Coordination of traffic lights evaluation

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June 17, 2013
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Chapter 1

Introduction

This case study consists in the evaluation of the Kaunas city traffic speed taking into consideration that traffic lights were coordinated. Kaunas suffers from high traffic intensity and, as a consequence, traffic jams often, and happens mainly because the city can only be crossed by the center.

Lithuania, as the rest of Europe experienced a big growth, from 1995 to 2005 coinciding with the crisis, that is to say that number of cars increased to highest levels as well as the traffic intensity. Moreover, by comfortability has to be borne in mind that a lot of people prefer to drive by car since takes much less time to get to a place and in cold winters don’t have to reach any bus stop nor waiting for the bus. The city was not ready for such an amount of cars thus generating traffic jams.

So that, the aim and main goal of the project is to evaluate one way of clearing the streets and letting the vehicles run faster, which is would be to evaluate its actual theoretical traffic speed, comparing it to experimental ones and calculate it again assuming all traffic lights coordinated. This will allow to see how necessary is the coordination as well as other conclusions regarding objects in infrastructure.

1.1 Aim

Evaluation of the traffic average speed after a theoretical coordination of the traffic lights along the studied streets.

1.2 Scope

The study concerns two routes starting in the outskirts of Kaunas to after the center. Moreover, data provided is experimental, belonging to gathered data in different studies, and theoretical.
Chapter 2

City of Kaunas

2.1 In brief

Kaunas is the city where the project has been developed. It is the second largest city in Lithuania and has historically been a leading centre of Lithuanian economic, academic and cultural life. The city covers 15,700 hectares and has a population of 311,148 inhabitants, though in its region (Kaunas County) increases to 673,706 inhabitants.

The city is located in the center of Lithuania, thus becoming a very important reference point within the country, and so, for Baltic States and Poland. It has access by highway, railway and airport.

When focusing to the city itself, is located in the meeting point of the country’s two
biggest rivers, the Nemunas and the Neris, which establish somehow its geography and climate. Lithuania lies at the edge of Northern European Plain and its terrain is an alternation of moderate lowlands and highlands. Kaunas is no exception given its height difference is of approximately 60 meters.

Its climate is temperate. It ranges between maritime and continental. Summers can be very hot, with weeks above the 30\(^\circ\)C. However, it has average daytime temperatures of 20\(^\circ\)C. On the other hand, winters can be very cold. With usual temperatures of -10\(^\circ\)C, it is no strange to drop below -15\(^\circ\)C. Because of the cold temperatures during winter and together with the precipitation, snow become a common factor during an important part of the year.

2.2 Focusing on transport and mobility

Kaunas has –like any other important city– main streets that serve as a spinal column of the city itself. These streets circle the city and also cross it: Savanorių, Islandijos, Tvirtovės, Gertrūdos, Šauklių, Jurbarko, Raudonvario, Šiaurės, Karaliaus Mindaugo, and Gimnazijos, among others. The city enjoys a good public transport net, with buses, trolleybuses and also minibuses. Trolleybuses net consists of a 13 units fleet which drive mainly through the main streets aforementioned even though there are also more streets with catenary structure. On the other hand, buses –40 units fleet– drive through streets with and without catenary and
CHAPTER 2. CITY OF KAUNAS

minibuses as well but with a more direct route.

However, number of passenger cars has grown up last years reaching highest city history levels. The low temperatures and the cold winter with the streets full of snow could be an explanation of it, along with good economical times before crisis and a big parking place offer. Consequently, with the big number of people who works in the city, traffic jams are becoming a usual issue that has to be solved, or at least, their impact in the traffic flow minimized.

Firstly, the following plot shows the average snow thickness during last winters in Kaunas as well as the temperature. In terms of comfort is understandable why people prefer going by car:

And what is more, the car growth can be observed below regarding the prosperity years before the current crisis, when the GDP per capita experimented also one of the bigger growths of the history. That allowed the people to afford a new car, so many decided to buy.
As a consequence of the car number and its increase, traffic intensity in the cities grew as well, thus traffic jams becoming every time of a more usual thing. Currently, the car sale is stuck, and amount of cars keep constant since more or less the beginning of the economic crisis but traffic jams are still.
Chapter 3

Analysis

3.1 Analysis of the flow speed in the cities

Cities in Europe have undergone many changes last sixty years related to growth. The amount of passenger cars has been doubled or even tripled and also more or less the same happened with trucks, vans and buses. Must be borne in mind that most of the city streets weren’t designed it its moment to absorb such quantity of traffic reached in the last years. Given that, most of the cities are having problems to manage traffic intensity since during peak hours large caravans are formed thus diminishing to very low levels of traffic speed.

As it can be seen, United States, as well as Center Europe or Japan started with an exponential growth at the beginning of the sixties and kept growing almost constant. It can be supposed that it reached its maximum value before the global crisis. Despite this phenomenon it has just reduced the growth speed but still keeps rising.

In order to evaluate and compare the average traffic speed in different European cities, some of them are shown in the table below.

