Advanced Optimization Method for Improving the Urban Traffic Management

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***Abstract*—The Smart City as a concept of future cities anticipates the smart and efficient traffic management. Current situation of traffic management did not offer a sufficient solution and it is not wise to use the current technology to improve the traffic situation on the city roads. This paper deals with advanced methods for optimization, the genetic algorithms, for using in urban traffic management. Implementation of genetic algorithm and also implementation of classical static solution were provided. We try to prove the advantages of modern optimization methods, which could bring more fluent traffic to the cities and solve the current challenges as i.e. high emissions, big delay, higher probability of accidents. The paper provides comparison measurements of static and dynamic solution in discrete time, discussion of the possible implementation in praxis and evaluation of the advantages and disadvantages for both methods.**

I. INTRODUCTION

The Smart City is nowadays a current topic. Considering only the situation in Europe, the European Union (EU), State governments itself and also private companies are investing every year considerable part of their budget to research, develop and implement the concept of Smart City. The term Smart City has many different ways how to define it. We are considering the term as a "*How to improve a city on different levels*", which could be levels of different users (i.e. government, authorities, private companies, citizens) or different fields (i.e. mobility, open data, energy efficiency & low carbon solutions, policy & regulation).

The annual growth of population in cities brings also the common problem with urban traffic density. Around 74% of Europes population lives and works in cities and towns (for 2050 it should be around 82 %). According to the European Union efficient urban traffic is essential for the future cities. The EU introduces three main challenges in this field - traffic congestion, mobility culture and social/environmental challenges **??**

The traffic congestion is responsible for many kinds of problems, as higher noise emissions, slower city traffic, higher probability of accidents or worse air conditions [2]. The big impact on the environment is proved also in the European Commission summary book [3], where is shown that congestion is responsible for more than 20 % (15 % of light-duty vehicles and the rest are heavy-duty vehicles) of all emission in EU - Greenhouse gases, acidifying gases or general ozone precursors. These and many other problems have a big impact on the living standard of citizens and also on the economical competitiveness of the cities.

We can improve the urban traffic situation on several different levels:

- Policy - solutions contain different restrictions and steps, i.e. cars are not allowed any more in city centres, special restrictions for trucks and heavy-duty vehicles, higher car fees, higher parking costs, financial support for public transport, car emission zones and restrictions, open data policy (which data should be shared, stored).
- Social - includes mainly change of habits as i.e. more frequent use of bikes and alternative transport, education in the new traffic trends, open mind for data and information sharing.
- Technology - includes all technological solutions from new innovative transportation, more effective solutions for vehicles, fuel quality improvement, advanced and smart traffic management systems, systems for open data and data sharing, sensor systems for safety.

This paper deals with urban traffic issue on technology level with design of advanced urban traffic management. We provide results of simulations for comparison of static and dynamic solutions based on the real streets. We use a simulation as a best tool for early technology testing, which should provide a clear view of the effectiveness of dynamic solution. We compare a common static solution on the chosen street with the implementation of genetic algorithm used as an optimization algorithm for our dynamic solution. Our solution provides an alternative to the urban traffic management for cities. We consider an existing sensor network as a data source for our algorithm.

The rest of the paper is organized as follows. The next chapter II provides our motivation for dealing with the topic, followed by chapter III - the overview of the current solutions, common methods for optimization and traffic management. The chapter IV explains the basics of our implementation of genetic algorithms and measurements. The chapter V provides the experimental results from our measurement and also the comparison of dynamic and static solution. Last chapter VII is conclusion, which summarized our work.

II. MOTIVATION

The cities are investing yearly a big part of their budget into the traffic infrastructure, which though has not every time the desired effect. Some roads are staying busy, while others are staying still empty [4]. The first step for the continuous driving was the roundabout, where the drivers do not need to wait at the traffic lights. Next step was achieved in the computer era, when the cities for time optimization start to use computers [5]. The growth of the cities and traffic density makes also these static solutions insufficient [6]. Static solution has no ability to dynamically change in time, based on the traffic situation. This makes the static solution very ineffective, mostly in the day-peak, when most of the cars are on the road. Static solution reacts very slowly to the traffic situation, mostly annually re-computed settings from statically collected data. There is not much space for improving the static solution and it is necessary to find a better solution, in the way that it will be able to dynamically react [7].

