Is it time to implement road charges in Budapest?

Early mover risks and advantages in fighting urban congestion

Iuliia MARUKHA

Supervisor

Zoltan Illes

A thesis submitted to the Department of Environmental Sciences and Policy of

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Abstract of thesis submitted by:

Iuliia MARUKHA for the degree of Master of Science and entitled: Is it time to implement road charges in Budapest? Early mover risks and advantages in fighting urban congestion.

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Urban roads are experiencing increasing traffic volumes in many cities around the globe. Increasing traffic volumes not only cause time and speed losses, they cause a wide range of motor vehicle externalities. Namely, dangerous air pollution which affects health of the population, emission of greenhouses gasses, soil and water contamination, noise pollution, ecosystem fragmentation. A considerable research has been conducted on the mechanism of road pricing, aimed to regulate demand on urban road space. This study firstly aims to understand why – despite its evident economic and environmental benefits – this mechanism has mostly developed in theory. This will be complemented with the analysis of the other possible mechanism to tackle congestion. Next, a case study research of the application of this mechanism in the EU will be conducted.

It is suggested that Budapest could became the next European capital to implement a road pricing mechanism. Prerequisites required for this are strong political will and effective stakeholder collaboration. There are valuable lessons from London and Stockholm cases to take into consideration when developing the Budapest scheme. However, it is also argued that prior the implementation, a comprehensive traffic monitoring system should be established. Subsequently, this will develop evidence and feasibility of the scheme. It appears that public acceptance raises when discourse concentrates around the health and environmental benefits, rather than technical infrastructure improvements. This paper analyses options for road charging schemes and suggests implementation of the dynamic elements to the model. This approach hasn't yet been implemented in any urban area, but it can overcome drawbacks of the fixed pricing schemes.

Keywords: urban traffic congestion, vehicle emissions, congestion pricing, Budapest road pricing

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To *Budapest*

and

those who don't give up

»

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List of Abbreviations

CO	carbon monoxide
DTS	distance-based toll system
EEA	European Environmental Agency
ETC	Electronic toll collection
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas(es)
GPS	global positioning system
HC	hydrocarbons
HGV	heavy goods vehicle
OECD	Organization for Economic Cooperation and Development
NMVOC	non-methane volatile organic compounds
NOx	oxides of nitrogen
PM2.5	particulate matter of diameter of less than 2.5 micrometers
PM10	particulate matter of diameter of less than 10 micrometers
SO_2	sulphur dioxide
TEL	tetraethyllead
TEN-T	Trans-European Transport Networks
the U.S.	the United States of America
WHO	World Health Organization

(the terms “congestion pricing,” “road pricing”, “road user charges” are used interchangeably)

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1 Introduction

1.1 A pressure of growing traffic in urban areas

Traffic volumes in urban areas have been in steep increase over the past decades, as the growing urban population and business indeed require greater mobility (Rodrigue *et al.* 2017; Kain and Beesley 1965). Although the future of car use will be shaped by new urban policies and social innovations (i.e. various types of shared mobility), private vehicle sales will likely continue growing (McKinsey & Company 2016). Meaning more drivers will aim to use limited road space, consequently affecting other road users, local population and the environment.

Frequent congestion events are the first best sign of growing traffic. They lead to enormous time loss, which amounts to nearly 1 % of EU's GDP annually (European Commission 2018). What is more, dense traffic increases volumes and concentrations of vehicle pollutants in urban air. According to the latest IPCC report, transportation sector is responsible for 13% of global anthropogenic green-house gas emissions, with largest share caused by passenger transport (IPCC 2013). Besides, vehicle exhaust gases contain nitrogen oxides (NOx) and particulate matter (PM) elements, harmful for human health.

For many urban areas the problem of congestion became alarming and different actions have been taking to manage it. They vary from building new roads to introduction of road pricing schemes. There is a lot of evidence however that infrastructural investments do not solve the problem of urban congestion (Iaione 2010). Many scholars agree that the problem will persist until the price of vehicle use accounted its social and environmental cost. (De Palma and Lindsey 2011; Viegas 2001).

1.2 Problem statement and research objectives

Cities exist because they enhance social cooperation, provide better work opportunities and access to wide range of public services. However, the most vibrant and industrious cities have the worst

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congestion problems, while economically distressed and less developed cities do not experience this problem on a comparable scale (Taylor 2002). Hungarian capital, Budapest, is a growing metropolitan area with an increasing share of economic activities. The city is the fourth by population growth in Europe, the 10% increase in citizens is expected by 2030[1](Euromonitor International 2012; 2017). Number of drivers on its roads has been increasing likewise (Szendrő 2011). Without changes in traffic patterns, congestion will become more severe. This has been the case for many growing metropolitan areas worldwide (Chang *et al.* 2017). Thus, the aim of this study is to examine the current situation and the opportunities for the implementation of traffic management mechanisms in Budapest.

The discussion around the road charges has already started among politicians and civil society (Levegő Munkacsoport 2016). The study aims to contribute to the discussion by addressing the main research questions: *is it time to implement road charges in Budapest?* The following sub-questions will enhance the deeper understanding of the topic and help in answering the main research question: What are the reasons for the introduction of road charges according to the theory and practice of urban road pricing? What are the lesson from the introduction of road pricing mechanisms in Europe? What are the option for Budapest road pricing schemes under the current circumstances?

The corresponding research objective of the study are:

1. To identify the benefits and drawbacks of the application of road pricing mechanisms in urban areas;

2. To summarize the lessons of London and Stockholm urban charging systems based on the case study research;

3. To identify the local negative effect of urban road transport in Budapest;

4. To review the options and provide recommendations for the design of Budapest road charges.

[1] Comparing to the population of Budapest in 2005.

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It must be mentioned that current research has been a learning process for the author. The objectives of the study have transformed over time due to identified limitations. However, the findings along the process enhanced better understanding of the problem and broadened the recommendation section of the study. This work will contribute to the efforts of Levegő Munkacsoport in advocating for the cleaner air in Budapest. It could also be used by concerned members of the public to gain a better understanding of why new road infrastructure is unable to satisfy growing demand on road space and mitigate other traffic externalities. The opportunities for the further research are outlined in the conclusions chapter.

1.3 Theoretical framework

This section provides an overview of the theories and concepts used to answer the main research question. The current research will look at urban roads from the lens of the three perspectives: the economic theory of externalities, the concept of the tragedy of the commons, and a theory of justice. This combined approach is aimed to provide a broad overview of the complex problem of road space overuse and its consequences.

The economic concept of externalities applied in contexts of urban road use explains the social cost of vehicle use. In his book *The Economics of Welfare* Pigou (1920) was first to distinguish between private and social costs of industrial activities. This difference in costs he called externalities. In the contemporary economic studies, the term is generalized as "a positive or negative consequence (benefits or costs) of an action that affects someone other than the agent undertaking that action and for which the agent is neither compensated nor penalized through the markets" (IPBS 2018). In this study we will discuss the externalities of motor vehicle use, i.e. congestion, air pollution, health risks, road infrastructure deterioration, ecosystem fragmentation and so on. The theory further explains that the way to manage the externalities is in identifying their marginal social costs. These are the external

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negative effects of each additional vehicle on the road. Estimation of marginal social costs of vehicle use is a difficult task. But if preformed comprehensively, it develops solid evidence for the road user charging scheme. This is why the elements of this theory will be often applied in course of the current research.

The concept of the tragedy of the commons (Hardin 1968), applied in context of the current research explains why the overuse of road capacity is taking place. This perspective, in contrast to the first framework focused on drivers, focuses on the road space. With this, the reoccurring problem of road space scarcity is the same problem as with any open access resource. Not until the roads become highly congested, drivers limit their use of a free "common good" (i.e. roads). However, the negative effects of increasing delays, air-pollution they start experiencing way before that. According to Hardin (1968), only by limiting access to the common resource it is possible to retain its capacity. This concept will be applied in the discussion about the possible mechanisms of tackling congestion in urban areas.

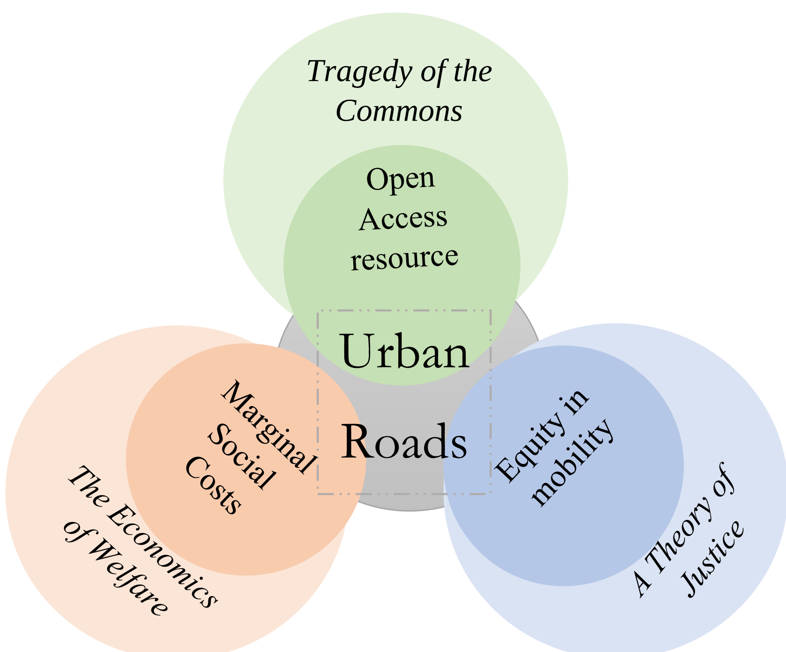

Fig. 1. Visualization of the theoretical framework.

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A theory of justice (Rawls 1971) framework applied in the current research connects principles of liberty, equal opportunities, and difference with questions of social equity in urban mobility. Thus, contextualized Rawls' principles discuss the right to mobility, "polluter pays" principle and the welfare of the underprivileged respectively. While the application of the first right is debatable in the context of private vehicles use, the two other principles represent important aspects in a discussion of public acceptance of road pricing schemes.

Thus, the information collected during this research will be evaluated with regard to these concepts to corroborate the findings from a theoretical point of view.

1.4 Thesis outline

The current study is structured in accordance with the outlined research statement, aims and objectives. Chapter 2 presents a literature review on the topic of road congestion in contest of increasing traffic volumes on urban roads worldwide. Besides congestion events, it discusses the wider range of vehicle use externalities. The review outlines the two main concepts in dealing with limited urban space – supply and demand oriented. Explaining why new road space cannot solve the problem, it focuses on the demand side of the problem. The study by no means suggests that investments in road infrastructure development should be eliminated. It emphasizes, however, that there is significant potential in the mechanism of urban road pricing. Thus, economic, social and environmental perspectives of the mechanism are reviewed, and gaps in available studies are outlined. Besides, comparative analysis of types of road pricing schemes and technologies they use is completed to meet current research objectives.

Methodology section of the current research is outlined in Chapter 3. Methods of data collection and analysis are explained. Acknowledged limitations of the current research are also outlined in this section. The advantages and disadvantages of the chosen research methods revealed and discussed.

Chapter 4 is devoted to the case study research of road charging schemes used in the European Union.

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The systems for trucks charges, London and Stockholm congestion charges are analyzed against the chosen theoretical framework. The lessons from the schemes' implementation and operation are summarized for the further discussion.

The main discussion is conducted in Chapter 5. It interprets the comprehensive set of data collected about Budapest and discusses the local effects of urban traffic. It defines the constraints and opportunities for the implementation of the city urban road pricing scheme.

Summary of findings, recommendations and future research opportunities are provided in Chapter 6.

In the printing version of this document all colored figures will be transferred into the gray ink-saving scale unless the color is necessary for the understanding of the content.

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2 Literature review

"In the 20th century, Man conquered Mount Everest, walked on the Moon and plunged to the icy depths of the Atlantic Ocean. However, despite these huge advances in pedestrian, aviation and maritime exploration, our surface transport remains constrained by increasing roadway congestion…"

– Organization for Economic Cooperation and Development (2012)

This literature review is aimed to allocate the research problem of the present thesis in context of the available literature and establish a background for the further discussion. Following the funnel method of writing (Hofstee 2006), it starts with an overview of the recent urbanization trends and related changes in modes of passenger transport. The focus is placed on the European Union (EU), with few broader examples provided for the comparative analysis. Further, the traffic congestion dynamics is outlined in the context of the increasing urban road mobility. The review continues with the identification and overview of the health and environmental impacts of urban traffic. This is followed by the review of available methods for tackling urban congestion. Ultimately, it summarizes arguments about the introduction of road pricing schemes in contemporary urban areas. Recognizing the broad range of traffic congestion causes, the current overview does not include topics of urban planning theories and traffic engineering methods, non-urban congestion, congestion created by accidents. This is explained by the research aim and objectives of the present thesis.

2.1 What is driving urban road congestion

Traffic congestion had become a part of daily life of thousands of people around the world. In 2016 a driver in Europe spent on average 30 hours in congestion, with figures higher in some Asian cities and in the U.S. (Cookson and Pishue 2017).

The road congestion is not exclusively a challenge of the recent years. The history keeps records of some of the most severe cases, for instance, in New York city in 1969, Paris in 1980, Tokyo in 1990 (Gorzelany 2013). They were caused by the combination of the weather, infrastructure and social

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factors. The congestion events in the 21st century differ significantly - by their bigger scale and higher frequency. Today's driver spends 3 times more time in congestion comparing to a driver of the last decades of the 20th century (Rodrigue *et al.* 2017).

Modern megapolises are uniting more and more people, thus increasing demand on urban roads. According to the United Nations (UN) report, around 55% of world's population lived in the cities in 2016. This number – if global population continue to grow - is expected to reach 70% in 2050 (United Nations 2017). Not surprisingly, the research by Chang *et al.* (2017) shows a positive correlation between the size of the agglomeration and intensity of congestion in urban areas. Furthermore, the number of passenger car owners between 1997 and 2016 in all EU member states, except France, increased (Eurostat 2018). The use of passenger cars in the EU increased by 20.9% over the 20 years from 1995 to 2015 (Fig. 2). There are fluctuations in the data on the severity of urban congestion over the last decades, but the long-term trend is rising (Xu *et al.* 2013).

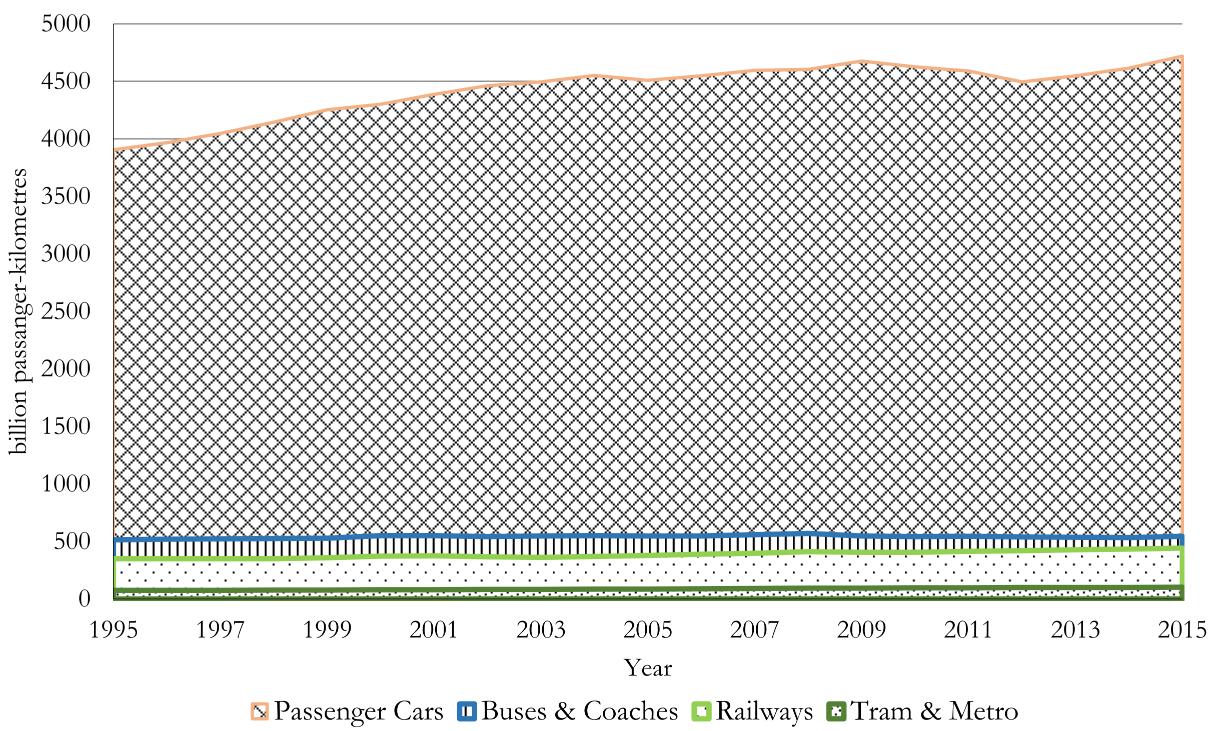

Fig. 2. EU passenger transportation trend. Data source: European Commission 2017.

