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Green wave optimisation

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ABSTRACT

In this paper we present the results of global optimization of green wave parameters (offsets, opening times, speed limit) for the main artery in the city of Wrocław (Poland). The optimization process was performed in ArsNumerica Execution Environment [1] and involved two different objective functions: the average waiting time and the average queue length. Both approaches were compared by calculating the number of vehicles that passed the artery in a prescribed time.

KEYWORDS: green wave optimization, ITS simulation, road traffic simulation

1. Introduction

To provide an efficient and safe pass through the main arteries is an important issue in the process of the optimization of the traffic flow in the urban area. Many researchers and practitioners have undertook this task during last one and a half decade since the computing power rapidly increased and the data from such systems as Intelligent Transportation Systems became available. The use of non-constant traffic signalization parameters (i.e. adjustable to the traffic flow green light openings, cycle durations or even offsets) opened new possibilities for improvements in contrast to former traditional analytical algorithm that assumed static behaviour of the artery signalization settings.

A comprehensive survey of the literature in the field of the traffic green wave optimization in the sequence of intersections can be found in [12]. The authors present the formulation of the problem in a mathematical form as a constrained optimization process. As the most important design parameters in the green wave optimization process for the sequence of synchronized intersections the authors identify

a. a cycle time length – which limit an opening time
b. an opening time – green time on the major directions, defines a green split between major and minor directions,
c. offset – stipulated shift of the opening phase with respect to the 0 reference point in time associated with the first intersection .

All known methods to optimize green wave use all or chosen ones of the above design parameters.

As a common objective function in a traffic control optimization the average delay as well as an average queue length is used in most of the cited articles [2,3,7] but also the number of stops per unit of time can be used. Both of the latter measures of effectiveness of the green wave were combined in [15] to form a multi-objective optimization problem. In [7,6] as an objective for the optimization the number of vehicles that pass the artery without any stop is proposed to be maximized. In our case however it turned out that in a congested traffic and on a long artery this objective function gave always zero value, and turned out to be unpractical.

There are two approaches to optimize the objective function in the green wave optimization. The first one is the analytical one [5] i.e. the MAXBAND and MULTIBAND algorithms – for a literature survey on this algorithm one can also see references in [7]. The ideas of these algorithms goes back to 60ties where the computer power was not as available as nowadays. The second approach is based on an optimization process using one of non-gradient global optimization algorithms. We made use of the latter approach in our work.

For the optimization of the objective function which is usually continuous in this process any global optimization algorithm with constraints are used particle swarm algorithm[3] fishing algorithms [14]. The great attention is paid in this field however to genetic algorithms [2,3,9,10,11,13,15]. In our application we use the MATLAB implementation of a genetic algorithm for global optimisation with constraints that is based on [17]. This algorithm enables to work on continuous design variables.

As an engine to calculate the objective function we used the ArsNumerica Execution Envirionment (AEE). The AEE is an optimization layer above the SUMO [8] simulator that

1. enables to parametrize a description of a dynamic road traffic simulation,
2. enables to perform the global optimization of the various measures of performance for any road traffic scenario,
3. has its own language based on TCL TK [22], that enables to write micro-programs for all intersections (the parameters of micro-programs may be subject of the optimization process).

The remainder of the paper is organized as follows. In section 2 we describe our strategy to synchronization of the intersections in the road system, that base on genetic algorithms.

In section 3 we describe how to setup the simulation for SUMO. In section 4 we describe the way of use of the AEE. In section 4 we present results of the application of our strategy for the main artery in Wrocław (Poland). Finally we draw conclusions.

2. Strategy to calculate settings of traffic light signalisation on an urban artery

2.1. The problem formulation

The mathematical formulation of the problem as a non-linear constrained problem can be found in [11] or in a survey paper [12]. Design parameters that are subject to the optimization are green splits, green-phase durations on the major direction, offsets, optionally also the length of the cycle. For our case also the possible prolongations of green phases are optimized (see section 4.1). This is specific to the Intelligent Transportation System in Wrocław. Usually the cycle duration is fixed for the whole artery and is not directly a subject of the optimization. To find the optimal cycle duration time various settings within a prescribe feasible range are checked. For Wrocław the range is from 80 to 120 seconds. Tests with changeable cycle time show that the optimization process does not converge or converges very slowly. To be as close as possible to reality bi-directional traffic has to be considered.

