ZADÁNÍ BAKALÁŘSKÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Zadávající katedra/ústav: **Katedra počítačů**

Studijní program: **Softwarové inženýrství a technologie**

II. ÚDAJE K BAKALÁŘSKÉ PRÁCI

Název bakalářské práce:

Estimating Impact of New Street Designs on Urban Traffic Flows by Computer Simulation

Název bakalářské práce anglicky:

Pokyny pro vypracování:

1. Study the existing urban traffic simulation tools with a focus on large-scale traffic flow modeling.
2. Prepare a short review of the available tools and choose the proper tool for analyzing the impact of street design changes on urban traffic flows.
3. In collaboration with the Faculty of Architecture at TU Delft, specify a concrete scenario of street design change.
4. Implement features necessary to perform the study.
5. Perform an analysis of the impact of street design change on traffic flows using the chosen simulation tool.

Seznam doporučené literatury:

[1] D. Fiedler, M. Čertický, J. Alonso-Mora and M. Čáp, "The Impact of Ridesharing in Mobility-on-Demand Systems: Simulation Case Study in Prague," 2018 21st International Conference on Intelligent Transportation Systems (ITSC), 2018, pp. 1173-1178.

[2] Daniel Krajzewicz, Jakob Erdmann, Michael Behrisch, and Laura Bieker. "Recent Development and Applications of SUMO - Simulation of Urban MObility"; International Journal On Advances in Systems and Measurements, 5 (3&4):128-138, December 2012

[3] Horni, A., Nagel, K. and Axhausen, K.W. (eds.) 2016 The Multi-Agent Transport Simulation MATSim. London: Ubiquity Press.

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Datum zadání bakalářské práce: **24.01.2019** Termín odevzdání bakalářské práce: **24.05.2019**

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III. PŘEVZETÍ ZADÁNÍ

Studentka bere na vědomí, že je povinna vypracovat bakalářskou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v bakalářské práci.

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Datum převzetí zadání   Podpis studentky

Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Computer Science

Bachelor's Thesis

Estimating Impact of New Street Designs on Urban Traffic Flows by Computer Simulation

Aleksandra Pravednikova

Study Programme: Software Engineering and Technology
Supervisor: Ing. David Fiedler

May 2019

Acknowledgement

I would like to express great appreciation to my supervisor, Ing. David Fiedler, for his valuable advice, support, and patient guidance during the writing of this thesis. I am also especially grateful to Anca Ioana Ionescu for her help with urban planning part and for providing the specific urban design to be implemented. I would also like to thank Ing. Martin Schaefer for his useful advice and help with the project.

Declaration

I declare that I have elaborated this thesis on my own and I have quoted all used information sources in accordance with the Methodical instructions about compliance with ethical principles for writing academic theses

In Prague on May 23rd, 2019 ____________________________

Abstract

In this work, we evaluate the impact of an urban planning strategy in Prague using a multi-agent large-scale simulation framework Agentpolis. In collaboration with the Faculty of Architecture at TU Delft, we have selected a specific street design based on the already existing project and adapted it for one of the Prague's districts. This selected scenario reduced the maximum allowed speed and banned traffic on specified streets. Through adjusting Agentpolis to the selected scenario, we performed a traffic simulation of the whole city of Prague with the modified road network and obtained the data about traffic density and travel delays. The comparison of data before and after modifications has shown a slight increase in traffic densities in the selected district and the emergence of travel delays. However, no additional congestion has appeared, and more than 60% of travel delays are under 5 minutes.

Abstrakt

V této práci, my vyhodnocujeme dopad strategii urbanistického plánování v Praze za použití multi-agentního simulačního frameworku velkého měřítka Agentpolis. Ve spolupráci s Fakultou architektury z TU Delft jsme zvolili konkrétní návrh ulic, založený na již existujícím projektu, a přizpůsobili jsme ho jedné z pražských čtvrti. V tomto zvoleném scénáři jsme snížili maximálně povolenou rychlost a zakázali provoz aut v konkrétních ulicích. Po úpravách Agentpolisu s ohledem na zvolený scénář, provedli jsme dopravní simulaci celého města Prahy s upravenou silniční síti, a obdrželi jsme data o hustotě dopravního toku a zpoždění cest. Porovnání dat před a po úpravách ukázalo, že se hustoty dopravních toku lehce zvedly ve vybrané čtvrti, a že se objevily cestovní zpoždění. Nicméně, nevznikly nové zácpy, a více než 60% cest bylo zpožděno o méně než 5 minut.

Keywords

traffic simulation, urban planning, urbanism, multi-agent simulation, traffic flow

Klíčová slova

simulace dopravy, urbanistické plánování, urbanismus, multi-agentní simulace, dopravní tok

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Chapter 1

Introduction

For more than half a century, cities around the world have been built around an automobile. A car was considered as a futuristic element, which would transform the lives of people and bring them the freedom of movement. That led to high automobilization when a family is expected to have a car. With the growing number of automobiles kilometers of highways are appearing, and buildings are being destroyed to provide more parking space. This does not only destroy the image of cities but also negatively influences people's health and quality of air.

