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Graduate School of Management

Master in Public Management

ROLE OF GEOGRAPHIC INFORMATION SYSTEMS FOR TRANSPORT SYSTEM IMPROVEMENT

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ABSTRACT

Master Student's Name	Andrei A. Ternikov
Master Thesis Title	Role of Geographic Information Systems for Transport System Improvement
Educational Program	Management
Main field of study	Master in Public Management (MPM)
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Academic Advisor's Name	Ekaterina V. Sokolova
Description of the goal, tasks and main results	**Goal**: Assess the opportunities of GIS for transport system performance improvement. **Objectives:** 1. Define the GIS for end users in transport sphere. 2. Define the quality of transport system and methods of how to measure it. 1. Define GIS in transport sphere. 2. Analyze GIS projects in Russia and foreign countries. 3. Define ICT for end users in transport sphere. 4. Define drivers related to the use of GIS in transport sphere. 5. Define the quality of transport system and methods of how to measure it. 6. Assess the quality of transport system based on the GIS data. **Results:** 1. The role of GIS in transport system congestion prediction is assessed. 2. The criteria and methods assessing transport system congestion using GIS data are proposed.
Keywords	GIS in transport, quality of transport system, urban development

АННОТАЦИЯ

Автор	Андрей Александрович Терников
Название ВКР	Роль геоинформационных систем в повышении качества городской транспортной системы
Образовательная программа	Менеджмент
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Научный руководитель	Екатерина Владимировна Соколова
Описание цели, задач и основных результатов	**Цель**: Оценить возможности геоинформационных систем для повышения эффективности транспортной системы. **Задачи:** 1. Определить геоинформационные системы в транспортной сфере. 2. Проанализировать проекты, основанные на геоинформационных системах в России и зарубежом. 3. Определить ИКТ для конечных пользователей в транспортной сфере. 4. Определить драйверы использования геоинформационных систем в транспортной сфере. 5. Определить понятие качества транспортной системы и методы её оценки. 6. Оценить качество транспортной системы на основе данных, полученных из геоинформационной системы. **Результаты:** 1. Оценена роль геоинформационных систем в прогнозировании транспортных заторов. 2. Предложены критерии и методы оценивания заторов на транспортной системе при использовании данных геоинформационных систем.
Ключевые слова	ГИС в транспорте, качество городской транспортной системы, городское развитие

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INTRODUCTION

The role of transport system for the city development is significant. Firstly, transportation is involved in daily life of the region. Citizens use both private and public vehicles to get to the destination in order to make their trips faster and more convenient. Secondly, transport development connects with the economy of the city. Business can get, operate, deliver their goods and services in different districts that are far from each other. It allows to decrease and redistribute transportation costs between suppliers. Thirdly, the competent management in transport sphere can provide better access, facilities and ways of travel for citizens. Hence, government gets beneficial impact from citizens in terms of quality of living by improving transport infrastructure (Vuchic 2017). However, along with the population growth in the cities and new territories exploration, the transport sphere faces several difficulties. Congestion – is the one of the most harmful consequences affecting both life of citizens and the condition of transport infrastructure. It is not only increasing the load on road network that amortize it but also the negative impact of people's wealth. This appears in environment worsening due to concentration of emissions increase. In addition, the trips become time-consuming because of traffic jams, the increase of private transport users and public way of traveling overload.

In order to overcome the growing amount of problems mentioned above and monitor the state of transport sphere with its infrastructure, the support of Information and Communications Technology (ICT) is introduced. From the side of increasing number of trips, people and operations, ICT is the tool to facilitate and automatize the information collection and processing. As a part of ICT, Geographic Information Systems (GIS) allows to monitor and predict the events connected with traffic and citizens, that creates the basis for better managerial decisions by the government. However, the implementation of such a concept demands the understanding of regional specific.

The scientific society has large discussion about possibilities of GIS introduction for transport sphere improvement. Firstly, the potential of intellectual informational systems correlates with the Internet use in the region. Setting up of electronic government (E-government) concept is dependent from level of Internet usage but not on the access to the world wide web (Zhao, Collier, and Deng 2014). Economic status, that is supported by information technologies introduction, does not straightly relate to E-government development. So, the key potential for GIS depends mostly on the government policy and readiness of the users to follow the information development trend, neither on the overall economic state. Secondly, wide distribution of GIS in transport sphere generates the changes related on both public and private transport usage. It creates the new value for users and promotes the attractiveness of the region (Kos-Łabędowicz and Urbanek 2017; Zedgenizov and Burkov 2017).

Along with the problems of increasing load on road networks and overloaded public transport issues, several models of wise transport management based on GIS are used. Again in terms of road safety, reduction of accidents and amount of injured people on transport cost-effective model that allocate funds in order to stimulate public and private participation in traffic problems is introduced in USA (Tsapakis et al. 2017). Highway Safety Improvement Program (HSIP) connected to the automatize services, which provides information about car crash data, road network screening and visualization, promoting the overall transport system diagnostics for better managerial decisions in transport sphere. The other example relates to the European Union framework (Harris, Wang, and Wang 2015). Researchers stated that the GIS adoption in transport sphere in this region is developed slowly. Despite the fact of effectiveness of the ICT systems, several barriers exists, such as the lack of integration of such a system and quick adaptation to new technologies. These barriers could be undertaken in smart cities with the use of open and transparent GIS platforms (Pflügler et al. 2016; Mendiola et al. 2017). Furthermore, it is also analyzed that traffic engineering issues which started to be introduced in the cities have changed their standards, that made it difficult to use various traffic monitoring instruments simultaneously. GIS in transport sphere is projected to open the new way of city management. GIS introduction is not the simple substitution of the processes by mobile services adoption. It is the new instrument and point of interest from the side of government and citizens related to their positive expectations concerning additional informational technologies support in making decisions. Furthermore, ICT affects not only transport infrastructure but also the behavior of users (Cohen-Blankshtain and Rotem-Mindali 2016; Lee et al. 2016a; Snellen and Hollander 2017). This means the change in people's mind towards the flexibility in space and time orientation. The concept could be developed to the creation of autonomous Internet-based transport system, which could be similar to the Internet of Things but connected to the transport. In addition, ICT makes the overall transport system more complex and faces challenges such as higher accessibility and easy-in-use of transport. So, it provides the strong dependence from ICT, technologies become as independent agents that need to be regulated.

In Russia the GIS introduction in transport sphere is a problem related to regional differences. There is a large regional difference in the level of development of land transport infrastructure. The number of settlements without roads with solid surface exceeds the limit. For road density, Russia is lower than many developing countries. In many large cities there is the problem of long-term delays in the technical condition of the road network. For example, about 50% of freight transport vehicles in the fleet are out of date with the ten years lifetime (Ivanov 2016). Moreover, one of the main obstacles to Russia's transport development is climate, which is reflected in the high complexity of road construction in different regions of the country. It is also mentioned that the cluster model with polycentric agglomerations formation is needed to reduce traffic congestion in cities (Ivanov 2016; Tokunova 2017). All these models and measures could be combined and standardized in one common tool for transport system monitoring. At current moment in Saint-Petersburg the complex informational system managing transport is formed.[1] Over the past decade, the city has adopted numerous regulatory documents in the transport sector. Government of Saint-Petersburg has approved a set of industrial plans to identify

[1] Government of Saint-Petersburg. *O sozdanii gosudarstvennoj informacionnoj sistemy Sankt-Peterburga «Kompleksnaja informacionnaja sistema upravlenija gorodskim i prigorodnym passazhirskim transportom v Sankt-Peterburge» [On the creation of state information system of St. Petersburg «Integrated information system urban and suburban by passenger transport in St. Petersburg»].* St. Petersburg: Government of Saint-Petersburg, 2016. Accessed November 12, 2017. https://gov.spb.ru/law?d&nd=822405502&nh=3.

specific types of transport infrastructure in the city. It can be stated that the activities contained in the documents are not financially secure. As a result, the adoption of such documents does not allow for significant delays in the development of Saint-Petersburg transport system from major foreign cities, where quality of life is higher. So, the GIS introduction is an actual, widely discussed issue.

The goal of the research is to assess the opportunities of GIS for transport system performance improvement.

According to the goal the following objectives are stated:

1. Define GIS in transport sphere.
2. Analyze GIS projects in Russia and foreign countries.
3. Define ICT for end users in transport sphere.
4. Define drivers related to the use of GIS in transport sphere.
5. Define the quality of transport system and methods of how to measure it.
6. Assess the quality of transport system based on the GIS data.

In accordance with objectives the research has the following structure. First chapter introduces basic concepts that are used in the research, the overview of Russian and international experience of GIS solutions in transport sphere introduction and the definition of GIS for end users. Second chapter relates to drivers of GIS use in transport sphere overview and comparison of transport infrastructure quality assessment methods. Third chapter proposes the results of empirical study on quality assessment of transport system based on GIS data; recommendations in order to improve quality of transport system by congestion reduction using GIS data are provided.

Master thesis contains of 50 pages, including introduction, three chapters, conclusion, references (67 sources); 13 figures, 12 tables.

CHAPTER 1
GEOGRAPHIC INFORMATION SYSTEMS IN TRANSPORT

This chapter is devoted to the theoretical background overview related to the subject of the research. The first section of the chapter briefly describes the basic concepts, such as "ICT in transport sphere", "GIS", "transport infrastructure" and "sustainability", reflecting to the socio-economic effects for the region and end users. The second section contributes to the description and analysis of existing native and foreign experience of implementing GIS in transport sphere; theoretical approaches to assessing the quality of public service delivery in electronic format. The third section defines the GIS for end users in transport with the relation to the practical aspects of user-centered ICT solutions.

1.1. Transport system and information technologies

Understanding of interrelations between the creation of new technologies and improvements in transport sphere states from the basis of the notion of such terms as "Information and Communications Technology" (ICT) in transport sphere and "transport infrastructure". ICT in the sphere of transport is defined in differently in accordance with the vast variety of scientific sources. Some authors propose that ICT in transport is a tool (combination of tools), which is able to support infrastructure maintenance, the increase of mobility and accessibility of public transport, the improvement of transport providers' efficiency, and to solve problems connected to transport sector (Bąk and Borkowski 2015; Borkowski 2018; Gössling 2018; Snellen and Hollander 2017). One more definition of ICT in transport describes it as the potential technology, which can provide changes in the current technologies or even replace them by reducing their negative impact on transport sphere (Cohen-Blankshtain and Rotem-Mindali 2016; Kos-Łabędowicz and Urbanek 2017). However, the definition of ICT does not only imply the technological issues because the ICT introduction is aimed to satisfy public and private needs. Some other researchers underly that ICT in transport — is the combination of hardware and software infrastructure, consisting of different vehicles and transportation units, which provide opportunities to improve personal mobility of users (Bris, Pawlak, and Polak 2017; Harris, Wang, and Wang 2015; Klein and Ben-Elia 2016). In this case, the attention is paid on improvements, considering to be obtained by ICT introduction. From managerial point of view, concerning the role of ICT in transport sphere, the research interest in transport infrastructure improvement lies behind the relationships between public and citizens' needs. Thus, the following definition is the most applicable for the current research: "ICT in transport sphere" — is the technology, consisting of hardware and software infrastructure, aims to improve transport system in order to satisfy needs of government and citizens.

Within the definition of ICT, Geographic Information Systems (GIS) — is the part of ICT that manage, manipulate and analyze spatial data (Perez-Prada, Monzon, and Valdes 2017). It is highlighted that the development of transport system is the one of key drivers of social and economic development of any region, connected to the people's well-being, economic growth, industries' productivity (Ivanov 2016; Leviäkangas 2016; Palvia, Baqir, and Nemati 2018; Popova 2017; Saidi, Shahbaz, and Akhtar 2018). The successful (in terms of speed, time, convenience, continuity) functioning of such system highly depends on certain conditions. The creation of such conditions attributes to the infrastructure maintenance of a certain territory. The term "infrastructure" in economic sense implies a separate branch of the national economy that deals with the formation of external conditions for functioning of production and manufacturing. The "transport infrastructure" is a kind of infrastructure, that is, a combination of all branches of transport enterprises that perform transportation and ensure their implementation and maintenance. Objects of transport infrastructure include the following components: railways, automobile roads, internal and external waterways and airways, bus stations, airports and subway. It includes all buildings and facilities that are necessary for the functioning of the transport system, all the equipment necessary for transport functioning and GIS.

The most important issue for the transport system, beginning from the city level, is the modern transport infrastructure (Borkowski 2018). The means of transportation could be divided into two groups. The first group includes public transport. This sector of the economy relates to the needs of all sectors of the economy and population in the area of freight and passenger traffic. This group consists of rail transport, water transport, air and land transport. The second group consists of non-public transport. It connects to a transfer in production and transportation of any goods and services, which do not belong to transport organizations. The reason for the importance of the process of shipping is not only the carriage of products, which represents tangible assets of the production cycle. The transfer process is an integral part of the production cycle, affecting the duration of production of a particular product. The company's work and development depend on the creation of the optimal transport process.

From economic point of view, closeness of transport arteries is oriented to the creation of production lines and ensuring the progressive socio-economic development. So, transportation indicates the level of economic activity and could be represented as indicator of economic potential (Popova 2017; Skorobogatova and Kuzmina-Merlino 2017). On the one hand, the realization of the region's economic potential imposes demand on transport infrastructure. On the other hand, the opportunities provided by the infrastructure lead to a correction of priorities and directions for further social and economic development of the region. However, the economic effect of transport infrastructure deployment has negative impact on the environment (Broin and Guivarch 2017; De Gennaro, Paffumi, and Martini 2016; Gössling 2018). For example, the following phenomena exist: growth of air pollution caused by carbon dioxide emissions, greenhouse effect and energy demand increase. In order to improve the transport system and diminish negative consequences mentioned above, GIS solutions are introduced. For example, the monitoring and simulation systems are created. They have the potential to reduce emissions from vehicles by making the projections of traffic flow volumes (Perez-Prada, Monzon, and Valdes 2017; Umer et al. 2016; Wang and Moriarty 2017). Moreover, they help to establish "sustainable" (in terms of safety, mobility, environmental friendliness) transport infrastructure. Therefore, the issues of harmonious regional development affect the need in transport infrastructure improvement.