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2.2 Three-dimensional definition of congestion

From the observer's point of view, traffic congestion appears when too many cars are on the road at the same time. From a problem-solving perspective, however, the definition of congestion is more complex and versatile. To manage congestion, it is vital to quantify what does "too many cars" mean, in other words to understand the capacity of the road and identify the optimal level of the traffic flow. Traffic congestion is a dynamic structure, variable across space. This makes the development of all-purpose definition impossible (Downs 2004). Not surprisingly, the literature provides a wide range of definitions of road congestion.

In his comprehensive overview, Aftabuzzaman (2007) classified traffic congestion into the three groups. The first group applies to the infrastructural causes of congestion. A good example would be a definition by Rothenberg (1985): "congestion is a condition in which the number of vehicles attempting to use a roadway at any time exceeds the ability of the roadway to carry the load at generally acceptable service levels". The second category emphasizes the spatial application of congestion events. This characteristic of congestion is well described by Kockelman (2004): "congestion is the presence of delays along a physical pathway due to presence of other users". Both definitions apply to the practical, visible side of the congestion events, and are helpful in defining the technical solutions to the problem.

Finally, the third group is classified as "cost related" and presented by single definition from Canadian Policy Institute (Litman 2013): "traffic congestion refers to the incremental costs resulting from interference among road users". The definition comes addresses the economics perspective of traffic congestion. We find the definition by EFEU (2017) to best suit the purposes of the present research within this category:

"Traffic congestion is a point at which the costs of additional traffic on a road begin to exceed the benefits to users and to wider society."

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The above-mentioned definitions represent diversity of the approaches to analyze congestion in urban areas. What is more, the choice of the definition in many ways implies the techniques and strategies that are used to measure and tackle congestion. For the purpose of this thesis, the definition by EFEU (2017) will serve as a basis for the further discussion. Aside from time, demand and cost oriented view on congestion, there are two more forms of congestion that should be acknowledged (Table 1). They represent another dimension of the road congestion events, and their understanding is vital for the development and implementation of effective transportation policies and regulations.

Table 1. Recurrent and non-recurrent traffic congestion. Source: EFEU 2017 (with amendments)

Form of congestion	Description
Recurrent congestion (commuting)	This type of congestion has periodical or regular frequency. It's mainly expected during the "rush" hours on the main motorways of urban areas. The severity depends on multiple conditions and drivers' behavior.
Non-recurrent congestion (incident produced)	This type of congestion is unregular and unpredictable by road users. Its main causes are road accidents, vehicles breakdowns, road works, and other unexpected disruptions.

While both types of traffic congestion contribute to the travel delays and environmental pollution, the causes of the congestion events are largely different and, thus, require separate consideration and research. The current research is dedicated to the recurrent congestion, arising from the high traffic volumes on urban roads.

2.3 The environmental impacts of traffic congestion

The task of identifying and measuring environmental impacts of traffic congestion is very difficult. Urban congestion is a result of multiple infrastructural and operational imbalances. In their review of the Congestion Mitigation and Air Quality Improvement Program, the U.S. National Research Council (2002) outlined that a decade of program's implementation "did not provide a strong basis for either

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supporting or opposing continuation of the program". Hence the recognition of additional environmental and health risks arising from traffic congestion is still debatable. The following chapters will provide an overview of the studies related to the general vehicle pollution with the focus on congestion-related emissions.

2.3.1 An anthropocentric perspective

Numerous research had been conducted on the effects of the urban traffic on human health, air quality and other elements of the ecosystem. A study by World Health Organization (WHO) (2016) outlined that car-related air pollution is one of the major factors of 100,000 early adult deaths in WHO European region[2] annually. This corresponds with an earlier study (Ahrens 2003) estimating that around one billion people worldwide are exposed to the emissions from the motor vehicles on a daily base. These emissions increase the health risks for drivers, passengers, and communities located near the roadways (Health Effects Institute 2010).

From environmental perspective, automobile use is associated with three major forms of environmental pollution: air, soil and water pollution. In the recent literature, air pollution has been receiving most of the attention; while the research on ground and water pollution from vehicles was prominent in the 1970s and last decades of the 20th century. This was when the concerns were raised regarding the high concentrations of heavy metals in crops and vegetables grown in the neighborhoods next to the motorways (Daines *et al.* 1970; Little *et al.* 1981). Since tetraethyllead (TEL) additive, widely used to enhance the performance of petroleum, was recognized toxic, it had been banned in most

[2] WHO European Region includes: Albania, Andorra, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Malta, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Republic of Moldova, Romania, Russian Federation, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tajikistan, The former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Ukraine, United Kingdom, Uzbekistan.

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countries by the early 2000s (Tsai and Hatfield 2011). According to the most recent data (UNEP 2017), Algeria, Yemen, and Iraq still use leaded fuel. The withdrawal of TEL has shown significant change in the levels of lead concentrations in humans' blood. For instance, between 1976 and 1993 in the U.S. only it decreased by 78% (Pirkle *et al.* 1994). Most of the ongoing research is represented by case-by-case studies on remaining concentrations of lead in the soil and underground water. The further review will be focused on the air pollution externalities of urban traffic and congestion events.

2.3.2 Traffic-born air pollution

The effects of congestion on vehicle's emission levels are compound and variable (National Research Council 2002). There is, however, a strong consensus among researches that traffic is highly contributing to the deterioration of urban air quality. Not surprisingly, considerable research has been conducted on the specificity of air pollution from motor vehicles. Vehicle emissions are characterized by broad spatial distribution and proximity to the residential areas; high toxicity of pollutants and complexity of protection measures against pollution from these mobile sources (Brugge *et al.* 2007). Another problem with exhaust gases is their accumulation above the earth's surface within the breathing zone of pedestrians due to low wind dispersal (in comparison to the industrial pollution) (WHO 2005).

Air pollution from vehicles occurs as a result of fuel combustion. The chemical composition of emissions depends on many factors, namely the type and quality of the fuel, the technology of its production, engine type and its technical conditions. The principal pollutants in the exhaust gases of motor vehicles are carbon monoxide (CO), oxides of nitrogen (NOx), sulphur dioxide (SO2), particulate matter (PM) and hydrocarbons (HC) (Wallington *et al.* 2008). The *Air Quality Guidelines for Europe* (WHO 2006) define daily maximum concentration limits and emphasize the need for regular monitoring of these elements in urban air.

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Despite the incremental policies that have been applied to regulate the quality of the motor fuel in the EU, namely *Fuel Quality Directive* (Council of the European Union 2009), road transport is still a major source of air pollution. It has 60 to 90% share in total emissions from transport sector (Fig.3).

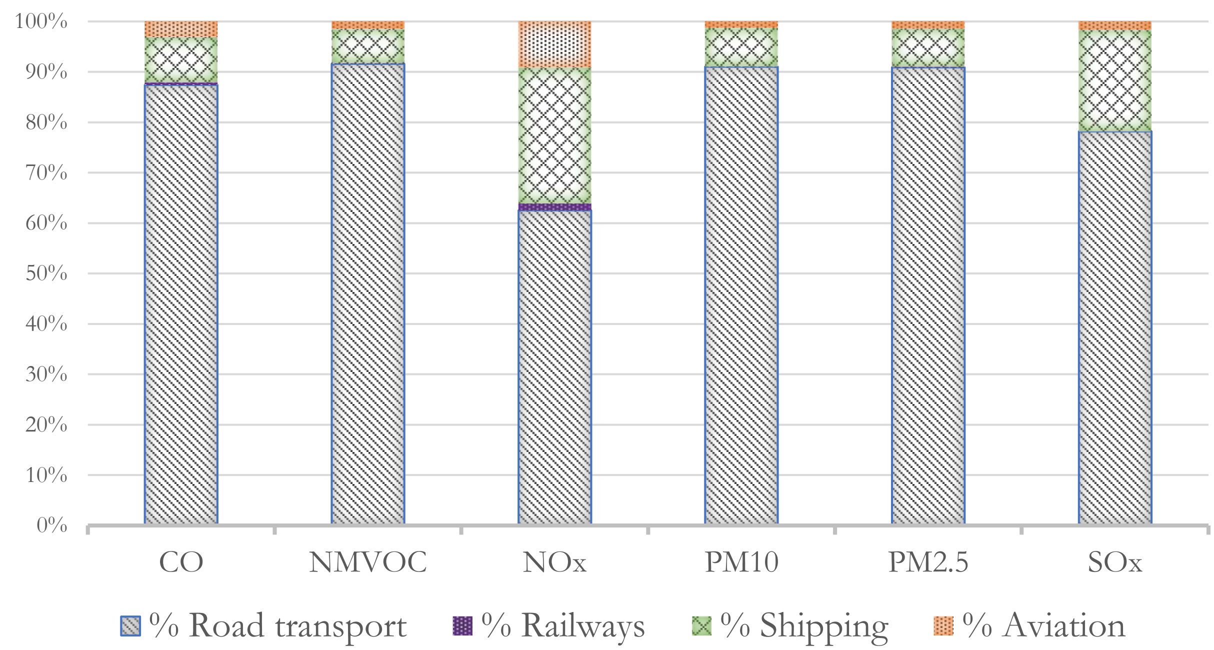

Fig. 3. Emissions from the transport in the EU. Data source: European Environment Agency 2017.

A table below summarizes major health risks from exposure to the pollutant (Table 2).

Table 2. Health risks of vehicle emissions. Data sources: Beker *et al.* 2000; Wallington *et al.* 2007.

Pollutant	Health risks of exposure
carbon monoxide (CO)	Prevents oxygen absorption by blood, weakens mental abilities, slows reflexes, causes drowsiness and loss of consciousness.
non-methane volatile organic compounds (NMVOC)	Cause allergies, headaches, loss of coordination; damages liver, kidney and central nervous system, carcinogen.
nitrogen oxides (NOx)	Irritate the lungs, cause cardiovascular and respiratory diseases (bronchitis and pneumonia), lung cancer.
particulate matter (PM)	Develops respiratory and cardiovascular problem causing heart and lung diseases.
sulphur oxides (Sox)	Cause inflammation and irritation of the respiratory system, affect lung function, worsen existing heart disease

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It is expected today that the discourse on the urban traffic and congestion integrates questions of environmental protection, air pollution and public health. However, it has not been this way until the recent decades. The questions that had been researched at the beginning and along the nineteenth century, during the rapid increase of automobile production and road infrastructure development, were far from acknowledging and focusing on the environment and health issues. However, when it comes to the policy and decision making, up until now the anthropocentric look manifests in the ways of approaching the problem. The following subsection will describe the broader range of environmental impacts of vehicle emissions. It is essentially important for the urban areas, where the environment is affected by multiple stress factors. The 11th sustainable development goal (UNDP 2015) calls for a broader understanding of the vehicle pollution to make our cities "safe, resilient and sustainable".

2.3.3 The broader look at vehicle emissions

The hostility toward traffic congestion and growing environmental pressures have brought the problem to the focus of various research groups and governmental officials. The emission rates and travel distances are the most basic ways of placing transport issues in an environmental context. In the literature, urban traffic and congestion is always coupled with air pollution challenges. However, besides the health risks associated with vehicle emissions [see section 2.3.2], there is a broader range of the negative environmental impacts of motor vehicles:

- Contribution to climate change. Champan (2007) accounts vehicles to be largely responsible for the long-term contribution to the accumulation of the greenhouse gases (GHG) in the atmosphere. This is due to the large amounts of CO2 that are released during the fuel combustion in motor vehicles. The lifecycle assessment of motor vehicle conducted by Potter (2003) showed that from total CO2 car emissions, 76% comes from the fuel usage.

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- NOx is the second major pollutant of exhaust gases which is responsible for the depletion of the ozone layer, acid rains and the deterioration of the air quality (Dasch 1991).

- Motor vehicles using leaded and low-quality fuel are sources of soil and water contamination by heavy metals. Their bioaccumulation is taking place in plants tissues and enters the food chain through the products of urban agriculture (Nabulo *et al.* 2006). Furthermore, oil spills from the traffic accidents penetrate the underground water of the urban areas.

- Urban ecosystems and biodiversity are threatened by the chemical and noise pollution from vehicles. Furthermore, land take and fragmentation of ecosystem highly affect the habitat. Besides that, vehicles create risks of invasive species in urban ecosystems (Kowarik 2011).

The difficulties in obtaining accurate data on urban traffic externalities diverts political will from this major issue worldwide. Without the availability of specific data, the research remains limited and coupled with the air pollution. One potential facilitator of changes is the implementation of the broad-scale scheme for reducing traffic externalities. The case for it will be developed in the following chapters.

2.3.4 Free-flow traffic mode

Free-flow traffic, on contrary to congestion, means that cars can move on the motorway at a maximum allowed speed without experiencing the limitations to road capacity. First and foremost, it is important to distinguish the characteristics of the vehicular emissions under normal traffic conditions and in congestion.

In case of free traffic flow, the movement of vehicles is not influenced by other road users and primarily defined by the vehicle itself. In their comprehensive literature review of the relationships between the vehicular characteristics and emissions, Pandian *et al.* (2009) analyze emission rates with

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such parameters as vehicle age, engine type and size, weight, producer, the fuel used etc. Concomitant vehicle-operating and environmental conditions are also addressed within this category (see also Beydoun and Guldmann 2006). For example, larger cars and heavier car in most cases, but not always, have higher rates of the pollutant emissions (Kim 2007). When it comes to the diesel fueled cars, Keller and Fulper (2000) demonstrated that the mass is the determining factor for the vehicle emissions. The quality and conditions of the motorway surface is another important parameter. In their study of road dust pollution Kupiainen and Klimont (2007) outlined that the degradation of tires, brakes, and pavement is a major source of car-related non-combustion PM pollution.

Furthermore, meteorological conditions and geographical characteristics of the area should be taken into consideration when analyzing vehicle emissions (e.g. pollutant dispersion is complicated in hilly and closed areas, under foggy and no-wind conditions etc.) (Perez et al. 2008).

While a discussion thereof is beyond the realms of this research, the driving culture and behavior of the road users are also important factors. Aggressive driving requires constant speedups and slowdowns, which cause increase in pollution levels. Such behavior is also likely to create tension on the road and may lead to congestion events.

Proceeding from all above-mentioned, for the implementation of any regulatory mechanism, it is essential to conduct preliminary studies and understand the local traffic characteristics. Without functioning data collection system and reliable data, the application of any mechanism to improve the situation on the roads has high chances of failure.

2.3.5 Vehicle emissions in congestion

The literature reveals that majority of the studies on traffic emissions do not separately account impacts of congestion events. Thus, few studies on direct impacts of road congestion are available for analysis. The lack of this information becomes more critical considering the increasing severity of road

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congestion. Congestion events call for changes in traffic patterns and create additional non-vehicle related emission factors. This is because each additional driver increases a marginal cost of pollution under high traffic volume conditions [see section 2.6].

There are three congestion-related factors that influence vehicle emission levels: increased travel time, change of driving dynamic, and lower pollutants dispersion (Zhang and Batterman 2013). Firstly, in congestion drivers constantly adjust their speed according to the traffic flow. Acceleration and deceleration modes of operation increase fuel consumption, increasing pollution emissions respectively. Secondly, lower speed increases the average travel time of a vehicle, generating additional pollution. Ultimately, due to lower vehicle speed, dispersion of pollutant drops, concentrations rise in the congested areas. Consequently, studies focused on emissions rates of passenger cars in congestion report that concentrations of pollutants increase significantly (Table 3).

Table 3. Pollutant emission in congestion compared to uncongested conditions.

<table>
<tr><th>Pollutant</th><th>Sjodin et al. (1998)</th><th>De Vlieger et al. (2000)</th><th>Anderson et al. (2003)</th><th>U.S. EPA (2008)</th><th>Frey et al. (2001)</th></tr>
<tr><td>CO</td><td>×4</td><td>10%</td><td>71%</td><td>×4</td><td rowspan="3">≈50%</td></tr>
<tr><td>NOx</td><td>×2</td><td>20%</td><td>4%</td><td>×2</td></tr>
<tr><td>NMVOC (HC)</td><td>×3</td><td>10%</td><td>53%</td><td>×2</td></tr>
</table>

As we can see, there is indeed a strong link between the traffic flow conditions and levels of vehicular emissions. However, the measurement results vary significantly. This creates obstacles for the assessment and justification of existing health and environmental risks of congestion. (Zhang and Batterman 2013). Without the quantitate estimations of this component, the problem of congestion shifts to the field of urban engineering and technological fixes. We have seen this happening through the enormous road construction and expansion since the middle of 20th century. The following section will explore the relations between urban road development and traffic congestion.

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2.4 Why new roads will not save the day

As previously mentioned, one of the ways of analyzing road congestion lies within the economic theory perspective. In basic economic terms, the road space is a resource, while the traffic congestion is a result of excessive demand for road usage (Lamotte *et al.* 2016). There is than a range of methods to achieve the desirable equilibrium between supply of the road space and demand on the road use.

