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Passenger vehicle applicability for alternative modes of individual transportation in urban areas

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Extract this sheet and replace it with the assignment of the Master´s Thesis.

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Acronyms

ACEA	the European Automobile Manufacturers' Association
B2C	Business to customer
CO_2	Carbon dioxide
CZ	the Czech Republic
EU	the European Union
GHG	Greenhouse gas
GM	General Motors
GPS	Global positioning system
Inc.	Incorporation
IPCC	the Intergovernmental Panel on Climate Change
N/A	not available
OECD	the Organisation for Economic Co-operation and Development
OICA	the Organisation Internationale des Constructeurs d'Automobiles
OPEC	Organization of the Petroleum Exporting Countries
UN	the United Nations
USA	the United States of America
USD	United States Dollar
WTI	West Texas Intermediate

Introduction

The role of transportation in modern society is of a vital importance. Essential daily errands of a large share of world population such as access to employment, education and health or leisure services are provided via some form oftransportation. Despite its significance for our society, transportation currently embodies a pressing concern troubling many urban areas around the world but one that thanks to the current state of technology could for the first time in the history be readily solvable.

The reasoning behind this situation is a long-term demographic development characterized by a rapid growth of urbanization rate, increasing population density, continuous spatial expansion of cities and understated urban planning (United Nations, 2015; World Bank, 2015). The intensifying concentration of economic activity, steadily growing population and ongoing urban sprawl in recent decades has inadvertently led to the emergence of so-called megacities and definition of various tiers of urban areas (United Nations, 2014, Swanson, 2016).

Closely connected with the growth of urban areas is the accelerating rate of motorization (Oak Ridge National Laboratory, 2015; The International Organisation of Motor Vehicles Manufacturers, 2016). The invention of passenger vehicle has not only irreversibly changed the notion of mobility but eventually become a de-facto synonym for individual transportation. And the social symbolism attributed to it has driven the demand even further beyond the actual transportation needs (Marsh, Collet, 1987; Garling, 2007). Automotive industry that has grown upon this grounds is now a century old ecosystem that some deem: „the most disruptable business on earth“ (Morgan Stanley, 2015, page 2).

A number of unsuccessful attempts to reinvent individual transportation had taken place around the world in the past decades (Anderson, 1996; Office of Technology Assessment (U.S. Congress, 1975; Robertson, 2016; Wolf, 1969). As a result, both individual and public transportation (Huckaby, 2016) in large urban areas becomes inefficient from the system perspective and troublesome and stressful from the point of view of individual travellers because the infrastructure increasingly fails to cope with intensifying traffic. The mobility demands of a growing population sharply exceed the capacity of existing transportation systems both in quality and quantity. The long term outlook was straightforwardly summarized by U.S. Transportation Secretary: „drivers in the future won't be moving on our highways, they will be crawling“ (Blake, 2016, paragraph 3). Frequent and recurring traffic congestions, growing costs of parking spaces, environmental impacts and other government imposed obstacles are all affecting the applicability of contemporary passenger vehicles for all modes of individual (also know as private) transportation.

Furthermore, numerous authors have established the causal relationship between use of passenger vehicle and health problems such as obesity, stress or increased blood pressure, social satisfaction and psychological wellbeing (Frank, Andresen, Schmid, 2004; Martina, Goryakina, Suhrckea, 2014; Delmellea, Haslauerb, Prinzc, 2013; Hamer, Chida, 2008; Legraina, Elurub, El-Geneidya, 2015). Cited source uniformly associated driving a passenger vehicle with serious negative implications and claimed it to be the most harmful mode of transportation. These factors strongly urge the creation of alternative modes of individual transportation and justifies the topic selection as a basis for this thesis.

Another aspect emphasizing the relevance and the justification of the topic studied is the accelerating involvement of actors with no automotive or transportation background such as various technology companies (Morgan Stanley, 2015; Warren, 2016; Ziegler, 2015a; Ziegler, 2016a). Such automotive non-traditionalists are firstly poised to alter the way vehicles are interacted with (Apple Inc., 2015; Google Inc., 2015a), then fundamentally reshape the future of the individual transportation landscape and urban environment (Google Inc, 2015b; Mayo, 2015; Nvidia Corporation, 2016; Uber, Inc., 2015e) and ultimately shift the very categorization of the industry (Morgan Stanley, 2015; Warren, 2016). Albeit in a reactive rather than proactive manner, the potential for such disruptions was acknowledged and reflected by legacy car manufacturers as well (Barra, 2016; Davies, 2015; Olin, 2015; Ziegler, 2015a; Ziegler, 2016a). In a recent interview, when speaking about the future of mobility, the CEO of Apple noted that the automotive industry is: „at an inflection point for massive change, not just evolutionary change“ (Cook, 2015, 25:23). Such prognosis was eventually conceded by CEO of General Motors Mary Barra on annual meeting of the World

Economic Forum: „I believe the auto industry will change more in the next five to 10 years than it has in the last 50“ (Barra, 2016, paragraph 3).

The main alleged drawback of the contemporary form of individual transportation was concisely identified already six years ago by Eric Schmidt from Google: „it's a bug that cars were invented before computers“ (Schmidt, 2010, 17:50). Although an undeniably radical claim, it appears to be no overstatement as it has been gradually gaining attention from other contenders from both inside and outside the industry (Audi, 2015; Golson, 2016; Mercedes-Benz, 2015; Tesla Motors, Inc., 2015; Uber, Inc., 2015g).

Main aims and objectives

The main aim of this thesis is to traverse the existing gap in the present knowledge base by examining the contemporary state of individual transportation within the context of world's largest and most populous urban areas. The objective is to methodically analyse the applicability of passenger vehicles for existing and prospective usage scenarios in urban environments, suggest potential alternatives to alleviate the identified shortcomings and in conclusion formulate actionable recommendations for a target audience. As such this study not only provides the description of existing situation and its rigorous analysis but also aims to deduce prospective forms of individual transportation and potential technological advancements that may affect the transportation landscape in general.

Therefore and in accordance to the author's proposition and research questions defined in chapter 5, a set of clearly defined objectives consisting of theory development, analysis of available data, discussion of existing alternatives and a case study inquiry concluded with plausible suggestions for future development is underlying this paper. Firstly a robust theoretical framework is developed to anchor the study firmly in the current knowledge base. That include the description of dominant modes of usage of passenger vehicles, followed by the examination of factors affecting usability of those modes in urban areas. Afterwards, the synthesis of existing evidence from the USA demonstrates the theoretical assumptions with real datasets, complemented by discussion of alternatives modes of individual transportation employing passenger vehicles. The next step in this research inquiry is an execution of a multiple in-depth holistic explanatory case studies. The ramifications of those are then analysed on individual as well as a cross case basis to provide broad and solid foundation for further discussion. Finally, obtained findings are compared with original propositions and conclusions are derived.

Audience

As this thesis focuses primarily on the utility of passenger vehicles as an individual mean of transport in large urban areas then its findings, deduced conclusions and most importantly formulated recommendations are intended mainly for the automotive industry and local transportation policy makers such as municipal authorities. This study intends to enable them to make educated decisions about the individual transportation and related topics. However other stakeholders such as national governing authorities, companies employing passenger vehicles for alternative transportation modes or professionals in the field of urban planning may also benefit from this study.

Structure of the thesis

The first chapter formulates the theoretical background starting with a description of the existing predominant usage modes of passenger vehicles in individual transportation. These include private ownership, rental services, taxis and operational leases of passenger vehicles, all discussed in respective individual sub-chapters. In the following section, obstacles and challenges related to the discussed travel modes are described and illustrated with existing examples. The ramifications of such situation are elaborated in chapter 3. Subsequent part introduces alternatives for prevailing vehicle operational modes and describes in detail positive and negative implications for transport situation of each alternative. Section 5 explains applied research methodology and the next chapter presents the results of multiple in-depth case studies conducted in eight selected urban areas. Subsequently, proposition formulated in chapter 5 is reflected and either validated or rejected within an appropriate discussion. A suggested solution is then detailed, including plausible impacts on current transport situation as well as automotive sector, potential obstacles that may prevent its deployment and adoption and recommended actions to overcome such barriers. The last section summarizes acquired knowledge, proposes recommendations for target audience and formulates conclusions.

Definition of the scope

The scope of this study is inherently limited by the character and the purpose of a master thesis as a final academic assignment. Therefore it focuses strictly on individual transportation only. Albeit the interrelation between individual and public transportation is unquestionable, the overbearing complexity of the latter prevents a meaningful incorporation within the scope of this thesis. Contemporary passenger vehicles as a means of individual transportation is the singular focal point of this study. Other modes of individual transportation such as biking and walking are not examined separately in detail but their role as a substitute for passenger vehicle is not omitted and the implications of such preference among travellers are documented with available datasets and existing studies. The study also only focuses on urban areas only which are defined further in this subsection. Rural areas are not covered.

Passenger vehicle

For the purposes of this thesis, a contemporary passenger vehicle is considered as a four wheel road vehicle powered by internal combustion engine (regardless of the type of fuel used), electric engine or combination of both. Additional characteristics and attributes defined and distinguished by various public and private institutions, such as body configuration, number of seats, engine power or fuel type, are intentionally not reflected due to the low relevance to the studied topic. Unless otherwise stated, motorcycles are also included because majority of studied sources does not differentiate between two and four wheelers.

Commercial vehicles such as trucks and other kinds of goods vehicles are not included in the analysis. Furthermore, the commercial use of passenger vehicles, for example in company or government fleets is not covered due to the limited scope of the master thesis and considerably different usage patterns that does reflect business rather than individual mobility needs.

Urban area

The exact definition of urban area, often referred to as urban agglomerations, varies greatly across countries and regions. For instance the U.S. Census Bureau defines the so-called Core Based Statistical Area and its subdivisions including Metropolitan Statistical Areas, Micropolitan Statistical Areas and Combined Statistical Areas (Executive Office of the President of the United States, 2013). Each category is characterized by a specific amount of population and level of social, cultural and economical facilities (Executive Office of the President of the United States, 2013). A two factor method based on population density threshold and minimum population size is used to define and categorize urban areas is applied by Eurostat institution (Eurostat, 2013d; Eurostat, 2015e).

Tab. 1 Categorization of urban agglomeration by United Nations

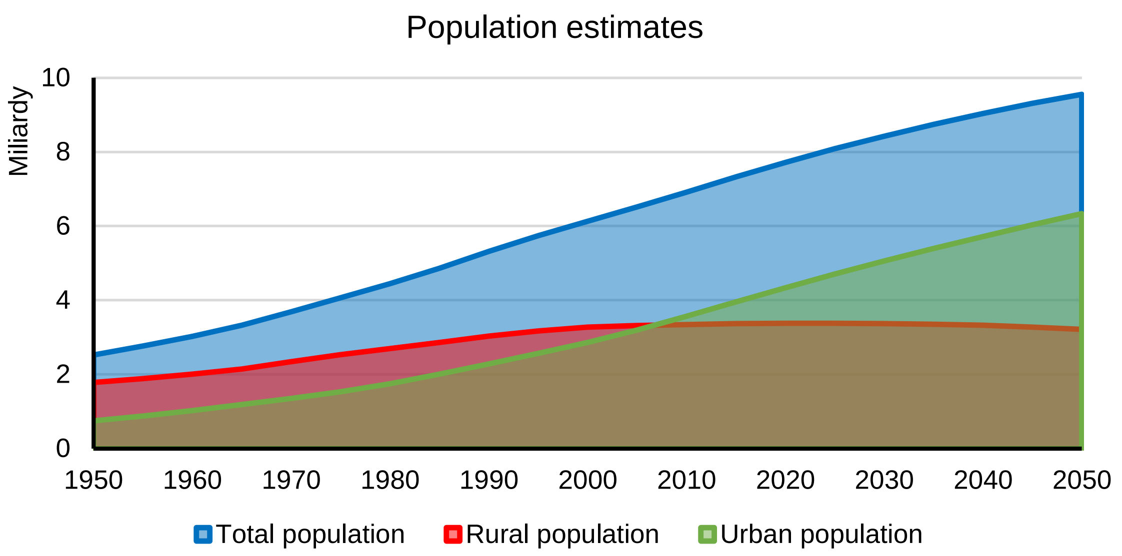
Definition	Population	No. of units in 1990	No. of units in 2014	No. of units in 2030
Megacity	10 million or more	10	28	41
Large city	5 to 10 million	21	43	63
Medium-sized city	1 to 5 million	239	417	558
City	0,5 to 1 million	294	525	731

Source: adapted from United Nations (2014)

The United Nations recognizes five categories of urban areas based on the total number of inhabitants only (United Nations, 2014). Due to the inconsistencies in urban area classification and categorization and with regard to the aim of this thesis, strict adherence to existing definitions would not be beneficial. Rather, different realias and worldwide phenomenon relevant for the topic from differing urban area are presented, synthesized and analysed in theoretical part in order to exemplify arguments, enhance applicability and bolster generalization of the thesis. Thereby urban areas discussed in 1. and 2. chapter may fit into multiple different definitions of urban areas depending on the applied methodology. Selection procedure of urban areas for individual case studies is described in detail in chapter 5 as well as data collection process.

1. Demographical trends and passenger vehicle as an individual transportation mean

According to United Nations projections the world population is expected to exceed over 9.5 billion (United Nations, 2015; World Bank, 2015) by year 2050, the majority of which is attributed to urban areas (United Nations, 2015; World Bank, 2015) as the total rural population is expected to remain flat and eventually decline in upcoming years (United Nations, 2015; United Nations, 2014; World Bank, 2015).



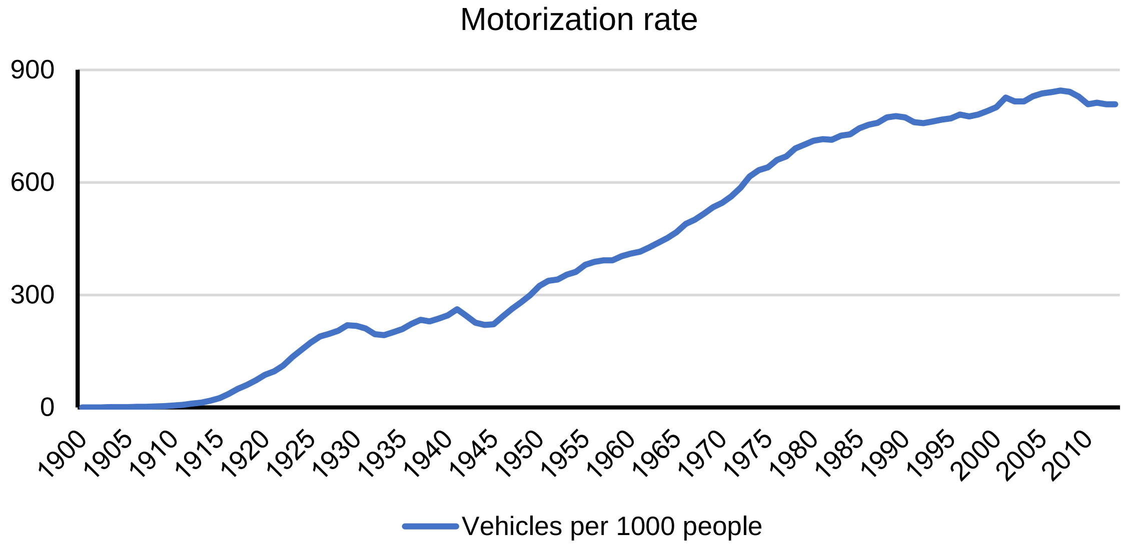
Source: adapted from the United Nations (2015)

Fig. 1 World population between the years 1950 – 2050

This paradigm is well documented by historical data (United Nations, 2014; Bairchor, Goertz, 1986; Davis, 1955). For instance 75% of the U.S. population expansion since 1980 has taken place in urban areas (U.S. Department of Transportation, 2015) and in the latest U.S. census, over 81% of the population resided in urban areas compared to 19% in rural territories (U.S. Census Bureau, 2011). The UN's forecast expects most of the projected growth happening in medium, large and megacities (United Nations, 2014). On the global scale, individual countries demonstrate a great variance in absolute numbers, nevertheless the discussed tendency of accelerating urbanization rate is present in all regions (United Nations, 2014, Swanson, 2016). The outlined population trends considerably stimulate global mobility demands which greatly stretches existing transportation infrastructure particularly in densely populated areas.

Motorization rate

Following its introduction at the end of the 19th century, the passenger vehicle has quickly matured from rare technological novelty into a predominant form of passenger transport. Supported by the rapid advances in technology and the large scale deployment of assembly line concept, passenger vehicles quickly became a ubiquitous presence especially in urban areas. The efficiency of powertrain systems used in contemporary vehicles borders its thermodynamic limits and reliability. In addition safety equipment has improved greatly since in recent periods. The comfortable travel, a high degree of flexibility and independence on external factors defines the passenger vehicles as transportation mean.



Source: adapted from Oak Ridge National Laboratory Transportation Energy Data Book (2014)

Fig. 2 Number of vehicles per thousand inhabitant in the USA between the years 1900 and 2013

Unfortunately, various sources provide inconsistent information about the total number of passenger vehicles in the world. The exact quantification of world vehicle stock is impossible if only due to the absence or shortcomings in statistical information from several countries such as developing ones. Some associations have published a brief report stating that there were approximately 1 billion vehicles in operation worldwide in 2010 (Sousanis, 2011). However the OECD Transportation Outlook for 2012 concluded that passenger vehicle stock reached 841 million units in 2010 and projects two possible growth scenarios of 3,3 or 2,1 billion vehicles by year 2050 depending on the development in the emerging economies, mainly in China and India (International Transport Forum, 2012).

Tab. 2 Modal split of passenger transport in EU, CZ and USA in 2012

Transportation mode	**EU**	**CZ**	**USA**
	Share of total passenger kilometres	**Share of total passenger kilometres**	**Share of total passenger kilometres**
Passenger vehicle (including motorcycles)	74,14%	60,08%	80,95%
Bus, trolley bus and coach	8,23%	23,21%	6,41%
Railway, tram and metro	8,01%	6,79%	0,77%
Air	9,03%	9,92%	11,86%
Waterborne	0,59%	0,00%	0,01%

Source: adapted from Publications Office of the European Union (2014), CENIA, česká informační agentura životního prostředí (2014) and Bureau of Transportation Statistics (2015)

According to the U.S. Department of Transportation’s findings, automobiles accounted for the vast majority of passenger transport in 2012 (Bureau of Transportation Statistics, 2015). Similar compositions of transportation modes are also reported by European agencies (Publications Office of the European Union, 2014; Eurostat, 2015c). Albeit applied methodologies are not fully harmonised between EU and USA offices (for example slight differences in vehicle classifications) and therefore are not absolutely comparable, however the dominance of passenger vehicles in individual transportation fields is evident in both cases. For illustration of passenger transport situation in small central European countries, data from Czech Republic are also listed in the table and while the use of passenger vehicle is comparatively lower it still forms a dominant share of passenger transportation (CENIA, česká informační agentura životního prostředí, 2014).

The increased availability of individual transportation means has resulted in a major shift in the perception of individual mobility over the past decades which has in turn dramatically increased the reliance on passenger vehicles as a primary transportation option. Moreover, the growing differentiation of automakers over the time has led to the recognition of passenger vehicle as an important status symbol representing the owner's social standing. This has shifted the value of passenger vehicle beyond a mere transportation option and furthermore augmented its importance in a contemporary society as is discussed in secton 2.2. As a result, several new transportation modes have emerged and extended the list of available individual transportation options especially in large cities. The major ones will be examined individually in the following subchapters.

Automotive industry

The steady growth in demand for personal vehicles has greatly accelerated the formation of a highly concentrated and influential industry. According to OICA statistics global turnover of automotive industry in 2005 topped at €1,9 trillion (The International Organisation of Motor Vehicles Manufacturers, 2006). The analysis of the automotive industry tax contribution conducted by the Center for Automotive Research concluded that $205 billion in tax revenues was generated by American car manufacturers in the year 2013 (Center for Automotive Research, 2015a). A comprehensive impact study prepared for the Alliance of Automobile Manufacturers credited the U.S. automotive industry with direct or indirect creation of 7,2 million jobs in 2014 and nearly $500 billion paid in compensations (Center for Automotive Research, 2015b). On a national level, the sector contribution to GDP amounts to 3,5% in 2014 (Center for Automotive Research, 2015b).

The latest numbers from Europe report that the aggregated turnover of automotive sector is €843 billions which equals 6,6% of the EU's total GDP and generates a tax revenue of €388,8 billion (European Automobile Manufacturer's Association, 2014). The industry accounted for 26% of total European research and development spending in 2013 with the total investment of €41,5 billion (European Automobile Manufacturer's Association, 2015). Direct and indirect employment attributed to the sector in year 2011 reached 12,1 million, approximately 10,4% of the EU's manufacturing employment and 5,6% of the EU's total employment (European Automobile Manufacturer's Association, 2015). Japanese statistics record 5,5 million jobs directly or indirectly related to car manufacturing activities, which represent 8,7% of the total Japanese employment

(Japan Automobile Manufacturers Association, 2014). The value of automotive shipments represents 7,9% of Japan's manufacturing output (Japan Automobile Manufacturers Association, 2014).

Tab. 3 Selected financial and non-financial indicators of leading car manufacturing groups in 2014

Indicator	VW Group	Toyota Motor Corporation[1]	General Motors Company	Hyundai Motor Company	Ford Motor Company
Sales revenue (millions of USD)	269 208	242 973	155 929	84 821	144 077
Net Income (millions of USD)	14 717	17 240	2 804	7 269	3 186
Vehicle sales	10 217 003	9 116 000	4 621 000	4 835 000	8 790 000
Number of employees	592 586	338 875	216 000	78 000	187 000

Source: adapted from Ford Motor Company (2015a), Volkswagen Group (2015), Toyota Motor Corporation (2014), Hyundai Motor Company (2015a), Hyundai Motor Company (2015b) and General Motors Company (2015)

[1] data from annual report for fiscal year ended 31st March 2014

Variances in the degree of economic dependence on the automotive industry are in line with an OECD analysis conducted in 2009 which concluded that while the overall global impact of the automobile industry in terms of added value and employment is comparatively low, several countries demonstrated a considerable dependence of national output and total exports on its domestic car production (Organisation for Economic Co-operation and Development, 2010).

1.1. Private ownership

By far the most prominent contemporary mode of use of passenger vehicles in individual transportation is a private ownership which constitutes the bulk of worldwide individual transportation (Bureau of Transportation Statistics, 2015; Publications Office of the European Union, 2014). From a legal point of view, the private ownership stands for the paid transfer of ownership right to the vehicle from the automaker, respectively its dealer to the buyer. This includes all rights and obligations imposed by the legislation in force as is discussed in subchapter

2.3. And although a commonly used purchase method - a financial leasing postpones the transition of rights for the duration of the lease, the utility and availability of vehicle is not impacted. Therefore financial leasing and direct purchase is not differentiated in this research unless otherwise stated.

