, which are causing un-sustainability in transport system and should be changed. Consequently the transport system could meet the future demands and challenges.

Opportunities: Future trends and actions that may improve sustainability in transport system.

Threats: Future trends and actions that may be a barrier for the further improvements or potential problems, which must be solved or minimized.

Lithuania has only a few possibilities to increase the energy efficiency in its transport sector and the main groups are as follows: promotion of bio-fuels, development of more energy efficient and non-motorized transport, and integrated land use and transport planning.

Table 3: SWOT analysis for the transportation sector

Strengths	Weaknesses
Relatively good Lithuanian transport infrastructure, safeguarding effective passenger and cargo transportation.	Infrastructure of rail, inland water and non-motorized transport is very old or insufficiently developed. Such deprivation increases energy consumption and inaction will cause higher energy intensity in the future.
Transport development policy conforms to EU requirements and chosen projects will be financed from EU funds. Such funding will ensure a permanent development transport sector.	Increasing car ownership, transit flows and mobility of inhabitants will determine higher demand on energy in Lithuania. There is no economical motivation to purchase new and more energy efficient cars, and consequently second-hand cars predominate in Lithuania's transport stock.
There are modest oil recourses in Lithuania but oil recourses will run out in 20 years (under current extraction rates). Lithuanian oil can cover only small part of primary energy consumption, and therefore can secure operation only under extreme conditions.	The larger part of energy recourses are/will be imported from other countries, mainly Russia. Legal base to promote bio-fuels are not properly developed. Hence, Lithuanian transport sector fully depends on political issues.
Spatial arrangement of major cities in Lithuania's territory is more sustainable as hierarchy of major cities is fairly continuous.	Urban infrastructure were planned during the Soviet period and not developed during an economical stagnation period. Urban transport infrastructure is overloaded and not adequate to meet current conditions.
Road transport consumes roughly 90 % of total transport sectors' energy and therefore the greatest potential for energy savings should concentrate on changes in this sub-sector.	More energy efficient transport modes are not well developed and promoted (especially inland water transport).
Diversified energy supply system (possible import of oil from Eastern and Western countries).	Poor interaction between transport modes, old infrastructure and vehicles cause higher pollution.
Relatively good positions of Public transport and integration of transport issues into Comprehensive plans.	Number of passengers is decreasing rapidly in the public transport sector, because of organizational problems and a lack of financing.
	Lack of attention to preventive measures and non-motorized transport. Current urban planning practice promotes motorized mobility and do not include integrated transport-land use issues.
Opportunities	**Threats**
There are good possibilities to modernize Lithuanian's transport sector according to EU requirements as Lithuania can employ EU funds.	Total Lithuanian transports' dependence on imported fossil fuels and economical sensitivity.
Promotion of alternative fuel usage in transport and development of non-motorized transport infrastructure in urban territories.	Increasing number of car ownership and transit transport exceeds the capacity of current transport infrastructure in vital places. Time losses and energy consumption are much higher in saturated segments.
Development of qualitative public transport and an increase of the quantity of such services. Integration of land use and public transport planning.	Disregard of public transport problems (legal and economical) will increase significance use of personal cars and consequently more energy consumption.
Changes in taxation, that are stimulating procurement of new and more energy efficient vehicles.	Unlimited imports of second-hand cars from Western Europe (that are not up to date) consume more energy and cause more environmental problems.
Modernization of traffic control systems. Development of urban transport infrastructure, particularly city bypasses.	Further inadequate development of transport's infrastructure will lead to higher energy consumption and pollution.
Development of energy efficient transport, particularly inland water -transport.	Uncertain legal situation concerning promotion bio-fuels will complicate further promotion of such fuels.
Multi-modal logistic centers next to main transport corridors and centers of attraction.	Land use policies are long-term actions and great potential could be unutilized without further research.
Studies of the integration of land use and transport planning issues under Lithuanian conditions.	

1.11 Key actions to increase sustainability in transport and relevance of the work

The United Nations (UN) World commission on Environment and Development (Brundland Commission) in its report "Our Common Future" (WCED, 1987) emphasized that reducing of consumption and effective use of energy will solve a lot of economical, social, environmental problems which are getting more and more actual. The United Nations Conference on Environment and Development, held in Rio de Janeiro (1992), agreed that protection of the environment and social and economic development are fundamental to sustainable development. To achieve such development, the UN adopted the global program entitled Agenda 21 and the Rio Declaration on Environment and Development [40]. Johannesburg Summit 2002 – the World Summit on Sustainable Development –focused the world's attention and direct action towards meeting difficult challenges, including improvement of people's lives and conserving our natural resources in a world that is growing in population, and with ever-increasing demands for food, water, shelter, sanitation, energy, health services and economic security [41].

Modal shifts away from individual cars to mass transit and will have long-term benefits for individuals or regions, therefore transport and infrastructure aspects are included into the UN indicator's database [42]. With economic growth, globalization and the expected increases in world trade, the need for international and regional cooperation regarding transport is highlighted. Because of large capital investments required for infrastructure, innovative approaches and public-private partnerships it will be essential to make the shifts necessary for sustainable development.

Many European Commissions' documents also are promoting energy efficient and environmentally friendly transport. It would be quite complicated to cover all documents in this short overview. The White Paper of the European Union on European transport policy [31] forms the framework for transport policies in the EU member states. The White Paper is based on a long-term strategy with an overall target of developing a sustainable transport system - an ambitious objective considering the increasing problems in transport, like worsening congestion, damage to the environment, and isolation of some regions, etc. caused by increasing demands for motorized mobility. The European Commission emphasizes that road transport emissions account for 84 % of total transport emissions. Such emissions cause

environmental problems at local and global levels. Consequently, new vehicle technologies, better quality of fossil fuels and promotion of bio-fuels (20 % of fossil fuels should be changed by bio-fuels) would be the main areas for technological research. Land use and transport policies are indicated as key planning measures for a more sustainable transport system.

Lithuania's legal base already includes all the main and strategic EU guidelines. Lithuanian Parliament has already changed transport and energy legal bases in order to implement Community acquis. Lithuania after recent negotiations assumed the following key-obligations:

- Bio-fuels should cover not less than 2 % of total fuel consumption in the transport sector till 2006 and not less than 5.75 % till 2011 [43].
- Energy strategy aims to cover 12 % of total energy consumption in Lithuania till 2010 [37].
- Lithuania ratified the Kyoto protocol and is committed to decrease greenhouse emissions by 8 % during 2008-2012 as compared to 1990.

More sustainable transport systems are discussed in a number of Lithuanian documents such as Long-Term Development Strategy of the State, National strategy for sustainable development and the Long-term development strategy of the Lithuanian transport system [32,33,44]. Sustainable transport is an objective in all strategies and numbers of measures are projected, but land use and integrated transport planning is not discussed. However, preventive measures could suppress energy consumption and that will take less exertion to meet obligations.

Integrated land use and transport planning is a state of the art issue in EU and many other countries. Land use and transport topic – Land-use and Transport Research cluster - was funded by the European Commission under the City of Tomorrow and Cultural Heritage key action, which is part of the Commission's Energy, Environment and Sustainable Development research program (5th RTD Framework). This cluster covers issues of transport and land-use policies in general and in particular aims at increasing urban sustainability; the reduction of travel demand; socio-economic and spatial impacts of transport infrastructure investments and transport system improvements; procedures for recommending optimal sustainable planning of city transport and

generally the interaction between transport planning, land-use and sustainability. These issues are closely related to energy consumption for transportation, particularly with travel demand and sustainable planning of a city.

There are currently six research projects in the LUTR cluster: PROMT (New means to promote pedestrian movement in cities), PROPOLIS (Planning and research of policies for land-use and transport for increasing sustainability), PROSPECTS (Procedures for recommending optimal sustainable planning of European city transport systems), SUTRA (Sustainable urban transportation), TRANSPLUS (Transport Planning, land-use and sustainability) and ISHTAR (Integrated Software for Health, Transport Efficiency and Artistic Heritage Recovery) and other projects may join at a later stage.

There are more European projects directly related to energy consumption in transport. The most recent finalized Europe-wide research activities concerning energy consumption and pollutant emissions from transport were COST 319 and MEET. These projects are concentrating on the relationship between the local and regional urban transport, and the energy consumption and the related environmental impacts.

Two initiatives to monitor the quality of life in European cities and improvement measures towards sustainability are particularly relevant to the PROSPECTS project. The initiative “Towards a Local Sustainability Profile – European Common Indicators” [45], which has likewise been given the support of the European Commission as well as the European Environmental Agency, and the Urban Audit initiative were launched by the European Commission in 1997 [46].

The Urban Audit is an initiative managed by the DG Regional Policy and EUROSTAT, and its purpose is to assess the quality of life in European cities. The Urban Audit indicators cover socio-economic aspects, participation in civic life, education and training, environment, culture and recreation. There are 21 indicators, among them land-use and travel patterns.

Towards a Local Sustainability Profile – European Common Indicators is an element of a Europe-wide sustainability monitoring initiative. A joint initiative from the European Commission (DG Environment), the European Environment Agency and the Expert’s Group on the Urban Environment has so far resulted in a set of first generation of common indicators, as developed by a Working Group of the Expert’s Group in close consultation with local authorities across Europe. The initiative aims at encouraging

European local communities to use common indicators in order to measure their recorded progress towards sustainable local development. The initiative is not a one-off project, but the start of a long-term process that will gradually improve the monitoring of progress towards sustainability and to produce objective and comparable information on local sustainability across Europe. The outcome of numerous and extensive expert consultations rounds with 42 towns and cities, was a result of the agreement of a list of 10 main indicators. *Local mobility and passenger transportation* and *Sustainable land use* correlative to *Quality of the air* and *Noise pollution* indicators are among these 10 main issues. Local mobility and transport indicator represents the mobility of citizens living within urban areas: number of trips, reason for the trips and regularity, average distance and time taken for the trip, modes used for trips, and the percentage of trips by private motorized transport. Urbanized land/total municipal area ratio and the intensity of use, new developments and the restoration of urban areas represent sustainable land use indicators.

Australian researches made a review of the international experiences to determine definitions of sustainable urban transportation and its land use system, and the objectives that form the basis for determining suitable indicators of performance [47]. The first step before using urban structure as a tool to achieve sustainable transportation is to understand how the urban structure influences travel patterns. A careful inspection of indicators revealed that travel patterns are a component of environmentally sustainable transportation indicators. Aspects of travel such as vehicle kilometers traveled, trip's length and mode choices can be used as a proxy for energy consumption and transport emissions.

Lithuanian researchers, P. Juskevicius, and M. Burinskiene [21,48,49] also analyzed this area and propose groups of conceptual indicators (to measure interaction between urban structures and transport): indicators of urban structure (land use, integrity, allocation of residences and workplaces), and indicators of urban transport (modal split, travel patterns, speed, rate of transport infrastructure exploitation), performance indicators (energy consumption, noise, pollution, traffic safety) and urban management indicators (information, traffic management, priority of public transport and etc).

A group of Lithuanian scientists have prepared a theoretical model, allowing for the evaluation of urban sustainability and urban development in the future with the help of multi-attribute decision-making methods [50-53]. Such a model is based on experts'

methods and can be employed to evaluate urban sustainability, though cost-benefit analysis based on forecasts or other numeric expressions cannot be obtained.

1.12 Chapter I: Conclusions and recommendations

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

2. The conventional understanding of sustainable development covers economical, social and ecological subsystems as well technological, socio-economical and natural interactions. Urban areas and processes within these areas are hard to describe by unified and weighted indicators as all cities are rather special and have specific features. Consequently, identification of main elements influencing energy consumption in urban transport should be analyzed in a geographically defined territory. Vilnius is a geographically defined object in this dissertation.

3. Sustainable development covers a lot of various fields and multidisciplinary subjects emerge. The object of the study is to cover technological sciences such as territory planning (civil engineering), transport, energy and social sciences such as economics or sociology. There are three main opportunities to increase energy efficiency in Lithuania's transport sector: promotion of bio-fuels, development of a more energy efficient and non-motorized transport system, integrated land use and transport planning. Further research will concentrate on the energy consumption in Vilnius's transport system and its dependency on land-use and mobility of inhabitants.

4. Two major approaches can be employed to define and model the interaction between energy consumption in transport and urban structures. An empirical approach is reasonable if comprehensive information of the transport system's performance is available and theoretical models can be employed if research of all the system is too complicated and costly.

2. Research of Influences of Vilnius Urban Structures on Energy Consumption in Public Transport[3]

2.1 Energy planning, transport and Land-use

Transport technologies and energy supply networks increased personal mobility, and released industry from location constrains, helped to turn a city into suburbs and provided the fundamental permitting factors for urban growth to spread and in decreasing densities. The form and spaciousness of cities are also determined by intangibles such as history, cultural traditions and values [54]. These main groups of factors determine the current energy consumption in cities.

Cheap and reliable energy supplies and the distribution of energy are the most important factors shaping an urban and regional system. Once in place, land-use patterns and urbanized environment interact with the energy system in two important ways. First, they are among the determinants of the level and pattern of energy demand. In low density suburbs, for example, segregated from employment and services, and poorly served by public transport, people are necessarily dependant on a high level of personal mobility, and their travel patterns are inevitably energy intensive. Second, the spatial structure is an important determinant of the feasibility of future alternative transport systems, such as tram or metro, which have particular requirements in terms of density, layout and orientation (neighborhood design).

Town planners are increasingly considering how town development might be shaped to reduce dependence on the private car and the amount of travels in total, using a combination of land-use and transport measures. The objective to reduce car dependence has not been seen previously as a key issue and it is a turning point. Land-use planning has the potential to shape the pattern of urban development and reduce social exclusion and segregation, guide the location of major travel-generating uses and ensure a wide range of opportunities that are available at the local level. It is an essential

[3] Chapter is based on author's publications III, IV, V, VII and IX that are listed on page 148-149.

part of the long-term strategy for ensuring more sustainable patterns of urban developing and urban travel. Land use policies can seek to limit travel through two main mechanisms [55]:

- Reducing the need to travel, either through ensuring reasonable proximity between places of residence, employment and other facilities, thereby minimizing the length of the trip necessary to access particular opportunities; or through creating mixes of facilities, which increase the scope for multipurpose trips
- Increasing the scope for non-motorized travel, such as walking and cycling, or by forms of public transport, such as rail and bus, which are likely to be less environmentally damaging than private cars.

The topic of "Energy planning, transport and Land-use" although it sounds general, it is rather complex since it covers various related aspects. The two main aspects according to ELTIS [56] are the general-spatial and land-use patterns that have an impact on transport volumes and the spatial/land-use requirements of a transport infrastructure. The first aspect is related to the growing suburbanization and the urban sprawl, which have led to increasing dependencies on the private car and to substantially increased trip lengths and higher energy consumption. Widespread ownership and use of cars is also related to this phenomenon. The second aspect requires planners to distinguish between different transport modes, which have varying land-use requirements and energy use.

2.2 Global, state, local level transport planning

By pursuing the planning goals, any system being modeled and analyzed should be divided into certain geographical areas, and usually based on administrational borders, i.e. national, regional, or municipal boundaries [47,57]. Firstly, this is done for institutional reasons, such as the jurisdiction of administrational bodies (state, regions, or towns) related to the geographically defined planning. There also are other reasons why the planning should be attributed to controlled geographical regions of an analytically proper size. These reasons are incidental to the value and significance of the results of the transport system's analysis. It should be mentioned that transport flows crossing borders of the geographical system, i.e. between the system and its

geographical environment, might be much more crucial than the flows among the internal sub-systems of the system, irrespective of how the geographical borders are set.

Sustainability is an expression with broad meanings in the fields of ecology and economy (Illustration 13). The establishment of a universal computer simulation model for sustainability that covers all resources and environments is nearly impossible [58]. For the broad understanding of sustainable development, items such as seasonal changes, timing of restrained harvesting and the rate of the regeneration of natural resources, land use, infrastructure, fuel consumption and pollution as well as theories on population growth are crucial. Similarly, in the world of computing, as a whole, and computing simulation in particular, three important components of models are *theory, data and program*. A model for a global sustainability should include sub-models for different resources and consumers in the system, urban territory, district or state.

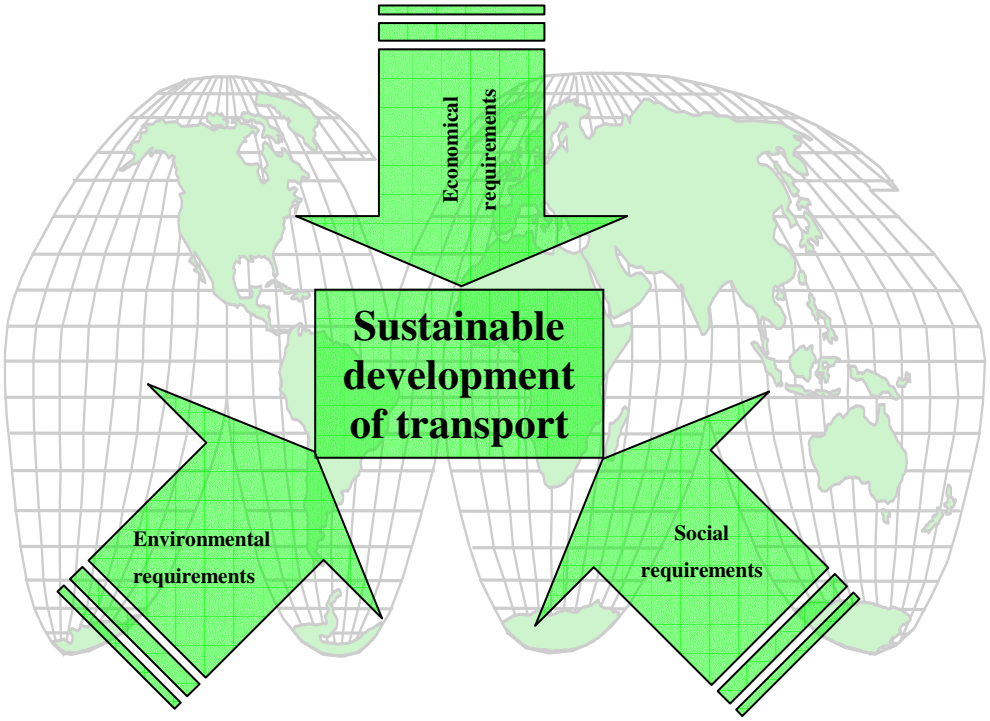


Illustration 13: Sustainable development factors

The followings are models covering various themes and dealing with different resources or factors that should be included in sustainability: human population growth models, water models, greenhouse effect and CO2 models, conservation models, forests models, harvesting models, models for the timing and management, pollution models, waste models, ozone models, and soil and land models etc.

When it comes to energy and transport models, different aspects of its spatial structure become important at different scales, from the regional, where the broad pattern of settlements is significant, to the local, where what matters is in relation to layout and centralization. Structural variables affecting energy requirements at different scales are shown in the Table 4.

Table 4: Significant structural variables at different scales

Structural variable	Scale
Settlement pattern (e.g. size and spacing of settlements, etc)	Regional
Communication network between settlements	Sub regional
Size of the settlement (area)	
Shape of the settlement (circular, linear, etc)	
Communications network within settlement (radial, grid, etc)	Individual settlement
Density	
Interspersion of land uses	
Degree of centralization of facilities	
Layout (estates, etc)	Neighborhood
Orientation (of buildings or groups of buildings and bus stops)	

Further, the study will cover the level of comprehensive plan (variables and variables under this level). At the city level (size of the settlement), highway, transit systems and major transport terminals are the dominant elements that impact the spatial structure. At the city district level, which can be seen as a conglomeration of various communities, the urban-spatial structure is influenced by the main roads and the specific employment of zoning. At the community level, the urban-spatial structure is influenced by street patterns and the location of residences and basic services.

2.3 Land use, urban form and mobility patterns studies

The form of cities is historically bound to the technological advances of transportation systems. Cars and suburbanization (in America of 1920s and for the rest of the world in 1950s) had meant that the new residential developments were nearly all further from employment opportunities, and similarly they were more distant from the new higher-level shopping places, entertainment, educational and cultural facilities [59,60]. This caused longer distances to be traveled and mobility developments. All these developments finally required more land and a more efficient infrastructure.

A number of studies have attempted to understand the relationship between land use, urban forms and energy consumption for urban travels, and try to provide empirical evidence. At first, attention of the academic world concentrated on the possibility that some urban forms may involve less fuel consumption and less pollution. The debate on land use and energy issues started with the work of Newmann and Kenworthy (1987) in their work titled "Transport energy conservation policies for Australian cities" and later articles published in different journals [61-63]. Two researchers present an analysis of the relation between fuel consumption and transport planning parameters such as private car use, public transport use, proportion of workers walking/biking, road supply, parking supply, average traffic speed, average speed of public transport modes and physical planning variables such as density of people and of jobs in the total city (Illustration 14), central city, inner area and outer area (covered thirty-two worldwide cities). Analysis has shown that land use intensity, orientation to non-automobile modes, level of traffic restrains, degree of centralization and public transport performance have the strongest influence on energy consumption per capita. Among these parameters, residential density is considered as the most important for fuel consumption: high density in inner areas and a high provision of public transport are correlated to low annual fuel consumption per person. This is explained by observing that low densities imply long distances and make essential the use of automobile and result in expensive and ineffective public transportation systems. Newman and Kenworthy suggest some political guidelines to reduce fuel consumption in Australian cities: inner area population and job densities are 40-45 persons per ha in European energy conserving cities category, middle and outer areas should be developed on rapid transit routes with innovative medium and high density housing, develop intense sub-centers in order to minimize mobility. The provision of roads of around 3 m per person

would appear to be sufficient, 160 parking spaces per 1000 CBD (central business district) jobs would also reduce energy consumption. Energy efficient cities show significant improvements in their orientation away from cars towards public transport. For example, the number of passenger kilometers per person on public transport and the proportion of total passenger transport task on public transport are more than two and a half times greater than for the highest energy cities. The proportion of people using public transport to go to work is over twice as high. Most significantly however, is the dramatic increase of the importance of rail systems in energy efficient cities – the proportion of the public transport tasks performed by trains, increases by over 4 times than in the very poor energy conserving cities. Studies highlight that US and Australian cities are most automobile dependant, and European and Asian cities are 2-6 times less so. The authors of these articles emphasize New Urbanism, i.e. movement towards a city where there is more emphasis on transit transport and that has less need to travel or determines inherently shorter time/route through higher densities of inhabitants and mixed land use.

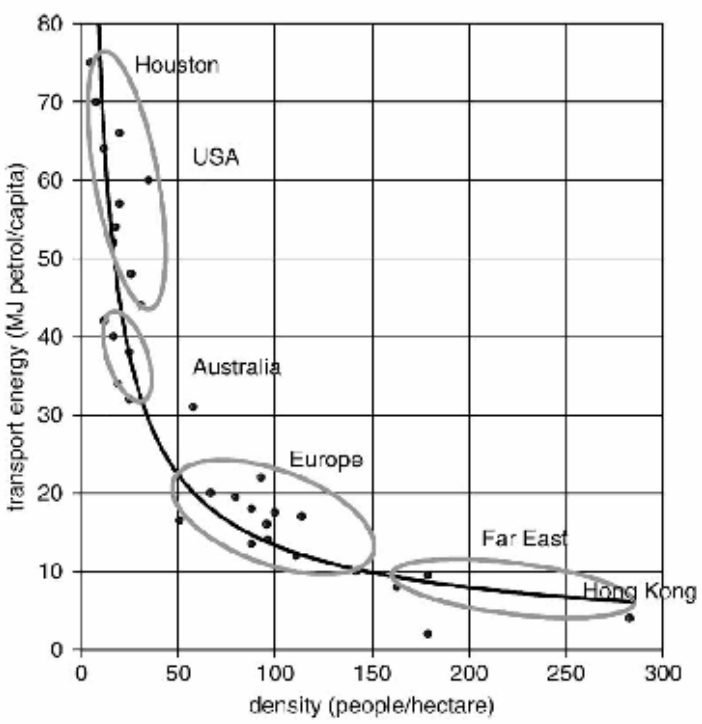


Illustration 14: Transport energy vs. urban density for 32 cities

It is reasonable to hypothesize that urban patterns influence energy consumption for transportation and more studies were performed by other researches. Most other theoretical studies concluded that compact and concentrated development of city is

favorable from an energy minimizing point of view (Lundquist, Mattson and Eriksson 1985 and 1989; Owens 1986). A model study carried out by Lundquist, Mattson and Eriksson (1985) concluded that a difference of 6.5 % between the overall urban population densities of different developmental alternatives for Stockholm was likely to lead to a difference of 5.4 % in energy use for commuting trips.