“Sustainability” is defined as performance of infrastructure lifecycle, which attributes to social and environmental impact on the transport system (Bueno, Vassallo, and Cheung 2015; Umer et al. 2016). This is closely connected to environmental issues, such as air pollution; the degree of safety; convenience in use. The assessment of issues mentioned above has different dimensions, that contains estimation of transport accessibility (Berežný and Konečný 2017; Curtis and Scheurer 2017; Milevich et al. 2016; Roşu and Blăgeanu 2015), service quality (Allard and Moura 2016; Androniceanu 2016; Bąk and Borkowski 2015; Filippi, Fusco, and Nanni 2013; Mugion et al. 2018) and quality of transport infrastructure (Barakchi, Torp, and Belay 2017; Danilina and Chebotarev 2017; Kaundinya et al. 2016). Transport networks are tended to unify parts of region or country. They help to maintain the integrity of economic space of a certain territory, to provide financial baseline for foreign economic partners and support integration to the global economic transport flows. The modernization of transport system seems unrealistic without quality of infrastructure improvement.

Transport infrastructure as one of the leading components of economic development has a widespread impact on the production site, performance, and functioning of region’s spatial displacement. Therefore, the linkage between production and consumption sides provides the understanding of its potential. The primary task of transport policy is to form the economic independence of the region, by providing its economy with both material and human resources. The solution to this issue lies in the process of close coordination between transport sector and all the other branches of the economy. One of the major outcomes of the policy application relates to transport infrastructure improvement. Moreover, in the process of improving quality and increasing rates of productive forces, the transport system is needed to be modernized in its material and technical base within the improvement of the organizational and administrative mechanisms in the system. The worsening of transport conditions is associated with the growth of city boundaries and the increasing number of vehicles that harms the environment. Policies, connecting to transport infrastructure planning, integrated land use management, require proper coordination of transport system within the broader urban development strategy.

In most countries, the urban sector accounts for at least the half of GNP, and about one-third of the investments are needed for the infrastructure in the transport sector. Despite recent changes in transport infrastructure financing with private sector involvement, the most of investments are still covered by the city budget (Ivanov 2016; Gadelshina and Vakhitova 2015). The urban economy is closely linked to the regional economy, primarily in the spheres of production and trade. In cities, the primary mean of transportation is ground transport. Despite the fact that the transportation of goods and passengers over long distances across the railways is the most cost-efficient, ground transport in cities is the most appropriate for short trips (Gadelshina and Vakhitova 2015). The transport infrastructure in the settlements with a small population differs from transport infrastructure of cities by its high costs of internal transportation and polluted environment. It is essential to solving problems strategically in cities, as they indicate the social and economic development of the region. It is necessary to gain the economic benefits on the city level through reducing transport sector problem, which relates to city size and people density.

According to the problem stated above, cities vary significantly by their economic, social and spatial characteristics. Moreover, any city changes over time. In general, the more developed regions have a more sophisticated transport infrastructure. Cities and regions with high socio-economic indicators have more roads with a solid surface. With revenue growth, urban road space will grow at a slower rate than traffic. As the city spatial limits increase, the average time of a daily trip increases, road congestion appears influencing negatively on the environment. Thus, cities suffer from low road capacity.

Factors mentioned above intersect and interact with each other. There is an increase in road load in areas with high economic potential, but at the same time, there is a tendency to provide public transport systems based on railways and use ICTs. However, in regions with rapid economic growth, the development of public transport is not keeping up. In regions with slow population growth, the probability of a stable infrastructure creation for public transport is higher than expected, based only on economic indicators.

Generally speaking, any potential technological change in the transport system, is aimed to bring the value for end users. In other words, fore example, the proper informatization about public transport routs and schedule, managing flows of vehicles in order to reduce trip time and amount of traffic jams allow to generate additional intention for users to shift from car trips towards alternative ways of transportation (Berežný and Konečný 2017; Borkowski 2018; Chowdhury et al. 2018; Julsrud and Denstadli 2017; Mugion et al. 2018). Thus, the interrelations between ICT and transport infrastructure could be presented in the form of concept map (fig. 1.1). It could be seen that ICTs as technology may improve the transport system. Therefore, the attention on quantity and quality of both mentioned phenomena has to be paid in accordance to the national and foreign experience of ICT solutions in transport.

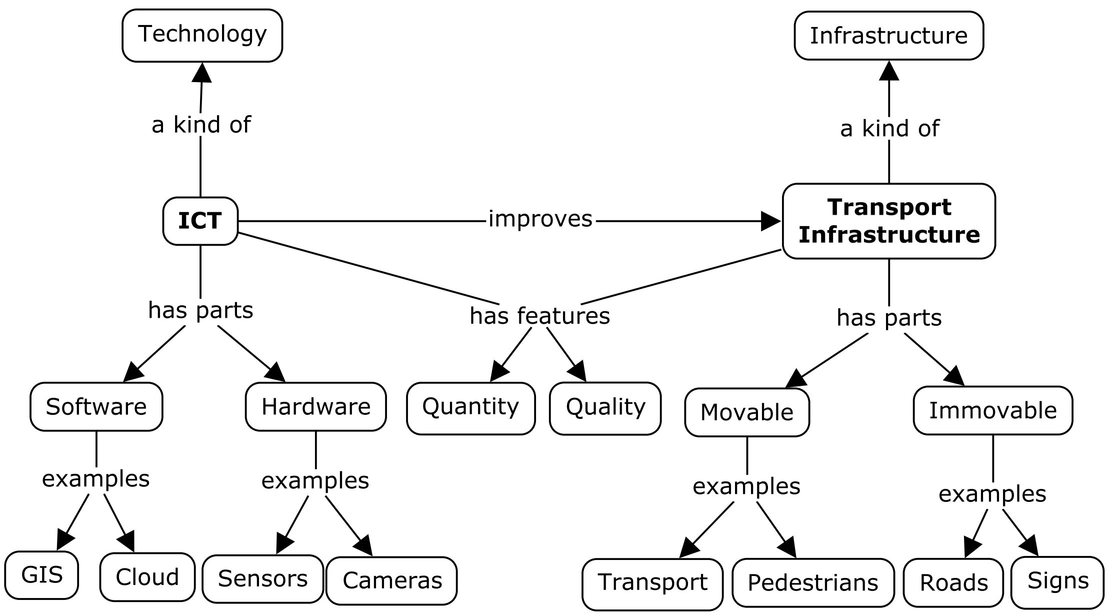

Figure 1.1 Concept map of ICT in transport sphere

Source: composed by the author

Transport system development is one of the major drivers of the social and economic development in most of countries, including, the Russian Federation. The role of transport system and its infrastructure is to provide all that is necessary to increase the indicators of economic growth, the level of competitiveness of the local economy and provide the conditions suitable for the sustainable living of citizens. Besides, competition for established transit capabilities in transportation is developed, all rivals are motivated to ensure safe and well-managed transportation services. Based on this, the quantitative and qualitative characteristics of the transport system, which could be assessed with GIS, plays an essential role in the social and economic development of any country.

The spatial characteristics of transport services have a direct impact on the integrity of financial communications inside and outside the country, to ensure the access to the common needs of all transport sector stakeholders. The problem of growing costs of a passenger travel tickets, which certainly reduces the amount of local transit is presented. In most cases, some low-paid citizens cannot use several means of transportation at all. The measures taken by the government to reduce the cost of a passenger ticket is one of the principal directions for social and economic development. So, specific characteristics of the transport service such as speed, safety and environmental friendliness of the transport infrastructure have to be improved. The speed of transport connectivity has a direct impact on the effectiveness of economic structures and population growth. High speed in the products and citizens transition contributes to tremendous economic and social implications. Thus, timely delivery of products to the enterprise ensures the appearance of other means of production, and the rapid transfer of citizens helps people to use their free time and resources for economic value added provision. Measures such as reducing transportation costs and increasing transport speeds in public transport ensure that the different regions of the country are integrated. Thus, this may improve population satisfaction of the quality of life, increase the number of business initiatives, maintain the geographical integrity of the nation and contribute to the emergence of more stable conditions for the regional development of economic and social potential.

1.2. Geographic Information Systems in transport: Russia and abroad

The transport system occupies one of the main positions in public policy of any country. The current socio-economic situation has reflected the strategic priorities development of the transport sphere and government functions in the field of transport infrastructure. For example, the basic law in Russia, contributing to the main priorities and objectives of the transport infrastructure development, is the Transport strategy of the Russian Federation.[2] The numerical assessment of the document is based primarily on the current economic situation and the directions of the social and economic improvement of the Russian Federation, its citizens in the short and long term prospective. The strategy sets up basic priorities for the development of transport

[2]Government of the Russian Federation. *Order of the Government of the Russian Federation of November 22, 2008 № 1734-r (as amended on June 11, 2014) «Ob utverzhdenii Transportnoj strategii Rossijskoj Federacii na period do 2030 goda» [«On the approval of the Transport Strategy of the Russian Federation for the period up to 2030»].* Russian Federation: Government of the Russian Federation, 2014. Accessed January 15, 2018. http://docs.cntd.ru/document/902132678.

infrastructure in the country, the main drivers to support the transport sector and elements of institutional transport reformation. Moreover, the main components of transport infrastructure and the organization of their functioning for specific transport, its characteristics and assessing indicators, are taken into account. The strategy includes five sections, the first of which states the mission in the performance and development of the transport system, outlines the main objectives for transport policy. The next section of the strategy is devoted to the description of priority indicators of public transport policy. They are based on the transport sphere management, the transport infrastructure maintenance and improvement, investments, profit maximization from the use of the state ownership, international partnerships. The third sector contains guidelines for public policy and mandatory structural improvements on specific types of transport. The fourth section refers to the development of the basic principles of the transport network, relating to certain types of transport projects (including GIS based projects). The last section contains all stages and mechanisms for the implementation of the transport strategy. The main tasks of military security in the transport strategy are the priorities of the military transport policy of the country. Its main objective is to develop the transport system in certain types of vehicles with regard to their characteristics.

The transport strategy of the Russian Federation also contains a framework for the development of programs oriented in the system of transport areas with connection to the economic sphere, society, military and the others. In addition, the overview of problems caused by the transport sphere are presented in order to develop certain regions and the economy of the whole country. The provisions of the document are the basis for a common understanding of the role of transport and its future directions in relation with legislative and executive authorities, private organizations and society.

The Russian transport system was formed under the Soviet planned economy when there were programs for industrialization and military interests in transport development. The balance between the demand from end users, their satisfaction and the need to serve global industrial partnerships, which are essential elements of economic growth, have not been in the interest of state policy. Thus, in Russia, there is a continuing drift in improving the transport system towards ensuring sustainable economic growth (Ivanov 2016; Mayburov and Leontyeva 2017). Over the years, the attitude towards economic reforms of the budget system in Russia has undergone significant changes. However, the responsibility for the functioning of the transport system is also still under the public control. Such situation involves severe problems that provide barriers to further stable development of transport infrastructure in Russia. For example, production mismatch due to change in the transport system. A sudden shift in demand in the transport sector is caused by the presence of new transport services demanding substantial production forces, which also led to the lack of transport capacity in the short term, a sharp increase in transport costs, also influencing households expenditures. The other issue concerns the lack of production elements in transport infrastructure. With no market indicators on the transport services providers, the efficiency of the modern transport systems decreases. So, the level of platform development is mainly ineffective for both individual transport infrastructure entities and, in general, for the entire transport system. Thus, all the costs of reconstructing and maintaining a network, while the core of its territory remains in the most substantial demand among consumers without financial support and thus become lagging behind.

The problems are also related to the pricing policy, which is based on the principle of protected cost investment, resulting in inefficient price increases, discouraging transport infrastructure progress and improper disposal of economic costs and benefits. Under the transport system in Russia, transport facilities are not defined as a standard private object of ownership, so, the government has lots of obligations granted to the third parties. Legal owners in Russia have rights to use the transport industry and its facilities. These rights, except the economic losses, are acceptable in general sense because these objects of the transport system were still left over from the presence of the Soviet heritage when the property was common and emerged as a result of activities of the people. Today there is a problem of adoption of the transport industry in the system of the state budget forming (Teslya 2014). The existence of a large number of obligations, which fall under the weight of the transport industry, leads to compulsory state expenditure on compensation, which is financed by budget. With the lack of private ownership and market pricing, the amount of benefits that operate in the transport infrastructure is formed by the government. Therefore, the productive activity of organizations does not depend on the results of economic operations, but primarily on the global funding attraction. In the context of market relations, the central management tool of the transport system does not play any significant role. However, this mechanism lives and implements its activities, gathering more or less accurate predictions. The central authority operates only in particular settings, not across the entire region, so, errors occur in the compilation of these predictions are highly probable to exist. The results of this economic activity are indirect and may be distorted in the absence of price signals. By the size and long-term characteristics of the transport industry, any error by the scheme could lead to a large deficit for the entire national economy.

The lack of market value of elements and transport infrastructure services to change the prevailing attitudes on both the efficiency of labor and transportation and interaction with the transport industry led the emerging costs in the economic sphere. This phenomenon is typical of both the administrative situation, concerning tariffs, and the non-commercial use of transport services. This is also supported by the low level paid on the importance of safety of transport networks. The reorganization of slow production mechanisms requires a decrease in the level of safety in transport. Moreover, the lack of management of environmental risks makes it impossible for rational use of natural goods to establish transport networks storage facilities. Thus, land use operations of transport infrastructure exacerbate pollution of nature. The performance of the state and local authorities, under their direct responsibility for transport regulation, have performed the functions of economic control and management and redistribution of the state and municipal property. Consequently, the main activities of government and municipal bodies are ineffective, and unnecessary functions lead to increased budget costs. In addition, the mismatch in public policy is supported by the lack of the common opinion on the implementation of public activities in the transport system. Actions of the state regulatory organization for transport is divided into different ministries and departments. Each body has its own rules, which are often incompatible with each other. There is no single concept of implementing state regulation for all directions of the transport system as a whole. This problem is one of the main reason for the lack of unified state transport organization in Russia.