The trends outlined in previous paragraphs are reflected by the equally rapid expansion in vehicle ownership. Only 9,1% of U.S. households did not own a passenger vehicle at the end of 2013 (Bureau of Transportation Statistics, 2014; U.S. Census Bureau, 2015a). On the individual level the maximum of almost 845 cars for every 1000 citizens was recorded in the 2007 (Oak Ridge National Laboratory, 2015). For 2013, sources from the EU reported 564 cars per 1000 inhabitants which is approximately one vehicle for every two EU citizens (European Automobile Manufacturer's Association, 2015). In addition, Australia reached a level of 756 vehicles per 1000 inhabitants in 2014 (Australian Bureau of Statistics, 2014).

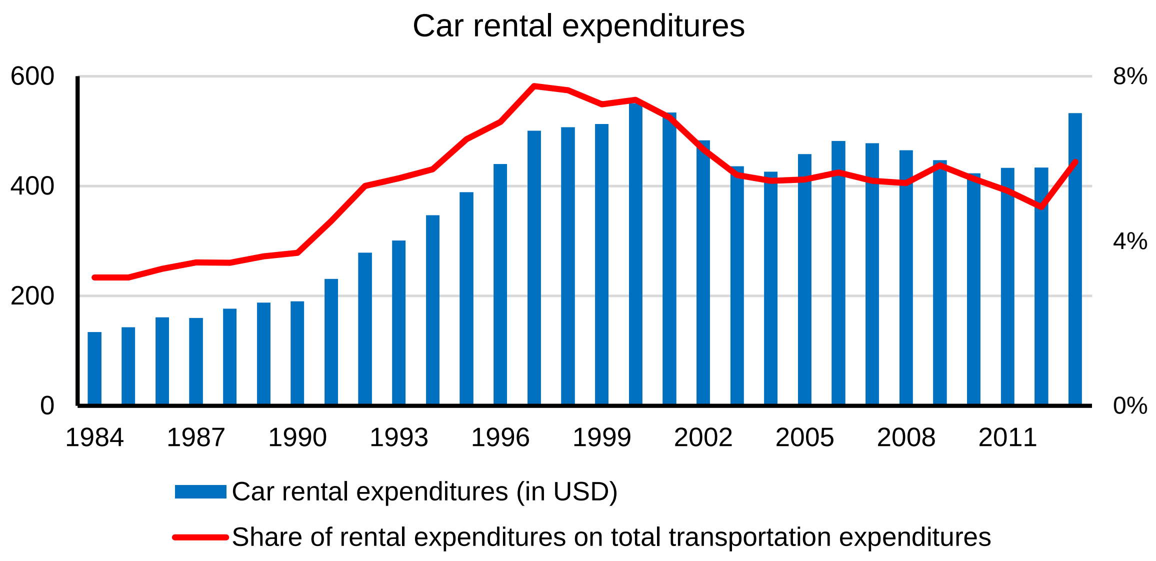
Private ownership is favoured mainly for the high level of flexibility and independence it provides to the vehicle owner. Key decisions about timing and destinations of trips are fully under control of the owner. As is examined in chapter 2.2, vehicle ownership may also represent a considerable status symbol and thereby leads to the satisfaction of an individual's psychological needs and desires.

The negative aspects mainly include high initial costs for buying a vehicle and accompanying administration such as vehicle registration. Although the cost issue can partially be mitigated by some financial methods, purchase costs represented 26% of total household transportation expenditures in the EU in 2012 (Publications Office of the European Union, 2014) and 36% in USA in 2013 (Bureau of Labor Statistics, 2014).

Vehicle owners also bear the legal obligation to conform to all related regulations which may include insurance, regular technical inspections and ecological liquidation. The technical condition of the vehicle and its conformance to the legislation is another liability of the owner. Basic aspects such as the possession of a driving license, parking and the risk of theft or damage also need to be considered prior to the purchase of a passenger vehicle.

1.2. Car rental

This paragraph focuses on formalized charged rental service offered by commercial entities on a contractual basis. Historically the contemporary form of car rental was heavily influenced by the increasing popularity and affordability of air transportation after the Second World War. Combined with rapidly growing concentration of economic activity and tourism into large urban areas, rental services mainly address the needs of tourists and other travellers requiring mobility for the time of their stay in the location. Some providers also specifically target students by establishing additional garages in university campuses (Enterprise CarShare, 2015; Zipcar, 2015d). More than 2 million vehicles and 20 thousand stations were operated last year by rental companies in the USA (Auto Rental News, 2015). The impact of rental services is supported by the growth of rental expenses of U.S. consumers between the years 1984 and 2013 as documented in the graph below.



Source: adapted from the Bureau of Labor Statistics, Databases, Tables & Calculators by Subject (2015)

Fig. 3 Annual consumer car rental expenditures and its share of total transportation expenditures

The discussed institutional car rental is intended mainly for medium or long term rentals for a period of days or weeks. Such rental is often, but not always planned and reserved in advance and medium to long distance travels are performed with it. Vehicles are typically available at frequently visited locations such as airports, hotels, business districts and tourist attractions and have to be returned to one of those stations. Sometimes the pick-up and drop-off stations have to be exactly the same. Normally several types of cars are offered, ranging from compact family models to luxurious and sports cars in accordance to local demands (Avis, 2015; Hertz, 2015b; Sixt, 2015).

Specific conditions and level of service also differ greatly across markets and providers, however, common aspects usually consist of pricing models based on the duration of the rental which covers maintenance, oil refilling and often a basic level of liability insurance. Some providers also restrict the maximum mileage and charge extra fees if limits are exceeded. Vehicles are usually provided with full a tank of petrol and have to be returned in such a condition.

Operational lease is often used as a sourcing method in order to maintain low average age of vehicles in the fleet. Banks or other financial institutions often serve as mediators providing leasing service. If vehicles are purchased directly from the producer they are normally sold within or shortly after the expiration of the warranty period (Hertz, 2015a) to maintain reasonable level of service expenses and residual cost of the vehicle.

The main advantage of car rental as an individual transportation option is a relatively high financial accessibility and a high level of flexibility once the vehicle is picked-up. Albeit refundable deposit or fixed registration fee are sometimes required, payments are largely based on transparent combination of rental period and mileage and according to annual survey among 50 U.S. destinations range from $25 to $76 per day (CheapCarRental, 2014). Moreover, many of legal requirements for owning and using vehicles are usually addressed by the rental provider. Maintenance, permanent parking space and periodical technical inspections are also carried out by the operator. For reasons explained in the preceding paragraph vehicles in a rental fleets are mostly newer models with a relatively low mileage which is largely perceived as an additional benefit.

As for the negative aspects of car renting, possession of a driving license is essential but criminal record background checks, minimum age of driver or proven driving experience are additional requirements sometimes stipulated by rental companies. Albeit many providers allow rental without prior announcement, vehicles usually need to be reserved in advance in order to guarantee that there is a vehicle available. The necessity to return the vehicle to a specific location is another important negative.

1.3. Taxi

Although taxis are frequently referred to as a specific type of public transportation, the basic principle of the service corresponds more with individual transportation. While small groups of passengers may use taxis at the same time, only a single passenger is usually transported. Furthermore, taxis also provide a significantly greater degree of flexibility in terms of pick-up and drop-off locations as opposed to more or less dense network of stations used by traditional public transportation means.

In New York City alone almost 20 000 registered taxi drivers performed 485 000 trips per day and transported 600 000 passengers on a daily basis in 2014 (Taxi & Limousine Commission, 2015a). On a national level revenues generated in 2014 by taxi industry were estimated to be $11 billion (Statista, 2015b).

Even though an economically feasible taxi service can be operated by individual drivers with one vehicle, and the majority of taxi drivers in large cities often forms joint companies or enter existing ones. As in the case of car rental, vehicle fleet of taxi providers is wide but usually comprises of mainstream vehicles with a limited number of premium and sports cars due to the high purchase and operating costs. Similar to the car rental model, direct purchase and financial or operational lease is primarily used to acquire vehicles for taxi purposes.

Other characteristics of service such as hiring and payment options differ from provider to provider. The common characteristics of the taxi industry is a more or less rigorous form of legal regulation defining requirements for vehicles, drivers, insurance and other related issues. Taxi drivers are often obliged to obtain specific taxi licences from local or state authority. Moreover some countries subject taxi drivers to specific exams or stipulate use of preselected passenger vehicle. Local authorities, institutions and property owners also sanction or even create a specific parking lots serving as a dedicated queue area for taxis waiting for passengers. For example at airports or main train stations.

The taxi industry in several large cities is currently undergoing a period of dramatic changes (Peat, 2015; Rodriguez, 2016; Williams, 2015). Many new contenders are entering the market with more or less altered operational model. By fully exploiting the potential of contemporary technologies those companies offer dynamic hiring via mobile devices, ridesharing options, convenient payment options and by avoiding the legal status of taxi operator the necessity for costly licenses. Most notable and impactful of those newcomers certainly is the American company Uber (Popper, 2015). Due to the mostly ambiguous and repeatedly adjusted business model which overlaps with definition of alternative modes of individual transportation a detailed description of such undertakings are provided in chapter 4.

Arguably the greatest benefit of taxis is the extra convenience of not having to drive the vehicle. The additional time can freely be used at the discretion of passenger and also means that no driving license is required. In several cities taxi vehicles are allowed to park or enter otherwise restricted areas which is another advantage of this form of individual transportation. The abundance of continuously rotating independent taxi vehicles on one side and centralized call centers on the other side enable both - effective reservation system as well as unplanned on sight pick-ups.

The negatives of taxi are comparatively high cost of the service coupled with limited transparency of pricing because of complicated regulation (Taxi & Limousine Commission, 2015b) and effective inability to control the exact travelled distance. The base fare of $2,87 and $2,45 per mile charge is estimated for the USA (TaxiFareFinder, 2015) however the large cities often impose extra time and location based surcharges that considerably influence the final price of service. The overall flexibility is also undermined by the logical reluctance to travel to distant peripheries and other unattractive destination due to the low probability of finding return customers in such locations.

1.4. Operational lease

While private ownership still represents the prevailing form of acquisition and usage mode of passenger vehicles, several other possibilities also exist and some are continuously growing in popularity. The operational lease model is a long known and commonly used tool in the B2B area. Mainly for its benefits from an accounting standpoint, fleets of company cars of many firms from various industries are often secured via operational lease.

In the B2C environment operational lease has only recently gained wider attention of consumers, therefore its market impact is still relatively small but growing consistently. In the USA the share of newly leased vehicles on total sales of new vehicle grown from 7% in 1990 to 20% in 2010 (Bureau of Transportation Statistics, 2015). The volume of passenger vehicle leasing contracts in the EU increased from €80 billion in 2009 to €113 billion in 2013 (Leaseurope, 2010; Leaseurope, 2014). A total of 7 256 consumer leasing contracts were signed in the Czech Republic last year which represents a 32% growth over the previous year and 99,7% of those were vehicle leasing contract (Česká leasingová a finanční asociace, 2015).

Besides corporate accounting perspective, operational lease has several attractive advantages for consumers as well. The possibility to freely use passenger vehicle without the necessity of dealing with most of purchase accompanying administration is particularly appealing specifically for customers who do not perceive ownership of the vehicle as an important status symbol as is explained earlier.

Monthly lease payment often covers instalment, insurance, road tolls and, depending on the contract type, a prepaid maintenance service. As such operational lease represents a relatively convenient bundled service providing a specific option for individual transportation that complements three previously introduced modes of use of passenger vehicles.

Disadvantages of operational lease share many similarities with private ownership of vehicles such as the necessity of possession of valid driving license or the obligation to deal with a portion of legal regulations. Parking also has to be secured by the leaseholder.

2. Conditions for owning and operating passenger vehicle in large urban areas

This chapter examines the conditions for use of passenger vehicles as a primary transportation means in large cities and identifies the main shortcomings and mobility related challenges of such transportation mode. These include traffic congestion affecting moving vehicles, provision of parking spaces impacting standing cars or negative externalities of vehicle use to name a few.

The four dominant modes of use of automobiles presented in previous chapter are almost equally affected by issues discussed in the following paragraphs. And while for example the lack of parking spaces, cost of obtaining a driving license or vehicle quotas does not directly influence passengers of taxi services, it inherently reflects in the cost, quality and availability of the service itself thereby impacting all traffic participants equally.

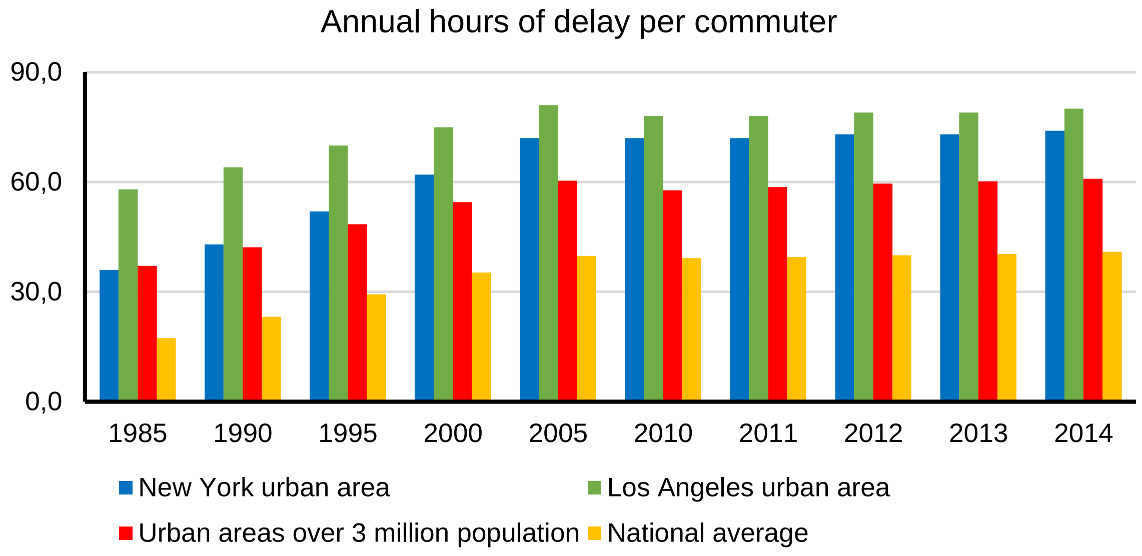
The described limitations can be divided into various categories. This chapter applies the following classification. Firstly, obstacles and impediments of the urban environment itself are introduced, followed by financial and social issues. The last part of this chapter deals with the administrative restrictions arising mainly from the valid legislation and local regulation.

2.1. Spatial and environmental conditions

First and foremost are the physical constraints presented by existing infrastructure. The needs of individual transportation and spatial disposition of densely urbanized agglomerations are often misaligned or even directly conflicting each other. Vehicle users in large cities are typically facing two crucial limitations associated to spatial limitations. Frequent traffic congestions and lack or misplacement of parking spaces.

2.1.1. Congestion

The demand for continuous and efficient traffic flow is implicitly limited by the number of available traffic lanes. As the number of used vehicles and urbanization rates gradually increase the maximum capacity of existing road infrastructure is exceeded and road networks are severely overloaded. That consequently leads to recurring traffic congestions afflicting mainly but not exclusively downtowns and business districts during peak hours (Lomax, Eisele, Schrank, 2015). Apart from the growing number of vehicles and limited land areas, the issue is also caused by low average vehicle occupancy which in the USA reached only 1,67 person per vehicle in 2009, a 12% decrease compared to year 1977 (Federal Highway Administration, 2011b). The value of 1,5 person was recorded in Germany in year 2005 (Rodt, 2010) and 1,4 in Czech Republic in 2008 (European Environment Agency, 2010).



Source: adapted from Lomax, Eisele and Schrank (2015) and the Bureau of Transportation Statistics (2014)

Fig. 4 Average annual hours of delay per commuter in the USA

It is estimated that on average more than 40 hours are spent every year in traffic congestions by the U.S. citizen and the number is notably higher for resident of large urban areas and even worse for those living in New York or Los Angeles urban area (Lomax, Eisele, Schrank, 2015). Approximately $121 billion congestion costs were calculated for the whole U.S. economy (Bureau of Transportation Statistics, 2014). Furthermore, the American authorities forecast that up to 37% of U.S. national highway system will suffer recurring congestion in 2040 (U.S. Department of Transportation, 2015).

European Commission reported more than €111 billion congestion costs for 2009 (Christidis, Rivas, 2012) and a recent study estimates an approximately 50% increase to nearly €200 billion annually by the end of 2050 (European

Commission, 2011). Congestion in six Australian capital cities costed $9,4 billion in 2005 and is expected to command a price of $20,4 billion by 2020 (Infrastructure Australia, 2015). National expenses related to traffic congestion rose to $13,7 billion in 2011 and should no countermeasures be deployed are expected to reach $53,3 billion in year 2031 (Infrastructure Australia, 2015).

Albeit extensive and reliable road transportation statistics are scarcely available for the rest of the world there is an abundance of indications that urban agglomerations worldwide are facing problems of similar magnitude as urban areas in the USA, the EU or Australia. For instance, the Asian Development Bank estimates that congestion costs in Asian economies form 2% to 5% of GDP (Asian Development Bank, 2015). Moreover, a transportation survey from Peking University calculated that the annual expenses for traffic congestion in China's capital amounted to ¥70 billion in 2013 (China Daily, 2014). An independent research estimates that the thirty world's most populous cities generated $266 billion in congestion costs in 2012 (Rossbach et al., 2013). In addition, statistical data from the leading GPS solution provider TomTom reports that average travel times in large South and Middle America megacities such as Mexico City or Rio de Janeiro are prolonged by more than 50% compared to theoretical free float situation (TomTom, 2015). And the renowned INRIX Scorecard report benchmarking the state of transportation in major metropolitan areas worldwide concluded that traffic congestion in a 2013 intensified in 105 of the 194 analysed cities (Inrix, 2014).

2.1.2. Parking spaces

The second issue closely related to the topic of road congestion is parking, respectively the lack of it and rapidly surging costs of the existing ones. Limited land resources are unable to cope with the growing number of vehicles operating in cities. Furthermore, the insufficient capacity, inadequate accessibility and high price cost of parking places stretches the infrastructure even further and amplifies the issue of traffic congestion. It is estimated that between 8% and 74% of the traffic in cities is devoted to cruising for parking (Shoup, 2006) and the issue is worse in large urban areas (Ommeren, Wentink, Rietveld, 2011). In heavily congested areas up to 40% of consumed fuel is expended in vehicles looking for parking (Keirstead, Shah, 2013).

Tab. 4 Monthly parking rates in USD

City	Monthly parking rate (USD)
London (City)	1 083,59
London (West End)	1 014,32
Zurich	822,15
Hong Kong	744,72
Tokyo	744,00
Rome	718,90
Perth	717,43
Geneva	704,70
Sydney	695,31
Oslo	612,15
Melbourne	598,39
Amsterdam	586,62
Vienna	575,12
Brisbane	568,89
Copenhagen	567,13
Stockholm	546,41
New York (Midtown)	541,00
New York (Downtown)	533,00
Milan	517,61
Birmingham	496,44

Source: adapted from Moore et al. (2011)

[1] including taxes, sample included only covered or underground garages in central business districts

A global parking rate survey published by Colliers International summarizes parking costs in 156 cities and albeit methodologically vague it clearly demonstrates the financial burden linked with the ownership of passenger vehicles in a large city (Moore et al., 2011). Other sources concur that for example monthly parking rates in Manhattan range from $400 to $600 without additional surcharge (Ziegler, 2015b; ParkWhiz, 2015). Another notable issue associated with parking is a very low utilization of passenger cars. Some estimate that vehicles are used less than 10% of the time (Kreč, Běhal, 2015; Mitchell, Borroni-Bird, Burns, 2010; Morgan Stanley, 2015; Neil, 2015), a recent European study concludes that average vehicle is parked for up to 22 hours a day during workdays and slightly more during weekends (Pasaoglu, 2012). Because of that passenger vehicles are estimated to be the world's most underutilized asset (Morgan Stanley, 2015).

2.1.3. Environmental impacts

The other general issue associated with the use of passenger vehicles are negative externalities, specifically the environmental impacts of internal combustion technology. Numerous studies have evaluated effects of human activities on the natural environment and the majority have concluded that a dominant or at least a major share of negative environmental externalities is produced by transportation activities (Intergovernmental Panel on Climate Change, 2015; U.S. Environmental Protection Agency, 2010; Fuglestvedt et al., 2010; Uherek et al., 2010).

Although harmful environmental and health impacts of noise and particulates emissions are proven by several studies (World Health Organization, 2013; U.S. Environmental Protection Agency, 2014b; World Health Organization, 2011; Stansfeld, Matheson, 2003; Boer, Schroten, 2007) and the severest impacts of air pollution include large number premature deaths on annual basis (Chu, 2013). Assessing the effects of CO2 and other so-called greenhouse gases (hereinafter referred to as GHG) emissions scientifically often leads to controversy due to the multitude of factors influencing climate, limitations of contemporary research tools and strong political interests in the topic (Geden, 2015; Roberts, 2015; U.S. Environmental Protection Agency, 2014a). Regardless of the exact categorization of impacts and the difficult establishment of the relationships and determination of links between causes and consequences, it is widely accepted that GHG emissions have negative environmental impacts and significantly contribute to current environmental problems such as frequent occurrence of storms, the rise in average temperatures, loss of ecosystems and biodiversity and life-threatening rise of sea levels (Intergovernmental Panel on Climate Change, 2015; National Climatic Data Center, 2008; U.S. Global Change Research Program, 2014; World Bank, 2012).

Albeit emissions standards for both passenger and commercial vehicles are getting more stringent on almost a yearly basis on the majority of automotive markets (U.S. Environmental Protection Agency, 2013; European Union, 2013; TransportPolicy.net, 2015), IPCC data concluded that in 2010 transportation accounted for 14% share of global GHG production (Intergovernmental Panel on Climate Change, 2015).