<table>
<thead>
<tr>
<th>City</th>
<th>Traffic speed</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vienna</td>
<td>46</td>
<td>1,731,236</td>
</tr>
<tr>
<td>Newcastle</td>
<td>42</td>
<td>279,000</td>
</tr>
<tr>
<td>Cardiff</td>
<td>38.9</td>
<td>346,100</td>
</tr>
<tr>
<td>Leeds</td>
<td>37.3</td>
<td>750,700</td>
</tr>
<tr>
<td>Prague</td>
<td>36.8</td>
<td>1,262,106</td>
</tr>
<tr>
<td>Barcelona</td>
<td>35.2</td>
<td>1,620,943</td>
</tr>
<tr>
<td>Birmingham</td>
<td>35</td>
<td>1,074,300</td>
</tr>
<tr>
<td>Dublin</td>
<td>34.7</td>
<td>527,612</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>34</td>
<td>820,654</td>
</tr>
<tr>
<td>Munich</td>
<td>32.3</td>
<td>1,378,176</td>
</tr>
</tbody>
</table>
### 3.1. Analysis of the Flow Speed in the Cities

<table>
<thead>
<tr>
<th>City</th>
<th>Traffic speed</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belfast</td>
<td>32</td>
<td>281,000</td>
</tr>
<tr>
<td>Paris</td>
<td>31.8</td>
<td>2,234,105</td>
</tr>
<tr>
<td>Bristol</td>
<td>31.5</td>
<td>428,100</td>
</tr>
<tr>
<td>Glasgow</td>
<td>30.5</td>
<td>598,830</td>
</tr>
<tr>
<td>Rome</td>
<td>30.1</td>
<td>2,777,979</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>29.8</td>
<td>495,360</td>
</tr>
<tr>
<td>Manchester</td>
<td>28</td>
<td>502,900</td>
</tr>
<tr>
<td>Berlin</td>
<td>24</td>
<td>3,538,652</td>
</tr>
<tr>
<td>Warsaw</td>
<td>25.9</td>
<td>1,708,491</td>
</tr>
<tr>
<td>London</td>
<td>19</td>
<td>8,173,194</td>
</tr>
</tbody>
</table>

Table 3.1: Traffic speed average in European cities

Once plotting the data in order to see if there is any relation between both labels is possible to appreciate some relationship by using a linear regression. Moreover can be supposed that the cities above the line have a better traffic distribution than the cities below given that being above means that the traffic speed is high in comparison with the population and vice versa.

**Traffic speed in European cities related to their population**
As it can be observed, Vienna has the best speed-population ratio on account to its public transport. In the last years, the city has made a great public transport investment in order to reduce traffic intensity, hence its success. On the other hand, Warsaw is the city with one of the worst ratios due to Communist times, when its urbanism was planned. At that time, very few people could own a car so the streets weren’t planned wide enough, and not only this but to cross the city it has to be through the center. In the last few years the amount of cars has been increased so much that traffic jams are the everyday problem. Nowadays some new projects are in course to moderate it.

3.2 Principles of the prognostication of the trip time in GPS navigation and internet maps

3.2.1 Basic principles of GPS navigation

A GPS receiver calculates its position by precisely timing the signals sent by GPS satellites high above the Earth. Each satellite continually transmits messages that include:

- The time the message was transmitted
- Satellite position at the time of the message transmission

In spite of four or more satellites are needed to determine an accurate position, actually in every point on the earth surface up to six or seven satellites can be detected. GPS receiver uses these signals to calculate its 3D: latitude, longitude and altitude. It can also be used a moving map display.

3.2.2 Determination of speed by GPS tracking unit

Instantaneous speed

It is usually not possible, but could be very accurate if measuring the doppler effect on the signals transmitted by satellites. However, with a 5 - 10 meters error is possible to obtain almost an instant speed.

Average speed

It is obtained by calculating distance travelled between points divided by the time taken. However, when the arrival time of a route has to be predicted, depending on the GPS brand calculations may vary. Garmin units assume the route will be driven at the speed limit thus being very accurate for interstate driving but inaccurate when it comes to traffic lights. TomTom\textregistered uses a database of average speeds, given that provide more conservative and accurate times as well as some units can also take advantage of traffic information.

3.2.3 Determination of speed by internet maps

As well as they work on maps, their speed calculations used are almost the same as with the GPS tracking unit when planning a trip and obtaining the arrival time. It is usually found first the fastest route by taking into account road type and speed limit. However, some current internet maps like Google Maps are also taking into consideration current
traffic conditions as well as average speeds collected from users, which often increase travel
time and so drop off average speed.

3.3 Analysis of the principles of traffic lights operation

The traffic signal is an electrically timed device usually situated in an intersection that
assigns the right-of-way to one or more traffic streams so that these traffic streams can
pass through the intersection safely and efficiently. Traffic signals are appropriate for
minimizing:

- Excessive delays at stop signs and yield signs
- Problems caused by turning movements
- Angle and side collisions
- Pedestrian accidents

3.3.1 Purposes of traffic signals

Generally, a traffic signal is installed at an intersection:

- To improve overall safety
- To decrease average travel time through an intersection, and consequently increase
capacity
- To equalize the quality of service for all or most traffic streams

3.3.2 Definitions pertaining to Intersections and Traffic Signals

A number of terms used in following sections need to be defined:

**Cycle length** any complete sequences of signal indications

**Phase** the part of the cycle allocated to any combination of traffic movements receiving
right-of-way simultaneously during one or more intervals.

**Interval** the part or parts of the signal cycle during which signal indications do not
change.

**Green time** the length of a green phase plus its change interval, in seconds.

**Offset** the time lapse between the beginning of a green phase at the intersection and the
beginning of a green phase at the next intersection.

**Intergreen** the time betewwn the end of a green indication for one phase and the be-
ingning of a green indication for another.

**All-red interval** the display time of a red indication for all approaches. In some cases,
an all-red interval is used exclusively for pedestrians crossing very wide intersections.
Peak-hour factor in the case of intersections, the ratio of the number of vehicles entering the intersection during the peak hour to four times the number of vehicles entering during the peak 15-minute period.

