Study of Traffic Flow Controlled with Independent Agent-Based Traffic Signals

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Abstract. Dealing with urban traffic is a highly complex task since it involves the coordination of many actors. Traditional approaches attempt to optimize traffic signal control for a particular vehicle density; the main disadvantage lies in the fact that traffic changes constantly. Managing traffic congestion seems to be a problem of adaptation rather than of optimization. In this work we present an agent-based traffic simulator which represents a traffic grid with two-way roads of three exclusive lanes per direction, with intersections regulated by signals. We study the repercussions on traffic flow of simple parametric behaviours when each light operates independently. A dominance analysis is applied to compare the strategies.

1 Introduction

Traffic congestion is a major recurring problem faced in many countries of the world due to the increased level of urbanization and the availability of cheaper vehicles [1].

There is no solution to the traffic congestion problem when the vehicle density saturates the streets, but there are many ways in which the vehicle flow can be constrained in order to improve traffic. Improvements aimed at reducing urban traffic congestion must focus on reducing internal bottlenecks in the network, rather than replacing the network itself. Signal (or traffic light) control is an easy way to improve traffic flow. There are basically two kinds of signal systems [2]: fixed-time and traffic-actuated. Each have their advantages and disadvantages [3]. However, their common objective is to minimize the vehicle delay and average queue length caused by intersections [4].

Since an intersection is the fundamental element of a traffic network, optimizing the performance of an isolated intersection can contribute to improving the performance of a network. Many studies in the literature have focused on

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isolated intersection strategies [5] [6]. Other studies, however, have been based on intersection grids [7] [8], and seem to be hopeful approaches to realistically solving the problem.

In this work we present an agent-based traffic simulator which represents a traffic grid with two-way roads of three exclusive lanes per direction and intersections regulated by signals. We study the repercussions on traffic flow of simple parametric behaviors for each light, that acts independently but respecting traffic restrictions.

Self regulated strategies [9] are implemented to model the behavior for each light. There were implemented different *selfish* strategies, where each light turns green in the moment it can; *cooperative* strategies, where lights respect other ones that need to turn green because of demand; and a classic *fixed time* strategy, where lights turn green according with a patron. Each strategy is executed under a different set of parameters and traffic grid configurations with the aim of search for the best configuration.

A dominance analysis is applied to compare strategies according with a wide set of parameters such as: number of collapsed lanes, stopped vehicles or averaged speed; with distinctions between left, straight and right lanes.

We describe first the implementation of an agent-based model (section 2), and then the design of the set of parametric strategies (section 3). In the experimental part of the work (section 4), a total of 27 strategies were tested in the simulator with different parameters values. Since it is very difficult to compare the performance of the strategies in all the measured aspects, the data were subjected to a dominance analysis (section 5). Finally, some concluding remarks and future works are presented (section 6).

2 Multiagent Model for Traffic Simulation

The simulation environment was implemented using *NetLogo* [10], a multiagent modeling environment. The developed model tries to approach a realistic traffic environment, where vehicles can turn right, left or continue straight when they reach an intersection.

The environment represents a $[n \times n]$ intersection grid controlled by light signals. Each road is divided into three exclusive lanes, one for each of the three possible manoeuvres at the next intersection: left turn, through, or right turn. Basic aspects and considerations on the agents involved are described below.

Each *vehicle* occupies the correspondent lane with the manoeuvre that intends to do. Vehicles try to go at a maximum speed but stop when a vehicle or a red/amber light is immediately in front of them. In case there is a green light in front of them, they initiates the manoeuvre.

There is a *traffic light* agent regulating each lane of each intersection. They have to satisfy the following constraints: i) amber state is maintained for a certain ammount of time (φ_{amber}). ii) traffic lights detect and count vehicles in a certain distance α in front of them, as shown in figure 1. iii) Each light has its own conflicting lights depending on the kind of manoeuvre regulated; figure 2 shows

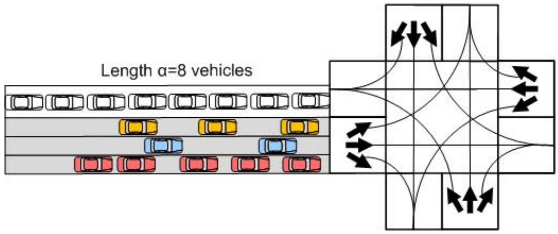

Fig. 1. Graphical representation of the *alpha* parameter which determines the detection range of the litght