Tab. 5 GHG emissions by sector in the EU and the USA

Source	EU (2012)	USA (2013)
Energy industry	31,0%	31,0%
Transportation	19,6%	27,0%
Manufacturing and construction	23,9%	21,0%
Commercial and residential	13,2%	12,0%
Agriculture	12,0%	9,0%

Source: adapted from the European Environment Agency (2015) and the U.S. Environmental Protection Agency (2015a)

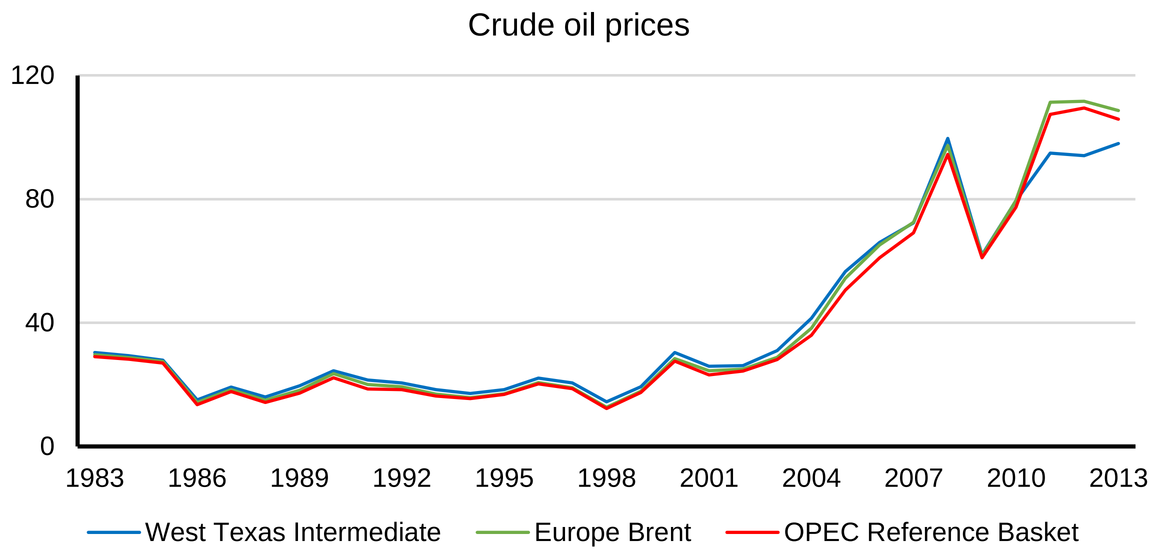
In the USA, with the highest rate of vehicle ownership per inhabitant, the share rose to 27% in year 2013 (U.S. Environmental Protection Agency, 2015a). More than 60% of that is directly attributed to passenger transportation (U.S. Environmental Protection Agency, 2015b). Transportation represented almost 20% of all GHG emissions produced in the EU in 2012 (European Environment Agency, 2015) and almost 72% accounted to road transportation (Publications Office of the European Union, 2014). Furthermore, historical data for the EU also show that between the years 1990 and 2012 the transportation related production of GHG increased by 14% (European Environment Agency, 2015). Japanese GHG emissions in the year 2013 comprised of 15,3% transportation related emissions of which 89,9% was contributed by road transportation (Greenhouse Gas Inventory Office of Japan, 2015). Transportation activities amounted to 13% of Australia's national GHG emissions in 2007, with passenger transportation reported as the largest source with 53,2% share (Australian Bureau of Statistics, 2010)

2.2. Financial and social conditions

Use and especially ownwership of passenger vehicle generates a considerable financial burden in a form of a one time purchase cost (which might be distributed in montly lease payments) and a regular operational costs. On the other hand perceived value of passenger vehicle is highly subjective and may extend beyond the transportation mean category. The perception of passenger vehicles is also dependable on social trends within the area.

2.2.1. Spatial and environmental conditions

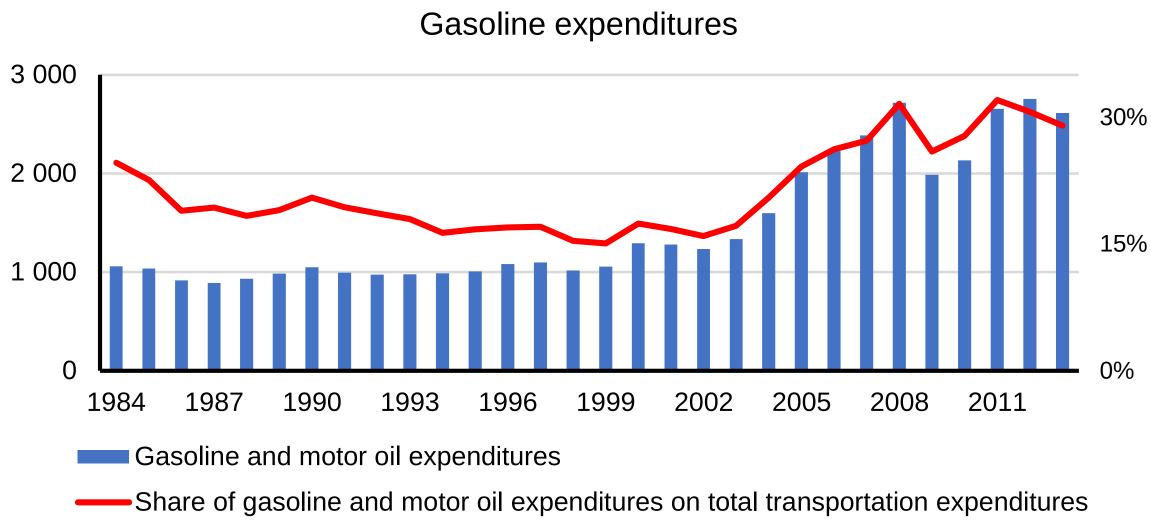
While the cost of vehicle ownership is determined by the type of purchased vehicle, the regular operating costs, consisting mainly of fuel, are faced by all vehicle users almost indiscriminately. Detailed statistical analysis from the USA documents that the nominal gasoline price have risen from $0,60 in 1976 to $3,36 per in gallon in last year (U.S. Energy Information Administration, 2015) and the same tendency/propensity can be observed in the case of diesel.



Source: adapted from the U.S. Energy Information Administration (2015) and Organization of the Petroleum Exporting Countries (2001 - 2015)

Fig. 5 Average nominal crude oil prices in USD per barrel

Moreover, the short term fuel prices are suffering significant instability reflecting the crude oil price on the global commodity markets. For example average OPEC crude oil prices per barrel soared from $2,7 in 1973 to $11 in 1974, from $12,79 in 1978 to $29,19 in 1979 or more recently from $69,04 in 2007 to $94,1 in 2008 (Statista, 2015a). And similarly volatility can be observed in the case of WTI and Brent crude oil prices (Statista, 2015c; Statista, 2015d). The impact of outlined price development is reflected by the structure of household expenditures. After housing expenses, transportation represents second largest spending for households both in the EU and the USA.



Source: adapted from the Bureau of Labor Statistics (2015)

Fig. 6 Annual consumer unit gasoline expenditures and its share of total transportation expenditures

In the USA the share of transportation expenses fluctuates around 20% on national level but reached almost 30% in 2013 (U.S. Department of Transportation, 2015). However the ratio varies significantly in accordance to the household location. Thereby the share of transportation expenses may go as high as 25% for household units that are heavily dependable on passenger vehicles for their transportation (Federal Highway Administration, 2014b). The average transportation expenditures in the USA in 2013 reached $9 004 of which $2 418 was directly attributed to fuel expenses (Bureau of Labor Statistics, 2014). Historically transportation expenses in the USA have been steadily growing with the exception of so-called Great Recession period between the years 2007 and 2009.

In Europe, transportation accounted for 13% of total household spending in 2012 which approximately equals €1900 per year (Eurostat, 2015a). Operation costs for passenger vehicles alone amounted to 7,1% of the total (Eurostat, 2015b) and harmonised index of consumer prices document 35% growth of vehicle operation costs between the years 2005 and 2013 (Publications Office of the European Union, 2014).

Tab. 6 Damage costs of vehicle emissions in the USA in 2010

Type of emission	Emission damage costs (USD per ton)
Volatile organic compounds	1 700,00
Nitrogen oxides	6 700,00
Particulate matter	306 500,00
Sulfur dioxide	39 600,00
Carbon dioxide	22,00

Source: adapted from the National Highway Traffic Safety Administration (2012a)

As is discussed in subchapter 2.1, the use of passenger vehicle is inseparably associated with negative externalities which, albeit with difficulty, were calculated by some authors. External costs of driving comprising of congestion, accidents and noise but excluding exhaust fumes amount to $0,081 per travelled vehicle mile in the USA (National Highway Traffic Safety Administration, 2012a). Per ton emission related costs are displayed in the table above. The total external costs of use of passenger vehicles in the EU were estimated to €373 billion in 2008 (Becker, Becker, Gerlach, 2012) and average climate change costs per travelled kilometer was calculated to €0,05 (Becker, Becker, Gerlach, 2012).

2.2.2. Perception of passenger vehicle

Except the practical aspects of improved mobility, ownership and the use of passenger vehicle is subject to various social trends and individual attitudes about travel. Historically, ownership of vehicles was perceived as an important symbol embodying the owner's social status (Marsh, Collet, 1987; Garling, 2007). The importance of an individual's inner desires and aspirations for purchase motivations and subsequent psychological attachment to the passenger vehicle has been broadly documented by different authors (Bloch, 1981; Dichter, 1964). However, the concept of emotional adherence to the vehicle has recently been challenged and subsequently refuted by several studies focusing on younger adults and their indifference towards owning a car (Sandqvist, Kriström, 2001; Aretun, Nordbakke, 2014; Delbosc, Currie, 2012).

According to a survey from Melbourne, while positive associations such as a symbol of freedom and independence are still linked to the ownership of a vehicle, an individual's perceived social status appears to be unrelated to the ownership of a car (Delbosc, Currie, 2012; Delbosc, Currie, 2014). On the contrary, financing a vehicle is considered a significant responsibility or even the forced necessity rather than a sign of wellbeing and success (Delbosc, Currie, 2012; Delbosc, Currie, 2014). Decoupling of social status and vehicle ownership is accelerated by external factors which gradually shift the reception of passenger vehicle towards a mere mean to an end. The rapid development of consumer market presents a significantly wide portfolio of objects that may substitute car in the role of a status symbol (King, King, 2014; Winterhoff et al., 2009; Aretun, Nordbakke, 2014). The greater range of available mobility options diminishes the dependence on passenger vehicles and thereby reduces its social importance (Winterhoff et al., 2009). However these conclusions may not be universally valid for all countries. The latest studies from Shanghai and Beijing suggest the opposite and claim that the social symbolism and the sense of pride in owning a passenger vehicle is strong in China, especially for foreign automotive brands (Zhao, Zhao, 2015; Schmidt, 2015). Though it can be argued that the entire Chinese society is heavily affected by political ethos and ideology of current regime that distorts the opinions of its citizens and is well known for installing of own symbols.

2.3. Legal obstacles imposed by governing authorities

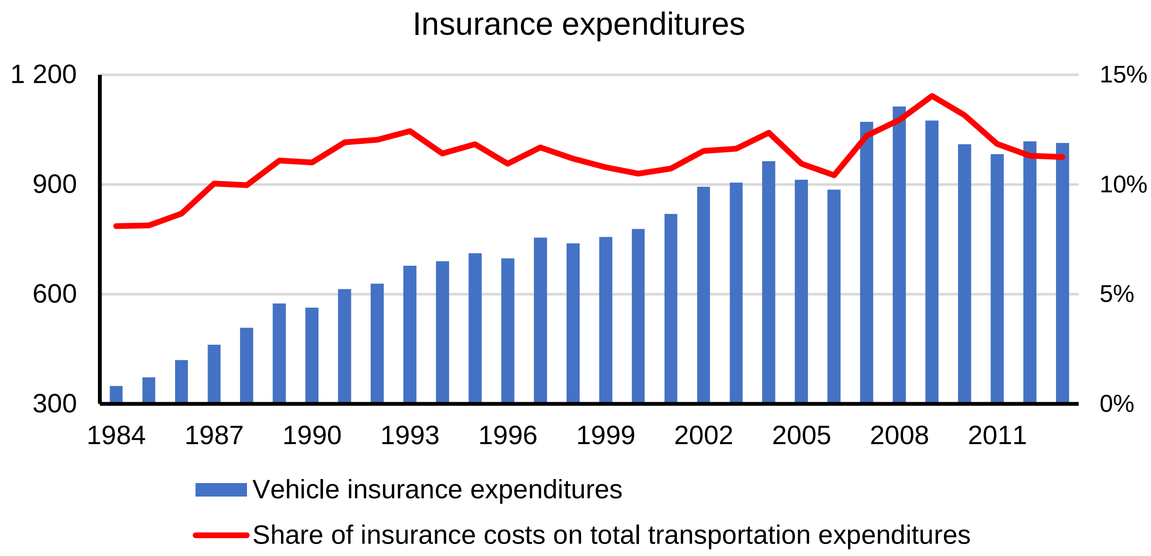
Due to already discussed externalities, ownership and use of passenger vehicle is generally a heavily regulated right. A basic and elementary regulation is usually imposed by national or international institutions while area specific issues are addressed by the local authorities.

2.3.1. Driving license

Besides the basic legal mechanism preventing the sale of passenger vehicles to children and juveniles, a prevailing majority of countries requires a driving licence of appropriate category in order to legally permit individuals to drive a car. Obtaining a driving license usually involves theoretical lessons about road traffic rules and regulations, several training sessions in closed and subsequently open roads and a final examination. While the process itself is relatively straightforward and generally does not change significantly over time or from country to country, the total costs are continuously rising mainly due to the growing fuel prices described in previous chapter and several weeks are often needed to complete the procedure and obtain a driving license. Additionally some states have already implemented (Connecticut Department of Motor Vehicles, 2014; Colorado Department of Transportation, 2015a; California Department of Motor Vehicles, 2015b, Roads and Maritime Services, 2015b) or are currently evaluating (European Commission, 2015a) the possibility of imposing additional limitations for newly qualified young drivers. Such measures often include restrictions on night time driving, limitations on transported passengers and zero alcohol limits.

2.3.2. Insurance

Another generally mandatory condition for legal ownership of passenger vehicle is an insurance (European Commission, 2014; Sage, 2015; Her Majesty's Government, 2015b). Various levels of insurance coverage are commanded by different states but a minimum, liability for third party personal injuries and property usually has to be covered (European Commission, 2015a). Additional coverage for own or third party property damages can be arranged on a voluntary basis. A recent study from independent consumer insurance website Insure.com documents a wide variety in average insurance prices between individual states in the USA with the cheapest options starting around $800 and the most expensive ones clocking almost $2 500 (Marquand, 2015). The impact of vehicle insurance on household expenses is demonstrated by the following table.



Source: adapted from the Bureau of Labor Statistics (2015)

Fig. 7 Annual consumer vehicle insurance expenditures and its share of total transportation expenditures

2.3.3. Use and ownership restrictions in urban areas

In order to alleviate or fully prevent the difficulties mentioned earlier, the local authorities of many large cities are continuously implementing or testing several different countermeasures (Borroni-Bird, 2012). These use and ownership restrictions have various forms which are thoroughly described in the following paragraphs. Practical examples of existing applications are also provided and summarizing table that provides a clear overview is concluding this subchapter.

Registration fee

Although registration fees or taxes are usually not enforced by municipalities but state authorities it is often the first procedure vehicle owners have to comply with regardless of his or her place of residence. While some form of vehicle registration fee exists in the majority of countries the small amount of the fee usually does not pose a significant barrier for vehicle ownership. Singapore has experimented with an elaborate system of registration fees and taxes imposed upon vehicle owners (Land Transport Authority, 2012). Some Scandinavian countries have introduced similar state wide schemes of extra fees which may significantly raise the purchase costs by up to two or three times (Confédération Fiscale Européenn, 2015; Speck et al., 2006). Albeit reduction of GHG emissions is partially attributed by some studies (Speck et al., 2006), such measures on its own prove inefficient and unable to stabilize or decrease vehicle growth rates in long term periods (May, 2004; Willoughby, 2001; Smith, 1992).

Vehicle quotas

Vehicle quotas represent the strictest restraining measures directly affecting the size of the vehicle population. Under vehicle quotas car the right to car ownership is subjected to additional conditions imposed by local officials. Such conditions are often a strictly limited number of available licenses accompanied by specific auction based purchase procedure. This allows the growth rate of vehicle registrations to be controlled effectively and accurately so that the fluency of traffic is not impacted by increased occurrence of congestion. Furthermore, in contrast to the above mentioned flat additional registration fee discriminating low income groups, carefully organized purchase schemes equal the access to the right to drive for everyone (Feng, Li, 2013). Extra revenues are usually designated for improvements to the existing road infrastructure. The system started in May 1990 in Singapore requires individuals intending to own a vehicle to first acquire a Certificate of Entitlement which is obtained through the public bidding system (Land Transport Authority, 2014). Shanghai has introduced a private vehicle plate auction mechanism in 1986. Since then a limited number of license plates are offered monthly in online auctions (Chen, Zhao, 2007). In Beijing, a license plate lottery system was implemented in 2011. Analysis of vehicle quota outcomes are mostly positive especially when combined with additional measures that prevent citizens from registering vehicles in different regions (Koh, Lee, 1994; Feng, Li, Xu, 2012; Feng, Ma, 2010; Tan, 2001). However the fairness of some purchasing schemes that favours wealthier individuals are often criticized and suggestions such as percentage ad valorem bids were raised to address deficiencies in existing mechanisms (Tan, 2001).

Dedicated lane

Dedicated lanes present a specialized method to mitigate traffic congestion in an indirect manner. Rather than just restricting the use of passenger vehicles and thereby control traffic demands it aims to attract individuals to public transport, taxis or incentivize vehicle owners to share their cars with more passengers. Dedicated lanes, as the name suggests, are an exclusive, separated traffic lanes that can be permanently or temporarily used for a specific type of or minimally occupied vehicles only. Bus only lanes are the most widespread example with cities such as London, Sydney, Guangzhou, Singapore and others employing or planning to implement the method to prioritize public over the individual transportation (Roads and Maritime Services, 2014; Land Transport Authority, 2015b; Zhu, 2012; Transport for London, 2015a; Brisbane City Council, 2014). Often bus lanes are also combined with additional measures to create a bus rapid transit system (Center for clean air policy, 2013; AECOM, 2012; Urbanization of Curitiba, 2015; Municipal Transportation in Rio de Janeiro, 2015; ColombiaInfo, 2008). And although such schemes undoubtedly impact individual transportation, detailed description of such programmes is well beyond the scope of this thesis.

Another slightly different application of dedicated lane mechanism is the so-called high occupancy vehicle lanes operated mainly in the USA (Colorado Department of Transportation, 2015b; Texas Department of Transportation, 2015; State Highway Administration, 2015; Washington Department of Transportation, 2015; Ontario Ministry of Transportation, 2015). High occupancy lanes are priority lanes designated specifically for buses and vehicles with predefined minimum number of passengers (U.S. Environmental Protection Agency, 2012). Vehicles that fail to comply with the required occupancy minimum are fined (U.S. Environmental Protection Agency, 2012). However this measure is applied mainly on highways and thereby has limited influence of transportation in large cities.

Restricted and low emission zone

Although restricted zones, also known as space rationing, are sometimes considered only a special variation of road pricing (see following subchapter), they are a commonly used method to mitigate the impacts of a growing number of vehicles used in urban areas with a long and rich history and thereby is described in this separate subchapter. Traffic in selected areas of the city is limited temporarily or permanently based on a specific rule, for example possession of special license, combination of last digits and characters of license plate, during certain time periods or combination of all (Cambridge Systematics, 2007). Road rationing is a commonly used option to manage traffic especially in downtown areas in peak hours. Additionally license plate restriction rules are often used in conjunction with vehicle quotas to prevent individuals from abusing the system and registering their vehicle in a different authority (Feng, Li, 2013).

So-called low and zero emission zones are recognized as a specific form of road space rationing, because the main intention of such measures is to improve air quality. Access to those zones is banned or charged depending on the volume and composition of exhaust gases produced by the vehicle.

Various kinds of restricted zones are or were used on most continents with a notable exception of North America. Singapore implemented probably the first road rationing system called area licensing scheme in June 1975 (Ang, 1995). Initially the system worked with simple one-day paper licenses bought at post offices and petrol stations. Over time, Singapore has continuously refined the system and eventually transitioned from a combination of manual congestion road pricing and restricted zones to fully automatic electronic road pricing model.

Beijing introduced its well-known road rationing system based on license plate numbering during the Olympic Games in 2008 and subsequently modified the policy so each registered vehicle is banned from use for at least one day per week (Feng, Li, 2013). Similar systems are used in Mexico City, São Paulo and Bogota (Cambridge Systematics, 2007). During the weekday peak hours passenger vehicles are prohibited into restricted areas (in case of Bogota into the whole city) based on last digit of license plate (Secretaría de Turismo, 2015; Companhia de Engenharia de Tráfego, 2015c; Alcaldía Mayor de Bogotá, 2014)

In accordance to EU policy regarding air standards many cities across the Europe recently implemented or plan to introduce its low emission zones. Those include for example London, Berlin, Prague, Milano, Vienna, Munich and several others (Sadler Consultants, 2015a). Policies in different municipalities are not fully harmonized yet, but basically are following. Vehicles entering such zones must meet certain minimum emission standards and prove it by respective license (mostly in a form of a sticker) issued by local or national authority. Compliance with stricter standards results in significantly lower license costs. Electric or hybrid vehicles are usually allowed to enter for free.

Albeit it is by far not classifiable as a large urban area it is worth mentioning a car-free suburb Vauban in Germany (Vauban, 2013). Citizens of the district are greatly discouraged from owning passenger vehicles by strict regulations which results in 40% car-less households and an almost car free city center (Sustainability Victoria, 2011; Danish Architecture Centre, 2014).

Road tolls

The most basic form of road pricing, sometimes referred to as a congestion pricing is a regular fee based on vehicle weight, horsepower or other parameter periodically levied on vehicle owners - is used for example on a national level in countries such as Denmark and Finland (Speck et al., 2006) or locally in the city of Madrid (Ayuntamiento de Madrid, 2015). Other forms, such as distance based tolls, time of day tolls or fixed tolls for certain sections of roadway are also utilized (Roads and Maritime Services, 2016b). Advances in technology enable charges to be adjusted dynamically in a real time, surging as traffic intensifies and vice versa (Davies, 2013). Regardless its specific form, the road pricing is another mechanism geared specifically towards a reduction and theoretically a total prevention of traffic congestion by controlling traffic demand. It is often referred as pay-as-you-use principle as it bears a form of an extra fee levied for the use of selected roads.

Enforcement is usually automatized via cameras scanning license plate numbers of passing vehicles or mandatory transponders placed in vehicles that communicate wirelessly with system checkpoints (Sadler Consultants, 2015b). Systems are situated mainly in city centers, vital ring roads and other roadways prone to congestion. Thereby road pricing can actively manage volume of traffic. Additionally, prediction algorithms based on historical data can be applied to pro-actively steer traffic through the city and discourage drivers from congestion areas which further prevents the risk of creation of congestion (IBM, 2007).

As discussed earlier, Singapore was among the first cities that started pioneering various anti-congestion measures. The first version of road pricing system called Electronic Road Pricing was implemented in 1998 (Land Transport Authority, 2011) and replaced existing restricted zones and manual highway road pricing programme completely. The system consists of toll gates installed around the downtown area and along highways and so-called in vehicle unit that is an obligatory equipment for all registered vehicles (Land Transport Authority, 2013). Passing through the gate results in a deduction of appropriate charge that is based on the time of day and category of used vehicle (Land Transport Authority, 2015a).