One of the issues of this approach is congestion. With the rising number of cars, the capacity of roads becomes not enough to accommodate more vehicles, and as an expected solution, city planners propose to enlarge the roads, adding more lanes, which are often made from sidewalks. Ironically, this motivates people to use a car, which, consequently, raises the number of automobiles.

A concept of walkability is proposed as an alternative to automobilization. This contrarily encourages people to leave a car, creating the necessary conditions for that and making a city more friendly to pedestrians. Basing ourselves on this concept, we choose a specific urban planning strategy in collaboration with the Faculty of Architecture in TU Delft and try to evaluate its impact on the city of Prague.This strategy is oriented on the decrease of maximum allowed speeds and slight modification of the road network.

For this purpose, we perform the simulation of traffic flows using a large-scale multi-agent simulation framework Agentpolis, which is written in Java. To do so, we adjust the framework to the specifics of the case, which required creation of a new type of an agent, representing a private car. The adaptations are also done in order to obtain the data relevant for the study, as traffic density for the road segments and difference between travel times of both scenarios. After that, we manually modify the road network accordingly to the selected strategy, using a specific software tool. After the simulation, we process the data from the simulation using Python scripts adapted for this particular case in order to obtain information relevant for evaluation.

Chapter 2

Urbanism

Urbanism studies the image and shape of cities, what affects it and how to make cities better from different aspects.

The basic needs of city residents stay the same throughout the centuries. Walking and accessibility remain important through many trends. After several decades of automobilization, when cars got the highest priority, the urban image has fundamentally transformed. Instead of small streets have appeared broad highways, able to accommodate hundreds of cars. Many cities became divided into several areas with different purposes - residential, industrial, commercial areas. It became complicated to get from one area to another just walking, people needed a private car to achieve the required mobility. Suburban sprawls, characteristic for the majority of American cities, are directly connected with high automobile dependency. However, lately, it becomes obvious that automobilization brings many negatives, like health issues, air pollution, higher risk of car accidents. It also can weaken social connections between people.

Now the attention of urban planners turns back to people. Many urbanism trends now propose building cities around people and their activities. They encourage re-urbanisation, to mix residences, offices, and institutions in one area instead of dividing them apart. They also motivate urban planners to create spaces explicitly for pedestrians. Switching priorities from cars to people also means put the interest of a human first. People need to walk, communicate with other people, to be able to get whenever they need. Thus, the theory of walkability became very popular in the world.

Among other trends, there are many ones based on nature and health. Some urbanists are looking for inspiration in nature, creating "green cities". Much effort is put into reducing air and water pollution. Thousands of trees are planted on streets and rooftops.

Many restrictions are introduced for automobiles. Many European cities limit cars in city centers, using lower automobile speeds, making the parking price extremely high, or completely banning cars in some areas. Many street design elements are used to make drivers drive slower - for example, elevated pedestrian crossing, chicanes, reduced lane number on a road, or narrow line width. The research, done by World Resource Institute[1], shows that a pedestrian has 15% chance to survive accident involving car moving with speed of 50km/h. However, with decreased speed, the chance to survive an accident drastically grows, when a pedestrian has a 90% chance to stay alive when an automobile has speed 30km/h.

Chapter 3

Connecting Urban Planning and IT

3.1 Role of IT in Urbanism

New technologies have the potential to closely intertwine with urban planning. Expected future trends involve the maximal usage of technologies to modify the shape of cities. A concept of a smart city integrates technology and Internet-of-Things(IoT) into a city. This concept is based on data collection, its analysis and following management of different systems and objects. The areas of a smart city functionality can be, for example, traffic regulation, energy consumption, information providing, and many other options. Autonomous vehicles are also expected to change completely the transportation.

However, some technology may be already used for urban planning. A transition to new urbanism strategies in a city may be complicated. It is hard to predict how the city would react to the new changes due to the high complexity of a city structure and large scale. Moreover, those changes often cannot be canceled easily. To predict the possible outcomes of new strategy implementation, urban planners can use visualization and simulation tools. This stage of computer simulation allows to test planned changes in a secure environment and to adjust the plan if necessary until it matches the expected result.

Many different aspects of city planning can be simulated, from traffic flows through walkability to whole cities. Virtual environments are able to show visually the result of a project, simulation tools allow to test and compare alternative hypotheses. Even city-building games can be considered as a mix of visualization and simulation tools.

The scale of visualization or a simulation may highly depend on computational resources; however, recent computers are mainly able to perform these activities. However, some of them, like 3D modeling, may be very demanding, the same as detailed large-scale simulations.

When implementing an urban planning project, one might want to know how pedestrians and traffic would react to those changes. There are many simulation tools that allow simulating pedestrian and traffic flow on different scales, from one street up to the whole country. In turn, traffic can be divided to distinct modes as well: private vehicles, public transport, bikes, emergency cars, autonomous vehicles. Some software can simulate different modes at the same time, including the combination of vehicle and pedestrian flows.

In this work, we focus only on the simulation of traffic flows, in particular, private vehicles. For this case, we use a multi-agent large-scale simulation software, which is based on actions of individual agents - entities with their particular goals and pre-described behavior. The large-scale simulator is required to be able to reproduce the whole city.

