COMPARISONS OF ACCESSIBILITY TO PUBLIC TRANSIT STATIONS BY RIDESOURCING AND ITS COMPETITORS

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Dedication

I would like to dedicate this thesis to my grandmother PhDr. Ivana Marková who has encouraged me and helped me to study abroad.

I would also like to dedicate this thesis to my family and friends that have always supported me and motivated me during my studies.

COMPARISONS OF ACCESSIBILITY TO PUBLIC TRANSIT STATIONS BY UBER AND ITS COMPETITORS

by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Civil Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

May 2018

Acknowledgements

I would like to thank my advisors Dr. Ruey Long Cheu and Dr. Tomáš Horák for their guidance, feedback and consultations. I would also like to thank Dr. Miroslav Svítek for providing me very helpful suggestions.

Declaration

This thesis is an output of the Transatlantic Dual Master's Degree Program in Transportation Science and Logistic Systems, a joint project between Czech Technical University, Czech Republic, The University of Texas at El Paso, U.S., and University of Žilina, Slovak Republic.

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May 1, 2018

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Kód studijního programu a studijní obor studenta:

N 3710 – TR – Transport and Logistics Systems

Název tématu (česky): **Srovnání dostupnosti stanic MHD ridesourcingem a konkurenčními obchodními modely**

Název tématu (anglicky): Comparisons of Access. to Public Trans. St. by Ridesourcing and Its Competitors

Zásady pro vypracování

Při zpracování diplomové práce se řiďte osnovou uvedenou v následujících bodech:

- Review of Business Models
- Review of Regulations in US and EU
- Methodology
- Analysis of Accessibility of a Public Transportation Station in El Paso
- Analysis of Accessibility of a Public Transportation Station in Prague

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Rozsah grafických prací: podle pokynů vedoucího diplomové práce

Rozsah průvodní zprávy: minimálně 55 stran textu (včetně obrázků, grafů a tabulek, které jsou součástí průvodní zprávy)

Seznam odborné literatury: Chandra, S. et al. (2013). "Accessibility evaluations of feeder transit services." Transportation Research Part A, 52, 47-63.

Wardman, M. et al (2016). "Values of travel time in Europe: Review and meta-analysis." Trnasportation Research Part A, 94, 93-111.

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Datum zadání diplomové práce: **30. června 2017**

(datum prvního zadání této práce, které musí být nejpozději 10 měsíců před datem prvního předpokládaného odevzdání této práce vyplývajícího ze standardní doby studia)

Datum odevzdání diplomové práce: **29. května 2018**

a) datum prvního předpokládaného odevzdání práce vyplývající ze standardní doby studia a z doporučeného časového plánu studia
b) v případě odkladu odevzdání práce následující datum odevzdání práce vyplývající z doporučeného časového plánu studia

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V Praze dne .... 30. června 2017

Abstract

This thesis assesses the role of ridesourcing as a mode of first and last mile transport. Review of ridesourcing and taxi business models has been provided as well as a comparative review of laws and regulations regarding ridesourcing and taxi. A potential accessibility gravity based model and logit mode choice model have been applied to compare ridesourcing with other possible modes for first and last mile transport that serve a transit station in Prague, Czech Republic and a transit station in El Paso, Texas. Based on the results, recommendations for ridesourcing companies and local authorities and transportation systems managers are provided.

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Chapter 1: Introduction

1.1 Background

Transportation demand develops together with economic activities. The higher the economic activity level in a city or region, the higher is the need for transportation of goods and passengers. This also works in the opposite way: the higher the mobility of people in the region, the more economic activities people are able to perform. Therefore, the need for more efficient transportation grows every year in economically thriving cities such as El Paso and Prague.

A growing transport demand cannot be satisfied just by expanding the capacity of current modes of transport. Building new parking lots or expanding current ones, and adding lanes to existing roads or building new roads is limited by the available space and economic resources. It often does not improve the traffic situation because it induces more traffic feeding the expanded road. Moreover, it often worsens the traffic conditions of the expanded road itself (Wendover Productions, 2017). Adding public transit lines, and making shorter headways and intervals between connections will not attract enough ridership to justify the investment in low-density areas. In the cities in U.S., it challenging to convince the majority of people to use transit systems. Because of the above reasons there is no will to subsidy and develop transit systems, although public transit systems in combination with shared use vehicle systems could be a solution.

1.1.1 Shared use vehicle systems

Barth & Shaheen (2002) define a shared use vehicle system as a system that consists *"of a fleet of vehicles that are used by several different individuals throughout a day"*. This means that a shared use vehicle system refers to a fleet of vehicles which usage is being shared by a group of users. The shared use vehicle system manages vehicles and passengers in such a way that one car (or bike) is used by multiple drivers and/or passengers at the different or the same time throughout the day. Shared use vehicle systems are the result of the effort to overcome challenges described in subchapter 1.1.1. The idea is by optimizing the way we use the current transport modes without increasing the volumes of private car and public transit systems.

One type of shared use vehicle systems is carsharing. It is a form of a short-term (less than one day) car rental. The idea of carsharing is as follow: If the car is owned and used only by one person, it is usually used for only a small part of the day. If the car is used by more people in the different parts of the day car ownership can be smaller (Namazu & Dowlatabadi, 2018). As this concept allows vehicles to be in use most of the day, it helps to save parking spots in cities. It also can possibly reduce the number of so-called cold starts. During cold starts, the car produces more emissions than during the standard operation (Reiter & Kockelman, 2016).

Bike sharing is based on the same principle as carsharing. However, the way bicycle sharing impacts the traffic in the city is different from carsharing. While the main benefit of carsharing is lowering parking demand, bike sharing has a potential to attract more people to use bicycles in general. Bicycle sharing allows travelers to use bicycles for only a part of their trip that is suitable for this transportation mode. Bicycles can be used for the first/last mile transport to supplement trips made by bus or train. The fact that transit passengers do not have to bring their own bicycles with them onto train, bus etc. makes using of bicycles as a part multi-modal trips much more comfortable. It also allows using bicycles for commuting even people who use them only occasionally. For this type of travelers, buying their own bicycle does not make economic sense but they may be willing to pay to use shared bicycles.

The other shared use vehicle system helps to get together people who have the similar origins and destinations of their trips so that they can travel together in one car instead of everybody using their own vehicle. This is called carpooling or ridesharing. People were encouraged to carpool by the government in the past, especially during oil crises. But it required people to put extra effort in finding a suitable match. Therefore, it was common to carpool with people from the same community and for regular commuting mostly. Nowadays, modern technologies, namely smartphones with an access to the internet, enable much efficient real-time trip matching which is much more flexible. It is more comfortable for users and it allows them to carpool even during one-time trips. Carpooling helps to reduce traffic volume and fuel consumption and it is more environmentally friendly than to drive alone.

1.1.2 Sharing economy

Shared use vehicle systems (or shared mobility) can be considered as a part of broader concept of sharing economy. Since the concept is rather new, there is no common definition of what sharing economy is. Acquier et al. (2017) state that sharing economy is based on three organizing cores:

1) access economy;
2) platform economy and;
3) community-based economy.

Access economy is based on selling access to product or resource without transferring the ownership of the product or service to its user. This concept helps to improve utilization of products by providing access to it to as many people as possible. Therefore, multiple users can use one product at different times of the day. As the result, the total number of resources required to satisfy the demand for using the product is reduced. Typical examples of access economy are carsharing, car-rental or libraries.

Access economy is also beneficial for customers. As they do not have to buy the product but only the access to it, they pay only for the time they actually use the product. That lowers their total costs for using the product contrary to owning it. They also do not have to care about maintenance of it. The drawback of this is user's lower motivation to treat it carefully. Therefore, the provider of the product must spend extra costs to implement monitoring technology that ensures that the users can be held responsible for the damages caused by them.

Acquier et al. (2017) define platform economy as *"a set of initiatives that intermediate decentralized exchanges between peers through digital platforms"*. These platforms utilize interaction between service or product providers and their customers. Platforms like Amazon or eBay allow to compare more providers of one type of product and they simplify the whole transaction process. Together with many others, they make it much easier to provide customers feedback.

Platform economy disrupts bypass bureaucracy that is implemented to protect customer protection and to document financial operations. Emerging platforms provide both functions by digital means. For instance, set of regulations on taxi prices, local geography knowledge and mandatory equipment (e.g. taximeter) for taxi drivers is not necessary since companies like Uber or Lyft provide smart phone applications that substitute all of these. This gives easier access to urban transportation market for drivers by cutting down initial costs and reducing bureaucracy.

The third core of sharing economy is community based economy. It is defined by Acquier et al. (2017) as "*initiatives coordinating through non-contractual, non-hierarchical or non-monetized forms of interaction (to perform work, participate in a project, or form exchange* *relationships)*". They claim that cooperation in communities has been almost never driven directly by a desire to maximize the economic value but its purpose was rather to contribute to a project beneficial for community, "*to create social bonding, to promote values or to achieve a social mission through a collective project"*.

Communities in the past were usually defined by a geographical area (e.g. village or neighborhood) and all the inhabitants of the area used to be members of the community. The community was not focused only on a specific area of life but it involved major aspects of a person's lives ranging from economic activities to family life. Contrary to that, current technologies enable people to form communities across the world. Nowadays, as communities usually focus on one activity, people are able to be part of multiple communities at the same time. These activities may be education, developing freeware (e.g. Linux) or hobbies (e.g. sharing recipes). As these communities are usually non-monetary, they tend to become something called post-market societies (Bauwens and Kostakis, 2014).

If all three bases meet in one business model, the model is considered to be a sharing economy. The situation where only two of basis meet is called either community-based access, access platform or community-based platform.

Sharing economy seems to have some common basic traits with communism such as common access to resources, non-monetized forms of interaction and absence (or reduction) of private ownership. However, contrary to the way communism worked in history, sharing economy does not give the right to access to the resources to everybody regardless of the value they bring into the system. Sharing economy has a working mechanism to reward people for the value of the input they give into the system. The other difference between those two economy models is that sharing economy allows the participants to stay in the system as long as they wish to. Everybody can leave the sharing economy if it stops being profitable for them. Sharing economy is not enforced by a state but businesses offer sharing economy based services on the free market.

1.1.3 Ridesourcing

In 2011, a new business model entered urban public transportation market. Uber, a company founded in 2009, launched its mobile application for a first time in San Francisco. The founder of Uber came up with an idea how to offer better taxi-like services when he was displeased by the cab services he received during one of his trips. He did not like the fact that taxi companies did not let riders know in advance how much they were going to pay. He was also outraged by rude behavior of many taxi drivers and by them often cheating on passengers. These two problems were caused by the fact that there was no way to give positive or negative feedback to the taxi company on a specific driver. Taxi drivers could mistreat their passengers without paying any serious consequences.

The Uber mobile application requires the passenger to rate the driver after the trip is finished. It also requires the driver to rate the passenger. The passenger and the driver can see the average rating of each other before they confirm they want to be paired with the specific driver (respective passenger). Drivers and riders with rating lower than a specified value are not allowed to the system. This ensures that the drivers provide top quality services for the right price. It also helps to increase safety of both, the driver and the passenger.

In Uber, fare payments can be done via the mobile application. The application also serves as navigation device and taximeter. The fares are set by Uber and they depend on the actual supply of drivers and demand of passengers in an area. The passenger can see the total price of the trip before he places the trip request. As the passenger can watch the vehicle’s actual position on the map as the trip progresses that is mapped with the fastest route, the drivers cannot cheat on passengers by taking a longer path.

A year later, the second company called Lyft launched its own mobile application providing similar services as Uber. The service both companies provide is called ridesourcing. Other terms used for ridesourcing are: transportation network company, ride-hailing and e-hailing (Feigon & Murphy, 2016).

Uber also often promotes itself as a ridesharing company. However, ridesharing is when two or more people who have similar locations of trip origins and trip destinations decide to use one car and split the travel costs. When the ride share driver gives a ride to a passenger, he does it not to gain the profit. Ridesourcing drivers behave more like taxi drivers than ridesharers. On the other hand, Uber is now testing a service called UberPOOL, which allows passengers with similar origins, destinations and pick-up times to share a vehicle. The passengers then split the fare for the part of the route that they are traveling together. Only UberPOOL can be classified as ridesharing because it merges trips of more people who would not travel together otherwise. UberPOOL contributes to only a small portion of Uber's customer trips. It is not accurate to call Uber a ridesharing company.

Nowadays, Uber serves over 300 cities in North America, 150 cities in Central and South America and nearly 100 cities in Europe. People can ride Uber also in 15 African cities, 23 Australian and New Zealand cities and in more than 100 cities in Asia (Uber Technologies Inc., 2017). Lyft is operating just in the United States. On February 2017, Lyft expanded into 54 new American cities and reached almost 300 served cities (Korosec, 2017).

Ridesourcing companies are often viewed as part of sharing economy (Jin, et al., 2018) (Ganapati & Reddick, 2018). But according to the definition of sharing economy that is described by Acquire et al. (2017) Uber and similar companies can be classified as a platform economy.

First, it might seem that ridesourcing is access economy because it helps car owners (drivers) to provide access for other people (riders) to use their cars. However, for example, railway companies have been providing access for their passengers to use their trains for more than one century and it was never called sharing economy too. In the context of sharing economy, the access economy principle is to provide the access to the resources for more people so that they can use them on their own. Contrary to that, ridesourcing drivers actually do not provide access for riders to use their vehicle but the drivers themselves use the vehicle to provide the transportation service to the riders.

Second, current ridesourcing business models do not have many common attributes with community economy. Uber mobile application users create some kind of community but it is not a community economy as we understand it in the context of sharing economy. In sharing economy all members of the community (drivers and riders) contribute to the community with their own resources that are ideally non-monetary. In the case of Uber, riders contribute to the system only by paying the fare that is set by Uber.

However, although Uber might not fit the academic definition of sharing economy it has promoted this concept. It also brought a cheaper and more comfortable alternative to current taxi service and it pushes taxi companies to improve their services, cut fares and utilize their operation in order to stay competitive.

Ridesoucing companies are the centers of many controversies. Taxi companies accuse Uber of unfair competition due to the fact that Uber does not require its drivers to fulfil the conditions that taxi drivers have to. Uber argues that its drivers are not taxi drivers but only regular people sharing their vehicle with other people so they do not have to follow the rules for taxi drivers. Some authorities also fear that Uber might take away passengers from public transit and therefore worsen the traffic congestion in any city. As the result of these controversies, Uber was banned in some European cities. This is why ridesourcing companies needs to convince the authorities that its services are complementary to public transit.

1.1.4 Autonomous vehicles

Autonomous vehicles are vehicles that are able to perform some of the driving tasks independently from the driver. The Society of Automotive Engineers (2014) defined 6 levels of automation based on 30 areas that are controlled by human driver or autonomous vehicle system. These areas are:

1) Execution of Steering and Acceleration/Deceleration;
2) Monitoring of Driving Environment;
3) Fallback Performance;
4) System Capability (conditions under which the system is able to operate, e.g. dry surface, all conditions etc.).

The levels of automation are:

- **Level 0**: No Automation – human driver performs all driving tasks in every situation;
- **Level 1**: Driver Assistance – steering or acceleration is controlled by the system only in some driving modes. Human driver has to be ready to take over the control in case of system fallback and he must monitor the driving environment;

- **Level 2**: Partial Automation – steering and acceleration are controlled by the system only in some driving modes. Human driver has to be ready to take over the control in case of system fallback and he must monitor the driving environment; **Level 3**: Conditional Automation – steering and acceleration is controlled by the system and the system monitors driving environment, both only in some driving modes. The driver has to be ready to take over the control in case of the fallback of the system;
- **Level 4**: High Automation – steering and acceleration is controlled by the system, the system monitors driving environment and it is able to safely stop the vehicle in case of fallback if the driver does not react to the request to take over the control, all only in some driving modes;
- **Level 5**: Full Automation – the system is in control of steering and acceleration, monitors driving environment, is able to safely stop in case of fallback if the driver does not react to the request to take over the control. It is able perform all of the driving tasks in all driving modes.

Major car manufacturers and Uber are currently developing autonomous vehicles that are supposed to replace human driven vehicles. When the technology is ready Uber will provide access to public to use autonomous vehicles on their own. This will be similar to the principle of carsharing: one car is used by multiple uses at different time of the day.

Fagnant et al. (2015) modeled a shared autonomous vehicle fleet in Austin, TX to find out that it can serve 28.5 trips per day in average compared to 3.02 trips per day for conventional vehicles. This means that in high density areas shared autonomous vehicles would be able to replace 9.34 vehicles in private ownership. Simulated autonomous vehicles had also better performance than New York Yellow Taxis vehicles. While New York Yellow Taxis had 51.5% of unoccupied share of vehicle movement time, the unoccupied time of shared autonomous vehicles in Fagnant's model was only 8%. This was due to the relocation algorithm based on predicted demand. The results of Fagnant's study suggest that autonomous vehicles will be a much more efficient way of transportation in city centers compared to conventional taxi. Besides, using autonomous vehicles will cut operation costs because there will be no need to hire drivers. Autonomous vehicles will be also more feasible as carsharing vehicles because passengers will not have to pick up the vehicle limited number of locations but they will be picked up by the autonomous vehicles in any location they wish.

1.1.5 First/last mile problem

First/last mile problem is one of the main challenges of public transit systems. While it is easy to provide high level of service public transport between sets of public transit stations and stops defined in advance, public transit agencies struggle to provide transport between people's very origins (final destinations) and the closest public transit stop. Such transport has been very costly and it has been almost impossible to design the time schedule of vehicles operating on first/last mile in a financially and time efficient way. This is called a first/last mile problem.