The one of the examples of well-managed transport system in Russia on the regional level is the case of Saint-Petersburg. In the Strategy of Economic and Social Development of Saint-Petersburg for the period up to 2030 on the development of the street road network within the direction named as "1.2. Improving the quality of the urban environment" the Strategic objective is highlighted:[3]

> 1.2.2. Providing for all categories of the population and guests of the city opportunities free, safe and reliable movement using vehicles or on foot, based on the harmonious development of the transport system.

The following target issues are proposed in the Strategy:

1. Increase of accessibility and quality of services of overland urban and suburban passenger transport of general use for all categories of citizens, expansion of its network coverage.
2. Increase of accessibility and quality of metro services, the development of its network in areas of the city not covered by this mean of transport.
3. Maintenance quality improvement of public roads of regional importance in Saint-Petersburg, pedestrian zones and the other facilities for improvement of public services, reducing the impact of cargo road transport on the street road network of Saint-Petersburg.
4. Provision of organizational and technical measures for the creation and development of the parking space in Saint-Petersburg.
5. Ensuring the effectiveness of the technical means of the organization and traffic management systems in Saint-Petersburg.
6. Ensuring the effectiveness of transport planning, design and operation of transport infrastructure facilities.
7. Increase of accessibility and quality of services of external transport.
8. Ensuring the safety of citizens on all means of transport.
9. Maintenance in a normative condition and modernization of road facilities.

Target indicators of social and economic development of Saint-Petersburg mentioned in the Strategy:

1. The proportion of population of Saint-Petersburg, living in the pedestrian access zone of metro stations.
2. The proportion of residents who are satisfied with the quality of service on the public transport (from the number of respondents).

[3] Government of Saint-Petersburg. *Decree of the Government of Saint-Petersburg of May 13, 2014 № 355 «O Strategii jekonomicheskogo i social'nogo razvitija Sankt-Peterburga na period do 2030 goda» [«About the Strategy of Economic and Social Development of Saint-Petersburg for the period up to 2030»].* Saint-Petersburg: Government of Saint-Petersburg, 2014. Accessed March 12, 2018. http://spbstrategy2030.ru/?page_id=102.

However, the managing of these indicators demands the assessment of the micro data and indicators, related to the certain road segments of transport network and congestion issues. In Saint-Petersburg this data is gathered by GIS systems such as “Automated control system for urban and suburban passenger transport of general use in Saint-Petersburg” [“Avtomatizirovannaya sistema upravleniya gorodskim i prigorodnym passazhirskim transportom obshhego pol’zovaniya v Sankt-Peterburge”] and “State information system of Saint-Petersburg Unified urban parking space” [“Gosudarstvennaya informatsionnaya sistema Sankt-Peterburga Edinoe gorodskoe parkovochnoe prostranstvo”].[4] In addition, these GIS are provided only of the committees and the government authorities, and have blocked access to ordinary users and for research purposes.

In some regions the problems caused by the presence of the relatively high rate of private transport (especially cars) stated on the level of governmental regulation. In order to reduce the traffic congestion and negative impacts on environment, several GIS based solutions in transport sphere are introduced. One of regulation directions relates to the making an intention to shift from the private car usage to public transport or environmentally friendly vehicles, for example bicycles. Some authors overview that in some regions these innovations could create both positive and neutral effect on the environment and the transport system as a whole.

The R&D project “Be4Schools” that is introduced in Portugal (the city of Águeda) is aimed to low the level of carbon emissions from car users through the shift to the electric bicycles (e-bikes) usage (Arsenio et al. 2017). It was found that the market potential of e-bikes introduction and switching process to them (tested on school trip routes) is significantly (1.7 times) higher with the use of ICT devices than – without, ceteris paribus. The findings attributes to the public environmental policies in the transport sphere in the case of innovative technologies uptake. The other ICT solution related to the environmental issues of the transport system is introduced in Australia (the city of Melbourne). The special traffic modeling software (applications for users, autonomous vehicles and transport network planning) was introduced for the car sharing and transport monitoring (Institute for Sensible Transport 2016). It allows get the access not only for informatization about public transport in the real time but also engages the citizens, developers and public agencies in the process of transport infrastructure maintenance.

One more ICT connected to lowering of carbon emission was introduced in Spain (Madrid Region). The special Geographic Information System (GIS) called “Green Navigation” is able to simulate the amount of emission generated from the transport flows and regulate them to maintain the appropriate level of air pollution (Perez-Prada, Monzon, and Valdes 2017). The results of such system introduction show the significant decrease of carbon dioxide emission by 10–15%. In addition, traffic flow’s volume has been decreased by about 13.5% with the travel time decrease. However, within the overall positive environmental effects, the air pollution reduction in certain urban regions is ineffective.

The other regulatory mechanism in the transport sphere relates to transport infrastructure renewal and maintenance. However, this policy could be ineffective due to wrong priority setting according to GIS introduction (Harris, Wang, and Wang 2015). For example, the Finland’s

[4]Register of state information systems of Saint-Petersburg. [In Russian]. https://reestr-gis.spb.ru/rgis/ (accessed 20 April, 2018).

government investments in GIS were inadequately redistributed: from the one side, the digital disruption was expected but, from the other side, the transport sector share in the public priority spendings was not largely represented (Leviäkangas 2016). There are also examples of the due policy set up. In Latvia the transport infrastructure performance is set up as the key strategic priority to increase the economic potential (Skorobogatova and Kuzmina-Merlino 2017). As a result the wise attribution and the understanding of the role of transport system (including GIS in transport infrastructure development) is connected to the sustainable economic growth. In United Kingdom the user-driven approach was used (Knoeri, Steinberger, and Roelich 2016). The combination between energy and water provisions was applied to assess the transport infrastructure performance in accordance with the end user transport services. Therefore, one more possible regulatory direction relates to the system of public transport accessibility development (based on transport infrastructure improvement). The alternative to car traveling routes of public transport are suggested in Europe and North America through spatial network analysis models (Bąk and Borkowski 2015; Curtis and Scheurer 2017; Locatelli, Invernizzi, and Brookes 2017). This instrument is able to help policymakers to obtain decision in accordance with public transport system development based on such characteristics as people density, transport network coverage, service usage intensity, etc. Findings propose that in different regions with different socio-economic characteristics the attitude to the ICT introduction is relatively the same, that made possible to implement ICT in various regions. In addition, the proper governmental financial support is needed to obtain huge GIS based transport infrastructure projects. The other experience of public transport accessibility increase demonstrates Greece (the city of Thessaloniki). Despite the tense economic situation the affordable and high-quality public transport was introduced (Morfoulaki, Myrovali, and Kotoula 2015). As a result of the Greek government policy the passengers have been encouraged by the ICT to use public transport more often by introducing with such issues as electronic tickets purchase, real time notifications about strikes and road accidents along the travel route, the probability of late arrival, etc. The other positive GIS solutions aimed at end users were represented in New Zealand (Chowdhury et al. 2018) and Norway (Julsrud and Denstadli 2017). These countries have transport services, which are attributed to the needs of citizen in order to ensure the sustainable city development and create attitudes to switch from personal transport to public one.

Foreign experience in the development of the project has shown the decision-making in transport systems that in most cases to a leading position has not released indicators and economic criteria for the qualitative evaluation of projects from the point of view of end users (people and companies receive transport services). These factors can be indicators of affordability and transport accessibility, which should be taken into account as a priority in the development of systematic assessment plans investment projects of the development of means of communication, transport and refurbishment rolling equipment.

1.3. Information and Communications Technologies for end users in transport sphere

After analyzing the experience of different countries, they could be grouped into two branches. First, the traditional infrastructure approach for the transport improvement relates to the creation of new principles of economic sectors and public authorities interaction towards the quality of transport infrastructure renovation. Second, the transition to the information society provides the people's need differentiation due to the presence of inequality, particularly, in the access to new knowledge and innovations. Thus, the role of R&D and equal opportunities provision for citizens becomes one of the crucial tasks in transport system regulation. In addition, the construction of the Intelligent Transport System (ITS), which is the part of ICT in transport sphere, are based on informational, technological and economic development (see fig. 1.2). In this case, the accent is paid on the end users of such technologies with their individual preferences and social interests.

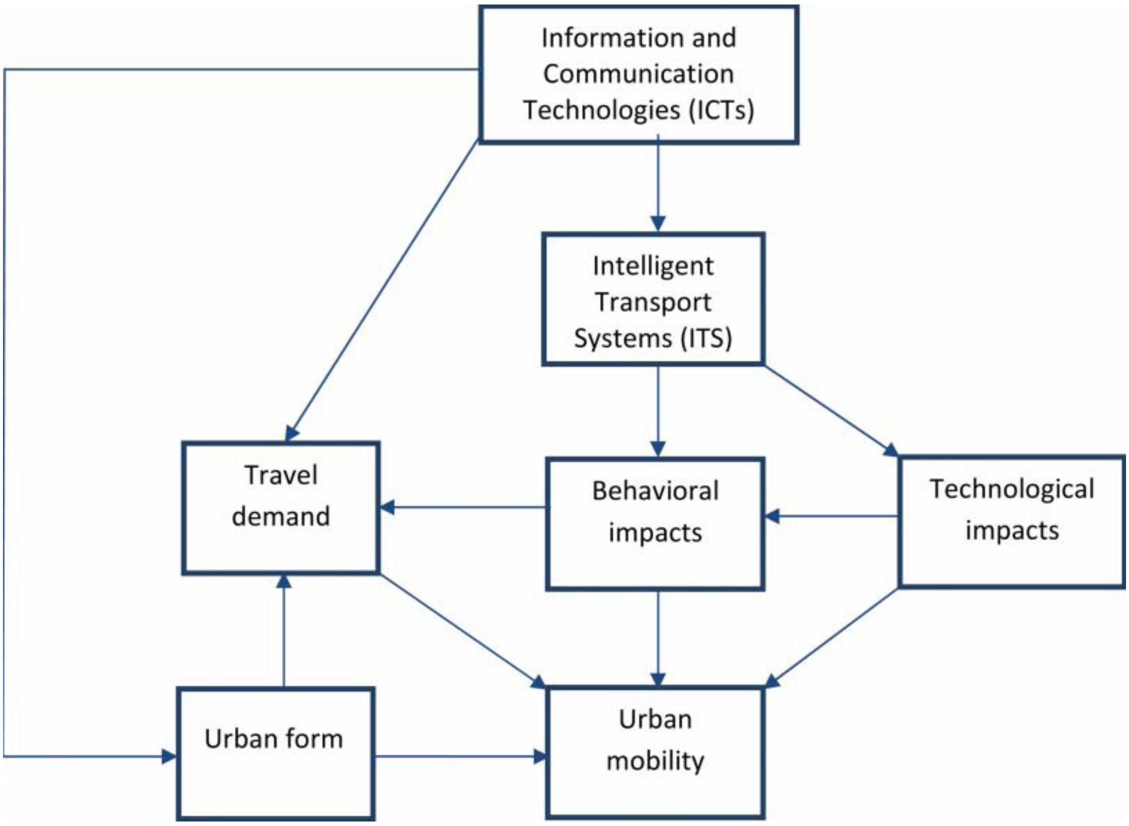

Figure 1.2 Potential effects of ICTs on urban mobility
Source: Cohen-Blankshtain and Rotem-Mindali (2016)

The key role in setting up any ICT is played by the end user, generally, the person who uses the certain services. The importance of interaction between physical transport infrastructure operations and end user transport services demand is highlighted as a crucial point to be taken into account for the purposes of sustainable development of a region (Knoeri, Steinberger, and Roelich 2016; Palvia, Baqir, and Nemati 2018). Citizens in this case are the final consumers of ICT and one of the key stakeholders of the process of ICT introduction. In scientific literature the notion of ICT for end user is described in different ways. Some authors pay attention on the social and economic impact for people due to the accessibility improvement by ICT introduction, therefore, ICT for end users — is a combination of services, which provide opportunities for social activities and employment (Bąk and Borkowski 2015; Chowdhury et al. 2018; Palvia, Baqir, and Nemati 2018). The other definition relates to the overall sustainable development of the region, so, ICT for end users is the set of technologies aimed at transport service quality increase in order to provide the sustainable region's development (Arsenio et al. 2017; Filippi, Fusco, and Nanni 2013; Mugion et al. 2018). The transport sector can be interpreted as the regional integration of communication networks, technical equipment, and services from transport, ensuring economic development of the particular region of a country as a whole, by combining all means of transportation and all components of transport systems including infrastructure.

One of the part of ICT relates to GIS, that provide information mobility. This concept refers to provision the access to personalized information and services, taking into account their current geographical position (Teslya 2014). In addition, some of the systems developed under GIS, also refer to systems that provide information mobility users. The main objective of such systems is to increase the mobility of users by the information support, containing the planning of the trip time and routes. GIS relies on a wide range of technologies and functions (Grabaurov 2015), such as:

- mobile communications (used for real-time travel information);
- the Internet emergency response;
- geographical location is a global navigation technology based on positioning satellites in the vehicle's automatic location;
- camera systems and artificial motion control and safety;
- detection and classification used to manage road traffic, incident management and security;
- vehicle systems and vehicle monitoring systems used to obtain information about travel and accident prevention;
- digital mapping is the road and transport databases, are used to regulate road traffic, traffic information, route routing, parking management.