3.2 Simulator Choice

There is a broad choice of traffic flow simulation software of different scales and made for a diverse set of goals. For the selected scenario we need large-scale, microscopic or mesoscopic simulation tools. An available visualization is an advantage but is not strictly required. The final choice of possible variants was based on the research described in the article "A Comparative Study of Urban Road Traffic Simulators"[2]. The selection was narrowed to three candidates - SUMO, MATSim and Agentpolis packages. All of them adapt microscopic traffic model with space-continuous simulation. They provide a 2D visualization, and all three are capable of city-scale simulation. We take a more detailed look at these packages below.

3.2.1 MATSim

MATSim(Multi-Agent Transport Simulation)[3] is a simulation toolbox which provides several modules oriented on different aspects of traffic flow simulations. The modules can be modified for specific needs. MATSim, through its open-source code and modularity, supports high customizability, where a user can modify software behavior adapted for the specific scenario. The modifications are done via XML configuration files, including network adaptations. Visualization of simulation is presented by the Via application, which has certain limitations in the free version. MATSim also provides different types of transport, including public transport.

Through its 17 years of existence, this simulation software was used in many projects and currently it is mentioned in a broad number of publications, the majority of which are specialized in route planning, simulations of autonomous cars and others.[1]

3.2.2 SUMO

SUMO[4], which is an abbreviation for “Simulation of Urban MObility”, is a multi-modal simulation package with a wide range of provided functionality. The level of available traffic simulation is very detailed, where, amongst others, can be simulated such things as vehicle collisions, emergency transport, speed limit violations, drivers’ impatience being in a traffic jam, etc. The software also includes pedestrian mode and public transport. However, the main issue of this simulation tool is its low flexibility and high difficulty. Any adaptations in a road network may be very complicated, which is critical for our work. SUMO also can be demanding on computational resources.

SUMO is used in different research topics[5], amongst which are vehicular communication, route planning, and traffic light algorithms.[2]

3.2.3 Agentpolis

The third option was a multi-agent urban mobility simulation framework *Agentpolis*, which is being developed on the Faculty of Electrical Engineering in CTU, Prague. As the rest of the options, this is a large-scale multi-agent simulator, able to perform a whole city simulation. Its advantage is high flexibility, as thanks to its open-source code it can be modified easily according to one’s needs. The package includes supporting tools for analysis purposes, network modifications and others. Agentpolis is currently actively developed, and new functionality is planned to be added to suit new projects.Some of the recent works done in the framework were focused on the analysis of the different modes of autonomous vehicles in a city, for example, an impact of Mobility-on-Demand(MoD) and ridesharing[6].

3.2.4 Selected Option

After considering available options, we have selected Agentpolis as a framework for the scenario to be simulated. Agentpolis provides less functionality compared to other options, as there is no public transport mode or intermodal planning for agents. However, as the goal of the work is to test a strategy in the simplified environment, we do not need

[1]MATSim publications http://www.ivt.ethz.ch/en/research/matsim/publications.html
[2]Selected SUMO publications https://sumo.dlr.de/userdoc/Publications.html

transit mode or intermodal planning. The key arguments in the final selection were the simplicity of a simulator and fast preparation of a simulation. The Agentpolis framework was a leading option by these criteria, as the environment was already known, and the package is already pre-prepared for the Prague simulation.

3.3 Define a Strategy

All following urban planning decisions have been discussed and based on collaboration with Anca Ioana Ionescu from Faculty of Architecture in TU Delft.

We have narrowed an area of topics of interest to limited accessibility and slowing down allowed speeds. Prague was considered as a subject city to be tested from the beginning of this project. The main urbanistic idea throughout the decision process was European cities' trend of limiting cars accessibility in the city center. Several European capitals have restricted cars in the center, using different strategies. Generally, these strategies are based on encouraging people to use different transport modes like transit, bike or walk instead of using a private vehicle. These restrictions can be done in several ways: complicate parking by reducing parking space or introducing high parking fee, limit cars entrance in certain hours, or completely ban cars from a certain area and creating car-free zones[7].

Another concept which switches the focus from cars to people is shared space, where cars and people have the same rights and priorities, sometimes pedestrians have higher priority than cars. Often those areas do not have any territory marked as a road or a sidewalk; on those streets may even not have any traffic signs, which is a feature of so-called "naked streets". These measures, surprisingly, increase the attention of a driver to make his drive much safer. A more detailed description of these concepts can be found in the book "Walkable Cities" by Jeff Speck[8].

One of the successful experiments based on those principles - *Superblock* - was introduced in 2016 in Barcelona.[9] The reaction of the population of Barcelona was highly approving, so in the following years, other Superblocks were installed through all the city. Superblock's concepts can be described as follows: a large area of the central district of Barcelona, Eixample, is built in a well-known grid, where all square blocks have the same size. In this project, the first Superblock in Poblenou merges 9 such blocks into one Superblock, where the roads between individual blocks stop to belong essentially to cars. Instead of this, this road space between the small blocks is transformed into a shared space, which is returned to the residents of those streets and their children. This experiment resulted in a halved number of cars inside this block, reduced noise level and increased number of green zones and spaces for people. This has been achieved by decreasing the number of lanes on these streets to only one lane, forcing drivers to turn on each crossroad, and consequently, drive much slower.[10]

We have decided to implement an urban plan based on the Superblock project in a simulation. The advantage of this strategy is that it includes slowing down speeds and it may not require cardinal modifications in a road network.