The number of empirical studies is low compared to the much more common approach of theoretical modeling. The investigation of Swedish towns [3,4,64] shows that energy that is used for transport is influenced by population density. The more urban per capita, the higher is the inhabitants' average energy use for transport. Then the annual average of energy used for transport increases by approximately 12 % when the urban area per capita increases from 400-600 square meters. An empirical study of 22 Nordic towns performed by Ness, Sandberg, Roe [65] reveled that two aspects of an urban form significantly influence the energy use for transport: the size of urban area per capita and the degree of centralized pattern of residence. The Nordic study showed a 13 % increase of fuel consumption increase. The detailed study performed in 30 residential areas in Oslo [66] showed that urban form factors seem to have a considerable impact on energy use. An increase from 400 to 600 square meters per capita has been estimated to contribute to about 6 % more energy use per capita. Car ownership was found to exert the strongest influence on energy use per household member. In the study of the 6 workplaces (Ness and Sandberg 1996) scientists found that the distance from the workplace to downtown Oslo was the main urban form factor influencing energy use for commuting trips. The use of cars for work trips is much more frequent if workplace located further from the center of Oslo. Such trips are two and a half times energy intensive than work trips to downtown (and keeping constant other variables). This study indicated that the accessibility to the workplace by public transport had considerable influence on the modal split for commuting trips. For the visitor attracting, non-specialized functions with the primarily local catchment area, a decentralized location interspersed with residential areas seemed to be most favorable from an energy point of view. Examples are grocery shops, primary schools, kindergartens, post offices and branch offices of banks. For the other workplaces -i.e. businesses that are not visitor attractive and directed towards a local catchment area- a central location seemed to give the lowest energy use for transport. Next to this, an inner-area location in a relatively densely build-up local area with good public transport facilities seems to be preferential

from an energy point of view. If other considerations imply that the workplace should be given a peripheral location, a site close to one of the public transport nodes, in that part of the urban area, should be chosen.

Research has shown that the distance of work-travel increased during 1981-1991 in the biggest towns of Great Britain [67]. This increase is essentially due to counter-urbanization and other decentralization trends, also because of the increasing number of trips by private cars. On the other hand, a study of transport efficiency in Hong Kong Island [68] showed several benefits such as economy in land utilization, less roads and low car ownership rate, commercially viable public transport and high accessibility for residents.

2.4 Experiment on Vilnius public transport and land use

Every city is a framework directed by local inhabitant's needs and is filled with the ideas of local planners, global and local economical conditions and consequently it is crucial to find reasonable technical solutions to satisfy these needs. Public transport is a substantial part of the urban transport system. The quality and supply of public services very closely relate to environmental aspects and are one of the main indicators showing the quality of life in cities.

Therefore, a further analysis of the Vilnius public transport system concentrated on an analysis of Vilnius public transport system's performance, relations between urban structure factors and energy consumption in the public transport. The main objective of this analysis was to find the most important elements of an urban structure that influences the energy consumption of public urban transport and to evaluate the importance of these elements.

The experiment, in this study, was based on Vilnius as an example. An empirical study was built on the data collected during research that was completed in 2002 of the Vilnius public transport system. Data was also collected from interviews with passengers and from an on-site research in 2002. A number of students (52) calculated passenger flows in trolleybuses, and buses and minibuses during peak hours (6-10). The sample of vehicles was compiled by selective methods and covered 25% of vehicles operating on the transport network in Vilnius, therefore the statistical population could be described with 95 % accuracy [69]. Additionally, a research of 17 sections was

performed for the good measure, i.e. to monitor the number of private vehicles and adequacy of timetables.

The following characteristics of the transport's network were evaluated: total load of route and load between bus stops, average length and duration of trip, number of vehicle and passenger km, and number of runs. Consequently, a databank on the ground of GIS technologies was created, which was employed for further computations.

The influences of urban structure factors on energy consumption were defined from the collected data. These factors are ranked according to their importance and linear regression models were constructed. Changes in the urban structure and a comprehensive plan are part of the long-term actions and proposals have been grouped according to the estimated duration of such measures.

2.5 General information about Vilnius's public transport system

Whenever access to cars is limited to reduce congestion and adverse environmental impacts, land use and transport measures should be undertaken in parallel to ensure higher accessibility and better connections of public transport and non-motorized modes, creating attractive and environment-friendly alternatives to compete with private cars even for long distance trips.

The Lithuanian transport sector consumes about 28 % of Lithuania's final energy. The biggest part of vehicles is running on fossil fuels and road transport consumes around 90 % of Lithuania's final transport energy. Public transport consumes a small part of fossil fuels and it transports passengers in a more energy efficient way (see chapters 1.3, 1.5 and 1.6 for more details).

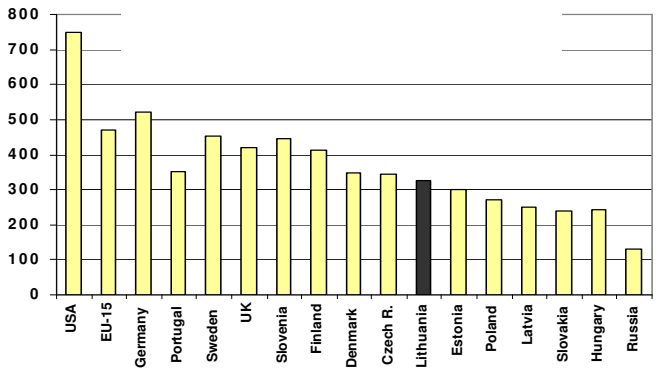


Illustration 15: Car ownership in Lithuania and other countries in 2001 (no of cars/1000 inh.)

In order to determine regional transport tendencies, a short analysis of global and national tendencies were helpful to those concerned. Lithuanian vehicle fleets have been increasing rapidly from 1991, despite increasing fuel prices and an unfavorable economical situation. The constantly growing demand for personal mobility has mostly been met by an important increase in the number of passenger cars. Lithuanians have fewer cars than the inhabitants of earlier EU members. Lithuanian inhabitants have more cars per person than other new EU members such as Estonia, Latvia, Poland, Slovakia or Hungary (see Illustration 15) [70].

At the same time demand on fuels is rising, new requirements for the infrastructure's emergence and the reconstruction of transport corridors, connection of corridors with urban transport systems, removal of bottlenecks etc still needs to be accomplished. Inadequate developments cause higher pollution, time loses and traffic safety problems.

As was already mentioned, land use measures influence energy consumption for transportation. On the other hand, in accordance to Lithuania's legal base, land use is one of the most essential regulations defining the spatial configuration of the Vilnius (purpose of the land, land use characteristics, development intensity and restraints). There are 5 main land use types according to the Lithuanian legal base [71,72]: agricultural, forestry, conservation, water/reservoir and other land uses. Urban areas are mostly defined by other land uses and its main purpose such as: multistory residential buildings, low story residential buildings, public buildings, industrial and commercial territories, land for infrastructure, excavation of minerals, public and recreational spaces, military territories and waste dumps. Special laws provide land use regulations for protected areas (heritage, conservation areas, reservations and etc.), but it is hardly a changeable land use pattern and interaction with transport system is minimal.

Land use in the biggest Lithuanian cities is still very homogeneous, i.e. division of urban area into residential, industrial and commercial districts is still an earmark of the urban plans [73]. This is a soviet heritage based on contemporary planning models, when industrial, residential, recreational and commercial activities were concentrated in different Vilnius zones [21,74]. That caused higher mobility of inhabitants and greater demands on transport.

Vilnius has been expanding on account of private construction and the growth of its suburban areas. Usually, construction consists of semi-detached or detached private

houses, which decrease the population's density. A comprehensive plan of Vilnius [75] forecasted faster development of low story residential areas and densification in multistory areas. The construction of multi-apartment houses has been very slow during the last years, although Vilnius's construction rate is the fastest in Lithuania. The average population density in Vilnius was quite low - 13.8 inhabitants per hectare in 2003, but high densities in "overnight" districts across the main transport corridors retain quite good PT positions in the transport system of Vilnius.

The last survey performed by Vilnius's municipality shows (see Illustration 16 and 17) that the use of personal cars increased from 1998-2002. Public transport still dominates city transport, providing 59 % of total transport needs (compared to 63 % in 1998). The route network in Vilnius was originally developed during soviet period with trolleybuses primarily serving central areas, while buses operated on the outskirts and in the suburbs.

According to research into the Vilnius's public transport system in 1998, passengers preferred trolleybuses (57.8 percent) and buses (39.3 percent) during peak hours. The share of private buses and minibuses was minimal (1.5 and 1.4 %, respectively). The number of trips performed daily by one Vilnius inhabitant (only public transport) was 1.43 in 1998 (total number of Vilnius inhabitants is 578,400), but no such survey was conducted during 2002 [69].

Illustration 16 shows that the total load of public transport's infrastructure decreased in the biggest part of the transportation regions and the total decrease is 29 %. The situation is spatially visualized on the Vilnius map. Passenger transportation by public transport increased in some further transportation regions, where the construction of new buildings and particularly single houses take place.

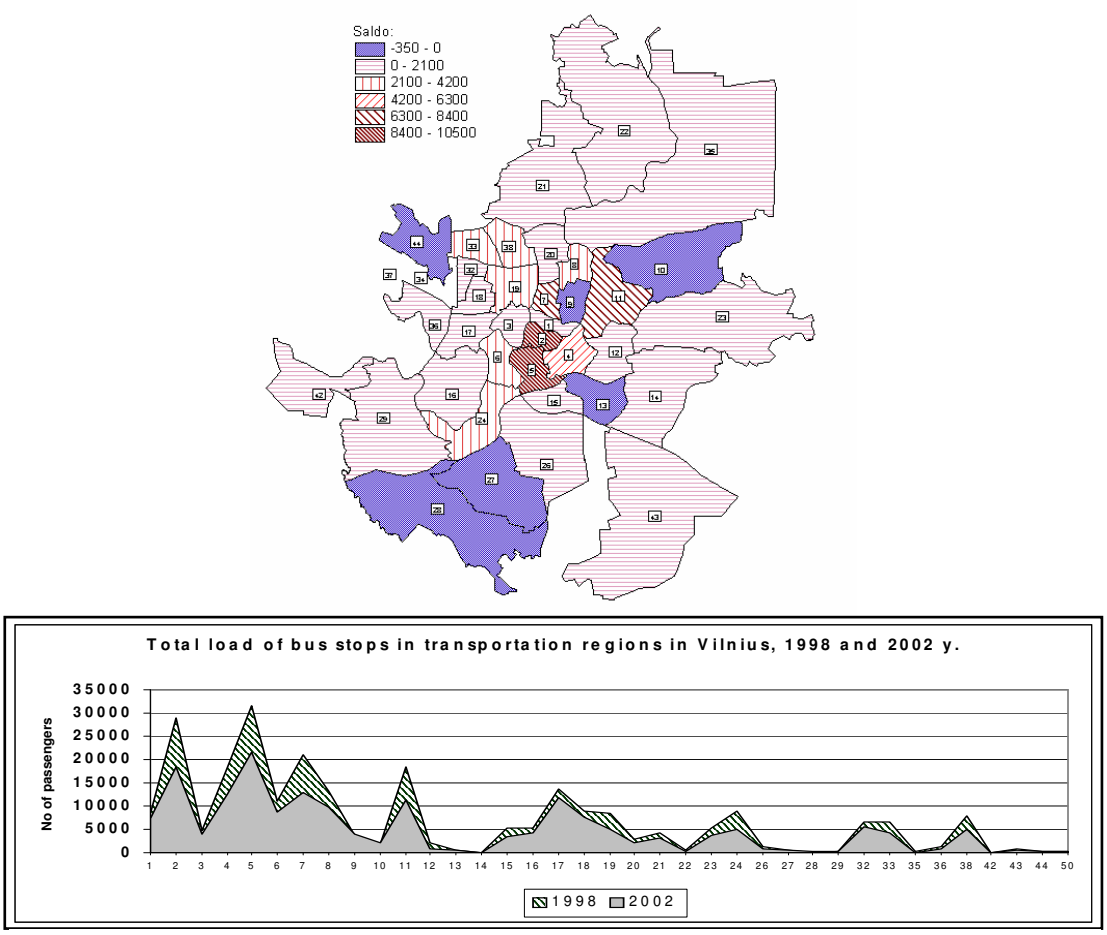


Illustration 16: Comparison of bus stop's load in Vilnius transport regions, 1998 and 2002

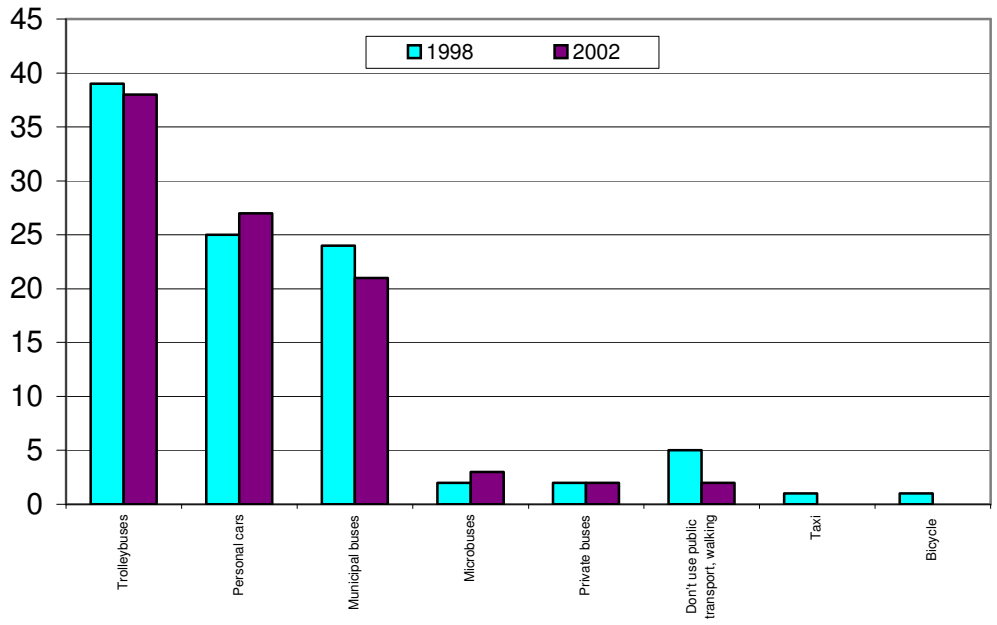


Illustration 17: Modal split (percentage) in 1998 and 2002

Recent development is the relocation of the inhabitants to Vilnius's outskirts goes with decreasing mobility in the central part of the city. The explanation of these processes could be - decreasing number of workplaces in the central part of the city or by changes in the modal split (Illustration 17). Inhabitants prefer walking in the central parts of the city and a good public transport system (trolleybuses and autobuses) creates a need only for longer distances. Moreover, journeys in the central part of the city are multipurpose and walking is the best option to achieve people's goals. The territorial differentiations of Vilnius were explained by research [74]: central part of the city's walking zone, further from the central to the peripheral part of the city modes vary from limited movement (trolleybuses and buses) to unlimited movement modes (private cars).

According to interviews, trolleybuses are the most popular in central part of the city (approximately 1/3 of Zirmūnai, Karoliniskes, Zverynas inhabitants use trolleybuses) and the buses are more used in the outskirt zones without trolleybuses infrastructure (a half of respondents in Rasos, Naujoji Vilnia, Pilate). The private cars are also the most popular mean in peripheral zones where are living middle class inhabitants (or higher level, probably with higher incomes) [76].

According to research in 2002 [69], trolleybuses transported 47.8 % of all passengers, buses 41.5 % and private operators 10.7 %. The share of private operators increased, with private buses carrying 4.3 % of all passengers, and private minibuses at 6.4 %. Trolleybuses are working in the central part of Vilnius and buses perform the function of transportation to the trolleybus network. The average length of one trip in 1998 and 2002 accordingly: trolleybuses – 3.01 and 3.46 km, buses – 4.45 and 5.05, private buses – 8.89 and 7.85 and minibuses – 7.39 and 7.05.

Vilnius buses are mostly run on diesel while trolleybuses consume electricity that does not pollute the urban territory. Fuel prices in Lithuania more or less depend on the situation in the global oil market and the taxes set by the Lithuanian Government. The excise tax is also balanced and increased up to minimum requirements of the EU Commission. Electricity prices have remained stable, but may rise in the nearest future because of the intended decommission of the first block of the Ignalina Nuclear Power Plant in 2005.

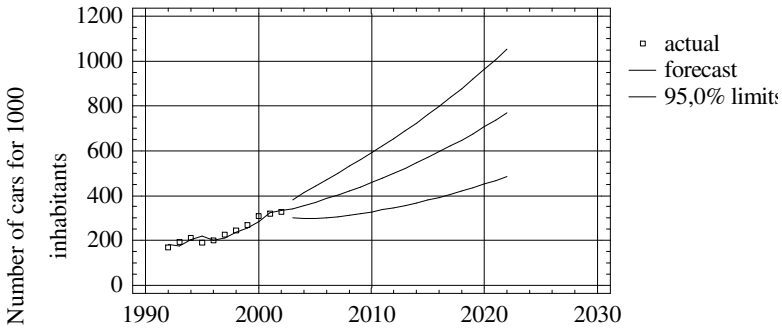


Illustration 18: Forecast of car ownership in Vilnius (1,000 inhabitants)

Vilnius public transport is under great pressure from individual transport companies and so current developments in car fleets and public transport will possibly determine future energy efficiency in the Vilnius transport system. For instance, an autoregressive integrated moving average (ARIMA) model has been selected to predict the number of cars for 1,000 inhabitants (see Illustration 18). This model assumes that the best forecast for future data is given by a parametric model and relates the most recent data value to previous data values and previous noise levels.

2.6 Vilnius compared with other EU cities

In assessing the overall situation of the Public Transport (PT) system in Vilnius, it would be natural to compare it with a set of other European cities. The following is a simple comparison based on statistical data that on the one hand, is not quite sufficient for a comparison and, on the other hand, might give an impression or indication of the situation in Vilnius in comparison with other 29 cities in West (26) and East (3) Europe. The cities selected are from UK, Austria, Switzerland, Italy, France, Spain, Germany, Poland, Netherlands, Finland, Sweden, Norway, Denmark, Belgium, Czech Republic, and Hungary [77].

The data for these cities was exclusively borrowed from the Millennium Database – a research document made for the UITP (International Union of Public Transport) [78]. Vilnius is not included into the Database, but similar data for Vilnius has been collected and is presented in an appropriate form to make comparisons.

Firstly, it is likely that there is bias because the data was not collected under the same conditions/levels as was in the other cities and does not cover precisely defined areas. Secondly, there are some systematic problems concerning differences of PT general conditions in the compared cities, such as topography, living standards and infrastructure. As to the possibilities and quality of the urban PT system, only three from the compared cities (Vilnius, Bologna and Copenhagen) have no trams or light rails that have implications on both economy and the use of PT.

Illustration 19 presents the situation of the PT system in Vilnius in comparison with other selected European cities regarding their specific data on general conditions, economy, the service level and the use of PT.

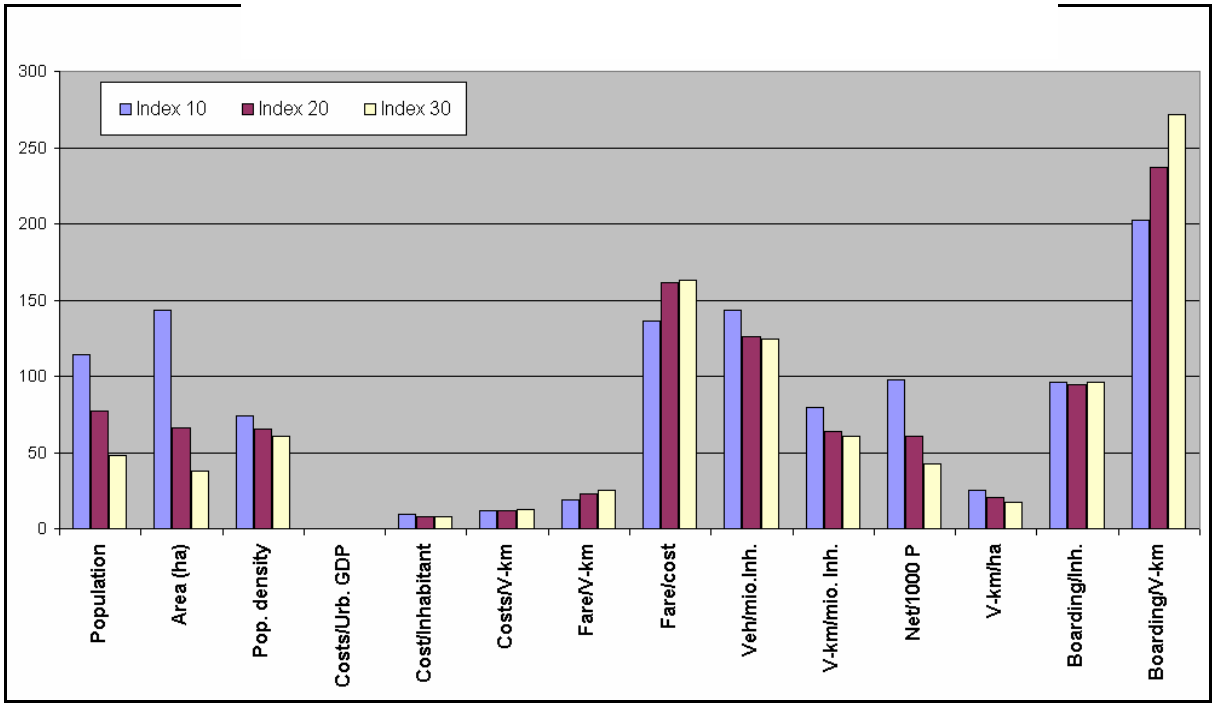


Illustration 19: Vilnius PT data in comparison with average values for 9, 19 and 29 other cities in West and East Europe regarding their specific data

General conditions

The general conditions to be considered in the PT system analysis are:

- Population of a city, including suburban areas (varying from 240,000 to 2.8 million of inhabitants),
- Area where these inhabitants live (12,600–649,000 ha),
- Population density calculated from 2 to 84 inhabitants per ha.

Economy

Only operating costs are considered here, infrastructure investments and depreciation were excluded:

- Ratio of operating costs with the overall PT budget for a city or region,
- Operating costs calculated per inhabitant,
- Operating costs calculated per vehicle km,
- Total fare revenue (income from tickets and compensations) per vehicle km,
- Ratio of the total fare revenue with operating costs.

As to costs and revenue, it should be noted that a relatively low level of living standards automatically gives revenue amounts for the PT in Vilnius and the other East European cities.

PT service level

Here the following data was considered:

- Number of vehicles per a million of inhabitants,
- Annual number of vehicles km per inhabitant,
- Contact network (in one direction) in m per 1,000of inhabitants,
- Annual number of vehicles km per ha.

Use of PT

This was based on:

- Annual number of boardings per inhabitant,
- Number of boardings per vehicle km.

Illustration 19 shows the differences between Vilnius data in comparison with the other 10, 20 and 30 European cities as arranged according to their population. (10 cities are taken with the lowest population). To have all the data in the same graph illustrations are shown using indexes the average of which is 100. For example, in the case of the 10 cities, Vilnius population index is 114 because the average population of the 10 smallest cities is 505,000, and Vilnius's population is 578,000. In the case of the 30 cities, the Vilnius index drops to 48 and indicates that Vilnius is one of the smallest cities among the compared cities.

Vilnius and its region is relatively large and not very densely populated and that could provide worse conditions for the PT. (this might be an example of bias in the data because some Scandinavian cities seem to have large areas).

There exists almost no rail transport, tramway or light rail in combination with the use of minibuses in Vilnius and that is a very rare combination in urban PT. Therefore, costs and fares in Vilnius are much lower than in West European cities. An investigation of figures indicates a relatively higher fare level for Vilnius than in other European cities. Costs per inhabitant in Lithuania and per vehicle km are lower than fares per vehicle km, and the amount of vehicle km per inhabitant is smaller than the average and boardings per inhabitant are close to the average. This indicates that less passenger boardings give a relatively larger contribution to the PT than on average in other European cities.

The investigation of figures indicates relatively higher operating costs for Vilnius than in other European cities. Costs per inhabitant are lower than per vehicle km, and the amount of vehicle km per inhabitant is less than the average, while the number of vehicles per inhabitant is lager than the average in Europe. This indicates that more buses perform less vehicle km and is more expensive. This difference can be explained by differences in the use of trams and light rail with a developed infrastructure, and lower operating costs and a higher vehicle capacity. The problem is that the infrastructure costs are excluded from the comparison for practical reasons.

A comparison of operating costs coverage by fares shows that Vilnius with its 99.5 % coverage is at the top among the 30 cities compared, except for Barcelona where a relative profit is achieved. Depreciation expenses and infrastructure investments are excluded from these calculations – a real lack of coverage of all the costs is practically

much lower in Vilnius. In Vilnius the general subsidy for PT is not fully covered and that is a major financial problem in the PT sector. The relative amount of compensation for concessionary fares is higher in Vilnius because there is no general subsidizing of transport operators. The revenue from sold tickets covers 67 % of operating costs and places Vilnius in the 20th position on the list of the compared cities. This could indicate that so far PT has a greater commercial viability in Vilnius than in many other European cities or that the fare level is relatively high here in Lithuania.

Concerning the service level, Vilnius has many more vehicles for a relative number of inhabitants than the other cities, but vehicles perform relatively less vehicle km on the network and it is also significantly less than in the larger cities. This indicates that there is plenty of room for improvement in the system. At the same time the number of boardings per inhabitant is close to the average, and the number of boardings per vehicle km is much higher than in the other cities. This also indicates that vehicles could be overcrowded, and it is also a basis for improvement. On the other hand, it could also be a result of the extremely short travel lengths in the PT system of Vilnius.