The first/last mile problem is a challenging issue especially in low-density areas. To provide a regular public transportation with short waiting times going whenever a passenger needs, it is necessary that public transit vehicles arrive to a station in short time headways. In high-density areas, it is possible design very dense set of station that are served in very short intervals because there is always demand high enough to fill the capacity of vehicles (and therefore enough customers to pay for the operational costs of a vehicle). Contrary to that, in low-density areas, the transportation demand is not big enough and it is not economically viable to serve the area with high number of public transit vehicles in short headways.

The possible solution for low-density areas might be dynamic route (Chandra, et al., 2013) or dynamic schedule public transit. The public transit vehicles would serve only locations where there is actual demand and at the time when the transport is actually requested. This could improve public transit efficiency. Another possible solution might be ridesourcing. Uber representative in Prague claimed that Uber is not in Prague to replace public transit but to be a complementary service to the public transit by providing first/last mile transport. He supported this statement by a map showing that the most of the trips begin or end in close proximity of the important public transit stations. However, there may by also another explanation of such data. Public transit stations are built in locations with high transportation demand. Also in cities like Prague, people chose to live and businesses chose to reside close to public transit stations. As the result of this, transportation demand close to public transit stations (especially underground and train stations) grows even more. As the transportation demand around public transit stations grows, so does the demand for transport by Uber. The best way to assess if Uber has anything to do with first/last mile transport would be to study the trip origin data but Uber did not provide such data for this research. Therefore, this research studies this first/last mile problem using data gathered by other means.

1.2 Objective

The main objective of this thesis is to evaluate ridesourcing complementarity with public transit. Public transit can be very competitive in travel times in high density areas due to the high demand that allows short service headways. To attract public transit users in low density areas, the first/last mile trips might be better served by ridesourcing due to its flexibility. Therefore, this thesis focuses on comparing accessibility for first/last mile trips in low density areas from transit stations in El Paso, TX and in Prague, Czech Republic, using ridesourcing as a possible mode.

In order to fulfil the main objective of the thesis, the following tasks were defined and executed. The first task is to review the existing business models and transportation modes that are the most likely to be used for first/last mile trips from public transit station. Part of this objective is also to review legislation related to these business models, especially ridesourcing.

The second task is to provide detailed review of ridesourcing operations in the related literature.

The third task is to build accessibility model and incorporate it into a mode choice model for first/last mile trips to and from underground station Černý Most and train station Praha-Horní Počernice in Prague and Brio station Mesa/Balboa in El Paso.

The fourth task is to analyze the mode shares and conduct sensitivity tests on selected parameters.

The fifth task is to provide recommendations for the authorities of integrated public transit systems in El Paso and Prague and for Uber.

1.3 Thesis outline

Chapter 1 provides an introduction to the topics of shared mobility and sharing economy. It also provides brief information about ridesourcing in general and the controversies related to it.

Chapter 2 reviews sharing mobility business models that can be used for first and last mile transport, namely bike sharing, taxi, and ridesourcing.

Chapter 3 focuses on laws and regulations related to bike sharing, taxi, bus transit and ridesourcing.

Chapter 4 reviews the main approaches to measuring the accessibility and it provides the detailed description of the accessibility models used in this thesis. It also describes a modal split model used in this thesis.

Chapter 5 analyzes the results of the accessibility and modal split models in El Paso.

Chapter 6 analyzes the results of the accessibility and modal split models in Prague.

Chapter 7 compares the differences between the results in El Paso and Prague.

Chapter 8 summarizes the thesis, provides recommendations for local authorities and ridesourcing companies, and suggests the future research topics.

Chapter 2: Review of Business Models

This chapter reviews different transportation modes and business models behind them that can be used for the first/last mile trips in low-density areas of Prague and El Paso. Therefore this chapter describes bike sharing, taxi, buses and ridesourcing business models. It also contains some of the necessary information that will be used as inputs for a mode-choice model of the study areas in El Paso and in Prague.

2.1 Bike sharing

Bike sharing is a business model that provides access to bicycles for public to travel between two locations in urban areas. As the network of the bike sharing stations is usually very dense in the areas they serve, users can use bicycles as (almost) door-to-door transportation on a short distance trips or as first/last mile transport in combination with public transit. It also allows passengers to keep the bicycle and pay for the bicycle only while they are actually using it. After the trip is finished they can drop the bicycles off very close to or exactly at their destinations. This is why most of the riders rent shared bicycles only for very short period of time. Bike sharing companies usually encourage this behavior by setting the fare for the first 15-30 minutes relatively low and making it higher after the initial period.

Bike sharing started in 1960's but because of the lack of sufficient technologies, it did not experience a big success during the first 40 years of its existence. DeMario (2009) divides bike sharing evolution into three generations. The first generation was launched in 1965 in Amsterdam and it lasted only for a few days. The reason was that this system did not have any mechanism to protect the bicycles so they were being thrown into canals by vandals or stolen by thieves. The bicycles were just painted white without any feature that would make them different from regular bicycles.

The second generation of bike sharing systems was implemented almost 30 years later and partially solved this identity problem by using wheels with advertising plates. The bigger scale system of this type of shared bicycles was first put into operation in Copenhagen. However, as the riders were still anonymous, there was no way to make them liable for lost and damages they caused.

De Mario (2009) describes how this was finally solved in the third generation of shared bicycles. This kind of system was introduced in 1996 at Portsmouth University in England. Students used the magnetic stripes to identify themselves and to unlock the bicycles they were about to use. Because of that, the system was able to keep track bicycle users. Since then the means of identifying the users have been improved. Nowadays, many bike sharing systems are connected with a smartphone application that usually provides customers with information about location of nearby bike sharing stations, the number of accessible bicycles at the station etc. Bicycles can have a GPS navigation device that gives directions to users to ride to the desired destinations.

Researchers have different findings about the impact of bike sharing on modal split. Bullock et al. (2017) found out that most of the people using bike sharing in Dublin switched from walking. The second biggest group of bike sharing users came from public transit. Martin and Shaheen (2014) observed different trends. Implementation of bike sharing in Washington DC resulted in substantially decreased use of taxi (53.1% of respondents), rail (47.4% of respondents), drive (40.6% of respondents), bus (39.1% of respondents). On the other hand, 17.4% of respondents answered that they started to walk more after they adapted bike sharing and 11.9% of claimed that bike sharing was the cause for them to use public transit more.

2.1.1 Bike sharing in El Paso

BCycle is currently the only bike sharing system in El Paso. The system has 13 active stations around The University of Texas at El Paso campus and in El Paso downtown as can be seen in the Figure 2.1. The positions of the stations are designed to serve short trips in high density office areas and university campus. The stations are placed next to the points of interest in the center of El Paso like restaurants, museums, banks, bus stops etc. Shared bicycles can be used as first/last mile transport to get from bus stops to these points. Contrary to that, it is not probably used very often for first/last mile transport from/to people's homes because the station network is not near residential areas.

BCycle offers four types of pass: daily pass, monthly pass, semester pass, and annual pass. The pricing policy for daily pass is opposite to what is usual for most of the bike hsaring companies: \$6 for the first 30 minutes and \$2 every 30 minutes thereafter. The monthly membership costs \$30, the semester (120 days) membership costs \$50, and the annual membership costs \$75. The max charge per day is \$65 in all cases including the daily pass. Such price structure encourages memberships than occasional riders. The membership allows riders to use bicycles without additional fee for the first 30 minutes per ride. Each time they return the bicycle to a station and check it back out they have another "first" 30 minutes for free. Each 30 minutes period after the initial 30-minute free period costs \$2 in addition to the annual membership fee.

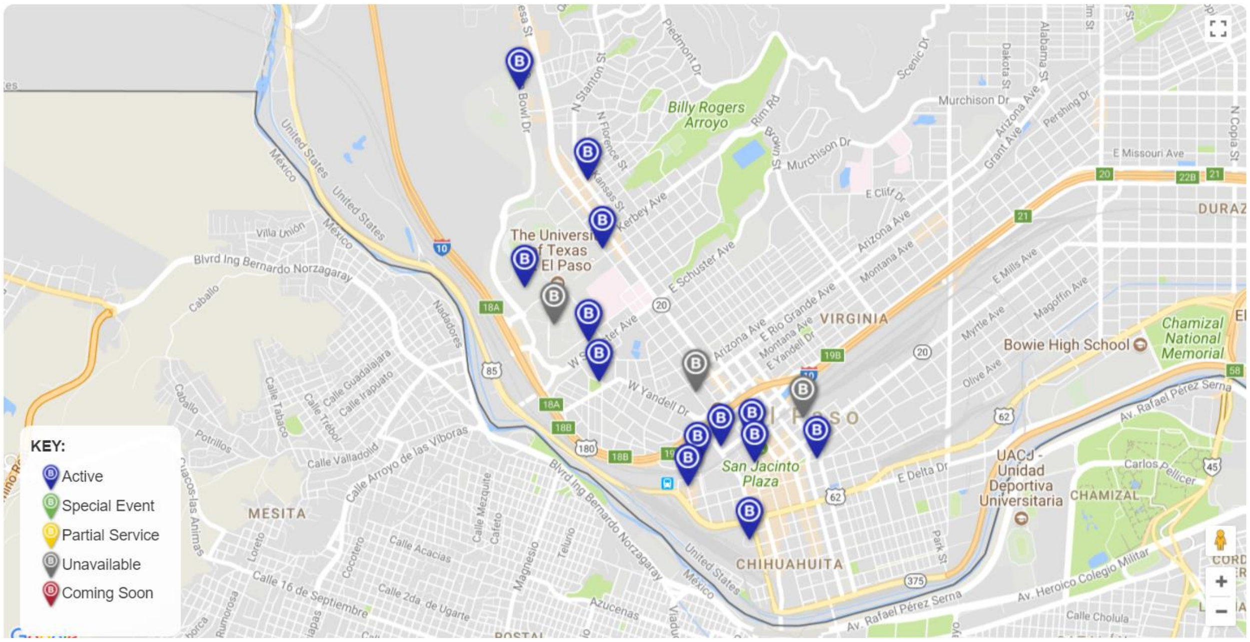

Figure 2.1 The map of BCycle stations in El Paso

(B-cycle, 2015)

The riders can use the mobile application to access the bicycles. Annual members get a B-Card that contains an RFID chip and a magnetic strip. All the bicycles are tracked by the GPS system. The application provides users with their ridership statistics such as distance traveled or burned calories.

2.1.2 Bike sharing in Prague

There are three bike sharing companies in Prague: Rekola, Homeport and international company OFO. Rekola operates mainly in the central area of Prague. As it does not use any fixed station it is very flexible. Riders can leave bicycle at any location in the area depicted in the Figure 2.2. They are only required to mount and lock the bicycle to any public bicycle stall or to a railing using the electronic bicycle lock. Then they must mark the location of the locked bicycle in the smartphone application and take a picture of the bicycle. The application shows locations of available bicycles. To unlock the bicycle, the rider has to take a picture of a code on the bicycle and the application provides him with the code to unlock the bicycle lock.

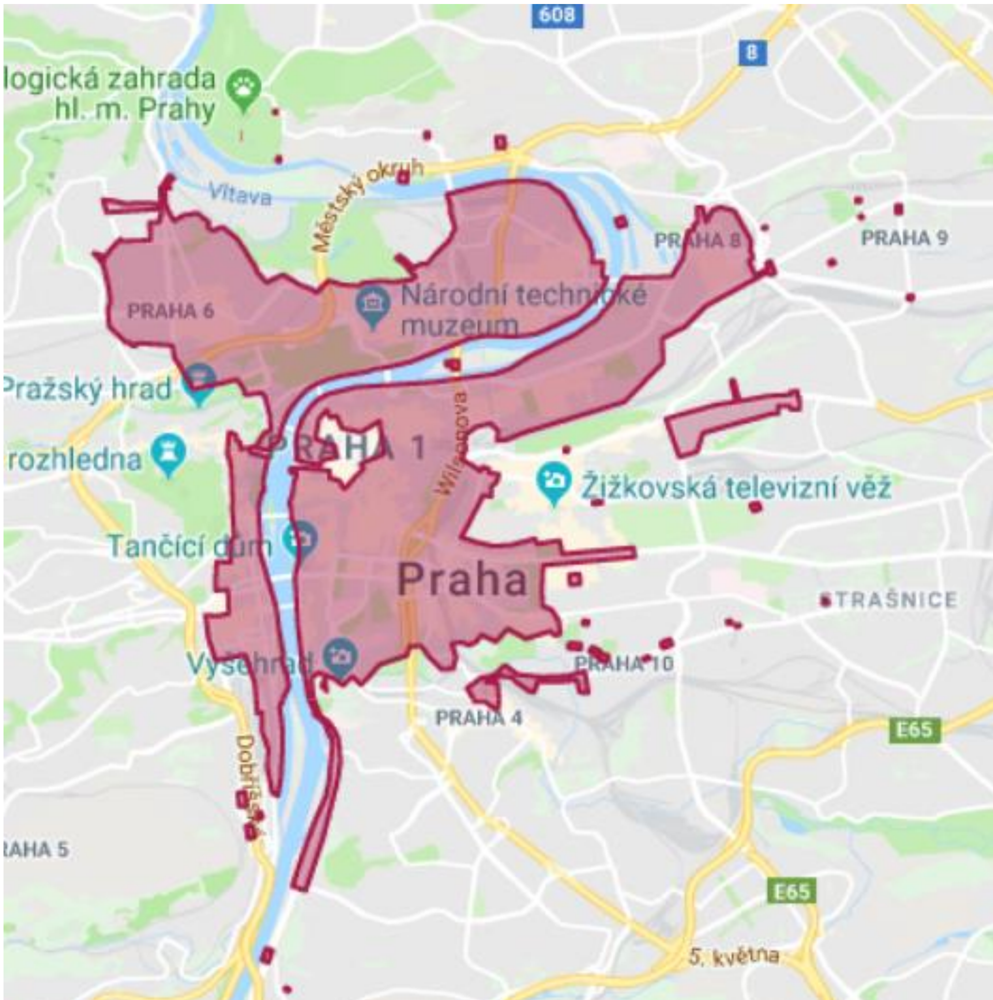

Figure 2.2 The map of areas for drop-off of Rekola bicycles in Prague

(Rekola Bikesharing s.r.o, 2017)

Rekola provides four types of passes: single rides, package of 15 rides for the price of 10, monthly pass and annual pass. For case of single rides, the first 15 minutes is for free, then next

45 minutes is for 24 CZK (about 1 USD). After the first hour, each additional 15 minutes costs 8 CZK (about 0.3 USD). The value package also allows people to ride 15 times for free up to one hour for 320 CZK (about 15 USD). After the initial hour, each additional 15 minutes cost 8 CZK. The monthly pass costs 320 CZK and the annual pass price is 1199 CZK (about 56 USD). Both, monthly and annual pass allows passengers to ride for free the initial hour. Every additional 15 minutes costs 8 CZK.

Homeport operates in city district of Karlín (Prague 8). The Figure 2.3 shows the map of the locations of the stations. Customers can buy daily or weekly pass for 250 CZK (about 12 USD) and 800 CZK (about 38 USD) that allows them to use one bicycle for 24 hours a day. The other possibility is to buy annual pass for 300 CZK (about 14 USD) that gives its holders access to the bicycles for 2 hours a day.

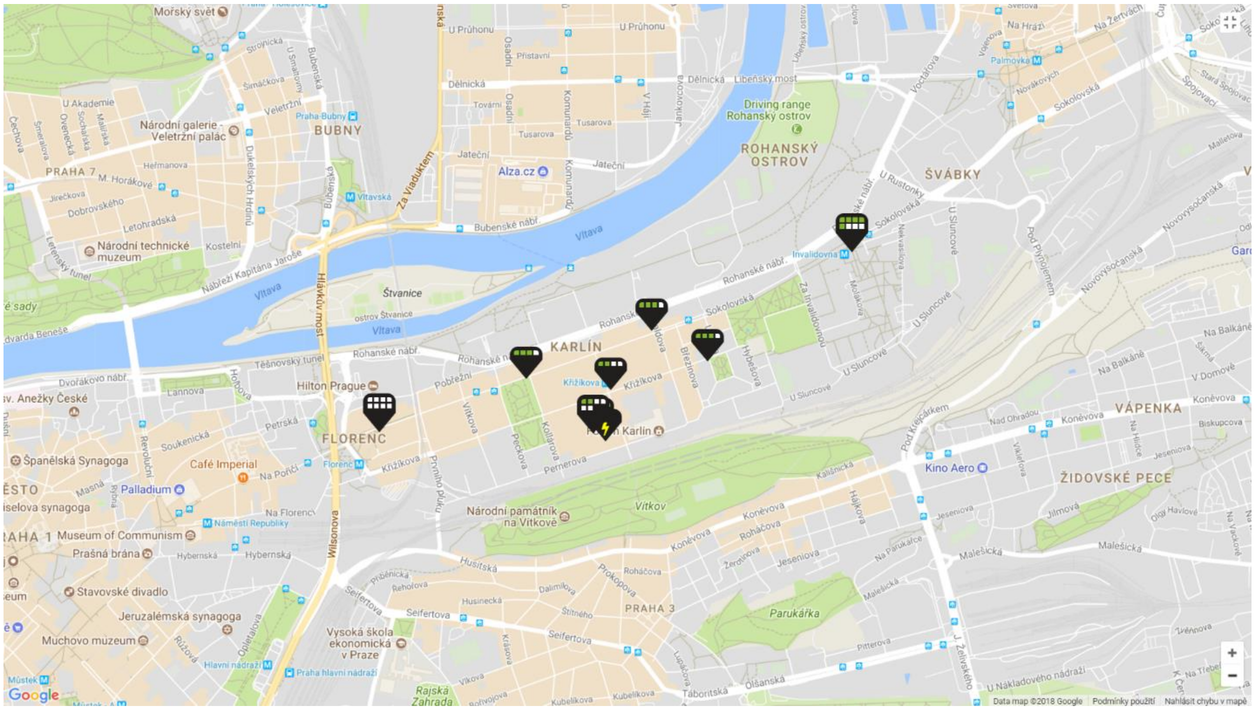

Figure 2.3 The map of Homeport bike sharing station locations

(HOMEPORT s.r.o., 2018)

OFO entered Prague bike sharing business in 2017 and the service was for free until the end of that year. Since the beginning of 2018, the price is 10 CZK (about 0.5 USD) for every 30 minutes. OFO does not use any bike sharing stations. It is possible to lock and leave bicycles anywhere in the designated zone. The bicycles have GPS tracking system. This enables the company to prevent stealing and customers to see the location of nearby available bicycles. The bicycles have integrated lock that can be unlocked via smartphone application.