Chapter 4

Methodology

To estimate the impact of the chosen urban planning design, we go through the following steps: 1)select an area in Prague, matching the requirements of the chosen strategy; 2)define an exact urban plan and adapt the road network accordingly; 3)prepare Agentpolis for the simulation; 4)perform a simulation of scenarios; 5)evaluate the results using Python scripts. Next sections describe those steps in detail.

4.1 New Urban Plan

4.1.1 Select a City Area

We have decided to select one district of the city for the experiment. The choice of the area was based on several factors:

- Grid-structured streets for better imitation of Superblock
- Riverbank is an advantage
- Struggles with traffic issues
- Cultural or recreational influence in the city(the selected neighborhood should not be strictly residential)
- Located in the extended city center

These conditions left us with two final candidates - Holešovice(an area to the right from Argentinská street) and Vinohrady(an area between Náměstí Míru a Flora). In the end, we have chosen Holešovice district, as it also satisfies the condition of recommended location nearby riverbank.

The Holešovice district is especially suitable for Superblock implementation thanks to its design - the main part of the streets crosses each other at the right angle, creating a grid structure. The set of the streets can be divided into minor and major streets. Major streets have a higher traffic load, are more often congested, they connect the district with the other ones, so the traffic flow here is much higher. Minor streets are the streets that are less used, have less capacity and are usually used only to get from main streets to particular houses or for parking.

The district is surrounded by the river from three sides. There is a port on the northern side, so this area is still mainly industrial, but the situation changes towards the eastern and southern part - the roads form an embankment there. Although there is a sidewalk on the embankment, the street is clearly unattractive for pedestrians, as it was designed mainly for cars and the traffic flow here is too high for a comfortable walk. The whole neighborhood is currently not adapted for walkability, despite the wide sidewalks, trees on several streets and rare points of local business. We can suppose that the reason for it lies in the traffic situation and industrial past of the district. As the roads are clearly adapted for higher traffic flow and the average speed is between 35 and 50 km/hour, it encourages drivers to drive faster. However, the Prague city hall has decided to reduce maximum allowed speed in the next years down to 30 km/hour on selected areas in the Holešovice district.[11]

The selected district has another feature which is partly connected with the speed limits. On the eastern side, the district is connected via a bridge with another neighborhood. Several months ago the bridge has obtained a status of endangered, which led to a traffic ban for 6 weeks. Now the traffic has been allowed, but with several restrictions. The future of the bridge remains unclear. In our design, we propose an alternative scenario for it.

4.1.2 New Design

Basing on the selected strategy, we have selected a road network design in collaboration with Faculty of Architecture in TU Delft[7]. The strategy is applied exclusively on the Holešovice district. The set of streets in the district was divided into "Superblock contour" and "inside Superblock contour". These two sets correspond with the general vision of major and minor streets in Holešovice. The main part of adjustments can be expressed in the rule: "contour" streets allowed speed is reduced to 30km/h and "inside the contour" streets allowed speed reduced to 10km/h. We have also banned traffic from one street on the embankment and from Libeňský bridge, leaving these streets potentially open only for pedestrians, bikes and public transport.

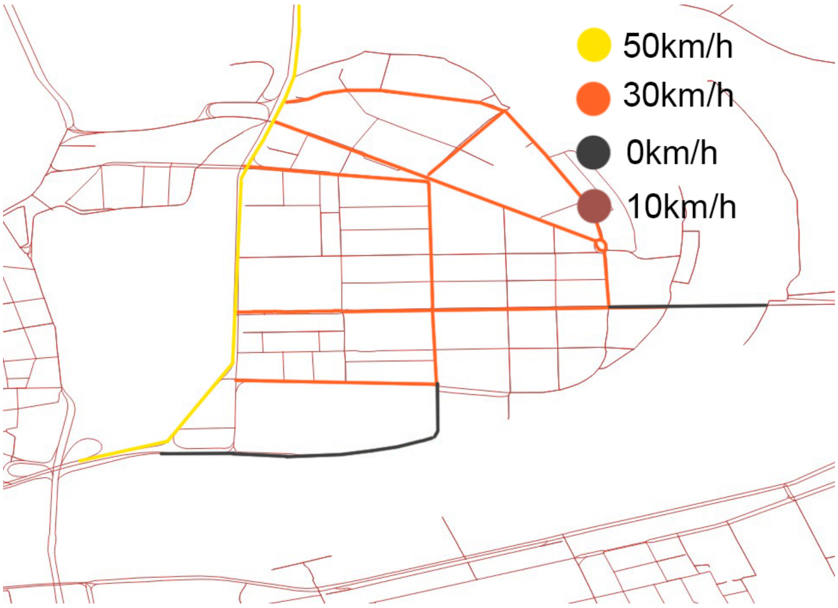

Figure 4.1: A new plan of the Holešovice district. The shown speeds are valid only inside the district

4.1.3 Road Network Adaptations

A city *road network* in the simulator is represented in the form of a directed graph, where edges are road segments and nodes are all the connecting points, intersections, etc. As an input Agentpolis uses .geoJSON files to create a road graph. The road network of Prague was obtained from OpenStreetMap(OSM)[1], which was later converted into the required format. Elements in the .geoJSON format contain several parameters which bring additional information about the road network structure. One of the relevant parameters for the scenario is the maximum allowed speed which is set for every given road segments. The speed limits were obtained from OSM map as well.

