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USING PSO ALGORITHM FOR THE TRAFFIC LIGHTS SETTING PROBLEM WITH CELLULAR AUTOMATON MODEL

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ABSTRACT

The problem of traffic light optimization has been studied in the past twenty years. Since too many factors in the real traffic could be involved, lots of researchers proposed different kinds of models with various assumptions. In this paper, we propose a PSO algorithm based model to investigate how to set the given traffic lights such as that the total waiting time of roads is minimized. We demonstrate that PSO algorithm provides an optimal solution to traffic signal timing, leading therefore to improve the total flow and minimize the waiting times behind crossing points.

Keywords: *traffic signal timing, cellular automata models, PSO algorithm*

1. INTRODUCTION

Because the number of vehicles grows rapidly, most cities face the serious problem of traffic congestion, especially around rush hours. During this period, traffic lights on major road corridors need to manage traffic flows and reduce vehicle delay and emissions, while providing opportunities for vehicles in side streets to enter or cross the major road. Since the quality of traffic in a city is mainly controlled by traffic lights, the traffic jam, and so the total waiting time of conductors, can be reduced if proper setting on traffic lights can be adopted. Therefore, it is a very important issue to find a good strategy which efficiently sets up the traffic light on all intersections. In other words, the main concern of the researchers is to minimize the overall penalty of all vehicles on traffic network.

Actually, there are two primary types of traffic signal control that are commonly used to improve pedestrians, cyclists and drivers safety at significant road intersections: fixed-time procedure and coordinated one. In fixed time procedure, signal control uses preset time intervals. These time intervals are the same every time in the signal cycles, regardless of changes in traffic volumes. This procedure determines the best signal settings on a given time period, basing on demand flows obtained by historical surveys [1].

In addition to timing an individual traffic signal, some signals are timed as a coordinated network. The goal of signal coordination is to help traffic flow through a series of signals at a pre-determined speed to minimize or avoid stops. In other words, the signal at an intersection turns green just as you arrive. This isn't always possible because of the need to provide smooth flow in two or more directions. This is why traffic engineers use computer programs to determine the best compromise between all the competing directions of traffic

Several attempts were made to model mathematically traffic flows. The earliest ones were based on fluid dynamics, but more recently, cellular automata based models have been gaining popularity. The choice of cellular automata is because simulations are easy to implement and to run very quickly. The cellular automata models analyses the traffic microscopically. In microscopic analysis, the movement of individual vehicles and the interaction between them are represented explicitly [2-9]. In the case of macroscopic analysis, by contrast, the whole system (i.e. the car traffic) is considered as one dimensional compressible fluid [10, 11].

This paper aims to create a system by which traffic lights change their behavior to respond to changing traffic conditions. We used PSO algorithm to determine the best traffic light timing to generate optimal values of the global flow. This paper is organized as follows. A brief review of PSO algorithm is presented in section 2. Some

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theoretical concepts used in domain of traffic lights, followed by the formulation of our problem are presented in section 3. In section 4, the simulation of traffic at signal controlled-junctions using the cellular automata is discussed. Finally, in section 5, we present the conclusion and possible future works.

2. PSO ALGORITHM

The PSO algorithm [12] models social behaviors observed in flocks of birds, schools of fish, etc., from which certain aspects of intelligence emerge. The standard PSO model consists of swarm of particles, moving interactively through the feasible problem space to find new solutions. Each particle i is associated with two vectors. The velocity vector $V_i=[v_i^1, v_i^2, \ldots, v_i^d]$ and the position vector $X_i=[x_i^1, x_i^2,\ldots, x_i^d]$, where d stands for the dimension of the solution space. Each particle memorizes its own best position so far in the vector pbest and the best position vector among the swarm is stored in a vector gbest. The search for the optimal position (solution) advances as the particle's velocities and positions are updated. During the evolutionary process, the velocity and position of each particle i is updated as:

$$V_i^d(t+1) = w^* v_i^d(t) + c_1{*}rand_1(t){*}(pbest_i^d - x_i^d(t)) + c_2{*}rand_2(t){*}(gbest - x_i^d(t))$$

$$X_i^d(t+1) = x_i^d(t) + v_i^d(t+1)$$

Where w is the inertia weight, c_1 and c_2 are the acceleration coefficients, and rand1 and rand2 are two uniformly distributed random numbers indepently generated within [0, 1].

The inertia weight w was introduced by Shi and Eberhat [13]. They proposed an inertia weight linearly decreasing with the iterative generations as:

$$W = w_{max} - (w_{max} - w_{min})g/G$$

Where g is the generation index representing the current number of evolutionary generations, and G is a predefined maximum number of generations. The maximal and minimal weights w_{max} and w_{min} are usually set to 0.9 and 0.4, respectively [13]

Finally, a user specified parameter V_{max}^d is applied to clamp the maximum velocity of each particle on the d^{th} dimension. Thus, if the magnitude of the updated velocity $|v_i^d|$ exceeds V_{max}^d, the v_i^d is assigned the value $sign(v_i^d)V_{max}^d$.