Historically, the supply-oriented side of the equation, generally determined by the capacity of the urban road infrastructure, was regarded as an effective way of tackling congestion. The problems of road capacity were aimed to be solved by construction of new roads, widening the existing motorways, constantly improving the road surface to allow free-flow traffic (Thomson 1997). This approach is still supported by some authors, mainly those conducting case study researches of the areas with low road network performance (Osetrin and Dvorko 2015; Voronina 2016; Gajjar and Mohandas 2016).

However, the above-mentioned capacity-oriented approach has shown to cause the so-called "induced demand": the infrastructural improvements of the road aimed to reduce congestion are resulting in an increase of its usage by drivers in the long-term. The traffic shifts from the alternative routes and the road becomes congested again (Goodwin 1996). Most scholars agree that increased road capacity will not save the day (distinguishing from the road improvements in underdeveloped regions).

Interesting in this context is the analysis of public spending on development of transport infrastructure in the EU countries over the last two decades (Fig. 4). Road infrastructure development was the major recipient of investments in the analyzed period, with some decrease in share (52.4% of all investments in 2014 vs 61.4% in 1995; average annual share amounted 56.2%). Furthermore, expenditures on roads had been increasing since 1995 until the economic crises of 2007-2009 (25% rise between 1995 and 2007). By 2014 the amounts of annual investment were slightly below the levels of 1995, but still the highest among other types of infrastructure (European Environment Agency (EEA) 2016).

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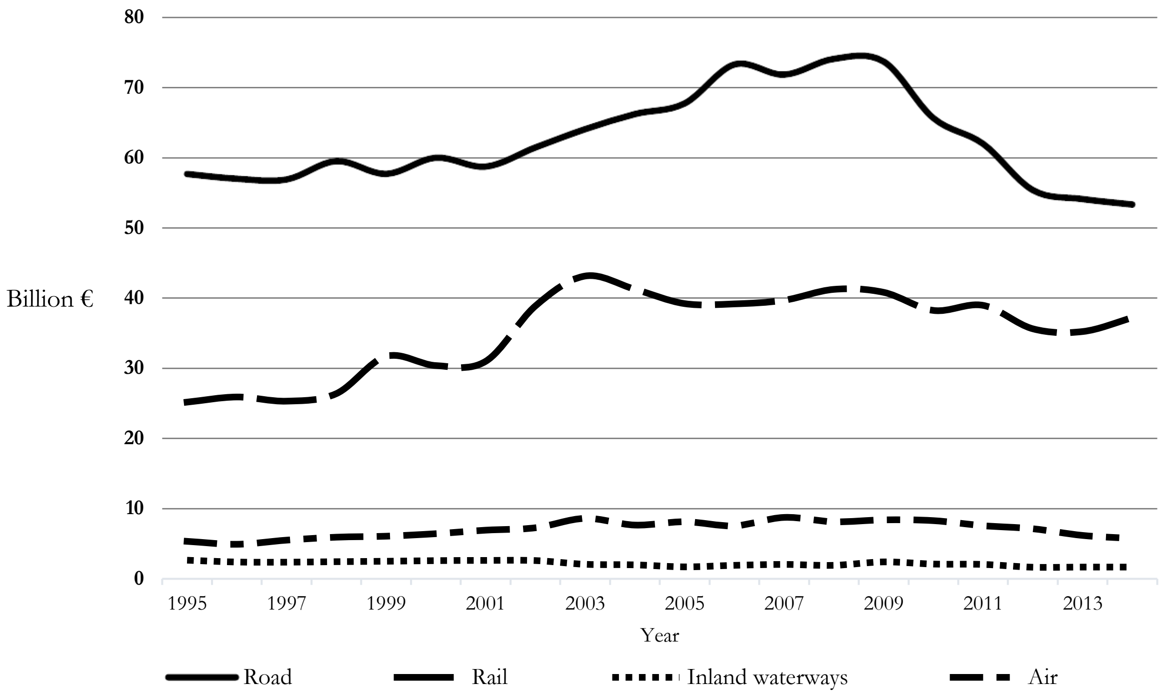

Fig. 4. Public investments in transport infrastructure in the EU. Data source: EEA 2016.

It is important to recognize that urban roads receive only part of the total road infrastructure expenditures, competing with the construction of highways, bridges, tunnels and their maintenance. To our knowledge, the information of such scale is not presented publicly for the EU level. *The performance report for the Trans-European Transport Networks (TEN-T)* (Conference of European Directors of Roads (CEDR) 2015) showed that as of 2015, the network consisted of 43,150 km of motorways and 28,727 km of non-motorways (in other terms: "expressways" and "ordinary roads"). This data represents that non-motorways, which most of the urban roads are, make roughly 40% of the network (see Table 4). It is essentially correct to expect that state highways on average receive higher amounts of investments, largely due to their economic importance. However, the ratio is a subject of local circumstances. For instance, in countries like Estonia, Ireland, Malta more than 90% of the roads are non-motorways, whereas in Switzerland only 15% (CEDR 2015). Referring back to the phenomenon of induced demand, it should be underlined that construction of major highways as well impacts urban

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traffic to a certain degree. Increasing mobility between urban areas, investments into motorways incentivize higher volumes of economic activities, bringing more drivers into the urban areas. It's fallacious to consider the highways as dangling parts of the roadway, as after all their primarily goal is to connect the departure and destination places. And these places will experience increase in the traffic flow as described above. That being said, a layman's perspective on the road infrastructure investments could be a simple way to assess their efficiency: new motorways should allow drivers to rich their destination faster (the safety and environmental factors were deliberately excluded from the context). The answer to this has been partly addressed in section 2.1. To continue, below is the data derived from one of the two biggest worldwide platforms which collects information on traffic conditions in urban areas:

Table 4. Road congestion statistics based on TomTom traffic index. Data source: TomTom 2018a.

City[3]	World city ranking[4]	Annual extra travel time, hours/year,	Road network length, km	Non-highways in city's total road length, %	Increase in travel time when compared to free-flow, %	
					highway	non-highway
London	25	152	48 952	98.5	21	47
Singapore	55	131	8 518	95.4	24	37
Vienna	67	115	5 746	96.0	26	34
Milan	72	132	16 335	97.7	20	36
Stockholm	92	126	7 630	97	22	33
Budapest	130	100	14 854	97.6	2	37

In the attempts to literally build the way out of the problem of congestion, major European cities seem

[3] The selection of cities is based on one of the following criteria: cities which implemented any type of urban road pricing scheme before 2016 or cities comparable in size and population to Budapest.
[4] TomTom traffic index historical database for 2016 contained 390 cities with a population greater than 800,000. Ranking range between 1 and 390, where 1 – city with the highest extra travel time experienced by drivers.

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to be bogged down in congestion. London, one of the European most congested cities has a road network of about 50,000 km (which is equal to around 300 m of road per each km2 of its area) (Table 4). With different level of severity, traffic congestion affects population in each city, causing them to spend on average between 26 (Budapest) to 40 (London) minutes in traffic congestion daily.

Therefore, the problem outlined by Goodwin (1996) several decades back remains topical; the price of vehicle use continues to poorly reflect its social and environmental cost. Requiring constantly high levels of public expenditures, urban roads still cannot saturate the supply of urban space. The single best example of this is the severity of congestion in many urban areas across countries.

2.5 Urban roads are yet another tragedy of the commons

Johanson and Mattsson (1995) called an automobile "the Janus symbol of freedom and environmental threat". The freedom of movement, however, is becoming more and more limited by traffic congestion events in urban areas. Environmental and health threats caused by vehicle emissions, on the contrary, continue to grow [see sections 2.1-2.3].

Some drivers perceive congestion as an inevitable part of urban mobility. Majority of the others urge the municipality to take an action in dealing with the problem: often, by adding more lines to the urban motorways. For instance, Taylor (2002) states that "automobiles are central to metropolitan life, and efforts to manage congestion must accept this fact". Criticizing the orthodox theory of road pricing, he mentions that drivers in urban areas have high tolerance for them. This context recalls the key question in the discourse about traffic congestion: whether it is the road infrastructure development that is lacking behind or is it the number of cars that increases enormously, so that any existing road network can satisfy the demand on road space? As a matter of fact, the first side is likely to be supported by the drivers experiencing severe and frequent congestion, while the second is supported by numerous scholars researching the problem of urban congestion [see section 2.4].

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Several authors (Iaione 2010; Minett 2015) analyzing the demand side of road use applied Hardin's Tragedy of the Commons (1968) framework to look at urban road space. The concept of unrestricted demand exhausting finite resource can indeed with amendments be applied to urban roads. Receiving "something for nothing", drivers manifest their historically rooted right to use road space without paying its full social and environmental costs. Not until the roads become highly congested, drivers limit their use of a free "common good". This is when the users start experiencing negative consequence of resource (i.e. road space) overuse.

Though the roads in theory can be extended unlike grazing land or an aquifer in most cases, wider roadways will attract more drivers, and the outcome will remain the same it in the long-term (Iaione 2010). Thereof, user's contribution to the "tragedy" is applicable to the case. Overuse of road capacity by each driver leads to everyone's losses of time and road degradation. Non-users at the same time are also experiencing the negative effects of air-pollution and increased health risks. According to Hardin (1968), the solution in tragedies of the commons is either privatization or public regulation of the resource. Later Ostrom (1990) offered the third solution of common ownership. They argue that only by setting the rules and limiting access to the common resource it is possible to retain its capacity.

The urban transport economics theory has a similar explanation of the congestion challenge. The concept of marginal cost pricing is used by several authors in their research on urban traffic externalities in theory (Johansson and Mattsson 1995; Button and Verhoef 1998) and in case studies (Gonzalez-Calderon *et al.* 2012; Thune-Larsen *et al.* 2014). In the disentangled representation, the marginal cost of the road use is the cost which each driver imposes on others deciding to use the limited road space. In case if the use of the road is free of charge, the drivers only take into consideration their private costs of travel (i.e. fuel prices, maintenance costs, journey time etc.). The cost of the loss of time caused by congestion to other users, as well as the damages to human health and the environmental are not acknowledged. Thus, the price paid by a driver is lower than the cost

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of the journey to the society. We strongly disagree with the authors who see congestion event as the turning point to recognize that public costs of road use are exceeding the private driver's costs (Winaisathaporn 2013). Such approach neglects the externalities appearing already in the moment the driver enters the traffic flow [see section 2.3.4]. In practice, the proper application of the marginal cost mechanism will exclude the trips with the social cost higher than its benefits to the driver (Federal Highway Administration 2008).

Recognizing that in real life situation drivers do not know the full social cost of their trips, well-developed pricing mechanism could serve as a regulating tool to manage demand for travel at a given time and location (Harrison 2012). Development of the pricing scheme for urban road use per se is a difficult task. This is the reason why despite the preponderance of theoretical evidence of its effectiveness to date, there are few cities across the globe which implemented the pricing scheme for urban roads. Aside from the economic efficiency, questions of social equity, public acceptability and political will are playing important roles in the implementation of this mechanism.

However, recognizing all the complexity, it is generally agreed among the scholars that charging for congestion and environmental externalities is "better than to charge for nothing at all or to charge a price that is unconnected with the costs that are generated at the margin" (Raux and Souche 2004). Considering futile attempts to manage the growing volumes of urban traffic with infrastructural improvements, inadequacy of current free-access approach to account all the externalities of vehicle use, the introduction of road pricing could be the way to go.

The following section will demonstrate the main economic and social challenges of the current mechanism. Some attention will be given to technological and operational side of the system. Only limited attention will be given to the policy development processes and procedures needed for the implementing the road pricing scheme.

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2.6 The case for road user charges

The economic theory of congestion pricing was set by Pigou in his book *The Economics of Welfare* (1920). The ingenuity of author's approach laid in the idea that the introduction of road tax can decrease time losses. Ever since road pricing had become a constantly expanding field of academic research. Many economists and urban planners see road charging as a powerful instrument in managing demand on road space (Viegas 2001). If effectively implemented, it regulates the number of cars on the given road at a particular time of day (De Palma and Lindsey 2011).

Until the current stage of this academic literature review, we have been using the terms "congestion pricing," "road pricing", and "road user charges" interchangeably with no difference in meaning. This is explained by the application of the general approach used by many scholars. For the further discussion of the topic in context of this research, it becomes essentially important to distinguish these terms. The classic economic term for any pricing mechanism applied for road use is congestion pricing. It reflects its original goal of mitigating congestion. However, the theory of road pricing has evolved in principle and now considers other forms of traffic externalities. Thus, as used today, congestion pricing includes a broad set of travel demand management instruments involving charges for road use (Federal Highway Administration 2008). Congestion is the "second last" externality on the time scale of vehicle use (of the consumption stage of vehicle's lifecycle): environmental and health impacts appear at the moment driver starts the vehicle's engine; congestion events happen in the areas with high traffic flow, causing time loss and increasing vehicle emissions; traffic accidents as the last major negative "side effect" of mobility occur in emergency situations. Therefore, the term "congestion charging" does not represent the complexity of the mechanism. According to the research conducted by Certu (2001), addressing this complexity is a *sine qua non* for public acceptance. Henceforth, the term "urban road pricing" will be used to describe the mechanism of internalizing all traffic related externalities, while "congestion charging" will be applied for the travel demand element of the scheme.

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2.6.1 Road pricing schemes

Considerable research dedicated to addressing vehicles externalities contributed to development of diverse road charging schemes. They vary by scale, flexibility, charging methods etc. Their summary and general characteristics are provided below (Tables 5, 6).

Table 5. Types of road pricing schemes by scale. Data sources: Federal Highway Administration 2008; De Palma and Lindsey 2011.

Type of the scheme	Description	Main goal	Implementation[5]
Priced lines[6]	Applied for a limited number of roadway lines.	Maintain optimal driving conditions (possibly free-flow speeds) in response to changing conditions.	Various locations across the U.S. (San Diego; Minneapolis; Seattle; Houston)
Priced roadways	Applied to all roadway lines.	Encourage drivers to seek alternatives to driving alone or during peak traffic periods.	Singapore, Vancouver (the U.S.), Texas
Distance-based toll-system (DTS)	Applied to multiple roads or regions.	Recover the infrastructure costs (e.g. caused by heavy vehicles).	Switzerland, Hungary, Germany, Austria, Italy
Zonal pricing	Applied for a specified zone.	Lower traffic flow in congested central business districts in urban areas. Decrease air-pollution and health risks of vehicle emissions. Invest into public transport network.	
area charge	Fees are payable to move within the zone's boundaries.		London
cordons	Fees are payable to enter/exit a specified zone.		Stockholm

[for a case study analysis of zonal pricing schemes in London and Stockholm see chapter 3].

[5] Selected examples.
[6] Other terms: express lines, high-occupancy toll lanes.

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Table 6. Types of road pricing schemes by time differentiation. Data source: Palma and Lindsey 2011.

Type of the scheme	Description[7]	Main goal	Implementation[8]
Flat	Rate is constant over time. Can be applied for 24 hours or for the certain periods of the day.	Account vehicle externalities while minimizing administrative and difficulties.	London
Time-of-day (scheduled)	Fee varies by the time of day, day of week, season.	Tackle congestion while adjusting the fee in non-congested periods.	Stockholm
Responsive (dynamic)	Fee varies in real time as a function of revealing traffic conditions; increases if lane occupancy exceeds a target level.	Maintain free-flow conditions while maximizing throughput.	Trial phase in Cambridge in 1990s.
Predictive (anticipatory)	Fee is based on forecast congestion.	Foresee congestion events.	n/a[9]

Considering the above, road pricing schemes aim to incorporate factors of the local traffic conditions (real-time or statistical) into their structure. What is more, vehicle characteristics define the price for road use in some schemes [see chapter 3]. In practice, however, complexity of the pricing system, i.e. frequency of toll variation and other administrative questions, may become the largest barrier to its implementation. Thus, the structure of the road charge is required to be concurrently communicable and representative (Bonsall *et al.* 2007). Otherwise, even theoretically coherent and impartial, it will face technological and administrative limitations, or will not gain public support. Hence, the efficiency of the scheme depends on its accuracy, while acceptance - on its transparency and level of complexity.

[7] Discounts and exemptions for certain categories of vehicles and drivers are common in each scheme.
[8] Selected examples.
[9] Such type of scheme has not been applied in practice. Dong *et al.* (2007) developed an algorithm for the scheme implementation.

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2.6.2 Technologies for road pricing

Regardless the type of pricing scheme, technologies used for the road pricing, should as a minimum perform the following functions: measure road usage, calculate charges, and transmit data to a control station (Iseki *et al.* 2010). Advanced technologies are creating more convenient ways to administrate and enforce the system of road charging. Selected schemes are described below (Table 7).

Table 7. Technologies used in existing road-pricing schemes. Source: De Palma and Lindsey 2011 (with amendments).