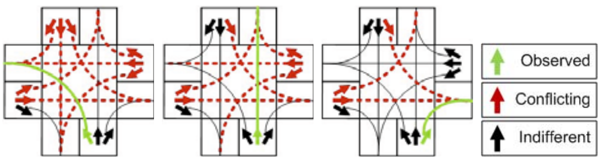

Fig. 2. Conflicting lights for a light to turn green for a left-turn (left), straight (centre), and right-turn (right) manoeuvre. A light cannot be turned green while any of its conflicting lights is green or amber.

the conflicts graphically. iv) Each light knows the state of its own conflicting lights.

Generators insert (if possible) new vehicles into the roads. The insertion is governed by three probabilities, P_r, P_s, and P_l, corresponding to the probability of creating a vehicle with a right turn, straight, or left turn intention ($P_r + P_s + P_s \leq 1$ to allow no vehicle to be created in a timestep), and γ represents the total number of vehicles to be created.

Vehicles are eliminated of the environment once they reach one road ending without intersection. Once a vehicle finalizes a manoeuvre it generates (randomly) the new desired manoeuvre to realize when reach the next intersection.

In sum, to define an environment in which to test the different strategies, the following parameters must be set: n to define the size of the world and the number of vertical and horizontal streets; φ_{amber} to define the time restriction on the amber lights; α the range of the vehicle detector in each signal; and (P_r, P_s, P_l,γ) to define the way the vehicles are generated.

3 Traffic Lights Behavior

Each traffic light agent maintains the following internal variables:

- χ represents the number of vehicles within a distance α in front of the traffic light.
- S is the current state of the light (*red*, *amber* or *green*).
- φ stores timesteps without the current state having changed.

– C represents the set of conflicting lights.
– NC represents the set of non-conflicting lights.
– $S_{C|NC}$ are defined as the current state of the conflicting/non-conflicting lights.

Following subsections explain in detail each one of the agent oriented light behaviors.

3.1 Fixed Time Control

This is a simple *non-adaptive* method (henceforward $Fix(\psi)$) whose main idea is to synchronize all traffic lights in time under a single pre-defined parameter ψ such that each ψ timesteps one of the four incoming roads to an intersection is assigned priority over the rest, and all traffic lights on that road change to green while the rest remain to red. Note that the traffic light on the right lane of the intersecting road to the left of the priority road can also be turned green because it generates no conflict anywhere, as can be seen in figure 3.

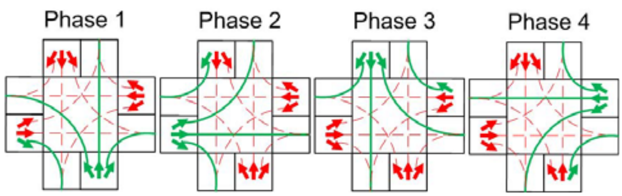

Fig. 3. Four phases used in Fixed Time Prioritization

3.2 Basic Selfish Strategy

In this strategy (henceforward $Selfish_{Basic}(\alpha, \varphi_{min})$) each traffic light turns green if there are vehicles waiting and all the conflicting lights are red; the green state is maintained while vehicles are detected within a radius α. Formally, the strategy is defined as:

– Red lights change to green if $[\chi > 0$ and $S(C) = red$ and $\varphi > \varphi_{min}]$
– Green lights change to amber if $[\chi = 0$ and $\varphi > \varphi_{min}]$
– Amber lights change to red if $[\varphi = \varphi_{amber}]$

3.3 Cooperative Selfish Strategy

This strategy (henceforward $Selfish_{Cooperative}(\alpha, \varphi_{min}, \varphi_C)$)is based on the previous one, the main idea is to maintain the same policy for switching from the red to the green state, while adding a *cooperative* situation in which green lights turn amber if any of the conflicting lights on red ($\varphi(C_{red})$) has demand during an established time φ_C. Formally, the cooperative selfish strategy is defined as:

– Red lights change to green if $[\chi > 0$ and $S(C) = red$ and $\varphi > \varphi_{min}]$
– Green lights change to amber if $[(\chi = 0$ or $\varphi(C_{red}) > \varphi_C)$ and $\varphi > \varphi_{min}]$
– Amber lights change to red if $[\varphi = \varphi_{amber}]$

4 Experimentation Setup

Each strategy is tested for in scenarios: an isolated intersection and a 4×4 intersection grid. All the cases use $\varphi_{amber} = 5$ and uniform vehicle generation probabilities ($P_r = P_s = P_l = 0.33$). Each generator inserts one vehicle/timestep into the grid until it generates $\gamma = 150$ vehicles[1]. The simulation runs until all the vehicles leave the simulation world and each run is repeated 50 times, taking averaged measures.

The following variables are used to assess the effectiveness of the considered strategy (suffices r, s, and l correspond to right-turn, straight, and left-turn lanes): (C_r, C_s, C_l) represent the average % of collapsed lanes (lanes with more than 10 vehicles stopped in front of a signal). (S_r, S_s, S_l) represent the average speed of the vehicles. (R_r, R_s, R_l) represent the average % of the time of the red state of a traffic light with demand ($\chi > 0$). A final set of variables (C, S, R) represent the respective average values independently of the lane observed.

The strategies tested are: $Fix(\psi = \{20, 50, 100\})$ for fixed time control; $Selfish_{Basic}(\alpha = \{0.5, 5, 10\}, \varphi_{min} = \{10, 20\})$ for the basic selfish strategy; and $Selfish_{Cooperative}(\alpha = \{0.5, 5, 10\}, \varphi_{min} = \{20, 50\}, \varphi_C = \{20, 50, 100\})$. That sum a total of 27 different strategies.

5 Overall Analysis

Twenty seven different strategies were tested in two different scenarios, reporting each a total of twelve variables that can be grouped in three sets (collapsed streets, vehicle speeds, and time on red with demand) of 4 elements each (the three lanes and the average).

An overall analysis to determine which strategy performs the best would involve many correlations. We therefore performed a Pareto-type [11] dominance analysis. The results are given in Table 1 grouped by four criteria: i) **Overall**: This column lists the number of strategies that dominate the given strategy in all 24 variables. ii) **Scenario**: These two columns list the number of strategies that dominate the given strategy in the 12 variables referred to the isolated intersection (D_I) and the 12 referred to the 4×4 intersection grid (D_G) separately. iii) **Aspect**: These three columns list the number of strategies that dominate the given strategy in each aspect studied. There are 8 variables for each aspect: *collapsed streets* (D_C), *speed of the vehicles* (D_S), and *time on red with demand* (D_T). iv) **Lane**: These three columns list the number of strategies that dominate the given strategy in the three different lanes; D_R, D_S, and D_L for right, straight, and left lanes, respectively.

The following four subsections analyze each of these criteria.

[1] There are 4 generators in the isolated intersection scenario (600 vehicles in total) and 16 in the intersection grid scenario (2400 vehicles in total).

Table 1. Overall Pareto analysis table

	Overall	Scenario		Aspect			Lane		
Strategy	D	D_I	D_G	D_C	D_S	D_T	D_R	D_S	D_L
$F(20)$	0	3	0	2	0	5	3	5	0
$F(50)$	0	0	0	1	0	3	0	1	0
$F(100)$	0	0	0	0	0	0	0	0	0
$SB(0.5, 10)$	2	5	6	19	3	5	7	2	9
$SB(5, 10)$	0	0	0	6	0	0	1	0	0
$SB(10, 10)$	0	0	0	0	0	0	0	0	0
$SB(0.5, 50)$	1	1	11	17	2	4	10	6	2
$SB(5, 50)$	0	0	7	2	1	2	3	3	0
$SB(10, 50)$	0	1	0	2	2	0	1	0	0
$SC(0.5, 10, 20)$	2	7	8	21	9	7	19	3	11
$SC(5, 10, 20)$	3	8	6	13	11	11	13	3	12
$SC(10, 10, 20)$	0	1	1	0	5	14	8	2	5
$SC(0.5, 50, 20)$	0	0	10	19	0	5	15	1	4
$SC(5, 50, 20)$	1	2	9	10	5	6	10	6	3
$SC(10, 50, 20)$	0	0	0	0	0	5	0	0	4
$SC(0.5, 10, 50)$	2	11	0	13	2	4	3	2	3
$SC(5, 10, 50)$	4	6	11	13	15	6	12	5	10
$SC(10, 10, 50)$	0	0	0	0	4	1	1	0	3
$SC(0.5, 50, 50)$	1	1	7	14	1	4	4	1	4
$SC(5, 50, 50)$	2	3	8	11	3	4	6	3	4
$SC(10, 50, 50)$	0	0	1	1	0	4	6	1	1
$SC(0.5, 10, 100)$	2	5	6	17	6	6	6	6	10
$SC(5, 10, 100)$	3	3	10	11	9	3	3	11	10
$SC(10, 10, 100)$	0	0	0	0	3	5	0	2	1
$SC(0.5, 50, 100)$	0	0	9	15	0	4	14	0	3
$SC(5, 50, 100)$	1	2	0	10	1	3	2	1	2
$SC(10, 50, 100)$	0	0	0	2	4	1	0	2	2