2.7 Methods and calculations of energy consumption in Vilnius's transport modes

The structure of the urban area constitutes a set of incentives, facilitating certain kinds of transportation behavior and discouraging other types of behavior (Illustration 20). People are trying to minimize their efforts/costs when reaching their daily activities. The efforts may include money, time, inconvenience, and energy etc. The closer a destination is to the place where one is, and the faster, cheaper and more convenient ways of transportation that are at the hand, the lower will be one's generalized traveling costs of going to this destination, smaller fuel intensity and the higher accessibility. In addition to the accessibility of a location, trips to the destination also depend on the reasons people may have for going there. Here, factors like the number and diversity of jobs and service facilities in the area, or the number of the residents, will be important to the extent of which trips are attracted to a certain location.

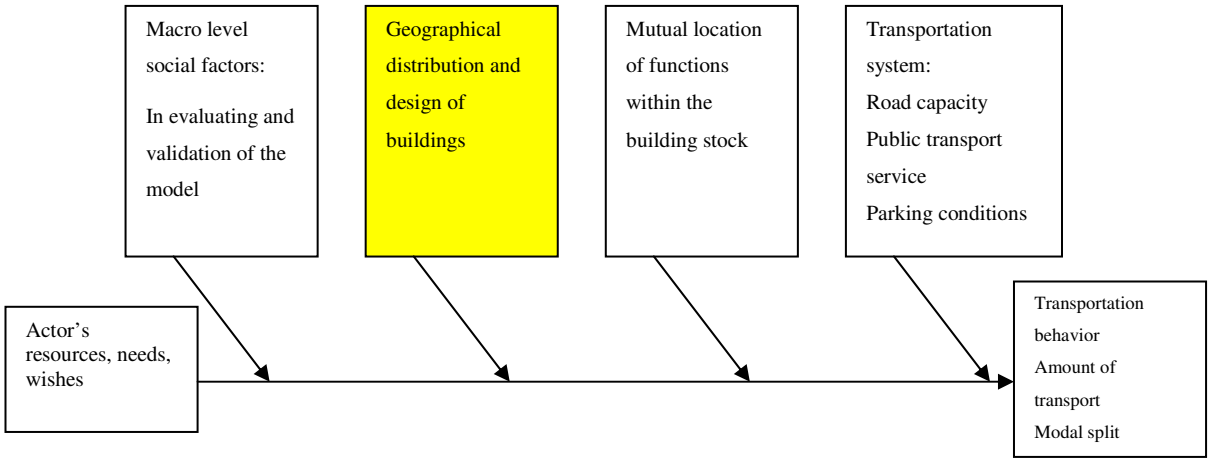
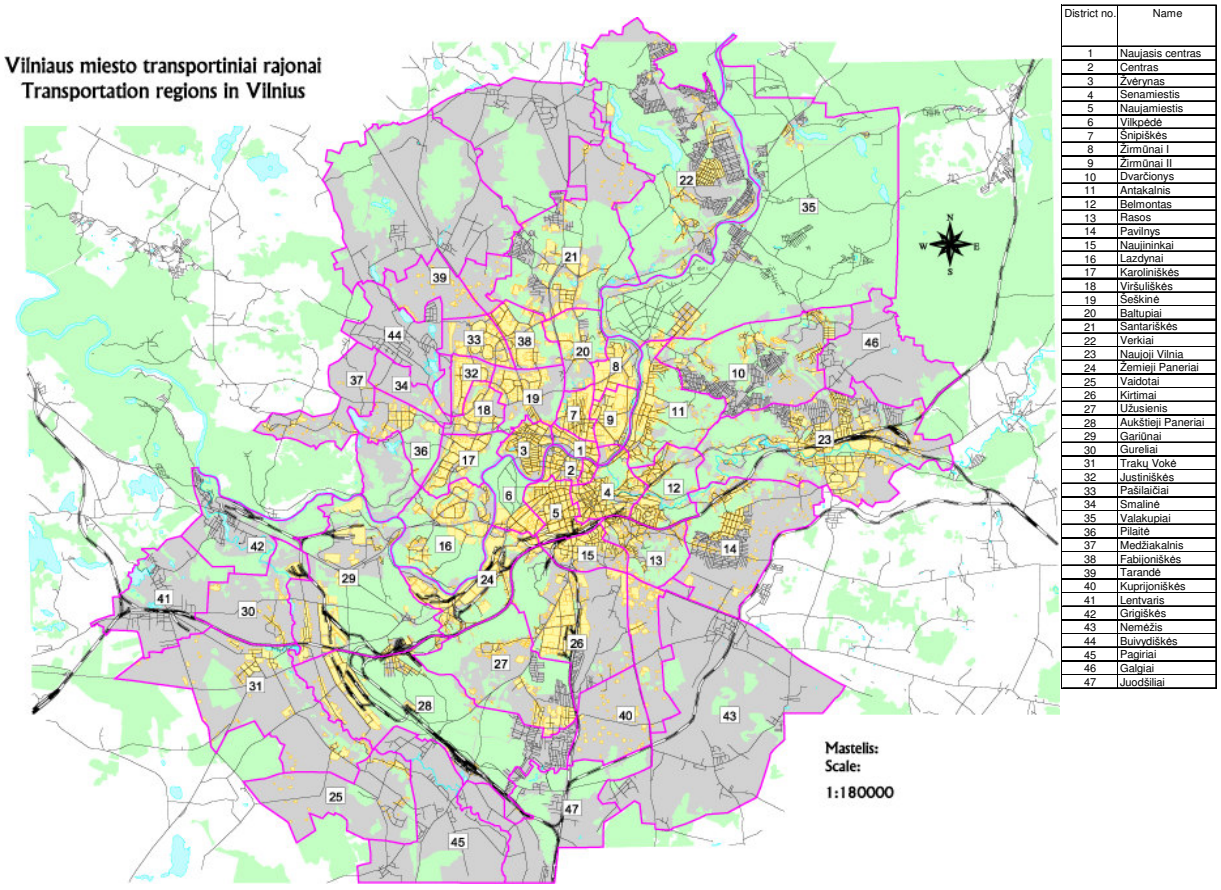


Illustration 20: Transportation behavior as a function of land use characteristics and individual characteristics of travelers and freighters [Ness]

In practice a number of other factors influence transportation behavior. These factors include personal socio-economic characteristics of the travelers (age, sex, income, and professional status, etc) as well as their values, norms, lifestyles and acquaintances. Human behavior is influenced by structural constrains and initiatives (among which material urban structure is one category) as well as resources, preferences and the aspirations of individuals. Also, symbolic and cultural features attributed to an area may affect the number of visitors that are attracted. Emerging transportation pattern is a result of people's resources, needs and wishes, as modified by the constrains and opportunities given by the development of society/welfare [3,64].

Hence, transport system consists of various physical complexes and its characteristics (transport network, vehicles) and social factors defining origins and destinations. Territory planning and transport network issues are widely covered in OECD and EU countries and were described in the previous chapters. A number of Lithuanian research projects included such issues into their consideration [73,79-82]. Territory planning, energy and transportation issues have not been objects of in-depth analysis in Lithuania.

Vilnius is divided into transportation districts (see Illustration 21). Transportation districts were selected according to the following features: similar density pattern, activity pattern in transportation districts, possibility to communicate on foot in the transportation region and whether demarcation lines overlap natural geographical boundaries (boundaries of city districts, bystreets, rivers, forests and etc).



District no.	Name
1	Naujasis centras
2	Centras
3	Žvėrynas
4	Senamiestis
5	Naujamiestis
6	Vilkpėdė
7	Šnipiškės
8	Žirmūnai I
9	Žirmūnai II
10	Dvarčionys
11	Antakalnis
12	Belmontas
13	Rasos
14	Pavilnys
15	Naujininkai
16	Lazdynai
17	Karoliniškės
18	Viršuliškės
19	Šeškinė
20	Baltupiai
21	Santariškės
22	Verkiai
23	Naujoji Vilnia
24	Žemieji Paneriai
25	Vaidotai
26	Kirtimai
27	Užusienis
28	Aukštieji Paneriai
29	Gariūnai
30	Gureliai
31	Trakų Vokė
32	Justiniškės
33	Pašilaičiai
34	Smalinė
35	Valakupiai
36	Pilaitė
37	Medžiakalnis
38	Fabijoniškės
39	Tarandė
40	Kuprijoniškės
41	Lentvaris
42	Grigiškės
43	Nemėžis
44	Buivydiškės
45	Pagiriai
46	Galgiai
47	Juodšiliai

Illustration 21: Division of Vilnius into transportation districts

There are four groups of main factors in the Vilnius: residential, industrial and commercial areas (employment), public and entertainment establishments (recreational). The main urban streets connect the transportation districts and it is typical to walk within a transportation district instead of using other transportation modes. Vilnius (Illustration 20) is divided into zones: departure zone $i=1, \ldots, I$, and destination zone $j=1, \ldots, J$. The density of inhabitants d reflects origins and destinations. Households are divided into groups $h=1, \ldots, H$. Public transport and the infrastructure includes information about public transport modes and quality, general data on the network and infrastructure PI. The modal split shows a division of the performed trips according to the available modes.

The density of the transport network in the transportation district can be defined by the equation:

$$\delta_i = \frac{L_i}{Q_i} \qquad (1)$$

Where δ_i is a density of transportation network in the transportation region *i* (km/km^2), L_i - length of the network (km) and Q_i is the area of the transportation district (km^2). The transportation network is very diverse in Vilnius and a strict theoretical shape would hardly be applicable. The main geometric shapes of the transport's network (triangular, quadrangular, and hexagonal) can be divided into triangles (see Illustration 22).

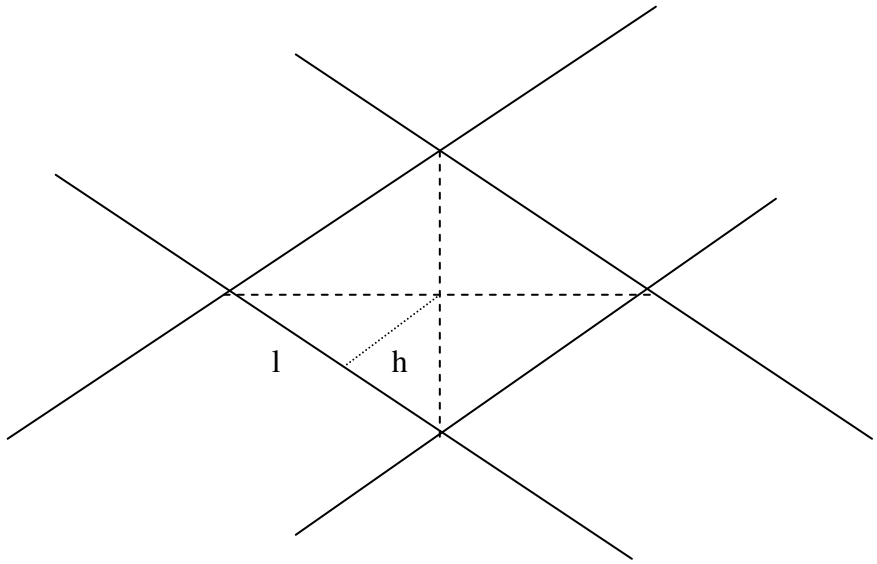


Illustration 22: Division of transportation network into triangles

The main urban street is accessible from both sides of the district and if to assume shape of the cell as a triangular, the equation changes in the following way:

$$\delta_i = \frac{\rho_i}{2q_i} \quad (2),$$

Where ρ_i - perimeter of *i* transportation district (km), q_i - area of *i* transportation district (km^2), coefficient 2 indicates the area served by transport network (along both sides of the network). A geometrical development of the territories expresses *h*, i.e. the furthest point from network in the area [79]:

$$h_i = \frac{2q_i}{\rho_i} \quad (3).$$

The furthest point from the network in the area can be expressed by equations (2) and (3):

$$h_i = \frac{1}{\rho_i} \quad (4).$$

Hence, it can be concluded that the maximal distance *h* are inversely proportional to the density and not so much depends on the network's shape. The distance *h* is longer in reality because access paths are curved.

Duration of the journey is usually expressed in the following way:

$$T_{ij} = t_{acc} + t_{wait} + t_{tr1} + t_{ch} + t_{tr2} + ... + t_{walk} \quad (5),$$

Where T_{ij} - duration of journey (min), t_{acc} - access time to bus stop(min), t_{wait} - waiting time at a bus stop (min), t_{tr1} - transportation time by certain transportation mode, t_{ch} - time for changing the transportation mode (min), t_{walk} - walking from the last bus stop to a destination place.

In the most cases people are not willing to walk longer distances than 500 meters [73,74] and regulations recommend a 500-meter distance between public transport stops [83]. Therefore access time t_{acc} from the inner area should not exceed 8-10 minutes and the optimal size of the cell is 0,5 km^2. Usually it is hard to manipulate with such cells in suburbs as the density of inhabitants is quite low (a lot of free spaces) and planners increase access time in calculations (size of the cell could reach 1-1.5 km^2) [84,85].

Transportation districts are defined by geographical boundaries and structural similarities. Such districts encompass 6-8 cells and the area could differ from 3 -4 km^2 in the central part of the city up to 10 km^2 in the suburbs.

Each transportation district is defined by a number of attributes such as identification number, number of inhabitants, number of workplaces, density of trolleybus lines, density of bus lines, energy consumption in trolleybuses and buses $T_i \in (ID, N_j, P_i, D_t, D_b, E_t, E_b)$. Database was prepared by using ArcView 3.2 (GIS) software and a number of numeric values were calculated and prepared by employing queries and geo-processing tools. Data on bus stops load in Vilnius's transport regions

were extracted from previous research that were performed by the Department of Urban Engineering [69].

Energy consumption in buses

The default technical state of buses and their energy consumption is defined by internal norms and signed by the Director of the Vilnius Bus depot. Buses are divided into categories according to traffic conditions on the route and each bus type has a specific fuel quota for the category (liters/100 km). The run of buses is also indicated in documents of the Vilnius bus depot [86,87].

Total energy consumption E_{bi} on route *i* per day can be calculated as:

$$E_{bi} = \frac{\sum_{j=1}^{n}(c_{ji} * r_{ji})}{\sum_{j=1}^{n}(r_{ji})} \quad (6),$$

Where c_{ji} - energy consumption in *j* type of the bus on route *i* per workday, r_{ji} - run of *j* type bus on route *i* per day. These values were obtained from the on-desk research and converted into MJ, where 1 liter of diesel is equal to 36 MJ prime energy if density of diesel – 0.84 kg/l [7,88]. Intersection of transportation districts with route themes and further data processing produce the average number of passengers on route *i* within transportation district *j* - K_{ij}^{b}, length of route *i* within the transportation district *j* - L_{ij}^{b} and the average speed of vehicles on route *i* within transportation district *j* - V_{ij}^{b}. Average energy consumption depending on the length of the route *i* in the transportation district *j* is calculated by the equation:

$$E_{bij}^{L} = \frac{E_{bi} \times L_{ij}^{b}}{\sum_{i=1}^{n} L_{ij}^{b}} \quad (7).$$

Passenger kilometers are very useful for evaluating different conditions and to compare the energy consumption values among transportation districts. The average energy consumption for one passenger-km on route *i* within a transportation district *j* would be calculated as follows:

$$E_{bij}^{p} = \frac{E_{bij}^{L}}{K_{ij}^{b} \times L_{ij}^{b}} \quad (8).$$

Energy consumption varies across transportation districts because average speed varies depending on traffic conditions. Correction coefficients should be introduced in the equations. These correction coefficients were calculated with reference to functions presented in the MEET methodology [38]. Calculation of these coefficients start from emission calculations and only distribution fitting were applied later because actual fuel consumption is known of each route.

Emission factors were derived by using data from engine test-bed measurements. The types of engines that were tested were identified from an analysis of the vehicle fleet in the Federal Republic of Germany, which showed that 300 types of heavy-duty vehicles were in use. A total of 36 diesel engines were tested, representing the range of engines used in the 300 vehicle types. They included 18 engines of mid-1980s technology, 12 state-of-the-art engines of 1990 technology, and 6 other engines so as to take into account the Swiss fleet composition. Each engine was categorized according to the type of vehicle in which it was used. The four vehicle categories were truck, articulated vehicle, coach, and bus, and each category was further sub-divided according to mass, body style, and model year band.

In order to produce characteristic emission maps, each engine was run on a test-bed under steady-state conditions and transient conditions (using the 13-mode, US transient, and TÜV-FIGE cycles). Within MEET, from a statistical curve fitting to the data on the workbook continuous functions of emission rates depending on the average speed of the vehicle were derived. The functions have the following form:

$$\varepsilon = K + a v + b v^2 + c v^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3} \quad (9),$$

Where:

ε is the rate of emission in g/km for an unloaded goods vehicle, or for a bus or coach carrying a mean load, on a road with no gradient (0%),

K is a constant,

a - f are coefficients,

v is the mean velocity of the vehicle in km/h.

The concerned pollutants are carbon monoxide, carbon dioxide, hydrocarbons, oxides of nitrogen and particulates. Coefficients for these equations are available for four classes of heavy goods vehicle, as well as for urban buses (see table 5) and coaches, and are presented in tables.

Table 5: Coefficients of emission functions for urban buses

	K	a	b	c	d	e	f
CO	1.64	0	0	0	132	0	0
CO_2	679	0	0	-0.00268	9635	0	0
VOC	0.0778	0	0	0	41.2	0	184
NO_X	16.3	-0.173	0	0	111	0	0
PM	0.0694	0	0.000366	-8.71E-6	13.9	0	0

In practice, fuel combustion does not proceed according to the ideal equation; some of the carbon is incompletely oxidized and is emitted as CO or carbon particles (PM), and some fuel escapes combustion and is emitted as VOC, and NO_X (oxides of nitrogen) that are produced because of the oxidation of nitrogen in the air and traces in the fuel itself. Nevertheless, the same principle as in ideal equation may be used to calculate the amount of fuel that would produce a certain combination of CO_2 (carbon dioxide), CO (carbon monoxide), VOC (volatile organic compounds, also referred to as hydrocarbons) and PM since there must be a balance between the total carbon in the fuel and the total carbon in all of the combustion products. Alternatively, the mass of any one of the carbon containing pollutants can be calculated from the mass of fuel and the amounts of the other compounds. However, this would be imprecise except for CO_2 because the other compounds are produced in relatively small amounts.

Emission tests usually include the measurement of CO_2 as well as other pollutants, and it is less frequent that fuel consumption is measured directly. For that reason, road transport emission factors are presented for the exhaust components, including CO_2, and fuel consumption can be derived by using the "carbon balance" method, and by using the following equation:

$$[FUEL] = (12 + r_1) \times \left[\frac{CO_2}{44} + \frac{CO}{28} + \frac{HC}{(12 + r_2)} + \frac{aPM}{12} \right] \quad (10),$$

Where:

[FUEL] is the mass of fuels,

[CO₂], [CO], [HC] and *[PM]* are the masses of exhaust pollutants,

r_1 and r_2 are the hydrogen to carbon ratios of the fuel and HC emissions respectively,

a is the proportion of carbon in the PM emission.

It can be assumed that r_1 and r_2 are equal, and typical values are 1.8 for petrol and 2.0 for diesel. Where this is not known, a value of 1 may be used for *a*. While it is not in fact the case that all of the PM is emitted as carbon, the assumption will make little difference to the calculated fuel consumption as the mass of PM is very small compared with those of the other emissions.

Energy consumption for one passenger-km on route *i* in district *j*:

$$E_{bij} = E_{bij}^{p} \times k_{ij} \quad (11),$$

Where $k_{ij} = f(v)$ - function of coefficients based on MEETs' equations and its fitted distribution (based on relation between speed and fuel consumption). The correction coefficient for buses varies across transportation districts in the range $0.73 < k_{ij} < 1.59$ and the complete distribution functions are presented in Illustration 23. Lower speed in transportation districts defines a higher coefficient, as energy consumption is higher under complex traffic conditions and vice versa. The coefficient $k_{ij}=1$ when $v_{ij} = \bar{v}_{ij}$, where $\bar{v}_i$ is an average speed on route *i*.

Data was analyzed in order to find a mathematical expression of the distribution function. The output shows the results of fitting a reciprocal-X model to describe the relationship between speed and calculated correction coefficients. The equation of the fitted model is

$$k_{ij} = 0{,}508962 + 9{,}13197/v_{ij} \quad (12).$$

There is a statistically significant relationship between correction coefficients and speed at the 99% confidence level.

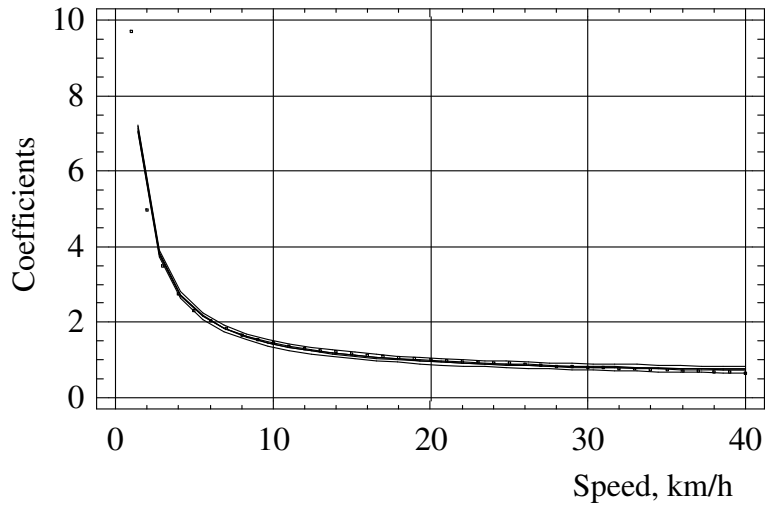


Illustration 23: Distribution fitting of coefficients depending on speed

The R-Squared statistic indicates that the model as fitted explains 99.93% of the variability in speed. The correlation coefficient equals 1, indicates a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.0417.

Final calculation results (average energy consumption for one passenger-km) were assigned to the transportation districts layer and visualized (see Illustration 25 and chapter 2.9 for the explanation of statistical estimations).

Energy consumption in trolleybuses

Despite the fact that Vilnius is one of the most progressive towns in Lithuania, technical conditions of its infrastructure and equipment are not good. The number of vehicles owned by transport enterprises in the Vilnius municipality in 2001 can be seen in Illustration 24.

As of June 2001, the Vilnius Bus Company had 246 buses, of which 98 buses (40 %) were up to 5 years old, 12 buses (5 %) 5 to 10 years old, and 136 buses (55 %) older than 10 years. The Trolley Bus Company had much more older vehicles. Of a total of 303 trolleybuses, 77 (25 %) were up to 5 years old, 7 (3 %) were 5 to 10 years old and 219 (72 %) were older than 10 years.

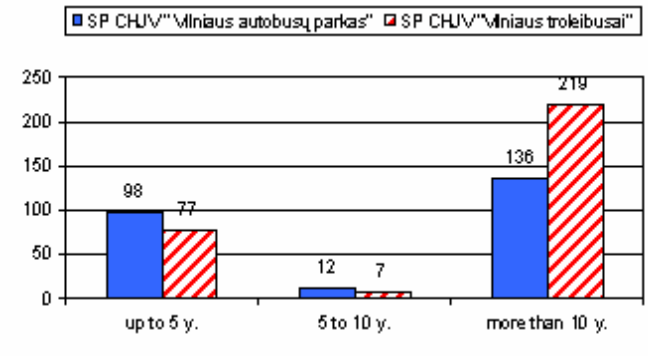


Illustration 24: Distribution of buses/trolleybuses by age in Vilnius (2001)

The technical state of trolleybuses was quite homogeneous in 2001. It was assumed that energy consumption depends on the number of the vehicles operating on route. Total energy consumption is E_t = 2.95 GWh per winter months for the transportation purposes (data obtained from Vilnius Trolleybuses). Thermodynamics evaluates electricity as a pure work and primary energy consumption in trolleybuses would be:

$$E_t^f = \frac{E_t}{0.34} \qquad (13),$$

Where 0.34 is a power efficiency of CHP [89,90]. Conversion factor 1 GWh = 3.6 TJ was used to express value in comparable units [57,9]. The average number of trolleybuses operating on the network during a workday is N_t=252, consequently energy consumption in one trolleybus operating on route is *i* per workday (MJ):

$$E_t^{/} = \frac{E_t^f \times L_i^t}{N_t \times L^t} \qquad (14),$$

Where L^t length of all routes and L_i^t length of route *i.*

Daily energy consumption on route *i* is:

$$E_{ti}^r = E_t^{/} * N_{ti}^r \qquad (15),$$

Where N_{ti}^r - number of trolleybuses on route *i,* is derived from research data. The average number of passengers on route *i* within transportation district *j* - K_{ij}^t, length of the route *i* within transportation district *j* - L_{ij}^t and the average speed of vehicles on route *i* within transportation district *j* - V_{ij}^t are also extracted from the research database.