Comparable system based on a license plate optical recognition mechanism is used in Sydney (Roads and Maritime Services, 2016b), was introduced in 2003 in London (Transport for London, 2014c), followed by Stockholm in 2007 (Transport Styrelsen, 2015) and a few other European cities (Municipality of Milan, 2015; Wærsted, 2009; Durham County Council, 2015). Other cities such as Sao Paulo and Beijing are planning to introduce road pricing systems to complement their existing traffic policies (BBC, 2011; Domingos, 2012). Another notable example of application of automated electronic road pricing is a Golden Gate bridge electronic tolling system which combines principles of road pricing and dedicated lanes (Highway and Transportation District, 2015) and Sydney Harbour Bridge and Harbour Tunnel tolls (Roads and Maritime Services, 2015c).

Tab. 7 Examples of application of vehicle ownership and use restrictions

Measure	Examples of use
Registration fees	Denmark, Finland, Norway, Singapore (small fee applied in most of countries)
Vehicle quota	Guangzhou, Shanghai, Singapore
Dedicated lane	Beijing, Delhi, Guangzhou, London, New York, Rio de Janeiro, Singapore, Sydney
Restricted and low emission zone	Auckland, Athens, Beijing, Berlin, Bogota, London, Mexico City, Santiago, Sao Paulo, Singapore
Road pricing	Denmark, Finland, Latvia, Milan, Norway, Singapore, Sweden, Stockholm

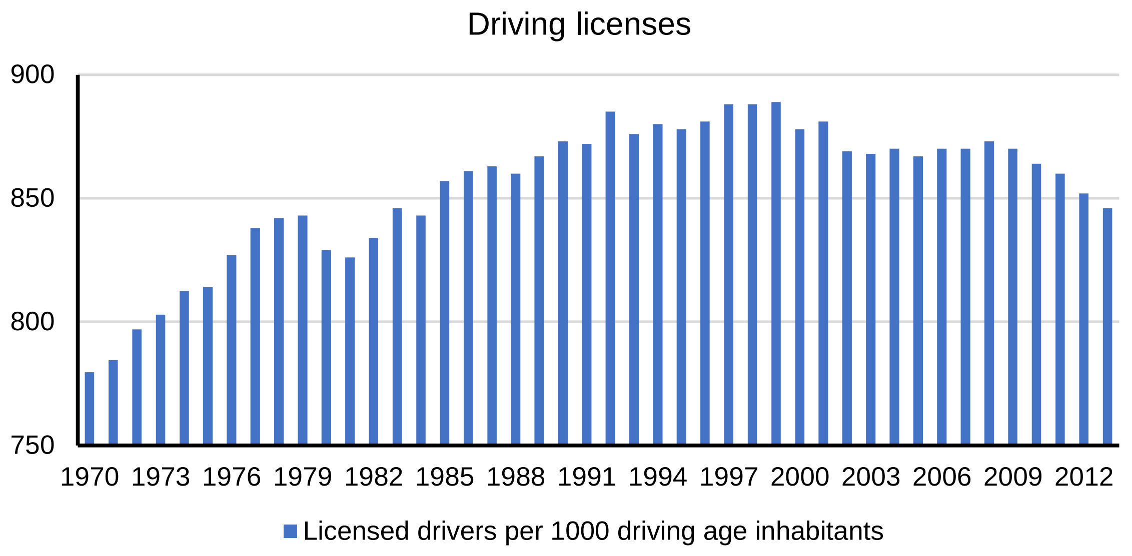
Source: adapted from the Land Transport Authority (2012, 2013, 2014, 2015b), Feng and Li, (2013), Cambridge Systematics (2007), Transport Styrelsen (2015), Municipality of Milan (2015), Transport for London (2014c), Speck et al. (2006), Roads and Maritime Services (2014)

3. Resulting transport situation in U.S. urban areas

Based on conditions described in the previous chapter, this chapter synthesizes recent empirical datasets from the USA and its major urban centers in particular. The USA was selected as the main example due to the richness, completeness and consistency of available data. Three different indicators describing the transport situation are studied in order to provide an accurate and holistic view of the population's contemporary travel behaviours and vehicle usage patterns. Firstly, the number and age composition of licensed drivers is examined. Subsequently, vehicle ownership rates especially in large cities are studied. Vehicle and passenger kilometres travelled are factored in as the final argument and a latest indication of changing mobility trends. Demographical aspects, specifically the impacts of age composition of population are briefly discussed in a separate paragraph. To further enhance the applicability of the study evidence from other mainly European countries is presented, concluded by a brief overview of existing scientific explanations and personal reflection of synthesized findings.

3.1. Driving licenses

The amount of issued driving licenses and the corresponding share of licensed drivers in total or driving age population are indicating both the changing attitudes about travel and interest in passenger vehicles as a transportation means. The age structure of licensed population provides additional explanations and insights for estimates of future development.



Source: adapted from the Federal Highway Administration (1971 - 2014a) [annual Highway Statistics series]

Fig. 8 Number of licensed drivers per 1000 driving age population in USA

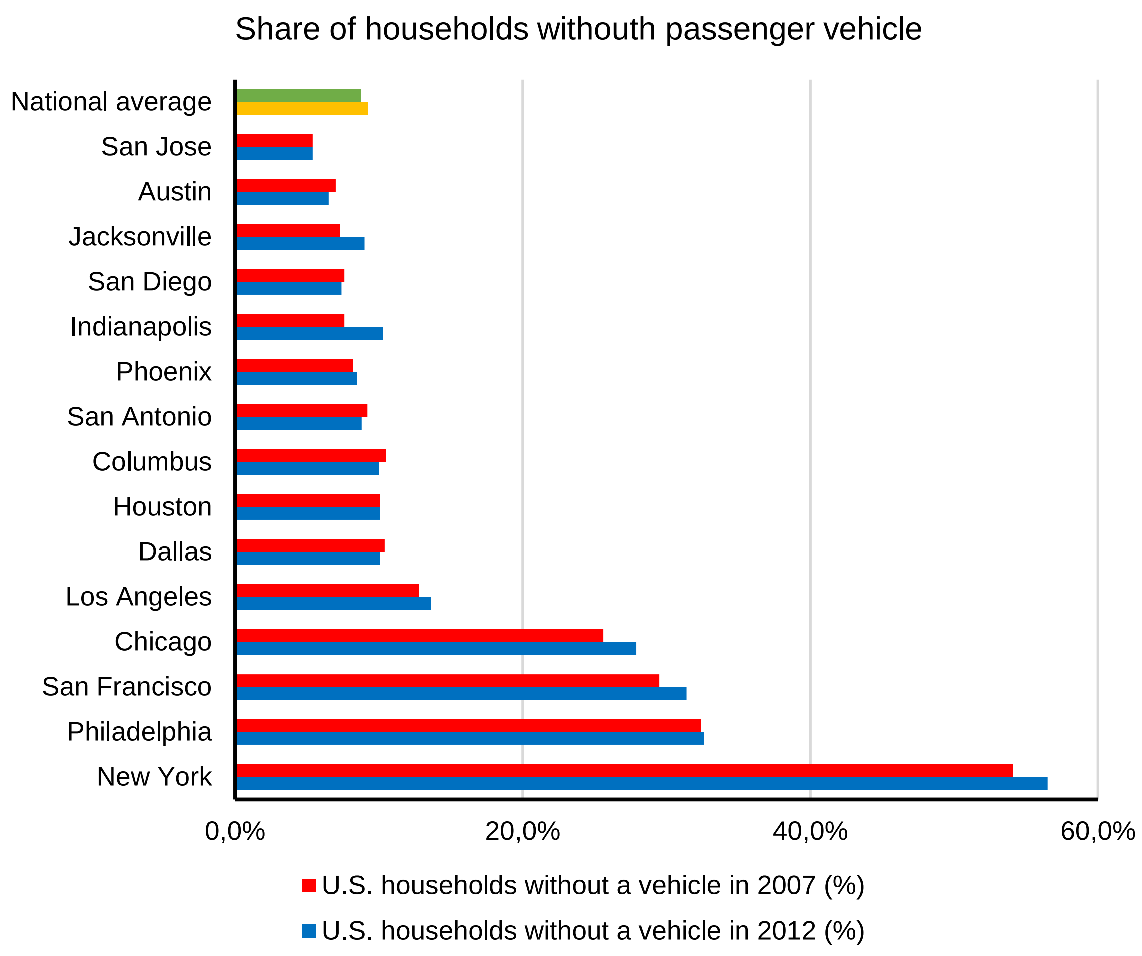
With the exception of oil crises and slight fluctuations limited to single period, the percentage of licensed drivers among driving age population in the USA has been steadily growing for several decades (Federal Highway Administration, 1971 - 2014a [annual Highway Statistics series]) and peaking at almost 90% percent in year 1999 (Federal Highway Administration, 2000). Since then, the share of license holders has stagnated for 10 consecutive years and began declining over the last 5 periods, eventually reaching the same values as in the year 1983 (Federal Highway Administration, 2014a; Federal Highway Administration, 1984).

Recent studies (Sivak, Schoettle, 2013; Sivak, Schoettle, 2011b) and current data support that the decline in driving licensing is stimulated mainly by younger generations (Federal Highway Administration, 2011). Between the years 1995 and 2013 the share of 19 year old and younger licensed drivers in their age group dropped from 63,9% to 45,2% (Federal Highway Administration, 1996; Federal Highway Administration, 2014a). The same percentage in age group between 20 and 24 years declined from 86,8% to 77,5% and similar tendency can be observed in age groups from 25 to 29 and 30 to 34 years of age (Federal Highway Administration, 1996; Federal Highway Administration, 2014a).

And albeit older generations partly offset this decrease, for example the share of licensed drivers in all age groups over 70 have expanded consistently since 1983 (Sivak, Schoettle, 2011b), the shift in licensing trends has already impacted peak licensing age in the USA which has shift from the group aged 30 to 34 in 1983 to those between 60 and 64 years in 2008 (Sivak, Schoettle, 2011b).

3.2. Vehicle ownership

Such values correspond with the latest findings about the stagnating number of vehicles per 1000 inhabitants (Oak Ridge National Laboratory, 2015) and increased number of households without a vehicle (Sivak, 2014). After a period of stable growth, vehicle registrations have been stagnating since 2002 (Federal Highway Administration, 1991 - 2014a [annual Highway Statistics series]) and the most recent data shows no signs of a rebound (Federal Highway Administration, 2013; Federal Highway Administration, 2014a).



Source: adapted from Sivak (2014)

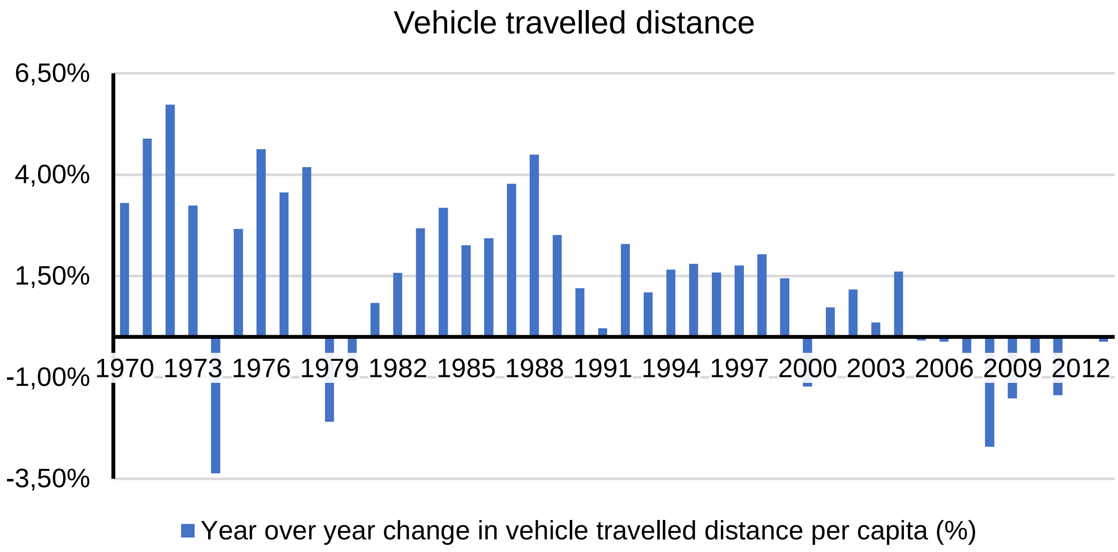
Fig. 9 Share of households without a vehicle in 15 most populous U.S. cities and national average in the years 2007 and 2012

Citizens in large urban areas appear to be the primary source in the reduction of vehicle ownership rate. In the period between the years 2007 and 2012 the share of car-less households in the 30 largest U.S. cities by population had risen in 21 of them (Sivak, 2014) and the 10 most populous recorded on average 18% of households without vehicle compared to national average of 9% (Sivak, 2014).

3.3. Distance travelled

Travelled vehicle and passenger kilometres are often considered to be the key factors depicting the state of both individual and public transport. The former indicates vehicle usage levels and is also often calculated on the individual level as a basic measure of how much people drive. The latter highlights distances travelled by the average individual passenger.

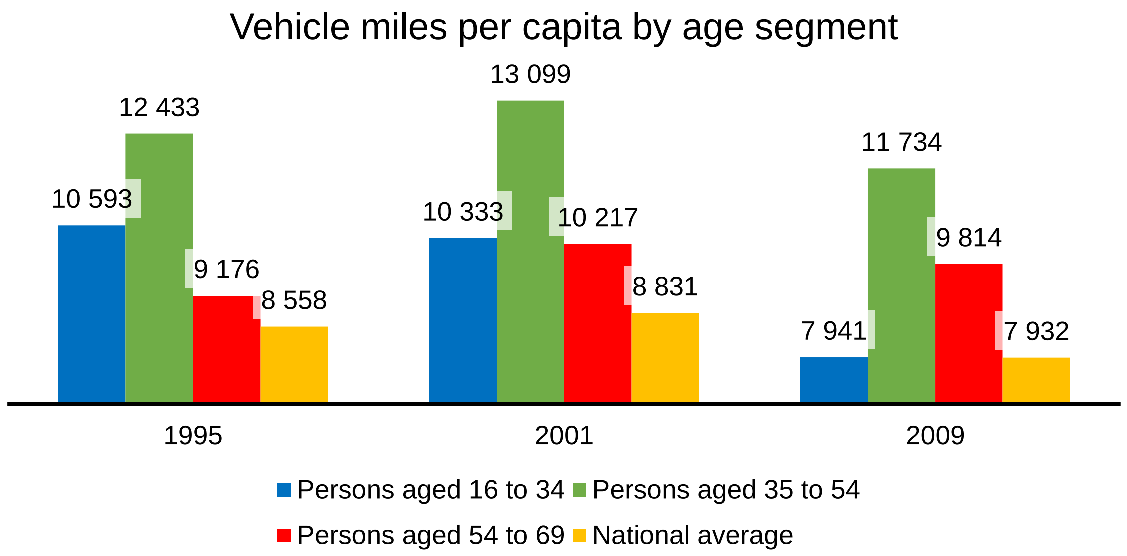
Historical data from the USA shows an almost uninterrupted annual growth in travelled vehicle miles for over five decades (Federal Highway Administration, 1981 - 2014a [annual Highway Statistics series]; Short, 2015) including derived vehicle miles per capita indicator (U.S. Department of Transportation, 2015; Short, 2015). Until recently, the only exceptions from this rule were the periods immediately preceding and following economic downturns and oil crises, such as years in 1974 or 2000 (Federal Highway Administration, 2014a; Short, 2015).



Source: adapted from the Federal Highway Administration (1971 - 2014a) [annual Highway Statistics series] and U.S. Census Bureau (2015a)

Fig. 10 Year over year percentage change in vehicle kilometres travelled per capita

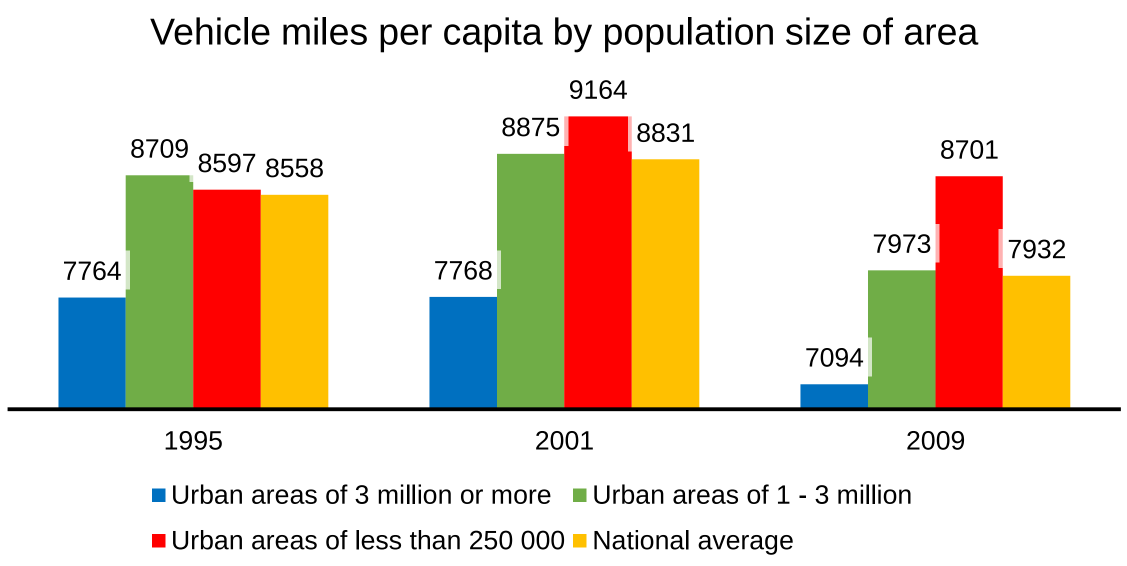
This prolonged period of upturn in per capita travelled distance was terminated in 2004 and the diminishing trend presently continues. And the equal trend reflects in a passenger mile parameter (Bureau of Transportation Statistics, 2015). Exact causes for this sudden shift remain yet to be determined as the economical situation of the USA as well as the development of oil prices provide no satisfying explanation for such phenomenon. More importantly available data report that there is a considerable difference in travelled distance between several population age segments.



Source: adapted from the Federal Highway Administration (2015)

Fig. 11 Vehicle miles per capita ofr Americans aged 18 - 34, 35 - 49 and 54 - 69 in years 1999, 2001 and 2009

The findings of the National Household Travel Survey conclude that between the years 2001 and 2009 young adults aged 16 - 34 reduced annual vehicle travelled distance per person by 23%, namely from 10 333 to 7 941 miles, but at the same time took 24% more bike trips for 31% larger distances, walked 13% more frequently over 13% greater distance. In addition, they considerably substituted individual transportation means with public ones which is documented by 36% increase of person miles travelled by public transport (Federal Highway Administration, 2015).



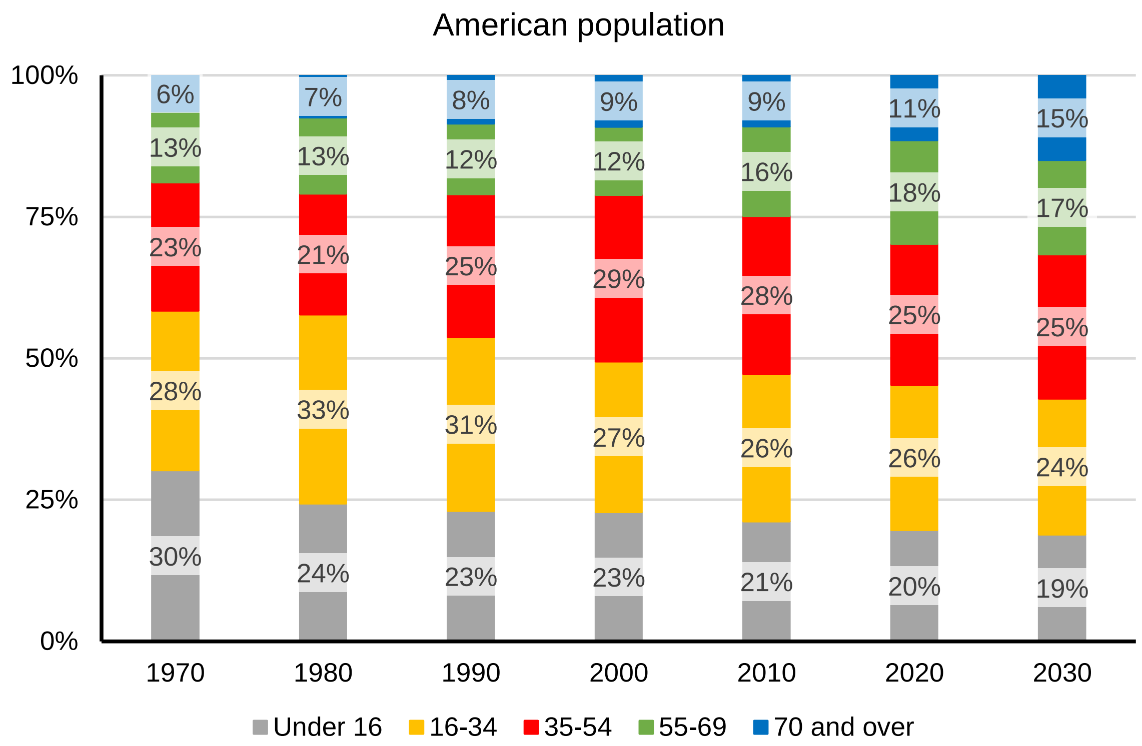
Source: adapted from the Federal Highway Administration (2015)

Fig. 12 Vehicle miles per capita for U.S. urban areas and national average in years 1999, 2001 and 2009

The declining interest in passenger vehicles and individual transportation among the younger generation is notably more evident in urban areas than in rural ones. Millennials living in urban areas aged 16 - 24 and 25 - 34 decreased the amount of daily travelled vehicle miles between the years 2001 and 2009 by 30% for the former and 20% for the latter age group (Federal Highway Administration, 2011b). While the same aged individuals in rural regions accounted only 8%, respectively an 18% reduction in the same period (Federal Highway Administration, 2011b). The population of large cities is credited with generally higher reluctance to travel by car. According to the data collected between the years 2006 and 2011, vehicle miles per capita has decreased in 54 out of 74 large U.S. urbanized areas and total vehicle miles dropped in 47 cases regardless of the 2,5 million population increase in the same time (Dutzik, Baxandall, 2013b).

3.4. Age structure

Albeit the influence of age on the travel behaviours is not the main aim of this study, its importance and interrelation to the topic of this thesis is evident and therefore this paragraph discusses the matter briefly. As is documented in previous paragraphs, the so-called Millennials are not only the underlying force driving the licensing downturn but are the same group that substantially alters its travel patterns and diverts from use and ownership of passenger vehicle in favour of alternative transportation options. These young Americans born between 1982 and 2000 exceeded the size of baby boomers and now form the largest U.S. population segment counting 83,1 million which represents more than one quarter of the American population (U.S. Census Bureau, 2015b; The Council of Economic Advisers, 2014).