5.1 Overall

One observes in column D that many strategies are not dominated by any other strategy. We shall study below, however, how some of them are more suitable in a subset of these aspects. To this end, we therefore first classify as bad strategies those with a non-null D value.

Thus, the following strategies are not considered in the more detailed analyses: $Selfish_{Basic}(0.5,\ \{10, 50\})$, $Selfish_{Cooperative}(5,\ \{10, 50\},\ \{20, 50, 100\})$ and $Selfish_{Cooperative}(5,\ 10,\ \{20, 50, 100\})$.

5.2 Scenario

In the scenario columns (D_I and D_G), one observes that most of the strategies with good overall suitability also present good behaviour in the isolated intersection scenario. The most important exception is $Fix(20)$ which is dominated by 3 different strategies. The other exceptions are $Selfish_{Basic}(10, 50)$ and $Selfish_{Cooperative}(10, 10, 20)$, each dominated by one other strategy.

$Selfish_{Cooperative}(10, \{10, 50\}, \{20, 50, 100\})$ show relatively good behaviour in both scenarios since they are dominated only by either 0 or 1 other strategies. The strategies $Fix(50)$, $Fix(100)$, and $Selfish_{Basic}(\{5, 10\}, 10)$ remain undominated in either scenario.

5.3 Aspect

With respect to the aspect columns (D_C, D_S, and D_T), only two strategies, $Fix(100)$ and $Selfish_{Basic}(10, 10)$, are not dominated in any aspect. None of the $Fix(\psi)$ strategies are dominated in vehicle speed.

The strategies $Selfish_{Cooperative}(0.5, 50, \{50, 100\})$ are dominated in collapsed streets by 19 and 15 strategies respectively, being hence unsuitable strategies. The same is the case with $Selfish_{Cooperative}(10, 10, 20)$ which is dominated by 14 other strategies in the time on red column. One observes that for the vehicle speeds column no strategy has such a high number of other strategies dominating it.

5.4 Lane

With respect to the lane columns (D_R, D_S, and D_L), the only strategies which are dominated by a major number of the others are $Selfish_{Cooperative}(0.5, 50, 20)$ and $Selfish_{Cooperative}(0.5, 50, 100)$, with 15 and 14 respectively in the right-turn column.

All three Fix and the four $Selfish_{Basic}(\{5, 10\}, \{10, 50\})$ strategies are undominated in the left-turn column. This is an important finding, since, as has been seen, this lane is the most conflictive, requiring most conditions to be satisfied to attain the green state.

6 Conclusions

We have here described a framework of intelligent traffic scheduling strategies using a novel agent-based simulation model to test their effectiveness. To this end, we performed experiments comparing 24 variables for each strategy, corresponding to the combinations of two scenarios, three aspects, and the three lanes and their average.

Several strategies showed good behaviour in a specific scenario, lane, or aspect. But deducing the overall effectiveness of a strategy is still an open problem in the study of systems of this kind where the number of measures of the outcome that need to be optimized conjointly can be very large. Nonetheless, the approach presented here would seem to be a good starting point for us to continue with our investigations in the field of ITS.

In future work, we shall be studying cooperative and competitive strategies for signal control in a traffic grid. It will also be interesting to study the effect of using several different strategies in the same grid, and how their distribution affects the different measures of effectiveness.

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