Prague City Hall intends to partially include bike sharing into Prague Integrated Public Transit System (Pražská Integrovaná Doprava). It has conducted negotiations with bike sharing operators about discount for public transit pass holders.

2.2 Taxi

Oxford University Press (2018) provides a general definition of taxi as *"a motor vehicle licensed to transport passengers in return for payment of a fare and typically fitted with a taximeter".* This definition covers all types of taxi including boat or motorbike taxi and it speaks about taxi as a vehicle. This definition is adjusted for the purpose of this thesis: taxi is considered as a business model or a service providing a licensed transportation to passengers using car(s) fitted with a taximeter in return for a payment of a fare. Passengers can be picked-up and dropped-off at any location in a service area (usually the city and its surroundings).

Taxi fare is usually fixed and it is regulated by the law in order to protect the customer from fraudulent charges. The fare consists from multiple components. Typically, they are:

1) per kilometer component;
2) traveling time (congestion charge) component;
3) waiting time component; and
4) meter start component.

There are many business sub-models in taxi services. The taxi driver can provide transportation as an independent businessman or he can be part of a bigger organization. Taxi companies can adapt one or more types of business models according to the independence they give to the drivers. They can either pay a fixed salary to their drivers or the salary is directly dependent on the profit generated by the driver. The taxi company usually coordinates drivers and pairs them with trip requests made online, smartphone application or by telephone. Taxi drivers can use their private cars fitted with the equipment required by law or the taxi company can provide drivers with cars. In such a case either the driver or the company or both will be responsible for operation and maintenance costs. The Figure 2.4 provides the summary of different taxi business models.

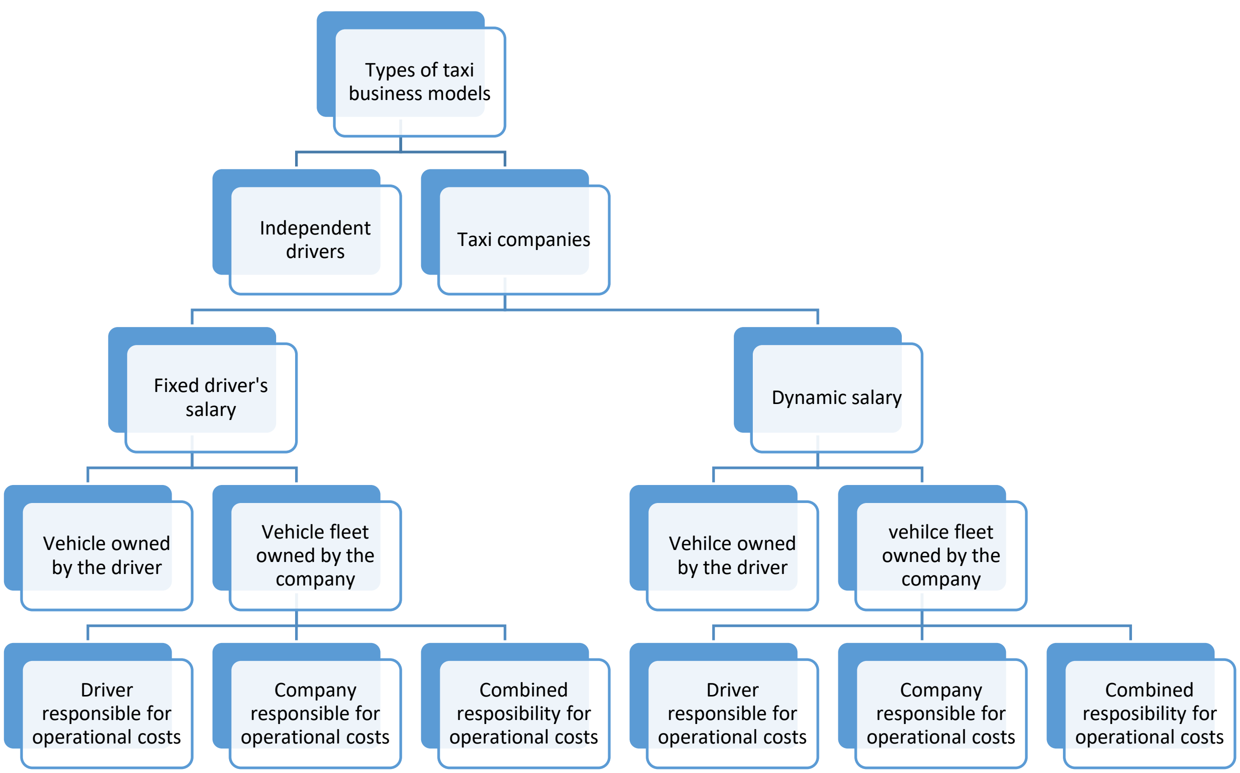

Figure 2.4: The summary of taxi business models

2.2.1 Taxi services in El Paso

There are more than ten companies that market themselves as taxi operators in El Paso. A few of them are private limousine providers, who do not provide fare information in the websites. Therefore, only those who offer regular taxi services and provide accessible information necessary to construct the mode choice model on their website were chosen. These companies are: Border Cab Co (Border Taxi), YellowCAB, Checker Taxi-Cab Co, Flitways, and Amigo Shuttle. Table 2.2 shows the fares charged by each of them. Border Cab Co and Flitways do not provide the information about how the fare is calculated but the price for the specific trip can be found in their website or in the smartphone application similar to Uber.

Table 2.1: Taxi Fares in El Paso

(YellowCab , 2017; Checker Taxi-Cab Co; 2014; Amigo Shuttle, n.d.)

	Fare		
Company	Per mile	Per Minute of Waiting	Meter Start
Border Cab Co	N/A		
YellowCAB	$ 2.25	$ 0.45	$ 1.65
Checker Tax-Cab Co	$ 2.25	$ 0.45	$ 1.65
Flitways	N/A		
Amigo Shuttle	$ 2.00	$ 0.33	$ -

2.2.2 Taxi services in Prague

As Prague city has more than 1 million people, there is huge number of taxi companies there. Table 2.3 shows the fares of the most popular ones. Ordering taxi via telephone is always cheaper than street hailing. Most of the companies haveaa the lowest fares if the ride is ordered via smartphone application except AAA Radiotaxi which has the lowest fare for rides ordered via telephone call.

Table 2.2: Taxi Fares in Prague

(Taxi Praha s.r.o., 2011; Tick Tack Taxi, 2016; Modrý Anděl s.r.o., 2018; Profi Taxi, 2018; ADgency s.r.o., 2015; AAA radiotaxi s.r.o., 2017; Sedop, 2018; Halotaxi Transport, 2017)

Company	Way of ordering/length of ride	Fare			
		Per kilometer	Per Minute of Waiting	Meter Start	Congestion Charge
AAA Radiotaxi	Taxi station	28.00 Kč	6.00 Kč	40.00 Kč	
	Street hailing	24.90 Kč	6.00 Kč	40.00 Kč	
	Phone call	19.90 Kč	6.00 Kč	40.00 Kč	
	Smartphone app	21.00 Kč	4.00 Kč	25.00 Kč	
City Taxi	Standard	20.00 Kč	4.00 Kč	12.00 Kč	
Sedop	<10 km	28.00 Kč	6.00 Kč	40.00 Kč	
	>10 km	23.00 Kč	4.00 Kč	30.00 Kč	
Halotaxi		23.90 Kč			
Profi Taxi	Street hailing	28.00 Kč	6.00 Kč	40.00 Kč	
	Phone call/message	26.00 Kč	4.00 Kč	30.00 Kč	
Modrý Anděl		21.00 Kč	6.00 Kč	40.00 Kč	2.00 Kč
Tick Tack taxi	Regular	28.00 Kč	6.00 Kč	40.00 Kč	
	Web/ smartphone app	25.00 Kč	6.00 Kč	30.00 Kč	
Taxi Praha	Phone call	23.90 Kč	4.00 Kč	30.00 Kč	
	Smartphone app	18.00 Kč	3.40 Kč	27.00 Kč	
	Street hailing	28.00 Kč	6.00 Kč	40.00 Kč	

2.3 RIDESOURCING COMPANIES

Feigon and Murphy (2016) define ridesourcing (or transportation network companies) as business model using *"online platforms to connect passengers with drivers and automate reservations, payments, and customer feedback…"*. Originally these platforms were meant to connect passengers with non-professional drivers using their personal vehicles but the definition of Feigon and Murphy includes even traditional taxis using the similar online platform.

Ridesourcing companies offer to their customers fast on-demand transportation similar to taxi. Uber, as a ridesourcing pioneer offers following additional value compared to the traditional taxi services:

- passenger knows the price before he makes an order;
- passenger can monitor the journey in real-time via smartphone application and GPS;
- the smartphone application provides passenger with estimated time of arrival
- the smartphone application provides both driver and passenger with the best route (based on which the price is calculated);
- passenger has easy access to driver's reviews and average rating that is based on huge statistical sample since every passenger must give feedback on every ride he/she takes. Only drivers maintaining the minimum required rating are allowed into the system; this works vice versa;
- as passenger enter his credit/debit card information when signing up to the smartphone application, the payments are processed automatically and the passenger only choses if and how much he/she wants to tip;
- the online platform simplifies the choice of vehicle class.

As drivers often use their private cars, they cannot be identified as providers of transportation by passengers without using the smartphone application. Therefore, street hailing is usually not possible. Other ridesourcing companies and taxi companies using online platforms provide most of these features. Uber is global company which gives a huge advantage to them. As people all over the world are familiar with the way it works, they most probably will prefer taking Uber instead of local taxis especially when traveling.

Ridesourcing is usually cheaper than traditional taxi service due to the lower operating costs. Another way Uber and Lyft use to keep their operational costs low is to officially consider drivers as business partners instead of employees. This allows ridesourcing companies to pay drivers less than the minimum wage (Doubek, 2018). Noam Scheiber (2017) in his The New York times article describes how Uber and Lyft use behavioral psychology knowledge to manipulate drivers to drive longer and in areas which the company needs them to drive. While dynamic pricing is a fair way to motivate drivers to drive in areas with higher demand and ensure that all customers are served quickly enough, there are another ways to manipulate drivers to drive more even when it is not profitable for them. Those can be creating income targets (Figure 2.4), sending trip requests before the previous ride has finished, creating statistics or rewarding drivers with worthless badges (e.g. “excellent-service badge”, “great-conversation badge” etc.) similar to achievements in computer gaming platforms. Some of Uber’s local managers also found out that more drivers follow application’s suggestions if they use female persona.

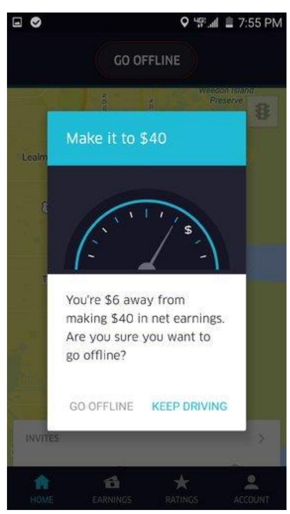

Figure 2.5 Income target offered by Uber application when the driver wants to go offline (Scheiber, 2017)

This is the reason why Uber is able to reduce both passengers waiting times and prices. Another reason why Uber's prices are almost always lower than traditional taxi's prices is the fact that Uber currently focuses on expansion and establishing customer's base rather than on generating profit for its investors. Uber was still unprofitable by June 2017 (Hook, 2017). It might be necessary for the company to raise prices in order to become profitable once it has been established and gained the upper hand in competing with others. Leveling prices with other taxi companies in such a case would not have to result in loss of large number of customers because Uber would still gain advantage from being a global company that customers know they can rely on.

Based on information from Uber's website (Uber Technologies Inc., 2018) and Ridster (2018) Uber's fare is calculated as following: The total fare for a ride E is:

$$E = E_T * B + p + T \,, \tag{2.1}$$

in which T is tolls paid during the trip, p is promotion (discount), B is surge or boost in unit price for trips in areas with high demand and E_T is base trip fare calculated by

$$E_T = E_B + E_t + E_D + E_{wt} + E_{pt} \,, \tag{2.2}$$

where E_B is the base fare, a constant component; E_t is the travel time fare; E_D is distance related component; E_{wt} is waiting time fare for the time when driver is waiting for the passenger; and E_{pt} is long pickup fee. There is also a minimum fare (its value is different for each area). Thit serves to attract enough of drivers needed to provide sufficiently low waiting times to areas with lower demand and to prevent situations when a passenger orders trip that is so short that it the fare does not cover travel costs of the driver (because of relatively long travel distance to pick-up point compared to the trip distance). If E is smaller than minimum fare, the passenger pays minimum fare. If E higher than minimum fare, the passenger pays E. Uber gives 80% (a value given on 15th

of January 2018 by interviewed Uber driver in El Paso and on autumn 2016 by interviewed driver in Prague) of the total fare revenue to the driver. Besides that, Uber often charges passengers with a booking fee. Drivers get nothing from the booking fee.

Per kilometer taxi fare in El Paso is 0.96 USD, per minute fare is 0.15 USD, the minimum fare is 6.15 USD and reservation fee is 2.75 USD. Per kilometer fare in Prague is 27 CZK (around 1.26 USD) if the trip starts in Horní Počernice and 9.90 CZK (around 0.47 USD) if the trip starts in Černý Most, per minute fare is 6 CZK (around 0.29 USD) if the trip starts in Horní Počernice and 3 CZK is the trip starts in Černý Most. The minimum fare 220 CZK (around 10.48 USD) if the trip starts in Horní Počernice and 110 CZK (around 5.24 USD) if the trip starts in Černý Most. These values will serve as one of the inputs to the accessibility and modal split model..

Uber passengers can choose from multiple service categories:

1) UberPOOL:merges similar trip origins and destinations so that more trip requests can be served by one vehicle at one time and the fare is split between riders;
2) UberX: This option offerd 4-door sedans with capacity of 4 passengers. The car must not be a truck or a van, it must not be taxi, government. UberESPAÑOL has the same requirements as UberX and connects Spanish speaking drivers and passengers. UberPOP has the same requirements as UberX but it is used in countries where laws forbid unlicensed taxi transportation;
3) UberXL: higher fare than UberX. Must have capacity of at least 6 passengers. Other vehicle requirements are the same as for UberX;
4) UberSELECT: higher fare than UberXL. Must be 2012 or newer model and must have leather or vinyl interior. Other requirements are the same as for UberX;

5) UberBLACK: higher fare than UberSELECT. Must have commercial insurance, TCP number. Car must be 2012 model or newer and must have black exteriors, black leather or vinyl interior and capacity of 4 passengers.
6) UberSUV: higher fare than UberBLACK. Must have capacity of at least 6 passengers. Other vehicle requirements are the same as for UberBLACK;
7) UberLUX: the same requirements as UberBLACK but more vehicle models are allowed in this category.

Each category and geographical area has different E_B, E_t, E_D, E_{wt} and E_{pt}. Uber offers only UberX and UberXL in El Paso and only UberPOP, UberSELECT and UberBLACK in Prague. The requirements for each category may also slightly differ in specific locations.

Chapter 3: Review of Regulations in US and EU

3.1 Bike sharing

3.1.1 El Paso

There is no specific legislature regulating bikesharing in El Paso or in Texas. B-cycle company only provides shared bicycles and their maintenance. Camino Real Regional Mobility Authority (CRRMA) is in charge of the pricing policy.

3.1.2 Prague

In Prague, the phenomenon of bikesharing is new and no regulation regarding customer protection, traffic conditions or use of public space. Therefore, Prague City Hall or Czech government has no need to regulate the bike sharing business. Some bikesharing companies in Prague do not use stations (or they do not strictly require customers to leave bicycles at the stations) which could cause passengers dropping off bicycles in public space designated for a different purpose. This might include entrances to buildings, public transit stop, narrow sidewalks, stairs railing etc. But this is already regulated by a decree for general bicycles.

3.2 Taxi

3.2.1 El Paso

Elliott (2016) describes history and current state of the US law regarding ridesourcing companies. She states that Uber does not accurately fit any definition of any of type of transportation service (Common Carrier, Contract Carrier, Transportation Broker). It is also not accurate to treat it as a Telecommunication Carrier or an Information Service provider. Therefore, Uber does not follow any regulation. This creates unfair competition because taxi companies that provide very similar services are required to follow regulation about Common Carriers. This usually makes their costs higher and they are not able to compete with Uber's lower prices. Elliott (2016) claims that there is a need to update the laws so that they take into account new technologies and the fact that ridesourcing companies are able to protect customers by using these technologies (etc. background check is can be partially substituted by drivers rating). The new laws should create the fair conditions for both, ridesourcing companies and taxi companies.

Texas State law provides regulations of transportation services in Occupations Code, Title 14, Subtitle C. Chapter 2401 is about regulations of transportation service providers (including taxi) and is very general. Specifics of taxi services regulations are mainly in jurisdiction of the local authorities. Chapter 2402 is about regulations for ridesourcing companies.