The increase in demand for transport services, on the one hand, stimulates the expansion of the transportation network and appearance of new transport infrastructure. On the other hand, it gives a stimulus to develop new transport technologies to provide adequate capacity, safety, and quality of services offered (Julsrud and Denstadli 2017). At the same time, comprehensive development of the transport system requires investments in environmental protection from the negative impact of transportation (Wang and Moriarty 2017). It requires coordination of the activities and interests of the various stakeholders in the transport industry: manufacturers of vehicles, equipment, elements of the transport network, infrastructure and construction, technology providers, transport service providers, government, cities and individual users. It should be mentioned that due to limited resources and the need for transport services, such coordination involves the interaction of all means of transportation, vehicles and stakeholders. This approach requires the development of the innovations of the system, which will conduct not only research and development of technologies and the production of new products but also ensure equal access to the market development in the selection and application of new technologies (see fig. 1.3). Innovation implementation system is the essential element in the innovation economy in the context of knowledge distribution, and there is a need for international coordination, usage of open models of innovation, the development of a network-based approach to innovation development.

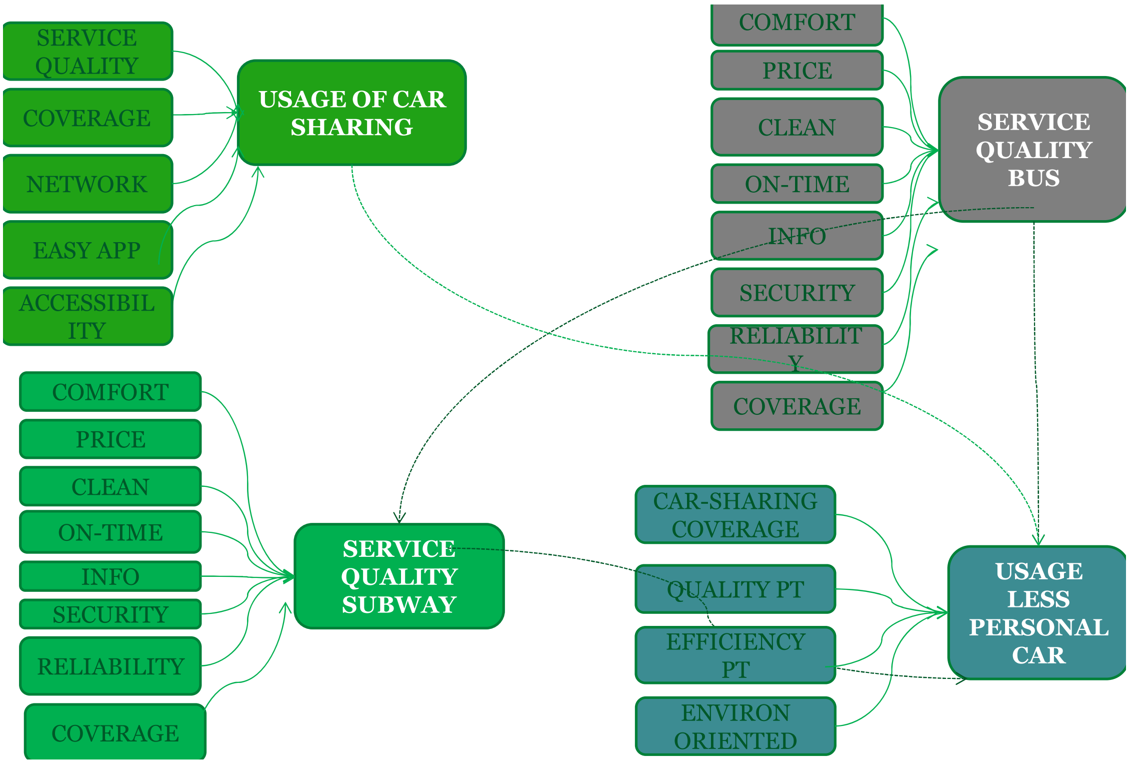

Figure 1.3 Qualitative cognitive map of ICT for end users

Source: Mugion et al. (2018)

GIS are aimed to provide end users with innovative services, related to different means of transportation and traffic management. These services provide information to users about the current road situation, which allows them to make more secure travel and make better use of existing transport network of the region. GIS integrates telecommunication, electronic and information technology for managing, planning, developing, maintenance of city transport systems. Application of information and communication technologies in the field of road transport and its relationship with other types transport significantly contributes to the effectiveness and efficiency of the transport sphere. It increases the safety of road transport and the mobility of passengers and goods.

CHAPTER 2
GEOGRAPHIC INFORMATION SYSTEMS AND TRANSPORT SYSTEM PERFORMANCE

This chapter relates to the methodology and methods for performance and quality assessment of transport system and its infrastructure. The first section contributes to factors and drivers influencing on the use of GIS in transport sphere. The second section of the chapter contains the definition and examples of transport system quality indicators and proposes the analysis of methods of transport system performance assessment.

2.1. Drivers of Geographic Information Systems use in transport sphere

According to researches of the transport infrastructure development in the big cities, several factors, which relate to the roads' safety, economic growth of the region and improvement of citizens' wealth are mentioned. Some studies describe correlation between the economic state of the region and safety of its transport system (Ichkitidze, Sarygulov, and Ungvari 2017; Dvořák et al. 2017; Tsapakis et al. 2017; Ngoc, Hung, and Tuan 2017). For example, it was found that transport infrastructure, including creation of separate bicycle and pedestrian lines, the overall condition of roads and share of non-car users, influences traffic safety. Moreover, in developed countries with transition economy the growth of car density does not necessarily lead to provision of measures for road accident rate decrease. For developed countries such dynamics is not obvious. The key point here is that transport infrastructure development mostly dependent on government decisions and citizens behavior. So, issues of consumer choice in terms of transport payments and tariffs are related to the setting up common quality standards of public transport usage, which can be based on classification of users.

The issue that is highlighted by the researchers is the behavior of citizens and factors influencing their choice of the district of living related to the transport infrastructure in the area (Lasley 2017; Wang et al. 2015). The quality of transportation facilities supported by factors of the distance from the home to the nearest highway, amount of bus stops in walking distance, factors of accessibility to the transport infrastructure and traffic congestion. These parameters are strongly correlated with the sales and rent prices on the residential property and, hence, with the citizens' behavior. A small amount of transportation problems in the area attracts new citizens, buyers of residential property. At the same time, the poor quality of transport does not have much effect on owners, who already live in the area. For users of transport, the transportation quality improvement relates to additional payments and fees. It was found that household transport expenditures could be negatively associated with the GIS technologies introduction and connected with the social optimum principle (Mayburov and Leontyeva 2017; Bris, Pawlak, and Polak 2017). This also relates to the regional specificity, the situation when transport payments differs along with the stage of GIS introduction and quality of transport services (Locatelli, Invernizzi, and Brookes 2017). So, the effect of GIS in different regions could be resulted on overall economic indicators and citizens' behavior in different ways.

GIS in transport sector provide a wide range of services, functioning as a recommendation system, searching for points of interest in an automatic way. These services provide information about places of attraction such as theaters, museums, bars, restaurants on the way user and give notifications about events on the road in real time. Moreover, GIS inform users about changes in public transport timetable, road accidents and works. One of the examples of GIS is the intermodal transport network, in which different transfer paths are suggested to the user on the way of the trip route to change several means of transport to get to the destination point faster. By the way, Teslya (2014) mentions several characteristics of such systems:

- Map display. The card can be downloaded from the internal memory or from external sources and must be updated, for providing the user with up-to-date information.
- Points of interest display. Among the points or places of interest are allocated sights (monuments, museums, memorial plaques, etc.), shops, cafes, and the others.
- Trip projections. Routes should be built both for all types of vehicles separately, and for their various combinations (intermodal route).
- Display events on the map. Congestion, traffic accidents, road repairs and other relevant information that adjust planned route.
- Mobility. The system entirely or partly (the main processing of information is made in the cloud computing systems, the user device is used only for data collection and display the result) works on the mobile device of the end user.
- Support for the user on a trip. Display of public transport schedules, navigation information, events.
- Information editor for the end user. During the trip, users can edit already available information about objects in the system or create new one associated with a certain geographical position.
- Additional services provision such as weather, booking hotels, car rental, availability of parking spaces, the cost of gasoline, etc.
- User preferences data gathering. All provided information should take into account user preferences.
- Recommendations. The information provided can be ranked based on the reviews of other users and the proximity of their interests to the interests of the certain user.

According to Snellen and Hollander (2017) the following changes and drivers in the transport sphere with ICT introduction are highlighted:

- users become more and more informed;
- transport options range increases;
- need to travel decreases;
- travel duration decreases;

- range of trip destinations broadens;
- mobility systems complexity increases;
- self-driving vehicles appearance.

Within the changes mentioned above the point of interest for the policymakers relates to the measurement of accessibility (the access to the range of transport alternatives), availability (the presence of mobile and immobile infrastructure), cost-efficiency (costs and gains proportion), acceptability (measuring internal and external effects due to ICT development).

So, the following drivers of GIS introduction, accordingly to Leviäkangas (2016), could be mentioned in accordance with transport infrastructure improvement:

- level of education;
- GDP value added;
- firm's profitability;
- traffic safety;
- security;
- access to transport services;
- GINI coefficient;
- life expectancy;
- amount of emissions;
- resource efficiency;
- rate of land use.

The other set of factors are presented by Pamplona and Oliveira (2016):

- total number of daily public transportation of passengers;
- consumer price index;
- average nominal wage rate;
- level of employment;
- population;
- economically active population;
- nominal rate of retail sales;
- nominal index rate of industry sales;
- the index utilization rate of the installed capacity in the industry;
- tax collection rate index on operations related to goods and on transport services;
- GNP;
- GDP.

According to Bąk and Borkowski (2015), such indicators mentioned above could be grouped into four categories:

1. Feasibility (including investment costs, operational and maintenance costs, financial viability, technical feasibility, organisational feasibility, administrative burden, legal feasibility, user acceptance, public acceptance).
2. Interest to travellers (including door-to-door travel time, door-to-door travel cost, comfort and convenience, safety, security, accessibility for mobility impaired).
3. Impact on modal change (including car usage, bus and coach usage, rail usage, ferry usage, aeroplane usage).
4. Other impacts, which covers mobility, congestion, CO2 emissions, contribution to user pays principle, contribution to European economic progress.

GIS are also driven by the gaining of environmental benefits. The traffic today continues to grow, so the impact on the environment of emissions and noise becomes serious. For example, reducing congestion on the road, or encouraging people to travel by public transport reduces the direct emissions of vehicles. Moreover, from the user side, the need for road confirmation, temporary travel estimates and reliable information provision exists. It includes such services as automatic vehicle location detection, automatic shipment tracking, vehicle compliance verification, driver monitoring. Speed control, warning of vehicle build-up and alternative route management help to make travel more comfortable and less stressful. Facilities such as multimedia systems provide entertainment and navigation. Public transport passengers also need to feel comfortable along the trip. So, the general priority, in this case, is to organize effective public transport system. At the regional level, it can manage requests and integrated information for different means of transport.

People have the opportunity to plan trips better, enjoy a safe trip, avoid delays and choose between alternative routes. Therefore, the role of public programs is essential in the way to provide end users with information about how they can enjoy greater safety, better information, more comfort, less travel time, and a cleaner environment.

The development of transport infrastructure determines the intensity, speed and volume of the total exchange of goods and services, which impedes the development of new areas and also causes the growth of investment attractiveness in the region. Also, the low level of development of transport infrastructure is one of the reasons for the underdevelopment of the labor market. The high level of misplacement costs significantly reduces the daily transit (migration), that reduces labor productivity. Moreover, low mobility has a negative social impact on the region. The high cost of housing in the city reduces the possibility of purchasing them, and underdeveloped traffic does not allow the fast access to the city center. As a result, quality of life declines.

2.2. Transport system performance and methods of its assessment using Geographic Information Systems

Socio-economic development of the region demands the well-structured transport system with modern transport infrastructure. The transport sphere affects the production site, so, it is impossible to achieve a proper distribution of productive forces without such system. Public transport services for passengers aim to reform the market in the way to create an environmentally-friendly sustainable system. In other words, the existence of public transport that meets the needs of the population. Ensuring proper quality of public transport services is an important task. The quality and performance of transport system is highly depends on the possibility to predict the transport congestion with the high probability. Understanding the quality of passenger transport services as a combination of transport characteristics is needed to analyze travel needs following regulatory requirements. Quality is an objective measure (feature) of the facility's state. Quality assessment is a process for comparing the actual level of indicator values with basic indicators (standards), identifying their differences and determining their causes. Currently, the need for transport infrastructure highly increases. This situation significantly limits the growth of the economy and reduces the quality of life of people.

GIS data can provide real-time information about the current status of the network for flight planning, road management, commercial transportation services. Lots of modern GIS used for urban transport monitoring systems. In addition, the data providing by such systems can be used for the traveling purposes. The main drivers of ICT development relate to the processes of transportation improvement by the increase of productivity, ensuring security and reducing travel time, cost and energy (Grabaurov 2015). They help to reduce congestion.

Congestion is a big problem for the whole transport system, increasing the efficiency of existing transport systems is the primary goal of GIS foundation. It includes traffic regulation throughout the region, advanced traffic management, road management systems, speed control infrastructure, driver reporting, etc. GIS services also make transportation safer, reducing the effects of natural disasters, by providing evacuation routes. They also maintain risk driving and control of dangerous road situations.

In order to connect the service and infrastructure quality the indicators, which are presented in tab. 2.1, are needed to be assessed.

The majority of the authors paid attention on transport services quality. Its assessment is devoted to the analysis of the following issues:

- safety and comfort;
- trip duration;
- environmental impact;
- service accessibility.