Capacity The maximum number of vehicles that has a reasonable expectation of passing over a given roadway or section of roadway in one direction during a given time period under prevailing roadway and traffic conditions.

3.3.3 Elements of a Signal Timing System

At signalised intersections, some traffic streams are allowed to have simultaneous right-of-way, while other streams are stopped. A signal phase is a period during which one or more movements concurrently are an own green indication. Safety considerations dictate that a phase may be shared only by those traffic streams whose paths do not intersect. Left turns are often allowed to clear an intersection through gaps in the traffic streams moving along the same street but in the opposite direction.

The time between the end of a green indication for one phase and the beginning of a green for another is called intergreen, or a clearance interval. An amber indication is shown through the intergreen period followed by red. Design of signal phases specifies a sequence of various phases following each other. A signal cycle is part of the sequence.

3.3.4 Signal Timing

Types of signal operation are:

1. Pretimed operation:
   - The cycle length, phases, green times and change intervals are all preset.
• Several preset timing patterns may be used, each being implemented automatically at fixed times of the day.

2. Semiactuated operation:
• The designated main street has a green indication at all time until detectors on the side street determine that a vehicle or vehicles have arrived one or both of the minor approaches. The signal then provides a "green" phase for the side street, after an appropriate change interval, which is retained until a preset maximum side street is reached.
• The cycle length and green times may vary from cycle to cycle in response to demand.

3. Fully-actuated operation:
• All signal phases are controlled by detector actuations.
• Minimum and maximum green times are specified for each phase, as is the phase sequence.
• Cycle lengths and green times may vary considerably in response to demand.
• Certain phases may be skipped entirely if no demand is sensed by detectors.

As mentioned, traffic lights can either be pretimed or traffic-actuated and also isolated or coordinated. All of them require from specific algorithms and calculations. However, Kaunas traffic lights are all of them pretimed, given that the only those required will be exposed. These can be calculated by Homburger and Kell’s Method based on traffic volumes as the basis for allocating time to approaches, keeping off-peak cycles as short as possible. Also by using Webster’s Method obtained from extensive field observations and computer simulation allows to calculate the average delay per vehicle on an intersection approach thus obtaining the optimum cycle time that produces the minimum vehicle delay. In case of a four-approach two-phase signal, an alternative way for calculating the timing is Pignataro’s Method.

On the other hand, Savanoriu’s street traffic lights are almost fully coordinated and based on a Balanced Two-Way Signal Progression, often desired on streets during off-peak hours or during the entire day. It needs to be drawn different lines in a time-space diagram in order to represent the traffic speed evolution along the street. Even though Savanoriu can be considered a main street and so, practically isolated in terms of calculating, there are many factors that raise its study complexity. Among them it is possible to find left turn phases, different block spacing, etc.

### 3.4 Traffic flow

In mathematics and civil engineering, traffic flow is the study of interactions between vehicles, drivers, and infrastructure (including highways, signage, and traffic control devices), with the aim of understanding and developing an optimal road network with efficient movement of traffic and minimal traffic congestion problems.

Traffic flow is generally constrained along a one-dimensional pathway (e.g. a travel lane). A time-space diagram provides a graphical depiction of the flow of vehicles along a pathway over time. Time is measured along the horizontal axis, and distance is measured...
CHAPTER 3. ANALYSIS

along the vertical axis. Traffic flow in a time-space diagram is represented by the individual trajectory lines of individual vehicles. Vehicles following each other along a given travel lane will have parallel trajectories, and trajectories will cross when one vehicle passes another. Time-space diagrams are useful tools for displaying and analyzing the traffic flow characteristics of a given roadway segment over time (e.g. analysing traffic flow congestion). There are three main variables to visualize a traffic stream: speed (v), density (k), and flow (q).

Moreover, traffic flow can be divided in two main types:

**Uninterrupted flow** flow regulated by vehicle-vehicle interactions and interactions between vehicles and the roadway. For example, vehicles travelling on an interstate highway are participating in uninterrupted flow.

**Interrupted flow** flow regulated by an external means, such as a traffic signal. Under interrupted flow conditions, vehicle-vehicle interactions and vehicle-roadway interactions play a secondary role in defining the traffic flow.

**Speed-flow-density relationship**

Speed, flow, and density are all related to each other. The relationships between speed and density are not difficult to observe in the real world, while the effects of speed and density on flow are not quite as apparent.

Under uninterrupted flow conditions, speed, density, and flow are all related by the following equation:

\[ q = k \cdot v \]

Where,

- \( q \) - Flow (vehicles/hour)
- \( v \) - Speed (kilometres/hour)
- \( k \) - Density (vehicles/kilometre)

Because flow is the product of speed and density, the flow is equal to zero when one or both of these terms is zero. It is also possible to deduce that the flow is maximized at some critical combination of speed and density.

Two common traffic conditions illustrate these points. The first is the modern traffic
3.4. TRAFFIC FLOW

jam, where traffic densities are very high and speeds are very low. This combination produces a very low flow. The second condition occurs when traffic densities are very low and drivers can obtain free flow speed without any undue stress caused by other vehicles on the roadway. The extremely low density compensates for the high speeds, and the resulting flow is very low.
Chapter 4

Methodology

The calculations related to traffic flow and velocity for city streets are usually very complex given that a lot of different factors take part in it. In order to calculate the average speed of the streets, this study make use of the maximum free flow speed and objects in infrastructure. Vehicle speed in the street sections where there are no interferences depend on speed limit. Usually real speed may vary from $5\frac{km}{h}$ less than speed limit to $5\frac{km}{h}$ more. To attain the second step, which is to calculate approximately the real speed of the street, 11 types of the objects of transport system infrastructure are to be identified along the route. Formulas used in each part of the methodology will be further explained in their corresponding section.