The regulations for ridesourcing were created in El Paso in 2016. Simultaneously, taxi companies were free to set their fees to create more fair competition (Guadian, 2016). El Paso, TX – Code of Ordinances, Title 6 – Transportation for Hire, Article II regulates the taxi service market. First, it defines the conditions under which taxicab zones can be used. Taxicab zones can be used only by taxi service vehicles (not by ridesouricng vehicles – the only exception is El Paso International Airport taxicab zone). Only drivers who have payed non-refundable fee and have been issued taxicab zone permit may use the taxicab zone. Taxicab zone permit validity is one year. Taxi vehicles must receive trip request in the same order they have arrived to a taxicab zone.

Second, El Paso, TX – Code of Ordinances, Title 6 – Transportation for Hire defines ordinances and regulations regarding using taximeter. If a taxi company does not use a digital network or fare calculator (similar to ridesourcing mobile application), vehicles must be equipped with taximeters fulfilling following requirements:

1) The taximeter must accurately show the legal fare for each trip, the minimum fare and the total fare based on real-time traveled distance and waiting time;
2) The taximeter must be installed and operated according to manufacturer's instructions;
3) The error of the traveled distance shown must not be higher than one hundred feet per mile;
4) The taximeter must be placed (and when necessary lighted) so that it is visible to all passengers.

Third, El Paso, TX – Code of Ordinances, Title 6 – Transportation for Hire specifies the rules regarding fares. Taxi vehicles using a taximeter can charge minimum fare of 5 USD for any trip less than one mile originating anywhere but El Paso International Airport. 10 USD minimum fare or the rate on the taximeter (whichever is higher) can be charged for trips originating at the airport. The taxicab vehicles must have a card legible from a 3 feet distance outside of vehicle and from rearmost seat of the vehicle including following information:

1) A schedule listing fare costs;
2) Taxicab company contact information;
3) A statement that wheelchair accessible vehicles are available upon request, or contact information for a provider of wheelchair-accessible vehicles; and
4) Instructions on how to report complaints to the taxi company and the city.

Fourth, El Paso, TX – Code of Ordinances, Title 6 – Transportation for Hire requests taxi service providers to provide the payer with a legible receipt at the time of payment. The receipt can be in a form of hard copy or it can be sent to the passenger electronically by e-mail or text message. It must contain the information about the fare rate, the total rate, the trip distance, the duration of the trip in minutes, the name of the taxi company, and the drivers first name or vehicle number.

Fifth, El Paso, TX – Code of Ordinances, Title 6 – Transportation for Hire requires that the taxi vehicle has the name and the telephone number of the taxi service painted on both sides of the vehicle so that the vehicle can be identified. The letters must be legible at a distance of thirty feet.

3.2.2 Prague

The Czech law 111/1994 Sb. § 2 defines taxi service as "*a personal transportation for somebody else's needs which provides transport of people and their baggage using vehicles with capacity up to 9 people including driver that is not line passenger transportation, international shuttle, or occasional personal transportation".* The same law defines line passenger transportation as *"a regular provision of transportation services on a defined route that allows passengers to get off and get on a vehicle on a set of stops specified in advance"* and occasional personal transportation as *"non-public personal transportation for somebody else's needs that is not line passenger transportation or international shuttle and that provides transportation of people and their baggage on the bases of a previous order by vehicles with capacity (a) up to 9 people including driver in case of international transport; (b) more than 9 people*". International shuttle is a transportation of a group of people to a foreign country followed by a transportation of the same group of people back to the Czech Republic. This includes in the most of the case international tourist trips with a travel agency.

In its § 21, the law 111/1994 specifies the conditions of providing taxi services that taxi carriers must follow. Taxi carrier can be self-employing taxi driver or a company employing taxi drivers. Taxi carrier can use for providing its services only a vehicle that is registered for him in taxi service vehicle register or a vehicle that belongs to a transported person. The taxi driver must be an employee of the taxi carrier, taxi carrier himself (self-employing taxi driver), spouse of self-employing taxi driver or registered partner and he must be a taxi driver permit holder.

During the transportation, the updated record of the taxi service vehicle register must be present in the car. The vehicle used for providing taxi services must have:

1) a yellow light sign "TAXI" on its roof;

2) the name of the taxi carrier placed visibly; and

3) a taximeter, taximeter book and taximeter records from current day.

The driver must print a receipt and if the passenger demands it he must give him the receipt.

An alternative to traditional taxi service allowed by the Czech law is *transportation based on a written contract signed in advance*. In this case, there must be a written contract present in the vehicle during the trip. The contract must contain the information about passengers, the date and the route of the trip. It also has to clearly state the fare or the algorithm according to which it will be calculated later. The contract must not be signed in the taxicab or any other place immediately before the beginning of the trip. During transportation based on a written contract signed in advance, the vehicle must not have a yellow light sign "TAXI" on its roof. For transportation based on a written contract signed in advance, the taxi carrier does not need to have its name placed on the vehicle and it is not necessary to use taximeter. The vehicle still has to be registered in taxi service vehicle register or it has to belong to a passenger and the driver still has to be a taxi driver permit holder.

The local authorities are allowed to issue a decree with additional requirements including passing a local topography exam, conditions of using taxi stations and under certain conditions specified by the law 526/1991 § 1 paragraph 6 (the law about prices) even the maximum fare. According to this law, local authorities are allowed to regulate prices:

a) *"if the market is threatened by the effects of restricting on competition;*
b) *if it is necessary because of an exceptional situation;*
c) *for the purpose of charging excise duty on cigarettes under a special legal regulation;*
d) *if it is required by regulations of European Communities; or*
e) *if it is in public interest and if it is necessary to maintain the positions of buyer and seller balanced in case of product pratially or fully subsidised by the state or other public institutions".*

In 2006, Prague City Hall issued a regulation 20/2006 determining the maximum taxi fares to be 28 CZK per kilometer, 40 CZK for meter start, and 6 CZK per minute of waiting. This regulation was a subject of controversies and Prague City Hall lost a case with a taxi driver who refused to pay a fine for exceeding the maximum fare (Kuchyňová, 2007). However the major taxi carriers with large fleets follow the regulation willingly.

3.3 RIDESOURCING

3.3.1 El Paso

The State law of Texas, Title 14, Subtitle C, Chapter 2402, requires a person that operates a ridesourcing company to have a permit issued by the State of Texas. All drivers have to have an automobile insurance. The ridesourcing company can make the passengers to share ride only if both of them agree. The estimated fare for requested trip has to be disclosed to the passenger by the ridesourcing company before the passengers accepts the ride. The ridesourcing company shall provide to the passenger the driver's first name and picture and the make, model, and license plate of the driver's vehicle before he enters the vehicle. After the ride is finished the passenger shall receive the electronic receipt containing the information about the origin and destination of the ride, the total time and distance of the ride, and an itemization of the total fare paid. Driver shall not drive intoxicated (zero tolerance) and the ridersourcing company has to inform drivers about this rule and enforce following of this rule. The drivers can provide a transport for compensation only to passengers that have requested a ride via the ridesourcing mobile application.

The driver must be at least 18 years old, he must hold a valid driver's license and is required to possess the proof of registration and automobile financial responsibility for the vehicles he is going to use. The ridesourcing company has to conduct a background check of the driver-parnters and obtain a review of their driving record. The ridecsourcing companies shall not allow to log in as a driver to anybody who has recently violated a defined list of legal rules.

The State law of Texas, Title 14, Subtitle C, Chapter 2402 also specifies the rules regarding, display of digital identification, vehicle requirements, accessibility and non-discrimination, disclosure of passenger information and data sharing with municipality.

El Paso, TX – Code of Ordinances, Title 6 – Transportation for Hire, Chapter 6.04.040 define transportation network company (ridesourcing) as *"a corporation, partnership, sole proprietorship, or other form of organization operating in this state that uses a digital network to connect a TNC passenger to a TNC driver for a prearranged ride. A TNC shall not be deemed to control, direct or manage the personal vehicles or TNC drivers that connect to its digital network, except where agreed to by written contract. The term does not include an entity arranging non-emergency medical transportation under a contract with the state or a managed care organization for individuals qualifying for Medicaid or Medicare".*

According to Article III of chapter 6.04 of El Paso, TX Code of Orinances, ridesourcing companies have to disclose to passengers the method of fare calculation. When the ride is requested, the potential customer must be able to receive an estimated fare. Than he must have the option to accept or reject the offer. Ridesourcing companies and their driver-partners are not allowed to accept cash payments from their customers. Article III also contains ordinance about customers' personal information protection and conditions under which they can be disclosed. Ridesourcing driver-partners cannot hold taxicab zone permit except taxicab zone at El Paso International Airoprt.

The ridesourcing company is allowed to use dynamic pricing in order to increase supply in areas with high demand. However, it is prohibited during periods of abnormal market disruptions[1]. In case of dynamic pricing, the potential passenger

1) has to be notified that the dynamic pricing is in effect;
2) must receive an estimated fare under dynamic pricing; and
3) has to confirm that he or she understands that dynamic pricing is in effect;

all of which has to happen before the transportation is accepted or rejected.

The application has to display driver's first name and his picture together with the license plate and the description (graphical or written) of the vehicle used for transportation before the transportation is accepted. This has to be done in order for the passenger to be able to identify the driver and his vehicle. After the transportation is finished, the customer shall receive an electronic receipt. The receipt must contain information about the origin and the destination of the trip, the total time and distance of the trip, and an itemization of total fare paid.

[1] Changes in the ground transportation market caused by stress of weather, convolution of nature, failure or shortage of electric power or the other source of energy, strike, civil disorder, war, military action, national or local emergency, or other cause of abnormal disruption which results in the declaration of a state of emergency by the governor

3.3.2 Prague

The Czech law does not define ridesourcing and there is no law or regulation specifically regarding this business model. This causes many people to believe that they do not have to follow any regulation. Contrary to that belief, the definition of taxi services in the law 111/1994 Sb. § 2 provided above covers even business of Uber's driver-partners and drivers of other ridesourcing companies as they provide transportation of people for somebody else's needs using vehicle with capacity up to 9 people (including driver) and that is not line passenger transportation, occasional transportation neither international shuttle. Ridesourcing is not line passenger transportation because the vehicles have no regular schedule and route and they do not stop only at stops specified in advance. It is also not occasional transportation. In order to be classified as providers of occasional transportation, drivers would have to use vehicles with capacity bigger than 9 people or they would have to use vehicles with capacity less than 9 people for international. Ridesourcing is also not international shuttle as it is primarily intra-urban transportation. Therefore, the whole ridesourcing business should be subject to taxi services laws and regulations in the Czech Republic.

In order to avoid the duty to follow taxi business regulation Uber also tries to classify its driver-partners services as ridesharing or as a transportation based on a written contract signed in advance. However, as stated before, ridesharing is a situation when two people with similar trip origins and destinations who need to travel at the same time agree to use the same vehicle and share the costs. Although, it might be true that driving for Uber in Prague may not be profitable because the earnings do not cover the travel costs, drivers still give rides to passengers in hope of gaining profit and they would not undertake the journey otherwise. We may talk about ridesharing only in case of UberPool, a service connecting unrelated passengers with similar trip origins and destinations. Although there is still a driver who would not undertake the journey for his own needs involved, it at least by some means follows the original idea of ridesharing.

In case of a transportation based on a written contract signed in advance, drivers are still required to be holders of taxi driver permit and the car used for the transportation have to be registered in taxi service vehicle register or it has to belong to a passenger in such case. The way Uber driver-partners usually conduct their business also does not follow rules for how the contract should be signed and what information the contract should contain.

On the other hand, the purpose of those regulations is mainly to protect the customer and Uber phone application is able to fulfill the same goal by its own means. Moreover, it is reasonable to say that it is more effective in ensuring that customers will be treated fairly than the regulations. This is why even the courts in different cities made contradictory decisions regarding ridesourcing. In fall 2016, Prague City Court cancelled a fine for an Uber driver-partner who was providing transportation services without taxi driver permit (ac, ČTK, 2016). Contrary to that, City Court in Brno (the second largest city in the Czech Republic) decided that even ridesourcing drivers must follow regulations for taxi drivers (Chvátal, 2017).

The current differences in a ways the courts view ridesourcing should be settled by the decision of European Court of Justice made on December 20, 2018. The court declared that Uber is a transportation service and that it must follow taxi service regulations (Scott, 2017). This is why it is necessary to update current taxi laws and regulations so that they take into account modern technologies. For example, there is no need for a taximeter if its function is provided by a smartphone application.

Chapter 4: Methodology

4.1 ACCESSIBILITY

There are different approaches to analyze accessibility. The floating catchment area method (Papacostas and Prevedouros, 2001) defines accessibility as a sum of opportunities reachable in a travel time that is smaller than the acceptable travel time. The drawback of this method is the difficulty with finding an acceptable travel time. The two-step floating catchment area method solves this problem (Xu, et al., 2015). The first step is to calculate the supply-to-demand ratio R_j of each supply point j:

$$R_j = \frac{S_j}{\sum_{k \in \{l_{kj} < l_0\}} D_k} \quad (4.1)$$

where j is index of the supply point within the catchment area; k is index of the demand point within the catchment area; l_{kj} the shortest path distance (or generalized travel cost) between point k and j; l_o is the individual shortest-path distance threshold (acceptable travel time, length or generalized travel costs); D_k is the demand of demand point k; and S_j is the supply of supply point j. The second step is to calculate accessibility of the demand points I, A_i^F:

$$A_i^F = \sum_{j \in \{l_{ij} < l_0\}} R_j \quad (4.2)$$

However, this method requires the researcher to accurately estimate not only the attraction (or supply) from the supply points but also the demands of the demand points. D_k can be easily expressed by the number of people living in the supply points. The demand of the demand point (e.g., bus transit stop) has to be based on travel. This method is helpful in cases when an analyst tries to compare accessibility from a set of origins (demand points) to more than one destination (supply points). Since in this thesis, in the morning commute, only accessibility to one demand point is measured, R_j value would be 1 and the first step of the method (Equation (4.1)) would be unnecessary. This would take us back to the simple floating catchment area method (Equation 4.2 except for the simple floating catchment area method R_j=1).

The discrete choice model focuses on the accessibility from the perspective of a single person based on his/her socio-economic characteristics and the trip characteristics. The method requires an extensive personal data collection using questionnaires (Xu, et al., 2015). This would need resources that are not available for this research.

The mathematical programming method is a very good tool to estimate the accessibility of a road network. It can be used for instance to plan the restoration of transport infrastructure (Aksu & Ozdamar, 2014). However, this method is not suitable for the problem this thesis because it does not evaluate the accessibility of a system of roads but the accessibility of a transit station by different modes that use the infrastructure.

Sinha and Labi (2007) measure accessibility as a function of public transit frequency, waiting times, and walking distance. This is a way to assess the accessibility of an area by public transit and does not enable the researcher to compare public transit with other transport modes.

Morris et al. (1979) defines accessibility as an *"ease with which activities may be reached from a given location using a particular transportation system"*. They distinguish between relative accessibility, which he states is *"a measure of the effort involved in making a trip"*, and integral accessibility – an ease of access to all travel opportunities (of all types or just a one type – e.g. shopping malls) in a system. The relative accessibility A_i can be expressed as

$$A_i = C_{ij} \tag{4.3}$$

where C_{ij} is calculated from accessibility indicators of which may be inversed of generalized cost. The integral accessibility A_i is calculated by the equation:

$$A_i = \frac{\sum C_{ij}}{n}, \quad j = 1, 2, \ldots, n \tag{4.4}$$

where C_{ij} is calculated from accessibility indicators and n is the total number of opportunities. There are four general guidelines for selecting accessibility indicators:

1) The indicator should incorporate an element of spatial separation;
2) The measure should have a sound behavioral foundation (based on a real data);
3) The indicator should be technically feasible and operationally simple; and
4) The measure should be easy to interpret, and preferably be intelligible to the layman.

Hansen (1959) defines accessibility as ”*a measure of intensity of the possibility of interaction”*. This definition is more suitable rather in the context of spatial and land use planning then in a transportation sense. Accessibility, according to Hansen (1959) was not determined only by the ability of people to overcome a distance between two points but also by the desire to overcome it. Therefore, he expressed relative measure of the accessibility from Zone 1 to an activity located within Zone 2, ${}_1A_2$, by an equation:

$${}_1A_2 = \frac{S_2}{T_{1-2}^x} \tag{4.5}$$

where S_2 is the size (attraction) of the activity in Zone 2; T_{1-2} is the travel time or cost between Zones 1 and 2; and x is an exponent describing the effect of T_{1-2} between the zones. This model form is called gravity based potential accessibility model (Chandra, et al., 2013).

Chandra et al. (2013) uses this model to compare the accessibility of a major public transit station from the surrounding area as a whole by two types of a feeder service: fixed route transit (FRT) and dynamic route transit (DRT). To assess the overall accessibility of multiple public transit terminals i from multiple locations j, he adjusted the model of the potential accessibility to a public transit terminal (P_i) to this form:

$$P_{ik} = \sum_j \frac{A_j}{C_{ijk}^{\beta}}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{4.6}$$

where A_j is the attraction from the origin j, C_{ijk} is the impedance between origin j and destination i using mode k, β is the impedance or decay factor, m is the number of destinations, and n is the number of origins. The attraction index is to measure the weight of an origin and can be, in general, expressed by the number of trip requests or the number of people living in the attraction area of a particular feeder service stop. In our case, A_j is the number of inhabitants living in origin j. The impedance can be travel time, travel cost or generalized travel costs.

The use of gravity based accessibility model requires the calibration of the impedance factor β. The value of the impedance decay factor β is dependent on factors other than average trip length (Chandra, et al., 2013). Chandra et al. (2013) used the maximum likelihood method to find out that the decay parameter for Xiamen, China, was 1.18. The decay factor calculated by them may not be applicable for El Paso and Prague since the central part of Xiamen is located on an island. Chen et al. (2017) claimed that the decay factor is usually between 1 and 2. As there is no Prague and El Paso travel data to calibrate the decay factor, six different values between 1 and 2 were assumed for the decay factor and their results were compared in the next two chapters.