As mentioned, the traffic situation in the city impacts everyday life of the citizens, companies and the city itself. The work [8] shows that if cars slow down under 45 mph then the emissions are growing (the problem is also that the cars are staying longer on the road or that they are changing often speed). In 2010 was the traffic congestion responsible for 38 % of all traffic accident fatalities [9]. The impact of the traffic congestion is discussed also in the work [10], where is shown that traffic congestion has impact to the safe driving and accident probability. The study [11] shows the economical impact of the traffic congestion (slower transportation of goods, time wasted, fuel wasted, car/trucks accidents). In 2030 the expected costs of traffic congestion are hundreds of billions of dollars.

The private and also public sector are investing yearly a big part of their budget into the telemetry networks [12]-[17]. These networks might be used for data collection and also as a tool for managing the specific situations in the city. Network telemetry is a solution for future cities [18]. It offers great analytical and statistical sources for dealing with difficult situations on the streets and roads. This network might be also used as a main sources for a dynamic solution for the urban traffic management. We are focused on the Genetic Algorithms used in traffic management process, where we see genetic algorithms as a strong computational tool, which could be used in real-time to search better solutions for current traffic needs.

III. Related works of genetic algorithm traffic management

The genetic algorithm is a part of artificial intelligence and an evolutionary algorithm in the field of problem solving and optimization. We use the genetic algorithm for solving the traffic management and the problem of traffic congestion. In the last century the genetic algorithm received increased attention in the field of traffic management. This section provides overview of works using the genetic algorithm for solving the traffic management and traffic situation in the cities.

In [19] is a suggestion for traffic management in Alexandria, Egypt (concrete and more specific data might be found in [20]). This work used collected real data, which were measured during the peaks of traffic in Alexandria. The work shows a very good mathematical background for this method and the basic genetic algorithm is used. What is rather poor explained is how they achieved the results. The paper does not clearly answer how and what was optimized by genetic algorithm, which might have had such a big impact on the traffic lights timing and the traffic speed. Also it is not explained how this method should be implemented in praxis and what are the needs or the preconditions. However, this work promises maximum improvement of traffic of 72 % in peak periods of city traffic. By taking a closer look, the results are between -25 % to +72 % for critical queue length and -52 % to +63 % for waiting times value. The negative values are in non-peak traffic and the positive in peak-traffic. The results are not sufficiently discussed and also due to not mentioned real implementation issue, is hard to evaluated the suitability for praxis and the results themselves.

The [21] is a solution proved by praxis in Istanbul, Turkey. The system called ATAK (Adaptive traffic control), it achieved 10 to 15 % improvement of traffic fluency by using basic genetic algorithms (discussed in their work [22]) and fuzzy logic (discussed in [23]). This system is using real-time measured data for current needs, historically data for statistical and prediction purpose, computed traffic volume expectations and determined occupational periods. The system includes few crossroads with traffic lights and also more difficult road structures (e.g. multiple-line road circles). The matter is the local-global (global-local) issue, when it is not mentioned how to use this system on global level or at least in different conditions.

Another work [24] provides the author's own system GAT-STM (Genetic Algorithm Traffic Signal Timing Management) for traffic management. This paper describe the actual needs and issues of the traffic and tries to solve it with genetic algorithm. The description of actual needs and real needs is the main advantages of the paper. This paper does not describe how the provided system should help to deal with these specific needs and if the needs were dealt at all. This paper also does not include concrete results, which could be reviewed. However, the authors promised the 90 % success rate for car detection in their system in laboratory environment, but other tests are needed. This paper does not include the used method of genetic algorithm.

The following work [25] provides a suggestion of an intelligent traffic light system based on real-data collection from a video image detection system and cell phone people detection in specific location. The intelligent system should work by using the genetic algorithms. This paper promises the real-time changes in the traffic-light timing, but it is not describing the way how the data should be collected or even the implementation needs and important parameters are missing (e.g. necessary performance). Also the image detection has in general many problems including the cost of the system, environmental implementation problems (e.g. it is not possible to use it around parking places or big buildings). The driver detection by cell phones is a very difficult specific issue mostly in urban areas, which includes not-only drivers, but also walkers, bikers and other non-drivers group (and in this paper is not sufficiently discussed, how to deal this problems with the provided techniques). The main problem is that the paper provides a poor description of the genetic algorithm and it is more focused to the image processing, but even this part is not satisfactorily dealt. The strong part of this paper is literature, included [26] and [27] from year 2012, where is well described the technique of image processing for traffic management. In [26] is provided a solution for vehicle tracking and recognition methods for urban traffic surveillance in a distributed cooperative manner and [27] is more focused on the framework, which should provides warnings and informations for the drivers or cars itself for right decisions during the ride and for statistic information collection and use it in real environment of VANET (vehicular ad hoc network) and smart city networks. The works described in [26] and [27] could be used for data collection and information sharing in the intelligent traffic management systems, which is also reason for mention these two works in this chapter.

