MANAGING LIGHT-SIGNALLING DEVICES IN VIEW OF CITY ECO-LOGISTICS

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Abstract The paper presents the issue of managing the control of vehicle traffic at crossroads by applying classical, traditional methods and a genetic algorithm. While carrying out the research, the authors indicated that genetic operators enable us to control lighting devices more efficiently by about 20% as compared to classical methods and by about 40% compared to traditional methods. Classical methods have been defined as models based on movement sensors only and the FIFO queue whereas the traditional method denotes permanent lighting cycles. Thanks to the elaborated method of controlling the traffic emission of CO_2 may be decreased. The paper also indicated further directions for research on methods related to fuzzy sets, neural networks, heuristics and hybrid methods.

Paper type: Research Paper

1. INTRODUCTION

Recently a huge emission of carbon dioxide and other harmful elements has been become one of the basic problems of the contemporary civilization.

The paper mainly focuses on presenting the method of reducing the emission of harmful substances to the atmosphere by smoothing the traffic in an urban agglomeration. Light-signalling is the most important element which facilitates controlling road traffic. Designated journey time and stops to a significant extent affect the course of road traffic as well as the amount of harmful substances released in town centres. Too limited traffic at crossroads also influences the economics and organization of urban transport (Urban, 2008).

They began to develop in 1868 in London at the crossroads of New Palace Yard and Bridge Street when one of the first signals was put. These were manually controlled devices equipped with a gas lamp transmitting green or red light. Unfortunately a few days after the device exploded its usage was stopped.

Subsequent attempts to implement the device controlling road traffic were made before the First World War in the USA where the first electrically controlled light-signalling device was installed. The next stage consisted in applying three-coloured lights and then in 1928 the first signal controlling traffic with a horn was installed. The first traffic light appeared in Poland in 1926 in Warsaw. However the first accommodative traffic lights were introduced in our country in the 70s.

Nowadays as years go by the technological progress allows us to face the challenge of controlling much heavier traffic than the traffic from the seventies or the eighties.

Depending on a situation we can choose from the following light-signalling systems: cyclic, accommodative ones and their variations.

All the values of particular components may be obtained by means of an appropriately considered model of road traffic as there are no detectors enabling tracing all changes occurring in the traffic.

Systems controlling road traffic designed this way should try to obtain the lowest value representing the traffic flow which can be calculated as follows:

$$Q = v * k,$$

where
Q – denotes the traffic flow expresses in [P/h],
v – the average speed of a vehicle on a specific section expressed in [km/h],
k – density of traffic expressed in [P/km].

For an appropriately small Q we can achieve a satisfactory traffic flow, analogically a big value of Q may denote very small movement of vehicles or its stoppage.

The traffic flow to a significant extent depends how the crossroad is designed (e.g. how many lanes for going straight, left or right there are) and depends on the way the traffic lights near the centre of traffic work as traffic jams cannot occur past the crossroads due to the cyclic system installed there. Such a situation may

make us wait in a traffic jam at the crossroads and when we see a green light we will have to continue waiting in the same place because of there is no place on the lane we want to go to.

One of the desired results from smart systems managing traffic lights is smooth, more economic movement of vehicles in crowded places. We do not want a situation when there is a green light in the street that no one is going and cars are unnecessarily waiting on perpendicular roads. That is why, whether we want or not, we will implement in our life systems based on artificial intelligence including evolution algorithms which can be used for solving optimization problems.

2. OPTIMIZATION OF TRAFFIC LIGHTS MANAGEMENT

In the research part the task of optimization of traffic lights management was completed by means of the author's method originating from genetic algorithms method.

By applying genetic algorithms each activity may be presented as a task. Its solution may be understood as searching a "better" solution in particluar space. Depending on the size of space various methods of solving a particular problem are used. In case of small spaces classical methods such as ordinary ones are enough. Bigger spaces require applying specialist methods of artificial intelligence out of which we can distinguish two genetic algorithms.

John Holland was the creator of genetic algorithms. Evaluation and genetics inspired the creation of this method namely processes occurring there. Individuals from a specific population are the probability of solving this problem. The individuals are subject to the process and reproduction. Mixing the genetic material from both parents generates new offspring. In the natural environment only the strongest who are best adjusted to the environment are likely to survive.

Genetic algorithms are applied to optimization tasks such as:
- Mapping out a route,
- Scheduling,
- Transport tasks,
- The problem of a travelling salesman.

In each task the genetic algorithm consists of the following elements:
- Building a basic base of probable solutions,
- Choosing a method of creating an initial population of probable solutions,
- Building an appropriate function,
- Selecting relevant parameters.

The research presented in the paper aim to optimize crossing the intersection. We want the highest number of cars to cross the intersection within the shortest time provided that none of them queues for too long. This measure aims to reduce harmful exhaust fumes released to the atmosphere as well as to increase

the capacity of streets by getting rid of bottlenecks at urban intersections.

The research makes use of the author's model of a genetic algorithm. By means of marking we define formally the correctness of a chromosome where k-vehicles:

$$\forall_{i,j,k} \left(K_{Gijk}\text{\`{}}\,!=1 \right) \tag{1}$$

Markings:
- i is the number of the group,
- j, k are indexes of elements in a particular group (k is different from j).