Chen et al. (2017) used only travel time as the indicator of impedance. Using travel time as the only indicator of impedance is sufficient when comparing different solutions that have all the same travel costs (e.g. comparing two different designs of bus routes). However, it cannot be used in this thesis because it compares accessibility by different transport modes with different fares. Therefore, the use of generalized travel costs is necessary. Koopmans et al. (2013) defined average generalized travel costs per kilometer, C_{it} as

$$C_{it} = PC_{it} + TT_{it}(VOT_{it} + VOR_{it} + DC_{it}) \quad (4.7)$$

where PC_{it} is out-of-pocket costs per kilometer, TT_{it} is average travel time per kilometer, VOT_{it} is average value-of-time per hour, VOR_{it} average value-of-unreliability per hour, and DC_{it} average inconvenience costs per hour. From this one can infer that the generalized travel costs for a trip between locations i, j using mode k as:

$$C_{ijk} = PC_{ijk} + TT_{ijk}(VOT_{it} + VOR_{it} + DC_{it}) \tag{4.8}$$

where PC_{ijk} is out-of-pocket costs for trip between i and j for a mode k, and TT_{ijk} is travel time between i and j using mode k.

Wardman et al. (2016) in their meta-analysis of 3,109 monetary valuations of time found out that value of travel time varies "*with type of time, GDP, distance, journey purpose, mode, and the monetary numeraire*". They provide equation for value of in vehicle time (value of travel time) VOT_{it}:

$$VOT_{it} = e^{-12.596-0.352FF+0.127C+0.282EBTU-0.373BU+0.334AU+0.555AV+0.324I} * GDP\_PPP^{1.031+0.079EB+0.025CU} \tag{4.9}$$

where GDP_PPP is per capita gross domestic product based on purchasing power parity. The other variables was 1 or 0 based on the calculation of VOT_{it}. FF is free flow, C is commuting, $EBTU$ is employer's business for a train user, BU is bus user, AU is airline passengers, AV is air valued, I is inter-urban trip, EB is employer's business trip, and CU is car user.

Athira et al. (2016) found out that the value of travel time is smaller for short trips than for long trips. As this thesis deals with first and last mile trips that are shorter than two miles, the real value of travel time might be lower than the one calculated according Equation (4.9). Therefore, the accessibility and modal split for smaller travel time values will be calculated too.

The average value-of-unreliability VOR_{it} is assumed to have very small effect in our problem, as the considered trips are shorter than two miles. Therefore, it will not be used in our model. Although, average inconvenience costs per hour DC_{it} for different modes probably have a significant impact on the accessibility and the modal split, there is no publicly available data that could be used to estimate them.

4.2 Modal split

Besides accessibility, the generalized travel costs can be used in logit model for the calculation of modal split:

$$MS(i,k) = \frac{e^{\alpha C_{ik}}}{\sum_k e^{\alpha C_{ik}}} \tag{4.10}$$

where $MS(i,k)$ is the share of mode k to (or from) public transit station i and α is a currency rate coeficient. C_{ik} is weighted average generalized transportation cost from all zones in a study area to the public transit station i:

$$C_{ik} = \frac{\sum_j C_{ijk} * A_j}{\sum_j A_j} \tag{4.11}$$

where A_j is the number of people living (attraction) in a zone j and C_{ijk} is generalized travel cost between zone j and public transit station i using mode k.

Equation (4.10) gives the modal split for those who have access to all modes included in the equation. Therefore, it is possible to use this equation only to calculate modal split for each of following groups separately:

GROUP 1: Passengers who own car and bicycle;

GROUP 2: Passengers who own only bicycle;

GROUP 3: Passengers who own only car;

GROUP 4: Passengers who do not own car nor bicycle.

To obain the overall modal split Equation (4.11) has to be adjusted to incorporate car and bicycle ownership rates. Assuming that car ownership amongst bus users is the same as the city or region's overall car ownership, and that car ownership and bicycle ownership are independent from each other, the overall modal split is

$$MS(i,k) = x * y\frac{e^{\alpha C_{ik}}}{\sum_k e^{\alpha C_{ik}}} + (1-x) * y * a\frac{e^{\alpha C_{ik}}}{\sum_k e^{\alpha C_{ik}}} + x * (1-y) * b\frac{e^{\alpha C_{ik}}}{\sum_k e^{\alpha C_{ik}}} + (1-x) * (1-y) * a * b\frac{e^{\alpha C_{ik}}}{\sum_k e^{\alpha C_{ik}}} \tag{4.12}$$

where C_{ik} is generalized travel costs from location i using mode k, α is currency rate and sensitivity coefficient, x is car ownership rate, y is bicycle ownership rate. If k=[personal vehicle], a=0, otherwise, a=1. If k=[bicycle], b=0, otherwise b=1. There are no data for bicycle ownership. The estimate for the bicycle ownership, for the purpose of this thesis, is 10% in both cities.

The currency rate coefficient is different for El Paso and for Prague depending on which currency is used to express generalized travel costs. Therefore, there is a need to calibrate α for each currency (U.S. Dollar and Czech Crown). For this, the modal split data are needed. However, such data are not available for the author of the thesis. Therefore, α will be considered as a variable. Six different values of α will be used for each study area.

Chapter 5: Analysis of Accessibility of a Public Transportation Station in El Paso

5.1 Public transportation in El Paso

There are over 90 regular bus routes in El Paso provided by Sun Metro. The buses at important routes have headways between 20 and 30 minutes during the peak hours on weekdays and 30 to 40 minutes outside of the peak hours and during weekends. Buses on the less important routes can have intervals of even longer than one hour. The waiting times for the connection at transfer points vary. They can be from 10-30 minutes (Sun Metro, n.d.). Therefore, using the bus service requires careful planning and this mode of transportation is not competitive with individual vehicle transport.

Beside those regular bus routes, El Paso also has a Rapid Transit System (known as Brio). It is a high quality type of public transit system. All the Brio vehicles are equipped with audio-visual information system for passengers and Automated Vehicle Location (AVL) for real time positioning. This intelligent transportation system gives passengers waiting at each stop the estimated bus arrival time. The buses and all the bus stops have features for increasing passengers comfort such as free internet connection, non-barrier access or bicycle racks (Sun Metro, n.d.).

When finished, the Brio system will consist of 4 bus lines with routes along the main transportation corridors in El Paso and making stops or terminating at 9 transfer centers:

1) Mesa Corridor: Downtown Transfer Center – Glory Road Transfer Center – Westside Transfer Center;
2) Alameda Corridor: Downtown Transfer Center – Five Points Terminal – Mission Valley Transfer Center;

3) Dyer Corridor: Downtown Transfer Center – Five Points Terminal – Northeast Terminal; and
4) Montana Corridor: Five Points Transfer Center – Eastside Transfer Center – Transit Operations Center – Far East Transfer Center (Sun Metro, n.d.).

The Alameda Corridor should be launched in the middle of 2018, Dyer Corridor in late 2018 and Montana Corridor in late 2019. Currently the only operational route the is the Mesa Corridor. It has been in service since fall 2014. It has 13 regular stops and one temporary stop on the 8.6-mile long route (each way). The headway of service is 10 minutes in peak hours (6 a.m. – 9 a.m. and 3 p.m. – 6 p.m.) and 15 minutes in non-peak hours (9 a.m. – 3 p.m. and 6 p.m. – 8 p.m.) on working days. On Saturday, it is in service from 9 a.m. to 6 p.m. with headways of 20 minutes. Figure 4.1 shows the locations of the Mesa Corridor bus stops (Sun Metro, n.d.).

Figure 5.1 Mesa Corridor route and stops

(Sun Metro, n.d.)

The current Brio route has short enough headways during the peak travel periods competitive with personal vehicle, make it an acceptable mode of transport even for daily commuting. However, this level of service is offered only to areas immediately surrounding the Brio stops. The current solution for first and last mile transportation to and from the Brio stations are walk or take a feeder bus. It is often faster to walk to the Brio station than to take a feeder bus. This discourages many travelers from using public transport and they rather use their personal vehicles for the whole trip. This is why this chapter compares the accessibility of the Balboa Brio station by different transport modes. The goal was to examine if ridesourcing could be a solution for the first and last mile problem in El Paso compared to other transport modes.

5.2 Methodology specifics for El Paso study area

Figure 5.2 shows the studied Brio station and the surrounding census tracts. The areas immediately next to the North Mesa Street are mostly commercial areas with restaurants, shops and other services. However, except immediately adjacent areas, there are mostly residential areas with many apartment complexes in the attraction area of the Balboa Brio station. As apartment complexes' residents are more likely to be from a lower income group, the public transit in the area has a bigger potential than in the richer parts of the city. The terrain around the station has an upgrade from the south to the north. This has influence on walking and cycling times and therefore, also on the accessibility and modal split.

The smallest zone in El Paso is a census tract. There are six census tracts in the attraction area of the Balboa station. To make the travel time and costs data more representative, PC_{ijk} and TT_{ijk} values were measured at three locations (origins) in each census tract. Therefore, the number of inhabitants in each census tract was divided by three to obtain A_j of the location (origin) j. The underlying assumption was that the density of each census tract was homogenous. There are six census tracts that are (at least partially) part of the attraction zone of the Brio station. However, not all of the locations j within a census tract might be in the attraction area of the Balboa station. This is why there were only 12 locations j. The other possibility was to use apartment complexes in the attraction area of the Balboa station instead of census tract. In that case, A_j would be the number of bedrooms in an apartment complex j or the number or the number of units in an apartment complex j. This variant would be more suitable for the U.S. city because it would include more lower-income families (compared to those living in a house). The idea behind this was that people living in houses are more likely to be able to afford a car and not to use the public transit at all. However, data about the number of bedrooms were not available and the data about the number of units were not complete.

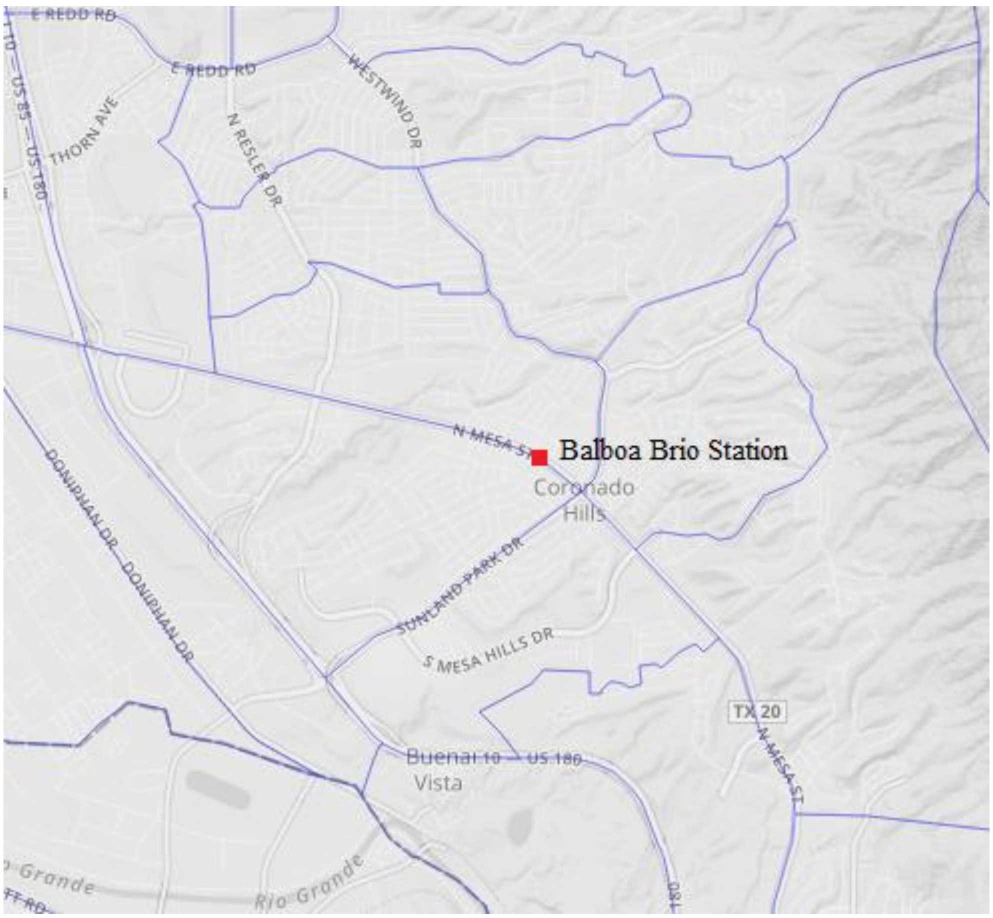

Figure 5.2 The map of studied location in El Paso and census tracts

(U.S. Census Bureau, 2016)

All the in-vehicle-times data were estimated by Google Maps (2018) for Wednesday March 14, 2018. The Uber waiting times data were from Wednesday August 9, 2017. The accessibility to (and from) the Brio station during morning and afternoon peak was examined. For the morning peak, travelers were assumed to arrive at the Brio station by 7:00 a.m.. For the afternoon peak, travelers were assumed to depart the Brio station at 5:00 p.m. or later in their trips home.

The fare system for buses in El Paso allows passengers to use the same ticket for transferring from one bus route to another. Since accessibility was measure to/from a public transit station, it was assumed that any person getting there will continue his/her journey by Brio. Therefore, the passenger can use the same ticket for the first or last mile trip. This means there were no additional costs for the passenger's first or last mile trip by bus and PC_{ijk} equals to zero.

Bus travel time $TT_{ij,bus}$ between locations i and j is

$$TT_{ij,bus} = IVT_{ij,bus} + WT_{ij,bus} \tag{5.1}$$

where $IVT_{ij,bus}$ is in-vehicle-time for bus and $WT_{ij,bus}$ is average waiting time during transfer (equals half of the headway of the follow-up connection). Both values were exported from Google Maps (2018).

Shared bicycle can be used by many people as a first and last mile transport in non-residential areas. It is inconvenient for the passengers who travel by Brio to bring their own bicycles by bus with them. However, for a first and last mile trip from/to home it is more economically feasible for passengers to use their own bicycles. This statement assumes that there is free bicycle parking at the public transit station. In such a case, $PC_{ij,bicycle}$ equals to zero. $TT_{ij,bicyckle}$ values were exported from Google Maps (2018).

The out-of-pocket costs for Uber, $PC_{ij,Uber,}$ in El Paso were calculated according to the equation:

$$PC_{ij,Uber} = \max(MF_{Uber} + RF, IVT_{ij,Uber} * c_{t,Uber} + s_{ij,Uber} * c_{s,Uber} + RF) \tag{5.2}$$

where MF_{Uber} is the Uber minimum fare, RF is the registration fee, $IVT_{ij,Uber}$ is the in-vehicle-time between locations i and j when traveling with Uber, c_t is Uber fare per unit of in-vehicle-time, $s_{ij,Uber}$ is the traveling distance between i and j when using Uber, and c_s is fare per unit of traveled distance.

Uber travel time $TT_{ij,Uber}$ between locations i and j in the morning is

$$TT_{ij,Uber} = IVT_{ij,Uber} + WT_{ij,Uber} + WT_{Brio} \tag{5.3}$$

and in the afternoon is

$$TT_{ij,Uber} = IVT_{ij,Uber} + WT_{ij,Uber} \tag{5.4}$$

where $WT_{ij,Uber}$ is the average waiting time in a specific zone and WT_{Brio} is the average waiting time for the Brio bus to arrive after a traveler is being dropped off by Uber at the station. WT_{Brio} has to be added because Uber passengers are not able to schedule their arrival to the Brio station. Therefore, WT_{Brio} is half of Brio buses headway. The average Uber waiting time in census tracts in El Paso have been provided by Uber Technologies Inc.

The travel time by personal vehicle, $TT_{ij,car}$, between location i and j is equal to $IVT_{ij,car}$ (and $IVT_{ij,Uber}$) because there is no waiting time and the parking lot is right next to the Brio station. The out-of-pocket costs for personal vehicle $PC_{ij,car}$ between locations i and j is calculated by the equation:

$$PC_{ij,car} = s_{ij,car} * f * c_f \tag{5.5}$$

where $s_{ij,car}$ is the traveled distance between locations i and j by car, f is the average fuel consumption per unit of distance (Federal Highway Administration, 2015), and c_f is cost of fuel per unit of volume in El Paso (ElPasoProud.com, 2018).

Taxi traveling time $TT_{ij,taxi}$ between locations i and j is considered to be the same as Uber although the taxi waiting time is probably longer. Therefore, the real taxi accessibility and modal split is probably smaller than the model's results. The out-of-pocket costs for taxi $PC_{ij,taxi}$ between locations i and j are calculated according to the equation:

$$PC_{ij,taxi} = \max(MF_{taxi}, s_{ij,taxi} * c_{s,taxi} + B) \tag{5.6}$$

where MF_{taxi} is taxi's minimum fare, $s_{ij,taxi}$ is traveled distance by taxi between i and j, $c_{s,taxi}$ is taxi fare per unit of distance in El Paso, and B is meter start charge.

Walking has zero out-of-pocket costs. Travel time $TT_{ij,walking}$ between i and j for walking was provided by Google Maps (2018).

The average car ownership per household in El Paso was 1.82 (Governing, 2016). The average number of household members in El Paso was three (Census Reporter, n.d.). Therefore, the average car ownership per person was 0.61. For the purpose of this model it was assumed that most of the travelers use first and last mile transport for commuting (therefore, in Equation (4.8), C=1), as the studied locations in El Paso were apartment complexes. Therefore, *EBTU* and *EB* in Equation (4.1) equal zero. The first and last mile accessibility of an urban area was studied. Therefore, *AU, AV* and *I* were zero too. The study times were morning and afternoon peaks, which means there was a low probability of free flow, so *FF* was zero as well. *CA* in the model was also zero. The accessibility for personal vehicles was calculated too but only for the first and last mile. The major part of the total trip was assumed to be made by public transit since the accessibility to public transit station was being assessed. Therefore, *BU* was set to one.