3. MODELS AND THEORITICAL CONCEPTS

A. Traffic light setting problem

The traffic light setting problem aims to investigate how to set the given traffic lights such as the total waiting of conductors behind crossing points is minimized. This problem is described by a certain number of concepts called timing variables. The first variable is the time duration of its lights (red, yellow and green). The sum of these durations for the three lights expresses the signal cycle T. In other words, we can define the signal cycle as the time period before the same light turns on again. Another important variable, the offset, expresses the time period between a common reference instant and the cycle start. At last, the time period in which every light on one signal is kept unchanged is called phase. Because of the complexity of the traffic network in a city and in order to simplify the problem, we adopt the same assumptions cited in [14] and reused in [15]:

- Only two light signals are considered: a green light and a red light.
- The duration of the red light Tr is equal to that of the green light Tg
- The cycle time T = Tg + Tr is the same for all lights.
- The offset time T_0 is null ($T_0 = 0$)
- Each intersection has two traffic lights with opposite signals. Therefore, a single traffic light is sufficient to represent these two lights.
- Each vehicle can either move forward or stay at its current position. That is to say, vehicles are not allowed to turn left or turn right.

B. The NaSch model

Before introducing the formulation of our problem and for sake of completeness we briefly recall the definition of the NaSch model [1]. The NaSch model is a discrete model for traffic flow. The road is divided into L cells of equal size numbered by i= 1, 2, ... L. Each cell can be either empty or occupied by exactly one car. The cars have a velocity v = 0, 1, ..., v_{max}, where v_{max} represents the speed limit. The cars move from the left to the right on a lane with periodic boundary conditions (the number of cars remains constant). Let x(i,t) and v(i,t) denote the position and the velocity of the i^{th} car at time t, respectively. The number of empty cells in front of the i^{th} vehicle is denoted by g(i,t) = x(i+1,t) – x(i,t) - 1.

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g(i,t) is the gap between the i^{th} car and the preceding one. The system update is performed in parallel for all cars according to the following rules:

Acceleration : $v(i,t+1) \leftarrow \min(v(i,t) + 1, v_{max})$
Deceleration : $v(i,t+1) \leftarrow \min(v(i,t+1), gap(i,t))$
Noise : $v(i,t+1) \leftarrow \max(v(i,t+1) - 1, 0)$, with probability p
Motion: $x(i,t+1) \leftarrow x(i,t) + v(i,t+1)$.

C. Problem formulation

The model assumed in this paper is as follows.

A main road is crossed by four others secondary roads to form a set of four junctions, each of them has its proper traffic light controller, as shown in figure 1.

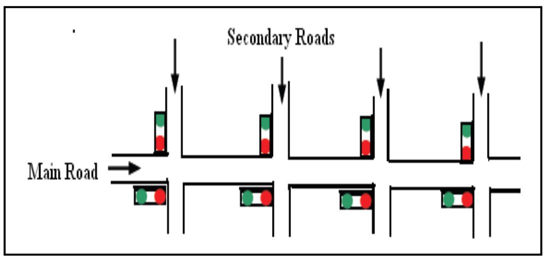

Figure 1 The Structure Of Our Car Traffic Network

Each road in the system is represented as one-dimensional cellular automaton grid of 1000 cells and has a closed boundary condition; so that it behaves as a ring. The distances between the intersections in the main road are the same, and are equals to 250 cells. Each junction is assigned a number. Each number in a junction denotes the starting time of the green light in that junction. If S(u) denotes the starting time of the green light on a junction u, then (with the previous assumptions) the interval of the green light on u can be written as follow :

$[S(u) + kT, S(u) + kT + T/2 -1]$, where T denotes the cycle time and k an integer >=0.

Since the crossing cell belongs to both roads, our model has to account for the fact that only one car may be in this intersection at one time. That is, during each time step, if the traffic light is red the vehicle approaching the junction, comes to a complete stop at the cell behind the crossing cell. At green light, the approaching vehicle progresses with respect to NaSch rules. However, at the end of the green phase some vehicles can occupy the crossing point. The stopped vehicle in the other direction, which is preparing to advance, must wait until the crossing cell becomes empty. To solve this problem, some authors use the inter-green period (IGP) [16]. Instead, in our model we have opted for a small improvement in rule 2 of the basic model. Thus, the new version of the NaSch model can be formulated as follows. Let d_1 be the number of empty cells ahead between the vehicle and its leading vehicle. And d_2 represents the number of empty cells ahead between the vehicle and the crossing point. We denote by pos the position of the crossing cell in the circuit. Then, the four rules of the NaSch model become:

1. Acceleration: $V(i, t+1) \leftarrow \min(V(i, t)+1, V_{max})$
2. Deceleration:
    If (the signal is red) then
        $gap(i, t) \leftarrow \min(d_1, d_2)$
    Else //the light is green
        If (a vehicle of a crossed road exists at pos) then
            $gap(i, t) \leftarrow \min(d_1, d_2)$
        else
            $gap(i, t) \leftarrow d_1$
        end if
    End if
    $V \leftarrow \min(V, gap(i, t) - 1)$
3. Braking: $V(i, t+1) \leftarrow \max(V(i, t+1) -1, 0)$ with probability p
4. Motion: $X(i, t+1) \leftarrow X(i, t) + V(i, t+1)$