Source: adapted from the U.S. Census Bureau (2015a)

Fig. 13 Age segmentation of U.S. population in the years between 1970 and 2030

From a historical perspective, drivers between 34 and 54 years accounted for the largest portion of vehicle miles travelled (Federal Highway Administration, 2011b). But the demographical share of this age segment has been shrinking since 2000 and as the Millennials approach this peak driving age present changes in driving trends are expected to persist and substantially influence travel behaviour on a national level (Sivak, Schoettle, 2011b; Davis, Dutzik and Baxandall, 2012; Dutzik, Baxandall, 2013a). The long term demographic overview also provides additional insights documenting the growth of the elderly population that is known to drive less frequently and for markedly shorter distances (Federal Highway Administration, 2011b; Sivak, Schoettle, 2011b).

3.5. Other countries

Although reliable and relevant data from other countries is rare and generally harder to obtain, several studies were conducted in multiple European and Asian countries and their findings are predominantly consistent with the evidence from the USA (Delbosc, Currie, 2013b; Kuhnimhof et al., 2012a; Kuhnimhof et al., 2012b; Transport for London, 2014a; Bureau of Infrastructure, Transport and Regional Economics, 2014a; Bureau of Infrastructure, Transport and Regional Economics, 2014b; Dender, Clever, 2013; Institute for Mobility Research, 2013; Schmidt, 2014). For example a recent study from the Czech Republic confirms a downturn in vehicle ownership in urban areas as the national average of only 14% of households does not possess a vehicle but that number goes up to 21% for households in urban areas with more than 100 000 inhabitants (Nielsen Admosphere, 2015). Some countries however demonstrate variances, such is a growth in share of licensed drivers in all observed age categories in Finland, Israel or Netherlands (Sivak, Schoettle, 2011a). Explanations for such contradiction among studied countries are limited and thereby formulation of any conclusions for non-U.S. states remain questionable mainly due to the lack of consistent and comprehensive historical data that could serve as a baseline for further studies.

3.6. Scientific explanations

Several authors and research institutions have applied diverse set of methodologies to investigate and explain or define mobility trends among young adults (Delbosc, Currie, 2012; Delbosc, Currie, 2013a; Aretun, Nordbakke, 2014; Le Vine, Latinopoulos, Polak, 2014; Delbosc, Currie, 2014; RSG, 2014; Transport for London, 2014a; Davis, Dutzik, Baxandall, 2012; Dutzik, Baxandall, 2013a; Puentes, 2013; Dender, Clever, 2013; Zipcar, 2014). Differing conclusions are provided, however several common arguments can be identified. The obtained findings often emphasize aspects such as character of place of residence, high operating and maintenance costs of passenger vehicle, improved level of service of public transportation and better accessibility of alternative transportation modes. Another indication of changing attitudes towards ownership and use of passenger vehicles is the shift in the perception of passenger vehicle discussed in chapter 2.2. Moreover, latest community survey reports that 52% of Americans would prefer to live in a place that does not require regular use of car and that percentage rises to 63% for US Millennials (Urban Land Institute, 2015).

A frequent subject of specific interest in some studies is the impact of access to the internet and of use of smart mobile devices on travel behaviours (Sivak, Schoettle, 2011a; Le Vine, Latinopoulos, Polak, 2014; Aretun, Nordbakke, 2014; Zwerts, Janssens, Wets, 2004). The so-called virtual mobility is often proposed as an underlying factor for current mobility trends (Sivak, Schoettle, 2011a; Zwerts, Janssens, Wets, 2004; Zipcar, 2014; Delbosc, Currie, 2013c). However proponents argue the opposite, claiming that active internet users are more likely to hold a driving license than their peers who do not use the internet (Delbosc, Currie, 2012; Le Vine, Latinopoulos, Polak, 2014). This inconsistency indicates the need for further studies establishing the unassailable relationship between mobility demands and internet usage patterns.

High and greatly fluctuating fuel prices as well as other costs incurred by ownership and use of passenger vehicle are often attributed to be a main cause for the recent downturn of use of passenger vehicles. But the correlation between travelled vehicle or passenger distance and changing fuel prices has yet to be established adequately. While the price elasticity mechanism between the two is supported mainly, but not exclusively by authors studying historical data and long span time series (Litman, 2012; Hatz, 2011), it is refuted by others analysing recent datasets (Short, 2015; Puentes, 2013; U.S. Energy Information Administration, 2014; Dargay, 2004). Regardless of contradictory conclusions, current fuel price - reaching the four year minimum (U.S. Energy Information Administration, 2015) - provide no clear explanation for diminishing travel demands. The same statement can be claimed for other costs related to vehicle ownership and operation as the average annual cost calculated by the U.S. Department of Transportation remain stable with no excessive fluctuations and therefore does not explain recent decline in travelled kilometres (Bureau of Transportation Statistics, 2015; American Automobile Association, 2015).

Despite differing methodologies and disparity in formulation of conclusions, prevailing majority of authors concurs that the historically stable state of individual transportation in large urban areas is changing dramatically and that the driving force of this transition are the travel behaviours and mobility demands of young adults aged 18 - 34. According to numerous scientists (Dender, Clever, 2013; U.S. Department of Transportation, 2015; Aretun, Nordbakke, 2014; Dutzik, Baxandall, 2013a, these changes are likely to continue because the inclination of Millennials select multimodal mobility as well as their growing indifference towards passenger vehicles core values appears to be a permanent behavioural shift rather than a temporary trend.

4. Alternative modes of individual transportation in urban areas

Due to constraints and limitations associated with the use of passenger vehicles as an individual transportation means a great number of alternative individual transportation solutions have emerged over the recent years. Numerous different approaches are applied ranging from already available free of charge mobile applications providing intermodal transport guidance (Urban Engines, 2015) and well-rounded community based navigation platform (Waze, 2015b) over online networks connecting passengers with drivers (Uber, Inc., 2015f) and Smartscooters paired with a network of charging stations (Gogoro, 2015) to resource intensive and potentially transformative long term endeavours such as a development of fully autonomous vehicles (Audi, 2015; General Motors Company, 2016; Google Inc., 2015b; Uber, 2015g). Recently, a very unconventional competition has been announced by U.S. Department of Transportation in order to incentivize municipalities of medium-sized cities to address arising mobility trends and challenges (U.S. Department of Transportation, 2016a). A common denominator for most of those solutions is the environmental and social awareness of their designs. Besides the necessary business objectives, environmentally benign operation and long term sustainability is often a key aspect of the proposed solutions. Targets such as the reduction of vehicle ownership rate and travelled distance or are an inherent part of alternative transportation models designed to address and alleviate many of mobility related issues discussed in 2. chapter. All types of stakeholders including government agencies, car manufacturers, GPS navigation providers, car rental companies, universities, small startup companies or civil associations are actively participating.

Due to the dynamic and often perpetually iterative approach of contributors, inadequate regulation and novelty or revolutionary and sometimes overlapping character of many of emerging solutions, no stable terminology has been established so far. A notable exception is an general term Transportation Network Companies defined for regulation purposes by California Public Utilities Commission (California Public Utilities Commission, 2013), referring to rather numerous and internally heterogenous group of online enabled transportation service providers (California Public Utilities Commission, 2015). Due to the considerable differences in operational model of individual transportation network companies, this chapter does not adhere to the proposed terminology but rather focuses on explanation of differing facets of operational principles of respective transportation solutions.

Two basic characteristics befitting the majority of alternative transportation solutions are “mobility as service” concept and “on demand” principle. The former indicates that mobility services instead of transportation means are sold by providers (Hawkins, 2015; Heikkilä, 2014; MaaS, 2015) which reflects the recent departure from private ownership of passenger vehicles discussed in 3 chapter. The latter defines that fixed routing and scheduling is abolished in favour of flexible responsive systems that react on actual passenger needs. Demand responsive systems were originally designed for public transportation yet the principle is utilized by many alternative individual transportation solutions.

The range of emerging options is wide and continuously expanding with often indefinite and ambiguous projects therefore listing all existing alternative mobility solutions is not possible, nor beneficial or desirable for this study. With regards to the aim of this thesis only established or most promising solutions that are based on a use of passenger vehicles are described in this chapter. Two application scenarios of contemporary passenger vehicles are presented in subchapter 4.1 and 4.2. Final section of this chapter discusses various facets of prospective use of autonomous (for the purpose of this thesis regarded as non-contemporary) passenger vehicles in individual transportation.

4.1. Carsharing

Carsharing is characterized by common use of the passenger vehicle by several independent users one after another (Harms, Truffer, 1999; Bart, Shaheen, 2002). Trip duration and destination is determined by each user within agreed boundaries. The key defining feature is a separation of vehicle ownership and vehicle use because the traditional individual ownership right is substituted with a collective one (Harms, Truffer, 1999). Vehicle itself becomes more and more immaterial to the transportation service that is provided. Although the irregular and informal carsharing practice without any contractual agreements and provided at no costs might be quite common between parents and their maturing children this subchapter focuses only on organized forms of carsharing.

It is worth to note that carsharing and car rental share many similarities and that an exact and clear distinction can oftentimes be problematic. The essential difference lies in the ownership right which in case of car renting company always remains with the service provider. Carsharing principles on the other hand typically lead to equal dissolution of ownership right among/amid its members. However the creation of professionalized carsharing operators blurs the line because in these business models shared vehicles are owned by the operators. The remaining differentiation thereby consists mainly of duration and length of trips and basic operational premises and principles. Carsharing generally aims for short time and short distance trips and by the nature of its design may lead to the considerable enhancement of vehicle utilization rate, mitigation of traffic congestion or reduction of GHG emissions (Carsharing Association, 2011).

The emergence of the first organized carsharing efforts interconnects with informal (private) forms of carsharing between family members and dates back to 1948 (Harms, Truffer, 1999) however these earliest providers do not remain operational till nowadays. Many of contemporary providers were founded in late 1990s, such as Switzerland ShareCom and ATG in 1987 or German StattAuto in 1988 (Harms, Truffer, 1999) or later. In the USA the first two temporary carsharing experiments ran from 1983 to 1985 and 1986 respectively, followed by regular services emerging since 1998 (Shaheen, Mallery and Kingsley, 2012; Ortega, 2010). Well established carsharing systems exist in Asia exist in Japan or Singapore (Matthew et al., 2006)

At present, carsharing has gained a significant attention and attracts many contenders. Recent statistics demonstrate a sharply growing popularity both in the USA and the EU. More than 1,3 million active members and almost 20 thousand vehicles operated by 23 different carsharing providers were recorded in the USA in 2014 (Shaheen and Cohen, 2014). The German carsharing association reports that 1 million users, which is a 37,4% increase from previous year, in 500 locations is served by fleet of 15 thousand vehicles (Bundesverband CarSharing e.V., 2015). The largest provider in Switzerland alone offers 2700 vehicles at 1400 location throughout the country (Mobility Cooperative, 2014).

Albeit a granular classification was developed by some authors (Bart, Shaheen, 2002), two main carsharing models are actually currently employed and distinguished. Station based model which typically requires members to reserves shared vehicle in advance and returned them to the same station from which they were taken from (Bart, Shaheen, 2002; Jorge, Correia, 2013; Zipcar, 2015e) and the free float model that enables spontaneous and flexible use without reservations and the necessity to return vehicle to a specifically defined place (Jorge, Correia, 2013; Le Vine, Zolfaghari, Polak, 2014). The former model is sometimes referred to as a two-way or a roundtrip system because it requires a secondary trip to return the vehicle. Some providers use a broader definition of “station” such a city district or other specifically delineated location (Car4way, 2015; Autonapůl, 2015). The possibility of so-called one-way model that allows its members to return vehicle to different stations is examined by some operators (Center for Environmental Research & Technology, 2013; GoDrive, 2016; DriveNow, 2015b) but at very limited scope and with mixed results. On the other hand, a free float model, as its name suggest, is characterized by fluent movement of shared vehicles within the area (Jorge, Correia, 2013; Le Vine, Zolfaghari, Polak, 2014). Users are allowed to freely leave vehicle anywhere within the delimited city boundaries on their discretion (Jorge, Correia, 2013; Communauto, 2015; car2go, 2015b). Charging scheme is usually simplified with no fixed, deposit or recurring fees. Payment usually consisting of single transparent per time unit rate. The biggest drawback of a free float model is a troublesome spatial distribution of vehicle. The arbitrary allocation of vehicles by users inevitably tips the balance between the user demand and the availability of vehicles. Relocation strategies to mitigate this effect need to be devised which leads to additional costs and complexity (Bruglieri, Colorni, Luèa, 2014; Boyaci, Geroliminis, Zografos; 2013; Weikl, Bogenberger, 2012). An original alteration to existing carsharing concepts was recently introduced by Ford Motor Company allowing groups of up to 6 individuals to share a leased Ford vehicle (Ford Credit, 2015). Albeit currently limited to Austin in Texas the experiment undoubtedly has a potential to be explored.

Station based providers include mainly larger companies specializing at the carsharing business only, such as American Zipcar (Zipcar, 2015e), Swiss Mobility Cooperative (Mobility Cooperative, 2014), German stadtmobil (stadtmobil, 2015) or Dutch Greenwheels (Greenwheels, 2015) or affiliate branches of car rental and car manufacturing companies that are usually embarking on operations in smaller extent. For instance Hertz on Demand (Hertz 24/7, 2015b), French Autolib (Autolib, 2015), Ford's GoDrive (GoDrive, 2016), BMW's DriveNow (DriveNow, 2015b), General Motors's (Maven, 2016) Volvo's Sunfleet (Sunfleet, 2016) or Volkswagen's Quicar (Quicar, 2015). A unique and notable synergy between carsharing and public railroad transportation was achieved in case of Flinkster (Flinkster, 2015), a subsidiary of Deutsche Bahn.

A free float model was popularized mainly by car2go subsidiary of Daimler AG and currently the largest and fastest growing carsharing programme in the world (PRNewswire, 2014). The model is currently used or tested by other operators in the industry such as Communauto (Communauto, 2015) or Zipcar (Zipcar, 2015f).

Impacts of carsharing services have been studied extensively and largely positive outcomes were identified (Litman, 1999; Cervero, Golub, Nee, 2006; Martin, Shaheen, 2010; Martin, Shaheen, Lidicker, 2010; Firnkorn, Müller, 2012; Baptista, Melo, Rolim, 2014; Haefeli et al., 2006; Shaheen, Cohen, Chung, 2009). Although unified and generally agreed methodology for measuring carsharing effects is still lacking, impacts per member, per household or per vehicle are often investigated and thereby well covered (Finkorn, 2012). The aggregate outcomes such as the reduction of ownership rates in area of operation are seldomly studied mainly due to the limited scale and relatively low market penetration of carsharing services (Firnkorn, Müller, 2012; Finkorn, 2012). While exact numbers differ from one to study to another (Millard-Ball, 2005; Litman, 1999; Shaheen, Cohen, Chung, 2009), several authors claim that the introduction of carsharing scheme has lead to a decrease in both the vehicle ownership rate by removal of approximately ten private vehicles per one shared and travelled distance by 40% on average (Millard-Ball, 2005; Shaheen, Cohen, Chung, 2009; Martin, Shaheen, Lidicker, 2010; Cervero, Golub, Nee, 2006). A bit counterintuitively, but simple and transparent pricing policy facilitates the realization of the vehicle's full operation costs which reduces the total travelled distance per member and together with use of modern and ecological vehicles in carsharing fleet also leads to considerable reduction of GHG emissions (Martin, Shaheen, 2010; Baptista, Melo, Rolim, 2014; Firnkorn, Müller, 2012). However some authors argue that the total travelled distance increased and the positive externalities of use of carsharing were achieved via the redistribution of modal split in favour of public transportation means, walking and bicycle riding (Firnkorn, Müller, 2012; Haefeli et al., 2006; Finkorn, 2012).

4.2. Ridesharing

Ridesharing, also known as liftsharing or carpooling, is another option frequently used by inhabitants of large cities to mitigate the dire transport situation. It is generally defined as a journey with more than one person traveling in a single vehicle (Chan, Shaheen, 2011; Texas A&M Transportation Institute, 2015a). From strictly theoretical perspective any journey with more than one traveller in the vehicle can be classified as ridesharing. Some authors are differentiating between multiple detailed descriptions (Chan, Shaheen, 2011; Texas A&M Transportation Institute, 2015a; Texas A&M Transportation Institute, 2015b), however this paragraph focuses on institutionalized form of ridesharing organized by third party regardless if it is an independent company of employer. Unlike the case of carsharing, ownership rights are not transferred or divided and trip destination is shared between the driver and other passengers. By its definition it specifically aims at increasing low average occupancy of vehicles discussed in subchapter 2.1 and appears to be an ideal solution for regular trips such as commuting to and from work.

Historically, organized ridesharing efforts began in USA during World War II with Car Sharing Club Exchange programme encouraging regularly commuting workers to share rides in order to conserve resources for war efforts (Chan, Shaheen, 2011). Popularity of ridesharing shortly grew during oil crises in the 1980s (Chan, Shaheen, 2011) but its share on modal split was declining for several decades afterwards representing only 12% of commuting trips in USA in the year 2000 (Pisarski, 2006). However the most recent data (Federal Highway Administration, 2011b) confirm renewed interest in ridesharing services mainly due to the advancement in technology that greatly enhance reliability and comfort of ridesharing as a transportation option (Chan, Shaheen, 2011). Over 400 operators was estimated to offers their services in the USA at the end of 2011 (Chan, Shaheen, 2011).

Contemporary organized ridesharing is mostly arranged via an online platform that provides real time connection between vehicle owners and travellers seeking a ride. Examples of existing ridesharing providers include American companies Lyft (Lyft, 2015a), Uber (Uber, Inc., 2015a) and Sidecar (Sidecar, 2015) or European BlaBlaCar (BlaBlaCar, 2015) and Israeli Waze (Waze, 2015a). Virtual marketplace matching supply with demand is often accompanied by electronic payment system allowing instantaneous, comfortable and transparent payment of costs.

While ridesharing for longer distance in the USA is encouraged by high occupancy lanes described in subchapter 2.3, incentives within boundaries of cities are mostly limited to dedicated parking spaces (Metropolitan Transportation Commission, 2015) and optional benefits provided by employers a voluntary basis (Chan, Shaheen, 2011; Texas A&M Transportation Institute, 2015a). Gauging the aggregate effects of ridesharing proves to be complicated because of lacking data and documentation particularly in case of non-organized forms of ridesharing (Chan, Shaheen, 2011). Nevertheless, some researchers have examined available datasets and favourable outcomes were identified. For example a ridesharing project in Washington conducted in 2010 decreased the amount of daily trips by almost 300 which translates in a reduction of daily travelled distance by 9296 miles (Meier, Martin, Filippelli, 2012). Another study quantifying financial and energy savings of ridesharing concludes that up to 3,5 million liters of fuel, 8200 tons of GHG emissions and more than $30 million are saved annually in the San Francisco area thanks to local ridesharing programmes and initiatives (Minett, Pearce, 2009). Employers promoting ridesharing may benefit from reduced parking demands ranging 11% to 21% (Texas A&M Transportation Institute, 2015a).

4.3. Autonomous vehicle

A fully autonomous vehicle, sometimes referred to as a self-driving or driverless, is a prospective forthcoming transformative technological advancement that as implied by the name itself enables the vehicle to drive without human assistance. Although there is no generally accepted definition of an autonomous vehicle (Schaub, West, 2015), five different levels of vehicle automation were suggested by the U.S. National Highway Traffic Safety Administration (National

Highway Traffic Safety Administration, 2013). Yet only vehicles included in the most advanced category may lead to a fundamental transformation of individual transport situation (Anderson et al., 2014). Therefore only vehicles capable of driving themselves without a human driver are considered autonomous for the purpose of this thesis. Such vehicles require “driver” to input target destination only and provides no control to him/her during the trip itself (National Highway Traffic Safety Administration, 2013).

Some of the first early prototypes aiming for full autonomy were constructed in 1984 at university research centers (Wallace, 1985; The Robotics Institute, 2015). Development of necessary technological advancements was greatly accelerated by three prize competitions held by the U.S. Defense Advanced Research Projects from 2003 to 2007 (Defense Advanced Research Projects Agency, 2004; Defense Advanced Research Projects Agency, 2007; Defense Advanced Research Projects Agency, 2008). Nowadays, self-driving vehicles are simultaneously developed by several companies and institutions (Audi AG., 2015; Daimler AG., 2015; Ford Motor Company, 2016; General Motors Company, 2016; Google Inc., 2015b; Kia Motors Corp., 2016; Tesla Motors, Inc., 2015; Uber, 2015g) and such efforts are not limited to passenger vehicles only (Freightliner, 2015). Most recently, an extensive scientific facility dedicated mainly but not only to collaborative research of autonomous vehicles was opened in Michigan (Mobility Transformation Center, 2015).

Despite only testing and pilot programmes with a very limited pool of vehicles are currently running, Google’s leading Self-Driving Car Project alone already recorded more than 1,5 million miles driven in autonomous mode (Google Inc., 2016a). The large scale deployment is however impeded not so much be the immaturity of technology but the lack of readiness on the legislation front (Bergen, 2016) as only a very few governments worldwide have readily passed laws necessary to permit self-driving cars to public roads (California Department of Motor Vehicles, 2015a; Florida Department of Transportation, 2015; Nevada Department of Motor Vehicles, 2015; Her Majesty's Government, 2015a; Anderson et al., 2014). Most recently a major breakthrough was achieved when U.S. government acknowledged that self-driving vehicle can be qualified as a driver (National Highway Traffic Safety Administration, 2016c).

Nevertheless, an adoption curve is anticipated to take 15 to 20 years after the introduction of first publicly available solution and is highly dependable on costs of components, relevant regulation and several other factors (Mosquet, 2015a). Specifically, the question of liability determination in case of accidents may significantly delay the widespread usage of autonomous technology as it still remains a divisive discussion topic with no consensus reached yet (Anderson et al., 2014; Ramsey, 2015; Villasenor, 2014). Regardless, the recent survey of 1500 U.S. consumers already indicates sufficient interest in autonomous vehicles citing safety and ability to perform other activities instead of driving as a main incentives (Mosquet, 2015a). Albeit several rollout scenarios were proposed (Mosquet, 2015a) the exact mode of use of autonomous vehicles in actual operation is yet undetermined. Indications from representatives of participating companies (Hall, 2015; Lambert, 2015; D'onfro, 2015; Stone, 2015; Ziegler, 2016d) as well as analysts forecasts (Morgan Stanley, 2015) strongly suggest that the most financially viable and efficient in alleviating the current shortcomings of transport situation in large cities (Mosquet, 2015b) could be an on demand mobility as a service operational model that would maximize the benefits of technology. Elements of ridesharing could then be easily infused by the implementation of background algorithm matching destination of existing and potential users. Such application of autonomous technology was openly proclaimed by the president of General Motors during the announcement of an alliance with ride-sharing leader Lyft (Ziegler, 2016b). Sales of self-driving vehicles to consumers, respectively into private ownership are highly unlikely at least initially because of the high costs of the technology and the inconsistency with general concept that promises significant reduction of motorization rate, major enhancement of traffic efficiency and has potential for fundamentally reshaping the long-held perception of individual transportation by foregoing the concept of/for ownership of passenger vehicle (Neil, 2015). In fact, executives of Tesla and Google equalize the impact of self-driving vehicle to that of the elevator, which is a complete shift of existing transportation paradigm (LaFrance, 2015). While some positive effects, lowered vehicle ownership and increased average vehicle occupancy to name a few, could theoretically be attained more easily by widespread application of car and ridesharing schemes there are two effects of self-driving technology that can not be replicated by other discussed transportation alternatives. The traffic accidents rate and the possibility to actively use the time which would otherwise be dedicated to driving. Following paragraphs briefly elaborate both topics in order to outline possible outcomes of deployment of self-driving vehicles.