5.3 Results in El Paso

5.3.1 Accessibility

Table 4.1 and Table 4.2 display how accessibility changes with different values of β (between 1 and 2) in the morning peak and afternoon peak respectively. The highest accessibility is personal vehicle assuming there is free parking next to the Brio station. Bicycle has also very high accessibility. On a first and last mile trip, the routes usually go through minor roads where vehicles and bicycles have almost the same speed, due to the low speed limit for vehicles. No waiting time makes personal vehicle and bicycle the two best modes for first and last mile transport. Accessibility by bus is comparable to accessibility by foot although the bus accessibility is slightly smaller. Ridesourcing and taxi accessibility are the smallest ones (ridesourcing is slightly higher).

The morning's accessibility is generally higher than the evening's accessibility. However, there are different causes of this phenomenon for each mode. Feeder bus lines have longer headways than main Brio line. This is why transfers from feeder line to Brio (morning) is in average shorter than the transfers from Brio to feeder line (afternoon). Majority of locations j is uphill from the Brio station. This is why their accessibility by bicycle is higher in the morning (downhill to the station) then in the afternoon (uphill to the residence). This is also the cause of higher morning accessibility by foot. Accessibility by personal vehicle is higher in the morning because Google Maps (2018) gave different routes in each direction (at different time of the day). This may be because of one-way roads and different traffic conditions. Uber and taxi have higher afternoon accessibility because their total travel time TT_{ijk} in the afternoon does not include average waiting time for Brio (WT_{Brio}).

Further analysis showed that ridesourcing (Uber) would have to cancel its minimum fare and reservation fee in order to be competitive in serving first and last mile trips. To have the same accessibility as other modes, Uber would have to reduce its fare. Below is the list of recommended values (for β=1.5) of per minute and per mile fares that would give Uber the same accessibility in the afternoon as the respective modes according to the accessibility model:

a) Bus – keep the original prices but cancel both reservation fee and minimum fare;

b) Foot – 0 USD per minute and 0.5 USD per mile; 0.09 USD per mile (and keep the original price per minute); or some combination of both.

In the morning, the adjustment of Uber's fare should be would be:

a) Bus – 0 USD per minute and 0.51 USD per mile; 0.09 USD per mile (and keep the original price per minute); or some combination of both;

b) Foot – 0 USD per minute and 0.34 USD per mile; 0 USD per mile and 0.13 USD per minute; or combination of both.

These values change only slightly with different values of β (between 1 and 2). Even if Uber was free, it cannot achieve the same accessibility on short first and last mile trips in the afternoon as bicycle or personal vehicle due to the long waiting times. However, it already has higher accessibility than taxi.

Table 5.1: Accessibility based on β, morning peak

β	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
1.0	8,952	31,703	2,184	36,595	1,977	9,635
1.2	7,520	34,838	1,364	40,704	1,211	8,304
1.4	6,343	38,617	852	45,459	741	7,210
1.6	5,372	43,152	533	50,970	454	6,303
1.8	4,566	48,583	333	57,366	278	5,546
2.0	3,895	55,079	208	64,799	170	4,908

Table 5.2: Accessibility based on β, afternoon peak

β	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
1.0	5,487	27,482	2,294	29,154	2,067	9,477
1.2	4,182	29,659	1,448	30,796	1,277	8,200
1.4	3,202	32,446	913	32,608	789	7,168
1.6	2,462	35,968	576	34,609	488	6,327
1.8	1,901	40,384	364	36,821	301	5,638
2.0	1,474	45,893	229	39,269	186	5,068

Since the value of travel time may be smaller for trips with short distances, the accessibility was measured for different values of travel time and constant β=1.5. Table 4.3 and Table 4.4 show the results for the morning peak and afternoon peak, respectively. The accessibility increases for all transport modes when the value of travel time is set to a lower value. This happens because a decrease in the value of travel time leads to decrease in the generalized travel costs. When the value of travel time decreases, accessibility increases the fastest for the modes that have major part of generalized travel costs dependent on travel time. Therefore, lower value of travel time causes the modes with no out-of-pocket costs to have higher accessibility. However, even for very low value of travel time, personal vehicle has the highest accessibility among all modes in the El Paso study area.

With the lower value of travel time (6.00 USD/hr) and without minimum fare and reservation fee, Uber should still have to lower per minute fare or per kilometer fare in order to have the same accessibility in the morning as:

a) Bus – 0 USD per minute and 0.48 USD per kilometer; 0.07 USD per kilometer (and keep the original price per minute); or combination of both;
b) Walking – 0 USD per minute and 0.35 USD per kilometer; 0 USD per kilometer and 0.13 USD per minute; or combination of both.

For the afternoon this would be:

a) Bus – 0.11 USD per minute (and keep the original price per kilometer); 0.86 USD per minute (and keep the original price per minute); or combination of both;

b) Walking – 0 USD per minute and 0.5 USD per kilometer; 0.09 USD per kilometer (and keep the original price per minute); or combination of both.

Table 5.3: Accessibility based on value of travel time, morning peak

Value of Travel Time [USD/hr]	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
6.6	5,823	40,703	674	48,036	580	6,723
6.4	6,098	42,625	678	49,898	584	7,040
6.2	6,396	44,704	683	51,884	587	7,384
6.0	6,718	46,958	688	54,005	591	7,756
5.8	7,069	49,408	693	56,276	595	8,160
5.6	7,451	52,078	698	58,710	599	8,601

Table 5.4: Accessibility based on value of travel time, afternoon peak

Value of Travel Time [USD/hr]	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
6.6	2,801	34,040	725	33,530	620	6,713
6.4	2,933	35,648	729	34,817	623	7,030
6.2	3,076	37,386	733	36,189	626	7,373
6.0	3,231	39,271	736	37,653	629	7,745
5.8	3,400	41,320	740	39,219	632	8,149
5.6	3,583	43,553	744	40,897	635	8,589

5.3.2 Modal split

Table 5.5 and Table 5.6 show how modal split changes with α. The closer α is to 0 the more uniform are the modal split. However, even with α=0 the sprit s are is not the same for all modes due to the fact that not everybody has the access to bicycle and car. The real value of α depends on the currency we use and also on how much is the population sensitive to changes in travel time and cost. With increasing value of α, the differences between usage of different modes grow. When α=9, everybody who owns car will use their car and everybody who does not own a car will walk.

The bus mode has higher share in the morning than in the afternoon. This is caused by shorter waiting times when a person transfer from bus to Brio in the morning. The headways of Brio is much shorter than the headways of regular bus. Therefore, in case of transfer from regular bus to Brio, there is much shorter waiting time the transferring from Brio to feeder bus.

Uber and taxi have higher shares in the afternoon than in the morning. The reason for this is the shorter waiting time in the afternoon. In the morning, the arrival at the Brio station by Uber is random because the passenger does not know the exact waiting time and he cannot exactly schedule the trip by Uber. This is why in addition to pick-up waiting time, it is necessary to add also the waiting time at the Brio station when transferring from Uber to Brio. In the opposite direction of travel in the afternoon, only Uber causes pick-up waiting time.

Bicycle has also higher share in the afternoon although it has higher accessibility in the morning. This is given by the fact that some passengers who traveled by bus in the morning return to the Brio station by other modes including bicycle. In reality, this is of course not possible because they do not have bicycle to use in the afternoon if they did not ride it to the Brio station in the morning. This similar problem is with the calculation of personal vehicle mode share (park and ride) which is also higher in the afternoon. The first reason for this is the same as for higher afternoon share of bicycles. The second reason are different traffic conditions and travel times, and one-way roads that make the drivers choose different paths on their way to/from the Brio station. Walking has higher share in the afternoon because passengers who traveled by bus in the morning from home to the Brio station choose not to wait for the bus connection at the Brio station in the return trip in the afternoon. Instead they choose to walk home from the Brio station.

If Uber cancels its minimum fare and reservation fee, it will have the same mode share value as bicycle (5%) in the morning. In the afternoon, it will be 8% which is more than bus and bicycle (both at 6%). These values are calculated for α=1. For instance, when α is set to 0.3 then Uber has 20%, bus 18% and bicycle 3% of mode share. If the α is 2.0 than Uber (2%) has smaller share than bicycle (6%) but still higher share than bus (1%). This clearly shows how important is to carefully calibrate α. If α=1, Uber would have to further reduce its fare to have the same modal split as the other modes. Below is the list of threshold values of per minute and per mile fares that would give Uber the same mode share in the morning as:

a) Walking – 0 USD per minute and 0.8 USD per mile; 0.45 USD per mile (and keep the original price per minute); or combination of both;
b) Personal vehicle – 0 USD per minute and 0.32 USD per mile; 0 USD per mile and 0.14 USD per minute; or combination of both.

Uber can achieve the same mode share although it can never achieve the same accessibility. This is caused by the fact that not everybody owns a car. However, none of these fare values are accurate. The drop in prices would cause the decreased number of Uber driver-partners which would result in longer waiting times thus higher generalized costs for Uber customers. The higher generalized costs would decrease the Uber mode share. However, the fare values from previous paragraph may serve to determine the value of subsidies needed to attract more people to use Uber as first and last mile transport.

Table 5.5: Modal split based on Alfa, morning peak

Alfa	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
0.3	0.32	0.04	0.03	0.28	0.02	0.31
0.6	0.28	0.05	0.00	0.39	0.00	0.28
0.9	0.24	0.05	0.00	0.46	0.00	0.24
1.2	0.22	0.06	0.00	0.52	0.00	0.21
1.5	0.20	0.06	0.00	0.55	0.00	0.19
1.8	0.19	0.06	0.00	0.57	0.00	0.18

Table 5.6: Modal split based on Alfa, afternoon peak

Alfa	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
0.3	0.22	0.04	0.05	0.31	0.03	0.36
0.6	0.14	0.05	0.01	0.43	0.00	0.37
0.9	0.08	0.06	0.00	0.51	0.00	0.35
1.2	0.05	0.06	0.00	0.55	0.00	0.35
1.5	0.03	0.06	0.00	0.57	0.00	0.34
1.8	0.02	0.06	0.00	0.58	0.00	0.34

Table 5.7 and Table 5.8 display the modal split based on the value of travel time. With decreasing value of travel time, the share of slow modes (bus and walking) increases.

Table 5.7: Modal split based on value of travel time, morning peak

Value of travel time [USD/hr]	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
6.6	0.23	0.05	0.00	0.48	0.00	0.23
6.4	0.24	0.05	0.00	0.48	0.00	0.23
6.2	0.24	0.05	0.00	0.47	0.00	0.23
6.0	0.24	0.05	0.00	0.46	0.00	0.24
5.8	0.25	0.05	0.00	0.46	0.00	0.24
5.6	0.25	0.05	0.00	0.45	0.00	0.25

Table 5.8: Modal split based on value of travel time, afternoon peak

Value of travel time [USD/hr]	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
6.6	0.07	0.06	0.00	0.52	0.00	0.35
6.4	0.07	0.06	0.00	0.52	0.00	0.35
6.2	0.08	0.06	0.00	0.51	0.00	0.35
6.0	0.08	0.06	0.00	0.51	0.00	0.36
5.8	0.08	0.06	0.00	0.50	0.00	0.36
5.6	0.09	0.06	0.00	0.50	0.00	0.36

Somebody might expect the modal split for first and last mile trips to change with Uber introducing (in general) cheaper UberPOOL service in El Paso. But, Uber tries to discourage passengers from taking UberPOOL for short trips by setting the minimum fare for UberPOOL even slightly higher than for UberX. The reason for this is probably the fact that it is more difficult to merge short trips than it is to merge long trips.

Chapter 6: Analysis of Accessibility of a Public Transportation Station in Prague

6.1 Public transportation in Prague

There are six modes of public transit services in Prague: underground trains, urban and suburban trains, trams, buses, ferry, and cableway. Figure 6.1 shows the map of underground and tram lines in Prague. Figure 6.2 is the map of underground and bus lines. Table 6.1 provides an overview of the number of routes of each mode and usual intervals during peak and off-peak. Moreover, there are more than 150 suburban bus lines. All these lines (together with cableway to the top of Petřín hill) operate between 5 a.m. and midnight. There is also a set of nine tram and 25 bus lines operating only at night.

Table 6.1 Overview of public transit routes in Prague

Mode	Number of routes	Peek-hours interval	Off-peak hours interval
Underground train	3	2-3 minutes	5 minutes
Surface train	33	10-30 minutes	30 minutes
Tram	30	2-7.5 mintes	5-15 minutes
Bus	40 metro; 100 feeder	5 minutes (metro); 7.5-15 minutes (feeder)	15 minutes (metro); 15-20 minutes (feeder)
Ferry	7	15 minutes	30 minutes
Cableway	1	10 minutes (summer); 15 minutes (winter)	10 minutes (summer); 15 minutes (winter)

The public transit network in Prague is very dense and the intervals are very short. This makes public transit often more attractive than personal vehicle. Especially in city central area, public transit is the fastest option during the peak hours. There is no need for additional feeder service in the center of Prague. However, planning public transit system is more challenging in places closer to the city limits and in suburbs where the density of trip origins and destinations is low. It is difficult to provide the same level of service in those areas as in the city center. People have to walk longer distances to bus stops and buses on lines that are designed to transport passenger on first and last mile from/to train or underground stations have longer headways. This chapter is to compare first and last mile accessibility of underground and train station in such area using different transportation modes.

Figure 6.1 Map of underground and tram lines in Prague

(Dopravní podnik hlavního města Prahy a.s., 2017)

The study area in Prague is the city's district named Horní Počernice. The goal is to assess the accessibility of this area to suburban train station Praha-Horní Počernice and the underground station Černý. Most travelers use different transportation modes: bicycle, bus, personal vehicle, taxi, Uber and walking to access the station. Horní Počernice is a district on the east edge of Prague. It is mostly low-density residential area separated from high-density residential area Černý Most (where has an underground train station with the same name). Underground station Černý Most is the terminal station of line B. The overall accessibility of Horní Počernice area is to ensure fast and cheap transport to this station or to the Praha-Horní Počernice train station. Underground trains from Černý Most depart every 2-3 minutes during peak hour and every 5 minutes during the off-peak hour. Trains from Praha-Horní Počernice leave every 15 minutes during peak hour and every 30 minutes during the off-peak hour.

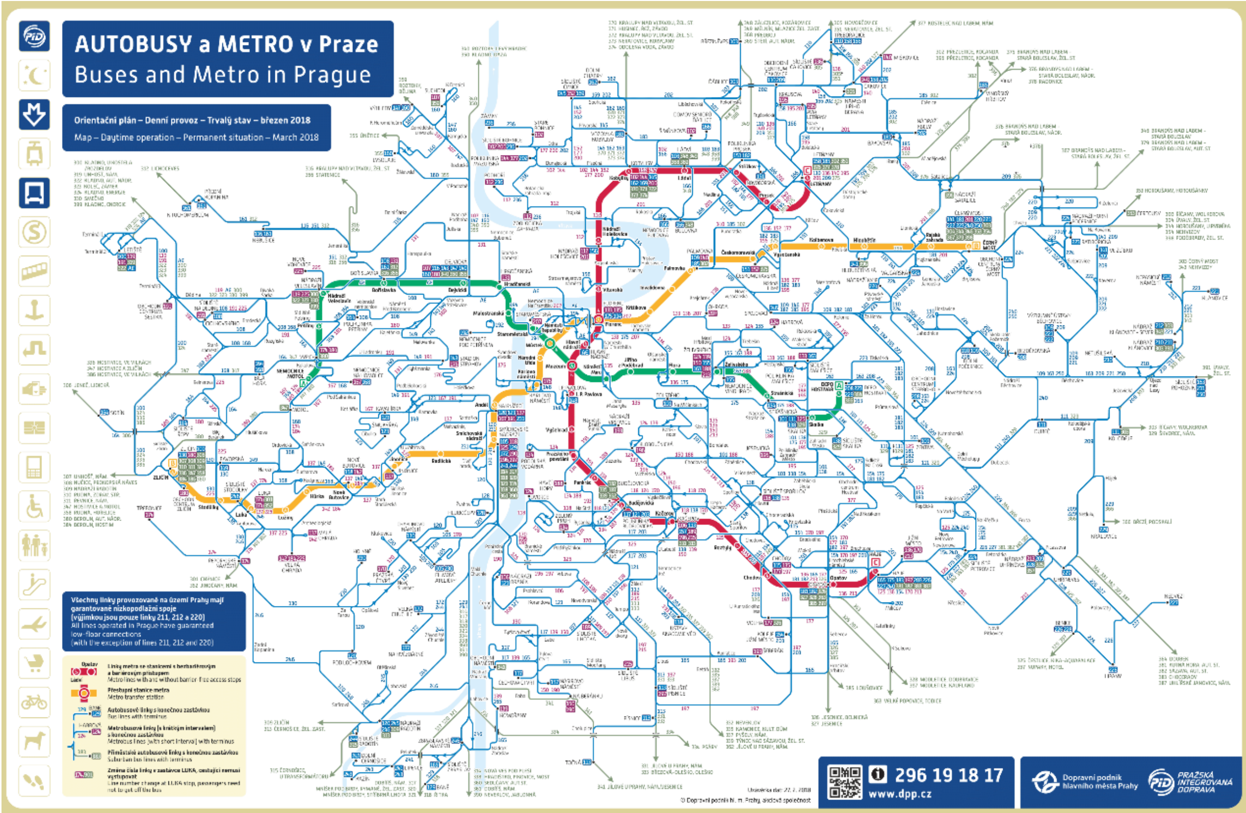

Figure 6.2 Map of underground and urban bus lines in Prague

(Dopravní podnik hlavního města Prahy a.s., 2017)

6.2 Methodology specifics for Prague

The statistical sectors is the most granulated area division in Prague for which there are statistical data about inhabitants. One statistical sector usually has less than 1,000 inhabitants. There are more than 40 statistical sectors in the study area. Those that contain only one high density residential building and are next to each other were merged for the purpose of this research. This makes no difference in the results and it was done only to ease data collection. Travel times TT_{ijk}

and out-of-pocket costs PC_{ijk} have been measured from the centroid of each statistical sector. The assumption is that density within each statistical sector is homogenous.

