Case study on effect of the machine learning on congestion handling

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***Abstract*—This case study tries to describe detailed, the effect of Machine Learning on traffic light program controls. It also shows in what way do ML solves complex traffic situations, in non-trivial cases**

Keywords*—*machine learning, traffic light, traffic control, case study, effect of machine learning *(key words)*

I. Introduction

This case study is paper, to the main thesis on a ralated topic and situation [2]. It tries to go deeply into the details to analize and argue on several optimization methods.

However this is a standalone study, but it will be followed ny several related studies and research papers.

II. Detailed situation overview

In the first part of the study i will describe the problem itself. This issue is an ongoing congestion around a residential part of Debrecen city in Hungary which is called Tócókert. The Derék street is an important part of the local transport system, and several institutions can be found around here.

The most important infrastructure places are:

- Jégcsarnok - the city's ice rink
- LIDL - supermarket
- Bus station endpoint - important bus station
- Residential living houses

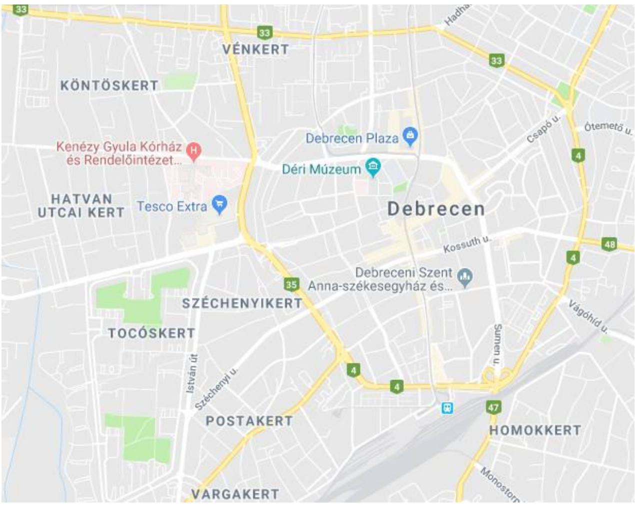

Fig 1. Location of city part

Fig 2. Detailed map

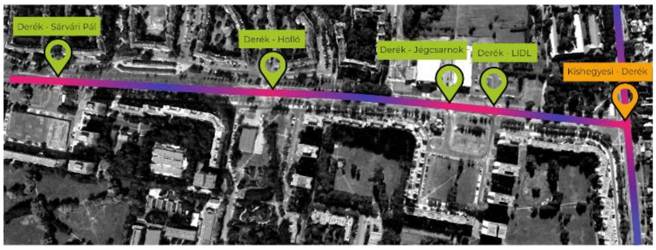

Fig 3. Sattelite image with marked junctions. Green marked ones - considered in this paper.

A. Map

On the map we can see described above places. Because these places have high customer flows, we need to take into consideration both the pedestrian and vehicle flows. At peak times, the parking lots getting use to their full capacity, and pedestrian crossings need to let through a lot of people.

Also, worth mentioning that in the city's perspective, this street lays right next to one of main entrance roads. This is the Kishegyesi street, and on this way a lot of people get to their jobs. One main flow generator is the National Instrument factory at the end of the Kishegyesi street. Around 1000 people work in this factory, generating high flow all the day, and the site is growing every year [1].

Here is the map of the junctions, altogether with lane descriptions, positions of the traffic lights and road signs.

B. Programs

In the traffic system right now, the following programs are active:

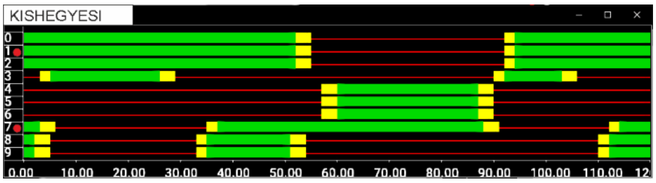

Fig 4. Kishegyesi junction now active TLP

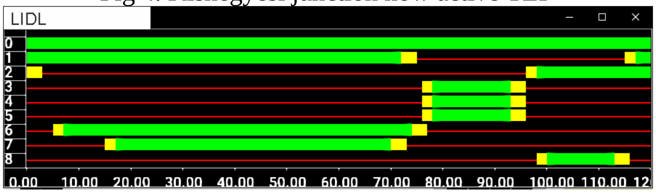

Fig 5. LIDL junction now active TLP

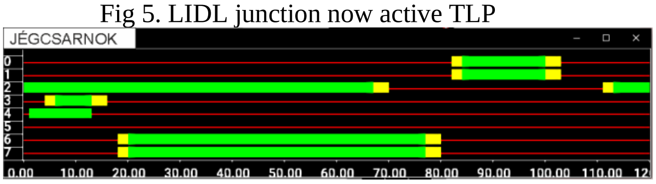

Fig 6. Jégcsarnok junction now active TLP

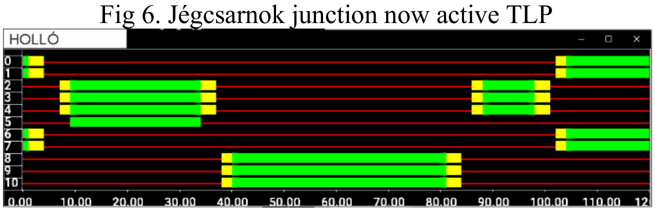

Fig 7. Holló junction now active TLP

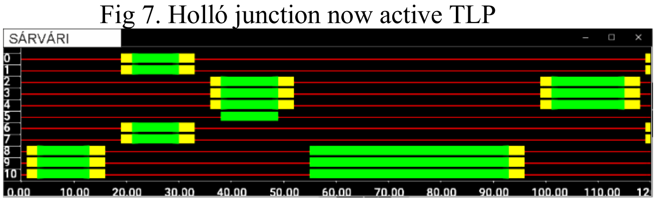

Fig 8. Sárvári junction now active TLP

Based on these programs, the maps, and also the measurements, we made the current model of the transportation system. This will be shown later in this article.

C. Issue

The main issue in this region is a congestion on the Derék street from the side of Kishegyesi junction, specifically on weekdays, afternoons. We made several visits to the location at those times when this congestion built up. Based on our observations, and some crowdsourced descriptions of the issue, we can draw a map and show where the congestion occurs, and what are the indirect effects.

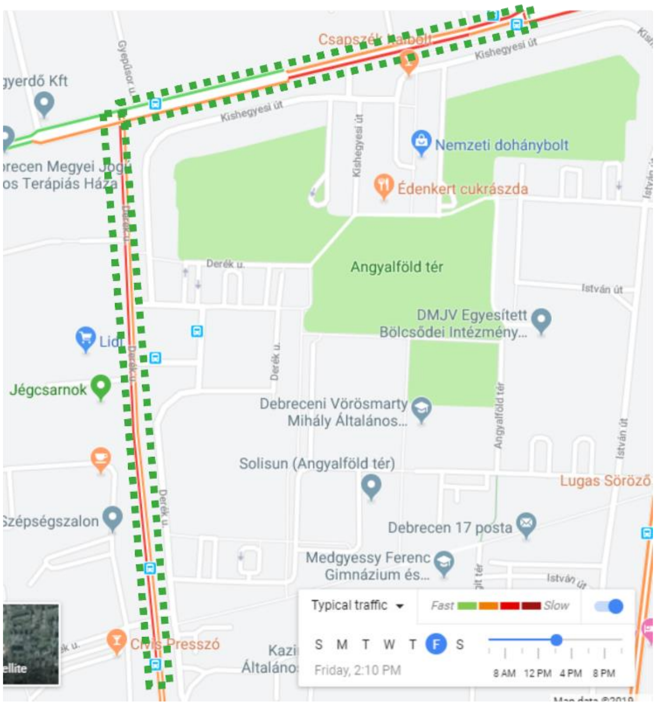

Fig 9. LILD side from Kishegyesi is congested, and the congestion follows up on the Kishegyesi street

As we see, the Kishegyesi street also affected because of this congestion. We can see, that only incoming lanes from Kishegyesi are affected. Based on this we started to discover in what ways we can gather scientifically correct data. We made research on what and how we should measure in the first place, that we can point at the real issue.

But worth mentioning that this paper is not about the "by hand solution" of the problem. These measurements were required mostly to make a reliable simulation model.

Until this moment, you might have your own assumptions on that what the issue might be. So, it's a good way of comparing the final solution of the machine learning, and your assumptions of what is the solution, to see the advantage of the machine learning in this field.

III. Preparation

By this time, we know only the basic issue of the congestion. We needed to gather information about the traffic volume, and the way it behaves.