4.1 Free flow traffic speed calculation

Free flow speed in a city depends basically on the transport flow intensity. A specific formula is used to obtain it, which will be very important for further calculations. Then:

$$V_{sr} = \frac{60}{v_l + (0.0008875 \cdot \frac{EI}{JS})^{4.4239}}$$

Where,

- $v_{sr}$ - traffic speed $[\frac{km}{h}]$
- $v_l$ - speed limit $[\frac{km}{h}]$
- EI - transport flow intensity [vehicles/h]
- JS - number of lanes

4.2 Intermediate sections

Each section, depending on its length and speed, is divided into various segments as stop and acceleration length as well as intermediate section length. These lengths will condition the average speed across the section:

$$l_{s/g} = k_{s/g} \cdot 2 \cdot v_{sr}$$
$$l_p = k_p \cdot 1.4 \cdot v_{sr}$$

Where,
4.3. OBJECTS IN INFRASTRUCTURE

\( l_{s/g} \) - stop/acceleration length [m]

\( l_p \) - intermediate length [m]

\( k_{s/g}, k_p \) - correction coefficients

\( v_{sr} \) - traffic speed \([km/h]\)

In case of single objects, transport flow speed is affected when distance to other objects is longer than \( l_{s/g} \) m.

* Correction coefficients are assumed as one for this case study.

4.3 Objects in infrastructure

Traffic can be either suspended or stopped due to objects found in infrastructure while driving across the city. These objects affect can alter the traffic speed a lot, as traffic must stop or at least brake in each one of them thus reducing its velocity many times. Moreover, they are very linked to section segments as based on the intermediate sections together with the objects found along the section will be possible to calculate the theoretical speed. Objects in infrastructure can be classified in two blocks:

4.3.1 Detection of objects

All objects along the route have been counted by using google street view and google earth. Then, written down in the following tables divided by sections.

Methodology

Each cell has either a number in the following manner:

0 No object of this type in the section

0.5 Section starts or finishes in an object of this type

1 or more According to number of times this object appears entirely.

As example of methodology the table below shows three imaginary sections in order to illustrate the method. All sections have been divided by traffic lights, so there will always be a 0, 0.5 or 1 written in those cells. First section has a 1 in the crossroad with traffic light cell, meaning that starts and finishes with a traffic light of this characteristics. Otherwise, second and third sections begin and finish with a different type of traffic light.

<table>
<thead>
<tr>
<th>Objects</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossroad with traffic light</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Crossing with traffic light</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Uncontrolled crossroads with main streets</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Uncontrolled crossroads with back streets and crossings</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Road curves less than 90 degrees</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Uncontrolled crossroads with back streets</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Single urban transport stops</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
CHAPTER 4. METHODOLOGY

4.3.2 Objects where traffic is suspended

Those of a softener effect in where there is no need of stopping always are related to intermediate sections.

<table>
<thead>
<tr>
<th>Object</th>
<th>Section length [m]</th>
<th>Traffic speed ( \frac{\text{km}}{\text{h}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncontrolled crossroads with back streets</td>
<td>( l_p )</td>
<td>0,6 ( \cdot v_{sr} )</td>
</tr>
<tr>
<td>Single urban transport stops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single uncontrolled crossroads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single left turns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road curves more than 90 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uphills</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Find here in yellow the segments in which the traffic is suspended:

4.3.3 Objects where traffic is stopped

Those of a bigger effect, in which stopping is a must, or almost, are related to stop/acceleration sections.

<table>
<thead>
<tr>
<th>Object</th>
<th>Section length [m]</th>
<th>Traffic speed ( \frac{\text{km}}{\text{h}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossroad with traffic-light</td>
<td>( l_s/g + l_p )</td>
<td>( 0,3 \cdot v_{sr} \cdot l_s/g ) ( \frac{\text{km}}{\text{h}} ) + ( 0,6 \cdot v_{sr} \cdot l_p ) ( \frac{\text{km}}{\text{h}} )</td>
</tr>
<tr>
<td>Crossing with traffic-light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncontrolled crossroads with main streets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncontrolled crossroads with back streets and crossings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road curves less than 90 degrees</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Find here in red the segments in which the traffic is stopped:
4.4 Length of section

Once obtained all intermediate sections and objects in infrastructure, all lengths can be related to the entire length of the section:

\[
\text{Steady mode: } l = L - l_{s/g} - 2l_p \\
\text{Stop/acceleration near crossroad with traffic light: } l_{s/g} + l_p \\
\text{Bus stop zone: } l_p
\]

4.5 Speed in all sections of street

Finally, average speed along the sections of the street is found by using the formula below, regarding free flow speeds, length of sections and number and amount of objects.

\[
v = v_{sr} \cdot \frac{l}{L} + 0.3 \cdot v_{sr} \cdot \frac{n_{s/g}}{L} \cdot l_{s/g} + 0.6 \cdot v_{sr} \cdot (n_{s/g} + n_p) \cdot \frac{l_p}{L}
\]

Where,

\(n_{s/g}\) - number of objects where the traffic is stopped
\(n_p\) - number of objects where the traffic is suspended
Chapter 5

Flow speed evaluation

This chapter focuses in the explanation of the results attained with the aforementioned methodology.