All the in-vehicle-times were estimated by Google Maps (2018) on Wednesday March 7, 2018. The Uber waiting times data were from Wednesday August 9, 2017. The accessibility to Černý Most and Praha-Horní Počernice were measured for morning and afternoon peak. Travel time values were exported from Google Maps (2018). TT_{ijk} and PC_{ijk} values were measured for passengers who needed to reach Praha-Horní Počernice for the train leaving at 7:01 a.m. and to Černý Most at 7 a.m. during morning rush hour. For the afternoon rush hour, this thesis considered passengers who arrived and needed to transfer to last mile transport at Černý Most at 5:00 p.m. and at Praha-Horní Počernice at 5:06 p.m. Arrival and departure times for Praha-Horní Počernice were set exactly according to the departure and arrival times of the train to/from the center of Prague because of the long train headway. The headway of underground train was 2-3 minutes. The average waiting time was half of the time headway.

The fare system in Prague allows travelers to use the same ticket for multiple public transit modes in a trip. Moreover, the majority of daily public transit commuters have season passes for public transit. Therefore, there are no additional costs for first and last mile trip by bus, and PC_{ijk} was set to zero. Bus travel time $TT_{ij,bus}$ between locations i and j was

$$TT_{ij,bus} = IVT_{ij,bus} + WT_{ij,bus} \tag{6.1}$$

where $IVT_{ij,bus}$ was in-vehicle-time for bus and $WT_{ij,bus}$ was average waiting time during transfer. Travel times were exported from Google Maps (2018). Waiting time was set to half of the headway of follow-up connection for Černý Most because the exact time of arrival/departure of underground related to its short headways is random. At Praha-Horní Počernice, the waiting time if the difference between scheduled arrival and departure of bus and train because it is very likely that passengers will plan their journey by bus to the train station due to long train headways and they will not arrive randomly. It is possible to assume that they will want to take the last bus connection before the train departure in the morning and the first bus that departures after the train arrival in the afternoon in order to minimize their waiting times.

The probability of people using shared bicycles for first and last mile commuting in residential area of Praha-Horní Počernice is low because of the same reasons as in El Paso residential area. Assuming there are free bicycle stalls at Černý Most and Praha-Horní Počernice, out-of-pocket costs for using bicycle are zero. $TT_{ij,bicyckle}$ value is not provided by Google Maps (2018) for Prague so it is derived from walking distance $s_{ij,bicycle}$ and average bicycle speed $u_{bicicle}$ (City of Copenhagen, 2013).

The out-of-pocket costs for Uber $PC_{ij,Uber}$ in Prague were calculated according to the equation

$$PC_{ij,Uber} = \max(MF, IVT_{ij,Uber} * c_{t,Uber} + s_{ij,Uber} * c_{s,Uber}) \tag{6.2}$$

where MF is minimum fare, $IVT_{ij,Uber}$ is in-vehicle-time between locations i and j when traveling with Uber, c_t is Uber fare per unit of in-vehicle-time, $s_{ij,Uber}$ is traveling distance between i and j when using Uber, and c_s is fare per unit of traveled distance.

Uber travel time $TT_{ij,Uber}$ between locations i and j in the morning is

$$TT_{ij,Uber} = IVT_{ij,Uber} + WT_{ij,Uber} + WT_{underground} \tag{6.3}$$

for underground station, and for train station

$$TT_{ij,Uber} = IVT_{ij,Uber} + WT_{ij,Uber} + WT_{train} \tag{6.4}$$

and for both stations in the afternoon

$$TT_{ij,Uber} = IVT_{ij,Uber} + WT_{ij,Uber} \tag{6.5}$$

where $WT_{ij,Uber}$ is average waiting time in a specific zone, $WT_{underground}$ is average waiting time for the underground to depart after being dropped off by Uber, and WT_{train} is waiting time for train to depart after being dropped-off by Uber. It is difficult to estimate the proper value of WT_{train} because Uber passengers do not know their exact waiting time before pick-up and they are no able to plan their journey to arrive to the train station on time without being too early. Uber average pick-up time in Horní Počernice is 7.3 minutes (half of the train headway). However, to estimate the average transition time, it would be necessary to know also the dispersion of Uber pick-up waiting times. Therefore, closest to reality is to assume that time of arrival to train station by Uber is also random and so the average transfer waiting time is half of the train headway. Average Uber waiting times in census tracts in El Paso have been provided by Uber Technologies Inc.

The P+R parking at Černý Most is at 4 minutes walking distance from underground station. Therefore when traveling to or from underground station

$$TT_{ij,car} = IVT_{jP+R,car} + t_{P+Ri,walking} \tag{6.6}$$

where $IVT_{ij,car}$ is in-vehicle-time between j and P+R parking at Černý Most when traveling by car and $t_{P+R,i,walking}$ is walking time from P+R to underground station. When traveling to or from train station $TT_{ij,car}$ between location i and j equals to $IVT_{ij,car}$ because there is parking lot right next to the train station. The parking has limited capacity. This sets also a maximum value for personal vehicle modal split. However, The total transportation demand to/from the train station is not known so it is not possible to tell what the maximum value of the personal vehicle modal split is. However, it is likely that if the capacity of the parking lot is exceeded, passengers will park their cars in the parking spots in the surrounding streets.

Out-of-pocket costs for personal vehicle $PC_{ij,car}$ between locations i and j were calculated according to equation:

$$PC_{ij,car} = s_{ij,car} * f * c_f \tag{6.7}$$

where $s_{ij,car}$ is traveled distance between locations i and j by car, f is average fuel consumption per unit of distance (Federal Highway Administration, 2015), and c_f is cost of fuel per unit of volume in El Paso (ElPasoProud.com, 2018).

Taxi traveling time $TT_{ij,taxi}$ between locations i and j is considered to be the same as for Uber except the taxi waiting time is assumed to be about 15 minutes (according to smartphone application Taxi 14007, 2018). A lot of taxi services were also not available in this part of Prague. Therefore, the real taxi accessibility and modal split is smaller than in the model results. Out-of-pocket costs for taxi $PC_{ij,taxi}$ between locations i and j were calculated according equation

$$PC_{ij,taxi} = s_{ij,taxi} * c_{s,taxi} + B \tag{6.8}$$

where $s_{ij,taxi}$ is traveled distance by taxi between i and j, $c_{s,taxi}$ is average taxi fare per unit of distance in El Paso, and B is meter start charge.

Walking has zero out-of-pocket costs. Travel time $TT_{ij,walking}$ between i and j for walking is provided by Google Maps (2018).

The number of personal vehicles registered in Prague in September 2017 was 1,268,781 (Magistát hlavního města Prahy, 2017). The number of inhabitants in Prague was on 31st of December 2017 1,294,513. Therefore the average number of vehicle per person in Prague is approximately 0.98. For Prague study area, there were the same assumptions as for El Paso. Therefore, values in Equation (4.8) were the same as for El Paso: C=1; $EBTU$=0; EB=0; AU=0; AV=0; I=0; FF=0; CA=0; BU=1.

6.3 Results in Prague

6.3.1 Accessibility

Table 6.2 and Table 6.3 show the dependency of accessibility of train station on value of β. With higher value of β the value of accessibility decreases for all modes. However, their relative value is different. With higher β, there were relatively (compared to their sum) bigger differences between accessibility values of different modes because β is the measure how much were people sensitive to changes in travel time and travel cost. However, the order of modes based on their accessibility stays the same regardless of the β value.

The highest accessibility has bicycle because there were no out-of-pocket costs, no waiting time and its dependency on traffic conditions is very low. This gives bicycle advantage before personal vehicle. Although, personal vehicle has also no waiting times and in general is faster than bicycle, its actual travel time depends on traffic conditions diminishes its advantage over bicycle in this matter. The main factor that decreases accessibility of train station by personal vehicle is high out-of-pocket costs. The third highest accessibility is by walking. There were no out-of-pocket costs and no waiting times. The accessibility using bus is slightly smaller than by foot due to the fact that bus lines in Horní Počernice were designed primarily to transport people to the underground station Černý Most. The lowest accessibility to train station is by taxi and Uber due to long waiting times. Accessibility by Uber is lower than by taxi. Uber has shorter average waiting time but contrary to taxi services Uber has a minimum fare that is very high (220 CZK, about 10 USD) in Horní Počernice.

Morning and afternoon accessibility is relatively the same for bus and bicycle. The difference between morning and afternoon accessibility for Uber and taxi is caused by the extra waiting time on transfer from Uber or taxi to the train. Accessibility of train station by personal vehicle is smaller in the afternoon due to the worse traffic conditions in the afternoon (especially at Náchodská street) the in the morning. Moreover, there is a system of one-way roads in Horní Počernice so the drivers have to change one route on their way to the train station and the other one on their way from the train station. The accessibility by foot is a little bit higher in the morning than in the afternoon because the train station is slightly downhill from the rest of Horní Počernice.

Table 6.2: Accessibility based on β, train station, morning peak

	Accessibility					
β	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
1.0	196.8	717.5	40.9	447.6	79.0	239.6
1.2	88.7	410.8	12.8	230.2	28.3	115.0
1.4	40.7	237.9	4.0	119.2	10.2	57.3
1.6	19.0	139.6	1.3	62.1	3.7	29.8
1.8	9.0	83.0	0.4	32.5	1.3	16.3
2.0	4.3	50.0	0.1	17.2	0.5	9.3

Table 6.3: Accessibility based on β, train station, afternoon peak

	Accessibility					
β	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
1.0	191.7	696.3	46.1	356.1	98.7	216.0
1.2	87.1	397.4	14.8	172.7	37.0	97.6
1.4	40.6	229.8	4.8	83.8	13.9	44.7
1.6	19.6	134.7	1.5	40.7	5.2	20.8
1.8	9.7	80.1	0.5	19.8	2.0	9.8
2.0	5.0	48.4	0.2	9.6	0.7	4.7

As it has been stated before, the minimum fare is the reason why accessibility by Uber is very low speaking of first and last mile trips. If Uber cancels minimum fare, it will reach the same accessibility as taxi in the morning and the afternoon. If Uber was for free (or financed from Prague integrated public transit system budget), it would almost reach the accessibility as bus in the afternoon assuming β=1. With increasing β the difference between Uber and bus accessibility is increasing too. The fact that buses follow a schedule and passengers can reduce their waiting times by planning their trip according to the schedule makes buses faster transport mode than Uber. In the morning, it is not possible for Uber to reach the same accessibility as bus because of the uncertain time of arrival to the train station.

Table 6.4 and Table 6.5 display the accessibility to underground station Černý Most for different modes based on the value of β. In the morning for $\beta \leq 1.2$, the highest accessibility is by bus. The accessibility by bicycle is only slightly smaller and if $\beta > 1.2$, the accessibility by bicycle is the highest one. In the afternoon, the accessibility by bicycle is the highest regardless of value of β because there is longer average waiting time in case of the transfer from the underground to the bus than in case of the transfer from the bus to the underground. The third highest accessibility is by personal vehicle. Accessibility when using taxi and when walking is almost the same. Taxi is slightly higher in the morning and walking is a little bit higher in the afternoon. This may cause by different traffic conditions in different parts of the day. The lowest accessibility is by Uber because of the minimum fare.

Assuming β=1.5, canceling minimum fare make Uber accessibility higher than taxi accessibility in the afternoon but it will not be enough in the morning. Here is the list of threshold values (for β=1.5) of per minute and per mile fares that would give Uber the same accessibility in the morning as:

a) Taxi – 2 CZK per minute (and keep the original per kilometer fare); 16 CZK per kilometer (and keep the original per minute fare); or combination of both;
b) Foot – 0 CZK per minute and 23 CZK per kilometer; 6 CZK per kilometer (and keep the original price per minute); or combination of both.

For the afternoon it is:

a) Foot – 0 CZK per minute (and keep the original price per kilometer); 2 CZK per kilometer (and the original price per minute); or combination of both;

b) Personal vehicle – if Uber is fully financed from Prague integrated public transit system, it will have almost the same accessibility as personal vehicle.

Table 6.4: Accessibility based on β, underground station, morning peak

β	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
1.0	216.1	214.8	42.8	174.1	69.7	66.3
1.2	95.3	95.0	13.5	73.3	24.4	23.1
1.4	42.1	42.2	4.3	30.9	8.6	8.0
1.6	18.7	18.8	1.4	13.0	3.0	2.8
1.8	8.3	8.5	0.4	5.5	1.1	1.0
2.0	3.7	3.8	0.1	2.3	0.4	0.3

Table 6.5: Accessibility based on β, underground station, afternoon peak

β	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
1.0	189.1	207.2	67.7	171.2	76.8	77.9
1.2	81.6	90.5	23.5	71.8	27.4	30.6
1.4	35.4	39.6	8.2	30.1	9.8	12.7
1.6	15.4	17.4	2.8	12.7	3.5	5.6
1.8	6.7	7.6	1.0	5.3	1.3	2.7
2.0	3.0	3.4	0.3	2.2	0.4	1.3

Table 6.6 and Table 6.7 provide accessibility values for different values of travel time. With lower values of travel time, the accessibility increases the most for modes that have long travel times and were cheap (bicycle, walking, bus). Contrary to that, small value of travel time does not result in a big increase in accessibility of Uber and taxi because those modes were too

expensive. Moreover, even if Uber rides were 100% financed from Prague integrated public transit system, it does not improve its accessibility on the level of any other mode but taxi due to long waiting times.

Table 6.6: Accessibility based on value of travel time, train station, morning peak

Value of Travel Time [CZK/hr]	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	27.7	181.8	2.3	85.9	6.1	41.1
300	31.2	205.0	2.3	95.3	6.6	46.3
275	35.6	233.6	2.4	106.6	7.1	52.7
250	41.1	269.5	2.5	120.2	7.7	60.9
225	48.1	315.7	2.6	137.1	8.5	71.3
200	57.4	376.7	2.8	158.4	9.3	85.0

Table 6.7: Accessibility based on value of travel time, train station, afternoon peak

Value of Travel Time [CZK/hr]	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	28.1	175.5	2.7	58.4	8.5	30.4
300	31.6	197.9	2.8	64.9	9.1	34.3
275	36.1	225.5	2.9	72.7	9.7	39.0
250	41.6	260.2	2.9	82.1	10.4	45.0
225	48.7	304.7	3.0	93.8	11.2	52.8
200	58.1	363.6	3.1	108.7	12.1	63.0

Table 6.8 and Table 6.9 show how the accessibility of underground station Černý Most changes with decreasing value of the travel time. Uber can achieve higher accessibility than taxi by cancelling the minimum fare. To achieve the same accessibility as walking, Uber would have to change its fare to 0 CZK per minute and 23 CZK per kilometer, 6 CZK per kilometer (and keep the original fare per minute), or combination of both in the morning. For the afternoon it is 0.4

CZK per minute (and keep the original fare per kilometer), 2 CZK per kilometer (and keep the original price), or combination of both. Uber can never achieve the same accessibility as bus, bicycle and personal vehicle because of the long waiting times.

Table 6.8: Accessibility based on value of travel time, underground station, morning peak

Value of Travel Time [CZK/hr]	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	28.0	28.2	2.4	20.0	5.1	4.7
300	31.6	31.7	2.5	22.2	5.4	5.4
275	36.0	36.2	2.6	24.8	5.7	6.1
250	41.5	41.7	2.7	28.0	6.1	7.0
225	48.7	48.9	2.8	32.0	6.5	8.2
200	58.1	58.3	2.9	36.9	7.0	9.8

Table 6.9: Accessibility based on value of travel time, underground station, afternoon peak

Value of Travel Time [CZK/hr]	Accessibility					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	23.3	26.2	4.8	19.5	5.9	8.4
300	26.3	29.6	5.1	21.7	6.2	9.4
275	30.0	33.7	5.4	24.3	6.5	10.8
250	34.6	38.9	5.7	27.5	6.9	12.4
225	40.5	45.5	6.0	31.5	7.4	14.5
200	48.3	54.3	6.4	36.5	7.8	17.4

6.3.2 Modal split

Table 6.10 and Table 6.11 show the dependency of modal split on α. With increasing α, the share of bicycles and personal vehicles increases too. It is because α shows how sensitive is the population to changes in generalized travel costs. Higher α means higher sensitivity. Therefore, with α>0.23, everybody who can (10% due to the estimated bicycle ownership) will use bicycle because it has the lowest generalized travel costs. Everybody who has a car and does not have bicycle will use a personal vehicle. The rest of people will walk. However, the value of α is probably much lower.

Uber and taxi will have 3% and 4% share only in case α=0.02 in the morning and with increasing α, the modal split of these two modes quickly falls down. Bus has small share because bus lines are designed to transport people from Horní Počernice to the underground station Černý Most rather than to the train station Praha-Horní Počernice. Bicycle share is limited by the bicycle ownership value set. This is why, although it has the smallest generalized costs, bicycle has much smaller share than personal vehicle and for lower values of α smaller than walking and bus. Personal vehicle has the second smallest generalized travel costs and car ownership rate in Prague is 0.98 so it has the highest share regardless of the value of α.