Average energy consumption depending on the length of route *i* in the transportation district *j* is calculated by the equation:

$$E_{tij}^{L} = \frac{E_{ti}^{r} \times L_{ij}^{t}}{\sum_{i=1}^{n} L_{ij}^{t}} \quad (16).$$

Average use of primary energy (MJ) for one passenger-km on route *i* within the transportation district *j*:

$$E_{tij}^{p} = \frac{E_{tij}^{L}}{K_{ij}^{t} \times L_{ij}^{t}} \quad (17).$$

Energy consumption also depends on traffic conditions in transportation districts and correction coefficients should be introduced. There is lack of thorough research in the field of electricity consumption in trolleybuses under urban conditions. Consequently correction coefficients were calculated by using a speed matrix of trolleybuses among transportation districts:

$$k_{ij} = \frac{v_{ij}}{\bar{v}_{i}} \quad (18).$$

The coefficient k_{ij}=1 when $v_{ij} = \bar{v}_{ij}$, where $\bar{v}_{i}$ is an average speed on route is *i*. Calculated correction coefficients vary across transportation districts in a range $0.50 < k_{ij} < 2.14$. Lower speed in the transportation districts defines a higher co-efficient because energy consumption is higher under complex traffic conditions and vice versa.

Energy intensities are calculated for buses and trolleybuses and are attached to the transportation district's theme and presented in Illustration 25. Trolleybuses are operating in densely populated central districts and buses operate in city suburbs. This aspect determines the more diverse energy consumption in the bus's network.

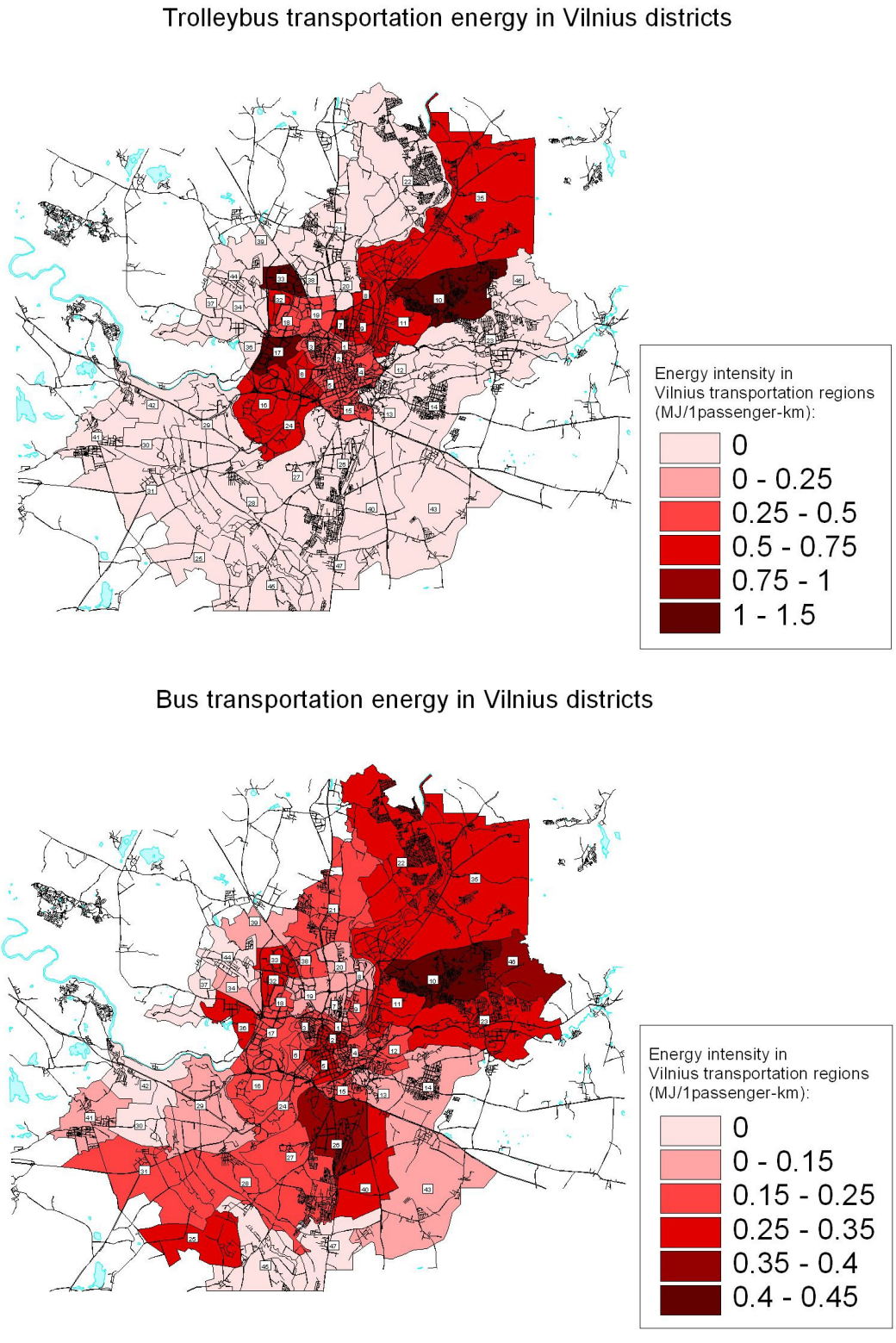


Illustration 25: Modal energy intensities in Vilnius transport districts (2002)

Research forecasts no huge changes in travel time budgets, i.e. the average person has a fixed travel time budget and does not tend to spend more time for travel. However, growth of the GDP and wealth leads to faster and more flexible transport means. Rail, bus and trolleybus travels are transitional point in evolution. The share of such means declines due to the rapidly rising share of the automobile traffic, although it constrained access to individual modes of transport in the soviet system [91].

Providing sufficient access by private car in Vilnius is unsustainable on account of the limited capacity of the street's network, the environmental and social problems caused by the consequent congestion. This situation is an opportunity for the city's authorities to provide the required level of public transport in Vilnius and to ensure access to the city's center in order to maintain its economic viability.

2.8 Comparison of average energy consumption in transport modes

Energy consumption in Vilnius's transport modes were calculated on the basis of the Vilnius public transport system's research made in 2002 and data collected during surveys at bus and trolleybus depots (see Illustration 26). To that end, assumptions on rough energy consumption and the load of private transport should be generalized.

Average energy consumption in private car was evaluated during research project in Vilnius and assumed for rough comparison as - 10.3 l/100km [92]. Fuel consumption per 100 km will be revised in later research. Similarly, the average load of private cars was determined during the Vilnius transport system research and found – 1.3 persons in each car [93]. The data on fuel consumption in private transport companies is not available, but according to research its part is still very small in Vilnius [69]. Assumptions for rough calculations, i.e. that energy consumption in the private sector is almost the same as in municipal buses, though they are operating on more loaded routes (more economically reasonable) and the average trip is a little longer.

Previous calculations have shown that aggregated energy consumption is smaller in the central part of the city where the number of passengers is higher than in the suburban areas. The drive to reduce energy consumption arises from the need to reduce overall transport emissions and particulates in the urban territory. This is substantial in densely

populated territories (such as hospitals, central business districts) as cause up to 8-10 times greater damage [82].

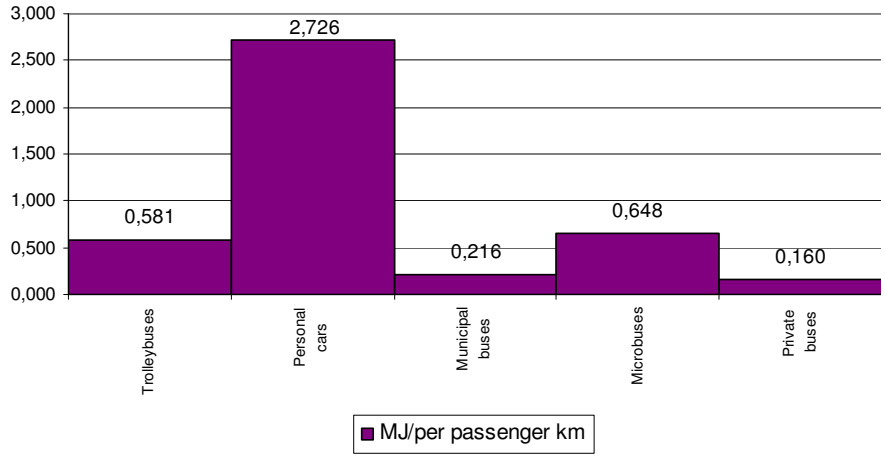


Illustration 26: Modal energy intensities in Vilnius transport modes in 2002

Trolleybuses consume less energy than buses and the assumption that electricity produced at a cogeneration plant with an efficiency of 0.34 was used in this research. The average car's age is 14 years in Lithuania and consequently fuel consumption to transport one passenger per kilometer is high compared to other countries (see Table 1 for a comparison). The Vilnius data was calculated exclusively for urban conditions. The aggregated comparison clearly shows the disadvantages of private cars and indicates higher energy intensity and higher pollution.

2.9 Construction of a multiple linear regression model

A hypothesis on influences of the urban structure on energy consumption in Lithuanian's transport sector can be verified by statistical methods. The transport system is one of the indicators showing sustainability in the city, therefore sustainable land use planning could change energy consumption pattern in the city.

Public transport plays a great role in the local transport of Vilnius. Within the main urban settlement, travel trips are short enough so that the public transport could appear as a more relevant alternative to the car. Most of the urban structural factors, including the public transport provisions near residences, appear to exert influence on the share of the public transport's mode.

Table 6: Database of urban structure elements used for analysis

VILN_PL_ID	Identification no of Transport district	Nature of indicator
GYV_SK	No. of inhabitants in TD	
DARB_SK	No. of work places in TD	
TROL_ILG	Length of trolleybus routes, km	
AUT_MAR	Length of municipal bus routes, km	
PRIV_AUT_M	Length of private bus routes, km	
PLOTAS_M2	Area of TD in m2	
PLOTAS_HA	Area of TD in hectare	
ST_AP_2002	Load of bus stops in TD passengers/day	
GYV_TANK	Density of inhabitants inh/hectare	Socio-economical
DARB_TANK	Density of work places inh/hectare	Socio-economical
TROL_HA	Density of trolleybus routes km/hectare	Technological
TROL_GYV	Trolleybus route length km per capita	Technological
TROL_DARB	Trolleybus route length km per work place	Technological
AUT_HA	Density of municipal bus routes km/hectare	Technological
AUT_GYV	Municipal bus route length km per capita	Technological
AUT_DARB	Municipal bus route length km per work place	Technological
PRIV_HA	Density of private bus routes km/hectare	Technological
PRIV_GYV	Private bus route length km per capita	Technological
PRIV_DARB	Private bus route length km per work place	Technological
BENDRAS_TA	Aggregate length of all routes km (private buses excluded)	Technological
BENDR_HA	Aggregate density of all routes km/hectare (private buses excluded)	Technological
BENDR_GYV	Aggregate length of all routes km/capita (private buses excluded)	Technological
BENDR_DARB	Aggregate length of all routes km/work place (private buses excluded)	Technological
VISI_TA_PA	Aggregate length of all routes km	Technological
VISI_HA	Aggregate density of all routes km/hectare	Technological
VISI_GYV	Aggregate length of all routes km/capita	Technological
VISI_DARB	Aggregate length of all routes km/work place	Technological
Energ_Trol_n	Consumption of energy in trolleybuses to transport one passenger (MJ/1 passenger-km)	Environmental, Economical
Energ_Au_n	Consumption of energy in buses to transport one passenger (MJ/1 passenger-km)	Environmental, Economical
UA_inh	Urban area per inhabitant (ha)	Socio-economical
UA_work	Urban area per worker (ha)	Socio-economical
ST_AP_1000g	Load of bus stops in TD passengers per day/1000 inhabitants	Technological
ST_AP_1000d	Load of bus stops in TD passengers per day/1000 workers	Technological

The number of urban structure elements was calculated and a database for the statistical analysis was created (see Table 6 and Appendix 1 with full database). Indicators were classified, but it is quite complicated to attach an indicator to a single category, as relations are multiple. Geographical recordings were derived from the available statistical yearbooks, GIS databases on public transport routes, and residents and work places. The number of passengers was derived from previous research by applying various GIS methods. Urban structure elements were calculated for 1,000 inhabitants.

Multiple linear regression models evaluated the influence of variables x_m to variable y. We can suppose that m is a number of independent variables and y_i is a linear function [94]:

$$y_i = \alpha + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_m + \varepsilon_i \quad (19).$$

Each index of the variable shows one value of the set. This equation consists of α - independent variable of the model, $\beta_1, \beta_2, ... \beta_n$ - coefficients of the regression model, and ε_i - is a random error. Taking y_i as energy consumption in transportation district i and $x_1, x_2, ..., x_m$ - factors of the urban structure that influence the energy consumption in transport, this model will describe the energy consumption depending on future

developments in the urban structure such as densification of inhabitants or urban sprawl, and development or reduction of public transport lines and etc.

The importance of each factor is determined by several statistical parameters. One of these is Pearson's coefficient of correlation:

$$r = \frac{\sum xy - m\overline{xy}}{\sqrt{(x^2 - m\overline{x^2})(y^2 - m\overline{y^2})}} \quad (20),$$

Where $\overline{x}$ and $\overline{y}$ - average of the variables.

The multiple coefficient of the determination R^2 (R-squared statistics) is defined as [95-97]

$$R^2 = 1 - \frac{s_\varepsilon^2}{s_y^2} = 1 - \frac{\sum(y - \hat{y})^2}{\sum(y - \overline{y})^2} = \frac{variation_explained_by_the_model}{all_variation} \quad (21),$$

Where s_ε^2 - variance of residuals (ε_i), s_y^2 - variance of observed variables (y), $\hat{y}$ - is the predicted value of y for the multiple regression model, $\overline{y}$ - average of the dependant variable. R^2 defines relationship if there are 2 variables and in the case of the linear regression this statistic could be defined as:

$$r_{xy}^2 = R^2 \quad (22).$$

Standardized non-dimensional coefficient beta can be described by the following equation:

$$beta = B_1 \frac{s_x}{s_y} \quad (23).$$

Beta coefficient can be calculated if X and Y variables are standardized, i.e. the mean is 0 and standard error is 1 $\left(z_i = \frac{x_i - \overline{x}}{s}\right)$. Calculated standardized regression coefficients for several independent variables shows influence of each independent variable on the dependent variable's forecast.

If coefficients a and b are calculated from a certain sample, they will differ from α and β as they are derived from the population (statistical universe). Hypothesis tests prove

that if calculated coefficients for the certain sample are not equal then 0 should be based on a distribution fitting. These coefficients α and β in the case of linear regression have a normal distribution with mean *a* and *b*. Standard error for coefficient α could be calculated as follows:

$$\sigma_\alpha = \sigma \sqrt{\frac{1}{n} + \frac{\overline{x^2}}{(n-1)s_x^2}} \tag{24}.$$

Standard error for β:

$$\sigma_\beta = \frac{\sigma}{\sqrt{(n-1)s_x^2}} \tag{25},$$

Where σ is a dispersion of residuals ε_i. It is unknown, but also could be obtained from the equation (mean squared error):

$$s^2 = \frac{\sum_{i=1}^{n} (y_i - \alpha - \beta x_i)^2}{n-2} \tag{26}.$$

Square root of s^2 is a so-called standard error of estimate.

Hypothesis test. A test statistic is used when population variances are not known, for example in the test for the equality of means across populations. Hypothesis if $\beta = 0$ and there is no relation between x and y could be tested by the following statistic:

$$t = \frac{\beta}{s_\beta} \tag{27}.$$

If null hypothesis (there is no relation) is not rejected then this statistic has Student's *t* distribution with *(n-2)* degrees of freedom.

Other hypothesis concerning whether the line crosses the origin of coordinates (in other words, if $\alpha = 0$) could be verified by the following statistic:

$$t = \frac{\alpha}{s_\alpha} \tag{28}.$$

This statistic also has Student's *t* distribution with *(n-2)* degrees of freedom.

Analysis of fitting various multiple regression models to describe the relationship between Energ_Au_n, Energ_Trol_n and number predictor variables were performed. Models were selected by using multiple coefficient of determination R^2 and adjusted multiple coefficient of determination R_a^2, employed a backwards elimination method using *p*-value and standard error of the estimate *s* (analysis of residuals ε_i).

The hypothesis that the correlation coefficient is not significant could be tested by T-statistic:

$$t = r\sqrt{\frac{n-2}{1-r^2}} \qquad (29),$$

Where *r* is coefficient of correlation, *n* – sample size, *(n-2)* – degrees of freedom of Student's distribution.

The *p*-value provides an objective measure of the strength of evidence that the data supplies in favor of the null hypothesis. This is the probability of getting a result as extreme or more extreme than the one observed if the proposed null hypothesis is correct. A small p-value provides evidence against the null hypothesis, because data has been observed that would be unlikely if the null hypothesis were correct. Thus, we reject the null hypothesis when the p-value is sufficiently small.

Multiple coefficient of determination R^2 evaluates the adequacy of the applied model, but such an evaluation is frequently too optimistic. Adjusted multiple coefficient of the determination R_a^2 more precisely evaluates goodness of fit:

$$R_a^2 = R^2 - \frac{p(1-R^2)}{N-p-1} \qquad (30),$$

Where *p* is the number of independent variables. High value of this coefficient indicates that data is close to the line, which is derived by the least square's estimation. If data fits regression line perfectly, i.e. all y values fall under the regression line, then the coefficient equals 1. And vice versa, if the coefficients are close to 0 - regression line and the equation misfit data is not suitable for making forecasts. The optional value of adjusted R_a^2 would be $R_a^2 \geq 0.25$ and if the model application is doubtful then $R_a^2 \leq 0.25$.

A regression residual is defined as the difference between an observed y value and its corresponding predicted value: $Residual = y - \hat{y}$. One method for analyzing the residuals in a regression analysis is to plot the value of each residual versus the corresponding value of the independent variable x. If the model contains more than one independent variable, a plot would be constructed for each of the independent variables. This plot will aid in detecting whether one has incorrectly specified the deterministic component of the model.

To detect outliers it is necessary to construct horizontal lines that are located at a distance of 3s above and below 0 on a residual plot (Box and Whisker plot). Any residual falling outside the band formed by these lines would be considered an outlier. A researcher would then initiate an investigation to seek the cause of the departure of such an observation from the expected behavior.

2.10 Main urban structure factors influencing energy consumption in Vilnius public transport

Primary analysis of the calculated variables has shown that derived data has three abnormal values in the trolleybus case. Transportation districts No. 17, 33 and 35 were excluded from the analysis as the main terminals are located there and apparently distort data on energy consumption.

The bivariate analysis shows that energy used per passenger-km in trolleybuses strongly correlates with urban area per inhabitant and a worker (*r=0.7469* and *r=0.7849*; for more estimators see Table 7). The more urban area per inhabitant or worker in a transportation district, the higher is the inhabitant's average energy use for transportation by trolleybuses. It is not surprising that the urban area per worker also strongly correlates with energy use because it generates longer working trips. Higher density of municipal bus routes indicates lower energy consumption in trolleybuses (*r=-0.4218*) and it can be explained more precisely by the fact that the length of the bus routes per capita or workplace also correlate with energy consumption in trolleybuses (*r=0.3614* and *r=0.4825*). Buses compete with trolleybuses on some routes (or transportation districts) and consequently energy intensity increases.

Table 7: Bivariate correlations between different variables and energy consumption in trolleybuses per passenger-km

Independent variable	Explanation	r -correlation coefficient	P-value, level of significance	t-statistic	N - is the number of pairs of data values used to compute each coefficient
GYV_TANK	Density of inhabitants inh/hectare	-0,1773	0,4959	-0,698	17
DARB_TANK	**Density of work places inh/hectare**	**-0,3443**	**0,1760**	-1,420	**17**
TROL_HA	**Density of trolleybus routes km/hectare**	**-0,3526**	**0,1651**	-1,459	**17**
TROL_GYV	Trolleybus route length per capita	-0,145	0,5788	-0,568	17
TROL_DARB	Trolleybus route length per work place	0,002	0,9940	0,008	17
AUT_HA	**Density of municipal bus routes km/hectare**	**-0,4218**	**0,0917**	-1,802	**17**
AUT_GYV	**Municipal bus route length per capita**	**0,3614**	**0,1540**	1,501	**17**
AUT_DARB	**Municipal bus route length per work place**	**0,4825**	**0,0498**	2,133	**17**
PRIV_HA	Density of private bus routes km/hectare	-0,0674	0,8190	-0,234	14
PRIV_GYV	Private bus route length per capita	-0,1553	0,5960	-0,545	14
PRIV_DARB	Private bus route length per work place	0,1336	0,6489	0,467	14
BENDRAS_TA	Aggregate length of all routes km (private buses excluded)	-0,0918	0,7262	-0,357	17
BENDR_HA	**Aggregate density of all routes km/hectare (private buses excluded)**	**-0,4254**	**0,0887**	-1,821	**17**
BENDR_GYV	Aggregate length of all routes km/capita (private buses excluded)	0,1455	0,5773	0,570	17
BENDR_DARB	**Aggregate length of all routes km/work place (private buses excluded)**	**0,4085**	**0,1035**	1,733	**17**
VISI_TA_PA	Aggregate length of all routes km	-0,1007	0,7007	-0,392	17
VISI_HA	**Aggregate density of all routes km/hectare**	**-0,4281**	**0,0087**	-1,835	**17**
VISI_GYV	Aggregate length of all routes km/capita	0,072	0,7838	0,280	17
VISI_DARB	Aggregate length of all routes km/work place	0,2854	0,2668	1,153	17
UA_inh	**Urban area per inhabitant (ha)**	**0,7469**	**0,0006**	4,350	**17**
UA_work	**Urban area per worker (ha)**	**0,7849**	**0,0002**	4,906	**17**
ST_AP_1000g	Load of bus stops in TD passengers per day/1000 inhabitants	-0,2115	0,4152	-0,838	17
ST_AP_1000d	Load of bus stops in TD passengers per day/1000 workers	0,0597	0,82	0,232	17

Higher density of workplaces (*r=-0.3443*) decreases the energy consumption in trolleybuses, but such a geographical aspect is better described by urban area per inhabitant. The aggregate length of all municipal routes per workplace (*r=0.4085*) and density of all routes per hectare (*r=-0.4281*) indicate that there is interaction between subsystems such as municipal buses transport passengers to trolleybus network. Working trips are likely to be based on changes when traveling from suburbs to the central part of the city. Other variables do not substantially influence energy consumption in trolleybuses as trolleybuses are operating in homogeneous transportation districts.

Energy consumption in buses has a lesser aspect than other patterns and this can be explained by its interaction with other public transport subsystems. Initial data analysis has shown abnormal value in transportation district No.34 as it had a very low populated in 2002.

Further data analysis does not indicate any serious problems, but derived correlations are very weak. The highest correlation (*r=0.1950*) is observed between energy consumption in buses for one passenger-km and the urban area per capita. Energy consumption for passenger-km in buses is higher if the route crosses under-populated areas. Other factors have no significant influence, as Vilnius's urban structure is very scattered.

A second approach is to eliminate transportation districts with low density of inhabitants as such districts are not as much associated/interact with municipal public transport and other transportation means that dominate, and consequently transit passengers are also not associated with district's work or residential pattern. It is quite complicated to define the separation line between populated and under-populated areas, but transportation districts are eliminated if there are more than 0.6 ha of area per inhabitant, i.e. the area is urbanized and the territory is evenly populated.

On the other hand histogram of variable "urban area per inhabitant" (Illustration 27) shows that most of the values lie in the range 0-0.6 ha and such an assumption approaches the trolleybus case and eliminates "cavities" within Vilnius's urban structure.

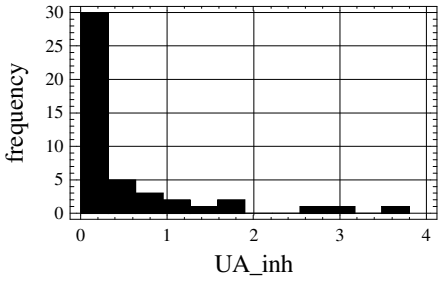


Illustration 27: Histogram of urban area per inhabitant

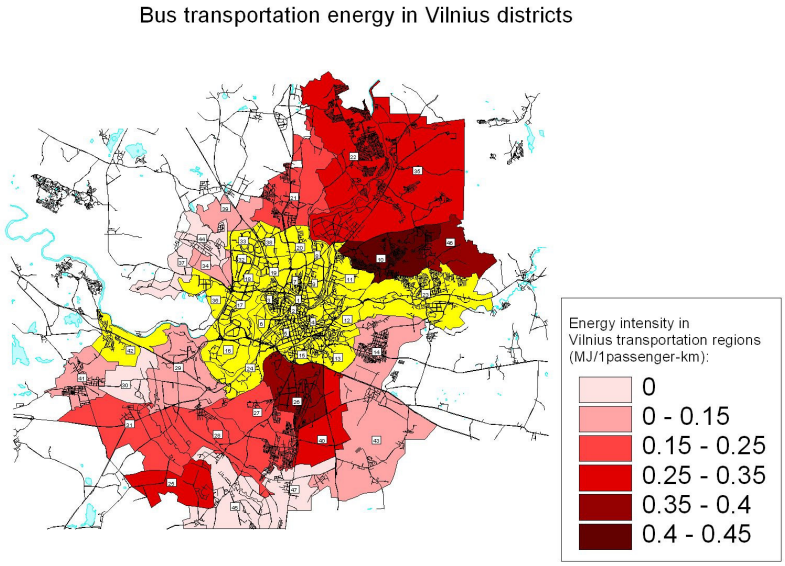


Illustration 28: Evaluated modal energy intensities in Vilnius transport districts during second approach (2002)

This graph shows the frequency tabulation by dividing the range of urban area per inhabitant (UA_inh) into equal width intervals and counting the number of data values at each interval. The frequencies show the number of data values at each interval, while the relative frequencies show the proportions at each interval. Illustration 28 shows the nuclear of the city that was used for a further analysis.