The network adjustments were done in QGIS, which is an open-source Geographic Information System(GIS) application[2]. This software allows, amongst many other functions, adjusting a road network and its parameters. The required modifications were done manually, manipulating the maximum speed parameter on the streets to be updated. We have also forbidden the traffic movement on the selected streets, setting the maximum allowed speed to 0 km/h. Both map variants - original and Superblock adaptation - created a base for two scenarios for future simulation.

[1]© OpenStreetMap contributors, openstreetmap.org

[2]QGIS Development Team (2019). QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Figure 4.2: An example of a road nework in QGIS

4.2 Agentpolis Adaptation

Agentpolis is a simulation software written in Java. The advantage of Agentpolis was the possibility to adapt it for our needs, modifying the code to reach the required properties. For the scenario, we use an additional Amodsim package, which prepares a simulation environment for Prague experiment.

The main difference between the original version of Agentpolis and the version prepared for our case lies in the agents' behavior. The base version, which is adapted for the simulation of Mobility-on-Demand(MoD), uses two types of agents - "on demand" vehicle and passenger. When a demand appears, a passenger agent is created at this moment. Then the vehicle is chosen by the system to serve the demand. When the passenger arrives at the finish point, the passenger agent disappears, and the vehicle returns to a station or serves next demand. However, in our scenario, we use only private vehicles, which leads to modification of agents' system. We also had to update the surrounding infrastructure to match the new type of agent and to obtain relevant statistical data, which was later used in Python analysis scripts.

For our scenario, the preferred type of agent would be a privately-owned vehicle. We have simplified the functionality of an agent in MoD, and merged passenger and "on-demand" vehicle into one agent to simulate the behavior of a private vehicle, belonging to an agent. In brief, the behavior of the simplified agent can be described as following: at the moment of a newly occurred demand, a vehicle is created at the starting point of the demand. When the vehicle arrives at the finish point of the demand, the vehicle agent disappears.

To do so, we created a new Java class PrivateVehicleAgent. This agent is based on two agents from the previous version of Agentpolis - OnDemandVehicle and DemandAgent. The main changes were done in methods called on agent's creation and removal. When an agent is created, it is added into the storage of all currently alive agents. At the same time, the current time is saved to be used later for statistics. After performing the trip, the agent saves statistical data and removes itself, at the same time removing its entity from the agents' storage.

The events processing was also updated. When the system receives an event of new demand, it manages the serving agent's cycle of life, creating it, passing to it the order to drive and deleting the agent afterward.

Addition of the new type of agent required updates of corresponding classes from the system infrastructure. For example, the statistics computation had to be adapted for PrivateVehicleAgent class. The visualization was updated to be able to show new agents on a map.

For each simulation of the scenarios we manually set the framework to use different road networks, prepared in the required format.

4.3 Scenarios Simulations

Both scenarios, regular and adapted, were run for 1 hour of simulation time with the start at 6 a.m. The list of trip demands was generated by the activity-based agents model, used in Agentpolis. For both scenarios, the number of served demands was under 3000.

A simulation in Agentpolis begins with internal preparation of the environment, where the road network is being set and demands are loaded. The road network is taken from the pre-prepared .json files, which were created earlier. When the simulation starts, demands begin to appear as an event at the corresponding start time of the demand. When an demand event appears, a private vehicle agent is created at the start point of the demand and this demand is assigned to this vehicle. The vehicle agent retrieves a plan of the trip and follows it until the finish point of the demand. At the end of the trip, the information of the demand is written into the statistics file; after that, the private vehicle agent disappears. During the simulation, every 10 minutes for each road segment is counted its load, which equals to the number of vehicles passing through the selected segment. This information is also saved into a file.