The measurement of the transport infrastructure quality usually contributes to indicators of territorial development of street road network, which are stated in public documents and

Table 2.1 Indicators of the state of the infrastructure development of the urban economy

Indicator	Calculation
Transport infrastructure	
Density of the road network km/thous. sq.km. of the territory	Length of public roads/area of the city territory
Provision of public roads with gas stations, units per 1,000 km	Number of gas stations/length of public roads
Proportion of hard-top roads in the public road network, %	Length of hard-top roads/total length of public roads
Proportion of roads with improved surface in the public road network, %	Length of roads with improved surface/total length of public roads
Communal infrastructure	
Level of illumination of streets, driveways, embankments, %	Length of illuminated parts of streets/total length of streets, driveways, embankments
Level of technical serviceability of gas networks, %	Length of the street gas network in need of replacement and repair/total length of the street gas network
Level of upgrade of gas networks, %	Street gas network replaced and repaired in the reporting year/total length of the street gas network
Level of technical serviceability of heat and steam networks, %	Length of two-pipe heat and steam networks in need of replacement/Length of heat and steam networks
Level of upgrade of heat and steam networks, %	Heat and steam networks replaced/Length of heat and steam networks
Level of technical serviceability of water supply networks, %	Length of two-pipe water supply networks in need of replacement/Length of water supply networks
Level of upgrade of water supply networks, %	Water supply networks replaced/Length of water supply networks
Level of technical serviceability of sewage networks	Length of two-pipe sewage networks in need of replacement/Length of sewage networks
Level of upgrade of sewage networks	Sewage networks replaced/Length of sewage networks

Source: Danilina and Chebotarev (2017)

regulations. For example, in accordance with the Master Plan of Saint-Petersburg, the following indicators are required to analyze the development of street road network:[5]

[5]Saint-Petersburg Legislative Assembly. *Law of Saint-Petersburg of December 22, 2005 № 728-99 (as amended on July 6, 2017) «O General'nom plane Sankt-Peterburga» [«About the Master Plan of Saint-Petersburg»].* Saint-Petersburg: Saint-Petersburg Legislative Assembly, 2017. Accessed April 9, 2018. https://www.gov.spb.ru/law?d&nd=8422495.

1. The maximum number of vehicles, located simultaneously on the main roads:
   (a) quantity of main roads;
   (b) length of main roads;
   (c) roadway area of main roads;
   (d) capacity of main roads.
2. The maximum number of vehicles, located simultaneously on the main streets:
   (a) quantity of main streets;
   (b) length of main streets;
   (c) roadway area of main streets.
3. The maximum number of vehicles, located simultaneously on the road junctions.
4. The maximum number of vehicles, located simultaneously on the bridge crossings.
5. The maximum number of vehicles, located simultaneously on the local streets and roads.
6. Number of vehicles provided with parking spaces for permanent storage:
   (a) number of permanent storage parking spaces near house territory;
   (b) total area of permanent storage parking spaces near house territory;
   (c) number of permanent storage parking spaces in garages and parking lots;
   (d) total area of permanent storage parking spaces in garages and parking lots;
   (e) number of permanent storage parking spaces on street road network;
   (f) total area of permanent storage parking spaces on street road network.
7. Number of vehicles provided with parking spaces for temporary storage:
   (a) number of temporary storage parking spaces on the objects belonging to the subjects of economic activity;
   (b) total area of temporary storage parking spaces on the objects belonging to the subjects of economic activity;
   (c) number of temporary storage parking spaces on street road network;
   (d) total area of temporary storage parking spaces on street road network.
8. The maximum number of pedestrians in the zone of out-of-the-way pedestrian crossings:
   (a) number of pedestrian crossings on street road network;
   (b) length of pedestrian crossings on street road network;
   (c) total area of pedestrian crossings on street road network.
9. The length of the route network per 1 km^2 per 1000 inhabitants.
10. The area of infrastructure facilities of urban public transport services, per 100 units of vehicles.
11. The area of the street road network in square meters for 1 vehicle.
12. The length of allocated lanes for urban land passenger transport to 1 km of the route network per 1,000 passengers.
13. Number of systematic jams of vehicles at road crosses per one traffic junction.

14. The number of transport interchange nodes for 10,000 passengers (from one type to another).
15. Number of parking places per 1000 cars.
16. Number of out-of-town crosswalks per 10,000 people.
17. Information on roads (type, length, geographical coordinates, subordination).
18. Information on traffic restrictions (with coordinates).
19. Information on emerging problems with the road surface and improvement on the road network.
20. The average speed of traffic on the sections of the road network (with coordinates, date and time).
21. Public transport routes with indication of the established and actual arrival time at stops in dynamics.

Thus, transport system quality reflects to the measure of region's economic activity influencing on the sustainable economic development (Popova 2017; Saidi, Shahbaz, and Akhtar 2018; Skorobogatova and Kuzmina-Merlino 2017). It could be also measured through the assessment of economic indicators (population density, GDP growth, etc) and characteristics of the transport system (road density, length of public roads, freight turnover, etc). Both ways of the assessment (objective quality) are widely discussed and implemented in scientific literature (Allard and Moura 2016; Androniceanu 2016; Dvořák et al. 2017; Kaundinya et al. 2016; Roşu and Blăgeanu 2015). Some researchers introduce the importance of social aspects of people's behavior and preferences (subjective quality) in transport infrastructure quality assessment (Berežný and Konečný 2017; Leviäkangas 2016; Mugion et al. 2018).

Summing up, along with mentioned above, the indicators of the current and future state of street road network of transport system should correspond to the following characteristics:

1. Internal characteristics:
   (a) Reliability:
      - The quality of maintenance of public roads, pedestrian areas, public services objects.
   (b) Speed:
      - Land transport coverage network.
      - Parking space.
2. External characteristics:
   (a) Safety and security:
      - Traffic control systems.
      - Maintaining the normative state and upgrading of street road network facilities.
   (b) Accessibility:
      - Creation and development of parking space.
      - Transportation planning, design and operation of street road network objects.
      - Quality of transport services.

Modeling the transport improvement decisions are based on users of the transport infrastructure and the policymakers. The effective cooperation between the state and citizens in terms of transport infrastructure improvement, including railroad, is more effective with the presence of ICT (Gadelshina and Vakhitova 2015; Klein and Ben-Elia 2016; Liu and Ceder 2017). For example, the one of useful instruments is public transport timetable synchronization, which helps to assess and stimulate demand both on ICT and public transport use. This kind of intelligent tools relates to big amount of data streams, that are needed to be collected and processed. Researchers faced the problem of automatize the big data collection. The sources of data could be rather different from GPS signals to social media data (De Gennaro, Paffumi, and Martini 2016; Lee et al. 2016b; Nour, Hellinga, and Casello 2016; Vlasov et al. 2017). The generalization of GPS data is attributed to the probability to define correct transit trips concerning similar speed and acceleration. The social media data could be also useful and easy to obtain. For example, within Twitter data the users' roots could be projected by the most attended by certain users places according to their geoposition. The other solution, which is quite successful for transport monitoring and data collection, is satellite navigation introduction that helps intelligent transport system become embedded into the government ICT paradigm. So, the big data streams creates possibilities to see a general picture of transport issues in the city or region and could be an excellent instrument to improve governance and provide better managerial decisions. Thus, the researchers use various methods and data in the transport infrastructure assessment, that is presented in tab. 2.2.

Table 2.2 Infrastructure quality assessment methods and data

Methods	Data	Authors
Index analysis	Surveys, national statistics, theoretic framework	Morfoulaki, Myrovali, and Kotoula (2015); Danilina and Chebotarev (2017); Umer et al. (2016)
Econometric modeling & geospatial analysis	Surveys, national statistics, smartphone data, Twitter, OpenStreetMap	Arsenio et al. (2017); Pamplona and Oliveira (2016); De Gennaro, Paffumi, and Martini (2016); Ellison et al. (2015); Lee et al. (2016b); Nour, Hellinga, and Casello (2016); Roşu and Blăgeanu (2015)
Case-study & systematic literature review	National statistics, theoretic framework	Kaundinya et al. (2016); Petrov and Geraskina (2017); Berežný and Konečný (2017); Barakchi, Torp, and Belay (2017); Bueno, Vassallo, and Cheung (2015)
Economic modeling & agent-based modeling	National statistics, OpenStreetMap, theoretic framework	Broin and Guivarch (2017); Klein and Ben-Elia (2016); Krylatov (2017); Liu and Ceder (2017); Milevich et al. (2016); Karbovskii et al. (2014)

Source: composed by the author

Some authors are intended to provide evidence for bicycle transport development with the ICT calibration (Arsenio et al. 2017; Ellison et al. 2015; Behrendt 2016; Evseeva 2017). They introduced the methodology for the trip stops allocation and managing the transport system for bicycle users using the data from smartphones. The obtained by the authors results could be useful for management decisions improvements for bicycle lines construction or renovation. However, these methods of demand assessment could not be appropriate, for example, for monitoring of cycling traffic. Firstly, the special ICT infrastructure is needed. Secondly, the transport facilities such as separate bicycle lines demands improvement.

The wide range of instruments and analytical tools could be also useful to determine the impact of ICT introduction on transport infrastructure. In terms of safety the cloud computation platforms and agent-based approach helps to provide in-time decisions in extreme situation on roads and mass events, e.g. FIFA World Cup in Saint-Petersburg (Milevich et al. 2016; Karbovskii et al. 2014; Krylatov 2017). For provision of the road improvements along with simulation models, analytical optimizations were provided. It results to management decisions according to the new road construction in order to maximize road bandwidth. It was found that more effective way to achieve this goal is to maximize bandwidth on the shortest roots, which binds districts. Moreover, such approaches covers not only the people's behavior but also helps to monitor the road state, bandwidth and creation of new road roots, providing information for the management. So, along with the proposed methods the research findings could be presented as a form of table (see tab. 2.3).

Table 2.3 Modeling tools proposed by the researchers

Idea	Tools	Authors
Trip stops allocation and managing the transport system for bicycle users	Sensors' data collection; econometric modeling	Ellison et al. 2015; Behrendt 2016; Evseeva 2017
Assessing the safety of transport infrastructure for extreme situations and mass events	Mathematical models; agent-based modeling; forecasting	Milevich et al. 2016; Karbovskii et al. 2014; Krylatov 2017
Use of social media and GPS data for optimization transit trips	Big Data processing; machine learning; forecasting	De Gennaro, Paffumi, and Martini 2016; Lee et al. 2016; Nour et al. 2016; Vlasov et al. 2017

Source: composed by the author

Concentrating on the methods of forecasting with the use of regression models and machine learning for transport system quality assessment, the following algorithms are worth to be used in the analysis:

- Based on Logistic regression and Linear Discriminant Analysis (Arsenio et al. (2017); Julsrud and Denstadli (2017)).
- Based on k-Nearest Neighbors (Chowdhury et al. (2018); De Gennaro, Paffumi, and Martini (2016); Lee et al. (2016a)).

- Based on Decision Trees (Morfoulaki, Myrovali, and Kotoula (2015); Roşu and Blăgeanu (2015); Wang et al. (2015); Zedgenizov and Burkov (2017)).

Summing up, the mentioned algorithms could be the basis of the assessment of transport system quality in the following chapter.

CHAPTER 3
MODELING TRANSPORT SYSTEM QUALITY USING INRIX GIS DATA

This chapter is devoted to the congestion assessment and prediction for transport system in Saint-Petersburg using data from INRIX GIS. The first section of the chapter relates to the data and methodology description. The second section states the main model, proposes results and recommendations.

3.1. Data and methodology

In accordance with the goal of the research the following problems have an influence on quality of transport system:

1. Increase of load on road networks.
2. Increase of private transport users and traffic jams.
3. Overloaded public transport.

In order to assess the quality of transport system and role of GIS, the following hypothesis will be tested: the data obtained from GIS helps to assess the transport system quality and predict the future changes on road transport network.

The one of characteristics of transport system quality is the level of congestion, which is measured by the duration and length of congested road segments (traffic bottlenecks). The INRIX (https://inrix.com) is the global company, developing the GIS products for road traffic assessment and prediction for both business and government (including Russia). INRIX is currently the one of the most powerful, in terms of already gathered and processed data, systems suggesting the free open access (30-day trial period) to the historical data about traffic of more than 47 countries. For the current research the data were obtained for the part of Saint-Petersburg road network (the broadened zone of paid parking), which contains the most congested and dangerous segment (according to Yandex analytic report[6]) — Liteyny Bridge. The chosen road segments in INRIX interface are presented in figure 3.1.

Figure 3.1 Selected region for analysis from INRIX Roadway Analytics GIS
Source: road network segments obtained from INRIX Roadway Analytics

[6] Car crashes in Saint-Petersburg 2016-2017. [In Russian]. https://yandex.ru/company/researches/2017/spb/accidents (accessed May 3, 2018).

After downloading and processing raw *.xml-file data for bottlenecks and its characteristics from INRIX database (https://analytics.inrix.com), 108 bottlenecks from 9 May, 2017 till 19 April, 2018 were obtained. Each bottleneck has its own timestamps with the duration, length and time of appearance. In addition, the INRIX system provide information about the impact of each bottleneck on the whole chosen road segments (road network).

In order to consider the effects from road events and weather conditions the additional variables (features) were added to the dataset. The daily data for overall road restrictions in the chosen area were obtained and processed form Open Government platform (http://data.gov.spb.ru). The weather hourly data were merged by the closest timestamp to the dataset from the http://rp5.ru weather site. After the process of data processing and matching, 6228 unique timestamps for 108 bottlenecks were collected for 345-days period. The description of variables is presented in table 3.1.

Table 3.1 Variables description

Name	**Measure**	**Type**	**Object**	**Time scale**	**Description**
max.length	km	quantitative	bottleneck	day and time	maximum bottleneck's length
max.duration	min	quantitative	bottleneck	day and time	maximum bottleneck's duration
Impact.Factor	unit	quantitative	bottleneck	whole period	average duration × average length × number of occurrences
Occurrences	unit	quantitative	bottleneck	whole period	number of bottleneck's occurrences
av.length	km	quantitative	road network	day	average length of all bottlenecks
av.duration	km	quantitative	road network	day	average duration of all bottlenecks
restrict	unit	quantitative	road network	day	number of actual road restrictions in the area
temp	°C	quantitative	road network	day and time	air temperature
wind	km/h	quantitative	road network	day and time	speed of the wind
view	km	quantitative	road network	day and time	road visibility
Direction	4-level	factor	bottleneck	whole period	the direction of a bottleneck (E — east, N — north, S — south, W — west)
daypart	4-level	factor	bottleneck	day and time	part of the day
cloud	9-level	factor	road network	day and time	% range of clouds
event	2-level	factor	road network	day	proxy for celebrations and big events in the city
day	7-level	factor	road network	day	weekday

Source: composed by the author

Descriptive statistics for the variables are presented in the following tables (for quantitative — in table 3.2, and for factors — in table 3.3).