A. Gathering data

Most importantly we need to know the traffic volume. For this we did counting of vehicles on field measurements. Our measurements are explained in the following table.

Measurment time [a.m.]	Measurement intervall [sec]	Kishegyesi side [units]	Vincellér side [units]	LIDL side [units]	Kishegyesi side [units / hour]	Vincellér side [units / hour]	LIDL side [units / hour]
6:30	90	4	13		160	520	0
6:45	90	13	16		400	640	0
6:50	90	6	21		240	840	0
6:55	180	12	40		240	800	0
7:10	180	22	58	4	440	1160	80
7:22	90	8	18	1	320	720	40
7:30	120	10	25	2	300	750	60
7:40	120	12	24	0	360	720	0
7:47	120	11	18		330	540	0
8:00	120	7	16	3	210	480	90

Table 1. Measurements on 2018 october 30, at LIDL junction. With dark-red background marked the peak flows.

We took 2 more measurements at different times and selected the highest peak flows [2]. Based on those we selected flowrates showed in Table 2.

Kishegyesi side [units/hour]	Vincellér side [units/hour]	LIDL side [units/hour]
440	1160	90

Table 2. Highest flow data from the combined measurements.

These data are combined from multiple measurements, and they can help to build a valid and up-to-date model of the traffic flow on all the affected junctions on the Derék street.

B. *Traffic signal program design guidelines*

The following step is to overview the requirements of local standards. This is a complex overview, because we have multiple layer of guidelines and technical specifications.

Basically at a traffic light program we can change the length of the green phases or the order of phases [3]. Other little changes might also affect the signal program, but those are minor rules (for example: the crossing time needed for pedestrians to safely cross the road on pedestrian crossing, is defined in two ways. There is a “fast” speed, and a “normal” speed calculation. The “normal” way means it calculates like a pedestrian walk with speed of 1 m/s, and the needed green time is calculated to let the pedestrian cross the ⅔ of the pedestrian crossing during the green time. The “fast” way is to calculate the pedestrian speed at 1.2 m/s and the required distance to be covered by pedestrian is halfway of the pedestrian crossing. And to decide which calculation should be used, we need to consider not just the written requirements, but the local city development guidelines [4].legal procedure for data access

To have correct and up-to-date information about the junction’s layout and current signal programs, we need to access these data. This data accessing is varying city-by-city, and mostly require contacting the city transportation engineering department.

IV. Examination

A. *visual analysis*

First, we start off with visual analysis of the congestion. We can clearly see that the main issue is that the straight lane congesting up to that Derék - Kishegyesi street junction.This implies that maybe the synchronization of the two junctions is not correct. Take a look at the programs and synchronization diagram.

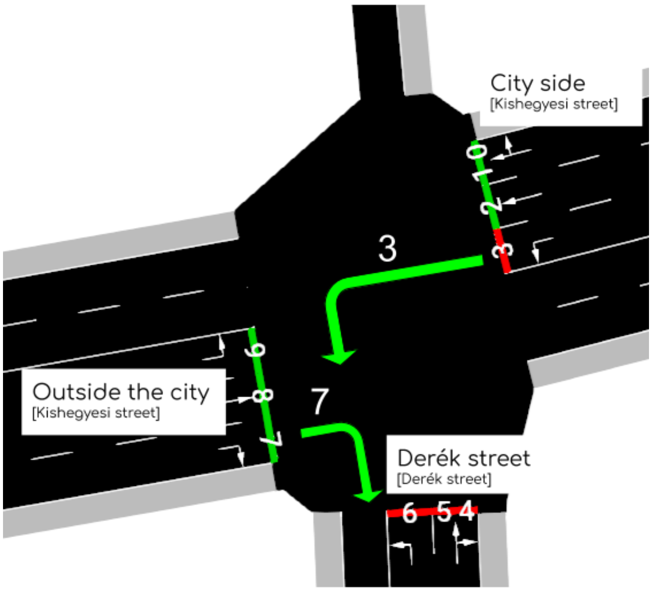

Fig. 10 Map of Kishegyesi junction, marked turning lanes from inside the city (3) and from outside of the city (7)