5.1 Structure

5.2 Selected route

As mentioned in the section *City of Kaunas*, the case study comprises two routes that almost cross all the city, from one side to another through the center and old town. The interesting point of them is that both start from Savanorių street –which is one of the largest in Kaunas and its importance resides in that drives directly to and from the center, thus becoming one of the most busy– until they fork before the old town.

**First route: Šiaurės - Karaliaus Mindaugo**

1. Savanorių

2. Šv. Gertrūdos

3. Gimnazijos

4. Birštono
Second route: Šiaurės - Kriščiukaičio

1. Savanorių
2. Šv. Gertrūdos
3. Šauklių
4. Jonavos
5. Jurbarko

It can be observed that both routes, after forking pass near the old town but very close.
5.3 Division by sections

In order to calculate the objects in the infrastructure easily, route streets are divided into sections. As an object to divide will be used the traffic lights along the route, thus simplifying the method. Once divided, it makes a total amount of seventeen sections, taking into account the sum of common and different sections for each route. The obtained sections are listed below and shown in the picture:

1. Šiaurės - P.Lukšio
2. P.Lukšio - Savanoriu 349
3. Savanoriu 349 - S.Žukausko
4. S.Žukausko - Mituvos
5. Mituvos - Uosio
6. Uosio - Kampo
7. Kampo - Tvirtovės
8. Tvirtovės - A.ir J.Vokietaičių
9. A.ir J.Vokietaičių - Utenos
10. Utenos - Aukštaicių
11. Aukštaicių - Žemiaičių
12. Žemiaičių - Laisves
13. Laisves - Gimnazijos
14. Šv.Gertrūdos - Karaliaus Mindaugo
15. Gimnazijos - Šv.Gertrūdos
16. Šv.Gertrūdos - Jonavos
17. Jonavos - Jurbarko

5.4 First step data gathering

To move forward to the following calculations, it is needed to gather all data provided by the streets. This data comprises: number of lanes (total/per side) ($JS$), section distance ($l_p$), speed limit ($v_l$), movement mode (one-side/double-side), traffic flow intensity ($EI$), objects in infrastructure and vehicle type proportion.
5.4. FIRST STEP DATA GATHERING

5.4.1 Section length

Nowadays, there are many applications that permits you to measure the length of a section in a map just by drawing a segment. Among them are Google Earth, Google Maps, Maps.lt, Mapquest, etc. In that case Maps.lt\(^1\) has been chosen to measure the sections due to its high precision and ease to use.

5.4.2 Number of lanes

The number of lanes does not appear in the map, given that all routes had to be tracked by making use of Google Street View\(^2\). As it can be seen in the table, Savanorių street has three lines in most of its sections, but as closer to the center it gets, the amount of lines per side diminishes to even one. The same happens with the rest of the streets, the further from the center, the more lines they have.

5.4.3 Traffic flow intensity

Data related to flow intensity has been gathered from a map belonging to Kaunas Traffic Dept. shown below. It contains the traffic flow intensity in the main streets of Kaunas in average.

---

\(^1\)Maps.lt is an Internet map site for interactive navigation within a territory, geographical location search on a map and introduction to geographical databases as well as digital maps.

\(^2\)Google Maps with Street View lets you explore places around the world through 360-degree street-level imagery.
However, this map shows the total traffic flow intensity. As buses, trolleybuses, trucks, minibuses, etc. are included in this traffic intensity, traffic composition has to take into account all of them with their own parameters.

Kaunas traffic composition

<table>
<thead>
<tr>
<th>Section type</th>
<th>Cars</th>
<th>Minibuses</th>
<th>Buses/Troll.</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sections with intensive urban transport</td>
<td>90%</td>
<td>5%</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>Periphery of town</td>
<td>95%</td>
<td>2%</td>
<td>1%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Each kind of vehicle is related to a coefficient that determinates its importance in the street by means of size and lane occupancy. It can be observed that despite e.g. only 5% of the total traffic flow are buses and trucks, their coefficient is 2.5 times bigger than car, thus increasing the traffic flow intensity.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>1</td>
</tr>
<tr>
<td>Minibus</td>
<td>1.5</td>
</tr>
<tr>
<td>Trolley, bus, truck, ...</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Final traffic theoretical traffic flow intensity can be now obtained by using the proper coefficient $C$ and traffic composition $P$:

$$EI_f = EI_0(P_{car} \cdot C_{car} + P_{minibus} \cdot C_{minibus} + P_{bus/trolley} \cdot C_{bus/trolley} + P_{truck} \cdot C_{truck})$$

Traffic flow average

Along the day, traffic flow experiments some variations that are particularly visible during morning, evening and noon, also known as peak-hours. Once obtained the average flow composition, will be easy in later sections to calculate also these traffic flow variations. By now, traffic flow average is:

<table>
<thead>
<tr>
<th>Section</th>
<th>Map EI</th>
<th>Average EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2657</td>
<td>2803</td>
</tr>
<tr>
<td>2</td>
<td>2844</td>
<td>3128</td>
</tr>
<tr>
<td>3</td>
<td>2844</td>
<td>3128</td>
</tr>
<tr>
<td>4</td>
<td>2803</td>
<td>3083</td>
</tr>
<tr>
<td>5</td>
<td>2803</td>
<td>3083</td>
</tr>
<tr>
<td>6</td>
<td>2803</td>
<td>3083</td>
</tr>
<tr>
<td>7</td>
<td>2803</td>
<td>3083</td>
</tr>
<tr>
<td>8</td>
<td>3353</td>
<td>3688</td>
</tr>
<tr>
<td>9</td>
<td>3353</td>
<td>3688</td>
</tr>
<tr>
<td>10</td>
<td>1941</td>
<td>2135</td>
</tr>
<tr>
<td>11</td>
<td>1941</td>
<td>2135</td>
</tr>
<tr>
<td>12</td>
<td>1941</td>
<td>2135</td>
</tr>
<tr>
<td>13</td>
<td>2191</td>
<td>2410</td>
</tr>
<tr>
<td>14</td>
<td>4132</td>
<td>4545</td>
</tr>
<tr>
<td>15</td>
<td>5267</td>
<td>5794</td>
</tr>
</tbody>
</table>
5.6 Simplification