The last reviewed work [28] is also connected with image processing and by using cameras tries to provide real-time traffic light control system, where the optimization process is based on basic genetic algorithms. The used genetic algorithm is good explained (mostly the parameters are very clearly defined). The system promises 12 % improvement compared with classical traffic management.

The general improvement of showed algorithms change according to where the experiments and measurements were done. In the laboratory, we could see around 70 % improvement and in the real-environment around 15 %. The weaker sides of selected papers were mostly poor description of genetic algorithms or parameters, missing discussion what data need to be stored or used and what was optimized to have the specific traffic improvement. We try to show the concrete settings of the algorithm, with clear definition of fitness function and specific description of the results. Our paper provides the clear definition of used genetic algorithm (explained also the used methods for implementation), reviewed current related works, two discrete time implementation (static and dynamic), measured data for different parameters and also a summary of advantages and disadvantages for static (classic) solutions compared with dynamic (genetic algorithm) solutions, related to the praxis.

IV. Traffic simulation and implementation

A. *Traffic (discrete) simulation*

We are using the discrete-time simulation as a tool for testing the dynamic and static traffic management solutions. The discrete time simulations (Sometimes also called discrete event simulation - DES) is a model of a system, where events occur at a particular instant in time and mark a change of state in the system [29]. The Fig. 1 shows the flow char of our implementation of this method.

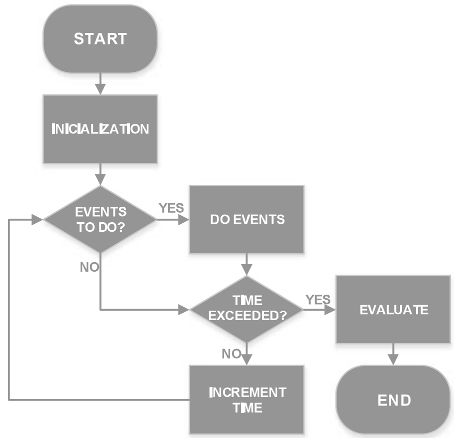

Fig. 1. Flowchart of our discrete urban traffic simulation

When the program starts, it first initialized the input variables and after it starts to process the planned events. The planned events are controlled in discrete time, if it is here tasks to do, program will do it in this specific discrete time. After we are controlling if the time was exceeded (there are also controlled all the possible properties for the decision, that the program should end). If the time was not exceeded, the program continues with incremented time (+1). When the program mechanisms decide that all conditions are fulfilled (cars are out of the system, setted time is exceeded) the program evaluates the results, recomputes the variables and saves them in the database and end the simulation. The logic of our discrete simulation is explained in Fig. 2 (t is time of the simulation).

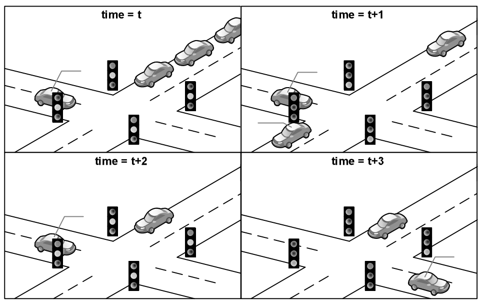

Fig. 2. The logic of our discrete-time urban traffic simulation

B. *Implementation of genetic algorithm*

The considered network for traffic-management using genetic algorithm is in Fig. 3, this network is used for the genetic managed traffic.