Road injuries are ranked as the ninth leading cause of death in the world with 1,3 million deaths in 2012 (World Health Organization, 2014). For Americans under the age of 40 car accidents are the most probable reason of premature death (Humes, 2016). In 2014, a total of 29 989 fatal crashes occurred in the USA claiming 32 675 lives (National Highway Traffic Safety Administration, 2016b). At least one alcohol impaired driver was involved in 31% of fatal accidents which lead to death of 9 967 people (National Highway Traffic Safety Administration, 2015a). Distraction affected crashes represent 10% of all fatal crashes and the same share of fatalities (National Highway Traffic Safety Administration, 2016a). Speeding as a contributing factor was recorder in 28% of fatal accidents which resulted in 9 262 deaths (Insurance Institute for Highway Safety, 2016). The recent analysis of weighted sample of 5 470 crashes concludes that the critical causes immediately preceding 94% of investigated accidents were attributed to drivers (National Highway Traffic Safety Administration, 2015c). While that does not implicitly mean the assignment of the fault to the driver as other factors may influence the situation and form the causal chain of events leading to the incident it outlines the potential safety benefits of self-driving technology. Assuming a stable bug-free software autonomous vehicle can eliminate substantial share of casualties by ensuring a “driver” that effectively cannot be distracted, does not exceed speed limits or deliberately breaks any other traffic regulations and cannot be impaired by alcohol and other narcotics. Furthermore, a possible reduction of the number of accidents not only lowers the number of injuries and casualties but also intrinsically induces significant costs saving. The aggregate economic costs of vehicle crashes in the USA reached $242 billion in 2010 (National Highway Traffic Safety Administration, 2015c). Out of that sum, $52,5 billion worth of damage was attributed to alcohol involved crashes, $52 billion to speed related ones and costs of driver’s distraction accidents were calculated to $39,7 billion (National Highway Traffic Safety Administration, 2015c).

The average commuting time (meaning trip duration both to get to and from work) in American in 2009 was 50 minutes and 76% of American commuters which means more than 105 million people drove passenger vehicle alone (McKenzie, Rapino, 2011). That equals into 3 662 361 wasted days every day. Numbers from Europe are slightly worse reaching 72 minutes on average for EU countries (Hofstra University, 2006). Furthermore, workers commuting to large populous cities recorded higher average travel times and longer travelled distance (Mckenzie, 2013; Rapino, Fields, 2012; Chartered Professional Accountants of Ontario, 2015). All that time could potentially be used productively or upon traveller’s discretion in autonomous vehicle.

5. Methodology

With respect to the main aim of this study which is described in detail in the first chapter of this paper and that can be condensed into: **a provision of a rich description of real life situation** which overlaps greatly with generally accepted definitions of case study (Baxter, Jack, 2008; Yin, 2003; Emory, Cooper, 1991). Therefore, case study methodology is selected as a research strategy for this thesis. The key distinctive feature of case study inquiry, an analytical generalization of findings to presented theoretical proposition should allow reliable explanation of presumed causal links and rich deductions about the investigated phenomenon to be concluded (Baxter, Jack, 2008; Yin, 2003; Štrach, 2007).

Based on the theoretical framework consisting of author's theoretical proposition, study questions, and a unit of analysis, a holistic explanatory multiple case scientific inquiry is implemented in this thesis. Multiple case study design enables cross comparison of obtained findings, and corroboration of derived extrapolations by replication of the inquiry procedure in different environments. Both literal replications predicting similar outcomes in similar conditions and theoretical replications proposing contrasting results by testing impacts of altered circumstances are conducted (Yin, 2003). Findings from separate cases are studied individually but cross case synthesis is also performed in order to obtain comprehensive insights and provide solid and compelling conclusions.

5.1. Proposition

The large scale use of contemporary passenger vehicles as a primary mean of individual transportation is credited with current troublesome transport situation in large cities. Restrictive countermeasures on one side and alternative modes of individual transportation on the other may temporarily decelerate an ongoing progress of this deterioration. However in the long term perspective the aggreagate mobility demands derived from growing population, rising urbanization rate and expanding mobility needs of individuals diminish this incremental benefits and continue to aggravate the transport situation. Therefore it could be argued that this status quo can be elevated by the adoption of autonomous technology, respectively by a **fleet of autonomous vehicles operated on the principle of on demand mobility as a service.**

5.2. Study questions

In order to direct this research towards a desired and concrete outcomes and avoid discussion of topics that are only remotely related to the scope a set of three study questions was formulated. The first two questions serve to specify the defined proposition and enable its critical evaluation. The third question focuses on practical aspects of a suggested solution, particularly facilitators necessary for its productive deployment. Answers to the latter question should form an actionable recommendations for policy makers as well as private businesses interested in the field of mobility.

a) What impacts do passenger vehicles have for individual transportation in large urban areas?

b) How can alternative modes of individual transportation affect transport situation in large urban areas?

c) What conditions and requirements need to be meet in order to further the adoption of autonomous technology in transport sector?

5.3. Unit of analysis and sampling method

Stemming from the proposed research proposition and study questions, the unit of analysis is an individual transport situation in urban areas with a particular focus on passenger vehicle as a primary mean of transportation. Parameters such as the number of vehicle registrations, modal split, average travel times, level of traffic congestion or travelled distance per vehicle were collected and analysed on individual and cross case basis. In order to achieve a desired level of representativeness, avoid incorporation of out of scope data and bind the study to focus on the original proposition a non-probability sampling is applied to cover intended variability of cases. A purposive sampling method, specifically the extreme cases strategy is employed to identify and select units of analysis (Baxter, Jack, 2008; Saunders, Lewis and Thornhill, 2009; Yin, 2003).

With account to the character and limitations of this paper eight holistic case studies covering desired urban and mobility settings were conducted. In order to strengthen external validity and derive robust and sound findings replication logic is applied across the cases. The UN’s list of 71 most populous urban agglomerations (United Nations, 2014) served as a starting point for case selection procedure. Additional cities were pooled in accordance to defined sampling methodology. An imperative determinant of the final selection was the accessibility of necessary data and reliability of its sources. Limitations of selected research strategy and applied methodology are described in detail in chapter 6.

Tab. 8 Selection criterions for units of analysis

	Primary criterion	**Alternative criterion**
Location	Each continent must be represented	
Population	More than 10 million inhabitants	More than 10% of country total population
Economic importance[1]	More than 250 millions of USD	More than 10% of country total gross product

[1] nominal exchange rate from Federal Reserve System for respective time period used for recalculations

To shortlist the pool of prospective units of analysis three initial criterions were formulated: **geographic location, population and economical significance**. In order to attain equal representation of all regions, urban areas from each continent with the exception of Antarctica were included in this study. Antarctica was omitted due to non-existence of any large urban settlements. In consistence with the current number and geographical location of the largest urban areas (United Nations, 2014), Asia and North America are represented by two, respectively three units. This helped to cover a wider spectrum of existing transportation landscapes. The population criterion would prevent the inclusion of any Australian and any European urban areas as well. However, to improve the quality of analytical generalization of the study and represent examples from all relevant continents, secondary set of criterions based on relative indicators was devised enabling two units from both continents to meet the requirements. The economical factor narrowed the pool of candidates to areas with high concentration of economic activity. Suitable indicators such as GDP or regional value added were evaluated in this stage of selection procedure. Certain level of economic development was a necessary precondition because passenger vehicles as a transportation mean necessitates the existence of a costly road infrastructure. This excludes all African agglomerations that fulfil the population criterion due to the inadequate level of socioeconomic development which effectively prevents widespread adoption of passenger vehicles.

Afterwards, identification and selection of extreme cases among the list of candidate urban areas was performed. That included parameters such as **peak and average population density, urban landscape and its patterns, historic motorization rates, structure, accessibility and serviceability of available public transport** (LSE Cities, 2011). Such factors have a substantial and quantifiable influence on transportation situation in respective regions. For example the existence of subway may shift the modal split towards the public transport substantially (U.S. Census Bureau, 2015a).

In order to finalize the selection two additional criterions: **vehicle ownership and use restrictions** and **accessibility of alternative modes of individual transportation**, were applied. A carefully curated and diligently weighted combination of those represents the intentional aspect of selection procedure and allows application of replication logic. Both literal and theoretical replications were used to collect rich and competent evidence and test the proposition thoroughly under various conditions. Urban areas with various levels of vehicle use and ownership limitations and availability of alternative transportation modes were evaluated and selected ones introduced in the practical section of this thesis.

5.4. Resources and data collection procedure

In order to eliminate accumulated conscious and curb inherent unconscious biases (Mackay, 2016) each case study followed the same logic that consist of acquisition of below listed datasets and subsequent qualitative analysis of over the time development with account to the urban characteristics of studied area. Only secondary sources were used and methodical consistency during the data collection phase ensures that the chain of evidence was maintained.

Tab. 9 Purpose and explanation of studied parameters

Parameter	Unit	Purpose
Population	Total number of residents	Selection criterion
Economic importance	GDP or equivalent indicator reflecting economic activity	Selection criterion
Land area	Total surface area in km^2	Selection criterion
Modal split	Shares of transportation modes on total number of trips or travelled distance in percentages	Indicates dependency on passenger vehicles and distribution of mobility demands
Number of registered passenger vehicles	Total number of passenger vehicles with valid registration	Indicates attractiveness of passenger vehicles as a transportation mean and asset and impact of carsharing services
Monthly parking rate	Average parking rate for one vehicle for one month	Indicates additional costs of use of passenger vehicle
Length of roadways	Total length of available roadway infrastructure	Indicates structural readiness for regular use of passenger vehicles
Travelled distance or number of trips	Vehicle or passenger travelled distance or number of trips per capita	Over the time development indicates willingness to use passenger vehicle
Average vehicle occupancy	Average number of occupants per vehicle	Indicates impact of ridesharing services and vehicle usage patterns
Level of congestion	Delay in hours per commuter or minutes per kilometre, increase of average travel time in percent or average vehicle speeds	Indicates impact of traffic congestion on vehicle users
Average travel time to work in minutes	Average time needed to travel to work in minutes (one-way)	Indicates the impact of peak hours on vehicle users
Traffic accidents / number of deaths	Number of traffic accidents / Number of fatalities caused by traffic accidents	Indicates risk vehicle users are undergoing

Data collection procedure for every case study follows „from top to bottom“ principle that starts with inquiry of ministry of transportation data (or equivalent governmental institution) and continued by exploration of databases of national statistical office. Subsequently local government organisations such as state, province or district authorities, followed by mayor’s offices, area transportation bureaus and other geographically specialized organizations were investigated to gather required area specific datasets. If nation, state and municipality level resources did not provide a complete list of necessary data or were contradicting each other, additional supplementary resources are employed to enhance reliability and validity of analysed data. Those included global statistics from leading manufacturer of GPS navigation units, studies from international organizations, venerable scholars and reputable analysts.

Complementary data such as the availability of individual transportation alternatives is firstly investigated via official websites of global mobility operators such as Uber, Lyft, car2go or Zipcar. Existence of local carsharing and ridesharing providers were examined via Google search engine and set of predefined keywords in English as well as in native language. For example: carsharing [urban area name] or carpooling [urban area name]. And the same method was applied for data about parking rates in each studied area.

6. Practical chapter - case studies

This chapter presents findings from individual case studies. Each unit represents a different transportation extreme according to the described selection strategy. Consistency throughout the process is guaranteed by adherence to defined methodology. All cases are firstly analysed on individual basis but for the sake of information density are organized in sections by two in order to deliver basic contextual information and provide a quick comparison. Each studied area is firstly introduced with emphasis on the factors relevant for the defined case selection procedure. Then an examination of the parameters and indicators describing the current state of individual transportation follows. Individual analyses are then complemented by a concise cross case synthesis that consolidates all findings and facilitates formulation of answers for study questions.

With the exception of North America and Asia, one case study from each continent (excluding Antarctica and Africa for above explained reasons) is included. North America is represented by three urban areas, two from USA and one from Mexico. The former are clustered together, while the latter is grouped with a South American unit. This division is introduced due to a social, economic and demographic similarities between Mexico and South American countries. Two units from Asia are analysed because of 28 existing megacities 16 is located in the continent (United Nations, 2014). Five literal replication cases serve to examine transport situation in conditions close to author's proposition and three theoretical replication cases corroborate the conclusions with findings from urban areas with intentionally different settings.

6.1. North American urban areas

In accordance with the selection procedure two densely populated urban areas in the USA representing North American continent are analysed. The New York-Newark-Jersey City metropolitan statistical area (hereinafter referred to as New York) that extends over New York, New Jersey, Connecticut and Pennsylvania state, includes multiple large cities such as New York, Newark, Bridgeport and Norwalk and encompasses 25 counties (Executive Office of the President of the United States, 2013). Second, the Los Angeles-Long Beach-Anaheim metropolitan statistical area (hereinafter referred to as Los Angeles) lies entirely in California and consist of two counties - Los Angeles and Orange County. Located within this area are for example city of Los Angeles, Anaheim, Santa Ana and Irvine (Executive Office of the President of the United States, 2013).

Tab. 10 Basic characteristics of New York and Los Angeles urban area

	New York	**Los Angeles**
Population (2014)	20 092 883	13 262 220
GDP (millions of USD, 2014)	1 558 518	866 745
Land area (km^2, 2015)	21 478	12 559

Source: adapted from the Bureau of Economic Analysis (2015), U.S. Census Bureau (2015a) and U.S. Census Bureau (2015c)

Being among the largest and most populated economic centers of the USA, both regions easily meet all primary selection criterions. Population in both areas is projected to grow at a very incremental rate (United Nations, 2014) and same can be anticipated for observed economical factor as is indicated by historical evidence (Bureau of Economic Analysis, 2015). As for additional selection measures, no prohibitive restrictions of permanent character are applied however the vehicle registration procedure in both areas is rather complex and incorporates several smaller fees (California Department of Motor Vehicles, 2015c; New York State Department of Motor Vehicles, 2015a). Additionally, restricted driving licenses are issued for young and inexperienced drivers in both regions (California Department of Motor Vehicles, 2015b; New York State Department of Motor Vehicles, 2015c) however such regulation aims on improving traffic safety rather than controlling the volume itself.

Passengers in New York have probably the widest selection of alternative modes of individual transportation including both station based and free float carsharing services such as Zipcar (Zipcar, 2015b), Enterprise CarShare (Enterprise CarShare; 2015), FlightCar (FlightCar, 2015) and car2go (car2go, 2015a). Ridesharing counterparts are represented by Lyft (Lyft, 2015b), Via (Via Transportation, 2015) or 511NY Rideshare (511NY Rideshare, 2015) and transportation network company Uber (Uber, Inc., 2015b). The latter itself operates over 14 000 vehicle which is more than the current number of licensed taxi vehicles (Melkorka et al., 2015). And albeit travellers in Las Vegas are presented with less generous portfolio of transportation alternatives (Lyft, 2015c; RelayRides,2015; Uber, 2015d; Zipcar, 2015c) a plentiful choices are still provided. As such both North American areas represent theoretical replication cases due to favourable conditions for owning and using of passenger vehicle on one side and wide selection of alternative transportation modes on the other one. Therefore it is expected that individual transport situation in both regions is considerably troublesome due to the lack of restrictive measures that outweighs the positive gains from available transportation alternatives.

Tab. 11 Characteristics of New York and Los Angeles transportation landscape

Parameter	**New York**	**Los Angeles**
Modal split (2014)[1] ● Passenger vehicle ● Public transport ● Taxi and motorcycle ● Bicycle ● Walk	 ● 59,11% ● 32,42% ● 6,26% ● 0,62% ● 1,59%	 ● 88,85% ● 6,07% ● 2,63% ● 1,04% ● 1,42%
Number of registered passenger vehicles (2014)	8 872 335	7 802 878
Monthly parking rate (USD, 2015)	670	154
Length of roads (km, 2013)	27 760	15 663

Source: adapted from the BestParking (2015), Federal Highway Administration (2014a), ParkWhiz (2015), U.S. Census Bureau (2015a)

1 calculation based on commuters only

2 calculation based on 15 Manhattan ParkWhiz listings

3 calculation based on all Los Angeles Downtown BestParking listings

Modal split in both areas demonstrates prevalence of passenger vehicle as a primary mean of transportation. The reliance on cars is especially noticeable in Los Angeles. Travellers in New York on the other hand benefit greatly from one of the largest transit systems in the world - New York City Subway which handles over 60% of all public transportation in the area (U.S. Census Bureau, 2015a). Modal split preferences are in consistence with incrementally growing number of registered vehicles in both areas (U.S. Census Bureau, 2015a) which implicates that available carsharing alternatives are not able to cope with or alleviate growing mobility demands. According to ParkWhiz (ParkWhiz, 2015), average monthly parking rate in New York amounts to $670 which presents a significant financial burden for vehicle owners travelling to and from the area. Los Angeles downtown parking rates average on $154,2 (BestParking, 2015) which again corresponds with modal split preference discussed earlier in this paragraph. The extent of available road infrastructure in both cases has not extended significantly in recent periods (Federal Highway Administration, 2004 - 2014a [annual Highway Statistics series]) which indicates that physical limits has been reached.

Tab. 12 Travel behaviour of travellers in New York and Los Angeles urban area

Parameter	**New York**				**Los Angeles**			
Daily vehicle kilometres travelled per capita	2000	2005	2010	2013	2000	2005	2010	2013
	9,6	10,48	9,69	10,32	14,09	14,27	13,85	13,85
Average vehicle occupancy (2014)[1]	1,07				1,07			
Annual hours of delay per commuter	2000	2005	2010	2014	2000	2005	2010	2014
	62	72	72	74	75	81	78	80
Average travel time to work in minutes (2014)	35,8				29,3			
Traffic accidents / fatalities (2014)[2]	299 452[2] / 1 026				N/A / 633			

Source: adapted from the Federal Highway Administration (2014a), Lomax, Eisele and Schrank (2015), National Highway Traffic Safety Administration (2016b), New York State Department of Motor Vehicles (2015b), U.S. Census Bureau (2015a)

[1] calculation based on commuters only

[2] data for New York valid for New York State, data for Los Angeles valid for Los Angeles County

While daily vehicle travelled distance per capita in Los Angeles urban area has been stagnating since 1990 (Federal Highway Administration, 1991 - 2014a [annual Highway Statistics series]), a 16,4% growth between the years 1990 and 2006 was recorder in New York area (Federal Highway Administration, 1991 - 2007 [annual Highway Statistics series]) followed by a period of minor fluctuations that lasts till nowadays (Federal Highway Administration, 2008 - 2014a [annual Highway Statistics series]).

Given the relatively stable growth of population (U.S. Census Bureau, 2015a) and per capita GDP in both regions (Bureau of Economic Analysis, 2015), it indicates not only that the maximum capacity of existing roadway infrastructure has been reached but also the reluctance of its citizens to increase vehicle travelled distance due to the unfavourable traffic conditions. Furthermore, a very low average vehicle occupancy suggests that even a considerable pool of ridesharing services existing in both areas has a very limited impact on travel behaviour of general population.

With the exception of 2009, congestion level illustrated by hours of delay per commuter has been gradually deteriorating in both regions, specifically by 60% in Los Angeles area and 131% in New York area between the years 1982 and 2014 (Lomax, Eisele and Schrank, 2015).

Travel times to work in New York and Los Angeles are by 37,7%, respectively 12,7% higher than the national average (U.S. Census Bureau, 2015a). Eight out of ten most frequent mega commuting flows (defined as traveling 90 or more minutes and 50 or more miles) occurred in one of studied areas (Rapino, Fields, 2012). Substantial amount of road accidents together with the number of casualties underlines the outcomes of dominance of passenger vehicles in both North American areas (National Highway Traffic Safety Administratio, 2016b; New York State Department of Motor Vehicles, 2015b).

Identified travel patterns illustrate previously discussed characteristics and corroborate the presumption of theoretical replication in both North American cases. Although key indicators such as travelled distance per capita or delay per commuter has declined recently, main credit is generally attributed to latest economic downturn period and both parameters are slowly rebounding to its pre-recession levels. And while some short term benefits could certainly be attributed to carsharing and ridesharing services, the launch of those is mostly overlapping with the recession period and the overall state of individual transport supports the author’s proposition in that the long term solution is yet to found. Furthermore both areas appear to have arrived at the limit of its road infrastructure and will not be able to cope with mobility demands of growing population.

6.2. European and Australian urban area

Although it can be argued that urban areas in Europe and Australia are generally far less populated than the rest of the studied regions, the aim of this study is to derive universal globally applicable conclusions. Therefore a single urban area from both continents is included to strengthen representatives and external validity of the paper. Furthermore, the rest of studied characteristics is in the range of other analysed units and thereby worth a close examination. From the list of European and Australian urban areas that meet the selection criterions Greater London (hereinafter referred to as London) and Greater Sydney (hereinafter referred to as Sydney) are selected.

London urban area was formally created in 1965 and is divided into 32 boroughs such as Camden, Greenwich or Westminster plus the sovereign City of London which is officially not a borough but 33rd principal division of Greater London area (Her Majesty's Stationery Office, 1963). London is an officially declared region with clearly defined boundaries and independent governing body (Her Majesty's Stationery Office, 1963; Her Majesty's Stationery Office, 1999; Her Majesty's Stationery Office, 2007). The area is dominated by the City of London and numerous commuter town and suburbs closely surrounding it.

Officially classified as Greater Capital City Statistical Area by Australian Bureau of Statistics (Australian Bureau of Statistics, 2012), Sydney is the largest (Australian Bureau of Statistics, 2016) and the most populated (Australian Bureau of Statistics, 2016) urban area on the continent. The area consists of 43 local municipalities (City of Sydney, 2014b) officially called councils such as City of Sydney, City of Canterbury or City of Auburn (Local Government NSW, 2016). However the structure and especially the total number of councils is about to change as the Government of New South Wales is currently reforming the system of local government (Office of Local Government - NWS Government, 2016).

Tab. 13 Basic characteristics of London and Sydne urban area

	London	**Sydney**
Population (2014)[1]	13%	21%
GDP (millions of US dollars, 2013/2015)[2]	529 444	284 312
Land area (km^2, 2015)	1 572	12 368

Source: adapted from the Australian Bureau of Statistics (2015), Australian Bureau of Statistics (2016), Greater London Authority (2015b), Office for National Statistics (2014), Office for National Statistics (2015), SGS Economics and Planning (2016)

[1] share of country's total population

[2] data for London is gross value added in millions of U.S. dollars in 2013, data for Sydney in 2015

Both London and Sydney fail to match primary population criterion. However both successfully meet alternative criterion (Australian Bureau of Statistics, 2015, Office for National Statistics,2015). Population of London urban area is expected to experience a moderate growth fostered mainly by the immigration (Greater London Authority, 2015) while projected development of Sydney's populace forecasts only a minimal growth in upcoming years (Australian Bureau of Statistics, 2015).