The results shown in the table aren’t believed to be totally correct since there are some non negative speeds but very slow ones. This happens as a consequence of short section lengths in combination with a lot of objects and low lane number. However, in order to improve those results and change them into positives, even increasing them, aforementioned sections will be joined into groups, thus simplifying and making calculations more reliable.

5.6.1 Section grouping

Many sections belong to the same street and with similar characteristics, so that, sections have been joined by street, outskirts/center or even number of lanes. Then, new grouped sections are:

<table>
<thead>
<tr>
<th>Section</th>
<th>Street</th>
<th>Street section</th>
<th>( l_p ) [m]</th>
<th>EI [veh.]</th>
<th>JS per side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Savanorių</td>
<td>Siaurės - P.Lukšio</td>
<td>758</td>
<td>2803</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Savanorių</td>
<td>P.Lukšio - Savanorių 349</td>
<td>481</td>
<td>3128</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Savanorių</td>
<td>Savanorių 349 - S.Zukausko</td>
<td>470</td>
<td>3128</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Savanorių</td>
<td>S.Zukausko - Mituvos</td>
<td>589</td>
<td>3128</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Savanorių</td>
<td>Mituvos - Uosio</td>
<td>254</td>
<td>3083</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Savanorių</td>
<td>Uosio - Kampo</td>
<td>165</td>
<td>3083</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Savanorių</td>
<td>Kampo - Tvirtovės</td>
<td>196</td>
<td>3083</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Savanorių</td>
<td>Tvirtovės - A.ir J.Vokietaičių</td>
<td>342</td>
<td>3688</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Savanorių</td>
<td>A.ir J.Vokietaičių - Utenos</td>
<td>275</td>
<td>3688</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Savanorių</td>
<td>Utenos - Aukštaičių</td>
<td>610</td>
<td>2135</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Savanorių</td>
<td>Aukštaičių - Žemaičių</td>
<td>360</td>
<td>2135</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Savanorių</td>
<td>Žemaičių - Laisves</td>
<td>1205</td>
<td>2135</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Sv. Gertrūdos</td>
<td>Laisves - Gimnazijos</td>
<td>272</td>
<td>2410</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Gimnazijos</td>
<td>Sv.Gertrūdos - Karaliaus Mindaugo</td>
<td>405</td>
<td>4545</td>
<td>3</td>
</tr>
<tr>
<td>15</td>
<td>Sv. Gertrūdos</td>
<td>Gimnazijos - Sv.Gertrūdos</td>
<td>228</td>
<td>5794</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>Sauklių</td>
<td>Sv.Gertrūdos - Jonavos</td>
<td>138</td>
<td>5794</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>Jonavos</td>
<td>Jonavos - Jurbarko</td>
<td>628</td>
<td>4181</td>
<td>2</td>
</tr>
</tbody>
</table>
Chapter 5. Flow Speed Evaluation

<table>
<thead>
<tr>
<th>Section</th>
<th>Street</th>
<th>Street section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Savanorių</td>
<td>Siaurės - Tvirtovės</td>
</tr>
<tr>
<td>2</td>
<td>Savanorių</td>
<td>Tvirtovės - Utenos</td>
</tr>
<tr>
<td>3</td>
<td>Savanorių</td>
<td>Utenos - Laisves</td>
</tr>
<tr>
<td>4</td>
<td>Sv. Gertrūdos</td>
<td>Laisves - Gimnazijos</td>
</tr>
<tr>
<td>5</td>
<td>Gimnazijos</td>
<td>Sv. Gertrūdos - Karaliaus Mindaugo</td>
</tr>
<tr>
<td>6</td>
<td>Šv. Gertrūdos</td>
<td>Gimnazijos - Šv. Gertrūdos</td>
</tr>
<tr>
<td>7</td>
<td>Sauklių</td>
<td>Sv. Gertrūdos - Jonavos</td>
</tr>
<tr>
<td>8</td>
<td>Jonavos</td>
<td>Jonavos - Jurbarko</td>
</tr>
</tbody>
</table>

Note that all Savanorių street, that is to say sections 1, 2 and 3, are shared by both routes.

5.7 Evaluation

To begin with, main speed for both routes are plotted below. It will be seen that speed may vary a lot depending on the section and also relation between free flow speed and average speed.
5.8 Free flow speed

Free flow speed across the city, with an average of 44.47 km/h, is a $1 - \frac{v_{sr}}{v_{lim}} = 11\%$ slower than the city speed limit. However, as it takes into account the high traffic intensity. Moreover,
route begins in the outskirts fast with an exception in the second section affected by its short length and big amount of infrastructure objects, then when getting closer to the old town, where the number of lanes reduces from three lanes to two or even one it diminishes again to low levels. Final average is not affected by the second section since it takes into account the length of each section by using

$$V_{avg} = \frac{1}{d_{total}} \cdot \sum v_id_i, \ d(section \ distance)$$

In the first route, as well as in the second one, free flow speed diminishes when gets close to the center and the old town and increases again when going out and far from it. The gap is bigger in the second route, where it not just drives close to the old town but crosses it. However, it can be appreciated in a more visual way when plotting it by before-grouping sections.