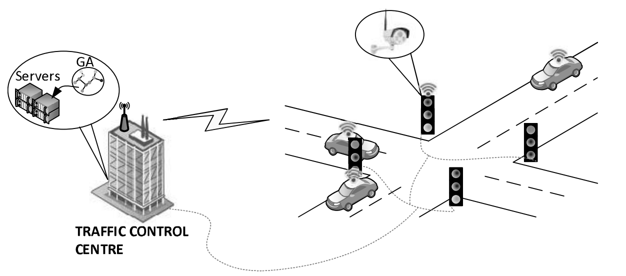

Fig. 3. Considered network and basic functionality of the Genetic Algorithm (GA)

The cars has the smart navigation system (i.e. car-navigation device, smart-phone), the roads has smart-sensors (on figure the cameras), the traffic control centre has the wire-connection for traffic-light settings and wireless connection for data storage from sensors and for providing the necessary informations. The genetic algorithm is implemented in the servers for managing the traffic situation and for evaluating the data collected from sensor network.

The basic logic of our implementation of genetic algorithm is shown on the Fig. 4. The initial population is randomly generated as first, next is coming the evaluation (fitness function), which always evaluated the closest best solution (lowest average delay). If the criteria are fulfilled (delay, simulation time, difference from the optimal solution or if the solution is not getting better - final solution) then the simulation ends, otherwise a new population is created by selection, recombination and mutation. The implementation is coming from the JGAP [30] library (JGAP is the genetic algorithm library for optimization purposes). The best 90 % of individuals from the population are selected. From the remaining 10 %, are 35 % used for recombination and 65 % for mutation. This settings shows the best results for traffic optimization. The recombination shows to be less effective in the right-way searching than the mutation.

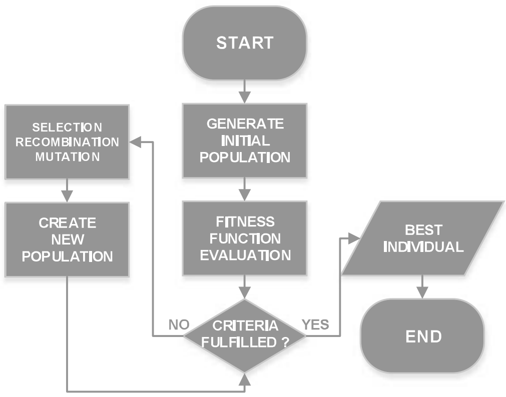

Fig. 4. Flowchart of the implemented genetic algorithm

We try to optimized the average waiting-time of all vehicles in the system with managing the best way to their final destination from the system. When the vehicle enters the system, the enter and final point is generated. The best way to the final point is computed based on the current traffic situation (the cars are not send to the over-loaded streets and every-time are using the best possible road).

V. Experimental results

We measured our implementation of the static and dynamic solution. This chapter provides the results of these measurements divided to three sub-chapters. First, the static solution results are introduced and explained, followed by results of dynamic solution (with genetic algorithm) and last sub-chapter is a comparison of these two methods. Both solutions were measured by using the discrete time simulation method. The goal of our measurement was to show, how both solution behave in the growing traffic-density. The car density is considered in vpc (vehicles per cycle), which means that the system is consistently loaded with this amount of vehicles for the whole measuring cycle. We consider this unit more valuable as a vph (vehicle per hour) for each crossroad, because we are measuring the average waiting-time of the all cars in the system and we also need to see the map (Fig. 5) as a complex system and not as a single crossroad. Average waiting-time (t_{avg}) is in seconds (s) and it is computed as follows:

$$t_{avg} = \frac{\sum_{i=1}^{n} t_i}{n}, \tag{1}$$

where t_i is waiting-time of single cars (measured in seconds from point, when the car enters the system, to point, when the car leaves the system) and n is number of cars. The Fig. 5 (right) shows the used map. The roads are one-line two-way roads. It is used real streets in Brno city. The left picture is our consideration for implementation of this road situation.

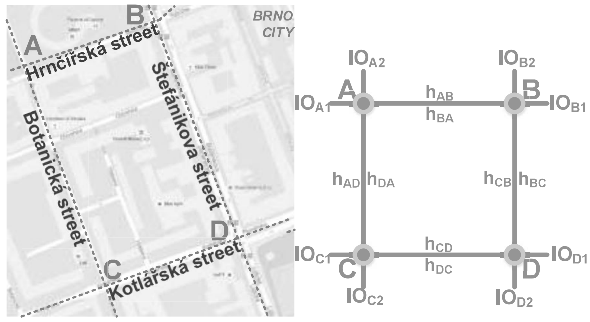

Fig. 5. Considered map for simulation environment (left is chosen street map, right is created simulation model from street map

The *A-D* are the crossroad marks, *IO* is input-output and *h* is the *h*-index of each street. The *h* is in our simulation computed as followed:

$$h = s \cdot \alpha, \tag{2}$$

where *s* is distance in meters (m) and α is the index of the road. The α should consider speed limit, road-difficulty and road density. The constant is evaluated by user and it should shows the difference of each road). Our implementation also consider the possibility where the *h*-index from the one of the lines is different. This could occur in the situation where the one line is more loaded or has some different difficulty. For our measurement we consider α = 1 for all lines and the distance *s* as a real measured distance. Tab. I shows the used values for the simulation.