4. SIMULATION RESULTS

In this section, a PSO algorithm based method for setting the traffic lights in the junctions is presented. This method uses PSO algorithm to generate four numbers representing the starting time of the green lights in the four junctions. This method will be called "PSO algorithm Timing Method (PSO-TM)". The results obtained are then compared to those provided by two other methods presented in [15], namely Random Timing Method (RTM) and Synchronous Timing Method (STM). Before going on, let's recall the principles of the latter two methods. In the first method (RTM), the system generates randomly four numbers representing the green time starts on the four junctions. In the second method (STM), we fix the starting times of the four traffic lights as, '0000', i.e. all the lights start at the same time.

The PSO-TM uses PSO algorithm for generating a particle as new solution. Solutions are generated for each density value in order to minimize the total delay in the car traffic network. Before going on on our analysis, let's introduce how we use PSO algorithm to measure the fitness score for a given light setting on the traffic network model. When a vehicle waits for a green light or other vehicles to

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move, a penalty is generated. For each time step, we calculate the overall penalty by summing up all the penalties of all waiting cars. This constitutes the overall penalty of the given setting. The less overall penalty generated, the better the traffic light setting is.

For the three methods, the randomization probability is assumed to be 0.3 in the NaSch model. The cycle time is equal to 6s. Initially, N cars are located randomly on the circuit (=1000 cells) and the velocity of each car is designated by an integer chosen from zero to the maximum v_{max}. Table 1 shows the parameters used in this work.

Table 1 Parameters Selected In The Simulation

Parameters of the model	Value
Length of each cell (m)	7.5
Length of each car (cell)	1
Total number of cells	1000
Maximum velocity (cell)	5
Randomization probability	0.3

Figure 3 represents the simulation results. It shows the fundamental diagram (representing the global flow over the entire network) for the three methods previously cited, using the parameters listed in table 1. The cars density in each secondary road is fixed to 0.2, but the main road density is varied from 0.02 to 0.98. The data are collected after that time evolution reaches 1000 iterations.

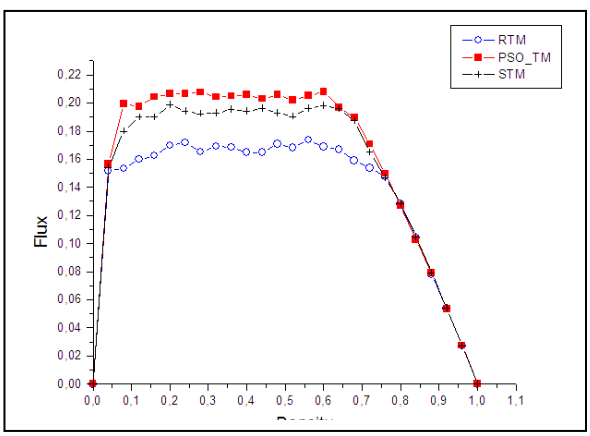

Figure 3 The Fundamental Diagram For The Three Methods.

Each point of the diagram represents the result from the latter 1000 iterations (to reach steady state) on a road of length 1000 starting from a random configuration.

From figure 3, we can see clearly that the flow obtained with the RTM is very low compared with the two other methods. On the other side, PSO-TM is the most efficient method to enhance the flow, but once the traffic approach the saturation state; all the methods have the same result.

The observed phenomena could be analyzed as follows. For simplicity and without loss of generality; let us consider only two junctions in the system. For the RTM, it seems obvious. Indeed, since the beginnings of green lights in various crossing are generated randomly, they have not necessarily the same values ('03', '62', for example). This leads to asynchronous timing of lights in different crossings. We will distinguish two cases: the first value is less than the second, and otherwise. In the first case, '03', for example, a vehicle with a green light in the first crossing at time 0 will arrive at the second portion of the road where it will stop, either because the starting time of the second light is not yet reached, or because the second green light is switched on with a delay; causing therefore a formation of queues behind the crossing cell. In the second case, '62', for example, vehicles of the first junction are blocked while the second traffic light is green, and once vehicles of the first intersection are allowed to move (1st light is green), they will be blocked by the second traffic light.

For STM, since the starting time of green lights has the same value, the lights are synchronized. When the lights are switched on, the vehicles moving downstream, find the road ahead free or less dense because the 2nd traffic light was green too. There is a synchronous traffic in the circuit.

For the PSO-TM, PSO algorithms seek a solution to minimize the waiting time. It is clear that the flow obtained in this case is optimal.

5. CONCLUSION AND FUTURE WORKS

In this work, we have used methods for controlling the traffic lights in road composed of several intersections. The method based on PSO algorithm provides an optimal solution to configure traffic light controllers in different junctions. The principal parameter adapted in this paper is the starting time of green lights in each intersection.

On the other hand, in previous work, we have combined genetic algorithms and the cellular automata to design new traffic light controller software. Our next task will be then to combine the Genetic Algorithms and PSO algorithm to take advantage of the two methods.

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