2.2. Objective functions

As the objective functions to minimize we used the average queue length and average waiting time called also waiting steps number i.e. the average number of seconds where the movement of a vehicle was less than 0.1 meter per second. The later objective function corresponds to the average waiting time. The objective functions may be optimized with the genetic algorithm [17].

2.3. A method to compare the obtained solutions

The results obtained from the optimization of both functions can be compared by checking the number of vehicles that pass the artery in a prescribed time period.

3. The SUMO simulator setup and output

The Simulator of Urban MObility (SUMO) is a traffic simulator [8] for microscopic simulations based on Krauss car following model [20]. To define the simulation scenario in SUMO one needs to

1. define a road network with detectors,
2. define traffic flow on directions and calculate routes that reflect traffic demand.

The output of the simulation describes the measures of performance that can be used for green wave optimization. In the following sections we describe the process of defining of a single simulation in SUMO divided into abovementioned stages.

3.1. A network setup

Before we are able to start a road traffic simulation, it is necessary to prepare some input parts to SUMO. The main part is *routes scenario* – map of routes to be simulated.

A creating process of a scenario consists of the following:

- cutting a selected area of the Open Street Map [16],
- erasing from this area all unnecessary objects such as buildings, parks etc.
- saving prepared area and then use *netconvert* tool to convert *.osm file into *.net file which can be used by the SUMO simulator.

The next step which has to be done is adding detectors to the network. This step is necessary, because detectors are placed on the beginning of each route which vehicles are arriving from. Afterwards the network can be opened in SUMO graphical mode. For the artery studied in this paper its graphical view is shown on Figure 1.

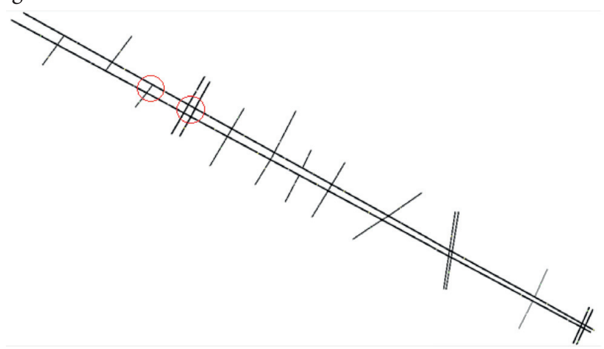

Fig. 1. Legnicka-Lotnicza Street in Wrocłąw SUMO model. As one can see it gets straightened compared to a real map. The straightening however kept proportions of distances between intersection. In circles are intersections from Fig. 2 [own study].

3.2. Traffic flow setup

The next stage, which should be performed before the simulation is started is a flow definition and routes calculation so that they reflect a traffic demand. For this task the DFROUTER program from the SUMO package is used. It works up to 15 intersections. For more intersections more sophisticated origination destination matrix algorithms have to be used (c.f. [19] and references therein). The DFROUTER calculates routes of vehicles during simulation so that the demand defined beforehand is preserved. In this purpose adequately spaced entrance detectors as well as information about the number of vehicles on each of the entries in the 10 minute interval have to be defined as an input.

In our case the whole simulation is set up to cover one hour, so 6 compartments are needed . When the program finishes computing the output is created in a form of an XML file which describes vehicles routes that are used as an input to the simulation.

3.3. A simulation and its output

The simulation input data is defined in a configuration XML file. In this file the user also defines an output of the simulation. The output is generated in an XML file which contains a full information of what happened during the simulation. We use it to calculate our objective functions: queue length and waiting steps. Each function has an xml tag assigned : <queuing-length> and <waitingsteps>. The first parameter describes the length of the queue of vehicles for the intersection and the second one a time of simulation when vehicle velocity was less than 0.1 meter per second. In both functions we collect data and compute mean value for each iteration of simulation on the level of AEE which is above the SUMO simulator.

4. ArsNumerica execution environment setup

The ArsNumerica Execution Environment is an optimization environment layer that enables to parametrize and execute a sequence of single dynamic road traffic simulations. It was introduced in [1] to audit the Intelligent Transportation System performance on chosen intersections in the city of Wrocław. The setup of this layer one has to

1. define sequence table for all or chosen intersections – the ones that take part in the optimization.
2. define micro-programs for all or chosen intersections. The defined micro-programs should correspond to ITS ones but it is not obligatory.