Type of scheme by scale	Type of scheme by time differentiation	Location	Fee differentiation	Data collection/ ways of payment
Priced line	Responsive	San Diego (2009) I-15 roadway	distanced-based	Dedicated Short Range Communications (DSRC) / Prepaid account
Area-based scheme	Time-of-day	Singapore (1998) Expressways, arterial roads	road type vehicle type	DSRC / smartcard
	Flat	London (2003) Charging zone	driving within the charging zone	Automatic Number Plate Recognition (ANPR)/ Manual payments
	Time-of-day	Stockholm (2007) Cordons	passing a control point; time-based	ANPR/Monthly bill
European distance-based HGV (>3.5 tons) schemes	Flat Distance-based	Switzerland (2001) All roads	number of axles, emissions class	DSRC /smartcard
		Germany (2005)[10] Federal motorways, some secondary roads.	road type, number of axles, time of day, emissions class	Global positioning system (GPS) / on-board unit (OBU)
		Hungary (2013) Motorways, some primary roads	road type, number of axles, emissions class	GPS / road ticket or via OBU

[10] Unlike other European countries, Germany applies fees for vehicles with gross weight >12 tons.

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The overview represents variety of electronic toll collection (ETC) systems available for the implementation of road pricing schemes. They are, however, based on one of the three technologies (Noordegraaf *et al.* 2009; De Palma and Lindsey 2011):

- Automated Number Plate Recognition System (ANPR): doesn't require in-vehicle equipment, uses roadside digital cameras and software which records the image of the vehicle and its license plate. The main technology used for London charging zone. In some systems is used as an additional control tool.
- Dedicated Short Range Communications (DSRC): the tag and beacon system, which operates in radio frequency, microwave or infrared range. Uses roadside equipment which communicates with tags on vehicles (smartcards). In addition, can work in combination with on-board units (OBU) to function as a zonal tolling scheme. This technology is used in Singapore, at most toll roads and in 2 European countries for HGV pricing schemes (i.e. Switzerland, Czech Republic).
- Satellite systems: operate via Global Navigation Satellite Systems (GPS etc.) and require in-vehicle equipment (OBU) that perform measurements based on geolocation data. This type is widely used for HGV pricing schemes. A weakness of the system is loss or reflection of a satellite signal therefore odometers are usually used to back up the road use metering.

Thus, ANPR and DSRC systems rely on roadside infrastructure to perform their functions and do not require installation of in-vehicle equipment. Satellite systems on the contrary require on-board equipment installed in each vehicle, but do not need special roadside infrastructure. In the U.S. cellular networks are also used for road pricing and operate similarly to the satellite systems. These factors are important when choosing the technological solutions for each urban area. Operating costs of roadside infrastructure and in-vehicle equipment, opportunities for future zone expansion and toll modification are largely determined by the type of applied technology (De Palma and Lindsey 2011). The social concerns, discussed further, as well influence the choice of road pricing schemes and technologies.

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2.7 To the question of equity in urban mobility

As mentioned previously, while the literature is rife with proposal of road pricing schemes, their implementation is still rare and lacking public support. Several studies have been conducted with focus on the question of acceptability of urban road charges. According to Raux and Souche (2004), levels of economic efficiency and social equity are the two main factors which define the acceptability of urban tolls. Analyzing road transportation equity in general, Litman (1997) defined horizontal and vertical equity. Raux and Souche (2004) developed the idea and linked it to Rawls' Theory of Justice, namely principles of liberty, equal opportunities, and difference (1971). The first principle of liberty corresponds to freedom of movement, thus the right to mobility, classified as spatial equity by Raux and Souche (2004). However, Viegas (2001) mentions that the right to drive a car freely in urban areas could be questioned. Exacerbating congestion, drivers' rights conflict with others' rights for safety, clean air etc. The second principle of equal opportunities is linked to the "polluter pays" principle, while the third considers the welfare of underprivileged (Raux and Souche 2004). The last two are the concepts of horizontal and vertical equity of road pricing, relevant to the current research, thus analyzed further.

2.7.1 Horizontal equity of road pricing

Through the lens of transportation justice, the horizontal equity of road pricing is represented by the application of the "polluter pays" principle (Raux and Souche 2004). According to the survey conducted by Certu (2007), around 70% of the respondents in Lyon and Marseille supported the idea of the drivers ("polluters") paying for the damages they cause by vehicle use. This is an important evidence in search of the support for the introduction of road pricing mechanism. However, other surveys showed that respondents also tend to see the situation as "pollution is caused by other people" (Certu 2007), meaning that their support could be strong until the fee is applied in practice. The way

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to avoid this pitfall could be in raising awareness about environmental consequences of vehicle use and traffic congestion. And still the case of London congestion charge showed that the environmental argument can increase the feasibility of the system [see section 3.2]. What is more, in their research Kaida and Kaida (2015) identified a possibility for pro-environmental changes in drivers' behavior with the introduction of urban road pricing scheme. They conducted a case study research of Stockholm's congestion tax (before and after the trial phase) and stated based on the results that it had "a considerable impact on facilitating pro-environmental behaviors and surrounding issues".

2.7.2 Vertical equity of road pricing

Not surprisingly, introduction of any type of the road pricing scheme will have different effects on road users from different social groups. From economic perspective, the road charge needs to be high enough to influence demand on road space. Otherwise, the charge will not be effective in the long-term and high traffic volumes will persist (Lake and Ferreira 2002). From social justice perspective, however, this means that the low-income social groups will be the most affected by the implementation of the scheme. It is a known fact that the most affordable property is in general located in the suburbs, and these areas are usually at risk of low public transportation coverage (Pooley *et. al.* 2013). Thus, travel conditions and available options should be considered for the "losers" of the road pricing schemes implementation. These are mainly the individuals who have to switch to different schedule, route or mode of transportation (Levinson 2009). In this context Adler and Cetin (2001) emphasized on redistribution of revenues from road pricing to assure improvements in transportation for those affected by the scheme. Hence, both horizontal and vertical dimensions of equity in urban mobility should be addressed to receive public acceptance and effectively implement the road pricing mechanism. The role of the social challenges will be further analyzed in case-studies of London and Stockholm road pricing schemes.

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2.8 Conclusion

The purpose of this review was to allocate the theory of urban road pricing in the context of the existing research on traffic congestion and broader environmental and health impacts of vehicle use. It is clear from the research reviewed that a great deal of attention was dedicated to the problem of increasing frequency and severity of road congestion in urban areas globally. Along with this, it is also clear that while ideas for improvements are rife, the actual implementation of road pricing schemes is rare. The reasons behind this arise from the complex interactions between economic, social and environmental factors.

It is a difficult task to estimate the cost of vehicle use to the environment and the society. What is more, significant part of the studies focuses primarily on congestion events omitting other vehicle externalities, developing fees for the overuse of "common" resource (i.e. road space). The vicious circle continues when the revenue from road charges is used to build new roads to satisfy demand. There is, however, a growing consensus among scholars that new roads, *ceteris paribus*, will not solve the problem. Thus, only by fully covering marginal social costs drivers can compensate the losses of their decision to drive a car. This reveals the economic perspective of the problem. The types of pricing systems vary by scale, time differentiation and some account additional vehicle characteristics. There are several examples of their implementation on national level and in urban areas [see section 2.6]. Advanced technologies that have developed over the last 30 years allow pricing schemes to be more flexible and autonomous in practice, cconcurrently lowering the cost of the system administration. For instance, algorithms for the anticipatory road pricing schemes in theory can foresee congestion and adjust the fee in real time conditions.

It must be remembered, however, that the implementation of any type of the road pricing scheme will have various social effects Thus, addressing equity concerns of road pricing schemes is necessary for

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public acceptance. Recognizing that the low-income social groups will be affected the most (vertical equity), analysis of available mobility options is required prior the implementation. Arguments regarding the horizontal equity of road pricing in turn can increase public support and feasibility of the road pricing. The "polluter pays" principle has shown to have support among residents of urban areas [see section 2.7.1].

The futility of attempts to "build the way out" from urban congestion by adding more road space is even more obvious when looking at urban traffic through the lens of the third, sustainability framework. The overuse of urban road space is another example of the "tragedy of the commons" (Hardin 1968). Therefore, only by limiting access to the urban space it is possible to retain its capacity.

Considering the dearth of data on the actual effects of the road pricing mechanisms, it is beneficial for the current research to conduct a focused case study analysis of the implemented schemes in the two European capitals – London and Stockholm. The results will be used in the further discussion on the implementation of urban road pricing in Budapest.

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3 Methodology

This chapter outlines methods used in the research's data collection process. It also explains how the gathered data was analyzed. The advantages and disadvantages of the chosen research methods are revealed here. The research limitations section reflects upon the challenges faced when conducting the research, recognizes the limitations and explains the nature of these limitations.

3.1 Research design

The original aim of my thesis research was to work on an existing project, preferably the one where I could combine the two field of my academic background – economics and environmental protection. I also aimed to contribute my time to the efforts of any social movement or organization advocating for important changes in a society. With this in mind, Levegő Munkacsoport, Hungarian NGO became the main partner in this research. During the winter course on sustainable transportation policies we were introduced to Lukács András, the NGO's Head. The organization is active in the sphere of air quality challenges in Hungary. Over the years they have been vocal about the dangerous pollution levels in the Hungarian capital. Thus, one of the ongoing projects of NOG has been focused on the implementation of the road pricing mechanism in Budapest to combat pollution. In 2016 they published a paper titled "It is time to implement congestion charges in Budapest" (Levegő Munkacsoport 2016). The difficult side of the mechanism they have been advocating for is the estimation of the road fee for driving in Budapest. This figure is important to call on the further actions and strengthen the communication to the public and the local authorities. Thus, rephrasing the initial title of their study, I joined the team with my research called "Is the time to implement road pricing in Budapest?" The aim of calculating the marginal social cost of vehicle pollution in Budapest developed into the comprehensive research on the topic of road pricing mechanisms. Parallel to this, the current research has shaped my understanding of economic, environmental and social roles of urban traffic.

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3.2 Methods of data collection

In this study numerous sources of data collection were used. The introductory materials were provided by the research partner - Levegő Munkacsoport. The periodical meetings and e-mail communications were the main means for the information exchange. Through the NGO's work network, Közlekedés Fővárosi Tervező Iroda Kft. (the Transport planning company; further Közlekedés Kft.), had been contacted for various data requests. The Budapesti Közlekedési Központ (Budapest public transport company; further BKK) was another prospective research partner, however, any information was received from it on request. During the initial steps of the research, the faculty of mathematical modelling department of Kharkiv University of Finance and International Trade were contacted for consultations and personal meetings were held in Ukraine.

The Central European University library catalogs and accessible online databases, namely JSTOR, Ebsco, Science Direct, Project Muse were used for the literature search. For instance, the search terms like "road pricing OR road charge OR road toll", "congestion and price", "congestion and urban roads" were used. The search narrowed down at the later stages: "urban- AND/OR vehicle externalities", "road pricing schemes", "urban congestion effects" etc. For the case-study analysis and main discussion the search was refined by mentioning the location. The literature in English was considered mainly, with few exceptions of studies in Ukrainian and official statistical information in Hungarian. The study was focused on the European Union, thus only several worldwide examples were considered. The most recent available data was targeted, however, historical studies on the topic were also considered in several cases. A Google search engine was used to access government official web-sites, relevant legislative and statistical databases, online maps and environmental monitoring platforms. For understanding purposes, the various online media sources were skimmed to acknowledge the ongoing discourse and dynamics of public opinion and acceptance of road pricing mechanisms in the analyzed cases.

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3.3 Methods of data analysis

First and foremost, it must be highlighted that this has been an exploratory research and a learning exercise for the author. The study was initially planned to combine quantitative and qualitative research methods. However, the initial targets had to adapt to the faced limitations in data collection and time constrains. The core of this research is developed through the extensive literature review and case study research methods. The case studies were particularly helpful in answering some of the research questions. The constant communications with the research partners benefited to the discussions reflected in the study. Due to the nature of the established communication, it is not possible to separate an interview method or to present the obtained information in a structured way. The economic calculations performed at the early stages of the research were omitted in the discussion part due to lack of the reliable local data. The findings of this preparatory process will however be reflected in the conclusions. The mathematic model aimed to offer options for Budapest road pricing scheme could not be applied in practice due to the same reasons. It will still be briefly outlined in the discussion part aiming to benefit the further research on the topic.

3.4 Research limitations

The main limitation of the current research is rooted in the constrains with obtaining the local data about Budapest. There were two types of data constrains: the absence of the necessary data and the usability of the available local data. The qualitative part of this study was shortened due to lack of the information on Budapest road traffic characteristics. In course of the in-depth case study research it was discovered that availability of data on city's non-residential and "active" residential traffic volumes, the average daily/monthly distances driven by cars; classification of the vehicles on the roads with regard to the emission standards is necessary for the calculations of marginal social costs of traffic in urban areas. As well required is the data on zonal distribution of congestion events and long-term

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trends on average speeds in the analyzed area. These are some of the parameters which define the vehicle use externality costs. Most of this information was not obtained in course of the current research. Assumptions were done based on the available local data. This was mainly the information obtained from the open access official resources and previous studies about Budapest available in English. Concerns arose that local data on air pollution levels in Budapest does not reflect the actual health risks. Thus, the usability of the data from the local monitoring system was questioned. Charging for the environmental pollution caused by traffic is an integral element of the road pricing mechanism. For this, the risks must be recognized, and costs of harmful pollution calculated. The most recent information on noise pollution levels in Budapest, second worst traffic externality affecting human health, is based on 2007 figures. The current research was adapted and conducted with the recognition of these limitation. Recognizing also the broad range of traffic related challenges, the current research was not aimed to research questions of urban planning and traffic engineering, non-urban congestion, congestion created by accidents, urban parking solutions. Finally, it was not possible to fully acknowledge the local discussion about road charges in Budapest due to the language barrier. Conduction of the interviews with related specialists would be beneficial to overcome this limitation. Due to the different primary focus of the current research this option was not considered timely.

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4 Case studies

As previously mentioned, the road charging schemes have only been implemented in few urban areas globally, thus there is limited data on the effects of this mechanism on lowering congestion and improving air quality in urban areas. Many heterogeneous factors contribute to this. Technological, economic, and social challenges must be acknowledged to validate the practical application of this, in theory, useful tool. First and foremost, this is of course a complex political decision. On the EU level, the question of designing urban road charging schemes has been discussed for a long time. The European Federation for Transport and Environment (Kenny 2017) has recently published a study on road charging for passenger cars, emphasizing on numerous economic and environmental benefits of the truck tolling systems operating in Europe. There are two prominent examples of urban road systems in the EU: London charging zone and Stockholm congestion charge. The following sections are aimed to analyze these schemes in light of the chosen theoretical framework [see section 1.4] and answer the following questions:

- Which vehicle externalities are covered by the urban pricing schemes?
- What are the effects of this mechanisms on congestion levels and air quality in the urban areas?
- How were the social equity issues addressed in the implemented schemes?

The outcomes of the analysis will be summarized to provide suggestions and recommendations for the development of Budapest urban road pricing scheme.

4.1The European Union framework for road charging

According to the European Commission (2018), the annual cost of congestion events in EU amounts to €100 billion or 1% of the total EU's GDP. By 2050 the number is expected to double if the congestion pattern is not influenced to change (European Commission 2017). The political discussion surrounding the topic underlines that the charging schemes must be adapted locally, but the general

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EU framework is needed to establish a shared approach and give guidance to national authorities. There's an increasing political support of that "road charging is not only very effective at managing congestion but may also be *the only* effective measure…" (Kenny 2017). Currently the charging schemes in the EU member states are mostly applied for HGVs, with some countries charging the passenger cars on the speed roads or specific sections. Below is the summary of the types of the charges applied across the EU countries (Table 8):

Table 8. Charging of HGVs and private vehicles in the EU. Data source: Rumscheidt 2014.

Country	HGVs		Private vehicles		Country	HGVs		Private vehicles	
	D[11]	T[12]	D	T		D	T	D	T
Austria	×			×	Italy	×		×	
Belgium		×	-		Latvia		×	-	
Bulgaria		×		×	Lithuania		×	-	
Croatia	×		×		Luxembourg		×	-	
Cyprus	×		×		Malta	×		×	
Czech Republic	×			×	Netherlands		×		×
Denmark		×	-		Poland	×		×	
Estonia	-		-		Portugal	×		×	
Finland	-		-		Romania		×		×
France	×		×		Slovakia	×			×
Germany	×		-		Slovenia	×			×
Greece	×		×		Spain	×		×	
Hungary	×			×	Sweden		×	-	
Ireland	×		×		United Kingdom[13]		×	-	

As we can see, only two EU member states do not have any kind of road charging scheme: Estonia and Finland. Eight countries do not charge private vehicles and apply time-based charges for HGVs.

[11] D = distance-based charge (both ETC and physical barriers).
[12] T = time-based charge (vignettes)
[13] During the time of the research UK remained a full member of the EU.

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They sell vignettes, i.e. charge for the road use in advance (for a fixed period of 10 days / month/ year). Ten countries apply the distance-based schemes, i.e. charge drivers for the actual road use. In the remaining six countries the combination of time and distance-based mechanisms is used. Such diversity of the road charging schemes reflects different political and social circumstances in the countries (Rumscheidt 2014).

Directive 2011/76/EU regulates the charges for HGVs, but there is no similar framework for private cars on motorways and urban areas in the EU. Based on the literature review of the topic, the EU's role in facilitating the implementation of the urban road pricing schemes could be in developing the structure of charges, advising on technologies and establishing the legal framework to address social justice and data protection issues.