The municipality of London employees a wide range of vehicle use restrictions including dedicated bus lanes (Transport for London, 2015a), low and ultra low emission zones (Transport for London, 2015d; Transport for London, 2015f), stricter traffic regulations for selected key roads (Transport for London, 2015e) and road pricing scheme aimed towards congestion reduction (Transport for London, 2014c). This combination creates one of the most of restricted environment for use of passenger vehicles in large urban areas in general. The excessive use of vehicles in Sydney is suppressed by collection of road tolls mainly on major ring roads (Roads and Maritime Services, 2016b) and Sydney Harbour Bridge and Harbour Tunnel (Roads and Maritime Services, 2015c). A two tier dedicated bus lane system is also employed in Australian area to promote public transport (Roads and Maritime Services, 2014) and vehicle owners are subjected to a moderately expensive vehicle registration costs (Roads and Maritime Services, 2016a). Focusing on traffic safety, an elaborate driver licensing scheme requires young drivers to pass multiple tests and gradually gain driving experience over time before gaining full (unrestricted) driving licence (Roads and Maritime Services, 2015b). On the other hand a well developed and established carsharing (Zipcar, 2015a; City Car Club, 2015; DriveNow, 2015a) and ridesharing (BlaBlaCar, 2015) options are available for travellers in London area. In Sydney alternative modes of individual transportation are also represented by rich selection of both local and global carsharing operators and ridesharing platforms. The most notable are Hertz 24/7 (Hertz 24/7, 2013a), GoGet (GoGet, 2016), Car Next Door (Car Next Door, 2016) and largest Australian community carsharing provider DriveMyCar (DriveMyCar, 2016). Uber's transportation network is present in both areas (Uber, Inc., 2015c, Uber, Inc., 2015e).

With regards to above described facts London exemplifies literal replications while Sydney represents a theoretical one. Great Britain's capital welcomes travellers with a complex set of vehicle ownership and use related restrictive measures and diverse mix of available alternative transportation modes. Therefore the state of individual transport is anticipated to be positively impacted by both yet the long term tendencies are expected to reveal issues troubling majority of traffic participants. Sydney's background provides an interesting starting point for further evaluation as described aspects should theoretically have mutually contradicting effects on resulting transport situation. Thereby Sydney represents a unique case due to its significantly lower population, no vehicle ownership restrictions and distinct spatial conditions. As such passenger vehicle is expected to be a much more attractive and viable transportation option than in other studied areas.

Tab. 14 Characteristics of London and Sydney transportation landscape

Parameter	**London**	**Sydney**
Modal split (2014/2013)[1] ● Passenger vehicle ● Public transport ● Taxi and motorcycle ● Bicycle ● Walk	 ● 38,17% ● 28,14% ● 1,29% ● 2,67% ● 29,73%	 ● 69 % ● 11,4 % ● 1 % ● 1,1 % ● 17,5 %
Number of registered passenger vehicles (2014/2013)[1]	2 709 825	2 689 000
Monthly parking rate (USD, 2015)[2]	1 498	343
Length of roads (km, 2014/2015)[3]	14 843	18 000

Source: adapted from the APCOA PARKING (2015), Department for Transport (2015a), Department for Transport (2015b), Q-Park (2015a), Roads and Maritime Services (2015a), Secure Parking (2015), Southbank Centre (2015), Transport for London (2015c), Transport for NSW (2014)

[1] data for London in 2014, data for Sydney in 2013

[2] calculation based on 2 Southbank Centre, 11 APCOA PARKING and 19 Q-Park London listings for London and 27 Sydney Secure Parking listings for Sydney

[3] data for London in 2014, data for Sydney valid for New South Wales state in 2015

Based on the number of trips, London demonstrates distinctly even distribution of transportation provision between the use of passenger vehicles, which is slightly dominant, public transport and walking (Transport for London, 2015c).

Furthermore, historical data document that while the share of trips by passenger vehicles has been stagnating since 2009, travelled distance has been gradually decreasing in the same period (Transport for London, 2015c), suggesting the shift in preferences of residents of London. In Sydney passenger vehicle is by far the most common transportation mean (Transport for NSW, 2014) which supports the initial assumption based on basic urban characteristics of the area. The dominance of individual motorized transportation is proportionate to the situation in New York and Los Angeles (U.S. Census Bureau, 2015a) and it coincides with missing subway infrastructure that handles a sizeable share of public transportation passengers in other studied areas. The dependency on passenger vehicles in Australian area is further underlined by 23,2% increase of registered vehicles in the decade between 2003 and 2013 (Transport for NSW, 2014) and 10,4% growth of number of vehicles per household in the same period (Transport for NSW, 2014). Contrary to that and after a prolonged period of growth, the amount of passenger vehicles registered in London topped in 2008 by 2 755 022 only to be followed by immediate sharp decline and stagnation that lasts till present (Department for Transport, 2015a). Eventually in 2011, the share of London households without the access to vehicle fell to the same value as in 1981 (Transport for London, 2014a). Parking rates in United Kingdom's capital are among the highest in the world (Q-Park, 2015a; Moore et al., 2011) which imposes a substantial burden on users of passenger vehicles and further explains the modal split preference. Short term parking in the Sydney city center is metered by hourly rates based on the daytime and location that range from approximately $1 to $5 (City of Sydney, 2016). The monthly parking costs are low, averaging at $343,3 (Secure Parking, 2015). On the contrary, parking problems were cited as a primary reason for travelling to work by public transport (Transport for NSW, 2014) which indicates that while parking is generally inexpensive it still discourages residents of Sydney from use of vehicles. Length of available roadways in London has not undergone significant changes in recent years suggesting that the maximum density has already been achieved (Department for Transport, 2015b). Information about exact length of motorways in Sydney has not been obtained however there is more than 18 000 km of roads in New South Wales state (Roads and Maritime Services, 2015a) undergoing periodical quality improvements and safety optimisation purposed to reduce the number of road accidents and fatalities.

Tab. 15 Travel behaviour of travellers in London and Sydney urban area

Parameter	**London**			**Sydney**			
Daily vehicle kilometres travelled per capita	2005	2010	2014	2003	2007	2010	2013
	7,48	7,58	7,2	18,9	18,3	17,5	18,5
Average vehicle occupancy (2012/2014)[1]	1,47			1,39			
Average delay in minutes per kilometre[2]	2007	2010	2013	2000	2005	2010	2016
	1,21	1,14	1,24	0,32	0,35	0,42	0,48
Average travel time to work in minutes (2014/2013)[3]	45,5			27			
Traffic accidents / fatalities (2014/2013)[4]	25 992 / 127			N/A / 340			

Source: adapted from the Bureau of Infrastructure, Transport and Regional Economics (2014), Bureau of Transport and Regional Economics (2007), Transport for London (2012), Transport for London (2014b), Transport for London (2015b), Transport for London (2015c), Transport for NSW (2014)

[1] data for London in 2012, data for Sydney in 2014

[2] data for years 2010 and 2016 in Sydney are projections calculated in 2007

[3] data for London in 2014, data for Sydney in 2013

[4] data for London in 2014, data for Sydney valid for New South Wales state in 2013

Travellers in London urban area have recently curbed the vehicle traveled distance thereby emphasizing the ongoing departure from passenger vehicles as a primary mean of transportation (Transport for London, 2015c). As is the case in both North American areas, this points to the inability of passenger vehicle to meet contemporary individual transportation needs of urban residents. That correlates with the latest national traffic volume trends where London urban area recorder the smallest annual increase (Department for Transport, 2015c). The amount of daily travelled kilometres of Sydney's residents has been declining during the Great recession between the years 2007 and 2009 (Transport for NSW, 2014). However as the economic difficulties wear off the growth of per capita travelled distance has been renewed (Transport for NSW, 2014). Both total indices of travelled vehicle and passenger kilometres follow a steady growing tendency with only a slight decrease in 2006 (Bureau of Infrastructure, Transport and Regional

Economics, 2014). Furthermore, projections are forecasting a 36,2% increase in vehicle travelled kilometres in Sydney between the years 2015 and 2030 (Bureau of Infrastructure, Transport and Regional Economics, 2015). Contrary to the travelled distance parameter, average vehicle occupancy in London (Transport for London, 2012) compares favourably with the national average (Office for National Statistics, 2013; Department for Transport, 2013) which indicates benefits of availability of alternative modes of individual transportation. In Sydney it is among the lowest of studied areas reaching less than one and half person per vehicle (Transport for NSW, 2014). Which strongly contradicts the idea of positive impacts of car and ridesharing services that are widely available within the area.

London traffic congestions is measured by average delay per kilometre reduced between the years 2008 and 2010, however in most recent periods it has returned to its pre-recession levels (Transport for London, 2014b). Travel times in London are not only the by far longest in the country but are also incrementally extending on an almost annual basis (Department for Transport, 2014). Sydney's commuting times are very low (Transport for NSW, 2014) which corresponds with favourable spatial conditions. This finding aligns well with modest congestion cause delays (Bureau of Transport and Regional Economics, 2007) which supports the initial presumption of comparatively positive individual transport situation due to the accommodating urban landscape. Although both parameters are growing the pace of changes is incremental thereby almost imperceptible in day to day traveling (Bureau of Transport and Regional Economics, 2007; Transport for NSW, 2014). The amount of car accident victims in London has been declining for several successive years but the accident rate is fluctuating which indicates a significant risk of non-fatal injuries Londoners are undergoing on daily basis while travelling around the city (Transport for London, 2015b). Conclusive evaluation of road safety in Sydney is not possible because necessary datasets are unavailable and the total number of fatalities in the state provides only a very limited indication about the situation in the studied area (Bureau of Infrastructure, Transport and Regional Economics, 2014).

The transport situation in London supports the idea of positive short term impacts of vehicle use and ownership restrictions as well as availability of alternative modes of individual transportation. Such outcomes include two years lasting deceleration of growth of registered vehicles and temporal decrease of average travel times. Any lasting shifts in analysed parameters appears to be caused mainly by changing travel behaviours and mobility preferences as Londoners are generally steering themselves away from all motorized forms of individual transportation in favour of walking, cycling and public transport. This has considerable negative implications for operators of alternative transportation solutions based on passenger vehicles as exemplified by termination of operation of elsewhere successfully car2go service (Wissenbach, Taylor, 2014). Regardless of that key characteristics defining individual transportation are depicting diminishing experience travellers are faced with. On the contrary, analysis of key parameters illustrating the state of Sydney's individual transportation are comparably positive regardless of a substantial reliance on cars (Transport for NSW, 2014). For example between 2003 and 2013 passenger vehicle had consistently been a primary mode of transportation with approximately 70% share on total number of trips and 80% of travelled distance (Transport for NSW, 2014). Nevertheless, travel times and congestions levels are far more acceptable than in other examined areas (Bureau of Transport and Regional Economics, 2007; Transport for NSW, 2014). This long term stability indicates that Sydney has reached a certain dynamic balance that provides its citizens with acceptable transportation conditions. Such outcomes validate the selection of Sydney as a literal replication and confirm that population density and physical environment have a major influence on the overall transport situation.

6.3. Asian urban areas

Asia, a continent rich with fast growing urban areas, is represented by two top tier Chinese municipalities Shanghai and Beijing. The former comprises of 18 districts and 1 county such as Huangpu, Minhang and Jiading and encompasses 109 towns (Shanghai Municipal Government, 2009). The latter consist of 14 districts and 2 counties which include Dongcheng, Xicheng and Haidian (National Bureau of Statistics, 2014, Beijing Municipal Bureau of Statistics, 2011). Both areas have historically been part of larger provinces but were separated in 20th century due to the political and economic importance and now hold the same rank and authority as provinces which represent the highest level of Chinese administrative division.

Tab. 16 Basic characteristics of Shanghai and Beijing urban area

	Shanghai	Beijing
Population (2014)	24 260 000	21 520 000
GDP (millions of US dollars, 2014)	382 359	346 167
Land area (km^2, 2015)	6 341	1 368

Source: adapted from the National Bureau of Statistics (2015), Ministry of Commerce of the People's Republic of China (2007a) and Ministry of Commerce of the People's Republic of China (2007b)

All primary selection criterions were meet by both areas and especially the number of inhabitants is expected to be soar (United Nations, 2014) and if past period provide any indication, the GDP of both Beijing and Shanghai is set on a growing trend as well (National Bureau of Statistics, 2015). The final selection rules are represented by a stringent set of vehicle ownership and use restrictions applied in both areas. Distribution of monthly allocation of available license plates in Shanghai is determined by a bidding mechanism instituted in 1986 (Feng, Li, 2013). This continuously refined measure enables local authorities to control the growth of vehicles registered within the area. Additionally, vehicle with non-local license plates are subject to specific traffic restrictions during peak hours. Beijing started introducing transport management measures after the Olympic Games in 2008 (Feng, Li, 2013). A complex two element system featuring a license plate lottery and use restriction based on license plate numbers is applied in the area (Feng, Li, 2013).

Only a very few service providers of alternative modes of individual transportation is currently operating in examined areas. Shanghai is served mainly by Dazhong Transportation Co., Ltd. (Dazhong Transportation Co., Ltd., 2015) which utilizes its fleet of almost 20 000 taxi vehicles to enable ridesharing via mobile application (Wang, Martin, Shaheen, 2011). EdoAuto and Evnet are a small scale community carsharing providers operating in Beijing with a rather limited fleets (Wang, Martin, Shaheen, 2011; Zeng, 2015). Present in both areas are fast growing Atzuche (Atzuche, 2015) and PPZuche (PPzuche, 2015) carsharing operators. Moreover the existing portfolio of alternatives may improve dramatically in the months ahead because of the legitimization of online car-hailing services that comprises of independent drivers in Shanghai (Bloomberg, 2015) and low market saturation that suggest substantial growth potential (Roland Berger Strategy Consultants, 2014; Shaheen, Elliot, 2010; Wang, Martin, Shaheen, 2011; Zeng, 2015).

Regardless of the comparatively weak selection of alternative transportation modes that sharply contrasts with accelerating expansion that both areas are undergoing, Shanghai and Beijing constitute literal replications. Authorities in both regions impose rigorous sets of restrictions for users and owners of passenger vehicles that are complemented by rapidly widening list of transportation alternatives. Therefore transportation situation should benefit from both. Restrictive measures disincentivizing regular use of vehicles and alternative modes further substituting the need for passenger vehicles.

Tab. 17 Characteristics of Shanghai and Beijing transportation landscape

Parameter	Shanghai	Beijing
Modal split (2009/2012)[1] ● Passenger vehicle[2] ● Public transport ● Taxi and motorcycle ● Bicycle ● Walk	 ● 20% ● 33% ● N/A ● 20% ● 27%	 ● 33% ● 44% ● 6% ● 14% ● 3%
Number of registered passenger vehicles (2014)	2 285 800	4 969 200
Monthly parking rate (USD, 2005)[3]	1 294	576
Length of roads (km, 2014)	12 900	21 800

Source: adapted from Haixiao et al. (2013), National Bureau of Statistics (2015), Sun et al. (2014)

[1] date for Shanghai in 2009, for Beijing in 2012

[2] share of passenger vehicle in Shanghai includes taxi

[3] calculation for Beijing is based on average hourly rates

Between the considerably low countrywide motorization rate and rigorous restrictions for users of passenger vehicle, Shanghai and Beijing demonstrate very low reliance of passenger vehicles. The actual distribution of transportation modes based on the total number of trips shows strong dependence on public transport in both Chinese areas. The share of trips performed by cars is especially low in Shanghai urban area which corresponds with a relatively small number of registered vehicles. However it is important to realize that countrywide motorization rate in China exceeded 105 vehicle per 1 000 inhabitants (EU SME

Centre, 2015) by the end of 2014 while the same parameters in the USA reached more than 800 in 2013 (Oak Ridge National Laboratory, 2015). Regardless of strict measures applied, vehicle registrations in Shanghai and Beijing were growing on average by 14%, respectively 12,3% annually between the years 2004 and 2014 (National Bureau of Statistics, 2015). The impact of elaborate ownership restrictions became more apparent in 2014 when growth rates in both areas reached a long term minimums (National Bureau of Statistics, 2015).

The calculation of average parking rates proved to be difficult due to the shortage of garages offering long term parking. Monthly rates in both areas are therefore based on average hourly rates (Haixiao et al., 2013). The road infrastructure is currently undergoing a substantial development both in quality and quantity (National Bureau of Statistics, 2015) enabled by massive public investments (Haixiao et al., 2013). However the expansion is inevitably bound to reach spatial limits imposed by rapid urban development as both already densely populated areas are still experiencing an influx of immigrants propelling its population growth (National Bureau of Statistics, 2014).

Tab. 18 Travel behaviour of travellers in Shanghai and Beijing urban area

Parameter	**Shanghai**				**Beijing**			
Daily passenger kilometres travelled per capita	2000	2005	2010	2014	2000	2005	2010	2013
	0,58	1,09	1,37	1,4	1,06	1,06	4,06	1,76
Average vehicle occupancy (2009)	1,7				-			
Congestion caused increase in average travel time	2014				2014			
	0,35				0,37			
Average travel time to work in minutes (2014)[1]	52				51			
Traffic accidents / fatalities (2014)	1 172 / 902				3 196 / 851			

Source: adapted from Chen (2015), National Bureau of Statistics (2015), Zhan, Zhao and Shen (2013), TomTom (2015a)

[1] including other modes of transport

Compared to previously studied urban areas, daily amounts of vehicle travelled distances in Shanghai and Beijing appear minimal which could translate into positive traffic conditions. However the long term trends reveal an average year over year increase of 6,8%, respectively 19,8% of travelled kilometres per capita between the years 2000 and 2014 (National Bureau of Statistics, 2015). Through, the pace of this growth in both areas has diminished in the most recent periods correlating well with above discussed developments of vehicle ownership rates (National Bureau of Statistics, 2015). Regretfully, Beijing's time series data include an two unexplained and abrupt falls (-63,5% and -56,3%) in 2005 and 2013 which could potentially be a result of changes in applied methodology however no explanation is provided by authors (National Bureau of Statistics, 2015).

Average vehicle occupancy of 1,7 people in Shanghai (Zhan, Zhao and Shen, 2013) translates into higher utilization of individual vehicles compared to for example New York or Los Angeles, yet the gains are marginal as single-occupancy vehicles are still constituting the majority of trips. Unfortunately vehicle occupancy data are not available for Beijing and the complexity of the metric effectively prevents any approximation or educated guess of the value.

Traffic congestion and gridlocks are reported to prolong the average travel times by 35% for Shanghai and 37% for Beijing compared with non-congested travel times (TomTom, 2015). According to Beijing's Department of Transportation calculation the city suffered from almost 2 hours of congestion on a daily basis in 2013 (China Daily, 2014). Commuting times in both regions are almost identical and far exceeding both national average and other analysed urban areas (Chen, 2015). The totals of traffic accidents are unrealistically low suggesting a large portion of undocumented accidents. The amount of casualties on the hand is much more in line of what could be expected and clearly illustrates the inadequacy of existing road safety measures in both Asian areas (National Bureau of Statistics, 2015).

Acquired data and most importantly their development over the time supports author's proposition that even a combination of restrictive measures and available transportation alternatives does not result in a long term sustainable transportation conditions. Situation in both Asian areas is undeniable affected by a specific socio-economic development in the region that is noticeable for example in the vehicle ownership rates that are far below the levels of other analysed urban areas, modal splits that favour public and non-motorized transport and finally an underdeveloped road infrastructure that may be subjected to improvements both in quantity and quality. Regardless of this historic „advantage“, transportation in both regions proves difficult as documented by travel times and the existence and considerable impact of traffic congestions on commuting population. The thorough restrictions applied in both cities certainly have an effect on transportation landscape and adjustment or specifically tightening of those may quickly yield a statistically observable short term benefits. But the long term trends appear to be far less sensible on those restrictions as well as recently introduced alternative modes of individual transportation.

6.4. South and Central American urban areas

As explained in the Methodology chapter, sociodemographic factors shaped by historical realias predetermined that selected Central and South American urban areas are evaluated together in this section. Metropolitan Area of the Valley of Mexico (hereinafter referred to as Mexico City) is representing a Central America continent while Greater São Paulo (hereinafter referred to as São Paulo) urban area was selected from eligible South American candidates.

Mexico City is the by far the most populous agglomeration in Mexico and comprises of 76 municipalities including Ecatepec de Morelos, Ciudad Nezahualcóyotl or Naucalpan de Juárez (Instituto Nacional de Estadística y Geografía, 2012). For administrative and electoral purposes further division into boroughs has been instituted and most recently the central area formerly known as Federal District was officially renamed to Mexico City (Mexico News Daily, 2016). While not an official designation, Greater São Paulo is a widely acknowledged term for a metropolitan urban area dominated by the municipality of São Paulo. It includes 38 other municipalities (Secretaria de Planejamento e Gestão do Estado de São Paulo, 2009) and houses 10,3% of the total Brazilian population (Instituto Brasileiro de Geografia e Estatística, 2010).

Tab. 19 Basic characteristics of Mexico City and São Paulo urban area

	Mexico City	São Paulo
Population (2010)	20 116 842	20 935 204
Economic importance (2008/2010)[1]	22%	398 727
Land area (km^2, 2010)	7 866	8 051

Source: adapted from the Instituto Brasileiro de Geografia e Estatística (2010), Instituto Nacional de Estadística y Geografía (2012), Instituto Nacional de Estadística y Geografía (2014), Secretaria de Planejamento e Gestão do Estado de São Paulo (2009), Secretaria de Planejamento e Gestão do Estado de São Paulo (2013)

1 value for Mexico City is share on Mexican national GDP from 2008, value for São Paulo is GDP in millions of USDsfrom 2010

Both the areas are listed in the top ten most populated urban agglomerations by United Nations organization (United Nations, 2014) and albeit their population expansion is forecasted to slow in next decade (United Nations, 2014) they both suit formulated sampling method easily. Despite stable growth of gross domestic product Mexico City has not meet the primary criterion of economical importance (Instituto Nacional de Estadística y Geografía, 2014). Nevertheless, secondary criterion is fulfilled by accounting for 22,32% share of national GDP (Instituto Nacional de Estadística y Geografía, 2016). Furthermore, some source credit Mexico City for generating more than 31% of national GDP (Asamblea Legislativa del Distrito Federal, 2005).