Both of abovementioned input components are used to generate a parametrized input data for a single SUMO simulation. The objective function is defined using the output tag from SUMO simulation. The value is calculated after the simulation run finishes. As described in previous sections as an optimization algorithm we use MATLAB genetic algorithm that bases on [17].

4.1. Sequence table

A sequence table is another necessary part of the input data for ArsNumerica Execution Environment. It is a structure which describes state of traffic lights on each junction in every moment of light cycle. It also describes possibility of dynamically fixing duration of specific phase of light cycle. Figure 2 shows examples of sequence tables. Each row describes one phase of cycle, and each column describes specific traffic light on intersection. Columns *Fix* and *T* contain in order: possible amount of changing duration of the phase and general duration of specific phase (both are parameters available for optimization). In Table 1. We show how many optimization parameters is available for optimization for the example calculated in this paper. These parameters are offsets green phase durations on a major direction and fix parameters. In our example in total there is 90 parameters.

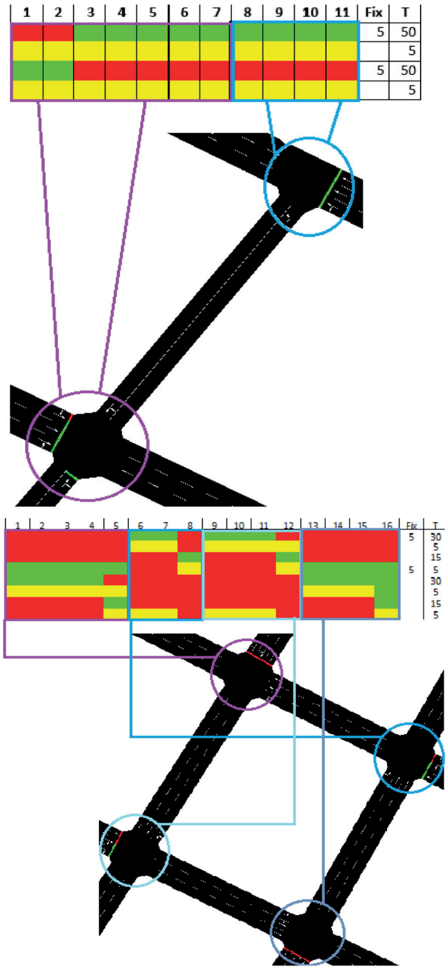

Figure 2. Sequence tables for two intersections. The intersections shown here are those marked in Fig 1. with red circles. The sequence table for the intersection on the left contains 6 parameters whereas the right hand side intersection consists of 4 logical intersections tightly coupled in the calculations and it is described by 12 parameters [own study].

Table 1. Number of sequence table parameters for all intersections in the considered artery

No	Intersected streets	Number of parameters
1	Podwale/Legnicka/Ruska	12
2	Sokolnicza/Legnicka	6
3	Nabycińska/Rybacka/Legnicka	12
4	Poznańska/pl. Strzegomski/Legnicka	6
5	Niedźwiedzia/Legnicka	6
6	Białowieska/Legnicka	6
7	Małopanewska/Rysia/Legnicka	6
8	Kwiska/Wejherowska/Legnicka	6
9	Na Ostatnim Groszu/Legnicka/Lotnicza	12
10	Bajana/Lotnicza	6
11	Hutnicza/Lotnicza	6
12	Metalowców/Lotnicza	6
		90

4.2. An intersection microprogram

A micro-program dynamically controls all traffic lights which are placed in the scenario. After creating sequence table it is another step in preparing simulation process. In this part, all used variables need to be specified. Example is shown in listings 1,2 and 3.

List. 1. The duration of the simulation, number of intersections and id's of detectors are set

```
set TS 3600
set LS 30
set idD1 ML6
set idD2 ML5
set idD3 ML7
set idD4 ML2
```

List. 2. A way of setting variable which contain sequence table and example of its use. The first sequence is separated from table and set on traffic light from a chosen intersection.

```
set tabsek30 GGGG6yyyy0rrrr6yyyy0
set sekw30 1
gettab tabsek30 pom $sekw30
setlights 30 $pom
```

During simulation all variable values are created dynamically from XML files. It is also possible to use basic logic and comparison operators. Example is showed in Listing 3 – if number of vehicles is greater than declared threshold, then add more time.