TABLE I. The parameters of the simulation for measuring the static and dynamic methods

***h*-index name**	**s [m]**	**α [-]**	***h*-index value [-]**
h_{AB}, h_{BA}	350	1	350
h_{AD}, h_{DA}	330	1	330
h_{BC}, h_{CB}	360	1	360
h_{CD}, h_{DC}	390	1	390

A. *Static solution of traffic management*

The static solution has a static period of green/red light. We used the most common traffic-light settings 30 and 60 seconds period (green/red), which is often used as a traffic-light period in the cities for the day-peak. The results of our measurements are in Fig. 6. The 30 seconds period shows much better results than the 60 seconds. The average waiting-time was constant till the roads start to be over-loaded by vehicles. The 35 000 vpc was critical for both periods, where the waiting-time starts to exponentially grow. With 75 000 vpc the waiting time for both solution was nearly same. This value was the dead-point (Dead-point is a situation on road, when the traffic rapidly slowdown) for the roads. The average waiting-time was more than 15 minutes for 75 000 vpc.

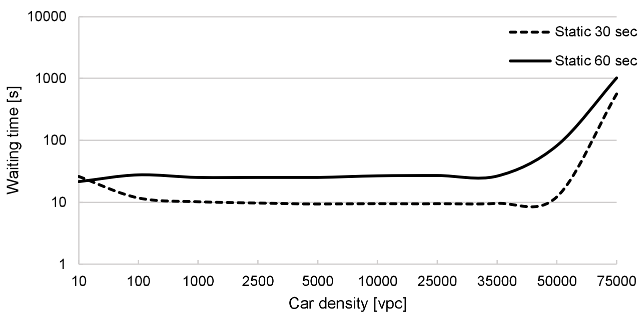

Fig. 6. Results of the static solution for intervals of 30 and 60 seconds

B. Dynamic solution of traffic management

The dynamic solution was measured for two kinds of settings. We change the population number as a factor for a better genetic algorithm solution. The first measurement was done in ratio 20:20 (iteration:population) and second measurement was done in ratio 20:50 (iteration:population). Both solutions were ending with very similar results, however the setting 20:50 shows better results. The final results are shown in Fig 7. The critical dead-point for this algorithm is also 35 000 vpc, where the effectiveness of the algorithm rapidly falls and waiting-time rapidly grows.

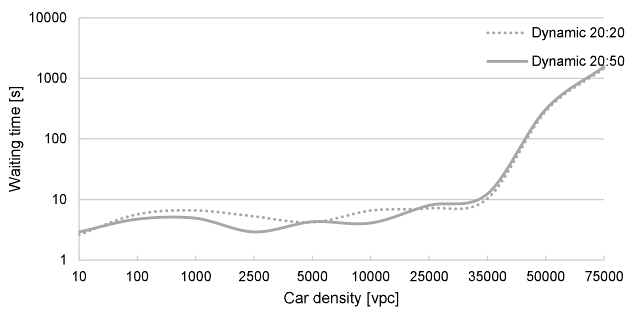

Fig. 7. Results of the dynamic solution for 20:20 and 20:50 (iteration:population) ratio

The size of population impacts the final solution, but also the needs for power. It is always necessary to make a compromise between population size and the speed of finding a best (better) solution.

C. Comparison of static and dynamic solutions

The Fig. 8 shows the comparison of static and dynamic solution. We show the best result of dynamic solution in comparison with both static solutions. The graph proves that the genetic algorithm could help with the traffic management in the cities, but it is ineffective in already over-loaded streets or cities. Both solutions (dynamic and also static) have the same critical vpc value, where the traffic falls to the dead-point. It is 35 000 vpc, where both solutions are getting ineffective. At this point the dynamic solution shows even worst results than the static solution. The algorithm is not able any-more find better solution, because it is not exist in the level of road-optimization and it has to be done in different level.