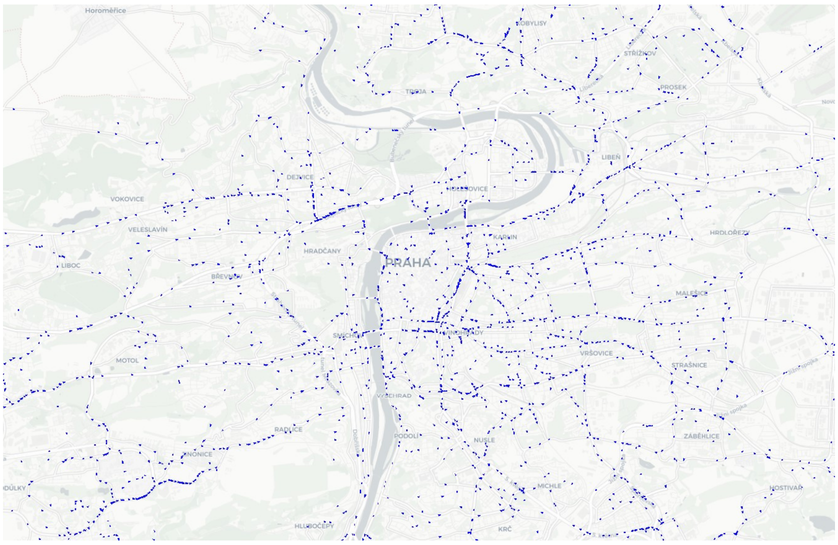

Figure 4.3: An example of Agentpolis visualization. Blue triangles represent private vehicles.

4.4 Processing Results

Several files with statistical data are generated after simulation, which still has to be processed to obtain necessary information about simulation results. We have used two sets of data produced after simulation - road segments loads and information about occurred demands.

Road segments loads represent a number of vehicles per road segment which is counted in certain time intervals(in this scenario, 10 minutes), which is basically a *traffic density*. This density is one of the most important properties of traffic, along with traffic flow. The fundamental diagram of traffic flow represents the relation between flow and density. Traffic flow is the number of vehicles per time unit passing through a reference point. The fundamental diagram shows that traffic flow rises until traffic reaches the point of the critical density. This is the point of the highest traffic flow when vehicles are still able to move freely without stops. After that point with increasing density, the flow begins to decrease until it reaches the level of zero. This point on the traffic density is the jam density when vehicle flow stops completely. The density between the critical density and jam points is considered as congestion. The critical density value is equal to 0.08 vehicle m^{-1}; this value is based on the research done in [12].

The demand data contains information about each demand - start time, finish time, an ID of a vehicle agent which served the demand. From this data, we have counted the travel time of each served demand as the difference between the demand start time and demand finish time. These values were later used in travel delays histogram, where were

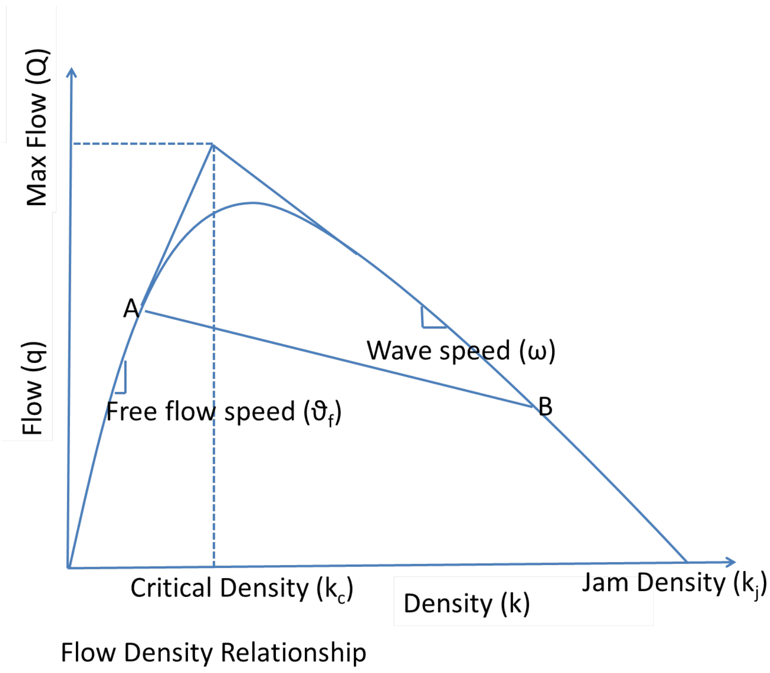

Figure 4.4: The Fundamental Diagram of Traffic Flows. Image from [13]

computed differences between travel times in regular scenario and modified one.

For the data analysis, we have used Python scripts from the Amodsim package with certain modifications. Generally, there were two types of data analysis - the analysis of traffic densities and travel time delays. The first one uses the data obtained from computed road segments loads - the traffic density. The script processes the obtained load to put the results on the road network map by color intensity. For the histogram of traffic densities, there is also a filtration applied by the location of the selected edge for the four last diagrams. We filter the edges to inspect only those which pass through the selected district.

The other analysis works with travel time delays. This script uses the data of demands, which were previously filtered by the location as well. The demands were filtered in Agentpolis during the simulation, where by the time of demand appearance, a trip planner creates a trajectory to be followed by vehicle, and the system controls if any of the edges of the proposed trip crosses the district. If yes, the data of this demand is written to the statistics file, which is later used by Python scripts.

The output results are provided in a visual form for clarity. Three diagrams were generated: a traffic density map of Prague of both scenarios, a histogram comparing traffic densities of both scenarios and a histogram representing the difference between travel times of both scenarios.

Chapter 5

Results and Discussion

5.1 Results

In this section, we discuss the impact done by new street designs, basing on the results obtained after simulation.