List. 3. IF statement in AEE micro-program language. As one can see the inverse Polish notation is used in a conditional expression.

```
if { > $vehn $threshold } {
    set time [ + $time 5 ]
}
```

With the use of this tool it is possible to create advanced control program logic for any kind of traffic simulation since one can modify a traffic light logic according to sequence table and to the current traffic dynamics.

5. Simulation results

As Table 1 shows the number of parameters of the optimization was 90. The parameters are offsets, green opening times and fixes i.e. how much the specific green phases may be prolonged. The ranges of changes of these parameters are shown in Table 2.

Table 2. Ranges of the optimization parameter changes

	Start	End
Fix	5	15
Green phase duration	40	60
Offset	10	110

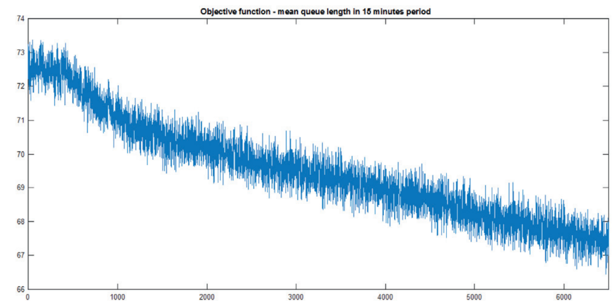

Fig. 3. The objective function – the average queue length optimization [own study]

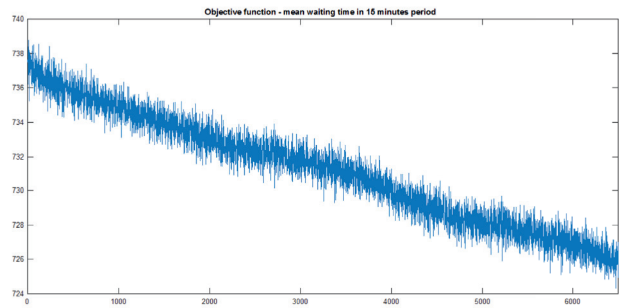

Fig. 4. The objective function – the average waiting steps number optimization [own study]

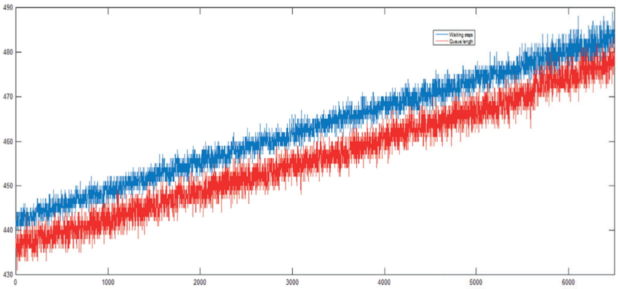

Fig. 4. The objective functions comparison – the number of vehicles that pass the whole artery within the period from 15-th minute to 30-th minute of the simulation. About 15 minutes is required for a single vehicle to pass the whole artery. Both functions are increasing and as one can see the systematic shift occurs for the optimization with waiting steps objective function. This phenomenon is not fully clear for us, but may be the result of the difference in scenario such that in waiting steps scenario only vehicles driving through the whole artery from the intersection 1 to intersection 9 and inversely were taken [own study]

6. Conclusion

In this paper we presented the ArsNumerica Execution Environment framework to perform a green wave optimization using the genetic algorithm. The presented tool uses SUMO simulator to perform traffic simulation with Krauss driving model and enables to model fully dynamic scenario similar to Intelligent Transportation System. The tool was applied to improve measures of performance such as a delay time as well as number of waiting steps for the main artery of the city of Wrocław. The tests were performed on real life data registered by the Intelligent Transportation System in Wrocław during the morning peak hours on weekdays in May 2014. In both cases after 7000 function evaluations the number of vehicles that passed the most crowded part of the artery was increased by about 10%. Both objective functions seems to be equivalent.

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