Table 8: Bivariate correlations between different variables (adjusted according inhabitants density) and energy consumption in buses per passenger-km

Independent variable	Explanation	r -correlation coefficient	P-value, level of significance	t-statistic	N - is the number of pairs of data values used to compute each coefficient
GYV_TANK	**Density of inhabitants inh/hectare**	**-0,237**	**0,2157**	**-1,268**	**29**
DARB_TANK	Density of work places inh/hectare	0,0018	0,9927	**0,009**	29
TROL_HA	Density of trolleybus routes km/hectare	-0,0543	0,8360	**-0,211**	17
TROL_GYV	Trolleybus route length per capita	0,0747	0,7756	**0,290**	17
TROL_DARB	Trolleybus route length per work place	-0,1554	0,5514	**-0,609**	17
AUT_HA	**Density of municipal bus routes km/hectare**	**-0,3194**	**0,0912**	**-1,751**	**29**
AUT_GYV	**Municipal bus route length per capita**	**0,3472**	**0,0650**	**1,924**	**29**
AUT_DARB	Municipal bus route length per work place	-0,0026	0,9895	**-0,014**	29
PRIV_HA	Density of private bus routes km/hectare	0,0586	0,7957	**0,263**	22
PRIV_GYV	Private bus route length per capita (value of 29th district eliminated)	0,0941	0,6771	**0,423**	22
PRIV_DARB	Private bus route length per work place	0,1425	0,5271	**0,644**	22
BENDRAS_TA	Aggregate length of all routes km (private buses excluded)	-0,0342	0,8603	**-0,178**	29
BENDR_HA	Aggregate density of all routes km/hectare (private buses excluded)	-0,242	0,2059	**-1,296**	29
BENDR_GYV	**Aggregate length of all routes km/capita (private buses excluded)**	**0,288**	**0,1297**	**1,563**	**29**
BENDR_DARB	Aggregate length of all routes km/work place (private buses excluded)	-0,0485	0,8027	**-0,252**	29
VISI_TA_PA	Aggregate length of all routes km	-0,1008	0,1603	**-0,526**	29
VISI_HA	**Aggregate density of all routes km/hectare**	**-0,2514**	**0,1884**	**-1,350**	**29**
VISI_GYV	**Aggregate length of all routes km/capita**	**0,2383**	**0,2132**	**1,275**	**29**
VISI_DARB	Aggregate length of all routes km/work place	-0,0769	0,6918	**-0,401**	29
UA_inh	**Urban area per inhabitant (ha)**	**0,6299**	**0,0003**	**4,214**	**29**
UA_work	**Urban area per worker (ha)**	**0,4795**	**0,0085**	**2,839**	**29**
ST_AP_1000g	Load of bus stops in TD passengers per day/1000 inhabitants	-0,0389	0,8471	**-0,195**	27
ST_AP_1000d	**Load of bus stops in TD passengers per day/1000 workers**	**-0,2918**	**0,1397**	**-1,525**	**27**

Results of further statistical analysis are presented in Table 8. Variables such as urban area per inhabitant or worker explain the variation of energy consumption in the best way (*r=0.6299* and *r=0.4795*), otherwise the higher density of inhabitants determines lower energy use(*r=-0.2370*). Higher density of selected municipal bus routes km/hectare indicates lower energy consumption (*r=-0.3194*) and that could be explained by a homogeneous urban pattern in these transportation districts. Other bus routes serve scattered settlements around Vilnius and accessibility factors define the number of passengers as in the case that was selected by municipal bus routes and per capita correlate with energy consumption for passenger-km (*r=0.3472*). Energy intensity increases as trolleybuses and private buses operate on more profitable routes (compete with municipal buses) and use a skimming strategy while the bus depot has to deal with concessionary fares in under-populated transportation districts. The aggregate density of all routes (km/hectare) and length of all routes per inhabitant positively influence energy consumption in municipal buses (*r=-0.2514*, *r=0.2383*). This aspect

can be explained by previously mentioned interaction between municipal trolleybuses and buses (competition and the same time symbiotic aspects).

2.11 Multiple linear models for buses and trolleybuses

As a result of the research - multiple regression models were constructed. Models have been fitted and contain all combinations of calculated variables with the highest R_a^2 coefficients. The results have shown that models describe the relations between fuel consumption in and urban structure elements well.

Model describing influences of urban structure on energy consumption in trolleybuses

Variables such as density of workplaces, trolleybus route lengths per hectare, municipal bus route lengths per hectare, workplace and capita, aggregated length of municipal routes per work place, aggregated length of all routes km/hectare, urban area per inhabitant and workplace, energy consumption in buses that have the highest correlation coefficients were selected for the model's construction.

The relationship between energy consumption per passenger-km in trolleybuses (Energ_Trol_n) and 10 predictor variables were analyzed in order to define the multiple regression model. Models have been fit containing all combinations of from 0 to 10 variables. The statistics tabulated include the mean squared error (s_ε^2), the adjusted R_a^2 and unadjusted R^2 values, and Mallows' *Cp* statistic. The *Cp* statistic is the one proposed by Mallows (1973) as a criterion for selecting a model. It is a measure of total squared error and defined as:

$$C_p = \frac{SSE_p}{s^2} - (N - 2p) \qquad (31),$$

Where *N* is the number of observations, *p* is the number of variables used for the model, s^2 is the mean squared error for the full model, and SSE_p is the sum-of-squares error for a model with *p* parameters including the intercept, if any.

C_p is a measure of the bias in a model, based on a comparison of the total mean squared error to the true error variance. Unbiased models have an expected value of

approximately *p*, where *p* is the number of coefficients in the fitted model (including the constant).

The output shows the results of fitting a multiple linear regression model to describe the relationship between Energ_Trol_n and 1 an independent variable. The equation of the fitted model is:

Energ_trol_n = 0.451 + 1.316*UA_work (32).

The R^2 statistic indicates that the model as fitted explains 61.6 % of the variability in Energ_trol_n. The R_a^2, which is more suitable for comparing models with different numbers of independent variables, is 59.04 %. The standard error of the estimate s_ε shows the standard deviation of the residuals to be 0.14. The mean absolute error ($MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Y_i - \hat{Y}_i\right|$) of 0.107 is the average value of the residuals.

Model describing influences of urban structure on energy consumption in buses

The relationship between energy consumption per passenger-km in buses (Energ_au_n) and 9 predictor variables were analyzed in order to define the multiple regression model. Models have been fit containing all combinations from 0 to 9 variables. The model was selected according to the same statistics as in the trolleybus case.

The output shows the results of fitting a multiple linear regression model to describe the relationship between Energ_au_n and 4 independent variables. The equation of the fitted model is as follows:

Energ_au_n = 0.219 – 49.668*AUT_GYV + 0.39*VISI_HA + 2.13*UA_inh – 0.0497*ST_AP_1000d (33).

Energy consumption of buses are influenced considerably by municipal bus route lengths per inhabitant, aggregated length of all routes per hectare, urban area per inhabitant, load of the bus stops per worker (indicating accessibility to bus stops) and these factors were selected to construct the final model.

The R^2 statistic indicates that the model as fitted explains 58.31 % of the variability in Energ_au_n. The R_a^2, which is more suitable for comparing models with different

numbers of independent variables is 50.73 %. The standard error of the estimate shows s_ε the standard deviation of the residuals to be 0.056. The mean absolute error (MAE) of 0.0427 is the average value of the residuals.

2.12 Discussion of the results

The correlation between energy use and urban structure is in accordance with theoretical considerations as well as previous empirical researches in Nordic cities (*r=0.762*, see Illustration 29) and all world cities together (*r=0.698*) [65].

Rough calculations based on a modal split (Vilnius) match the energy consumption in Nordic cities. Lower energy consumption could be explained by the comparatively higher share of public transport and the low number of car ownership per 1,000 inhabitants, and on the other hand – Vilnius's structure is scattered.

In empirical transportation energy studies, two different approaches were employed: an indirect method, where energy use is calculated from travel survey data, and a direct approach based on the actual fuel consumption within specific geographic areas. Indirect methods have an advantage when the units of analysis are individuals and households. However, indirect methods face some difficulties, e.g. enormous expenditures and time resources. Direct measures also could be questionable as fuel sale's data comprises of long-distance transport and stationary users. Hence, this study combines the best aspects of the following methods: comprehensive information from travel surveys and detailed information on fuel consumption derived from depots. Such information was attributed to each transportation district and analyzed in details, and is a new integrated approach.

This study does not cover all social and economical factors influencing mobility of the inhabitants (they could be defined indirectly by choice of residence), but study shows the importance of the urban structure factors. An investigation of 97 Swedish towns [98] has shown that if urban area increases from 400 to 600 square meters, annual average energy use for transport increases by approximately 12 per cent.

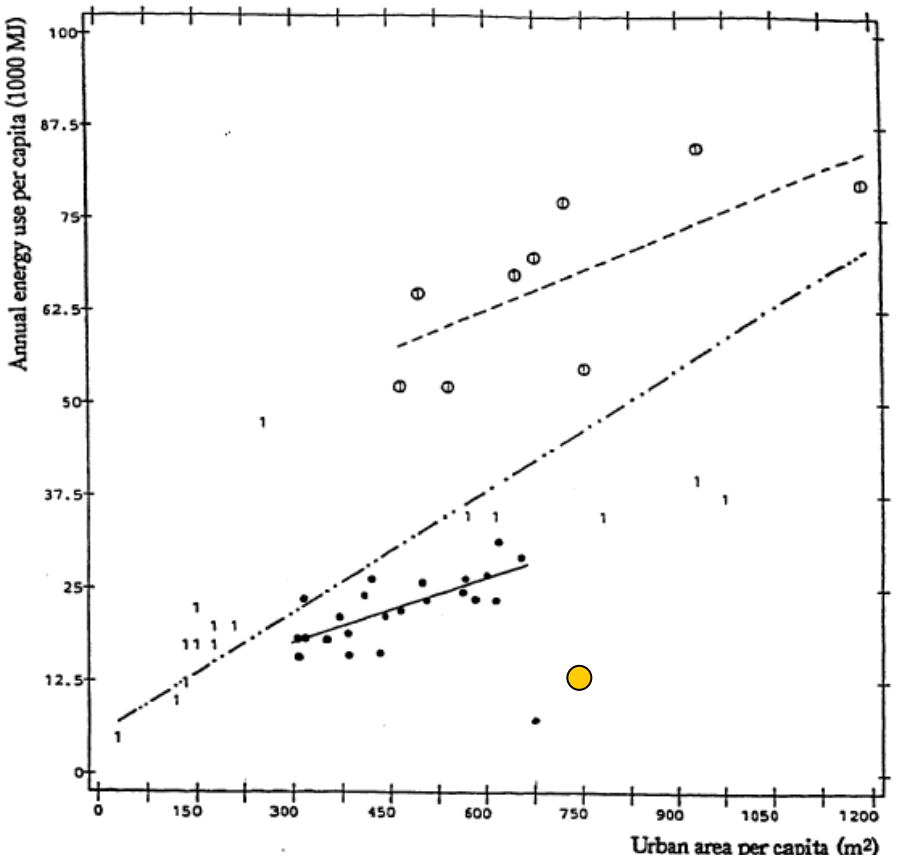


Illustration 29: Annual energy use per capita for transport (1000 MJ) in cities with differences in urban area (square meters) per inhabitant (•-22 Nordic cities, Ф- 9 US cities, 1- 15 Asian and European cities)[4]. [Sandberg, Roe, Ness]

Current study has shown that energy consumption in transportation districts if urban area per capita changes from 400 to 600 square meters will increase approximately by 50 % per passengers-km[5]. Theoretically, decrease of urban area from current 725 up to 450 (average in Nordic cities) square meters per capita will reduce fuel consumption in public transport per passenger-km by 61 % in Vilnius.

These results are hardly comparable with other countries as this part of study includes only the public transport system and only dense transportation districts were included in the analysis. Energy savings would be more considerable if the urban structure of

[4] Vilnius: urban area per capita – 725,4 m^2 and annual energy use per capita 13,2 MJ. Source: Counties of Lithuania, Economic and Social Development, 2003, Vilnius: Statistics Lithuania, 2004.

[5] Energ_au_n = 0.186977 + 0.645673*UA_inh, r=0.7469, p=0.006

Energ_trol_n = 0.453547 + 3.03386*UA_inh, r=0.6299, p=0.003

Vilnius would be improved. Densification is one of the main opportunities for further energy conservation in Vilnius's public transport, though social and environmental restrictions (e.g. protected territories, clashes of interests) may limit such a process.

Vilnius has a scattered structure and the urban area per capita varies from 53 to 28,000 square meters in different transportation districts. Therefore multiple linear models cover the benefits of densification from energy saving positions in such densification interval. Multiple linear models clearly show that the connection between different characteristics in the urban structure and the energy consumption are complex. Manipulation of urban structure factors such as density of residents and workplaces, integrated public transport and land use planning are often thought to have influence on energy consumption and environmental pollution. Moreover, densification in the neighborhood of current and planned transport corridors, provision of good public transport services will lead to lower energy consumption and pollution.

The European experience shows that tram or light rail vehicles are the least intrusive form of public transport in terms of compatibility with pedestrians, low noise and freedom from pollution [99]. Buses or trolleybuses can provide a lower cost alternative where such an infrastructure is lacking, but it is without a high quality of service as compared to light trains. The introduction of new bus routes and management are much cheaper than trolley bus routes because of the infrastructure needed for trolley buses. For regular bus routes only a particular width of asphalt street pavement and broadened places for stations are needed.

Differences between fuel consumption in bus and trolleybus are mostly explained by two factors. Trolleybuses are working in the central part of the city and the routes are located on the main transport corridors (i.e. denser building pattern) or streets while buses operate in suburbs and on the lower category streets. Bus transport of passengers to the main trolleybus network in the mornings as a larger part of the workplaces is located in the central part of the city and these buses carry them back to residences in the evening. Consequently, energy consumption in buses is explained by the factor "urban area per worker".

Another factor is the accessibility to the public transport's network, where trolleybuses are in a more favorable situation and trolleybus routes are located in more homogeneous transportation districts and consequently have strong influence on the energy

consumption. A denser network and stops interact with the pedestrian infrastructure and pedestrian's behavior in a better way. Absence of such a pattern responds to the construction of a multiple linear model for buses: higher density of bus network per inhabitant and the load of the bus stops per worker indicate that accessibility is an important factor and it defines the lower energy intensity in bus transport and from the strategic point of view pollution is eliminated from densely populated areas because electrical mode still dominates.

Hence, aggregated density of all routes per hectare defines the higher energy intensity in municipal bus transport. Route duplication especially when private buses skim the best passengers is very wasteful and municipality should revise its route planning policies. The problem could be solved by introduction of tendering system. In other words, a transport system based on competition, but regulated by the authorities and developed as a clear competitive alternative to private transport by car – paying high attention to the quality of the system, information level, route network and modern transport units.

2.13 Chapter II: Conclusions and recommendations

Lithuanian's Energy strategy forecasts rapid growth in transportation energy demand and raises ambitious targets to suppress such tendencies. There are only a few weighty instruments for the transport sector to deflect developments by more sustainable way. Political and economical instruments could provide a good opportunity for authorities to decrease energy dependency on exported oil and safeguard urban economies from fluctuations or skyrocket in fuel prices.

Current developments such as decreasing the number of public transport passengers and density of inhabitants, and the increasing number of cars in Vilnius has put pressure on the public transport system. Consequently, energy intensity and air pollution will increase if there will not be satisfactory actions taken to strengthen and improve the public transport system.

The following urban developmental *policies* can be recommended in order to help to reduce the number of trips, and to increase the share of the less polluting modes (bicycles, public transport) in modal split:

- Densification of Vilnius's urban structure and to avoid further urban sprawl, which is not favorable form the point of energy consumption and public transport supply. "Cavities" within urban structure are increasing energy consumption and

reasonable densification could increase energy saving effect according to constructed models,

- To ensure a sufficiently high density in new developmental areas so as to facilitate a good provision of local services and good public transport provisions. A gradual change in the urban structure may lead to changes in urban traveling, but this change is at best covered by very long-term changes. Long-term actions such as the implementation of new public transport means (e.g. tramway) are one of the options to controlling energy consumption and urban development. Concentrating urban development along transport corridors and around stations with a dense and mixed distribution of activities, so as to reduce the continuing urban sprawl and to provide higher accessibility of public transport;
- Energy consumption is more efficient in the central part of the city because of the more concentrated load of public transport network. Recent developments also show a decrease in the number of passengers in the central part of the city and a slight increase in the suburbs. This gives more potential to improving the energy intensity of districts that are served by buses. Integrated land-use and public transport planning measures such as placing new residential areas in places that are serviced by public transport or the encouragement of developers to support the supply of public transport would be an appropriate way to solve public transport problems;
- A balance between the residents and workplaces in the inner and central areas of the city would decrease energy consumption in the city as work trips will become shorter. Taxing limitations such as parking fees and tolls could promote idea of vehicle-free city centre.

It is possible to draw *scientific* conclusions from the performed analysis, though there is space for discussions as energy efficiency factors are prevailing in the research:

1. The hypothesis concerning the relationship between energy consumption in the public transport system and Vilnius's urban structure can be accepted and precautionary energy saving principle is applicable under the current technological, social and environmental conditions. Transportation is an element in pursuance of sustainable urban development and may be interrelated and rated identically to other principal issues in urban planning, such as housing, water and energy supply or waste disposal.

2. Although it is hard to evaluate sustainability, i.e. many interdependent and conflicting factors are involved, but statistical relations between energy consumption and urban structure factors and consequently multiple linear models describing interactions were prepared.

3. Bivarate correlations show the strongest relations between energy consumption in public transport means and an urban area per inhabitant or worker. Energy consumption in trolleybuses are strongly related with the distribution of workplaces (*r=0.7849*) and adjusted energy consumption in buses strongly correlate with urban area per inhabitant (*r=0.6299*). Vilnius trolleybuses work in more favorable spatial conditions compared to Vilnius buses. The study has shown that energy consumption in transportation districts if the urban area per capita changes from 400 to 600 square meters will increase approximately by 50% per passengers-km and vice versa. A decrease of the urban area from the current 725 to 450 square meters per capita in Vilnius (450 square meters of urban territory per capita is an average in Nordic cities) will reduce fuel consumption in public transport per passenger-km by 61 % according to the empirical model.

4. Multiple regression models have shown that Vilnius' buses deliver passengers to central areas that are mainly served by trolleybuses. Trolleybuses are more dependent on urban structure factors such as density of workplaces and prepared model explains 61.6% of the variability in trolleybus energy consumption. It is also clear, that good accessibility to the trolleybus network is the main reason why inhabitants use it more often than the bus network. Energy consumption in buses is related more to accessibility factors though it also influenced by urban structure factors (model as fitted explains 58.31% of the variability).

5. Models and relations could be employed to forecast energy consumption in Vilnius city when analyzing different scenarios of its urban development and the supply of the urban transport. However, private transport, which is related to city suburbs and under-populated areas is not covered here and will be explored in the next chapter.

3. Research of Influences of Vilnius Urban Structures on Energy Consumption in Private Transport[6]

Energy consumption in private transport is one of the main key issues influencing quality of life of the city. From 2004-2005 the influence of fuel consumption has been gaining increasingly higher importance, as petrol and diesel prices have skyrocketed and there is a heavy impact on other economy branches. Inflation and increased spending on energy affects social welfare, i.e. inhabitants allocate more money for transportation. Energy consumption in Lithuania's transport is still increasing and the current economical boost underpins the growth of the road transport sector despite the increasing fuel prices. With regard to the concept of sustainability, one has to search for the facilities to arrange local transport and land use as the bases of activities and life, with the intention of raising the quality of life and with regard to the ecological, economic, and social dimension including the intergenerational dimension [5,6,47,49,54].

Long term actions, such as land use planning, would be more perceptible in the long-term when energy prices will severely adjust to the current wasteful way of living. Private transport system should also be included into further land-use strategies to decrease energy consumption. Such an aim is complex and much research needs to be performed by applying empirical methods exclusively, and other than empirical approaches should be applied.

The major theoretical approaches are explaining two-way interaction of land-use and transport in metropolitan areas. Theoretical approaches include technical theories (urban mobility systems), economic theories (cities as markets) and social theories (society and urban space). The outcomes of these theories of land-use transport interaction are related to essential factors such as urban density, employment density, neighborhood design, location, city size, accessibility, travel cost and time. For example, the impact of high residential density in reducing average trip length is small (if costs are not

[6] Chapter is based on author's publications I, II, VI, VIII that are listed on page 148-149.

increasing), whereas a high density of work places is positively correlated with average trip length. Mixed land-use and attractive neighborhood facilities can be seen as a positive factor for reducing trip length.

Most studies in the field of land use and transport have taken into consideration only a few factors influencing travel behavior. Model simulations of hypothetical patterns of development dominated the first generation of studies, though they were associated with a number of assumptions and uncertainties [100]. Model simulations illustrate and synthesize existing knowledge about transportation consequences of alternative urban structures, but cannot be used to investigate whether the assumptions on which the model is based are fully correct.

Modeling a traffic and land-use phenomenon includes different tasks, e.g. problem formulation, development of database structures, gathering the basic data for the model, developing the model and modeling technique, tuning and validating of the selected modeling method, using the model itself, and the use, evaluation and dissemination of the modeling results (see Illustration 30). For the work of gathering input data, different databases and other information sources are very useful. The modeling techniques of the different phases of traffic modeling are developed either separately or all together.

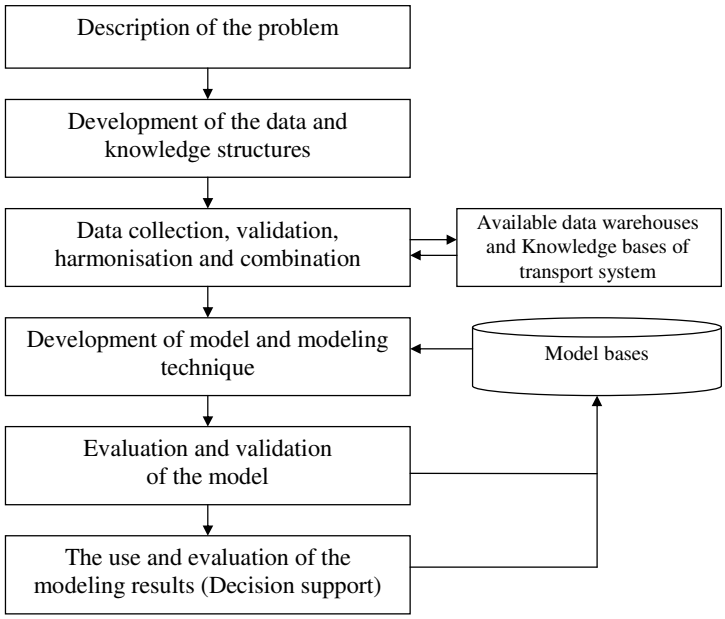


Illustration 30: The main components of Transport system modeling

Despite all this weaknesses, various models are very useful to predict key trends in the transport sector, e.g. influences of land-use changes to mobility or energy consumption. These issues are very important for the substantiation of transport infrastructure's development in Lithuanian urban areas [101, 102].

3.1 Objectives of transport modeling

Modeling concerns wide and small areas, and supports strategic level decision-making and long term planning. In this scope, future scenarios and other macro and micro level models are used. The construction of the model consists of four phases: determining the factors affecting the demand, trip generation and distribution, and determining the modal spit and the assignment. This procedure is used separately for passengers and freight modeling. New wide-scale models such as PTV vision, SIAS Paramics micro-simulation, and EMME/2 with small variations are also based on these planning phases [103-106].

Some varieties of the objectives and possibilities of traffic modeling are listed below [107]:

- To encourage new innovations by offering possibilities for the economical testing of new ideas,
- To support decision-makers in long-term investment and policy decisions concerning traffic, transportation, environmental and socio-economical aspects,
- To provide a tool for traffic planners,
- To participate in the traffic management actions by forming a general picture of the effects of different restrictions and control decisions,
- To find the best solutions to modal and route choices, from the economical or environmental point of view,
- To improve co-operation between transport modes and facilitate the interconnection and inter-operability of existing transport networks.

Urban transportation is associated with a spatial form that varies according to the modes being used within the city. In an age of motorization, an increasing number of cities are

developing a spatial structure that increases reliance on mechanized transportation, namely privately owned automobiles. Dispersion, or the urban sprawl, is taking place in many different types of cities, from dense, centralized European metropolises such as Madrid, Paris, and London, to rapidly industrializing metropolises such as Seoul, Shanghai, and Buenos Aires, and in those cities that are experiencing recent, fast and uncontrolled urban growth, such as Mumbai and Lagos.

Land consumption increases globally, especially in developing cities. One of the main objectives in land-use models is to safeguard the state of the environment, so that free space is ensured for development in the future generations. Modeling is a necessity to finding a balance between current development of transport systems, land use in the towns (or regions) and urban structures.

While all research of the possibilities has shortcomings, mathematical models are the only method to forecast still unknown situations and to determine the effect of a single factor while keeping all other factors fixed. Urban land-use transport models incorporate the most essential processes of spatial development including all types of land-uses.