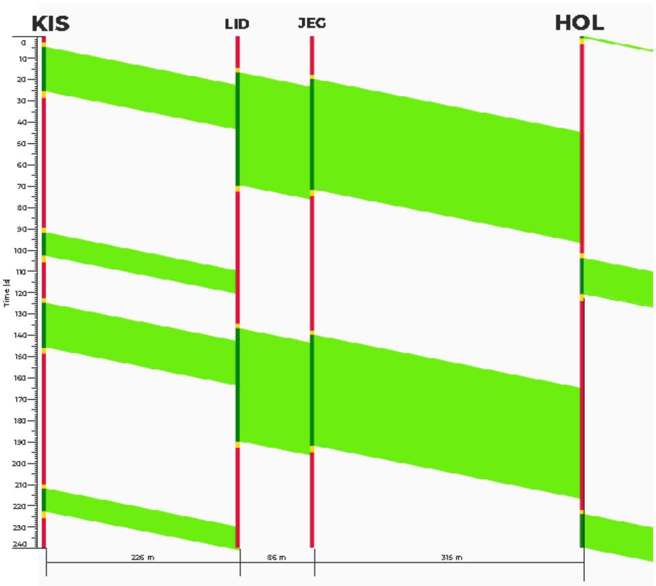

Fig. 11 Synchronization diagram, with incoming flow from the inner city

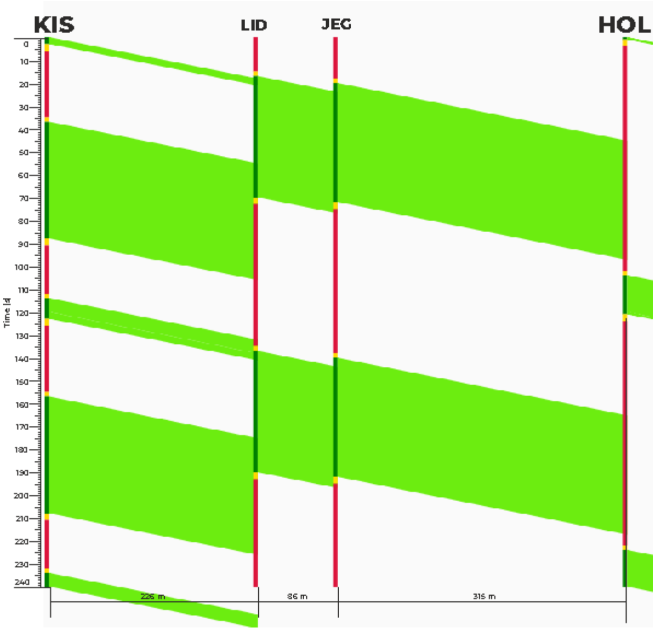

Fig. 12 Synchronization diagram, with incoming flow from outside of the city

We can see that the city side green phase (3), first green part, is in-sync with the LIDL junction straight. The turning lane from outside the city (7) is not in synch. And it is in the middle of the red phase for LIDL straight. We can assume by this, that the issue occurs because of the outer city - to Derék street traffic flow. So, we need to achive somehow that both from inside the city and outside the city arriving cars turning to the Derék street are in-synch with the following junctions' phases. Our idea at first was based on this thesis, and several solutions can be applied: an extra lane from the outer side of the city, so cars from that side can merge with flow from inner city - to Derék street flow. Or maybe shortening the city side greenlight in Derék - Kishegyesi junction, so we can quicker let cars from outer city onto the Derék street, so they can catch some synched green of the LIDL.

B. data analysis

We also gathered car flow data on the junctions. These data in the Table 1.

So, after analysing we can see that most of the cars at LIDL junction go straight to the Jégcsarnok junction.