The histogram on the figure 5.1 represents a percentage distribution of the travel delays,

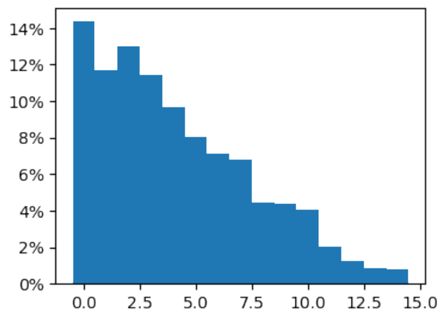

Figure 5.1: Histogram of differences between travel time in both scenarios

where a delay is a difference between travel times in both scenarios. Each bin shows a percentage ratio of travel delay times. Only trips from the Holesovice district were taken into consideration. As we can see, more than 60% of all trips were delayed no more than 5 minutes, from which 14% of trips were finished at the same time, despite the allowed speed reduction and traffic ban on several road segments.

The map on the figure 5.2 is a heat map of the traffic densities distribution in the city. The shown fragment of the density map shows the Holesovice district and its surrounding neighborhoods. Full city map can be found in the attachment. The colors from pale yellow to dark red represent road segments with high traffic densities, increasing with

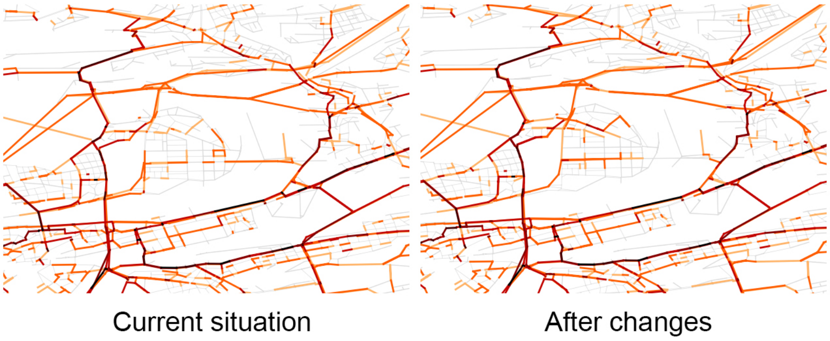

Figure 5.2: Traffic densities on the map of Holešovice

an intensity of a color. Black color shows congested roads. Inside the district, several differences can be seen between the scenarios: the density has decreased on certain road segments, but the traffic was balanced by rising density levels on other streets. The most noticeable changes are the decreased traffic level on the southern embankment and increased density in the southern part.

The traffic density histogram on figure 5.3 is another way to present information about traffic densities. This diagram is based on the same results as the previous map but brings a better numerical data demonstration. The first column shows the densities in the regular scenario and the second is the modified scenario. The first row displays densities through all the city network, the second one magnifies the histogram around critical density. The third row shows the data filtered on Holesovice district, again scaled up by the edge number. As we can see, the net number of edges with higher traffic density has increased, but only by a small number relative to the sum of all edges even inside the Holesovice district.

5.2 Discussion

The obtained data about traffic density shows that the proposed changes in the road network have slightly increased the intensity of traffic, but this difference is small. There are some major changes inside the Holesovice district like the decrease of traffic intensity near the embankment and increase in the northern part, but as we can see from the histograms, the numerical difference is not very noticeable. Some travel delays inside the district have appeared in comparison with the current situation, but as the majority of them is under only 5 minutes it should not bring much inconvenience.

To obtain more statistically reliable results from the simulation, we could extend the simulation to several agent types. In this scenario, we have used only one type - private