Table 3.2 Descriptive statistics of quantitative variables

Variable	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
max.length	0.26	1.58	2.17	2.21	2.95	5.83
max.duration	1.00	4.00	10.00	28.07	31.00	769.00
Impact.Factor	106.00	2,680.00	12,190.00	16,370.00	32,860.00	45,330.00
Occurrences	1.00	70.00	226.00	251.60	397.00	660.00
av.length	1.21	2.11	2.20	2.21	2.31	3.83
av.duration	2.00	21.64	27.74	28.07	33.75	137.00
restrict	5.00	19.00	28.00	30.09	40.00	60.00
temp	−20.80	0.20	8.00	6.87	14.40	26.00
wind	0.00	1.00	2.00	2.11	3.00	6.00
view	0.20	10.00	10.00	8.55	10.00	10.00

Source: composed by the author

Accordingly to presented tables, all quantitative variables, except, *temp* and *view* has a positive skew (right-skewed distribution) indicated by the greater mean over median value. It is considered as a presence of high values of inspected indicators. For example, the largest (not typical on average) *av.duration* in 137 minutes connected with the weekend restricted traffic and events dedicated to the day of unknown soldier. The other atypical value is demonstrated by the variable *max.duration*. It connected with the start of the road restrictions near Ligovsky Prospect. The largest *Occurences* of bottlenecks in the area of Fontanka embankment in May, 2017 also caused by the road construction works. In general, variables connected to the weather conditions are quite uniformly distributed, comparing the mean, median and quartiles values, which is caused by the relatively close amount of cold and hot days in the inspected period.

Considering the statistical properties of factor data, the portion of the data, distributed by the factor levels, is varies for all the variables. For example, the variable *Direction*, indicating the direction of the bottleneck (contraction to lower traffic speed), represents the south-western direction highly than direction to north and east. It indicates the congestion distributed higher at the entrance to city center. In addition, the bottlenecks appearing in the weekend are more than six times lower than the bottlenecks appearance at the weekdays. However, the data portions for the weekdays are relatively close to each other (from Tuesday to Friday) in 20–23% range of data obtained. Also the bottlenecks, accordingly to variable *daypart*, appear more often in the morning and afternoon (day-level) than in the evening and night. Furthermore, the weather conditions for the percentage rate of clouds is skewed towards 100% cloud days (when the bottlenecks appear frequently).

Table 3.3 Descriptive statistics of factor variables

Variable	**Observations**	**% from total**
Direction_E	1375	22.1
Direction_N	550	8.8
Direction_S	2384	38.3
Direction_W	1919	30.8
day_Sun	36	0.6
day_Mon	653	10.5
day_Tue	1262	20.3
day_Wed	1256	20.2
day_Thu	1429	23.0
day_Fri	1424	22.9
day_Sat	168	2.7
cloud_0%	624	10.0
cloud_0-10%	111	1.8
cloud_20-30%	231	3.7
cloud_40%	202	3.2
cloud_50%	133	2.1
cloud_60%	294	4.7
cloud_70-80%	663	10.6
cloud_90-100%	900	14.5
cloud_100%	3070	49.3
event_TRUE	1151	18.5
daypart_night	117	1.9
daypart_morning	1944	31.2
daypart_day	4098	65.8
daypart_evening	69	1.1

Source: composed by the author

On the next stage of analysis and further predictions, split the sample to two parts in such way that 80% — for training and 20% — for test samples is made. The range between maximum and minimum timestamps is 345 days. So, the date of division is 10th February, 2018. Taking into account that the sample contains not all the days in the range we get 241 timestamps (with 5235 observations) for training sample and 51 (with 993 observations) — for test sample.

Then, check the balance in two subsamples by the presence of similar portion of events and winter days to analyze their similarity. For big events: 19.2% — in train sample, 14.8% — in test sample. For winter days: 25.6% — in train sample, 27.9% — in test sample. Consequently, the two samples are balanced and relatively similar by amount of events and weather conditions, that is the reasonable way to the sample splitting.

Going to the next stage of the analysis, prepare the data in time prospective in order to identify key dependencies between variables. As a dependent (target) variable for the modeling use the *av.duration*, which fluctuates daily and represents the overall performance of transport system situation (with bottlenecks duration) in the selected area. Inspect the variable *av.duration* with the classical method of time series analysis and identify which variables could have an effect on the series behavior (fig. 3.2). P-value of Augmented Dickey-Fuller Test with null hypothesis about process non-stationarity equals 0.01. So, the process described by the *av.duration* series is stationary that the fact of the usage of the predictive modeling tools.

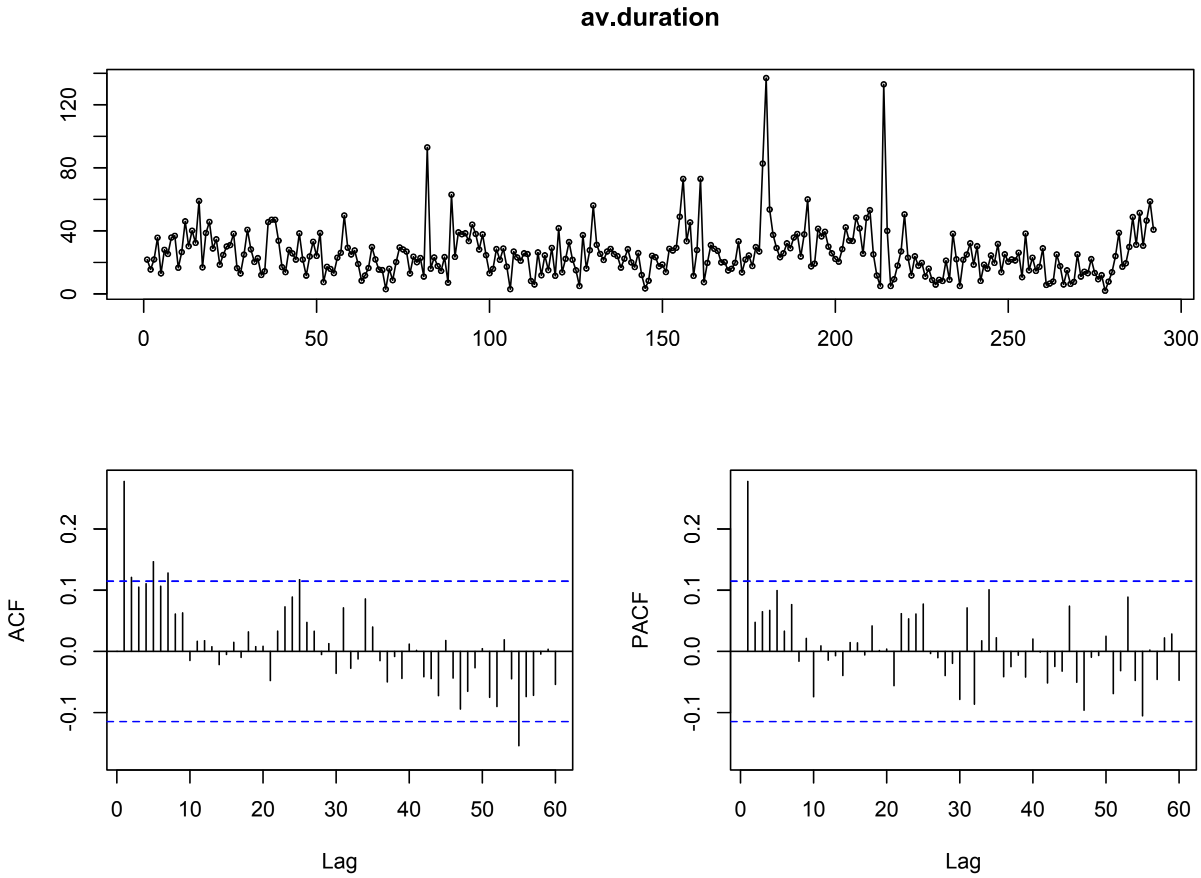

Figure 3.2 Time series diagnostic plots for variable *av.duration*
Source: composed by the author

For the timestamps the sample contains time varying variables such as *restrict*, *event* and *day*. Also the variable *Occurrences* is recalculated by days as the sum (new variable named *occur*). Construct also the lags of these variables, except *day* variable, for the purpose of the external variables inclusion in the model and keeping the effect of the past. After the division for training and test samples we get 241 vs. 51 observations relatively. The descriptive statistics are presented in the following tables (quantitative variables in tab. 3.4, factor variables in tab. 3.5).

Table 3.4 Descriptive statistics of quantitative variables for training sample in time series analysis

Variable	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
av.duration	3.00	16.86	24.50	26.93	32.39	137.00
occur	4.00	1,245.00	2,754.00	2,507.00	3,637.00	4,938.00
restrict	18.00	27.00	31.00	33.32	43.00	60.00

Source: composed by the author

Table 3.5 Descriptive statistics of factor variables for training sample in time series analysis

Variable	Observations	% from total
day_Sun	13	5.4
day_Mon	37	15.4
day_Tue	40	16.6
day_Wed	40	16.6
day_Thu	40	16.6
day_Fri	40	16.6
day_Sat	31	12.9
event_TRUE	41	17.0

Source: composed by the author

As presented in the last tables, the distribution of quantitative variables in training sample has quite close values in comparison between mean and median that does not indicate the skewness. For the factor data, the representation of days with bottlenecks occurrence resembles the relative distribution in the whole sample taken for all bottlenecks in time prospective. Furthermore, the representation of the big events (variable *event*) portion is also quite similar to the same rate in the large sample (17.0% vs. 18.5% respectively).

Next, check normality of the chosen dependent variable in training samples for all bottlenecks during the days and as a whole in time prospective graphically (fig. 3.3).

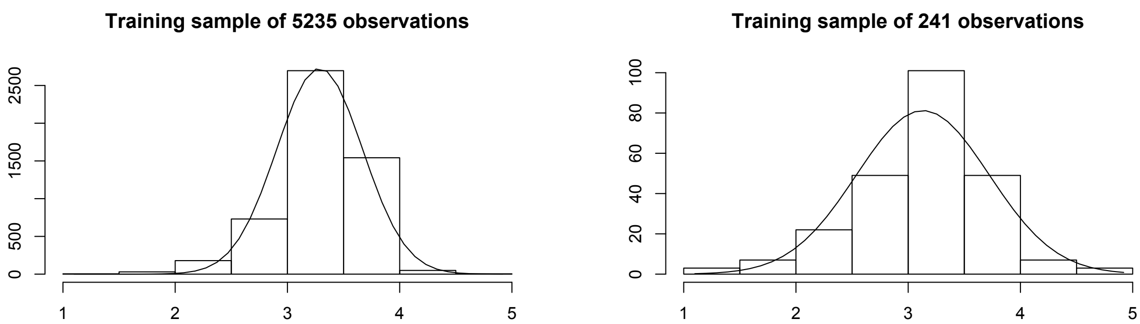

Figure 3.3 Histograms with normal curve overlay for variable *av.duration*

Source: composed by the author

As represented on the histograms, graphically the distributions resemble the behavior of normal one. However, the Kolmogorov-Smirnov test for normality for large (more than 5,000 observations) samples with null-hypothesis about the attitude to the normal distribution portion gives p-values close to zero (the null-hypothesis rejection). Along with the fact described previously, it can be assumed that the distribution of variable is close to normal because of the large amount of observations and for the purposes of considering all outliers with the additional proxy parameters for weather conditions and dummy for big events.

So, the following research design is taken into consideration. Firstly, the time series analysis with the addition of different factors with lags in order to identify key dependencies and relationships. Secondly, the choice of the best in terms of error minimization, significance of coefficients and portion of information described, model. Thirdly, the addition of predicted values of dependent variable by the chosen model in the dataset. Fourthly, the transformation of the variable to the factor one in order to solve the classification task about the average daily bottlenecks duration in the inspected area. Fifthly, identification of important in terms of described variance factors (features) on the level of each bottleneck occurrence with the machine learning algorithms. Finally, the choice of the best classification model for the description of large train sample and the prediction accuracy of the test sample.

3.2. Modeling

3.2.1. Time series analysis

Before the time series analysis conduction test the train sample date for stationarity in order to make forecasting models. Accordingly to Augmented Dickey-Fuller Test with p-value equals 0.01 for *av.duration* in training sample, the series is stationary. Then conduct several ARIMAX models in order to choose the time series terms and factors influencing better performance of the model. Models conducted for different set of external regressors with and without lags with the help of *auto.arima* algorithm (iteration of model terms in order to minimize Akaike Information Criteria — AIC) performed in "R" statistical package (library "forecast") are presented in table 3.6.

Referring to the models estimations outputs, all ARIMAX models with the lowest AIC has only the MA(1) term (first order of moving average component) that indicates the kind of dependency from the one previous period of time. Notice also that this term is significant for all five conducted models. Considering the external regressors, the lags for *occur* variable and *restrict* (and its lag) are insignificant that could be described as the absence of the path dependence process in terms of road restrictions (if they are already finished) or amount of bottlenecks in the previous period of time. However, the big events variable is significant and the dummies on weekdays (except Friday) are significant, too. It represents the relative impact of the day and events hold on the average duration of bottlenecks performance in the inspected area.