4.1.1 Road charging for trucks is a success

The experience gained with tolling HGVs is a valuable source of information for the topic of urban road charges. Since the introduction in 1999, the system has been in operation for 20 years, thus can help to meet the challenges of urban road pricing. In their analysis of the EU infrastructure charging policy, Gibson *et al.* (2014) outlined that distance-based schemes for HGVs have shown to have better results than time-based. Prepaid time-based vignettes were the first tool to pay for the road use. This was the most convenient instrument under the existing technological limitations. However, time-based schemes do not effectively influence the demand on road space, thus levels of congestion and air pollution. This applies for urban conditions as well. The Strategy for Low-Emission Mobility states that "across the EU, charging should move towards distance-based road charging systems based on actual kilometers driven, to reflect better the polluter-pays and user-pays principles" (European Commission 2016). This is the main lesson learned from the HGVs pricing schemes. Further analysis of London and Stockholm road tolls will identify the strengths and weaknesses of both systems.

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4.2 London congestion charging scheme

The Greater London Authority Act (1999) officially allowed introduction of road user charging in London. The preparations for the implementation started next year, and in three years the scheme was launched. The social surveys showed high rates of support with 90% of respondents classifying reduction of traffic congestion in central London as 'important' (Transport for London (TfL) 2002). The first fee amounted 5 GBP and the charging zone covered 21 km^2 of inner London urban area. The ANPR technology was chosen for the operation and enforcement of the scheme [see section 2.6.2 for technology description]. Table 9 summarizes main characteristics of the scheme:

Table 9. Characteristics of London congestion charge. Data source: Transport for London 2018a.

Launch year	2003
Pricing scheme	zonal area charge, daily-based, flat rate with unlimited entrances
Technology	Automatic Number Plate Recognition (ANPR)
Total city area	1,569 km^2
Congestion zone area	21 km^2 (1,3% of total city area)
Population[14]	8,8 million people
Daily average number of cars driving in the charging zone	20.000 trips inside or entering the area (before the scheme)
Daily fee	5 GBP (2003); 8 GBP (2005); 10 GBP (2011); 11.50 GBP (around 14.5 EUR) (since 2014)
Methods of payment	daily, weekly, monthly or annual passes
Application of charge	payable for entrance, exit, movements inside the area
Time of application	Monday-Friday, 7:00-18:00
Fines	65-195 GBP
Discounts	90% for residents of the zone; 100% for public transport, blue badge holders, taxis, motorbikes.
Use of the revenues	transport infrastructure needs

[14] mid-2017 estimations. Data source: Trust for London 2018.

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Since the implementation, considerable research has been conducted to identify effects of the road charge on congestion, traffic density, the environment etc. The initial aim of the scheme was set to decrease traffic volumes by 10-15% and travel time by 25% within the charging zone. First year showed 20% reduction of traffic and 30% reduction of congestion compared to the last few weeks before the launch (TfL 2004). According to the reports, after ten years of operation traffic levels were 10% lower comparing to the baseline conditions (Topham 2014). The scheme, however, wasn't designed to significantly affect air quality within the charging zone (TfL 2002). But still, the Fifth Annual Monitoring Report (TfL 2007) outlined that during the 3 years since introduction of the scheme, NO_X emissions fell by 17%, PM10 by 24% and CO2 by 3% in the charging zone, which was partly due to reduced traffic levels. Since 2006 the discussion started regarding the need for additional pollution charge to be introduced in the charging zone. The T (toxic)-charge was introduced in 2017 only.

Table 10. Characteristics of London T-charge and ULEZ. Data source: Transport for London 2018b,c.

	T-charge	ULEZ (planned)
Launch year	2017	2019
Pricing scheme	within congestion charging zone, time-based, flat rate	
Technology	Automatic Number Plate Recognition (ANPR)	
Daily fee	10 GBP 1 GBP for residents	12.50 GBP for cars 100 GBP for HGVs, busses
Application of charge	payable for entrance, exit, movements inside the area by petrol and diesel vehicles	
	which do not meet Euro 4 minimum engine emissions standards	below Euro 4 for petrol vehicles below Euro 6 for diesel vehicles
Time of application	Monday-Friday, 7:00-18:00	24/7, 365 days a year
Fines	135 GBP 65 GBP if payed within 14 days	130 GBP
Discounts	100% for motorcycles, blue badge holders	100% for ULEZ residents for three years (2019-2021)
Use of the revenues	transport investments	

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Since October 2017 vehicles which below Euro 4 emission standards are obliged to pay 10 GBP charge in addition to the congestion charge to enter or drive within congestion charge zone (Table 10). Thus, the owners of the old (usually these are those of 12 years old and more) polluting vehicles must pay 21.50 GBP to drive in central London. However, scientists urge for more radical actions to combat high pollution levels saying that the T-charge will not solve the air pollution problems (Cecil 2017). It has already been announced in 2019 the new regulations enforcing the Ultra Low Emission Zone (ULEZ) requirements (Table 10). Unlike the T-charge, it will be applied every day for 24 hours without exemptions. The ULEZ will be operating on the same area as the Congestion Charging Zone with planned expansion in 2021 (TfL 2018c).

To conclude, the London congestion charge has few specific features. From the economic perspective, the marginal social cost estimated to be paid by drivers included losses related to congestion events – i.e. extra travel time and delays. The decade results have shown improvements in congestion levels, however, the fee has more than doubled over this period to continuously influence the demand on road space. The effects were higher during the first years - for instance, 26% decrease was reported in 2006; by 2016 congestion events were still 10% less frequent and severe compared to 2003 (Centre for public impact 2016). There are reports that showed improvements in air quality since the introduction of the pricing scheme, however, the correlation between the two was later questioned (Kelly 2011). Thus, the environmental and health externalities of high traffic volumes in one of the largest megalopolises remained unaddressed under the congestion charge. In January 2017 London experienced extremely high pollution levels due to specific weather conditions which caused toxic pollutants to concentrate in the air (Freytas-Tamura 2017). Next month acting mayor of London introduced the T-charge in addition to the congestion charge to come into force in October 2017, which targeted vehicles with low engine emission standards. By the time of the current research, no data is available on the effects of the T-charge on air quality. However, by the time of implementation,

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it was already recognized that the T-charge will serve as an intermediary step towards stricter requirements, which come into force in 2019. The ULEZ's clearly stated goal is to improve the air quality as London's mayor S. Khan stated: "The air in London is lethal and I will not stand by and do nothing…I am introducing a new T-Charge this October and subject to consultation, I want to introduce the Ultra Low Emission Zone in central London in April 2019. This alone will mean the capital has the toughest emission standard of any world city."(London Assembly 2017). The public acceptance of congestion charge wasn't high at the beginning, however, voters supported Mayor candidate advocating for this mechanisms in 2000 and re-elected in 2004. Later social surveys showed that over time the charge become largely accepted by public, partly due to raising environmental concerns (Center for public impact 2016). Strong cooperation between involved authorities and effective public consultations prior implementation and in times of changes made the project politically and socially successful according to the International Council on Clean Transportation (Pike 2010).

4.3 Stockholm congestion charge

The implementation of Stockholm congestion charge started with a 7-month trial period in 2006, followed by referendums, and was implemented on a permanent base in 2007. Unlike London's scheme, charges in Stockholm are applied to each crossing of the charging zone boundaries. The same technologies are used (APRN) in both schemes, but the payment options differ (Table 11). However, there is a difference in use of the technology - while in London a driver is responsible for correct payments, in Stockholm the system calculates the amount of charge for the vehicle. This approach helped to apply different charges in different times of a day.

Geographical characteristics of Stockholm must be considered when describing the system operation. The city is located on fourteen islands connected by various bridges. The zone has 18 entrances located at the main motorways leading into to the inner city. The levels of congestion here were reaching

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200%, meaning that drivers were spending three times more time making a trip comparing to free-flow traffic conditions. Now under various exemptions, around 15% of cordon passes are free of charge. Until 2009 alternative-fuel cars were exempted from paying the charge, which increased their share from 3% to 15% in four years (Eliasson 2014). A round trip for a driver entering the congestion zone in Stockholm during peak hours will costs 40 SEK (around € 4).

Table 11. Characteristics of Stockholm congestion charge. Data source: Croci 2016; Swedish Transport Agency 2018.

Launch year	2007
Pricing scheme	cordon pricing, time-based differentiated rate
Technology	Automatic Number Plate Recognition (ANPR)
Total city area	188 km^2
Congestion zone area	30 km^2 (16% of total city area)
Population[15]	1.9 million people
Daily fee	20 SEK (2.16 EUR): 7:30-8:30, 16:00-17:30; 15 SEK (1.5 EUR) – 7:00-7:30, 8:30-9:00, 15:30-16:00, 17:30-18:00; 10 SEK (1 EUR) – the rest of the period between 6:30 and 18:30. Total cap for day: 60 SEK (around 6 EUR).
Methods of payment	Monthly bill
Application of charge	single crossing of the zone cordon (with daily maximum price limit)
Time of application	Monday-Friday, 6:30-18:30
Fines	500 SEK 70 SEK if paid within 5 days
Discounts	100% for emergency vehicles, buses, military vehicles, motorcycles; *alternative-fueled vehicles (until 2009);* *vehicles registered in a foreign country (until 2014)*
Use of the revenues	new road constructions in and around Stockholm

For Stockholm the discourse about urban road charges started in 1990s when government was developing investment ideas for new road infrastructure. It was supported by environmentalists, but

[15] mid-2017 estimations. Data source: Trust for London 2018.

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political and social circumstances did not allow to proceed any further. The discussion revived with change of political powers at the beginning of 2000s. It is recognized by many researches now, that the decision to have a trial phase before the actual implementation was one of the key factors of success. It switched public opinion from mainly hostile to positive. Before the trial phase, only 34% of citizens supported the scheme. The referendum held 7 months later gained 53% of votes in support of the pricing mechanism (Eliasson 2014).

The effects of the scheme on congestion and air pollution in the charging zone and on a broader scale were noticeable. After 5 years the congestion levels in the inner city were 22.1% lower comparing to 2005. The afternoon congestion decreased at a larger scale than morning. Notably, the traffic volumes in non-peak periods decreased at a similar rate. In their study Johansson *et al.* (2009) predicted that the scheme's introduction will save 25 to 30 lives annually in the Stockholm metropolitan area. The air pollution decreased by 10-15% over the 5 years, with lowest achievements for NOx – 8.5%. This is explained by pollution coming from public diesel fueled buses (Eliasson 2014).

The Stockholm case at best reflects the complex interplay between economic, environmental and social sides of urban road pricing mechanism. The system was not implemented until the discourse switched from technical and economic domain to health and environmental. This allowed to gain a momentum and launch the trial phase followed by the referendum. A considerable research on the transformation of public opinion in Stockholm identified the main apprehensions on the way. They are: ineffectiveness of the mechanism in the long-term, new congestion problems on free of charge motorways, and recurrence of traffic in the charging zone, i.e. low elasticity of demand. The practice has shown none of these to happen in Stockholm (Börjesson *et al.* 2012). Neither the low public acceptability of the proposed policy changes will lead to the failure of the system. The essential is political support, which grows strong when local authorities gain influence over the use of the revenues and the design of the system.

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Points of interest for Budapest context

Completed case study research provides various implications for consideration in the process of urban road pricing scheme development. While findings are largely determined by local social and political environment, there is an opportunity for generalized conclusions based on common elements of the two analyzed systems. They can be summarized under the three categories: legitimacy, policy and actions (Center for public impact 2016).

Legitimacy of the system of road pricing is essential for its implementation and effective functioning. Strong stakeholder engagement and political commitment were present in both cases. They became main prerequisites for further actions. In London's case the collaboration between Mayor, state and local managing authorities, together with expert working groups was outstanding. Political support in Stockholm's case grew stronger when the discourse shifted from purely technical to moral questions of public health and air pollution. Likewise, it strengthened when local authorities were granted a say in design of the scheme and use of the revenues. Public confidence, however, was at first low in both cases. The schemes were criticized by political opponents, vehicle owners, trade unions, media. In time public opinion has transformed in favor of the mechanism. This is largely due to citizens' growing health and pollution concerns, combined with feasible policies described further.

The quality of policies applied in analyzed cases had to improve over time. The policy's objectives have to be clearly outlined and explained. Their proper communication is vital for public acceptance. In London's case the goal was to reduce congestion and other vehicle externalities were not explicitly targeted. This required introduction of additional charge (T-charge) 15 years after implementation of the initial scheme. Stockholm's charge had this element from day one, albeit pollution levels were significantly lower. It was researched (Kaida and Kaida 2015) that the implementation of Stockholm scheme had spillover effects on drivers' pro-environmental behavior. The evidences to this are changes

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in preferable modes of transport, increase of alternative-fueled vehicles, and various non-transportation behavioral changes. Equally the evidence to efficiency and fairness of the scheme design is required to gain public acceptance. The findings of preliminary research and, in case of Stockholm results of the trial phase, allowed municipality to develop transport policies with reference to numerous studies and the expert working groups reports. This consequently developed the feasibility of the proposed pricing mechanism and helped to overcome numerous public concerns.

Ultimately, when it comes to implementation and operation, effective management system is responsible for delivering results. However, it was highlighted by developers of both schemes, that the system design is an iterative process (Eliasson 2010):

"It is absolutely necessary to have sufficient time, and access to a reasonably good transport model... Still there will almost certainly be surprises, and the first…charging system design will most likely not be optimal or even good – it may even make congestion worse overall by "moving congestion around".

Better yet, a clear management structure with aligned responsibilities and effectual internal communication will enhance timely response to the changing circumstances. Monitoring of traffic conditions and other characteristics according to set objectives is equally important prior and during the scheme operation. Collected data will serve as a base for the mandatory element of the system - monitoring reports. This is the case when "familiarity breeds acceptance". The data should be specific, relevant and time bound. A comprehensive monitoring program such as the one developed for the London congestion charging scheme had been the main source for communication about the results of the system operation. The discussion on the development of the urban road pricing scheme for Budapest will incorporate these findings.

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5 Discussion: is it time to implement road charges in Budapest?

5.1 Budapest roads: current situation

This section will first provide a brief overview of Budapest topological and geographical characteristics in the contexts of the current study. Next, it will mention the current demographic situation, forecasts, and population density figures. It will than represent data on Budapest road transportation system and city road network. Acknowledgement of these characteristics helps to understand local conditions and will benefit the further research.

Budapest is the capital city of Hungary, located in the country's central part. It is a political, economic, cultural and administrative center of the country. Budapest is the most populous city of Hungary and one of the largest cities in the European Union (Meer *et al.* 2014). Figures 5 and 6 represent topography and administrative maps of Budapest.

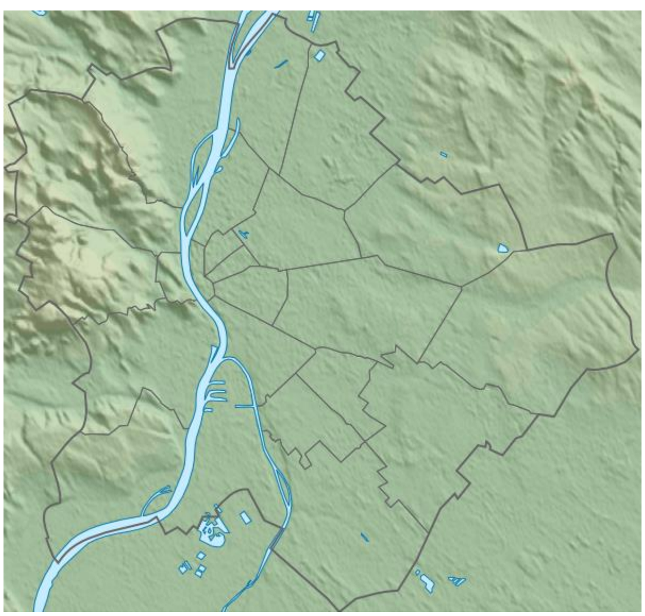

Fig. 5 Topographic map of Budapest.
Data source: Wikimedia Commons 2012.

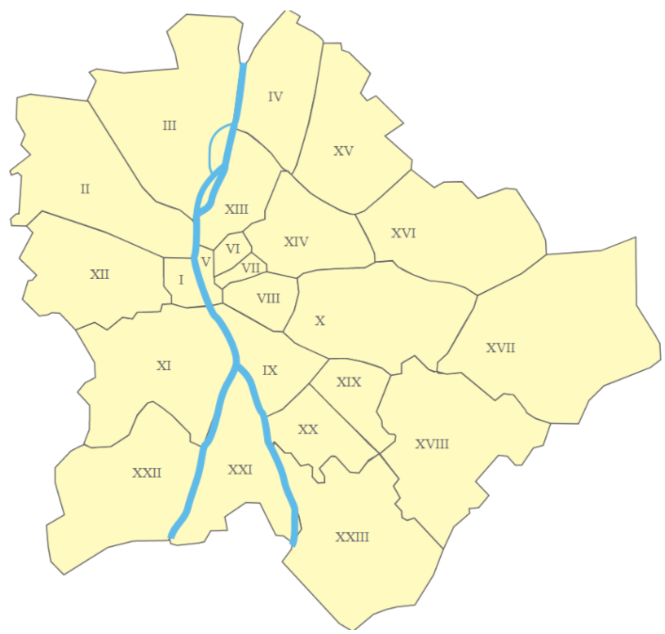

Fig. 6. Map of Budapest districts.
Data source: Wikimedia Commons 2008.