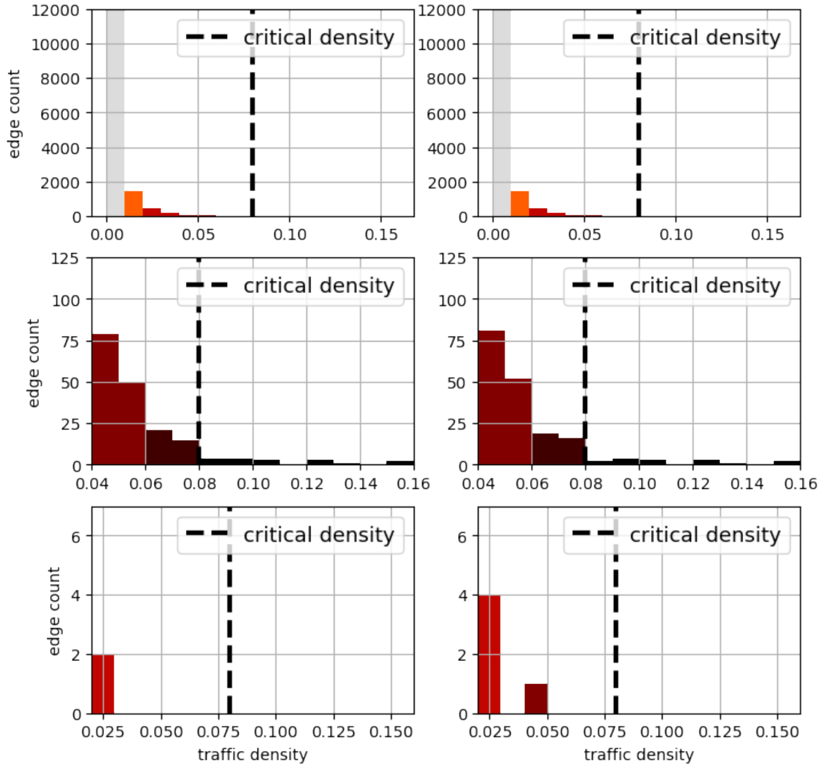

Figure 5.3: Traffic density histograms

vehicles. Extending the number of agents and setting communication between them could make the results more approximate to a real-life situation. One of the possible strategies could be to divide the private vehicle agent back to two entities - private vehicle and human. A human agent can have some goals to get from one point to another when he can select the most appealing way to get to the goal point. Implementing public transport and the possibility to walk can bring more options for route planning. We would also need to analyze the data taken from a longer simulation time, for example, 24 hours of simulation time for both scenarios. However, due to the limited computational performance available, it was not possible.

5.2.1 Transition to Urbanism

This work is mainly focused on the computer simulation and analysis of the obtained results. However, this topic may be extended more from the urban planning point of view. This could bring a better understanding of the consequences of the strategy which has been tested in the experiment. Even extending the functionality of the simulator, we still will not be able to provide the results describing the real situation for 100%. This is the influence of human behavior - we are not able to predict it just using a simulator. We cannot be sure if the neighborhood will really be more attractive for people and local business. But we can try to predict the possible outcomes, basing our assumptions on already existing examples of similar city changes.

A very important thing to mention is that the proposed maximum allowed speed cut and the modifications in the road network are only one step of many to achieve better walkability and higher life comfort. Jeff Speck in his book "Walkable City"[8] talks about 10 principles of a walkable city, where traffic centers the only haft of them. Those principles also describe the role of public transport, bike lanes, about the importance of surroundings in a city like trees, parking places, or even architecture.

As a part of future urbanism, one might also want to consider the possible coming of new transport types to cities. Many urbanists nowadays try to predict the influence of autonomous cars, which already begin to come to the streets in the form of a car with autopilot(for example, Tesla's autopilot[14]). There is also a certain chance that autonomous vehicles will replace completely the human-driven cars. As described in [15], many areas of traffic functionality may be changed after the transition to autonomous mobility. Those vehicles may introduce new ways of routing and trajectory planning; when vehicles are connected into a communication network, the way of route planning can completely change. It could allow coordination between individual vehicles in order to evade an appearance of congestion or to plan traffic light intervals accordingly to the current situation on the roads.

Chapter 6

Conclusion

The shape of modern-day cities rapidly transforms, adjusting to the needs of its residents. When, a couple of decades ago, the priority of car in a city became recognized as erroneous, urban planners have turned back their attention to people. In the last years, cities begin to transform their image to become more walkable, more adapted for pedestrians.

In this work, we selected one of the urban planning strategies, which also follows the concept of walkability. This strategy is based on the already existing project in Barcelona, Superblock. This project unites several adjacent blocks of the city's characteristical grid and transforms the streets between them into shared space, where a pedestrian now has higher priority than a vehicle. This noticeably reduces the speed of automobiles and decreases the traffic density, leaving this space for the residents.

This strategy adapted for one of Prague's district is mainly based on the impact done on traffic. We have manually reduced the allowed speed from previous 50km/h down to 30km/h and 10km/h, depending on the location of the selected street. We have also banned traffic from one of the streets on the embankment and from the bridge. Both scenarios, a current situation and the adapted one, were simulated in the multi-agent simulation framework Agentpolis. We have simulated traffic flows in the city, based on the demand model, which has created a set of trips to be done by agents.

The Agentpolis framework also required several updates in order to adjust it to our particular scenarios. We have created a new type of agent - a private vehicle, which has united the functionality of a passenger and vehicle agent. Several modifications were also done, so the simulator provided the data about simulation relevant to our case. That was mainly information about all travels and about densities on the road network. This data was processed by Python scripts to obtain numerical and visual results of the scenarios simulation.

The results of the simulation have shown a slight increase in traffic density in the area of the district. This design has also affected travel times counted in the district, which were prolonged up to 15 minutes in comparison with the current situation. However, more than 60% of travel delays are under only 5 minutes.

Despite the fact that the results of the simulation have shown a slight decrease in the comfort of travel through the selected district, this does not prove the selected strategy to be ineffective or harmful. In urbanism, this would be only one step of many required, in order to achieve higher comfort and walkability. In real life that would also mean to motivate people to use alternative transport modes like transit or bikes. Rising the level of walkability in the long term by different measures can, in the end, decrease the need of owning a private car and put people again on the first place in a city's priorities, returning them this position back which belonged to automobiles for several decades.

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Contents of the Enclosed CD

The enclosed CD includes following folders:

- /simulator/
  - /agentpolis/ the Agentpolis framework source code
  - /amod-to-agentpolis/ the additional Amodsim package
- /simulation_output/ contains the data from direct output from simulation of both scenarios
- /road_network/ contains road networks of Prague for both scenarios in .geoJSON format
- /images/ includes all images shown in this work