In terms of the coefficients significance and parsimonious approach (conducting compact models in terms of less amount of variables) the fifth model is better than the others. In addition, the AIC is the smallest in this model comparing with the four rest models that indicates about the less information in the series description is lost. Moreover, the Root-Mean-Square-Error indicator (RMSE), that represent the value of the deviation between real and fitted by the model values, is the smallest, too. So, for the further analysis the fifth model is chosen by mentioned above criteria.

Table 3.6 ARIMAX estimation results

	Dependent variable:				
	av.duration				
	(1)	(2)	(3)	(4)	(5)
ma1	0.211***	0.234***	0.233***	0.233***	0.234***
	(0.062)	(0.062)	(0.062)	(0.062)	(0.062)
intercept	27.333***	36.615***	36.530***	36.211***	35.279***
	(4.626)	(5.974)	(6.001)	(6.077)	(4.452)
lag.occur	0.0002	0.0001	0.0001	0.0002	
	(0.001)	(0.001)	(0.001)	(0.001)	
restrict	−0.066	−0.044	−0.084	−0.082	
	(0.120)	(0.120)	(0.298)	(0.298)	
lag.restrict			0.044	0.045	
			(0.299)	(0.298)	
event_TRUE	7.706**	7.324**	7.350**	7.015**	7.521**
	(3.042)	(3.049)	(3.053)	(3.217)	(2.997)
lag.event_TRUE				1.042	
				(3.180)	
day_Mon		−13.026***	−13.006***	−12.973***	−13.137***
		(4.782)	(4.785)	(4.785)	(4.770)
day_Tue		−10.212**	−10.236**	−10.307**	−10.185**
		(5.188)	(5.190)	(5.194)	(5.057)
day_Wed		−9.009*	−9.055*	−9.118*	−8.869*
		(5.447)	(5.456)	(5.458)	(5.072)
day_Thu		−11.199**	−11.263**	−11.323**	−11.015**
		(5.464)	(5.481)	(5.483)	(5.050)
day_Fri		−7.863	−7.906	−8.124	−7.613
		(5.529)	(5.537)	(5.576)	(5.039)
day_Sat		−10.789**	−10.785**	−10.884**	−10.586**
		(5.365)	(5.366)	(5.374)	(4.839)
AIC	2034.77	2037.66	2039.63	2041.53	2033.8
RMSE	16.08	15.78	15.78	15.77	15.78
Note:					*p<0.1; **p<0.05; ***p<0.01

Source: composed by the author

On the next stage, check the model quality with the help of formal statistical tests. Firstly, the Box-Ljung test for serial autocorrelation in the model residuals with the null hypothesis about no autocorrelation in the model has p-value equals 0.8. So, by not rejecting the null hypothesis it is assumed that the model is free of serial autocorrelation, which is a sign for the model usage in forecasting purposes. Graphically the autocorrelation check in chosen model is presented in figure 3.4.

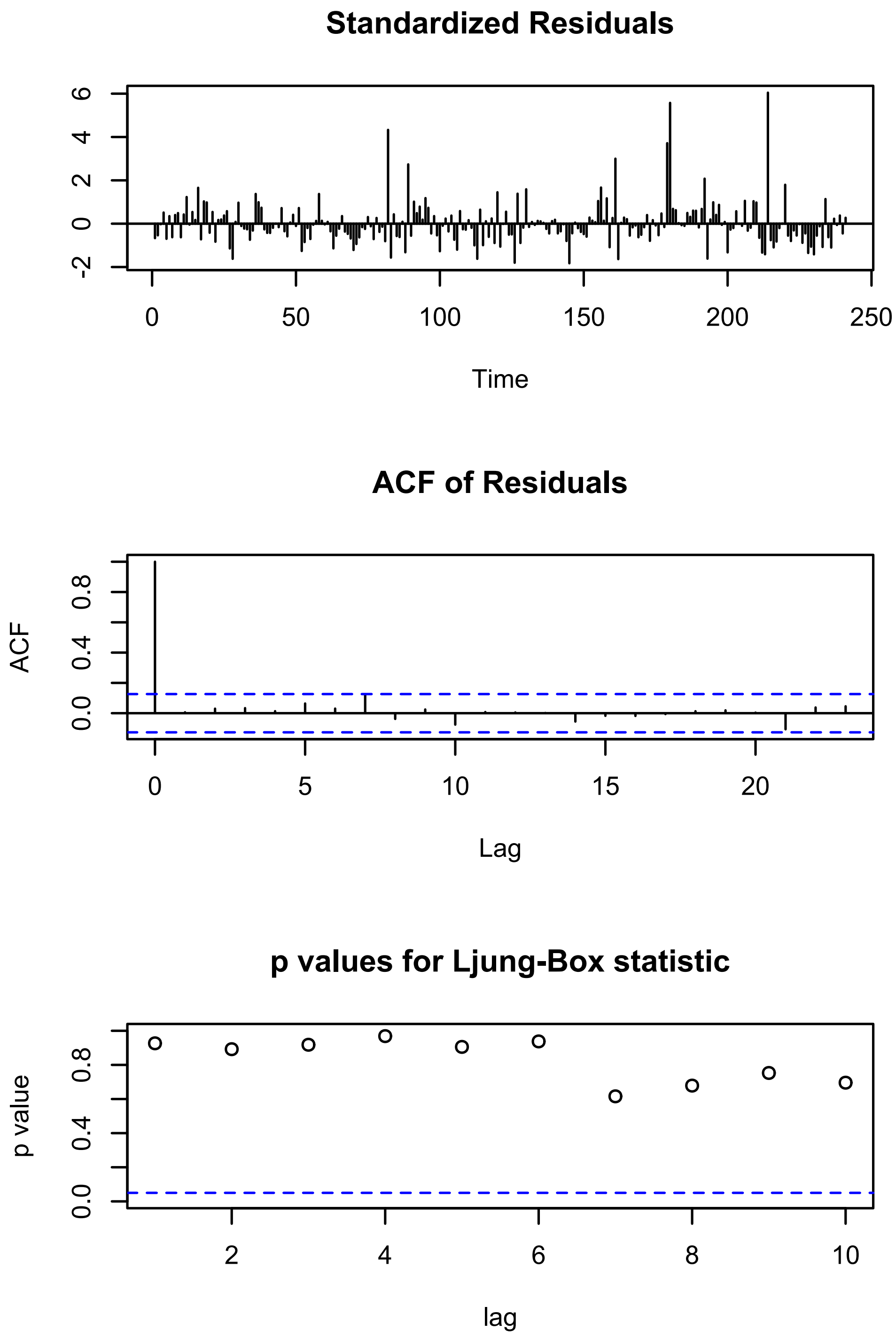

Figure 3.4 The chosen model autocorrelation diagnostic plots

Source: composed by the author

Then, check the model stability (for prediction purposes) with the graphical representation of the inverse MA root (fig. 3.5). So, the root locates inside the unit circle that gives an information about the model stability.

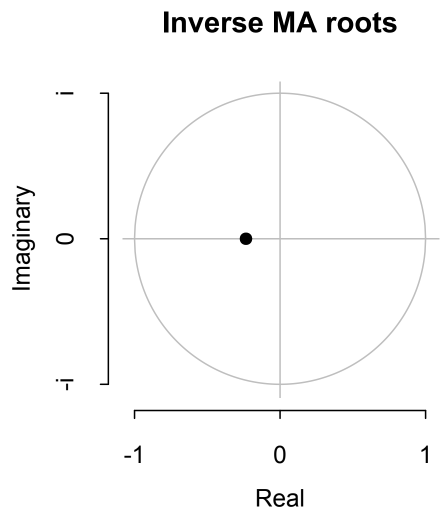

Figure 3.5 The chosen model stability diagnostic plot
Source: composed by the author

After that, perform the model forecasting and fitted values. In figure 3.6 the black line indicates the actual data, the red line perform the fitted values obtained by the fifth model in the training sample, the blue line (with the 0.1 and 0.05 levels of confidence) provides the predicted values for *av.duration*.

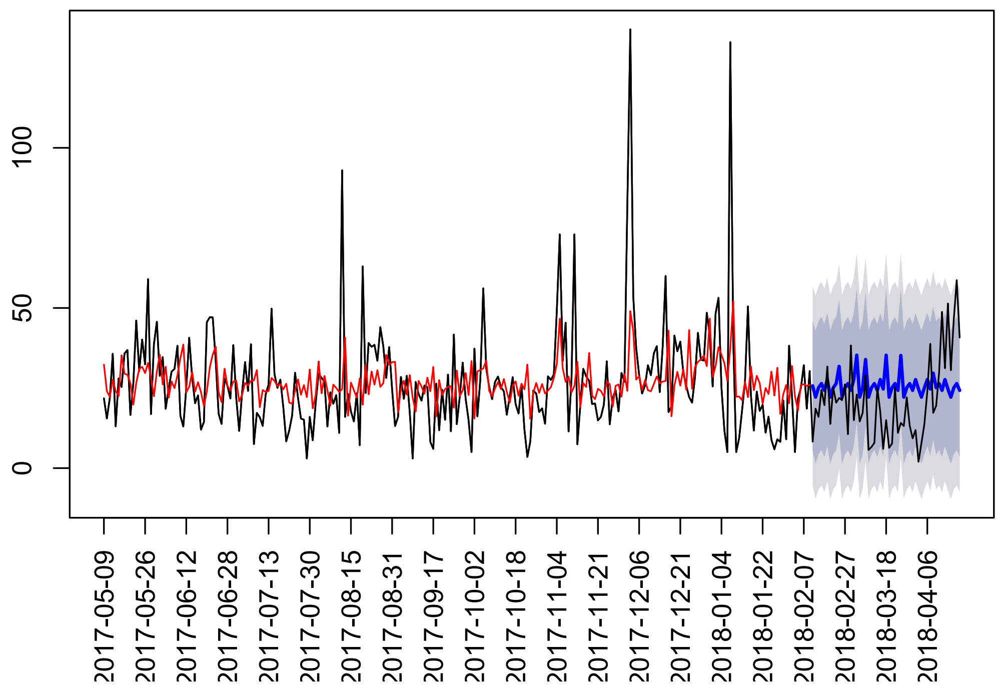

Figure 3.6 The chosen model forecast and fitted values for *av.duration*
Source: composed by the author

3.2.2. Machine learning modeling

Obtained values from the ARIMAX model for *av.duration* and *lag.av.duration* (lagged by one period target variable) are plugged in the large dataset with the bottlenecks objects. Than, in order to make more broaden predictions with the use of machine learning algorithms, the classes (for classification problem) are created for *av.duration* in such way "<20" (21% in whole, 17% in training), "20-30" (43% in whole, 44% in training), "30-40" (25% in whole, 28% in training), "⩾40" (11% in whole, 11% in training) and recorded to the new variable *duration*. Such division relates to relatively the same portion of data in the whole sample and in the training sample. Moreover, the representation of some factors (features) with boxplots indicates the relatively balanced division with the small portion of outliers (fig. 3.7).

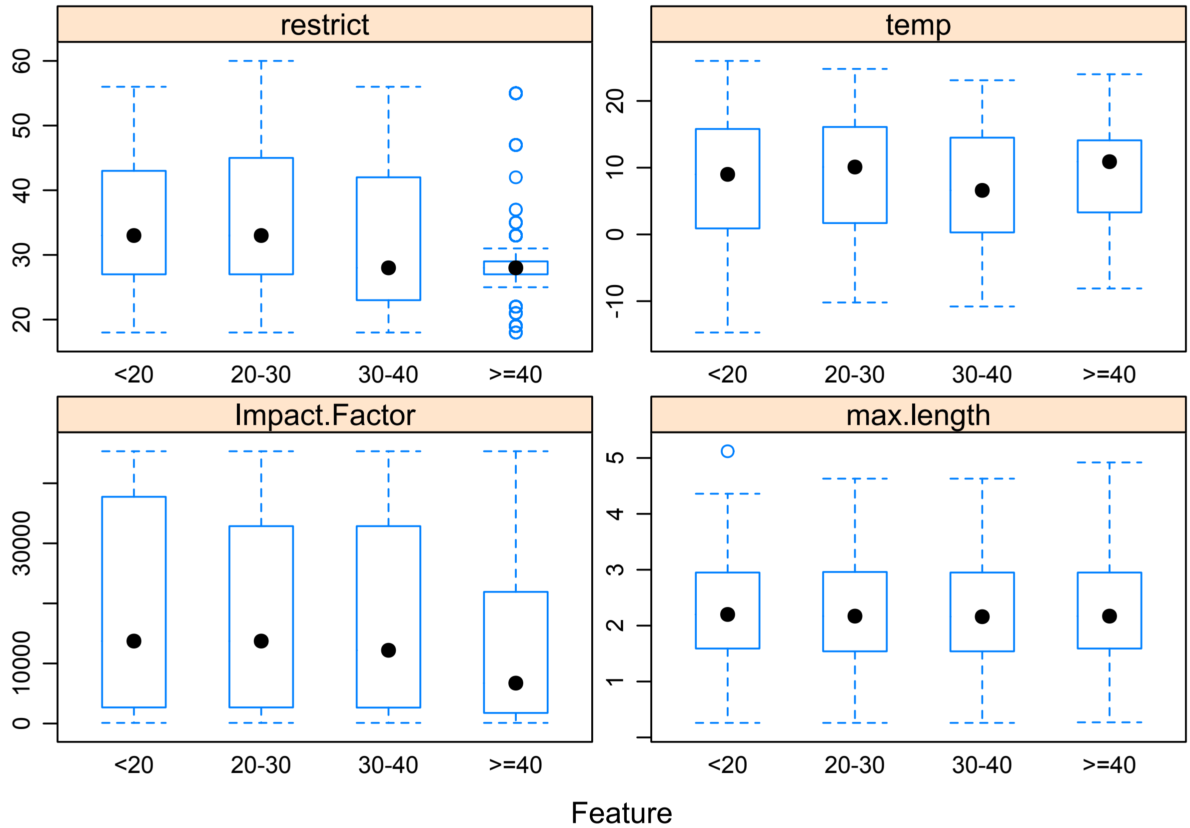

Figure 3.7 Feature plot for *duration*

Source: composed by the author

As could be seen from the boxplots by the groups of *av.duration*, for all presented features the mean and boundaries from minimum to maximum values are approximately the same. There are several outliers for *restrict* variables in the category "not less than 40 minutes", where the concentration for such type of congested days locates around 30 road restrictions in the inspected area of road network.