3.2 Transport and Land-use models

Land use and transport interactions are very complex and such relations were analyzed from the early 19th century. Transport systems influence allocation of residential places and workplaces, and reverse effects – development of territories are overloading the transport system because new users come on the scene. Hence, short and long term forecasting should be based on consistent patterns.

Traditionally, most land-use models have modeled the interaction between the infrastructure system and land-use in an aggregate way, most often using some kind of aggregate accessibility measure. Travel models, on the other hand, most often take land-use as being fixed, and also calculate trip generation in either a crude way, or treat trip frequencies as fixed.

Both land-use and travel models often deal with accessibility to employment and work trips. Land-use/transportation interaction models draw from several modeling traditions. This is natural, since the field encompasses so many human activities in general. The

three most influential approaches or traditions have been urban economics, spatial interaction (gravity) models and discrete choice models [108].

From the beginning, these approaches have had different aims and starting-points. Travel pattern implicitly is related with the research of Isaac Newton, i.e. discovered law of gravity and was later employed to describe transport issues. The gravity model that scientists refer to modified the law of gravitation, and it takes into account the population size of two places and their distance. Since various land-use and activities attract people and places closer together, the gravity model incorporates these two features.

Gravity model in general describes probability to live in the zone [79]:

$$P_{ij} = P_i \frac{d_{ij} k_i N_j}{\sum d_{ij} k_i N_j} \quad (34),$$

Where

P_{ij} - correspondence between transport regions *i* and *j*

P_i - number of work places in region *i*

N_j - number of employable person in region j

k_i - gravitation coefficient

d_{ij} - probability of workers distribution within city (travel time or distance).

The theoretical analysis of forces determining the urban shape can be said to have started with Thunen (1826), who analyzed the relative location of land developers around a central market place. Carrey (1859) is one of the pioneers who applied gravity models to trip calculations. Later E. Lill (1891) made an attempt to describe the frequency of trips by railway transport. These observations have shown that the frequency of trips and distance of a trip are related by the hyperbolic law. Lill's observations were based on data collected in small German cities. Further research was allied to gravity law, e.g. A. Young (1920) and J. Reilly (1929) modified the coefficients of the gravity equation. William J. Reilly in 1931 expanded the gravity model into Reilly's law of retail gravitation to calculate the breaking point between two places where customers will be drawn to one or another in two competing commercial

centers. T. Fratar (1954) developed a method to calculate and predict transport flows. Transport flows can be calculated according to following simplified equation:

$$P_{ij}^{'} = P_{ij} G_i G_j \left(\frac{L_i + L_j}{2} \right) \quad (35),$$

Where

$P_{ij}^{'}$ - forecasted number of trips from district *i* to district *j* for the estimated year;

P_{ij} - correspondence between transport districts *i* and *j* (base year);

$G_i G_j$ - development factors for the transport districts *i* and *j;*

L_i, L_j - local factors depending on t_i;

t_i - number of destinations in transport district *i.*

Losch (1954), Wingo (1961) and Alonso (1964) tried to understand the functioning of a city from an analytical point of view. With as few and general assumptions as possible, their purpose was to describe the general, aggregate behavior of a city in terms of land prices, lot sizes, commuting patterns, and the location of citizens of different categories etc. This helped planners and scientists to achieve a better understanding of what planning could accomplish and what it could not, and what kinds of measures would improve the functioning of a city.

The second tradition, the spatial interaction models (gravity) of the Lowry type, began with a completely opposite approach. While urban economists paid much attention to the basic assumptions, developing models with great mathematical rigor, and regarding applications as less important, spatial interaction models had from the beginning the opposite intentions. The theoretical content was mostly negligible, mathematical rigor was not the point of issue, and applications were the only thing that mattered. This came from the need of practitioners to be able to make at least crude forecasts of trade patterns, traffic flows, and energy consumption etc. The origin of these models can be said to be Hansen (1959). Lowry in 1964 and Echenique in 1968 developed some of the earliest models.

Spatial interaction models were constructed during the 1970s and become useful tool to estimate and predict as such models stood on a solid theoretical ground. These included

the works of Wilson (1974), Putman (1973, 1975), Coelho and Williams (1977), Lundqvist (1975) to mention a few. Many of these models are still operational and under continuing development [109]. Modeling results have shown mixed land use, concentration of commercial developments in central area of the city and limitations of developments in suburban areas that will lead to 7-15 percent fuel economy. The conclusion that poly-nucleated cities consume less transportation energy was also supported if the impact of transit is neglected.

The third tradition is the theory of discrete choice that is based on the random utility theory. While this theory dates back to work in mathematical psychology in the 1950s (Luce 1959), it was first introduced in the field of travel demand by McFadden (1974) and Domencich and McFadden (1975), as well as Cochrane (1975). In retrospect, it is hard to understand why it took so long to realize that the logit and entropy approaches were identical for all practical purposes (Anas, 1983; Mattsson, 1984). Today, it does not make much sense to distinguish between "logit models" and "gravity models", the only difference being the formulation of the assumptions [108].

The combination of the spatial interaction model with the "logit" transport modeling tradition has created a variety of powerful models. Some are very comprehensive, modeling as many aspects as possible of a region's or urban development. Examples are MEPLAN (Echenique et al., 1988), TRANUS (de la Barra, 1989) and the Dortmund model by Wegener (1985, 1986), and transport models such as EMME/2 (1984, INRO), Paramics micro-simulation (SIAS transport planners, 2004), PTV vision (PTV traffic mobility logistics, 2004) to mention just a few [103-106].

A number of integrated land-use transport systems are in use today. There are significant variations among the models that concern the overall structure, comprehensiveness, and theoretical foundations, modeling techniques, dynamics, data requirements and model calibration. Despite the achievements in developing these models further, there remain some challenges to be met. The transport sub-models used in current land-use transport models do not apply to state-of-the-art activities based modeling techniques, but the traditional four-step travel demand model sequence that is inadequate for modeling behavioral responses to many currently applied travel demand management policies [110]. The most promising technique for activity-based transport

modeling is micro-simulation, which makes it possible to reproduce the complex spatial behavior of individuals on a one-to-one basis.

In addition, the spatial resolution of present models is still too coarse to model neighborhood scale policies and effects. In the future, the integration of environmental sub-models for air quality, energy consumption, traffic noise, land-take and habitats are likely to play a prominent role. Issues of spatial equity and socio-economic distributions are expected to gain similar importance in model building.

Australian researchers are modeling the environmental impact at all stages of its transport network planning [111,112]. Such models are in operation and very valuable for good decision-making and public consultations, and indicate the benefits of increased densities. Japanese researchers are also searching for urban structures with minimal transportation energy consumption. The optimal structures calculated numerically for Tokyo illustrate that business areas are located around the center of the city while residential areas are in the suburbs. High-density land use development and encouraging job-residence proximity are reducing household's energy consumption in Japan [113,114].

Geographic information systems will become the mainstream data organization system of urban models in near future. Spatial dis-aggregation of land use and transport network data in raster GIS will permit the linkage between land-use transport models and dispersion (emission) air quality and noise propagation models. Multiple representation of spatial data in raster and vector GIS will combine the advantages of spatial dis-aggregation (raster) and efficient network algorithms (vector) [115].

Such models are based on simplifications and may not cover all variables (e.g. social behavior, fuel prices and etc.) or casual relations between covered variables in such models. While comprehensiveness may be desirable or necessary for many analyses, these models are seldom easy or even possible to overview or evaluate for someone that is not deeply involved in the model's construction. The models in the example are operational in the sense that they have been applied to real cities, but only few models are on their way to becoming standard software for a wider market.

3.3 Transport research and results in Lithuania

Lithuanian research performed in the field of transport modeling was related to the former USSR transport planning system. Department of Urban Engineering at current Vilnius Gediminas Technical University was one of the leading institutions in the transport field. V. Sestokas (1973) was a pioneer in the field of Lithuanian transport planning and urban development. Application of G. Sheleikovsky research to Lithuanian cities was performed and the law of normal distribution of workers matched the local conditions:

$$P_{ij} = F(L) \quad (36),$$

L – distance from workplace.

After further research it was noticed that location is better defined by the duration of trip:

$$P_{ij} = F(T_{ij}) \quad (37).$$

According to prepared methodology and tables (scale) the system had the following steps: city is divided in to transport districts, the number of workplaces is calculated in each of districts, and later according to Sheleikovsky's scale, workers are distributed by the time intervals and in order to equilibrate cohesion calculations should be repeated.

A. Jakshin made an offer to handle the problem not as an absolute value, but as a probability to living in the zone and the gravitational as the model shows (see formula 30). Attention is given to coefficients k_i and d_{ij}. The coefficient d_{ij} can be expressed as the function:

$$d_{ij} = f(T_{ij}) \quad (38).$$

The exponential function were offered by Jakshin :

$$d_{ij} = \frac{1}{T_{ij}^n} \quad (39).$$

A number of researchers in the Department of Urban Engineering calculated indexes for Lithuanian cities, but such mathematical expressions had weaknesses and search for other mathematical models continued.

The parameters in formulas are usually defined by inverse methods, and obtained results are inserted into formulas and approximated. In the gravitation model the results of research are calculated according the formula:

$$d_{ij} = \frac{P_{ij} N_j}{P_i} \quad (40),$$

The index n could vary in broad intervals $0.7<n<4.0$, and according to research parameters for the different journeys and zones vary and can be found in the tables. The exponential function has imperfection: in the zone of 0, the value of probability coefficient approximates infinity. Therefore other models were under consideration:

$$d_{ij} = c_0 + c_1 T_{ij} + c_2 T_{ij}^2 \ + ... + c_n T_{ij}^n \quad (41).$$

Values of parameters in the formula are calculated for Lithuanian towns. Other Lithuanian models made an attempt at introducing probabilistic elements, thus modeling the inherent uncertainty of choices made. One such attempt is due to Warner (1951), who elaborated a model by allowing to build a probability curve *P(z)*, which gives the probability for an individual to select a mode of transport *A* given the value of *z*. This introduces a notion of variability or non-rationality of individual's behavior.

P. Juskevicius (1973, 1995, 2004) analyzed the development of transport system in Lithuanian towns and prepared a number of studies. A number of such stochastic models were developed within framework of these studies. These models covered only mobility analysis and did not consistently analyze relations between land-use and energy consumption in transport. Moreover, sustainability issues were not objects of these studies and only recent works includes the transport sector as one of the factors [21,50-53,96-97,116].

The model should have two major analytical parts covering transport flow simulation and an estimation of fuel consumption in vehicles. Further research will be based on EMME/2 modeling software as it is widely accepted and verified, covers all classical modeling steps and not so costly. Detailed fuel consumption calculated in the simulation where factors will be urban structure performance parameters such as density, residences, attraction objects, public transport, and infrastructure and modal split. Where not available, consumption rates can be estimated on the bases of the vehicle's characteristics such as age, mileage and maintenance information.

3.4 Overview of EMME/2 software

EMME/2 is a state-of-the-art system for planning the transportation of people on multimodal networks. The acronym EMME/2 is derived from "Equilibre Multimodal, Multimodal Equilibrium" which refers, in French and English, to the theory of the network's equilibrium, and which underlines the multimodal travel forecasting models that may be implemented using EMME/2.

EMME/2 is an interactive-graphic multimodal urban transportation planning system. It offers the planner a complete and comprehensive set of tools for demand modeling, multimodal network modeling and analysis, and for the implementation of evaluation procedures. EMME/2 provides a general framework, supported by a consistent user interface, for implementing a wide variety of travel demand forecasting procedures. These range from the simple implementation of a four-step model to more refined demand models and their integration into multimodal equilibration procedures, via the use of direct demand functions with road and transit assignments. Also, various impact analyses and evaluation procedures are easily achieved. Software offers the planner a wide variety of tools for a direct comparison of future scenarios, which may reflect changes in the road and transit networks or changes in the socio-economic characteristics of the urban area that is studied.

EMME/2 is a comprehensive package consisting of 50 modules that are subdivided into the following groups: *Utilities*, *Network Editor*, *Matrix Editor*, *Function Editor*, *Assignment Procedures* and *Results*. EMME/2 features: matrix manipulation tools, which allow for the implementation of a wide variety of travel demand forecasting models; assignment procedures, based on sound theories; interactive calculators, which allow for the implementation of an evaluation and impact analysis methods; a powerful macro language, for automating repetitive procedures; comprehensive graphic display capabilities; and interactive/graphic network editors.

Modeling of transportation systems is conceptually divided into two parts: the "supply side" and the "demand side". The "supply side" consists of the available transportation's infrastructure. The "demand side" consists of models that determine the demand for travel based on the socio-economic characteristics of the urban area and the origin to destination service levels. Equilibration procedures determine the equilibrium

between the “demand side” and the performance of the “supply side” and predict the flow of vehicles and travelers on the transportation facilities.

An essential aspect of any urban transportation-planning endeavor is the construction of a data bank that will support the quantitative analysis and evaluation of the contemplated changes. The data bank is a representation of the transportation infrastructure, where the economic activities and the socio-economic characteristics of the population in the urban area studied. The data that corresponds to this image of an urban area is represented in the EMME/2 data bank as network scenarios, matrices and functions. Illustration 31 shows the EMME/2 data bank in diagrammatic form.

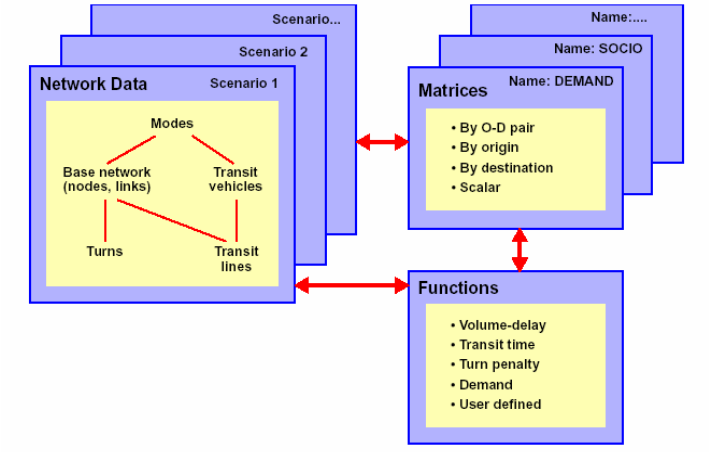


Illustration 31: Transport databank in EMME/2

To obtain energy consumption data, one has to undertake the following steps: build the base year origin-destination matrix, predict generations and attractions, obtain a predicted origin-destination matrix, distribute them on the network according to equilibrium models and build the energy consumption map.

The transportation theory has given rise to numerous studies encompassing various approaches, but in general, a common framework has emerged, which is often referred to as the "four steps" or "classical" method of travel prediction. This method is based on the hypothesis that any user, when it comes to travel, will make a series of successive independent choices: to travel or not, choice of destination, choice of time period of travel, and choice of means (mode) of transportation and choice of path followed.

The EMME/2 software package allows for making calculations for *trip distributions* and *route assignment* classes of models.

3.5 General principles and algorithms in EMME/2 transportation planning software

Trip distribution model [105]. In most cities, demand for trips usually increases with the population and the rise of living standards. It is then of vital importance to quantify this global mobility, since it will drive the needed global capacity of the network, and hence the necessary investments to be made. Trip generation models rely on both census studies and transportation surveys. In such surveys, users are asked a series of questions regarding their income, their home and workplace, the number and types of trips they make per day, and their mode of transportation, their alternatives if any, and so on. This allows one to calculate global mobility, which is usually expressed by a number of trips made per household and per day for all purposes (trip to work, shopping, leisure, etc).

Global mobility is usually divided into two elements:

1. A nearly fixed component denoted "alternate migrations", close to 2, which is the number of trips made per day to and from workplace.
2. A variable component, denoted "other trips", which is related to the city's structure, behavior of individuals, and living standards (income, availability of motor vehicles, spare time) that drive shopping, leisure, or even school trips (choice of schools farther from home).

Once all these elements are made available, one can divide the area under study into zones, and identify the number of different kinds of trips made from one zone to another. This leads to building a base Origin-Destination matrix. The prediction of future demand can be achieved in several ways see chapter 2.7 and 3.2 for more details):

- Either actual mobility is adjusted by a factor corresponding to population growth on the one hand, and by a factor related to predicted evolution of living standards;
- Or a comparison is made with other cities where mobility is higher to determine an average mobility on the time horizon considered.

With a base O-D matrix (illustration 32), predicted trip generations and attractions per zone, one can now obtain the predicted O-D matrix. This is done through trip distribution models.

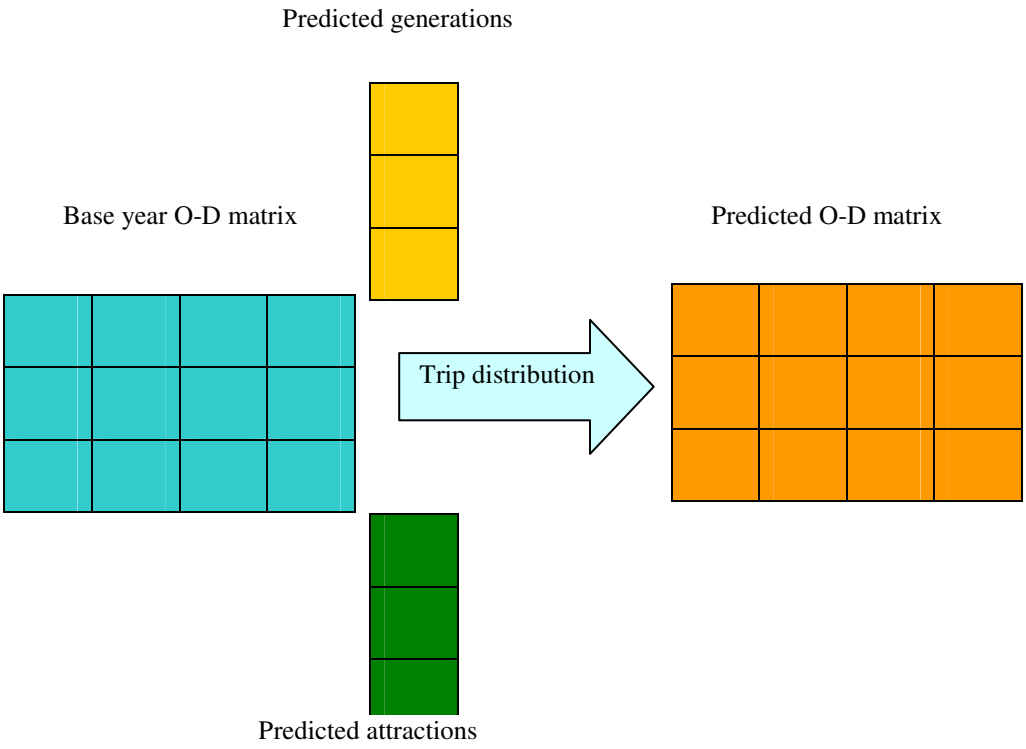


Illustration 32: Construction of O-D matrix

The most general assignment model that may be implemented by using EMME/2 is an equilibrium auto assignment that incorporates direct demand functions, i.e. demand functions that accomplish trip generation/attraction, trip distribution and mode choice simultaneously and a wide variety of demand functions may be integrated into such a procedure (see illustration 33).

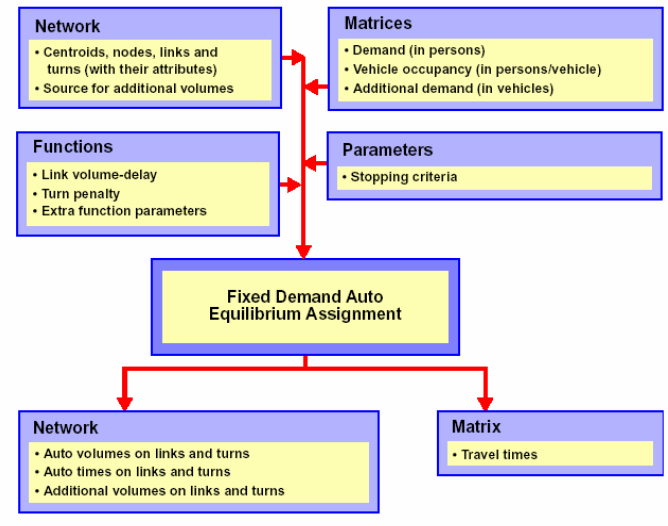


Illustration 33: Input and output of the fixed demand, single class auto assignment

Trip distribution models, that use two-dimensional matrix balancing, take as their input a matrix c_{pq}, an origin matrix O_p (the trip productions) and a destination matrix D_q (the attractions), in order to compute an origin-destination matrix g_{pq} (the balanced matrix) by finding origin balancing coefficients α_p and destination balancing coefficient β_q which satisfy:

$$g_{pq} = \alpha_p \times \beta_q \times c_{pq} \quad \text{for each O-D pair } (p,q) \quad (42)$$

$$\sum_q g_{pq} = O_p \quad \text{for each origin } p \quad (43)$$

$$\sum_p g_{pq} = D_q \quad \text{for each destination } q \quad (44)$$

$$g_{pq} \geq 0 \quad \text{for each O-D pair } (p,q) \quad (45).$$

It is also assumed that:

$$\sum_p O_p = \sum_q O_q \quad (46).$$

The problem consists of finding a proper distribution of flows that satisfies the following conditions:

- Every flow on a given origin-destination pair is proportional to the term $c_{pq;}$

- For each origin, the sum of trips to destinations equals the trips production of this origin;

- For each destination, the sum of trips "received" equals the trips attraction of this destination.

The solution algorithm, which is usually referred to as the “balancing method”, determines α_p, β_q and c_{pq}. Below is stated its implementation in EMME/2:

Initialization:

$l=0$ (iteration counter)

$\alpha_p^0 = 1$ for each p; $\beta_p^0 = 1$ for each q.

1. Balancing rows

$$\alpha_p^{l+1} = \frac{O_p}{\sum_q \beta_q^l \times c_{pq}} \text{ for each } p \quad (47).$$

2. Balancing columns

$$\beta_q^{l+1} = \frac{D_q}{\sum_p \alpha_p^{l+1} \times c_{pq}} \text{ for each } q \quad (48).$$

3. Stopping test

$$if_max\left(max_p \frac{\alpha_p^{l+1} - \alpha_p^l}{\alpha_p^{l+1}}, max_q \frac{\beta_q^{l+1} - \beta_q^l}{\beta_q^{l+1}} \right) \leq \varepsilon \quad (49),$$

or if $l + 1 = l_{max}$, then stop.

Otherwise $l = l + 1$ and return to step 1.

Two criteria are used in the stopping test:

1. The maximum relative error on origin and destination sums that in theory, should decrease towards 0. In practice, it is compared to the parameter ε, which takes a small but non-zero value. The maximum error is computed as one of its equivalent form:

$$\frac{\alpha_p^{l+1} - \alpha_p^l}{\alpha_p^{l+1}} = 1 - \frac{\alpha_p^l}{\alpha_p^{l+1}} = 1 - \frac{\alpha_p^l \times \sum_q \beta_q^l \times c_{pq}}{O_p} = \frac{O_p - \sum_q g_{pq}^l}{O_p} \quad (50).$$

2. The maximum number of balancing iterations to be performed, l_{max}. The algorithm terminates when one of these two criteria is satisfied. The balanced matrix is then given by $g_{pq} = \alpha_p^{l+1} \times \beta_q^{l+1} \times c_{pq}$, for each (p,q).

This method dates back to 1937 when Kruithof used it for the prediction of telephone traffic in Holland. Fratar (1954) and Furness (1965) applied it in the context of vehicular trip distribution and it is often called the Furness or Fratar method.

The Table 9 below gives examples of the type of trip distribution models that may be implemented by using only two-dimensional balancing. For each of these models, the production and attraction vectors correspond to predicted productions and attractions; and the resulting balanced matrix is a predicted O-D matrix. In this table u_{pq}, which are the travel times (sometimes called impedances) from origins *p* to destinations *q*.

Table 9:Most common types of trip distribution models

Model Type	**Matrix to balance**
Growth (Fratar model)	Base year O-D matrix
Entropy model (Wilson 1967, Evans 1970, 1971, 1973)	$e^{-\theta u_{pq}}$
General Gravity	Deterrence function $f(u_{pq})$

For each of these models, the origin matrix O_p and the destination matrix D_q correspond to predicted productions and attractions. The resulting balanced matrix is then a predicted Origin-Destination matrix.

Route assignment model

Auto assignment models are based on the assumption that each user will choose the path that he/she perceives as the best; if a shorter route than the one he/she is currently using exists, then he/she will select it. This will produce flows satisfying Wardrop's (1952) user optimal principle that is at equilibrium, and no user can improve his/her travel time by changing the route. All used paths between origin and destination are of equal time.

The solution to the equilibrium traffic assignment problem is equivalent to solving a problem where the area under the volume-delay curves is minimized. This can be seen intuitively from the little example shown in Illustration 34.