Bus has slightly smaller share in the morning. This is given by the shorter average waiting time on transition from train to bus. Bicycle has almost the same modal share in both directions. Uber has higher modal share in the morning. This result was not expected because there is an extra waiting time on transition from Uber to train because of uncertain time of Uber arrival. Higher morning modal share of Uber is probably caused by different traffic conditions in different parts of the day and the system of one-way roads. These two factor have probably bigger influence on Uber's generalized travel costs. This explanation is likely to be true because the same to factors also cause personal vehicle modal split to be higher in the morning than in the afternoon. On the other hand, these two factor apparently do not cause taxi to have smaller modal split in the afternoon. The reason for this is the fact that taxi do not have per time component in the total fare so the different traffic conditions do not have a negative influence on the total out-of-pocket costs of the trip. Walking has almost the same modal split for the morning and the afternoon.

If α=0.06, Uber can have higher modal split that taxi (which has 0%) in the morning if the company cancels minimum fare. Even if Uber is for free, it will never reach the same modal split as bus, bicycle, personal vehicle or walking. In the afternoon, Uber can be competitive with bus, bicycle and walking if the company cancels minimum fare. Here is the list of threshold values of per minute and per mile fares that would give Uber the same modal split in the afternoon as:

a) Bus – 0 CZK per minute and 26 CZK per kilometer; 2 CZK per kilometer (and keep the original price per minute); or combination of both;
b) Bicycle – 0 CZK per minute and 5 CZK per kilometer; 0 CZK per kilometer and 1 CZK per minute; or combination of both;
c) Walking – 0 CZK per minute and 3 CZK per kilometer; 0 CZK per kilometer and 0.5 CZK per minute; or combination of both.

With current waiting and traveling times, Uber cannot reach the same modal split as personal vehicle.

Table 6.10: Modal split based on Alfa, train station morning peak

	Modal Split					
Alfa	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
0.02	0.13	0.04	0.03	0.52	0.04	0.23
0.04	0.05	0.06	0.00	0.74	0.00	0.14
0.06	0.02	0.06	0.00	0.84	0.00	0.08
0.08	0.01	0.07	0.00	0.88	0.00	0.04
0.10	0.00	0.07	0.00	0.90	0.00	0.03
0.12	0.00	0.08	0.00	0.90	0.00	0.02

Table 6.11: Modal split based on Alfa, train station afternoon peak

Alfa	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
0.02	0.15	0.04	0.00	0.49	0.08	0.24
0.04	0.07	0.06	0.00	0.69	0.02	0.16
0.06	0.03	0.07	0.00	0.81	0.00	0.09
0.08	0.01	0.08	0.00	0.86	0.00	0.06
0.10	0.00	0.08	0.00	0.88	0.00	0.04
0.12	0.00	0.09	0.00	0.89	0.00	0.03

Table 6.12 and Table 6.13 display the modal split for trips from Hroní Počernice to underground station Černý Most based on the value of α. If α>2.12, everybody will use a bus for transport from Horní Počernice to underground station Černý Most in the morning. If α>6.94, everybody who can will use a bicycle for transport from underground station Černý Most to Horní Počernice in the afternoon. Those who cannot use a bicycle will use a bus according to the logit model.

In the morning, bus has the highest modal share regardless of α value. The second most used mode according to the model will personal vehicle. Uber, taxi and walking have 3%, 5% and 2% share with α=-0.02 and with increasing value of α, their share quickly falls down. Bicycle has 3% share with α=0.02 but with increasing α, its modal split slowly rises.

In the afternoon, there is a smaller modal share for bus. This is caused by longer average waiting time on transition from underground than in the opposite direction. However, bus is still the most used mode even in the afternoon according to the model. Uber and taxi modal split is higher in the afternoon because they do not have an extra waiting time during transition between underground and Uber/taxi contrary to the morning situation when a passenger has to wait half of the underground time headway on transfer in average. However, this is not the only cause for the difference between morning and afternoon values for Uber and taxi because 2-3 minutes interval between underground trains departure does not make a passenger wait very long. Personal vehicle has higher afternoon share too. Therefore, it can be inferred that higher afternoon share of all three modes is probably caused also by different traffic conditions and the system of one-way roads that makes drivers to use different route in the morning and in the afternoon. Walking has the same afternoon modal split as the morning one.

If α=0.06 canceling minimum fare will help Uber only to have higher modal split than taxi and walking in the afternoon (1%) but will not help to have higher modal split than 0% in the morning. In order to achieve that, Uber would have to cut per minute fare to 0 CZK and per kilometer fare to 18 CZK, or per kilometer fare to 3 CZK (and keep the original price per minute), or combination of both. Uber can have the same share as bicycle if the company cuts per minute fare to 0 CZK and per kilometer fare to 7 CZK, per kilometer fare to 0 CZK and per minute fare to 2.5 CZK, or combination of both in the morning. In the afternoon this would be 0 CZK per minute (and keep the original per kilometer fare), 1 CZK per kilometer (and keep the original per minute fare) or combination of both.

Table 6.12: Modal split based on Alfa, underground station morning peak

	Modal Split					
Alfa	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
0.02	0.49	0.03	0.03	0.38	0.05	0.02
0.04	0.60	0.04	0.00	0.36	0.01	0.00
0.06	0.65	0.04	0.00	0.31	0.00	0.00
0.08	0.70	0.04	0.00	0.26	0.00	0.00
0.10	0.74	0.04	0.00	0.22	0.00	0.00
0.12	0.78	0.04	0.00	0.18	0.00	0.00

Table 6.13: Modal split based on Alfa, underground station afternoon peak

Alfa	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
0.02	0.39	0.03	0.12	0.37	0.07	0.02
0.04	0.46	0.04	0.04	0.43	0.01	0.00
0.06	0.49	0.05	0.01	0.45	0.00	0.00
0.08	0.49	0.05	0.00	0.45	0.00	0.00
0.10	0.50	0.06	0.00	0.44	0.00	0.00
0.12	0.50	0.06	0.00	0.44	0.00	0.00

The value of α is assumed to be 0.06. Table 6.14 and Table 6.15 display how modal split for trips to (morning) and from (afternoon) train station changes with decreasing value of travel time. It can be observed that share of slow and cheap modes (in this case bus and walking) is growing with decreasing value of travel time. Contrary to that, the modal split of personal vehicles falls down with decreasing value of travel time.

For value 200 CZK per hour, Uber would have to cancel minimum fare to be competitive on first and last mile. In addition to that, the company would have to further cut per minute and per kilometer fares. Otherwise, it will have the same modal split as taxi (0%). Here is the list of threshold values of per minute and per mile fares that would give Uber the same modal split in the afternoon as:

a) Bicycle – 0 CZK per minute and 16 CZK per kilometer; 0 CZK per kilometer and 4 CZK per minute; or combination of both;
b) Bus – 0 CZK per minute and 12 CZK per kilometer; 0 CZK per kilometer and 3 CZK per minute; or combination of both;
c) Walking – 0 CZK per minute and 1 CZK per kilometer; 0 CZK per kilometer and 0.2 CZK per minute; or combination of both;

In the morning, Uber would have to be free to have almost the same modal split as bicycle and it can never reach the same modal split as bus, personal vehicle or walking.

Table 6.14: Modal split based on value of travel time, train station, morning peak

Value of travel time [CZK/hr]	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	0.02	0.06	0.00	0.84	0.00	0.08
300	0.02	0.06	0.00	0.83	0.00	0.09
275	0.03	0.06	0.00	0.80	0.00	0.11
250	0.04	0.06	0.00	0.78	0.00	0.12
225	0.05	0.06	0.00	0.75	0.00	0.15
200	0.06	0.06	0.00	0.71	0.00	0.17

Table 6.15: Modal split based on value of travel time, train station, afternoon peak

Value of travel time [CZK/hr]	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	0.03	0.07	0.00	0.81	0.00	0.09
300	0.03	0.07	0.00	0.79	0.00	0.11
275	0.04	0.07	0.00	0.76	0.00	0.13
250	0.05	0.06	0.00	0.73	0.01	0.15
225	0.07	0.06	0.00	0.70	0.01	0.17
200	0.08	0.06	0.00	0.66	0.01	0.19

For the same α, Table 6.16 and Table 6.17 show the change of modal split for trips to (morning) and from (afternoon) underground station with decreasing value of travel time. Contrary to the trips to the train station, in this case, bus should not be classified as a slow mode (compared to other modes) because its modal split changes only slightly with decreasing value of travel time and in the morning, it even slightly decreases. In general, the modal split in the morning and in the afternoon stays almost the same regardless of the value of travel time. Therefore, the changes in

Uber fare necessary to make it competitive with other modes in case α=0.06 and unchanged value of travel time (discussion about Table 6.9 and Table 6.10) apply even to this case.

Table 6.16: Modal split based on value of travel time, underground station, morning peak

Value of travel time [CZK/hr]	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	0.65	0.04	0.00	0.31	0.00	0.00
300	0.65	0.04	0.00	0.31	0.00	0.00
275	0.65	0.04	0.00	0.32	0.00	0.00
250	0.64	0.04	0.00	0.32	0.00	0.00
225	0.64	0.04	0.00	0.32	0.00	0.00
200	0.64	0.04	0.00	0.32	0.00	0.00

Table 6.17: Modal split based on value of travel time, underground station, afternoon peak

Value of travel time [CZK/hr]	Modal Split					
	Bus	Bicycle	Uber	Personal vehicle	Taxi	Foot
325	0.49	0.05	0.00	0.45	0.00	0.00
300	0.50	0.05	0.00	0.45	0.00	0.00
275	0.51	0.05	0.00	0.44	0.00	0.00
250	0.52	0.05	0.00	0.43	0.00	0.00
225	0.53	0.05	0.00	0.42	0.00	0.00
200	0.53	0.04	0.00	0.42	0.00	0.00

Chapter 7: Comparison of Approaches to Improve First and last Mile Accessibility in El Paso and Prague

To exactly determine the accessibility by different modes, β (Equation (4.6)) must be calibrated according to the real travel data. This factor is a measure of how much passengers react to the changes in generalized travel costs. To know the real differences between accessibilities by different modes, value of β needs to be determined. On the other hand, changing value of β does not change the order of modes based on the accessibility. Moreover, it is not necessary to know the exact value of β because the accessibility results with different β value do not change significantly.

The accessibility is only a relative number and it is not possible to use it to compare accessibility of two different geographical areas, for example, between El Paso and Prague. It can be used only to compare two or more different transportation solutions for the same area.

The highest accessibility in the El Paso study area is by personal vehicle and bicycle. The train station in Prague is the accessible by bicycle and personal vehicle while the underground station is best accessible by bicycle and bus (bus has lower accessibility in the afternoon). The bus lines in Horní Počernice (Prague) are designed to transport passengers between Horní Počernice and underground station Černý Most. This is why the accessibility by bus to the underground station is high while the accessibility by bus to the train station in Prague is small.

The accessibility of the Brio station by bus in El Paso is small (compared to other modes) because of the long headways of buses and therefore long waiting times during the transfer from feeder bus line to Brio. Feeder bus lines also often do not take the shortest journey to the Brio station which increases the traveling time and therefore decreases the accessibility.

The high accessibility of Brio station by personal vehicle is based on the assumption that there is free P+R parking with sufficient capacity next to the Brio station. The high accessibility by bicycle is based on the assumption that there is free bicycle stall with sufficient capacity at the Brio station. The actual accessibility is probably smaller and it could be increased by ensuring that these two facilities have been built next to the Brio station.

P+R parking already exists next to the underground station in Černý Most. However, next to the Praha-Horní Počernice train station there is only small parking lot. Since the accessibility of the train station by buses is smaller than personal vehicles, it is crucial to make sure that the parking lot next to the train station has sufficient capacity. Contrary to that, the accessibility of the Černý Most underground station can further be improved by making bus headway shorter..

Compared to other modes, with current fare, ridesourcing has only slightly higher accessibility than taxi in El Paso. In most of the cases in Prague, ridesourcing has even slightly smaller accessibility than taxi. In both cities, these two modes provide significantly smaller accessibility between studied locations than the other modes. Uber is not suitable for first and last mile transport at all under current pricing due to the minimum fare in both El Paso and Prague. The minimum fare causes the total trip price related to the traveled distance to be extremely high in comparison with other modes (except taxi). However, canceling the minimum fare may not improve the accessibility because without the minimum fare, part of the driver-partners could be discouraged from accepting short trip requests. This would make the average waiting time for first and last mile trips longer and therefore decrease accessibility.

The information of how much cheaper would Uber have to be to provide the same accessibility as bus can help the authorities to assess how big part of payment for each Uber ride would have to be subsidized to achieve the same (or higher) accessibility as other modes. This, together with the information about transportation demand between studied locations, would help the city authorities to decide ridesourcing should be part of the Prague or El Paso integrated public transit system as a first and last mile transport. However, the information about transportation demand was not available for this research.

While improving accessibility of the area by one or more transport modes is the aim of the local authorities, increasing modal share may be one of the goals of the companies operating each mode. To accurately estimate the modal split it is crucial to properly set the value of α. The value of this index describes the sensitivity of a group of passenger to generalized cost. If α=0, the passengers do not mind how big are generalized costs and the group will evenly split amongst all modes they have access to. If α is high enough (the exact threshold value is different in each case), all passengers will choose the mode with the lowest generalized travel costs according to the model. Neither of these extremes is true in reality. It is important to calibrate α according to the real data in order to get a proper modal split. The value of index α also depends on the currency used to express the generalized travel costs.

The order of modes based on the total modal split is similar to the order of modes based on the accessibility. However, contrary to the accessibility, the modal split does not depend only on the generalized travel costs but also on the car and bicycle ownership rates. As the result of this, there are some differences between the two measures. Bicycle modal share is smaller than 10% in all cases although it has one of the highest accessibility values. Also personal vehicle usage is diminished by the fact that not everybody has access to use it. According to the model, personal vehicle is still the most used mode on between locations where bus service is not good enough though. The second most used mode in such cases is usually walking.

Based on the model with other than extreme values of α (α=1 in El Paso, α=0.06 in Prague), Uber will not have almost any customers on first and last mile trips to/from the public station in any of the studied areas. This could be changed by canceling the minimum fare and the reservation fee in El Paso. It would also help to attract about 1% of transit customers on their trip from the underground station Černý Most to Horní Počernice. Regarding other trips in Prague, Uber would have to reduce its per minute and per kilometer fare in order to attract any customers on last mile trips from the train station. To attract at least 1% of the transit customers on the morning trip from Horní Počernice to Černý Most, Uber would have to cut the per minute fare and per kilometer fare to less than half.

Chapter 8: Conclusions

8.1 SUMMARY OF RESEARCH

This thesis compares the accessibility of first and last mile transport to/from public transit stations by ridesourcing and its competitors. In order to understand the concept and limitations of ridesourcing operation, and operation of its competitors, Chapter 2 reviewed their business models. Chapter 3 provided reviews of taxi and ridesourcing laws and regulations in El Paso and Prague, and proposed changes in legislation necessary to make the competition fair for both, taxi companies and ridesourcing companies. In order to choose the best model to measure accessibility, Chapter 4 reviewed the most frequently used accessibility models. It also describes in detail the gravity based model of accessibility and logit model to calculate the modal split. The following three chapters presented and discussed the results of both models, analyzed the causes of the results, and studied the sensitivities of the results in El Paso and Prague. Based on the results, it was concluded that Uber is not a suitable transport mode for first and last mile transport under current fare system due to the minimum fare.

8.2 RECOMMENDATIONS

El Paso has already adjusted the city legislation regarding transportation services. Taxi and ridesourcing follow different sets of rule. However, taxi regulations have been adjusted so that the legislation allows a fair competition between both business modes. Contrary to that, Prague (or Czech Republic) still needs to propose, pass and implement such changes in legislation. This can be done in two ways:

1) One set of rules for taxi and ridesourcing companies that is updated according to latest technological advancements (e.g. use an approved mobile app instead of a taximeter);

2) Similar to El Paso, two set of rules balanced in a way that it enables fair competition between all on-demand transport providers.

Based on the accessibility model for the study areas, if Uber really intends to serve as a complementary mode to the public transit on first and last mile trips by transit (instead of competing it), the company needs to stop charging the minimum fare. Otherwise, its service will not improve the accessibility of the main public transit stations in the studied areas and it is better for cities to stick with buses and Park and Ride (P+R) lots for personal vehicles. Moreover, to reach the same accessibility as the current first and last mile transport modes, Uber needs to cut down even other components of the fare while keeping the same driver earnings in order to maintain the same average waiting time. This might be done by financing part or the whole costs for Uber rides from public transit budged so that Uber would replace feeder bus lines in low-density areas. This thesis provides the highest prices that passengers shall pay Uber so that it provides the same accessibility as bus. These values can serve the public transit authorities to assess if it is cheaper to order bus service or pay part of public transit passengers' cost for Uber first and last mile services.

8.3 Future research

This thesis could not determine if it would be more economically viable to subsidize Uber instead of buses due to the lack of data. The future research can focus on the collection and evaluation of the data that could be used to calibrate the gravity based model for potential accessibility, to choose the right form and calibrate the logit model for modal split, and to determine if Uber would cost less on the first and last mile transport. These data are: real modal split for the first and last mile transport in the study areas or areas similar to them, total bus ridership for a first and last mile transport, and average cost per person-kilometer for buses.

Moreover, the basic form of logit model that is used in this thesis requires the calibration of only one index α. However, the real data may fit better the form of logit model in the following equations:

$$MS(i,k) = \frac{e^{\alpha_1 + \alpha_2 C_{ik} + \alpha_3 C_{ik}^2}}{\sum_k e^{\alpha_1 + \alpha_2 C_{ik} + \alpha_3 C_{ik}^2}} \tag{8.1}$$

or:

$$MS(i,k) = \frac{e^{\alpha_1 C_{ik}^{\alpha_2}}}{\sum_k e^{\alpha_1 C_{ik}^{\alpha_2}}} \tag{8.2}$$

The access to the modal split data in study areas is needed to determine which form of logit model better describes the real situation. This can be done in the future research too.

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