On lane i there are ai cars at a particular time (this can be a coefficient of the traffic flow on the particular lane appropriately scaled). Then the function of evaluating chromosome C looks as follows:

$$E(C) = \frac{\sum_{k=1}^{n} \min(R_{k,o}) - 0.1 * \left| R_{k,o} \right|}{\sum_{k=1}^{d} t_{k,o}} \tag{2}$$

and

$$R_{k,o} = P_{k,o} \cdot V \cdot t_{k,o} - \sum_{i \in G_{k,o}} a_{k,i,o} \tag{3}$$

Where:

V – coefficient of the speed of vehicles

P_k – will be a cardinal number of G_k (the number of elements of a particular set going in the same direction and turning back at the crossroads).

t_k – is the time of green light on for a specific group k of vehicles

n – the number of groups

d – the number of vehicles at the crossroads

a_i – the coefficient of a specific group of vehicles occurring

$$a_i = \begin{cases} 1 & for \ \ G_k > 0 \\ 0 & for \ \ G_k = 0 \end{cases} \tag{4}$$

If we assume the model analysing the flow at a few crossroads considering the interaction between many W crossroads, it will be described by means of the equation of chromosome correctness.

For the purposes of analysing numerous intersections the following equation is elaborated:

$$\forall W \quad E_W(C) = \sum_{o=1}^{W} \frac{\sum_{k=1}^{n} \min(R_{k,o}) - 0.1 * \left| R_{k,o} \right|}{\sum_{k=1}^{d} t_{k,o}} \tag{5}$$

As a result of all analyses the cycle is chosen that generates the highest continuity of traffic maximising the value of the function evaluating the chromosome according to the pattern:

$$E(C) = \max \left\{ \int_t \sum_{o=1}^W \frac{\sum_{k=1}^n \min(R_{k,o}) - 0{,}1 * \left| R_{k,o} \right|}{\sum_{k=1}^d t_{k,o}} dt \right\} \qquad (6)$$

In pattern 6 we can notice that the evaluation of the best chromosome is made through a modified plausibility function and a function of the centre of gravity originating from the theory of fuzzy logic. This way we indicate the best cycle out of many intersections allowing us to achieve the smoothest flow of vehicles at given parameters.

It is worthwhile remembering that in the event of combining dependent intersections we deal with the sequential system which can be successfully described by a model blending fuzzy logic with the mathematical theory of evidence (Topolski, 2008).

To equation (3) we can apply fuzzy sets (Topolski, 2008) and receive the value of chromosome evaluation:

$$E_k(C) = \sup_{R_{k,o}} \left\{ \mu\!\left(R_{k,o} \right) \right\} \cdot \max_{1 < k < M} \mu\!\left(R_{k,o} \right) \qquad (7)$$

Finally we choose the cycle which maximizes the value of chromosome evaluation by means of the combination rule originating from the mathematical theory of evidence (Markusik, 2009):

$$E(C) = \max\!\left[E_1(C) \oplus E_2(C) \oplus \ldots \oplus E_k(C) \right] \qquad (8)$$

Implementation of the function of chromosome plausibility provided by the equation (6) or (8) depends on the type of crossroads. However there are no clear premises for their logical selection. One has to assume applying the two methods or simulation testing these solutions in order to choose the best of them.

2. RESEARCH RESULTS

The research focused on verification of the described model using a chain of six crossroads and a random number of vehicles.

The result achieved by means of the model of genetic algorithm was compared to classical and traditional models. The traditional model assumes provision of stable lighting cycles. Whereas the classical model assumes controlling by means of motion sensors according to the algorithm based on the FIFO queue. Traffic smoothness and minimization of carbon dioxide emissions are measured by the medium stoppage time at a particular crossroads. The research was conducted using the function of the highest plausibility of chromosome for each cycle provided by equation 8. The fuzzy value $R_{k,o}$ was achieved by defuzzyficating the variable by three triangular fuzzy sets laid out evenly. Such a division is presented in Figure 1.
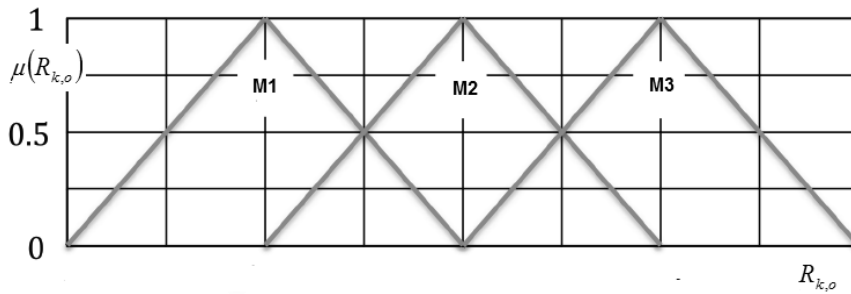