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The total city area amounts to 525 square kilometers. Nearly half of the area is built up, which automatically implies speed limits and high population density (see Fig. 7). The population of Budapest in 2018 was estimated at 1,749,734 citizens, which shows slight decline comparing to the three previous years (Hungarian Central Statistical Office 2018). It's around 60% of the total population of Budapest urban area. Budapest metropolitan area is home to 3.3 million people, which amounts to about 34% of Hungary's population. The city is the fourth by population growth in Europe, the 10% increase in citizens is expected by 2030[16](Euromonitor International 2012; 2017). Among other topological characteristics of the city are 3 islands within the city borders, around 20 hills in Buda part of the city, and 8 bridges built over Danube.

The population density of Budapest is around 30 persons per hectare (Atlas of urban expansion 2013). The official inner city of Budapest lies within V, VII, VIII and IX districts. This is where the density of population is the highest (Fig. 7). However, most citizens leave in districts III, XI, XIV, and XIII.

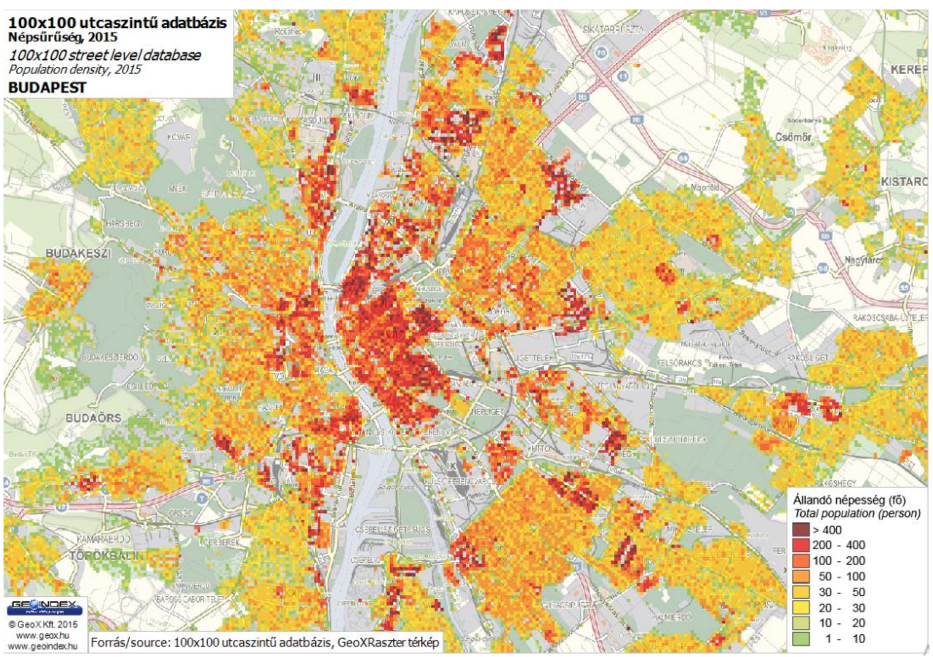

Fig. 7. Population density in Budapest. Source: GeoIndex 2015.

16 Comparing to population of Budapest in 2005.

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Consequently, high population density of downtown areas coupled with high concentration of business and governmental organizations, influences traffic patterns of this area [see section 5.2]. In light of all the above-mentioned characteristics, the high needs for mobility in Budapest come as no surprise. Budapest's geopolitical location has always benefited its economic and social development (Hungarian Chamber of Commerce and Industry 2018). Hungary's road system is centered in Budapest, thus major European motorways crossing Hungary's territory lead to Budapest. Arterial motorways in Budapest are: M1 motorway (towards Austria) from north-west, M2 motorway (towards Slovakia) from north, M3 motorway (towards Ukraine) from north-east with M31 motorway (between M0 and M3), M4 motorway (towards Romania) from east, M5 motorway (towards Serbia) from south-east with M51 motorway (between M0 and M5), M6 motorway (towards Croatia) from south, M7 motorway (towards Croatia via Balaton) from south-west. M0 motorway is a ring-road of Budapest which connects all arterial motorways.

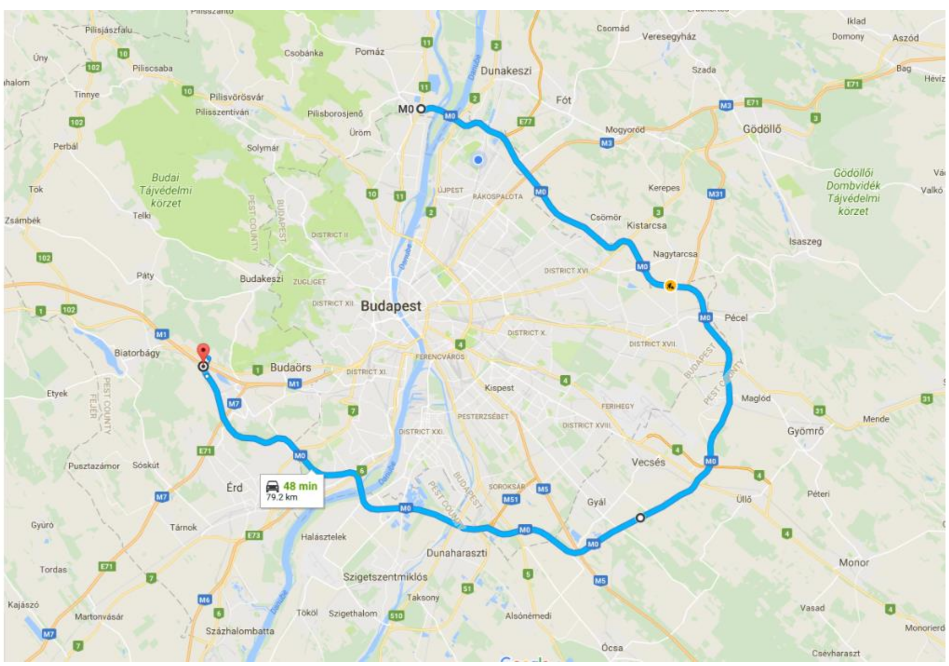

Fig. 8. Budapest ring road and connecting motorways.

This data highlights important aspect influencing traffic patterns in Budapest. Being a crossroad for

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national motorways, the city experiences the burden of extensive road freight activities. The mechanism of managing HGVs in Hungary will be discussed in the following sections. It has significant value in course of the current research due to use of the road pricing scheme.

Zooming in to Budapest urban road network, some historical patterns of city's development need to be highlighted. Starting from the 1960s, the urban development of Budapest was shaped according to the growing mobility needs (BKK 2014). Automobiles were prioritized over other modes of transportation, which lead to development of complex urban road network (Fig. 9).

Fig. 9. Road network of Budapest.
Source: Szabolcs 2018.

Fig. 10. Roads used by traffic coming from the agglomeration[17]. Source: Tenczer 2016.

Fig. 10 represents intensity of the traffic flow on Budapest roads created daily by commuters from the agglomeration. As it can be seen, the south- west, north-west, and north-east entrances to the city, as well as some secondary roads experience significant traffic volumes. The following section will explore in more details costs imposed by traffic in Budapest urban area. It will also attempt to evaluate the actions that have been taken by municipality to manage increasing traffic volumes.

[17] The width of the line represents traffic volumes. Roads with dense traffic are shown with wider lines.

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5.2 Defining local costs of vehicle externalities

In the current section we will conduct analysis of the data obtained in regard to negative traffic externalities in Budapest. Firstly, we will provide an overview of trends in car usage and congestion events in the area. Next, city's air pollution challenges and related local health risks will be outlined. Lastly, noise pollution levels in Budapest will be discussed.

Statistical data collection on the topic of car ownership in Budapest showed divergent trends. According to the research partner Közlekedés Fővárosi Tervező Iroda Kft. (Transport - Main Planning Office Ltd; further Közlekedés Kft.), the percentage of population owing a car in Budapest had slightly increased between 2008 and 2016. In 2011-2012 the figures had dropped by 2-2,5%, since than they were in steady increase. In general terms, data for 2018 represents 1 car per every 3 citizens in Budapest (Fig.11):

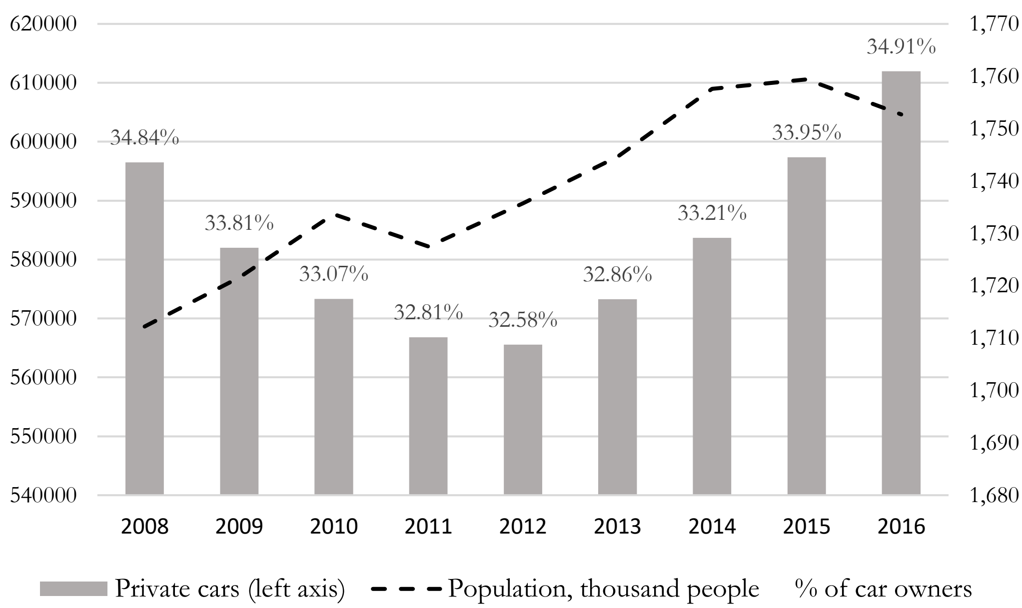

Fig. 11. Population and car ownership trends in Budapest in 2008-2016. Data source: Szabolcs 2018.

The number of cars increased in absolute values as well. While the population of Budapest increased by 40494 people, the number of cars was 15460 higher in 2016 comparing to 2008 (Table 12):

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Table 12. Changes in Budapest population and car numbers in 2008-2016. Data source: Szabolcs 2018.

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Number of private cars	596481	581991	573315	566790	565563	573264	583694	597337	611941
Population, thousand people	1.712	1.722	1.734	1.727	1.736	1.745	1.758	1.759	1.753

The detailed information of car numbers by districts shows changes in distribution of cars per inhabitant. In downtown districts (I, V, VI, VII, VIII) number of cars decreased. While in districts III, XI, XIII the figures increased. In the outskirt districts percentage of car ownership remained at a similar level [see section 5.1 for the map of Budapest districts]. This data can partly be explained by changes of population in the relevant districts. However, some districts showed decrease in number of cars, while population increased. Namely districts I, II, IV, XII. There are as well opposite divergencies of increased car numbers in districts with decreased population in districts X and XV.

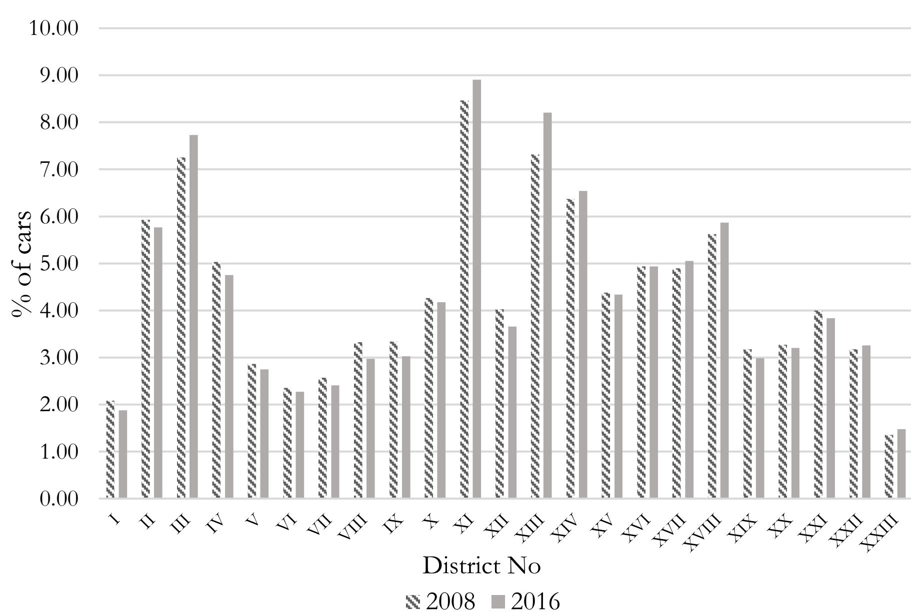

Fig. 12. Changes in car distribution by districts of Budapest. Data source: Szabolcs 2018.

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Collection of such detailed and up to date information is important for the analysis of urban traffic patterns. It allows to calculate the average travel distances for commuters, consider discounts for residents of central districts in case of application of zonal road pricing etc.

In context of this research, information obtained from other sources provided different data on the car ownership trends in Budapest. According to statistical information by Medián, Hungarian research company, the proportion of Budapestians owing at least one car was by 9% lower in 2016 when compared to 2009 (Adam 2016). Due to absence of methodological information of these estimations, the information received from Közlekedés Kft will be used as a reference.

Information about the congestion is central for the current research. Based on trends and extremes, it serves as a base for understanding of urban road traffic patterns. One of the main limitations faced during this research was absence of information on traffic volumes [see section 3.4]. Thus, the localized information obtained on this question is time-limited and general. According to the international navigation company TomTom NV (2018), Budapest is ranked as 130 in the world with 22% traffic index congestion level. Annual extra travel time due to congestion in Budapest amounts to 100 hours. To compare, this figure is 152 and 126 hours for London and Stockholm accordingly (Table 13). These cities were chosen for comparative analysis due to previously conducted case-studies. Notably the ranking was conducted in 2016 when both cities have already implemented road pricing mechanisms.

Table 13. Traffic congestion data for Budapest, London and Stockholm. Data source: TomTom 2018a.

City	Annual extra travel time, hours/year,	Road network length, km	Increase in travel time when compared to free-flow, %	
			highway	non-highway
Budapest	100	14 854	2	37
London	152	48 952	21	47
Stockholm	126	7 630	22	33

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The outstanding characteristics of Budapest urban congestion is that majority of events happens on the non-highway roads. Drivers on the highways and the ring-roads experience only 2% increase in travel time on average. Surprisingly, the trend of congestion level in Budapest is decreasing. From 29% in 2009 it dropped to 22% in 2016, according to the available information (Fig. 13).

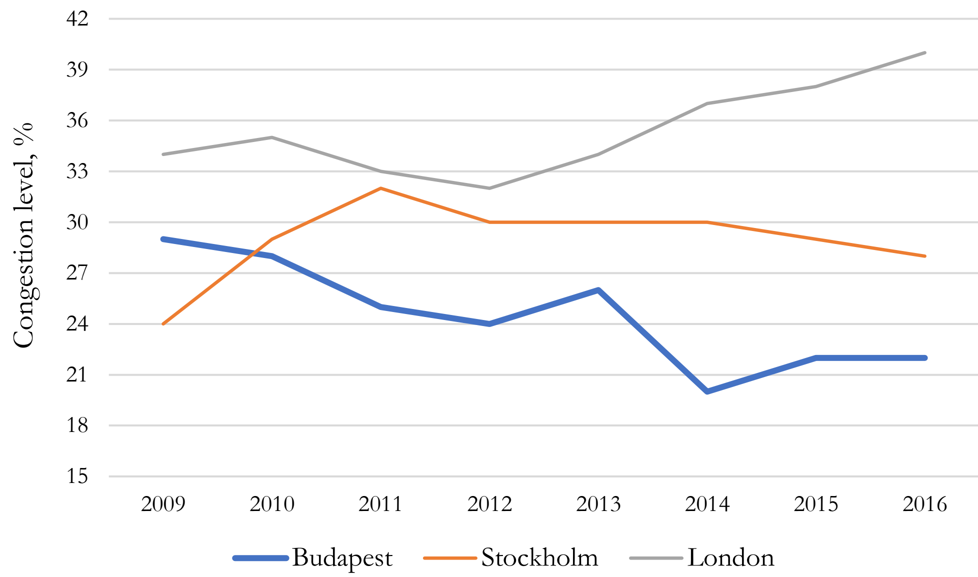

Fig. 13. Congestion level history for Budapest, London and Stockholm. Data source: TomTom 2018a[18]

However, this data requires additional context. Besides looking at congestion levels, two other factors should be considered, namely the average traffic speed and time distribution of peak traffic volumes. To the author's best knowledge, there is limited amount of research on road pricing mechanisms which had focused on the analysis of the average travel speeds. In their review Juhász *et al.* (2014) briefly mentioned the validity of this measurement. They claimed that when the travel speed in a city goes down to around 20 km/hour, it is the time for the road charges. This indeed was the case for London and Stockholm. Both cities implemented the pricing mechanism when the average travel speed was around 17-20 km/hour, with some 10km/hour in heavy rush hour traffic (Croci 2016). The current

[18] The methodology used by data provided is described at https://www.tomtom.com/en_gb/trafficindex/about.