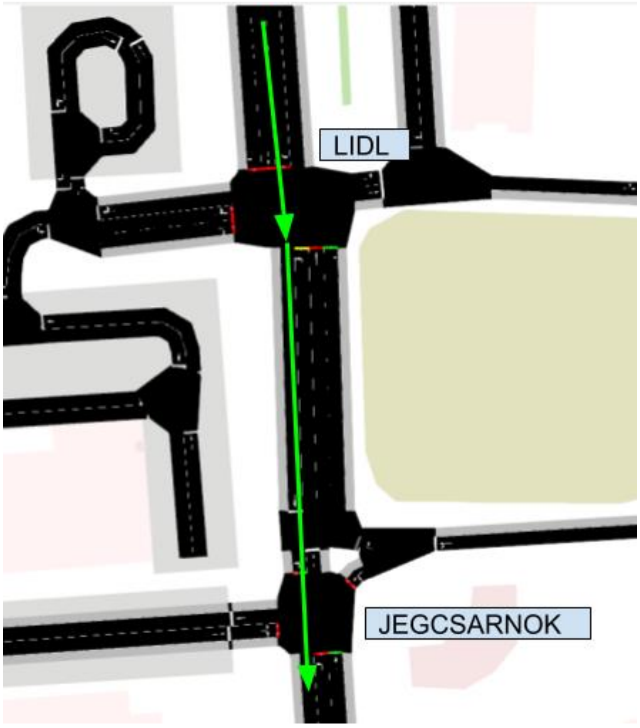

Fig. 13 The dominant flow at LIDL junction goes straight

Also, we have a considerable amount of left and right turning vehicles. The right turning vehicles already have an additional traffic signal light, so they do not cause high congestion generating effect. But the left turning lane, is only allowed if there is no flow from Vincellér street side straight** and no left turning vehicles from LIDL side.

Considering this we assumed that maybe a longer green phase can solve the congestion. We should move the green phase and expand, so it can handle some of the inner and outer city flow too. But also, we see that we have not so much green time that we can trade in, to make this change. The next largest green phase at the LIDL junction is the Vincellér side straight green, but from measurement data we see that it also having a high vehicle count. Our solution should eliminate current congestion, without making new ones. We also considered to change the phase time of the junction from 120s to 110, 90, 80, or even 60 seconds, but this is a huge work to test all the variations, and more like a reverse engineering method than a straight optimization method based on given situation.

C. projecting the results

After naive approaches to make solutions, we had a dilemma. Every change to the signal program seemed to be negative in some way. To handle all the needs of the vehicles, pedestrians and public transport we need to develop by hand signal programs and evaluate their pros and cons.

So, in this step we developed the machine learning system, that can handle the technically correct signal program generation, the simulation running, evaluation of signal programs, and evolving it to better performance.

D. execution, and data visualization

Firstly, we explored what measurable parameter of junction is the best to evaluate the performance of the control program. Basically, we can use any parameter that can be extracted directly or indirectly from the simulation logs. We used overall waiting time on junction.

Overall waiting time - describes how many seconds were waiting all the vehicles at red light at a given junction's every lane.

Example:

- No vehicle at the junction.
- Comes one car at the 3-rd second of operation, when the light to that lane is red.
- The timer for this car is started.
- After another 5 seconds, at 8-th second arrives the second car.
- They stand there 5 seconds at red light, and after this the traffic light changes to green, and both start moving at the same time.
- The overall waiting time in this 13 second simulation was (13-3) + (13-8)=15 seconds.
- This is only for one lane.

So, as we sum together all the waiting times, we get a measurable data, which directly reflects, how long were cars waiting in congestion at a given traffic control program.

Waiting time is the result of several factors. It encapsulates the capacity and the overall measure of waiting in que. This is a measure of comfort. We can assume that the lower the waiting time, the better the comfort felling, because we constantly moving. And, higher the capacity of junction, because cars wait less.

As we can evaluate and compare every different traffic light program, and we can run and extract data from simulations too, we started our experimentations with different setups of the system.

We ran several instances of the learning algorithm and selected the best one. Which is shown below.

Signal group Nu.	Safety matrix check	Direction	Time (0–110)	Green time [s]	Capacity [veh/h]
1.	5;6;9	Vincellér street straight	49	49	735
2.	3;4;6;8	Vincellér street left	55, 70	15	225
3.	2;9	Kishegyesi street right	49, 78, 98	69	1035
4.	2;6;7;9	Kishegyesi street straight	46, 77, 86	57	855
5.	1;6;9	Kishegyesi street left	77, 87	10	150
6.	1;2;4;5;8	LIDL side left+straight+right	93, 113	20	300
7.	4;8	LIDL side right additional	55, 70	15	225
8.	2;6;7	LIDL ped. crossing	44	44	660
9.	1;3;4;5	Kishegyesi street ped. crossing	55, 67	12	180

Fig. 14 Best TLP for LIDL

The system was able to solve the above described issue, in a unique way.

For comparison of the machine generated traffic light program versus the currently built in we can check the waiting time.

Waiting time in simulation [s]	
With original program	ML generated program
27399	16234

Table 3. Comparison of current TLP to machine learning generated, with the focus on waiting time

We can see that the machine was able to decrease the waiting time by 40%. Huge step into the right direction.