Fig. 1 Model of defuzzycated $R_{k,o}$ function Source: Elaboration of one's own

The stage of defuzzyfication of the chromosome evaluation function by means of equation 10 for example k=3 crossroads may be illustrated in Figure 2.
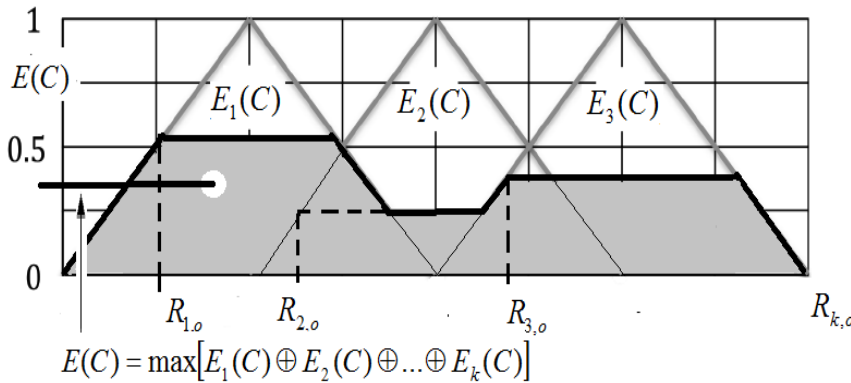

$$E(C) = \max\left[E_1(C) \oplus E_2(C) \oplus ... \oplus E_k(C)\right]$$

Fig. 2 Defuzzyfication model of chromosome evaluation Source: Elaboration of one's own

The traffic between two intersections was examined in the research. The smoothness of driving was checked by analysing the working time of the system and measuring the medium time of cars waiting to cross the intersection. The achieved results were illustrated in Figure 3.
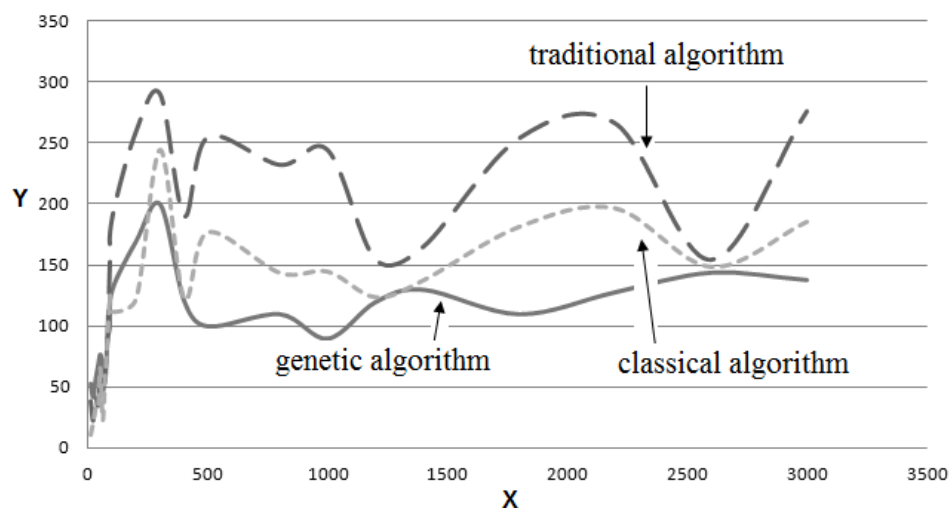
Fig. 3 The graph showing the average time a driver has to spend to cross the crossroads depending on working time of the genetic algorithm based system and the classical system. Y- the average time of going through the intersection in seconds, X- system working time in minutes, Source: Elaboration of one's own

The achieved results have shown that when traffic lights are controlled traditionally with a fixed number of cycles, the average waiting time for a vehicle at the crossroads is 157+/-94 seconds. The same time achieved by means of the classical algorithm amounts to 123+/67 seconds whereas when the genetic algorithm was applied it amounted to 104+/-40 seconds. Moreover for the fuzzy function of the highest plausibility applying fuzzy logic and the combination rule defined by pattern (9) we have received comparable results to those presented in Figure 1.

In the first phase of controlling the genetic algorithm learnt the best solutions in controlling the traffic lights and performed worse than the traditional method. Then in drawing 3 one can see that smart control turns out more effective than the traditional method in the long run. In the course of more detailed research and analyses we have noticed that the genetic algorithm enhances free-flow driving through a series of intersections by 40% as compared to the traditional method. However comparing the results with the application of the genetic algorithm to the classical method, we observe improvement by about 20%. Thus we can assume that the method based on smart control of traffic lights provides better traffic lights controlling methods than those available in the market. That is why it becomes obvious that by applying learning genetic method we are able to contribute to reduction of carbon dioxide emissions.

3. CONCLUSION

The paper indicates that there is a possibility of reducing CO_2 emissions to the atmosphere by making city traffic smoother. Apart from decreasing pollution, enhancing the traffic flow at crossroads may partially help with economics and organization of urban transport. The proposed method may be successfully applied to the cause and effect analysis of bottlenecks in the city. By analysing results one may define further directions for research. It is worthwhile focusing on other methods supporting the control i.e. fuzzy sets or neuron networks as well as hybrid and heuristics methods. The smallest improvement of traffic may bring enormous benefits both to the environment as well as to our organization from the time perspective.

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