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situation in Budapest shows that the average speed doesn't go below 27 km/hour (TomTom 2018b). The distribution of congestion events in time shows the morning peak between 8 a.m. and 9 a.m.; the evening peak between 4:30 p.m. and 5:30 p.m. This information must be considered when designing differentiated road toll scheme (Fig. 14).

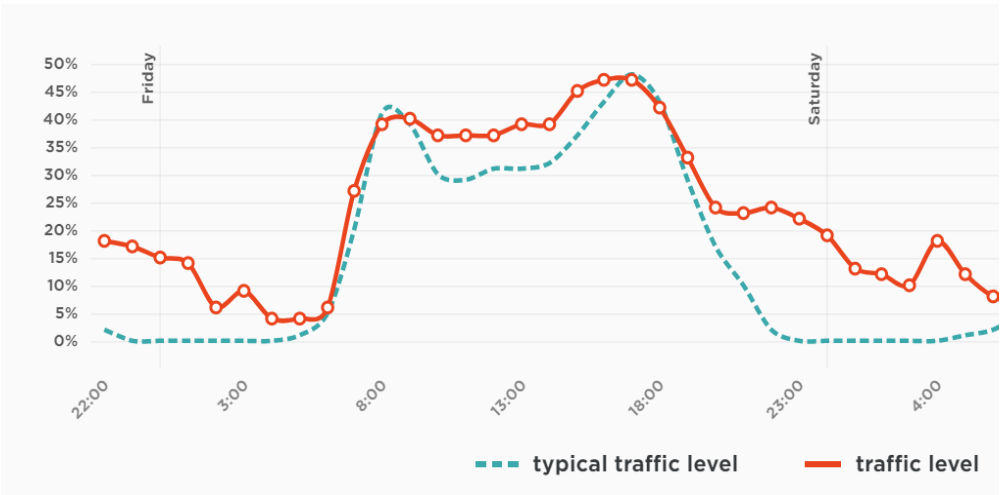
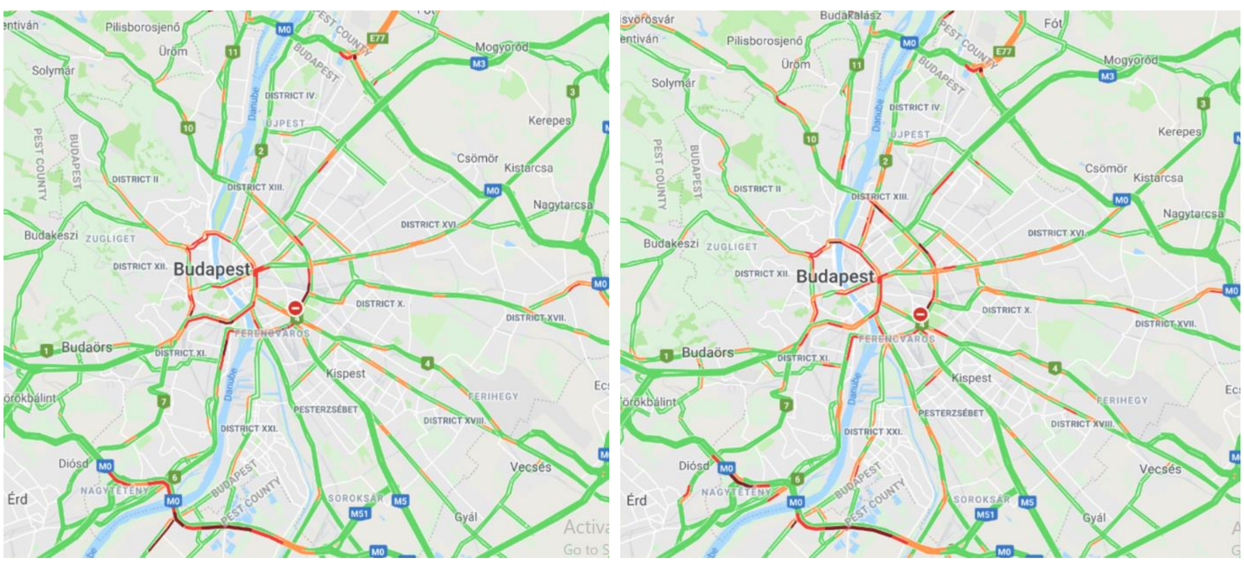


Fig. 14. Daily distribution of traffic volumes in Budapest. Source: TomTom 2018b.

The screenshots of the online traffic map below show traffic volumes at peak periods (Fig. 15):



a) 8:30 a.m.

b) 5:00 p.m.

Fig. 15. Map of traffic conditions in Budapest at peak traffic periods (green: fast progress, yellow: medium speed, maroon: slow progress, black: plug). Source: Google 2018.

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The maps show reoccurring high traffic volumes at the inner ring roads – Nagykörút and Hungária körgyűrű, and at most streets in the downtown area. The main city's central bridges (Rakoczi, Petofi, Erzebet, Margit) are congested. Some parts of the roads leading to the outer districts are also experiencing high traffic density. The information about city's most congested areas must be available for the pricing scheme design. It needs to be representative, meaning collected at different time periods, days of the week, seasons etc. To the extent of our knowledge, thus far in Budapest such data is not systematically collected. This makes it hardly possible to define the "problem" zones in urban road network.

In course of the current research, it was discovered that availability of the information about city's non-residential traffic; "active" residential traffic, the average daily/monthly distances driven by cars; classification of the vehicles on the roads with regard to the emission standards is necessary. Absence of such data restricts required calculations of marginal social costs of traffic. Moreover, the questions of efficiency, evidence and feasibility of data will occur during the road scheme implementation.

The data collection of the information on air quality in Budapest as well revealed complexities. The Hungarian Air Quality Network, subsidiary structure of the Ministry of Agriculture, runs the automatic monitoring network which consist of 12 monitoring stations in Budapest. Five of them are located in the inner city, the rest is distributed in circle-shape in the residential area around the city (Hungarian Air Quality Network 2018). Each station measures 7 pollutants: NO, NO_2, other NOx, SO_2, CO, O_3, PM_{10}. In course of the current research, the information from the monitoring stations had been accessed multiple times in different time periods. The results of the automatic system monitoring had always been between "excellent" and "good" with rare cases of "appropriate" for all pollutants concentrations. These findings were in contradiction to the numerous publication of the international observatory bodies (Roy and Braathen 2017; IAMAT 2016) highlighting air pollution in Budapest as one of the key health risks for the population.

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The annual average concentration limits for PM10 in Hungary are set at 40 µg/m3. However, WHO guidelines recommend the limit to be twice stricter - 20 µg/m3. Similar is the situation with PM2.5 pollution: in Hungary there are no daily limits for this measurement, and annual is set at 25.7 µg/m3, albeit WHO guidelines of 25 µg/m3 daily limits, and 10 µg/m3 annual mean. Limits for ozone pollution, NO2 and SO2 concentrations also differ (Table 14).

Table 14. Air pollution limits in Hungary and WHO guidelines. Data source: Hungarian Air Quality Network 2018; WHO 2006.

	Hungary		WHO recommendations	
Pollutant/period	24-hor	annual	24-hor	annual
PM10	50 µg/m3	**40 µg/m3**	50 µg/m3	20 µg/m3
PM2.5	N/A	**25.7 µg/m3**	25 µg/m3	10 µg/m3
O3 (8-hour mean)	**120 µg/m3**		100 µg/m3	
NO2	85 µg/m3	40 µg/m3	200 µg/m3	40 µg/m3
SO2	**125 µg/m3**	50 µg/m3	20 µg/m3	N/A

These pollutants are the major components of vehicle exhaust gases. Their health effects were outlined in section 2.3.2. Traffic congestion increases volumes and concentration of these harmful elements in urban areas [2.3.5]. Thus, in addition to existing problems of pollutants coming from other sources in Budapest, namely house hitting and industries (IAMAT 2018), traffic pollution has significant influence on urban air quality. Areas along the main roadways, frequently congested roads, complex crossroads are those where the pollution from vehicles is the highest. Thus, residents of these areas are exposed to high pollution concentrations on a daily base. According to the OECD estimations (Roy and Braathen 2017), in 2015 there were 869 premature deaths from PM pollution per 1 million inhabitants in Hungary (meaning almost 8000 citizens in total). As it was mentioned before, assessment

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of traffic environmental externalities is a complex task. Various input data is required to differentiate vehicle pollution, namely the cars' average travel times; vehicles numbers according to the emission standard; areas with reoccurring congestion etc. Such detailed information about Budapest was not obtained in course of the current research. Thus, it will be assumed further that the areas along the main roads and the downtown districts are suffering the most from traffic pollution. This assumption is supported by the observation of online traffic conditions in Budapest over time [see Fig. 15].

Noise pollution is another major transport externality. Constantly high noise levels are harmful to human health. These are the levels above 65 dB(A). Average daily noise levels in Budapest are shown on Fig. 16. The main roads and downtown streets are the most affected. The noise levels in some parts go beyond the 80-85 dB(A) levels. Thus, local population, as well as drivers themselves are suffering from heavy traffic on the roads.

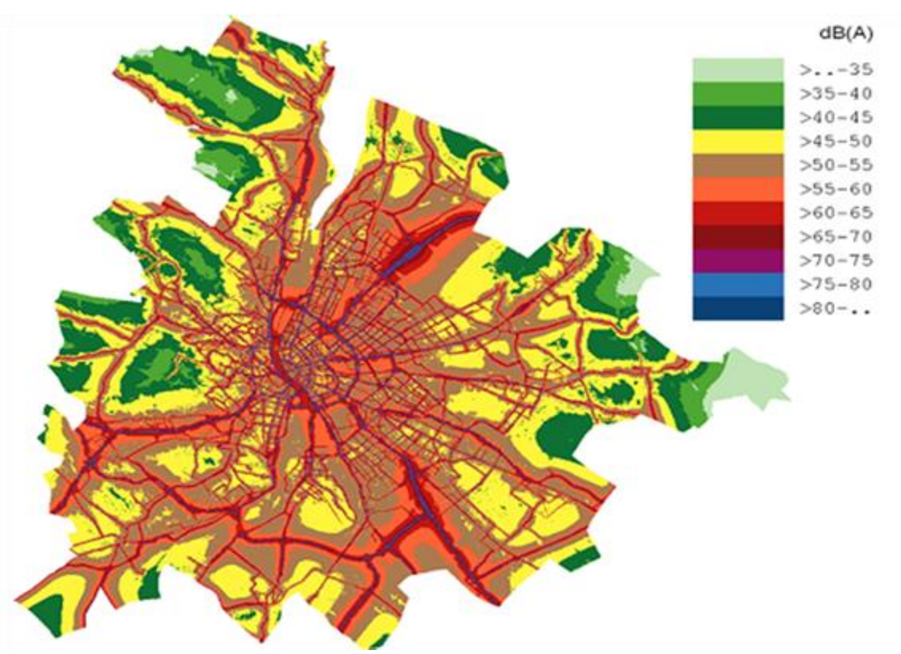

Fig. 16. Noise map of Budapest. Source: Geoportal 2007.

This chapter's discussions will further be used to identify the options for the road pricing schemes in Budapest. The limitations of data collection process are summarized in the methodology section 3.2.

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5.3 Lessons from truck tolls in Hungary

This section will first provide a brief overview of the historical development of the motorways in Hungary, outline the current situation and plans for the further infrastructure development. It than will describe the introduction of the motorway tolling system and its recent evolution. The financial and technological sides of the current mechanism will be estimated, and findings summarized.

The first masterplan for speedway construction in Hungary was developed in 1942. The construction began in 1961. By 1964 first seven kilometers of the roads were built. This motorway aimed to connect Budapest and lake Balaton located in central western part of the country. In 20 years the length of built speed roads amounted to 302 km, by 2006 - 967 km (Török *et.al* 2011). As of 2018 the speedway road network system of Hungary includes 1491 km of road surface (National Toll Payment Services PLC 2018a). These roads are classified as motorways, expressways, and fast roads. Each motorway has two lines in each direction, and an additional emergency lane. The speed limit is set at 130 km/h. The Hungarian motorway network currently comprises 13 motorways. The expressways are as well two-lined roads, but the standards of the road surface are lower. The speed limit is 110 km/h. The fast roads have even lower surface standards, and they can have intersection with secondary roads. The same speed limit of 110 km/h is applied here. There are 13 completed expressways and dozens of fast roads, large part of which are under construction. The Hungarian Public Road Company is responsible for the operation and maintenance of most motorways. Few motorways sections and several expressways are managed by concession companies (ASECAP 2016). Thus, while the construction of motorways started from the state budget, after various economic and policy reforms, the concession schemes for road construction were allowed in 1990s. The results of these decision were controversial, as they significantly increased the road tolls, which forced drivers to bypass these roads through the settlement areas. Especially remarkable were the figures for HGVs – around 75-80% of all vehicles traffic moved to secondary roads (Török *et.al* 2011).

The charges on concession roads in Hungary were up to 2 times higher than the average rates in the ASECAP[19] countries (ASECAP 2015). The solution came in 2000s when the government introduced the vignette system and canceled the concession on part of the roadways. This was the result of high tools and low traffic on priced roads. Trucks bypassing the tolled section raised protests among local residents. Thus, the question received political attention and by 2004 the vignette scheme became national-wide (Török *et.al* 2011).

The introduction of vignette scheme was presented by government as a temporary, integrating solution. The goal was to win time for the development of electronic mileage-based system. Thus, the returns from the vignette system were not used to cover the roads operation and maintenance costs. It was highlighted that supplying proper information to the public via consultations and reporting was an important element in gaining public acceptance (Siposs 2005). First, the system operated through the windshield stickers, from 2002 the electronic registration of vignettes became available. By this time all toll collection points were demolished, and the time-based vignette was operating in 4 categories depending on the vehicle weight: D1 $\leq$3.5 t <D2 $\leq$ 7.5 t < D3 $\leq$ 12t < D4.

The annual revenues of the system grew from 40 to 159 million EUR between 2000 to 2008. One of the main social drawbacks of the system was that frequent users paid much lower fees than occasional users if calculated per kilometer driven. The level of public opposition was at high rates in the beginning. However, by 2010 the two-thirds of road users became supportive to the tolling scheme (Török *et.al* 2011). Charges for trucks were prioritized in the development plans due to their high external costs and unproportionable charging comparing to other motor vehicles.

[19] The European Association of Operators of Toll Road Infrastructures (ASECAP) includes companies from the following countries: Andorra; Austria; Croatia; Denmark; Spain; France; Greece; Hungary; Ireland; Italy; Norway; The Netherlands; Poland; Portugal; United Kingdom; Serbia; Slovenia; Turkey; Morocco; Slovak Republic; Czech Republic; Germany; Russian Federation.

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This is why the electronic distance-based toll system (DTS) was introduced for HGVs on Hungarian speedways in 2013 (National Toll Payment Services PLC 2018b). It has been working in parallel with the e-vignette system for vehicles with total weight of less than 3.5 t. The second system continues to operate as a time-based scheme with weekly, monthly and yearly length passes (National Toll Payment Services PLC 2018c). The DTS uses different technology and operates on 6,500 km of the Hungarian public road network (motorways, expressways, fast roads). Below is the map showing toll-free (part of Budapest and other cities' ring-roads) and tolled speedways sections.