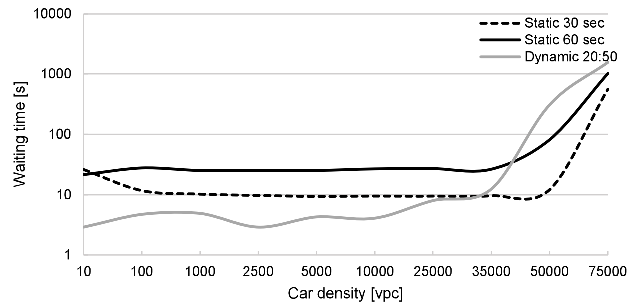

Fig. 8. Comparison of the dynamic and the static solutions

The genetic algorithm is very effective from low to middle loaded roads (100 to 25 000 vpc), where it achieves best results. The Fig. 9 shows also the load of the streets in the chosen part of the city (where fast means 0 seconds waiting-time and slow 100 seconds waiting-time).

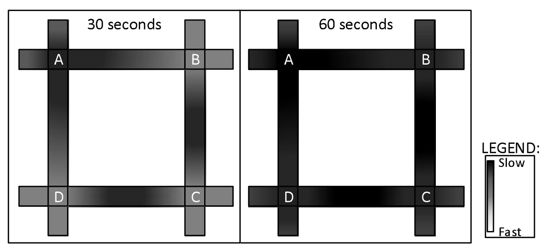

Fig. 9. The road-load of static solutions for car density 2 500 vpc

The big change is shown in Fig. 10, where the genetic algorithm was applied as a traffic-management optimization. There we can see a big improvement in the fluency of the traffic and rapid change in the waiting-time.

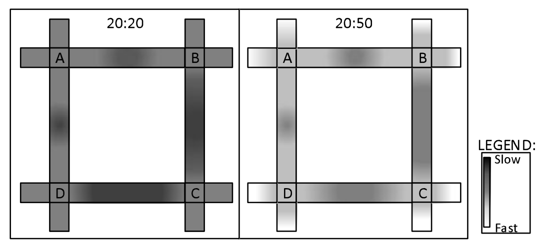

Fig. 10. The road-load of dynamic solution for car density 2 500 vpc

The final results are provided in the following Tab. II. The S30s is static solution 30 seconds timing period, the S60s is static solution 60 seconds timing period, the D20:20 is dynamic solution with 20:20 iteration:population ratio, the

D20:50 is dynamic solution with 20:50 iteration:population ratio (all values are in seconds). How we can see, the best results for dynamic solution are reached under 35 000 vpc (the critical dead-point). If we consider only use of the genetic algorithm in he time, when is effective and without extreme values (100 to 25 000 vpc), the average improvement is 41 % for the D20:20 and 52 % for the D20:50. The maximum improvement is 55 % for the D20:20 and 70 % for the D20:50.

TABLE II. THE SUMMARY OF MEASURED AVERAGE WAITING-TIME IN SEC FOR DIFFERENT DENSITY, FOR STATIC AND DYNAMIC SOLUTIONS

Density [vpc]	S30s [s]	S60s [s]	D20:20 [s]	D20:50 [s]
10	26,00	24,40	2,60	2,90
100	11,69	27,59	5,69	4,70
1 000	10,23	25,18	6,59	4,87
2 500	9,68	25,21	5,25	2,90
5 000	9,37	25,24	4,18	4,26
10 000	9,47	26,71	6,53	4,06
25 000	9,42	26,92	7,16	7,97
35 000	9,53	26,43	10,29	12,42
50 000	12,15	81,52	286,15	308,57
75 000	560,44	1 014,67	1 462,95	1 548,31

VI. CONCLUSION

We provide the summary of current works in the field of traffic optimization by genetic algorithm, we also shows the power of genetic algorithm in our implementation for the real chosen part of the Czech city Brno. The dynamic solution or the optimization by genetic algorithm offers to the urban traffic management big improvement. Our solution provide in average 50 % improvement compare to the static solution for the traffic day-peaks (or for medium loaded roads). The smart algorithms will always depend on the open data, which are provided to the devices, which are able to use them. Without good data (sensor network) is not possible to implement advanced solution for traffic management. In praxis, this could take a time till the full sensor network will be provided with fully open data (from technology and also legislative point of view). But the technological readiness already allows to create better solution than it is used today. Dynamic solution might be a future powerful tool for handling the growing difficult problem of the traffic density in the cities.

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