Worth mentioning that in this case we have not changed the traffic light program period time, so the resulting system have also 120 second period time.

V. Solution Explained

The solution basically is to split the one big green phase for the straight direction on LIDL junction from Kishegyesi street. The machine generated solution is split this one big part into two pieces: a bigger and a smaller part.

When splitting a green phase into two, we not only separate the parts and copy it to another part. Adding another green phase anywhere into the program, requires to check if there is no conflicting directions allowed, and whether there is enough time for vehicles from the previous green phase of a conflicting lane to leave the cross section of the junction without withholding the desired allowed phase.

A. *solution and its effectiveness*

After we got the results, we compared the video footage of both simulations.

Firstly, we thought that the program split the big green phase into two pieces, so it can synchronize the flow not only from inside the city but from outside the city side too. But actually, it was done for something else[1].

But after some further examination, we found that the issue was in the geometry of the road, connecting the Kishegyesi - Derék and Derék - LIDL junctions.

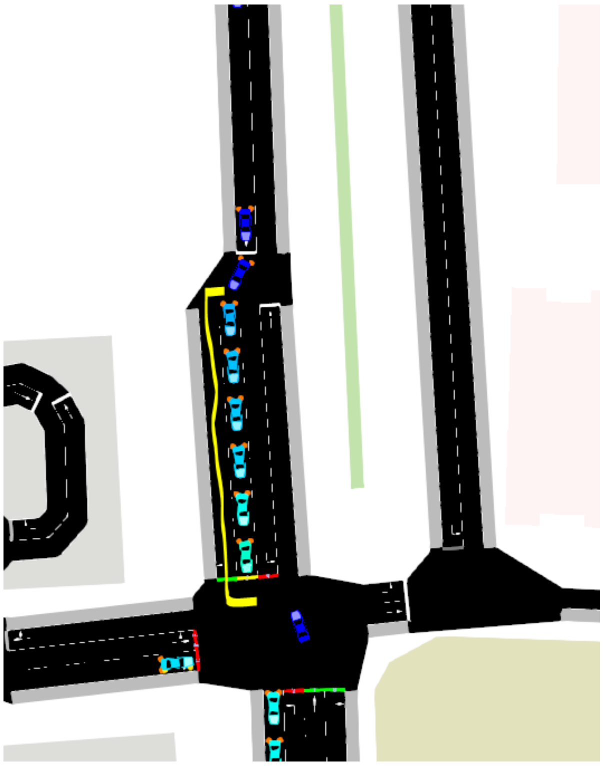

Fig. 15 After 6 consequent cars in LIDL straight, no more cars can enter to occupy left or right turning lanes. This enhances the effect of the congestion.

As we see, at the entrance of the LIDL junction, there is a lane separation into three sublanes: left, right and straight. This separated part is small, compared to the whole section. But if only 6 average sized vehicles were waiting in the straight lane, that would not allow any more vehicles to go into the left or right lane. And that is an issue, because if the first 6 cars would like to go straight, and the next 3 would like to go either left or right, they cannot move out to change lane, and ease off some of the gathering congestion. By splitting into two sections, during the 120 second phase time, vehicles were able to move much more frequently so they eased off more cars into left and right sublanes, which lead to fewer cars in the main lane up to the Kishegyesi - Derék junction.

Another effect is that however the overall green time for the straight lane at LIDL have not increased but the vehicles was moving twice as much, and the congestion had fewer time to build up, to the Kishegyesi - Derék junction.

VI. Conclusion

We can see the positive effect of the machine learning on the traffic flow and congestion management. To optimize a system to its better performance we always need a good measurement and comparison point. And as we have not enough input data for traffic light program effects on the real world, we need to have a great simulation environment too. Together, the synergy of these distant but still coherent fields as traffic light requirements, traffic simulations and machine

[1] because the green synchronizations from the outside of the city were not correctly aligned

learning can make huge impact on the developing of urban areas and improving mobility in highly loaded areas.

This case study is a part of a series, which will describe the impact and application of such an optimization system. Later, we will reference this machine learning based traffic light optimization system as Venturi.

VII. Thanks

Firstly, i would like to thank Kész Ákos for the help in developing the system on every step. Starting from the birth of idea, till the last written line in the code. Also, Dakó Lóránt Máté for multiple help in making reliable measurements on the field.

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