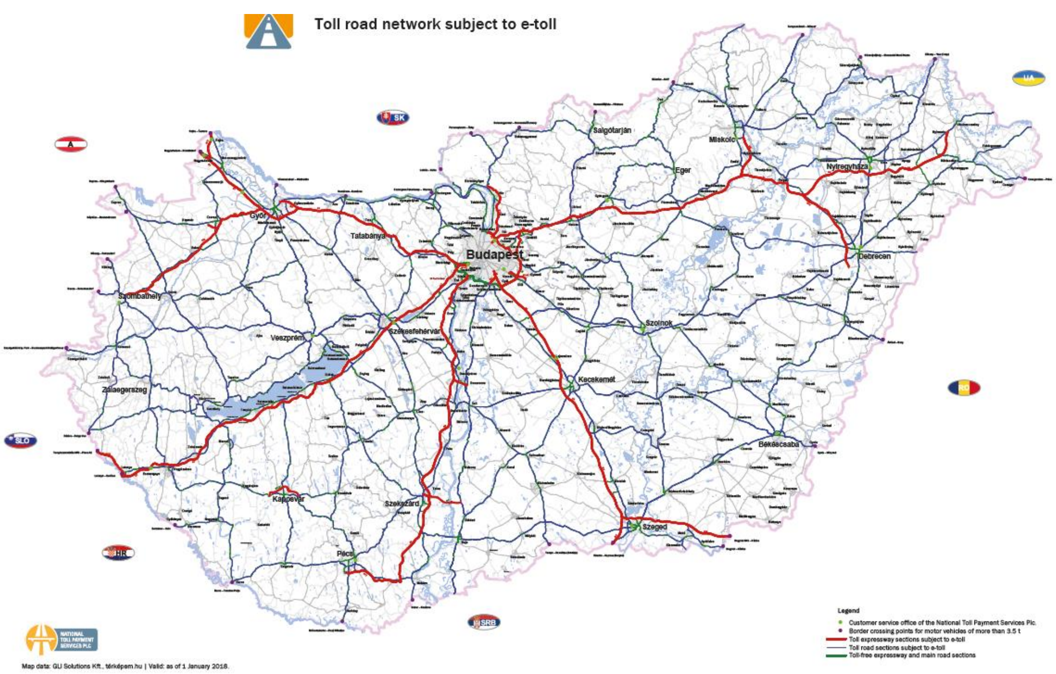

Fig. 17. Map of tolled roads in Hungary. Source: National Toll Payment Services 2018d.

Table 15. Charges for road use (HUF/km). Source: National Toll Payment Services PLC 2018e.

Vehicle category/Road category[20]	J2		J3		J4	
Environmental Classification	E	M	E	M	E	M
≥EURO III	44.54	18.95	62.49	32.80	91.04	56.78
EURO II	52.40	22.29	73.52	38.59	113.80	70.98
≤EURO I	60.26	25.63	84.55	44.38	136.56	85.18

[20]J-vehicle category by number of axles (2; 3; 4 and more respectively); E=expressway; M=motorway.

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The road charge under the DTS is distance-based and varies depending on vehicle characteristics. The fee should be paid before the trip, online or at the customer service offices. Only after the payment, the trip is considered authorized. Consequently, the route ticket is only valid according to the itinerary specified when paying the fee. Charge-free change of the route is only allowed in exceptional circumstances. One ticket is valid for one-way single time trip. Another option is to use on-board electronic device (OBU). It gives flexibility in journey route because operates via the registered account. The price of such unit in time of the current research amounted to 93 EUR (UTDIJ 2018).

Table 16. Characteristics of HGVs tolling system in Hungary

Launch year	2013
Pricing scheme	distance-based toll-system (DTS)
Technology	Global Navigation Satellite Systems (namely GPS)
Total operation area	national-wide, 6,500 km of speedways
Fee differentiation	by number of axles (2;3;4 and more); emission class (EURO standard); type of the road (motorway, expressway).
Methods of payment	pre-paid or via on-board unit (OBU)
Application of charge	use of the priced road
Time of application	24/7, 365 days per year
Fines	30,000-165,000 HUF (90-510 EUR) depending on vehicle type and delay in payment (2 to 8 hours)
Discounts	n/a
Use of the revenues	road infrastructure development

The technology used for the data collection and enforcement operates via Global Navigation Satellite systems (namely GPS). The use of OBU allows to identify the geolocation data of the vehicle. The system itself and the use of such devices complies with the European Union requirements for ETC (ASECAP 2016). There are 74 control stations on tolled roads, mobile road control is also present. The system has shown significant increase in revenues during the first ears of introduction. The share

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of payments received from the system comparing to the vignette system has also increased by nearly 20%. The number of sold E-vignettes has fluctuated and did not increase slightly (Table 14).

Table 17. Total revenues from the E-vignette and HU-GO[21] tolling systems. Source: Börzsei 2017.

	2013	2014	2015	2016
No. of E-vignettes	12.67 M	11.07 M	11.98 M	12.93 M
No. of HU-GO tickets	285.35 M	615.38 M	673.17 M	678.6 M
Total, HUF	135.16 bn	210.1 bn	243.47 bn	263.41 bn
Total, EUR	429,1 m	666,9 m	772,9 m	836,2 m
% of HU-GO payments in total revenues	58.4	77.5	76.3	75.7

Application of the theoretical framework [see section 1.3] in the analysis of the DTC represents that the social marginal cost was announced for HGVs on the national level in Hungary. The fee for road use incorporates estimated social and environmental externalities. It is worth underlining that most heavy-duty vehicles on the roads are powered by diesel engines (Leshchynskyy 2013). Thus, the CO_2, NOx, and PM emissions in exhaust gases are very high (Cullinane and Edwards 2010). As it has already been mentioned, when private motorways were built in Hungary in 1990s, the HGVs shifted to the toll- free secondary roads. The introduction of the vignette system in 2000s had one of its main goals to combat trucks' bypasses through the human settlements. Thus, the government was fighting against the "tragedy" of the free secondary roads. Implementation of the national-wide scheme allowed to overcome the problem. To achieve this, the government had to develop the scheme affordable and feasible for the road haulage sector. While doing so, the question of social equity was acknowledged and addresses. Ultimately, the "polluter pays" and "users pays" principles are reflected in the pricing scheme. Thus, the current analysis of the ETC for trucks in Hungary provided knowledge and information for the further discussion about the implementation of urban pricing scheme in Budapest.

[21] Name of the electronic toll system for HGVs in Hungary.

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5.4 Options for road charges in Budapest

The current research was designed to answer the main research question on the need for the implementation of Budapest road pricing scheme with regards to the assessed local circumstances. The previous sections discuss the available for the current research information about the effects of local road traffic volumes on the average driving speed, levels of congestion, health of Budapestians, and the environment. Combining this information with the lessons of the case study research of the implementation of road pricing schemes in London and Stockholm, the following can be concluded. Considering the global forecasts for the continuous growth in car sales, expected population growth in Budapest, and recognizing the current levels of air pollution, Budapest urban area will benefit from the introduction of the road pricing mechanism. This statement is based on the long-term vision of the situation and recognizes road charges as the only effective mechanism to combat high traffic volumes on the urban roads. The current research has provided numerous evidence thus far. However, significant preparatory steps are required to implement the scheme in Budapest. Though the discussion about the introduction of this mechanism started more than a decade ago, until now there was no political unity and will for its implementation. Not until now it has been mentioned that the commitment to implement road charges in Budapest was part of an agreement between Budapest Municipality and the EU (Levegő Munkacsoport 2018). The effects of the road charge were expected to provide sufficient volumes of passengers to make profitable the mew metro line completed in Budapest in 2014. Thus, there is a conflict of interest in this situation when observed from the political perspective. But the cooperation between municipality, local transportation authorities and specific expert groups is a prerequisite for the mechanism implementation as it was discovered during the case study research. Absence of political commitment makes further steps hardly possible. What is more, public acceptance is another important element of the debates. How likely is that residents of Budapest will support the implementation of the road pricing? Though this question was not a part of the current

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research, the assumption is seen reasonable here. Based on London and Stockholm cases, where congestion events were more severe, the initial public reaction to the mechanism was negative (Center for public impact 2016; Eliasson 2014). Moreover, if public opinion is not developed by the previous proper communications from the municipality, the chances for the acceptance are obviously even lower. The lessons of the transformation of public perception are rooted in the discourse itself. When advocated as a toll to accumulate funds for the road infrastructure development, the road pricing mechanism receives very limited support. But when the discourse starts to develop around the environmental and health concerns, the support is growing (Johansson *et al.* 2009). This is because the citizens of contemporary urban areas are likely to be in favor for the application of the "polluter pays" and "user pays" principles in transportation sector (Raux and Souche 2004). Therefore, the change of focus from technical to health and environmental benefits can possibly develop some level of bottom-up initiative for the implementation of the road pricing. This would happen if apprehensions towards equity in a society are weaker than health concerns. Increasing citizens' awareness about the negative impacts of high traffic volumes on the roads with limited capacities is one of the steps towards developing support. At later stages, the trial introduction of the proposed mechanism has shown to be another effective step in successful implementation of road charges. This is the case when "familiarity breeds acceptance". The further discussion within the theoretical framework requires mentioning the economic perspective of the prospective Budapest scheme. The introduction of road toll, first and foremost, is an economic tool. To be economically efficient it must be grounded on the reliable calculations. In our case economic efficiency means establishment of the road fee at a level which decreases road use to a targeted level. The fee which is too low will not influence the drivers' decisions. While the high fee will create excessive pressure on public transport and surely cause public protestations. The scope of relevant data needed to perform fee calculations is outlined in section 5.2. In course of the current research significant limitations in data available for Budapest were discovered.

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Taking into account that this research has been conducted in the cooperation with one of the prominent Hungarian NGOs and involvement of transport planning company, inability to obtain local data shows that it is missing in principle. If the information is not available in times when political will is available, considerable time will be lost to design an effective pricing mechanism. Opposite to this, in case if comprehensive traffic monitoring system is launched now, the road pricing mechanism could gain a momentum and be launched in a trial mode.

The remaining part of this section will be devoted to the discussion of the prospective road pricing schemes for Budapest based on the available information and recognized limitations. It will mostly address the operational and technological aspects of possible systems.

In 2012 when Budapest was still building the new metro line but had already agreed with the EU to introduce the road charges, the initial scheme design offer was outlined by the Mayor of Budapest (Wilson 2012). It included cordon pricing of the city area inside the Hungária körgyűrű – Duna outer ring-road. This amounts to 6% of total Budapest area. The design plans were similar to Stockholm congestion charge scheme with payments required for each crossing of the cordon. It was estimated that 265 000 drivers would be affected by the scheme. Between 2008 and 2013 several studies were conducted on possible road pricing methods for Budapest. They included cordon charging of city's central bridges, cordon or zonal pricing of the area inside the inner ring road (1% of city area) and outer ring road (6-8% of total area depending on the border outline). Establishment of the cordons along the city border was also reviewed as well as complex solutions of gradual increase of charging zone (Juhász *et al*. 2014). To our knowledge there hasn't been any study published on the lessons from Hungarian electronic toll system implementation for HGVs in context of Budapest road charges. As it was shown above, there are valuable findings that can be further researched. Its main advantages are the local knowledge and statistical data expectedly collected since launch. The technologies used in this pricing mechanism can also serve as an example for Budapest road charges.

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In their communication publication about road charging scheme for Budapest, Levegő Munkacsoport (2016) advocated for the introduction of zonal, distance-based scheme to be applied for the whole city area. Kilometer-based scheme has not been yet implemented in urban road tolls. The distance-based schemes, however, are widely used for truck tolls. This as well is the case for Hungarian HGVs charging scheme. The technology used for this scheme operates via the satellite navigation systems (e.g. GPS). For this, vehicles need to use the on-board unit (OBU) which transmits the truck's current geolocation. The other option for trucks is to buy the road ticket and follow the pre-paid route. However, none of these options seems feasible for urban traffic conditions. The obligation to buy the in-vehicle equipment could only be applied to the residents. The question remains how to administrate all other vehicles (visitors, foreign cars etc.). Stockholm congestion scheme at its first stages was planned to be implemented with the use of OBU and only be applied to the city residents. However, later the decision was taken in favor of the ANPR technology. The second option of pre-paid travel for the external users can hardly be imagined in urban traffic conditions.

Based on the knowledge obtained in course of this research, we strongly support the idea of the distance-based road scheme for Budapest. And would like to offer possible solution to this problem. It requires introduction of the dynamic modelling elements (Kuznecov 1994). In general terms dynamic modelling is the technology used in the GPS trackers to outline the optimal route from point A to point B. The outstanding feature of this method is the opportunity to choose the best possible option on each step of the decision-making process. Each intermediary decision moves the system into the state which is defined by all the previously taken decisions. The simple example to this is when the driver accidentally misses the turn and the GPS system builds the new shortest way to reach the destination. The other functions can be assigned for the system to refine the results. For instance, the route avoiding toll roads and vice versa. To apply this tool in our context the city should be divided into areas based on a certain criterion. In our case these zones should be defined according to the

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congestion and pollution levels. After we divide the city into n zones (this number could easily vary), we will see the map alike that on the Fig. 18.

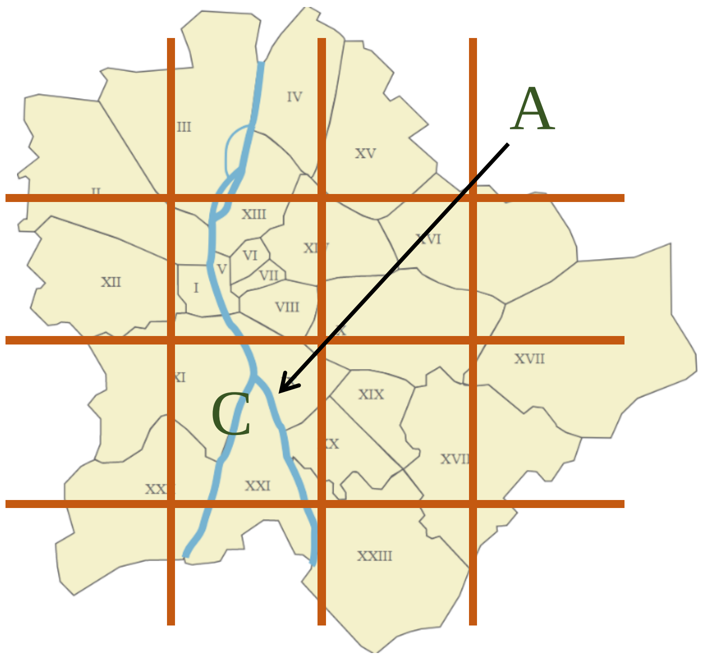

Fig. 18. The modelling map of Budapest.

The next step requires establishment of the fee for driving in each zone. In the areas with dense traffic flows and high pollution costs the charges should be set at a highest level. The cordon-based scheme can now be applied to each zone. The ANPR system, same as used in London and Stockholm should be used. It doesn't require OBUs but operates through the cameras installed at certain points. It would be recommended to use Stockholm's approach, when the system automatically generates monthly bills delivered later to the car owners. This simplifies the use of the scheme for drivers. One of the elements of this scheme should be an online platform based on dynamic modelling scheme outlined above. With such tool drivers will be able to calculate the price of the planned route and decide if its value is higher than its marginal social costs. This approach will require higher installment investments but will provide toll long term efficiency and flexibility.

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6 Conclusions and Recommendations

Design and implementation of the road pricing mechanism is a complex task. To achieve this goal "It is absolutely necessary to have sufficient time, and access to a reasonably good transport model..." (Eliasson 2010). Various factors must be acknowledged to assess whether or not should a city implement congestion charge. Moreover, sufficient information about local road traffic characteristics must be available for the analysis. This research attempted to continue discussion on the opportunities for the implementation of the road charges in Budapest which sparked over decade ago. This was performed through the application of framework based on the combination of economic, social, and environmental concepts. The case study research of the two prominent examples of urban road charges provided valuable findings. There are multiple differences between the current situation in Budapest and conditions that formed in London and Stockholm before the introduction of road charges. Basically, none of the prerequisites for successful launch are currently present in Budapest. From the other side, Budapest is a growing urban area with high rates of economic activities. The current traffic patterns can only be improved by complex aligned solutions. The road charging has never been a politically favorable mechanism. Uncertainties of its effects and initial public opposition have been postponing the launch of this mechanism in Budapest. Even despite the existing obligations of current municipality to implement one. Absence of political commitment is the main pull factor in Budapest case. It should not be expected that public support will be there from day one. Both case studies outlined this factor. However, public opinion transforms over time when the effective communication is used to promote the mechanism. Hungary has recently experienced development and introduction of the road tolls for HGVs. The system received high ranking among EU member states (Siposs 2005). This is a strong push factor for the further research and adaptation of the lessons into Budapest contexts. Especially beneficial will be the methodology used for the calculation of road tolls. After all, the negative vehicle externalities of passenger cars and trucks are similar in nature.

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Numerous recommendations were outlined in the main body of this research. Each chapter provides a summary of the main findings and points that should be considered. Concluding on the main research question we think that in current political, environmental and social circumstances it is time for Budapest to take clear action towards development of a comprehensive traffic monitoring system. With this, the road pricing mechanism can gain a momentum and be launched at least for the probation mode. In Central and Eastern Europe Budapest has chances to become an early mover in combating congestion with this market mechanism. Not just it could make the city a role model in case of successful implementation, but also address the problem before it becomes a burden for citizens and local businesses.

There are multiple directions for the future research on the topic. In our opinion, the challenge of the developing the methodology for estimation of road fees is one of the priority directions. They represent calculations of marginal social costs of vehicles use. Unless the methodology becomes usable and adaptable for the local circumstances, each city would struggle to solve the shared problem separately. There are EU regulations for road charges for HGVs, but there is no similar framework for private cars on motorways and in urban areas. Furthermore, if the necessary data can be obtained, the further research of the opportunities of dynamic modelling integration in the road charging schemes is reasonable. The contribution to the theoretical knowledge on the topic of urban road pricing can be found in research on combined urban road traffic management techniques. For instance, discover the co-existence of road pricing and parking policies. In this case, the failure of the first can be backed up by efficient implementation of the second.

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