Free flow speed could be assumed as the maximum velocity reachable with no objects and taking into account the traffic intensity. According to that, there is a free flow speed for each traffic intensity, thus being possible to increase it by lower traffic intensities.

5.9 Theoretical average speed

New results, in comparison with the ones before grouping, show in a more smooth way the behaviour of the speed, which at the same time, are more coherent by means of there are no very low speeds as well as big gaps. Speed average reached is $22.5 \frac{km}{h}$.

Amount and type of objects in infrastructure are a key factor. As it can be observed, the higher speed in both routes is reached in the section before arriving to the center, which consists in a large distance with almost no objects. Its dependence on infrastructure objects could become an overwhelming factor given that in the center, where there are less bus stops per section, crosses or even back streets, than in the outskirts, the theoretical speed does its biggest approach to the free flow speed.
Plotted barplots show the amount of infrastructure objects in each section for both routes. Those objects, in where the traffic is whether suspended or stopped, show up in a much bigger amount at the beginning, on the top of all in the first three sections, Savanorių street, thus explaining why the theoretical average speed is a little bit higher before the center.
5.9.1 Object influence ratio

In order to explain the influence of the objects in infrastructure over the traffic speed, can be observed the evolution of the theoretical average speed influence over free flow speed by means of a ratio:

\[ r_{obj} = \frac{v}{v_{sr}}, \in (0, 1] \]

In this way, the bigger the ratio the bigger the lower the amount of objects, thus bigger the average speed in comparison with free flow speed. It can be observed in the ratio graph at the beginning of the chapter how it raises when closer to the center.

5.10 Traffic intensity peaks

As it is mentioned in the section Traffic flow intensity, there are variations of the EI along the day. Those variations of a more relevance are in the morning, noon and evening. These three variations are peaks, and can grow up to almost a 9%. Logically coincide with a working timetable, as Kaunas is a manufacturer city. Growth of EI during peaks are:

<table>
<thead>
<tr>
<th>Peak</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>6.0%</td>
</tr>
<tr>
<td>Noon</td>
<td>7.5%</td>
</tr>
<tr>
<td>Evening</td>
<td>8.3%</td>
</tr>
</tbody>
</table>

As might be expected, a growth of 6-8% does not make such an extra difference, but enough to produce congestion in the streets, specially in the section in where the speed is bigger.
Theoretical speed in peak configurations in route 2

<table>
<thead>
<tr>
<th>Section</th>
<th>Average</th>
<th>Noon</th>
<th>Morning</th>
<th>Evening</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
</tbody>
</table>

Section: 1 2 3 4 5 6 7

Speed [km/h]: 0 5 10 15 20 25 30

Average, Noon, Morning, Evening
Chapter 6

Analytic research

6.1 Experimental data

6.1.1 Mean speed map

In 2009, the Kaunas department of transport developed a map with the mean traffic speed along the main streets of the city. The speed is presented in the format e.g. 84(79) km/h, which means 84 km/h as the mean transport speed in both directions and 79 km/h as the mean transport speed in the slowest direction. In this case study is only gathered the first one outside the brackets. The speed average belonging to both routes by using those map speeds is 22.9 km/h.

6.1.2 Experimental car

A second experimental way –and maybe the most realistic– to calculate traffic real flow speed is by measuring it when driving a car. In that case, KTU transport department
enjoys a laboratory car provided of speed sensors, timers, and memory to collect all data. This method was also used in the main streets of Kaunas, and its results concerning the case study streets gave a speed average of \(27.8 \frac{km}{h}\). This speed is a 23,6% bigger than theoretical speed and could be explained as the car have the property of changing line, thus passing other vehicles and gaining velocity as well as avoiding buses and trolleybuses.

### 6.2 Traffic lights coordination

After observing the results of the methodology and its relationship with experimental models, it is time to see which traffic flow speed average could be attained if all traffic lights along the routes were coordinated. This could be seen as a last section of the methodology because of the use made of its own steps to modify them. The step modified is going to be Objects in infrastructure. In order to simulate a coordination of the traffic lights, all rows belonging to them will be set to 0, thus pretending to be in the green phase along all route.

The table below show the same one in the section Detection of objects but currently, in green, the rows belonging to traffic lights are null.

<table>
<thead>
<tr>
<th>Objects</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossroad with traffic light</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Crossing with traffic light</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Uncontrolled crossroads with main streets</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Uncontrolled crossroads with back streets and crossings</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Road curves less than 90 degrees</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Uncontrolled crossroads with back streets</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Single urban transport stops</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Single uncontrolled crossroads</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Single left turns</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Road curves more than 90 degrees</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Uphills</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Then after assuming that traffic lights are not an obstacle anymore this is what happens with the speed along the routes:
As it was expected, the coordination of the traffic lights helped to rise the theoretical speed to almost similar levels as the free flow speed. In that case can be appreciated the sections with a several objects that aren’t traffic lights like back streets found along the routes, which despite have a lower impact in the traffic speed, when there’s big number its impact is relevant, e.g. the first two sections belonging to Savanorių street as well as
the 5th section of the first route, belonging to Gimnazi jos and Birštono streets. On the other hand, when driving in the old town where just a few traffic lights are found highest ratio level can be observed. Then, final theoretical speed average is $31 \, \text{km/h}$, thus raising a 37,8%.