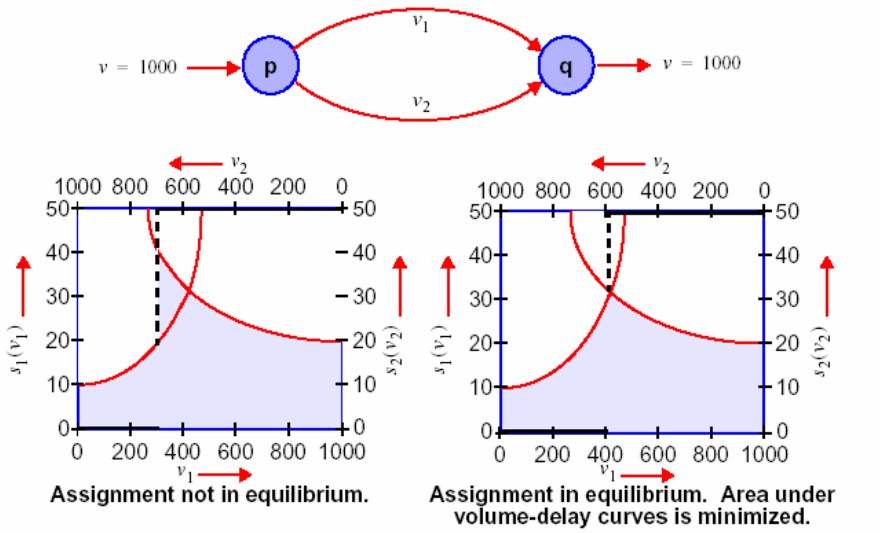


Illustration 34: Equilibrium assignment problem

The problem is to assign to each arc a flow v_1 and v_2, with costs $s_1(v_1)$ and $s_2(v_2)$, in such a way as to minimize the total cost and that cost is the same on each arc, i.e.

$$s_1(v_1) = s_2(v_2) \quad (51).$$

The solution to this problem is equivalent to solving a problem where the area under the "cost " functions is to be minimized. Let us consider a simple example to illustrate the solving procedure: total demand is 1000 trips from *p* to *q*. The problem is to assign trips to links in order to minimize the total travel time and that the travel time on each link is the same (Illustration 35).

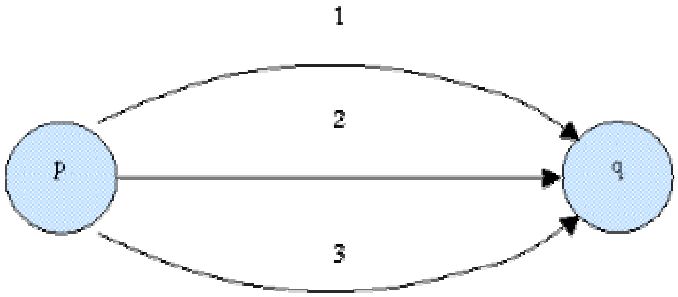


Illustration 35: Sample problem

The travel time functions for each link are given by:

$$s_1(v_1) = 10\{1+0.15(v_1/200)4\}$$

$$s_2(v_2) = 20\{1+0.15(v_2/400)4\}$$

$$s_3(v_3) = 25\{1+0.15(v_3/300)4\}$$

The problem can be formulated as:

$$Min \sum_i s_i(v_i) \quad (52)$$

s.t.

$$\sum_i v_i = 1000$$

$$s_i(v_i) = s_j(v_j) \text{ for each i-j pair} \quad (53)$$

$$v_i \geq 0 .$$

There are more auto assignment types: the incremental method, the capacity restrain method, the successive average method. Fixed demand models minimize the total volume-delay function, and variable demand models incorporate demand functions (instead of fixed demand matrix). The latter allows one to incorporate the modal split as well.

3.6 Vilnius Integrated Development Assessment System (VIDAS)

This project was carried out in cooperation with the Municipal Economy Department of City of Vilnius and Inregia AB. The Department of Urban Engineering was also involved in the development of the system. As a main result of the project, a computer based modeling system VIDAS for transportation analysis was created (2001). The Vilnius Municipality, SIDA (The Swedish International development Agency), and the Stockholm County Council financed the project.

The system was created on the EMME/2 modeling software basis and is a tool for strategic and transportation planning in the Vilnius region. 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 modeling 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 Illustration 21). The road system and public transport system were also described in the model.

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 as well as parts of Vilnius District and Traku district that generate traffic to the city (see Appendix 2). The used zone system consists of 240 smaller zones, of these 208 zones are in Vilnius, 15 zones in the Vilnius District, 5

zones in the Traku District, and 12 dummy zones (for representation of long distance traffic).

The VIDAS model uses a code of the real road network that contains important streets and roads to describe the main traffic flows. Streets that are only used for local traffic within a zone were not included in the code. The road network in the VIDAS model is based on the GIS map of Vilnius (2001), but major changes were performed during last 4 years on this map. The network development was updated for making further calculations of energy savings. The necessary characteristics of the road links were coded and inputted into database manually. Volume delay functions (VDF) were used to calculate travel time for the vehicles. VDF represents the correlation between traffic flow and travel time on each link. The time it takes to travel a certain distance on a link increases with the number of vehicles on the link. When the flow is greater than capacity, the link is congested and the travel time increases rapidly. Apart from traffic flow, the travel time given by the volume's delay function depends on the length of the link, the number of lanes and the presence of a traffic light at the end of the link. Different VDF were used for different road links because the speed limits and disturbance levels vary between the links.

3.7 Statistical information and Databases in VIDAS

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 1999). The population of each zone was calculated from a register of voters and an address table. There is no socio-economic data about the population by zones in this model. Information about the number of employees in each zone was obtained from SODRA (The Social Security) and additional information was collected by phone.

Traffic volumes at peak hour were estimated to calibrate the model. The traffic measures were performed in 1999 June at 210 locations in Vilnius. A probe car method was used to measure travel time and the probe car went four times along two routes in the city during the morning peak hour, and each route in two directions. Consequently, a delay was introduced to reflect delays at intersections with traffic lights.

Two databases were created (VIDAS):

1. The statistical database containing information about population, employment and travel data of Vilnius;

2. The transportation database containing data about the transportation system and traffic flows.

Data related to zones are stored in the EMME/2 databank as matrices and ensembles (zone groupings). The matrices permanently stored in the databank contain the following data for the base year:

- Population and employment by zones;
- Number of trips by car and by truck between the zones;
- Travel time by car between zones;
- Number of registered cars per resident;
- Number of registered trucks per employee;
- Truck auto equivalent.

Functions stored in the EMME/2 databank describe relations between various attributes belonging to links, turns and public transport lines. The VIDAS model uses functions for making calculation of travel times for cars, trucks and public transport vehicles.

3.8 Structure of the model

The VIDAS model calculates the car and truck traffic for the morning peak period, i.e. between 7.30-8.30 am. Model was corrected and verification of corrected version has shown very good results *(R^2=0.9, N=874)*. A trip means a movement with specific purpose from one geographical location to another. If a journey consists of different legs, then each leg is a trip. For example, if a person leaves his/her child at a kindergarten on his/her way to work, two trips are performed: one from home to kindergarten, another from kindergarten to work. On the other hand, a transfer between different public transport lines does not mean an end or a start of a trip.

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, excluding regular buses and trolleybuses.

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

The VIDAS model includes the following steps:

- Trip Generation;
- Trip Distribution;
- Auto Assignment;
- Transit Assignment;
- Emission 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. In the Transit Assignment step, 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, emission of pollutants from traffic sources is calculated for the whole network. The different steps and data flows in the model are shown in the Illustration 36.

As was mentioned, it is of significant importance to find out the average fuel consumption in the case of over-saturated transport flows, i.e. the flows on street sections where the average driving speed is 14-17 km/h, and which pass an intersection only during the second or the third cycle. To that end, specific models of other towns were used; but specific local traffic conditions – such as discipline of traffic participants and drivers, sticking to traffic rules, state of street pavement, operation schedules of traffic-lights at intersections, inter-coordination of operation of individual traffic-lights – should be also taken into consideration. Therefore, a specific energy consumption model also should be created for Vilnius' conditions.

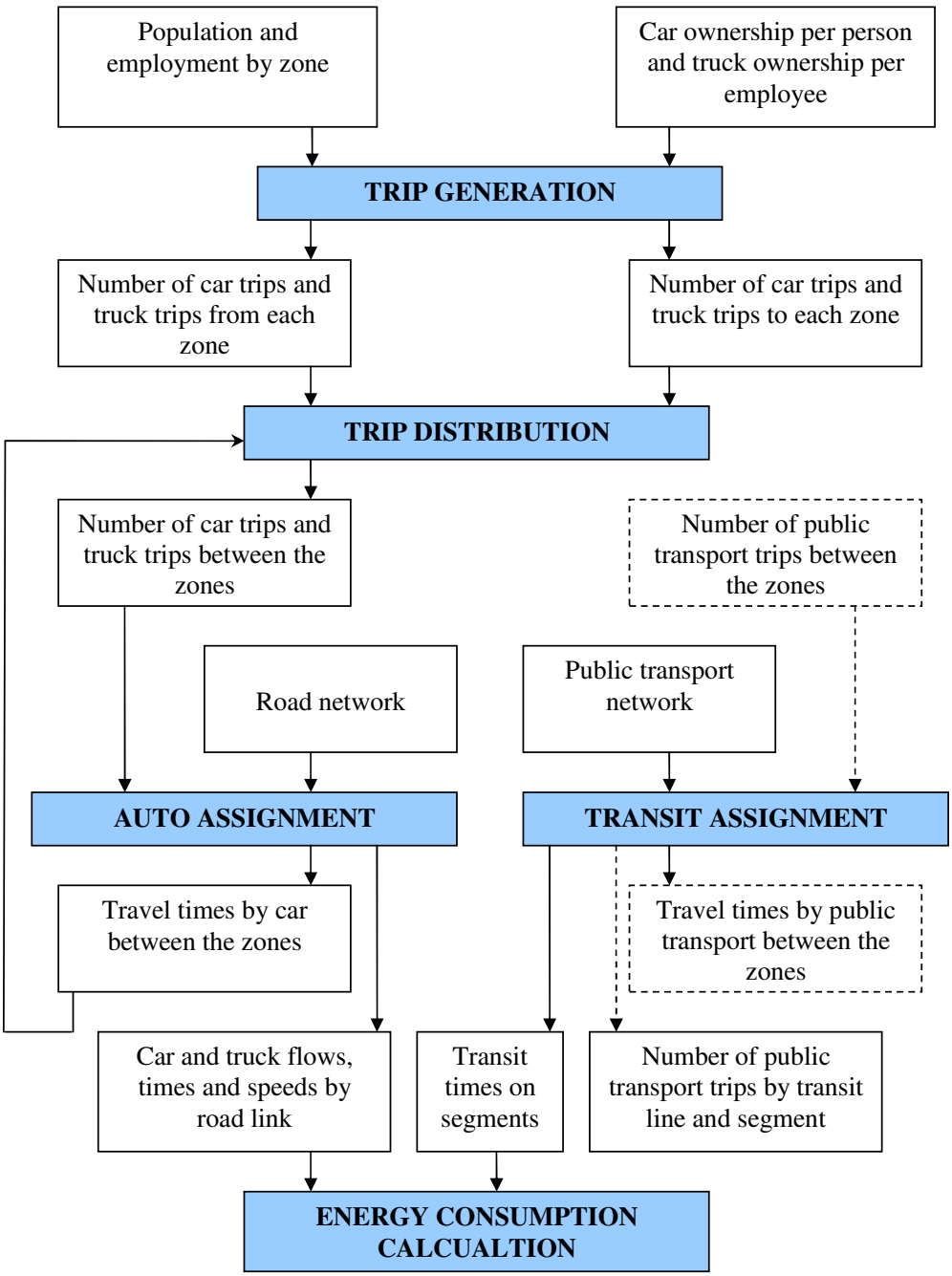


Illustration 36: Transport modeling steps

The VIDAS Model is an incremental model and means that the transport situation for a future scenario is calculated as a function of how that scenario differs from the base year situation regarding the following data:

• Car ownership;

• Truck ownership;

• Population;

• Workplaces;

• Travel times for cars.

The total number of car trips for a forecast scenario is calculated as a function of relative changes in the total population and of the number of cars per capita, and is compared to the base year situation (Trip generation). In a similar way, the total number of truck trips is calculated as a function of relative changes in total number of workplaces and in the number of trucks per workplace.

In the Trip Distribution Step, the car and truck trip matrices for the forecast year are calculated. The trip matrix contains the number of trips between each combination of origin and destination zones. The trip matrices are calculated in different ways depending on whether it is a short-term or long-term analysis.

For a short-term analysis, the car and truck trip matrices for the forecast year are obtained by balancing the corresponding matrices for the base year against trip productions and trip attractions calculated in the Trip Generation Step. This means that rows and columns of the matrices are multiplied by appropriate coefficients to satisfy both the production totals at origins and the attraction totals at destinations. The new trip pattern is calculated by using the two-dimensional matrix balancing procedure in EMME/2.

The assumption in the Short Term Trip Distribution Model is that changes of the travel times in the forecast scenario compared to the base year do not influence a traveler's choice of trip origin and destination.

For a long-term analysis, the car trip pattern is further adjusted to reflect the/altered travel conditions. The model redistributes the car trips between the origin and destinations zones according to changes in travel times between the forecast scenario and the base year situation. Under equal but other circumstances (trip production and attraction), car trips for an origin/destination combinations with reduced travel time will increase more than for a combination with unchanged travel time. The trip distribution

model for the long forecast of car trip demand is a logit model in its incremental form as applied to the trip pattern resulting from the short term forecast [117]:

$$T_{ij} = O_i \frac{exp(-\gamma c_{ij} + w_j)}{\sum_j exp(-\gamma c_{ij} + w_j)} \quad (54),$$

Where

T_{ij} is the number of trips from zone *i* to zone *j*;

O_i is the total number of trips from zone *i;*

c_{ij} is the generalized travel cost from zone *i* to zone *j*;

w_j is destination specific attraction grade;

γ is the cost sensitivity.

Such model uses differences between travel costs in the forecast year and the base year. The resulting matrix is balanced to satisfy the production and attraction totals.

To specify the model, the cost function must be determined and the cost sensitivity parameter must be estimated. The values of destination specific attraction grades are not important for the application of model.

Theoretically, the generalized cost should be an increasing function of travel time and monetary cost. The latter is supposed to be proportional to the travel distance. Data used for the estimation included the original (non smoothed) travel survey matrix and EMME/2 calculated travel times and travel distances. Finally, the generalized cost in the model's specification was replaced by the travel time. The parameter γ in this case was estimated to be -0.050 with the standard error 0.005 [117].

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. The behavior 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. When calculating the travel time, the number

of users is assumed as the number of cars plus the trebled number of trucks (due to the congestion effects).This result in flows that satisfy Wardrop's (1952) user optimal principle: No user can improve his/her travel time by changing to another route. The consequence is that, between each origin/destination pair, only the routes that have minimal travel time are used. In the VIDAS 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.

In the Transit Assignment Step, the average travel times between zones by public transport and transit times for each line and link are calculated. At the same time, the public transport demand matrix is assigned to the transit line network resulting in transit volumes (number of passengers on each transit line and each link of the network) and the number of boardings at each node. VIDAS model does not calculate the transit demand matrix and it is not possible to obtain correct transit volumes and number of boardings.

3.9 Construction of energy consumption model for specific Vilnius conditions

Present day challenges such as increasing car ownership and fuel consumption should be solved by adequate decision-making. For this reason, cost benefit analysis of various transport projects and/or alternatives must be performed. Fuel consumption is one of the key factors when evaluating variants of individual transport organization projects with economic and environmental regard [102]. Moreover, such models can be employed when evaluating the behavior of whole urban transportation system, i.e. modeling all interactions on network with EMME/2.

Recently (in 2004), the influence of fuel consumption has been gaining increasingly higher importance, as petrol and diesel prices skyrocket and have great impact on other economical branches in Lithuania. According to the results of studies performed at the Department of Urban Engineering of VGTU, non-linear simulation models of fuel consumption have been developed by taking into consideration the over-saturation of transport flows at street sections and intersections.

To evaluate the average energy consumption of car transport, a standard indicator – fuel consumption in liters per 100 km of the covered distance (l/100 km.) – is used.

Manufacturers provide standard fuel consumption for each specific car (model) in technical specification tables of a car.

The fuel consumption on a particular street segment is influenced by many factors: e.g. traffic control, state of the street pavement, construction and technical state of the car, climate conditions, driving behavior and legislation (taxation), flow saturation degree. Most of these factors could be controlled, and a solid black line shows direct influences and a dashed blue line shows the indirect influences on fuel consumption (see Illustration 37).

Such a complexity of factors leads to the unwanted effects and sometimes these effects are synergetic. The Vilnius study has shown that the average speed of the car at intersections is 14-17 km/h and the length of the transport line is longer than 1 km [118]. Consequently drivers are able to pass an intersection only after 2nd or 3rd control cycle and such delays increase the number of offenders and car accidents.

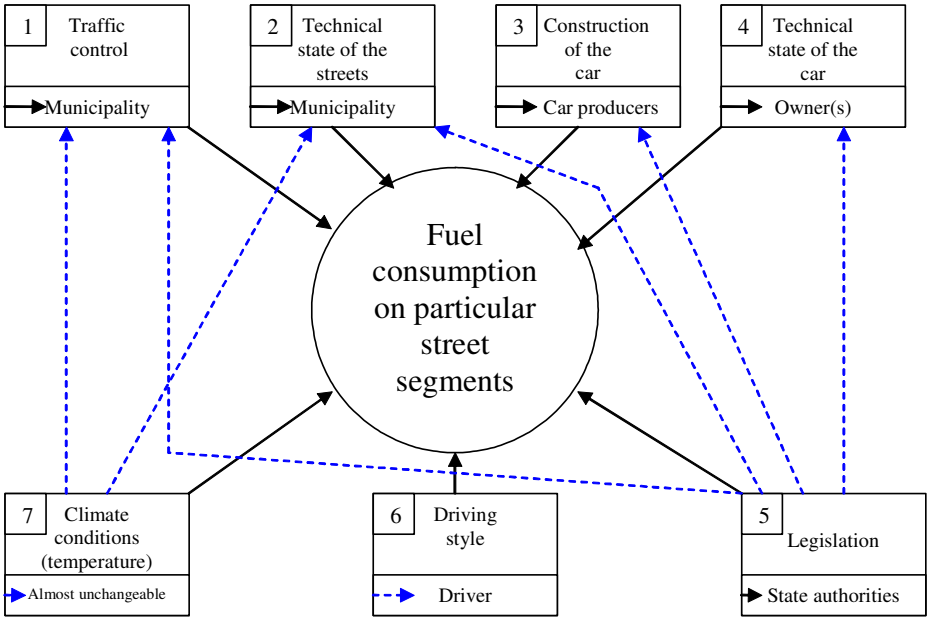


Illustration 37: Factors influencing energy consumption at particular street segments

Extra fuel consumption, which in individual cases may reach 24-38 % of the standard fuel consumption, are substantially influenced by transport flow over-saturation at intersections with traffic-lights also by the fact that all traffic participants (both, drivers and pedestrians) observe traffic rules properly [119-121].

It is important to find out the average fuel consumption in the case of over-saturated transport flows, i.e. the flows at street sections where the average driving speed is 14-17 km/h, and which pass an intersection only during the second or the third cycle. Based on the results of the transport time loss and fuel consumption measurement analysis, a simulation model should be developed, which would take into consideration the extra fuel consumption under the prevailing conditions in Lithuanian towns.

Therefore, in order to estimate the energy consumption of car transport under conditions that are specific to Lithuanian towns, the Department of Urban Engineering of VGTU performed a study of transport flows at intersections and analyzed transport time losses under different degrees of transport flow over-saturation at signalized intersections. Three main aspects were investigated:

1. Traffic flows at critical intersections (16 intersections were investigated);

2. Transport time losses under different degrees of transport flow over-saturation (test driving);

3. Simultaneously fuel consumption measurements ("beaker principle").

The simplest case is a car acceleration and deceleration at signalized intersection that is not over-saturated. The driver approaches the intersection, in the case of a red signal – begins deceleration and stops in the line waiting for the green signal. Then he/she begins acceleration on green signal and leaves the intersection. According to data from the study that was carried out on working days in 2004-2005, during the rush hours, long lines of cars formed at the STOP line (at the intersections of the downtown) where all cars standing are not able to cross the STOP line during one cycle of the green signal and have to wait for another green signal cycle. This is considered in such cases where the intersection operates in the mode as "over-saturated flows". The scheme of car movement at the STOP line in the case of over-saturated flows is presented in Illustration 38.

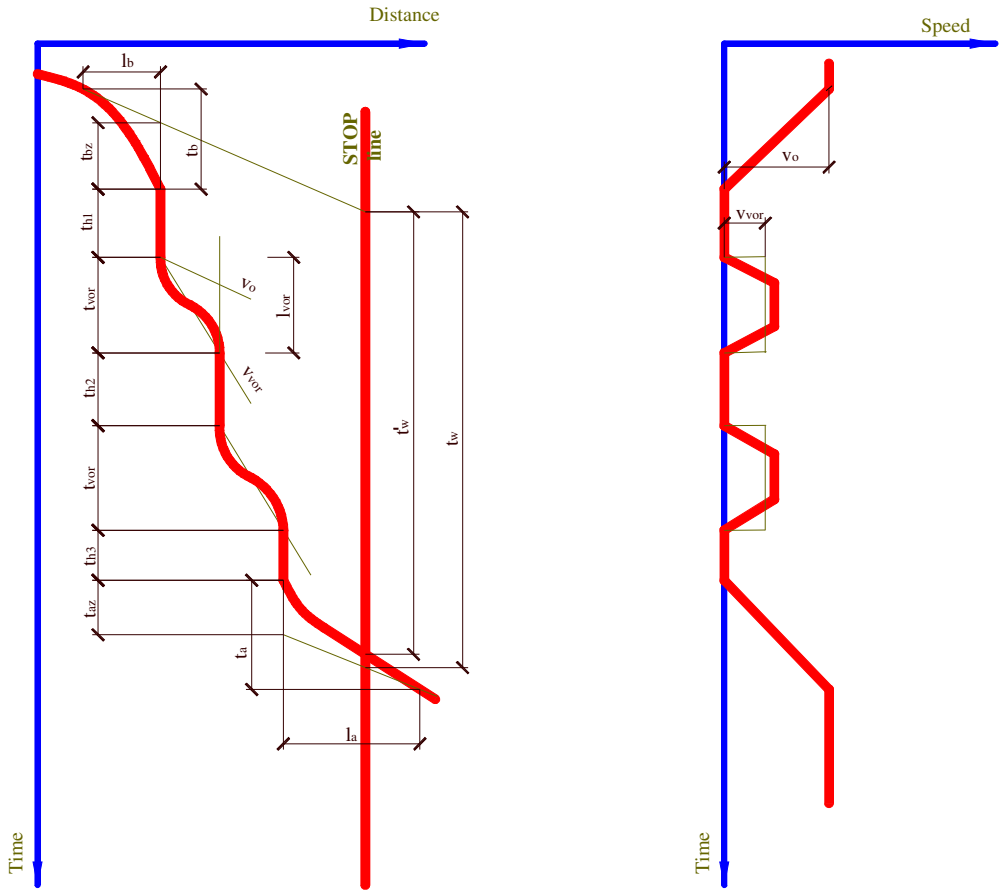


Illustration 38: Car acceleration and deceleration scheme at saturated signalized intersection

A model should take into consideration the processes of transport line formation and in the case of over-saturated flows a significant increase of fuel consumption due to the extra number of braking and idling are also observed and considered.

When calculating urban traffic organization schemes (special plans) and when transport time losses are now available at individual intersections, then the average fuel consumption can be calculated by taking into consideration the average driving speed. The fuel consumption at a street section, when the average traffic speed under urban conditions fluctuates between 3 and 60 km/h, may be calculated according to the following formula:

$$B_i = a \cdot V_i^{-b} \cdot e^{(c \cdot Vi)} \qquad (55),$$

Where B_i is the average fuel consumption under specific urban conditions (l/100 km), V_i is driving speed (km/h), for intersections of Vilnius a = 70,627; b = 0,7482; c = 0,01075.

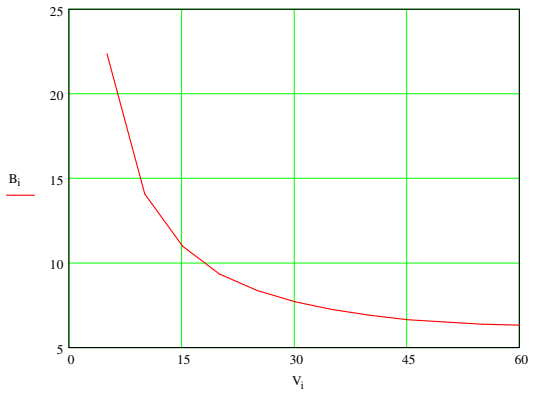


Illustration 39: Dependence of fuel consumption on the driving speed

At rush hours, when the average speed at intersections is 5-10 km/h, the fuel consumption for an average car would be 22-14 l/100 km. (see Illustration 39). The aggregated simulation model of fuel consumption, which would estimate the fuel consumption, depending on the average speed of traffic, should be used when calculating new projects of the transport's infrastructure (by-passes, new bridges) and evaluating the economic efficiency of traffic organization projects.

3.10 Model variables and scenario building principles

As was mentioned three main aspects can be changed and forecasted when modeling with VIDAS, i.e. land-use, transportation system, and car ownership. A scenario is a hypothetical sequence of logical and plausible events, constructed in order to focus attention on causal processes and decision-making points. A scenario is based planning that falls within the class of conjectural forecasting methods most commonly associated with future research [122].