The purposive part of sampling methodology is represented mainly by specific restrictions for use of passenger vehicles. Both areas apply slightly different variation of license plate numbering based road rationing system that limits vehicle circulation in specific downtown zones (Secretaría de Turismo del Gobierno del Distrito Federal, 2015; Companhia de Engenharia de Tráfego, 2015c). Residents of both areas also benefit from presence of alternative transportation modes, particularly carsharing service. A well established service provider named Carrot with more than 8,500 registered members offer both station based and free float services in Mexico City (Carrot, 2016). São Paulo is currently served by two competing carsharing operators Zazcar (Zazcar, 2016) and Joycar (Joycar, 2016). The latter provides a wider portfolio of services including carsharing schemes for companies and residential buildings (Joycar, 2016).

With regard to described transport situation and accessibility of alternative options both areas represent literal replications which may demonstrate a discernible short term benefits of restrictive measures for vehicle use and availability of carsharing systems. Still, the long term outlook of individual transportation is projected to be troublesome and inefficient.

Tab. 20 Characteristics of Mexico City and São Paulo transportation landscape

Parameter	**Mexico City**	**São Paulo**
Modal split (2007/2012)[1] ● Passenger vehicle ● Public transport ● Taxi and motorcycle ● Bicycle ● Walk	● 21 % ● 71,7 % ● 5,9 % ● 1,4% ● N/A	● 30,7 % ● 37 % ● 0,3 % ● 0,6 % ● 31,4 %
Number of registered passenger vehicles (2012/2016)[2]	6 976 079	8 456 587
Monthly parking rate (USD, 2015)[3]	150	2 045
Length of roads (km, 2001)	16 558	N/A

Source: adapted from the Departamento Nacional de Trânsito (2016), Diretoria de Planejamento e Expansão dos Transportes Metropolitanos (2013), Instituto Nacional de Estadística y Geografía (2007), Instituto Nacional de Estadística y Geografía (2014), Oficina de Coordinación Nacional de Programa en México (2015), River, García and Ramírez (2004), Rodriguez (2013)

1 data for Mexico City are based on trip segments in 2007, data for São Paulo are based on main transportation mode of the trip in 2012

2 data for Mexico City in 2012, data for São Paulo in 2016

3 calculation for Mexico City based on average hourly rates of ecoParq parking zones, calculation for São Paulo based on average hourly rates for Zona Azul

In São Paulo, the first parameter gives us an indication of a relatively even distribution of mobility needs among public (including subway), private and non-motorized transportation represented by walking a bicycle riding (Diretoria de Planejamento e Expansão dos Transportes Metropolitanos, 2013). Despite the ongoing long term trend favouring passenger vehicles (Zamudio, Alvarado, 2014), the public transport is a strongly preferred mobility option in Mexico City (Instituto Nacional de Estadística y Geografía, 2007). This might initially be accounted to the existence of extensive subway network (Companhia do Metropolitano de São

Paulo – Metrô, 2015) however further investigation reveals that public transport in Mexico City is dominated by minibuses and shuttles (collectively referred to as Combi) operated by individual or joined concessionaires (Organisation for Economic Co-operation and Development, 2015). That points to mismatch between subway coverage and mobility needs of resident. Albeit total number of registered vehicles varies from source to source (Instituto Nacional de Estadística y Geografía, 2014; Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2012) it appears that the steadily growing pace of Mexico City motorization rate has recently diminished (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2012) suggesting that the both artificial and natural constraints are discouraging residents from further vehicle purchases. On the other, hand booming number of registered vehicles in São Paulo (Departamento Nacional de Trânsito, 2016) emphasize missing vehicle ownership regulation that would enable local authorities to manage circulating vehicle fleet. Contrary to the other studied areas, parking charges in Mexico City are so low that they actually present an incentive for regular use of passenger vehicle (Organisation for Economic Co-operation and Development, 2015). Such situation is caused by oversupply of parking spaces and rigidity of parking rates that can only be modified on municipality level (Organisation for Economic Co-operation and Development, 2015). In second studied area the situation is rather opposite. On-street parking rules in São Paulo are strict and fees are high (Companhia de Engenharia de Tráfego, 2015d). Off-street supply is limited and almost as expensive (ParkMe, 2016). Furthermore an updated parking policy (Cidade Aberta, 2014) introduced a stringent set of citywide rules aiming to reduce traffic and encourage the use of public transit (Institute for Transportation and Development Policy, 2014). Taking into account the surface area of Mexico City, the length of road network is rather low (Rivera, García, Ramírez, 2004) and its development is greatly outpaced by motorization rate (Rivera, García, Ramírez, 2004; Stokenberga, 2012). State of road infrastructure in São Paulo is indeterminable because of absence of reliable data.

Tab. 21 Travel behaviour of travellers in Mexico City and São Paulo

Parameter	**Mexico City**				**São Paulo**			
Annual vehicle trips per capita (thousands)	1994		2007		1987	1997	2007	2012
	4841		6279		8187	9985	11254	13595
Average vehicle occupancy (1999/2011)[1]	1,5				1,4			
Average vehicle speeds (km/h)	2003	2004	2007	2012	2012		2013	
	28,1	21	17	12	23,3		21	
Average travel time in minutes (2007/2012)[2]	41				31			
Traffic accidents / fatalities (2014)[3]	18 385 / 1 402				23 547 /1 249			

Source: adapted from the Companhia de Engenharia de Tráfego (2015a), Companhia de Engenharia de Tráfego (2015b), Confederação Nacional dos Trabalhadores em Transportes e Logística (2011), Connolly (2009), Diretoria de Planejamento e Expansão dos Transportes Metropolitanos (2013), Estado de Minas (2014), Instituto Nacional de Estadística y Geografía (2007), Zamudio, Alvarado (2014), Zegras et al. (2000),

[1] data for Mexico City in 1999, data for São Paulo in 2011

[2] data for Mexico City in 2007, data for São Paulo in 2012

[3] data for Mexico City is valid for former Federal District only, data for São Paulo is valid for São Paulo municipality only

Despite vehicle use restrictions that are in place in both areas, the annual amount of vehicle trips is steadily rising (Connolly, 2009; Diretoria de Planejamento e Expansão dos Transportes Metropolitanos, 2013) in correlation with continuously increasing motorization rates in both cities. The growth rate of vehicle trips in São Paulo has accelerated from 12,7% between the years 1997 and 2007 to 20,8% for a period from 2007 to 2012 (Diretoria de Planejamento e Expansão dos Transportes Metropolitanos,2013).

Low average occupancy of circulating vehicles corroborates author’s proposition about the short term effects of contemporary alternative transportation modes on travel behaviour of studied area’s residents (Zegras et al., 2000; Confederação Nacional dos Trabalhadores em Transportes e Logística, 2011).

The mismatch between mobility demands and transportation infrastructure capacity is especially apparent in case of Mexico City where average vehicle speeds fell dramatically from acceptable 28,7 km/h in 2003 to alarming 12 km/h in 2012 (Zamudio, Alvarado, 2014). The situation in the Argentinian metropolis is of a lesser magnitude but a similar trend (Estado de Minas, 2014). It is estimated that external costs incurred by congestion in Mexico City amounted to $6,1 billions (Oficina de Coordinación Nacional de Programa en México, 2015). Extending average duration of trips in Mexico City aligns well with those findings (Instituto Nacional de Estadística y Geografía, 2007). But in São Paulo reported travel times in 2012 remained the same as those in 2007 (Diretoria de Planejamento e Expansão dos Transportes Metropolitanos, 2013) which contradicts with other findings about transport situation in the area. Furthermore, both areas rank among the most congested ones in TomTom's travel time report (TomTom, 2015). Deficiencies in traffic management are also evident in the accidents statistics which are the worst from all studied areas (Companhia de Engenharia de Tráfego, 2015b; Zamudio, Alvarado, 2014)

The state of individual transportation in Mexico City and São Paulo reflects situation in urban areas in many developing countries such as studied Chinese areas. A rapidly growing population (United Nations, 2014), deficient road infrastructure (Edwards, Smith, 2008; The National League of Cities, 2014) and accelerating motorization rate (Oak Ridge National Laboratory, 2015; The International Organisation of Motor Vehicles Manufacturers, 2016) force local governments to impose strict vehicle use and ownership restrictions that ultimately fail to efficiently cope with declining traffic situation. Annually increasing number of vehicle trips (Connolly, 2009; Diretoria de Planejamento e Expansão dos Transportes Metropolitanos, 2013) and ongoing reduction of average speeds (Estado de Minas, 2014; Zamudio, Alvarad, 2014) forms a compelling evidence that is supported by low vehicle occupancy (Zegras et al., 2000; Confederação Nacional dos Trabalhadores em Transportes e Logística, 2011) and suggest limited impact of transportation alternatives. Contradicting argument was identified in São Paulo average travel times that remained constant despite deterioration of other studied parameters (Diretoria de Planejamento e Expansão dos Transportes Metropolitanos, 2013). This questionable inconsistency may originate from a selected methodology and a particular sample used to collect the data.

6.5. Cross case analysis

The final section of this chapter contains a comprehensive cross case synthesis of the findings obtained in individual case studies which directly addresses first two study questions. Firstly essential findings from each case study are summarized and then compared. Consequently answers to study questions are extrapolated and formulated.

The North American theoretical replication cases confirmed that the absence of vehicle use and ownership restrictions leads to excessive use and alarming dependence on passenger vehicles as a transportation means. Modal splits in both New York and Los Angeles are dominated by vehicles occupied almost exclusively by driver only which predetermines troublesome transportation conditions with high travel times, frequent traffic congestions and abundance of traffic accidents. The analysis also implies that the existence of the subway has substantial positive effects on several studied parameters thereby suggesting its crucial importance for urban agglomeration of this size. That is supported by findings from London where modal split preferences are far less in favour of passenger vehicles and with surprisingly prominent share of walking. This constitutes a better starting point for travellers in London but study of time series revealed that important transportation characteristics such as average delay and travel time are still deteriorating incrementally but steadily. Sydney is the only case study which results are directly opposing the formulated proposition. Despite being by far the most common means of transportation, passenger vehicles respectively its users in Sydney are facing far better overall situation than in other studied areas. This unique long term balance of transportation landscape is most likely caused by considerably lower number of residents which results in much lesser population density. That in return appears to enable relatively efficient and comfortable use of passenger vehicles without the negative consequences observed in other urban areas. Shanghai and Beijing represent a model examples of literal replication conditions. Both are sprawling urban areas with booming populations and motorization rates. Authorities in both cities have applied various restrictive measures to manage individual transportation. However the outcomes of this approach are mixed at best because for examples the number of registered vehicles in both areas is increasing substantially on a yearly basis.

Aligned with this statistic are burdensome travel times, regular congestions afflicting mainly but not only downtown areas of both cities and high number of fatal traffic accidents. While temporal benefit can easily be extracted by introduction of even stricter set of limitations for vehicle users, the long term trends are mostly unchanged by such efforts. Selected Central and South American urban areas are characterized by a balanced mix of vehicle use limitations and alternative mobility operators offering both car and ridesharing services. Albeit both areas boast an extensive subway infrastructure seemingly only residents of Mexico City are benefiting of it according to the modal split values. However such assertion would be misleading because a prevalent form of public transport in Mexican capital is a minibus operated under individual concessions in almost an on-demand principle. Regardless of available public transport options both areas are struggling to maintain acceptable traffic conditions because of rapidly growing number of vehicle registrations. That is reflected by declining average vehicle speeds especially during the morning and afternoon peak hours which has a direct negative impact on travel times and road safety. A highest number of road traffic victims among studied areas was recorded in Mexico City followed closely by São Paulo.

The analysed cases have provided rich evidence about effects of passenger vehicles on the transportation situation in large urban areas and outcomes of introduction of different individual transportation alternatives. The main consequence linked to the extensive use of vehicles in urban environment is the overall degradation of transportation conditions illustrated by recurring traffic congestions, prolonging travel time and decreasing vehicle speeds. Inevitably interrelated to these trends are much higher accident rates and resulting number of fatalities that affect all traffic participants - vehicle drivers and passenger but also cyclists and pedestrians. Assessing the outcomes of existing alternative modes of individual transportation proved complicated because any attempts to discern impacts of availability of car and/or ridesharing services in any of studied areas were inconclusive. Vehicle registrations in studied areas were growing with the exception of London and average vehicle occupancy which off all studied parameters should demonstrate benefits of such services were stable or even declining. Therefore it is concluded that individual transportation alternatives have no insignificant effects on transportation landscape of large urban areas.

7. Discussion

Althought a review of existing literature in theoretical section of this study might leave a reader under the impression of rapidly declining popularity of passenger vehicles. However such assertion is in stark contrast with results from multitude case studies investigated in this research. Despite the abundance of disincentives detailed in chapter 2, passenger vehicle still plays a pivotal role in individual transportation and as such it represents an impactful factor that shapes not only traffic conditions but also the urban environment itself. Evidence acquired during this explanatory scientific inquiry illustrates transportation in large urban areas across the world as a stressful and unpleasant experience which confirms author's proposition.

That was the case for all studied areas with the exception of Sydney. While Australia's largest agglomeration reports growing vehicle fleet other investigated parameters indicate a balanced transport situation. This might be caused by several factors, the most probable being Sydney's far lower population compared to other studied areas. Therefore it is reasonable to believe that a certain population density threshold has to be reached in order to trigger the transformation of traffic conditions. In the same manner expanding population of other areas could have caused the absence of positive tendencies documented in theoretical section.

Nevertheless the examination of key datasets characterizing transportation situation in remaining studied units revealed a long term trend of deterioration that appear to be unaffected by both positive (alternative modes) and negative (use and ownership restrictions) incentives. Lasting departure from this direction was observed only in London where individual transportation in general is succeeded by public transport and various non-motorized forms of individual transport. This signals that Londoners are at least partially responsive to vehicle use restrictions introduced by local authorities. That could serve as an example for other urban areas but the measures applied in London are by no means a novelty. Rather it appears that London municipality has added so much burden to the regular usage of passenger vehicles it has compelled its citizens to alters their travel patterns altogether. Which has led to renewed popularity of public and non-motorized form of individual transport. In accordance with findings from other areas transportation alternatives based passenger vehicles failed to gain significant interest among London population. lack of observable effects of alternative modes may falsely be attributed to relative novelty and limited reach of such services but for example in New York both Uber and Lyft report dramatically growing driver pools (Bhuiyan, 2016; Melkorka et al., 2015) that exceed those of traditional taxis. And although alternatives in other examined areas may not have such a numerous fleets more than a couple of providers was usually present yet no impacts were measured.

Such findings verify the proposition that application of passenger vehicles for alternative modes of individual transportation is possible but provides no benefits for traffic conditions in urban areas. Together with impacts of traditional modes of individual transportation it is evident that identified deficiencies cannot be addressed successfully by contemporary passenger vehicles regardless of specific mode of use.

Therefore an application of autonomous technology is proposed as a possible resolution. Specifically **a fleet of fully autonomous vehicles operated on a mobility as a service principle** that could freely circulate urban areas and dynamically respond to changing mobility demands. Such service could soften the division between public and private transport and constitute a brand new form of mobility. And densely populated urban centers such as those studied in this thesis represent perfect candidates for pilot programmes.

Thought, as was discussed in section 4.3, adoption of such transformative concept may take up to decades from now because a number of different barriers prevents the adoption of autonomous vehicle at this moment. First is the already mentioned absence of appropriate legislation. Damage liability question remains open no precedents or applicable law to rely on. In order to further acceptance and foster trust in such innovative and uncommon technology policy makers should compose necessary bills and discuss them openly with involved parties to achieve functional legal framework in a reasonable time. A lobbying group with this very aim was created in USA (Hawkins, 2016) and the US secretary of transportation already proclaimed that a national policy should in the middle of this year (Ziegler, 2016c). Closely linked with the state of legislation is the topic of insurance. Should a proposed concept be implement a mandatory liability insurance as known nowadays could be obviate and replaced by B2B contracts between insurance companies and operators of autonomous fleets. Finally and despite the seeming readiness of technology for a mainstream operation the widespread implementation will require considerable investments on many fronts which is why the president of the USA pledged $3,9 billion to encourage self-driving car programmes (U.S. Department of Transportation, 2016b). Combined with previously announced Smart City challenge (U.S. Department of Transportation, 2016a) these incentives may greatly facilitate the adoption of autonomous technology in the USA and set an example for other governments to follow.

Potential of autonomous technology is yet to be fully understood and exploited but existing studies have already quantified the benefits of electronic assistance systems such as forward collision warning, lane departure warning or blind spot detection (Insurance Institute for Highway Safety, 2008; Insurance Institute for Highway Safety, 2010; Insurance Institute for Highway Safety, 2012; National Highway Traffic Safety Administration, 2012b). And albeit the data necessary for profound research is still unavailable autonomous technology has the potential to be the most efficient method to combat the deteriorating transport situation mainly in large cities. Estimated benefits include substantial reduction of vehicle ownership, land area necessary for parking spaces, congestion levels, external costs of driving and the number of car accidents (Anderson et al., 2014; Sivak, Schoettle, 2015; Shaheen, Galczynski, 2014). For example, as much as 50% of parking demand may be lost which would allow large areas of space to be reclaimed for public realm (Sisson, 2016). At the same time, increased vehicle utilization, road infrastructure throughput and the overall efficiency of vehicle operation, both in travel times and fuel economy, are also expected (Anderson et al., 2014). On the other hand, the rigid compliance of traffic laws and regulations could lead to difficult traffic situations because human drivers are naturally seeking advantages while autonomous vehicles are strictly adhering to the most cautious and safety approaches (Ritchel, Dougherty, 2015). Google’s regular monthly reports support this assertion because the prevailing majority of accidents involving self-driving vehicles is attributed to a human error (Google

Inc., 2016b). Though some of those may stem from an unexpected and seemingly illogical evasive manoeuvres performed by autonomous vehicle (Ritchel, Dougherty, 2015). A fact the company readily admits and already seeks its resolution (Barr, Ramsey, 2015). It is also assumed that travelled vehicle and passenger distances will grow as a consequence of higher accessibility of individual mobility for blind and otherwise disabled travellers and reduced cost of driving (Mosquet, 2015b).

Despite all those positives the widespread application of the autonomous technology will almost certainly and irreversibly affect several industries including automotive, transportation, logistics, insurance and host of other businesses. A large amount of production facilities, manufacturing workforce, professional drivers and insurance products could instantly become obsolete (Anderson et al., 2014; Michaeli et al., 2015; Sivak, Schoettle, 2015). A proper discussion of these potential implications requires a separate research inquiry however it is author's opinion that such consequences appear inevitable and theirs impact on global economy and society deserves an independent discussion in separate paper.

Limitations of this research derive mainly from its form and purpose. Master thesis admits only a certain scopes of research and provides corresponding time frame. No other researches are allowed to contribute to the paper. Therefore the most severe limitation is the absence of adequate analysis of public transportation. Although it can be studied separately findings from such research would undeniably enrich this paper as well, especially because the proposed solution combines element of both individual and public transport. The disproportionately superficial discussion of non-motorized forms of individual transportation can be considered another omission in scope of this study. Shortcomings of applied methodology consist mainly of a relatively narrow set of selection criterions and limited total number of analysed units. A broader list of evaluation metrics would enhance sampling method by more accurate identification of extreme cases and higher level of granularity of collected datasets. Similarly a larger set of analysed units will secure additional insights and enable better understanding of complexity of different transportation situation in various urban setting. The list of most populous urban centers provide plenty of potential candidates (United Nations, 2014). For example Tokyo, Delhi, Mumbai, Dhaka, Karachi, Manila, Buenos Aires, Istanbul, Paris or largest German polycentric metropolitan region Rhine-Ruhr. The robustness of individual case studies could then be further enhanced by collection of additional parameters such as relative fuel prices, share of vehicle purchase costs on total household expenditures, number and length of lines of public transport or portion of licenses drivers on total area population and their age distribution. These limitations leave opportunities for further research within urban mobility topic.

Conclusion

The final chapter summarizes all findings and conclusions formulated in this thesis. It provides readers with concise and "glanceable" overview of this study so they can quickly grasp the studied topic, gain basic understanding of applied logic and scientific methods and most importantly ascertain its results. First a theoretical section is outlined and then a synthesis of research outcomes is presented.

This thesis aims on critical yet often overlooked topic of individual mobility in large urban areas. Specifically, contemporary passenger vehicles and various modes of their use are the focal point of this study. Conducted literature review revealed a large spectrum of challenges that owners and users of vehicles are facing on a daily basis. Many of these obstacles are specific for large urban areas where consequences of regular use of cars are most pronounced.

Collected evidence exhibited a marked decline in popularity of vehicles especially among younger adults which was illustrated by diminishing interest in driving licenses, stagnating motorization rates, growing number of households without a vehicle and unprecedented downturn in travelled vehicle distance. Along the quantitative indicators were the shifting perceptions of passenger vehicle as an object. And although much harder to measure available studies concluded that social symbolism once firmly attached to ownership of vehicle is continuously undermined by multitude of factors. While statistics from the USA were the primary studied sources data from other countries corroborated these conclusions. Additionally two existing and one under development alternative modes of individual transportation were detailed and their impact, respectively potential of their implementation was studied.

Based on the acquired knowledge a research proposition was defined and study questions were formulated. An explanatory multiple case study research strategy was selected and robust methodology developed. Practical section then presented analysis of 8 urban areas illustrating different transportation settings. Thorough investigation of transportation conditions in selected units revealed results directly contradicting that from the theoretical part. The indicated downturn in popularity of passenger vehicles was not observed in examined agglomerations.

The dependence on passenger vehicles as primary transportation mean in majority of studied areas initiated a long term deterioration of traffic conditions which was documented by numerous declining parameters such as travel times, congestion caused delay and vehicle occupancy. Furthermore the existence of contemporary alternative modes of individual transportation had no measurable effects on transportation situation in large urban areas. Overall, tested proposition about diminishing positive effects of vehicle use and ownership restrictions and existence of alternative modes of individual transportation in large urban areas was validated in seven out of eight cases

Proposed solution - an autonomous technology - was elaborated in detail in discussion section including evaluation of obstacles preventing its adoption and possible facilitators that may help overcoming current barriers. A specific form of its application was proposed as a prospective solution to deficiencies of contemporary state of individual transportation.

The results of this master thesis enhance existing knowledge base with new insights and also provide essential guidelines for local and national policy makers as well as executives from automotive industry. Both academic and professional discussions can be enriched by conclusions formulated in this research.

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Figures and Tables

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ANNOTATION

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SUMMARY	**The purpose of this thesis is to map and analyse the applicability of contemporart passenger vehicles for different modes of individual transportation in large urban areas. Initially, the main modes of use of passenger vehicle in are described and consequence on transportation situation in urban areas is examined. Next, existing and emerging alternative modes of individual transportation based on cars are studied. In the practical section, a case study inquiry is conducted to test author's proposition. Findings from case studies are analysed on individual and cross case basis and the potential applicaibity of autonomous technology is then dicussed. Possibilities for further research are indicated and specific solution for idenfitied deficiencies is proposed.**
KEY WORDS	**Mobily, transportation, passenger vehicle, car, individual transport, private transport, carsharing, ridesharing, autonomous vehicle, self-diriving vehicle, traffic demands, Millennials,**

THESIS INCLUDES UNDISCLOSED PARTS: No