6.3 Traffic speeds comparison

Last but not least, after calculating and gathering all speeds belonging to Kaunas, experimental and by calculations, the average results are plotted below.

As said above and with the help of the plot, results are very similar, on the top of all, could be assumed no difference between theoretical speed and the average speed belonging to the Kaunas government map. These follow the experimental car speed, which just differs in $5 \, \text{km/h}$. As expected, when coordinating traffic lights theoretical speed obtained is higher than the those mentioned, thus overpassing $30 \, \text{km/h}$. Finally, the ideal speed, by means of no infrastructure objects along the route is the free flow speed, almost reaching the city speed limit.

<table>
<thead>
<tr>
<th>Name</th>
<th>Average [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing theoretical speed</td>
<td>22,5</td>
</tr>
<tr>
<td>Coordinated traffic lights speed</td>
<td>31,0</td>
</tr>
<tr>
<td>Traffic speed map</td>
<td>22,9</td>
</tr>
<tr>
<td>Experimental car speed</td>
<td>27,8</td>
</tr>
<tr>
<td>Free flow speed</td>
<td>44,5</td>
</tr>
</tbody>
</table>

As a way to compare them, the theoretical speed could be taken as a basis and see its relation with the rest by measuring the increase the following way:

$$\Delta V_i = \frac{v_i - v}{v}$$

With,
$v_i$ - speed to be compared $[\frac{km}{h}]$

$v$ - theoretical speed $[\frac{km}{h}]$

Then the results of the different velocities in comparison with the theoretical speed average are:

1. $\Delta V_{FreeFlowSpeed} = 98\%$

2. $\Delta V_{ExperimentalCarSpeed} = 24\%$

3. $\Delta V_{TrafficSpeedMap} = 2\%$

4. $\Delta V_{CoordinatedTrafficLights} = 38\%$

Results confirm what has been seen so far. Free flow speed act as a speed ceiling by being double the theoretical speed. Experimental car speed follows with an increase of 24%, results most probably attained by aforementioned reasons, e.g. line change and overtaking capacity. The traffic map speed, if assumed as the most relevant given that belongs to Kaunas government, gives to the employed methodology total credibility because its difference is no more than 2%. Last but not least, coordinated traffic lights speed shows that the reachable increase of speed could be up to 38%, which would solve several congestion problems.

### 6.4 Kaunas among other cities

In the section *Analysis of the flow speed of the cities* of the chapter *Analysis* there is a plot with several cities around Europe and the world with their average speed. After obtaining the speeds belonging to Kaunas, is time to situate them in the plot:
If only the free flow speed of Kaunas was observed, the city would be considered had a good traffic distribution since is situated above de line. However, regarding the experimental speed obtained by the car its traffic distribution becomes slow, in the same level as Manchester and Warsaw, thus being below the line. Despite the unfavourable results regarding Kaunas, must be borne in mind that not only a few streets have been considered but some of the most important and with higher traffic intensity in the city, hence this handicap. If long streets around the city with no infrastructure objects had been taken into account, results would have been much more favourable in terms of speed and traffic intensity. On the other hand, coordinated traffic lights speed demonstrates that Kaunas could move up several positions in the global city speed ranking hence almost reaching the average line. This could move even upper and cross the line if more infrastructure objects were converted into traffic lights and after, coordinated.
Chapter 7

Conclusions

Before the study could be easily guessed that coordination of the traffic lights along the streets would improve their average speed, but now not only has been proved but the approximate reachable speed is known. Moreover, when getting thoroughly into the issue more conclusions related to the general improvement of the speed have been exposed and ways to solve them thought.

The study found strong evidences of similarity between the theoretical speed calculated by using the methodology and the experimental one, calculated by Kaunas government. Since the average difference between both is no more than 2% –less than $1 \frac{km}{h}$, it can be assumed that the speed obtained by methodology makes no difference with the real one, thus proving its high accuracy and moreover, re-demonstrating the validity of the article Assessment of the flow speed in urban conditions. However, it makes more difference when compared to the experimental speed obtained by laboratory car, but as mentioned in several sections before, it might be as a consequence of the car abilities e.g. overtaking other vehicles or line changing, thus avoiding several objects in infrastructure and increasing its speed. What is more, when comparing theoretical and laboratory car speeds has to be taken into account that employed methodology in the first is based on a traffic intensity which concerns both heavy and light vehicles while the second one considers only a light vehicle, thus allowing a speed increase.

Secondly, after proving the validity of the methodology can be also assumed the validity when coordinating traffic lights. The study shows that if all traffic lights along both studied routes could be coordinated, the average speed could be in increased in a 38% ($10 \frac{km}{h}$ approximately). The main goal of this study was to find out which improvement in terms of average speed could be attained if the traffic lights were coordinated, so that, after achieving the main goal next step would be implementing it in the streets.

In terms of free flow speed, when taking into account it represents a speed ceiling, the main conclusion is that the city of Kaunas needs to invest in infrastructure. Driving at a free flow speed and with the average traffic intensity could not be possible to reach the streets speed limit given that there are too many objects in infrastructure. A first idea to solve it would be to place traffic lights in more backstreets and crossings, hence avoiding them if the traffic lights are coordinated.

Last but not least, in order to sum up the possible solutions would be:
1. Coordination of the traffic lights.

2. Placement of traffic lights in uncontrolled crossroads and other infrastructure objects.

3. Investment in infrastructure in order to change the course of cars crossing the city to make them drive by the outskirts hence avoiding high traffic intensity in the center.

4. Investment in infrastructure to avoid big crossings in main streets, e.g. underpass or a flyover.
Chapter 8

Bibliography