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 (Illustration 40 and 41).

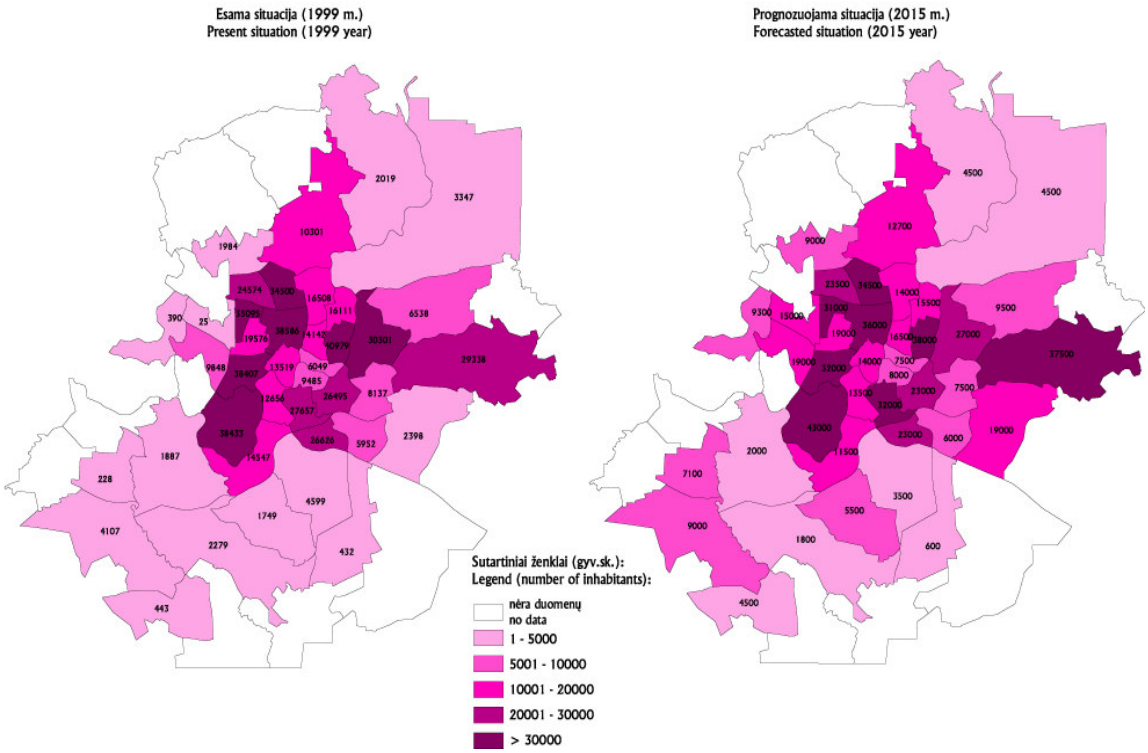


Illustration 40: Variation of inhabitants in Vilnius transportation regions (zones): 1999 and 2015

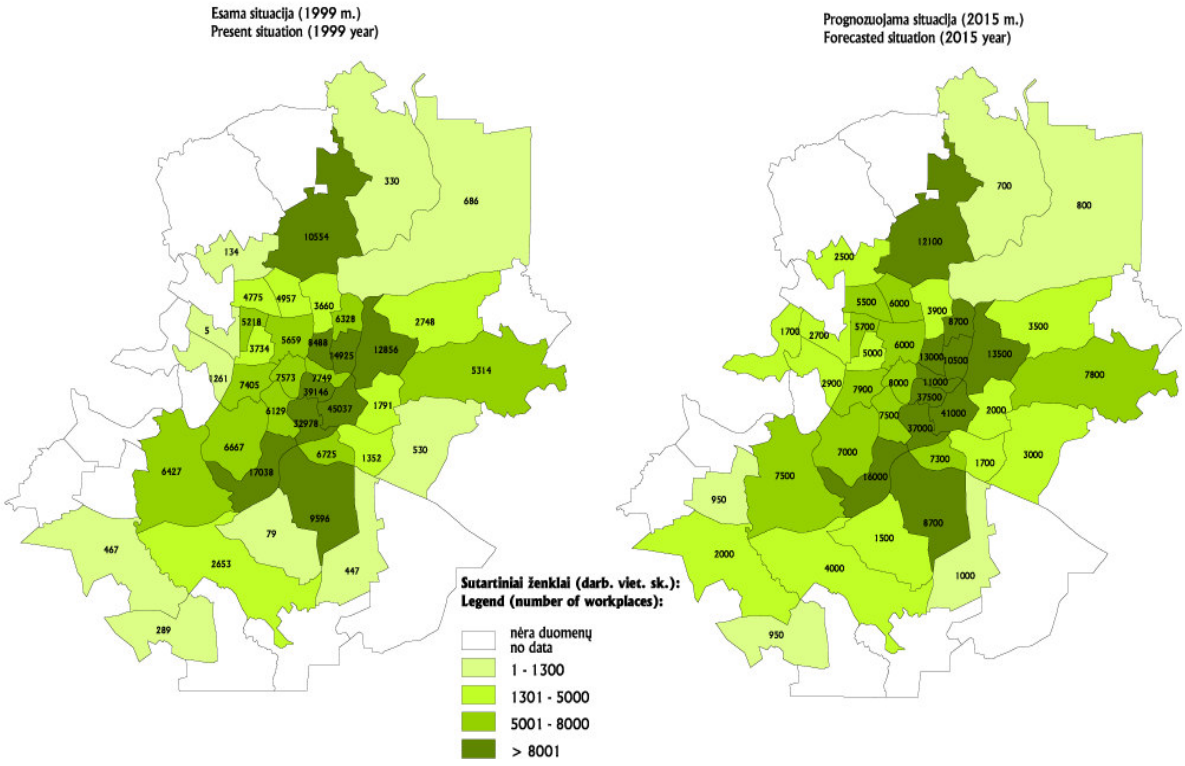


Illustration 41: Variation of workplaces in Vilnius transportation regions (zones): 1999 and 2015

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 [75].

The main aim of such developments was to strive for a balance between the ratio of workplaces and residents in transportation districts. This was an expert's based forecast and it was expected that development of new urban nucleus near "overnight" districts would reduce transport problems within the city. Moreover, such forecasted developments would be the most realistic scenario for the land-use changes.

It is possible to modify the transportation system (infrastructure) for cars and trucks by changing the following:

• Modify link data; for example modes allowed, distance weights for trucks, number of lanes or the index of volume delay function specified for the link may be changed;

• Modify turn data; for example turn prohibitions and indexes of turn penalty functions;

• Adding and deleting road links.

The transport infrastructure of Vilnius was developed according to general (Comprehensive) plans till 1980, but developments slowed down during last two decades. A number of changes such as the southern bypass of the old town, southern and western bypasses of city, Northern Street and various bridges and viaducts were not implemented (see Illustration 42). The increasing number of cars dramatically worsened traffic conditions in Vilnius, moreover the street network remained unstructured and some critical intersections were overloaded.

Hence, other forecast factors were development within Vilnius's transport infrastructure according to the Comprehensive Plan and its influence on traffic flows. Two main elements were segregated in the scenario preparations: development of new infrastructure (i.e. all planned bypasses) and reconstruction of the current infrastructure (increase of infrastructure capacity).

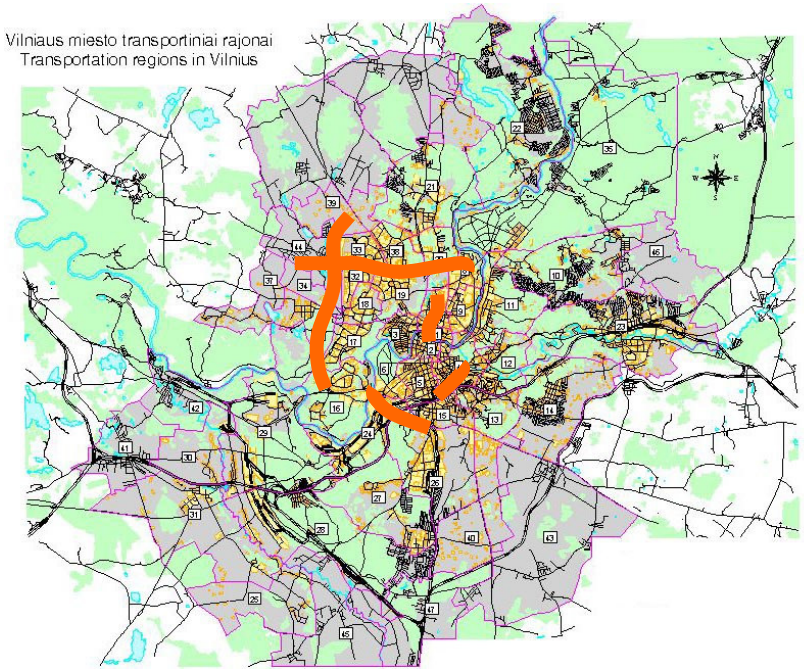


Illustration 42: Development of Vilnius bypasses according to Vilnius Comprehensive Plan

Reconstruction of the current infrastructure was reflected by the reconstruction of the most critical Gelezinio Vilko – Ukmerges intersection, located in the central part of the city (see Appendix 3 for the detailed schemes). The current triangular and one-level intersection is most loaded in Vilnius. Approximately 16,200 cars cross the intersection during morning peak hours and it is totally over-saturated.

It is possible to modify car ownership by changing the number of cars per person. The forecasted car ownership in 2015 is 550 cars per 1,000 inhabitants (see also Illustration 18). Changes in the level of car uses must be treated in a special way [123]. 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 total number of car trips can be expected to increase when a bigger share of the population is working because more people have to travel to their jobs and more people will have more money to spend on other type of trips. The way to introduce an increase

of the total number of car trips in this case is to increase the car ownership. The additional increase can be interpreted as- when unemployment decreases people tend to use the cars they already have to a higher extent.

The total number of truck trips is calculated as a function of changes in the total number of workplaces and the truck ownership as compared to the base year situation. The consequence is that the total number of truck trips will increase if the total number of workplaces in Vilnius District also increases.

The trip frequencies in the Trip Generation model are estimated and based on the travel behavior in 1999. 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.

3.11 Scenario building

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. For the sophisticated comparison number, scenarios should be limited, and "boundary" scenarios were chosen for the comparison (Table 10). Factors that were used in the scenarios are explained later.

Table 10: Summary of scenarios

	Base scenario (24)	2025	2045	240	2043	2042	2046	2036
Network	2004	2015	2004	2004	2015	2015	2004 (inters.)	2004 (inters.)
Land use	2004	2004	2015	2015	2015	2015	2004	2015
Car ownership	2004	2004	2004	2015	2004	2015	2004	2015

Network 2004 – means the current street network and other infrastructure, i.e. length of the streets, number of lanes, modes allowed, and volume-delay function index.

Network 2004 (inters.) – means the current street network, but Gelezinio Vilko – Ukmerges intersections were reconstructed according to a proposed scheme (2 levels).

Network 2015 – means the development of bypasses according to the Comprehensive Plan of Vilnius (see previous chapter).

Land use 2004 – current situation, i.e. total number of inhabitants is 580,000 and the rough number of workplaces is 300,000.

Land use 2015 – number of inhabitants that increased to 65,000 and the rough number of workplaces will be 326,000. 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.

Car ownership in 2004 – 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 550 cars per 1,000 inhabitants.

3.12 Modeling and Scenario results

A number of other tests were performed in order to see the changes in a single factor, though all factors will vary in parallel. All scenarios were evaluated by combining different factors and planning horizons according to energy consumption. The model produced rational results for a peak-hour and is presented in the Table 11 and Illustration 43. Energy consumption was converted: 1 liter of fuel equals 34.4 MJ of primer energy [7].

Table 11: Results of modeling for morning peak hour

	Base scenario (24)	2025	2045	240	2043	2042	2046	2036
Total driving time, hours	11255	10716	13662	43471	12572	40760	11181	42105
Total driven distance, km	497079	496040	576668	1019155	571897	1105366	496923	1024969
Length of the network, km	1614,5	1710,2	1614,5	1614,5	1710,2	1710,2	1618	1618
Total fuel consumption, ltr	35906,14	35347,2	42167,45	87315,47	40864,72	89334,57	35821,04	86699,8
Fuel consumption per 1 vehicle-km, ltr	0,0722	0,0713	0,0731	0,0857	0,0715	0,0808	0,0721	0,0846

A comparison of "straightaway" developments with base scenario and future scenarios with "worst future" scenario (240) 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).

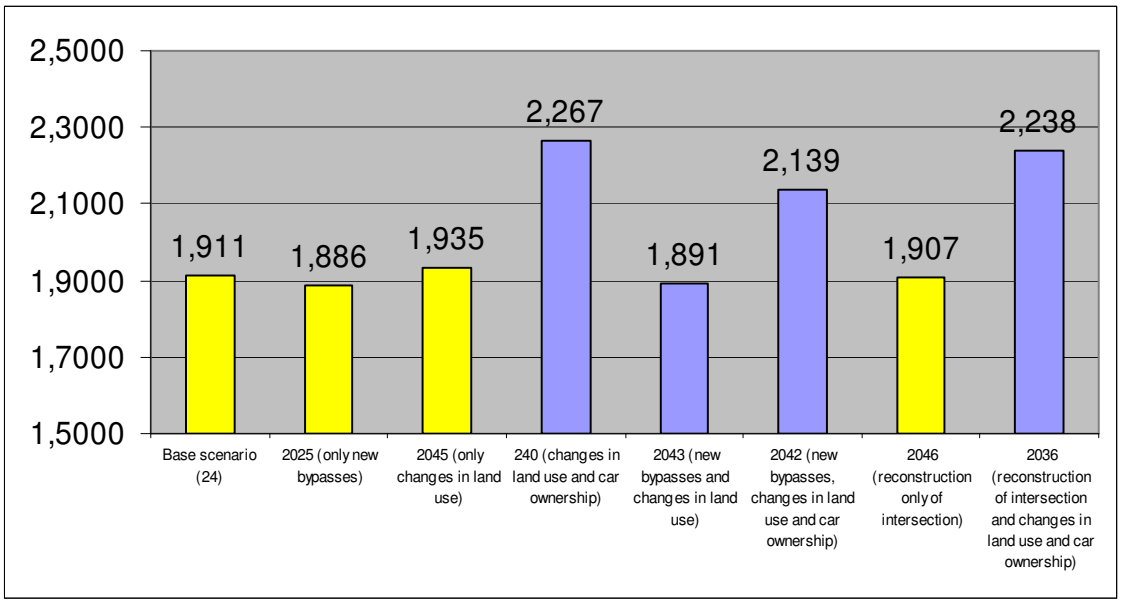


Illustration 43: Fuel consumption per 1 passenger-km in MJ during morning peak hour (colors indicate comparable scenarios)

Thus, base scenario and "worst future" scenario (240) could be compared by using the same factors: land-use, infrastructure and car ownership.

3.13 Analysis and discussion of results

Driving pattern is a complex phenomenon, which is influenced by several variables as the driver behavior, 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 [124,125]. In this part of the dissertation, the aim was to prepare model that would describe fuel consumption under traffic conditions in Vilnius. Further the aim was to employ VIDAS model and to investigate the effect of various infrastructure projects on energy consumption in private transport.

Modeling results clearly show that all infrastructure developments and changes in land use influence the energy consumption. The results are in compliance with general conclusions found by number of researchers (Wilson 1987, Mattson 1989 and 2000, Ness 1993, Akisawa 1998, Kitamura 1999) in that the traffic environment and denser

urban structure have significant effects on fuel consumption and that the variation of traffic environment has the greatest effect.

Generally, the exact extent of cause and effect between urban structures and energy consumption in transport is not conclusive. Often there are a number of local factors involved, relating to particular people behaviors 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 (base scenario 24) initially shows that 1.911 MJ is the consumption per one passenger kilometer. That is a little more than in Europe (1.73 per passenger km), though modeling reflects only the urban driving conditions in Vilnius. The "worst future" scenario indicates the huge increase of energy intensity (2.267 MJ/passenger-km), i.e. the number of cars will increase rapidly (speed will decrease) and inhabitants will move to the outskirts of the city, and consequently traffic congestion will increase and the average speed will decrease.

New bypasses considerably decrease energy consumption when comparing "straightaway changes" (comparing scenarios 24 and 2025) and in the long-term perspective (comparing scenarios 240 and 2042). Energy consumption will decrease to 0.0258 MJ per passenger-km in the first case and in the second case to – 0.1285 MJ per passenger-km.

Forecasted changes in land use, i.e. movement of residences to suburbs will increase the energy use in Vilnius's transport system. A comparison of scenarios 24 and 2045 shows an increase of 0.024 MJ per passenger-km, and is mainly due to the increased length of the trip. On the other hand, another marginal scenario (2043) indicates that car ownership is one of the main factors defining higher energy consumption, but only strong political backing and economical measures could influence such a subsystem.

Reconstruction of critical infra-structural points should also be evaluated from the energy efficiency point of view. It seems that there are no huge energy savings in the short-term (comparison of scenarios 24 and 2045), but in the long-term (comparison of scenarios 240 and 2036) such a reconstruction will lead to quite considerable reduction of fuel consumption (0.03 MJ/passenger-km).

Hence, all analyzed developments within Vilnius's urban structure have influence on energy consumption, but it is still difficult to distinguish the most essential. The whole problem of automobile dependence and high transport energy use must be tackled systematically by applying a pecuniary evaluation (cost benefit analysis). Moreover, other factors such as time losses should also be included into a cost benefit analysis.

Lastly, three main development alternatives will be compared: the "worst future development" (1st development from scenario 24 to 240), "development of new bypasses" (2nd development from scenario 2025 to 2042) and a "reconstruction of current infrastructure" (3rd development from scenario 2046 to 2036).

In each set of scenarios evaluation in the period from 2004-2015 linear methods approximated the step values. Economy of time and fuel should be based on an annual basis, and conversion of modeled information should be completed. A team of Territorial Planning Research Institute prepared the study of traffic flows in Vilnius' streets in 1999 [93]. According to the research data, a traffic intensity chart was prepared. It shows a comparison of traffic intensity during one day, i.e. peak hour 7-8 is a 100 % (see Illustration 44). Conversion of peak hour values were performed with reference to calculated coefficients for only 4 peak hours when the transport system was working under critical conditions (2 hours morning and 2 hours in the evening).

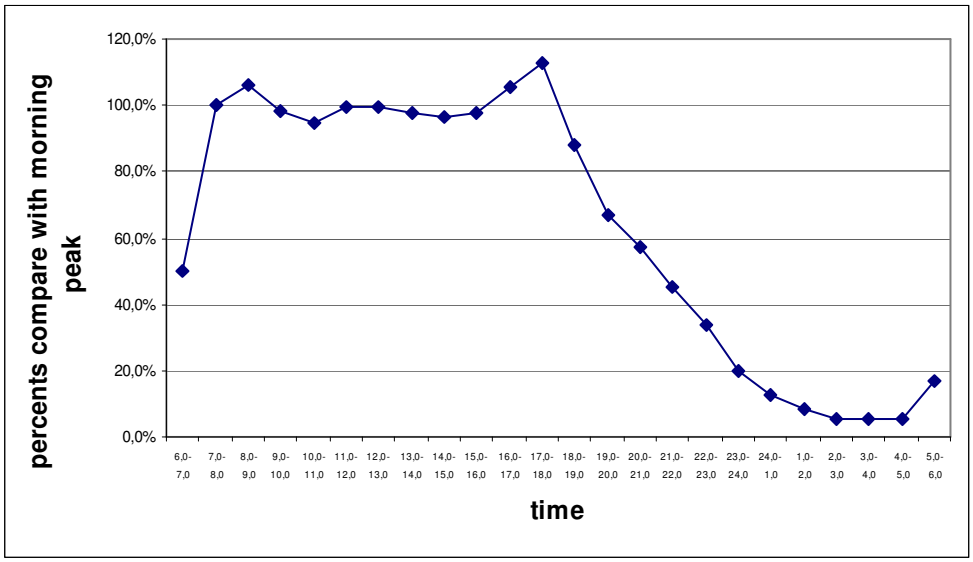


Illustration 44: Comparative traffic intensity in Vilnius (7-8=100%)

Further calculations of fuel and time saving were based on a methodology that is approved by the Ministry of Communications [102,126]. Fuel and time economy are one of the most essential factors when preparing a cost benefit analysis. Both factors are evaluated in the methodology and have a very practical monetary expression: fuel price is 2.6 Litas per liter and the average value of one vehicle-hour is 24.2 Litas (2004 year).

Second and third alternatives were compared with the 1st alternative from an economical point of view when a discount factor is 5 % and the lifetime of the project is 11 years. Results of such calculations are presented in Table 12.

Table 12: Comparison of alternatives: economy of fuel and time during next 11 years (discount factor – 5 per cent)

	Time savings	Fuel savings	Total savings
2	439525746,7	-20748369,66	418777377,1
3	193875346,4	10156315,32	204031661,7

It is obvious, that the 3rd alternative "reconstruction of current infrastructure" is more beneficial from an energy saving point of view. Huge traffic jams on arterial roads and consequently low speeds determine high-energy intensity and the pollution in populated areas. On other hand, time saving is incredibly high in the case of the 2nd alternative "development of new bypasses". Drivers in such a case will choose a less congested route and will spend more fuel and consequently such roundabouts should be planned distantly form highly populated areas.

3.14 Chapter III: conclusions and recommendations

1. Modeling results support the hypothesis of urban structure's influence on energy consumption in transportation. Moreover, results show that land use and the quality of the urban infrastructure are complex and depend on local technological, economical, social conditions.

2. The problems of energy use in transport cannot be solved by technological measures alone. Urban planning measures and transport infrastructure priorities could significantly determine how to cope with the dependency on imported fossil fuels problem.

3. Fuel consumption is one of the key factors when evaluating variants of individual transport organization projects when regarding economic and environmental aspects.

Time losses and increased fuel consumption should be taken into consideration according to the average driving speed at individual street sections.

4. An Energy consumption model was developed for Vilnius conditions, which estimates the fuel consumption and depending on the average speed of traffic. 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.

5. Application of model solved several practical problems. Development of Vilnius' bypasses would determine the lowest energy use per one passenger per kilometer, but it would also lead to longer (but faster) trips and consequently higher total fuel consumption. 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 energy intensity.

6. Hence, the above various developments have strengths and weaknesses. Reducing Lithuania's built-in energy dependency, however, has enormous positive spin-offs in the overall sustainability and livability of the Vilnius.

Conclusions and recommendations

1. Urban sustainability comprises of complex interrelations between socio-political, environmental and economical subsystems and consequently it is crucial to find reasonable technological solutions to the many problems in these areas. Analysis of international experiences and literature suggest that there are three main opportunities to increase the energy efficiency in Lithuania's transport sector: promotion of bio-fuels, development of a more energy efficient and non-motorized transport system, integrated land use and transport planning.
2. Urban sustainability is particular to each city, and therefore research concentrates on the energy consumption in Vilnius's transport system, and its dependency on land-use and the mobility of inhabitants. Two major approaches were employed in the research's problems: empirical and theoretical. The strength of the empirical research is in its consistency of estimation although it is static, and meanwhile theoretical studies enabled the author to forecast dynamics of various interactions between factors.
3. Empirical and theoretical approaches support hypothesis concerning the relationship between energy consumption in Vilnius's transport system and its urban structure, moreover a precautionary energy saving principle is applicable under current technological, social and environmental conditions.
4. The empirical study has shown that energy consumption in Vilnius's transportation districts strongly correlate with the urban area per inhabitant or workplace. A decrease of the urban area from the current 725 to 450 square meters per capita in Vilnius (450 square meters of urban territory per capita is an average in Nordic cities) will reduce fuel consumption in public transport per passenger-km by 61 % according to the empirical model.
5. Two multiple linear models (trolleybuses and autobuses) were developed during the empirical study and these models can be employed to forecast energy consumption in Vilnius when analyzing different scenarios of its urban development and the supply to urban transport. Integrated land-use and public transport planning measures such as placing new residential areas in areas that

are serviced by public transport or the encouragement of developers to support the supply of public transport would be an appropriate way to solve problems of energy efficiency in transport.

6. The energy consumption model was developed for Vilnius' conditions, which estimates fuel consumption in private transport depending on the average speed of traffic flow. This model should be used when calculating new projects for transport infrastructures (by-passes, new bridges) and when evaluating the economic efficiency of traffic organization projects.

7. Application of theoretical model solved several practical problems in Vilnius's private transport subsystem. The model indicated that the average fuel consumption is 1.911 MJ per 1 passenger-km under the current situation. Development of Vilnius's bypasses and reconstruction of current critical intersections would reduce the energy consumption to a 1.886 and 1.907 MJ per 1 passenger-km respectively. However in the long-term perspective, total fuel consumption will increase in the case of bypasses because longer (but faster) trips will predominate. Meanwhile, reconstruction of critical intersections will reduce the total fuel consumption and pollution in highly populated areas.

8. The main preconditions for a more sustainable development of Vilnius are complex and cannot be limited only by its energy efficiency. Both experiments indicated that more concentrated and mixed land use is definitely a better solution to lower the energy's intensity.

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Appendix 1

Appendix 2

Appendix 3