On the next stage, with the help of "R" statistical package (library "caret"), the Random Forest model is conducted (with target variable *duration*) with inclusion of all collected variables. For the purpose of overfitting problem avoidance, choose the most important, in terms of rate of described variance in the model, features, according to Random Forest importance plot (fig. 3.8).

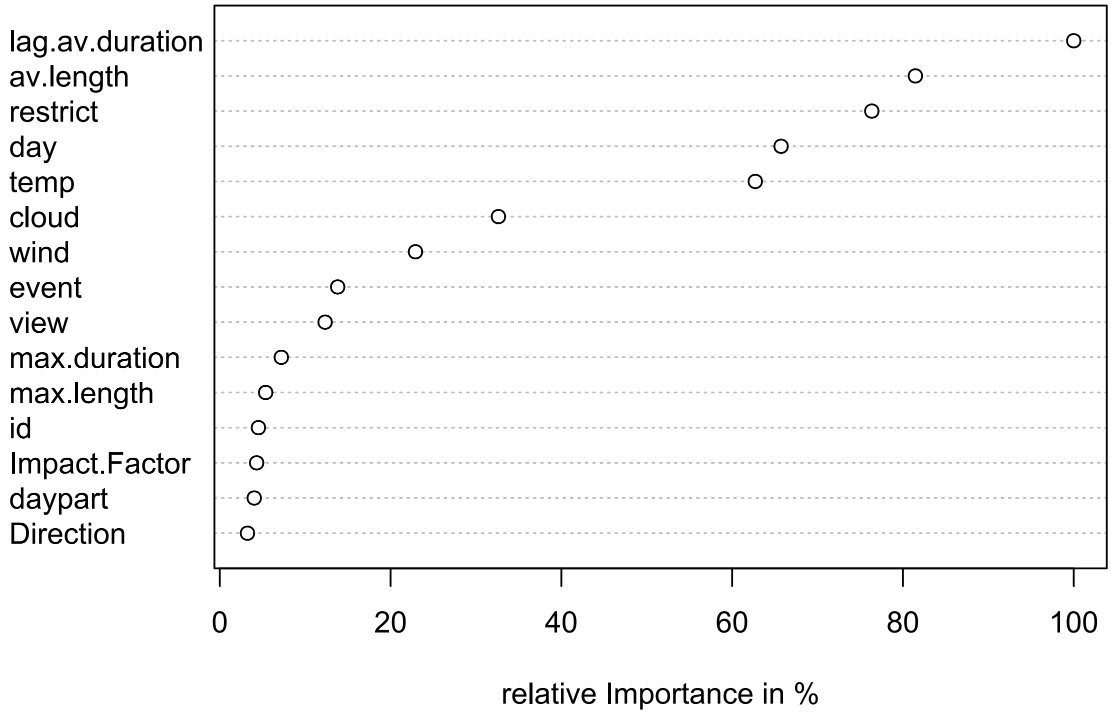

Figure 3.8 Importance of features in Random Forest model
Source: composed by the author

Use the first 10 features (excluding *max.duration* due to high variability demonstrated in the descriptive statistics section) in the further analysis. So, the following set of features with the dependent variable *duration* is obtained: *lag.av.duration*; *av.length*; *restrict*; *day*; *temp*; *cloud*; *wind*; *event*; *view*; *max.length*.

For the analysis widely applicable four machine learning algorithms (for classification problems solution) of different types are used:

- Linear Discriminant Analysis [LDA] — simple linear algorithm, obtaining the logistic function for classification purposes;
- k-Nearest Neighbors [KNN] — simple nonlinear algorithm, constructing the function for each class for minimization the distance between data points;
- Support Vector Machine [SVM] — complex nonlinear algorithm, separating classes by hyperplanes in n-dimensional (for number of features) space by their coordinates;
- Random Forest [RF] — complex nonlinear algorithm, constructing from different random portions of training sample the ensemble of decision trees, separating by classes and features.

The work of the algorithms could be presented in a graphical form in two-dimensional space (fig. 3.9).

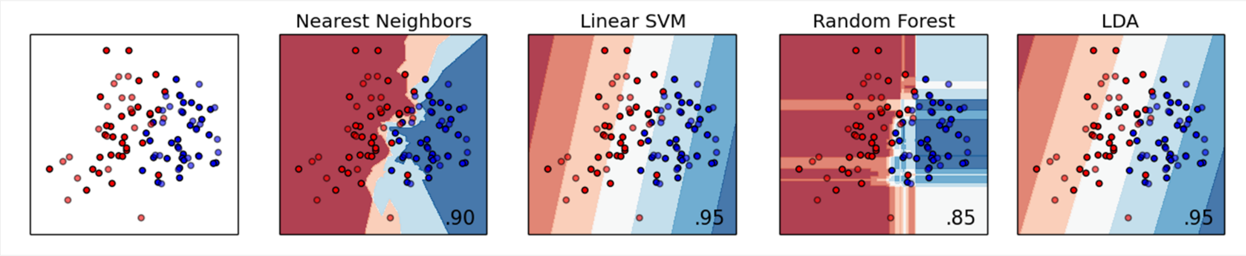

Figure 3.9 Machine learning classification algorithms comparison
Source: http://scikit-learn.org/0.15/auto_examples/plot_classifier_comparison.html (accessed May 10, 2018)

In order to assess the predictive power of constructed models the following performance metrics are assessed:

1. Accuracy $= \frac{\text{True Positive}+\text{True Negative}}{\text{True Positive}+\text{True Negative}+\text{False Positive}+\text{False Negative}}$ — the metric assessing the amount of correct predictions to all kind of forecasts made, where terms *true* and *false* relates to correct or incorrect class specification respectively; *positive* and *negative* — general notation for two classes in binary classification problem.
2. $\kappa = \frac{OA-EA}{1-EA}$ (Kappa) — the metric, comparing an Observed Accuracy (OA) for real values with an Expected Accuracy (EA) for predicted values, indicating of how closely the classified groups match the actual data.

So, the metrics such as Accuracy and κ (Kappa) for trained models are presented in the figure 3.10. The overall performance for two metrics has the same ranking for the models. The linear algorithm in this case is the worst, predicting correctly less than 60% of data. The other three algorithms perform better, predicting correctly more than 70% of the data.

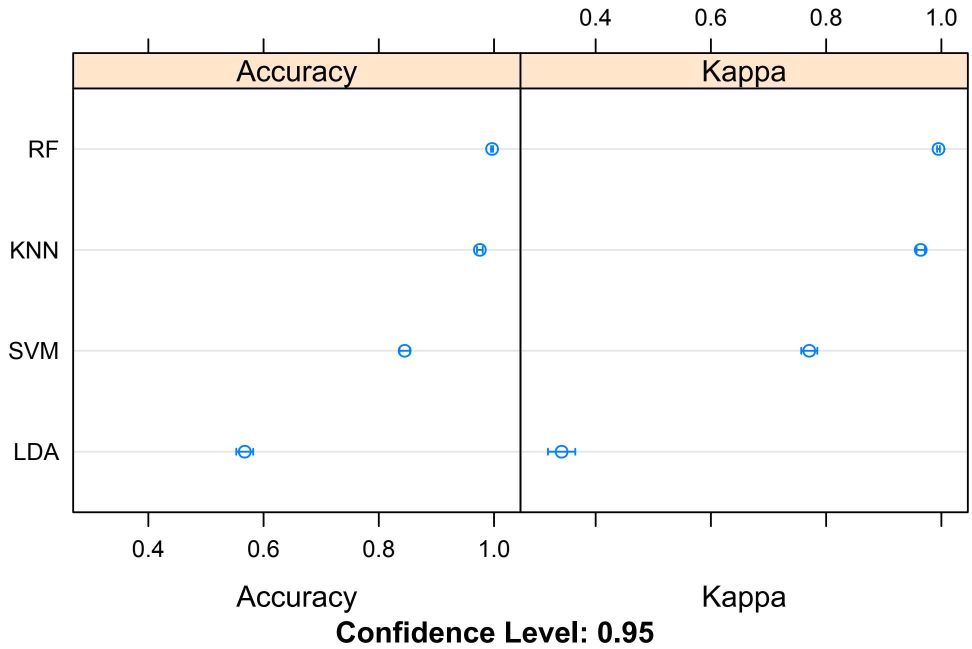

Figure 3.10 Models comparison by Accuracy and κ
Source: composed by the author

Then, for the trained models implement the test data portion. So, the following table with Accuracy metric for test sample by all models is obtained (tab. 3.7).

Table 3.7 Accuracy of forecasting by models

	Accuracy	Accuracy p-value
RF	0.362	0.62
KNN	0.217	1.00
SVM	0.442	0.00
LDA	0.436	0.00

Source: composed by the author

In this case two models has insignificant Accuracy metrics (RF and KNN), which are also less than for SVM and LDA. Thus, the only one algorithm, SVM, performs relatively stable and applicable results in terms of Accuracy metric (which has the highest and significant Accuracy on the test sample).

Then, choose the SVM model and represent its confusion matrix (number of correctly and incorrectly predicted data by classes) for test sample (tab. 3.8).

Table 3.8 SVM confusion matrix for test sample

Actual Predicted	<20	20-30	30-40	⩾40
<20	162	122	29	30
20-30	44	129	13	51
30-40	84	58	81	2
⩾40	73	48	0	67

Source: composed by the author

As we see, the model better predicted the medium congestion caused by bottlenecks (up to 30 minutes), than the atypical (more than 40 minutes) congestion. This bias could be caused by the lowest presence of high congested days and the lack of data obtained by the trial portion of data from INRIX GIS (only one year data with no access to the traffic jams and accidents data). However, assess the overall performance of the model on the whole (training and test samples) dataset with the predictions obtained with ARIMAX model (in *lag.av.duration* variable) because of the data access limitations.

So, the assessed Accuracy for the model (whole dataset) is significant and equals 0.8043 (κ =0.7185). Accuracy is distributed by classes in the following way: "<20" — 0.84; "20-30" — 0.86; "30-40" — 0.88; "⩾40" — 0.85. The confusion matrix of SVM for whole dataset is presented in table 3.9.

Table 3.9 SVM confusion matrix for whole dataset

Actual Predicted	<20	20-30	30-40	⩾40
<20	940	172	80	37
20-30	162	2242	196	122
30-40	102	171	1309	35
⩾40	74	65	3	518

Source: composed by the author

The overall results for whole dataset model represents the higher portion of truly predicted classes. Furthermore, the model catch more accurately the class indicating large bottlenecks in terms of its duration.

Results and recommendations for technical improvement

The performed forecasting techniques supports the stated hypothesis about the making predictions with higher accuracy and performance about the transport system conditions. The quality of the transport system in terms of congestion caused by the bottlenecks appearance is assessed with the use of Big Data algorithms. As a result the model based on Support Vector Machine algorithm is obtained, which represents the high rate of accuracy of more than 80% of correctly predicted time intervals of transport congestion in daily prospective on the example of the broadened paid parking area in Saint-Petersburg. The data obtained from the Geographic Information System (on the example of INRIX system) allows to make such forecasts with high prediction power. Despite the data limitations, such as the limited number of historical timestamps and historic traffic jams unavailability, the modeling is possible to provide. Finally, in order to increase the quality of the predictions made by proposed models, the additional data is needed. The public authorities has unlimited access to the data from GIS that allows to predict the transport system performance in more accurate way.

Recommendations for managerial use

Geographic Information Systems are valuable instrument for the purposes of road traffic prediction both for business and government representatives. On the basis of the data collected and processed by these systems different policies could be improved and proved from the analytical point of view with the models, which are presented in the current work. For example, the decisions about the road restrictions introduction or big events held and their influence on the overall transport congestion in certain segment of the road network. Thus, there is a need to broaden the usage of Geographic Information System among the government authorities. GIS allow to improve the reliability of transportation, provide real-time information in bus stations and so on. Geographic Information Systems can significantly reduce administrative and operational costs and increase productivity by making accurate travel time calculations using information and communication technologies and efficiently change the direction of traffic routes.

CONCLUSION

According to the methodology, the analysis of foreign and native experience of GIS introduction in transport sphere and used forecasting tools is presented. In addition, application of various forecasting techniques and scenario modeling based on the quality of results of predictions are also proposed and description of frameworks used in Russia and abroad for GIS development for transport sphere is stated. In current paper the quantitative methods are preferred over qualitative. However, case-study analysis, literature review (based on analysis of previous thoughts and findings in public management, indicators overview, legal acts overview) are also used. On the first stage the data is collected, then the statistical overview of the data is made. Based on this analysis, the data is processed and the set of time-series and Big Data models is provided. On the basis of built models, the appropriate one is chosen by checking the properties and quality of the model with formal statistical tests. After the model is proposed, the key dependences are found. Based on this the formal analytical model could be set up and key relationships could be compared with empirical findings. After comparison the corrections are made and forecasts are build, using such tools as hypothesis testing, time-series analysis and machine learning. After all the results are verbally described and recommendations for role of GIS data in transport system quality prediction is proposed.

In accordance with the predictive power of the models assessing transport system performance and predicting future congestion, Geographic Information Systems are the valuable tool for the purposes of public management. The convenience and simplicity of results obtained by the models allows to make decisions about redistributing traffic flows at big events, manage the periods of road restrictions in different transport system segments, deciding on introducing the new public transport roots, etc. Thus, the role of Geographic Information Systems for transport system improvement is assessed. In further works it is considered to broaden the dataset for the analysis, the region of road network segments and set of tools using for transport system performance prediction.

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