

An Implementation of Case-based Reasoning to Control Traffic Light Signals

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Abstract—This research work presents the previous results of implementing rational agents based autonomous traffic light control system to overcome problems like congestion, pollutant emissions and fuel consumption. The proposed agent based approach uses case-bases reasoning to provide green light intervals according to the demand level of the intersection. The effectiveness of this approach is tested in two traffic intersections.

Index Terms— Traffic light control systems, sophisticated agents, autonomous traffic lights, rational process, CBR, optimization, fuel consumption and pollutant emissions

I. INTRODUCTION

FAST transportation systems and rapid transit systems are nerves of economic development for any nation. All expanded cities have well developed transportation systems with efficient traffic control on road, rail, and air. The monitoring and control of city traffic is one of the key issues especially in metropolitan areas considering the increasing number of vehicles and pedestrians. Numerous methods are available to reduce delays and pollutant environmental problems caused by road traffic in major cities.

Research in the field of the optimization traffic-volume arteries has been one of the most pursuit challenges [1]. As the number of road users constantly increases and resources provided by current infrastructures are limited, a smarter intelligent control of traffic has become a very important issue. In this sense, intelligent systems have proven to be computational tools that cover substantially diverse research areas because of their decision-making paradigm based on reasoning processes. For instance, avoiding traffic jams has been thought to be beneficial to both environment and economy, but improving traffic-flow may also lead to an expansion of the demand of the service [2]. The optimal control of traffic lights using sophisticated sensors and intelligent optimization algorithms might therefore be very beneficial. Optimization of traffic lights switching improves traffic flow and prevents traffic congestion. Traffic lights control is a complex problem of optimization and several intelligent algorithms, such as fuzzy logic, evolutionary

algorithms and reinforcement learning (RL) have already been used in attempts to solve it. This paper describes a model-based rational multi-agent algorithm to control traffic lights. The presented approach introduces a formalization capable of taking flexible and autonomous decisions for the calibration of green light interval. To evaluate the efficiency of the proposal, the paper presents two studied cases and their results using a simulated tool developed for the project. Trends, conclusions and future work are presented at the end of the paper in order to emphasize the advantages and usefulness of the promising approach.

II. BACKGROUND OF TRAFFIC LIGHT CONTROL SYSTEMS

The monitoring and control of city traffic is one of the key issues especially in metropolitan areas considering the increasing number of vehicles and pedestrians. Numerous methods are available to reduce delays and pollutant environmental problems caused by road traffic in major cities. In traffic signal control systems, detection of traffic variables at intersections is very important and it is the basic input data to determine signal timing. According to this, an application of fuzzy logic for multi-agent based autonomous traffic lights control using wireless sensors to overcome problems like congestion, accidents, velocity and traffic irregularities is presented in [3]. In fact, this approach provides a preferred solution by minimizing the vehicles waiting time especially the emergency vehicles using fuzzy logic control under situations that normally occur during these situations. Likewise, a new infrastructure to vehicles communication and control system for intelligent speed control, which is based upon radio frequency identification (RFID) technology for identification of traffic signals on the road, and high accuracy vehicles speed measurement with Hall effect-based sensor is explained in [5]. To achieve a more efficient adaptation of the speed of the vehicle, the approach introduces an adaptation of a fuzzy logic controller based on sensor fusion of the information provided by the infrastructure installed on the road. Finally, the results suggest unexpected traffic circumstances and improve the safety of the occupants of the vehicle. In this light, an Intelligent Traffic Signal Controller using FPGA controller based on Neuro-Fuzzy system is presented in [11]. Such approach is capable of taking decision to reduce delays in an intersection. In particular, the fuzzy logic theory in the controller provides an intelligent green interval response based on dynamic traffic using the input variables of the weighed traffic flow at the current and neighboring intersections. The paper argues that it is able to overcome the weakness of conventional traffic controllers by using its capability of providing a variety of green cycle intervals

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based on dynamic traffic load changes at every lane in a 4-way junction control. Besides the current trends to solve the gap between traditional traffic control and advanced computational methods, the development of the field simulated test environments to control and to optimize urban arterials is another interesting and promising area for further study.

III. TRAFFIC LIGHT CONTROL

Optimizing the traffic flow in a particular network of interconnected intersections implies several point-of-views, i.e., software engineering, intelligent systems and optimization structures. Prior to this, an integrated simulator was developed in MatLab to plug the proposal of the paper. The simulator that outlines intersections with different characteristics, is capable of simulating the injection of vehicles in each lane according with the eq. (1).

$$\forall \text{ lane} \in I \exists e = \left[\frac{r * \mu_{\text{lane}}}{\sigma_{\text{lane}}} \right]_{t-1} \quad (1)$$

where r is a variable about the observed frequency of the vehicles and μ and σ are constant values obtained by a statistic analysis of the data and both are updated automatically by the simulator. To demonstrate the effectiveness of the proposed model, the Fig. 1 compares the incoming cars volume in a given intersection using the simulator versus the real data. This simple proof demonstrates the accuracy of the model.

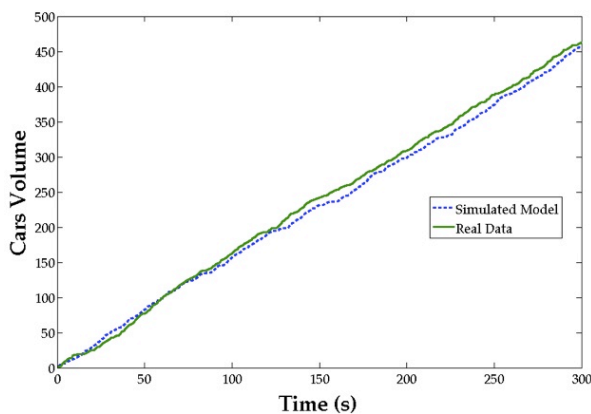


Fig. 1. Real data versus simulation model.

The new decision process proposed in this study differs from previous works [6-8] in that the decision-making process requires updated operators (i.e., rational agent) to know the constraints and requirements in their assigned intersection and to modify the length of the green light in each specific lane. Operators use this decision process to mimic the behavior of a transit officer taking into account the following variables:

Case_n

- V = the volume of vehicles.
- tg_i = length of green light for that lane.
- D= distance (quantity) between the first and the last vehicle in the longest rail.
- n = quantity of rails in each lane.

In a case given, the model performs an adaptation of the cases-based reasoning methodology aiming to provide operators with adaptive actions implementing a strategy to improve the green time interval efficiency. Retrieve - An operator must review the volume of vehicles injected by the traffic simulator before the green light turns on. Using the vehicles volume and the green time interval tg_i, the operator

looks inside the cases-base to extract the most similar cases using the Tanimoto index [9], where the variable ranges are: $\{-5 \leq V_L \leq +5\}$ and $\{-2s \leq tg_i \leq +2s\}$.

The operator retrieves n cases and computes the average green time interval. Such process allows obtaining a possible length of green light offering a proper solution for the presented conditions of the lane. Reuse - A new solution is generated from the retrieved cases according to the problem conditions. At this stage the recommended length for green interval is adjusted according to a suitable level of service and the performance of the entire intersection. Revise - the operator must evaluate the behavior of the implemented action measuring the volume of remaining vehicles V_Q in the studied lane. To do this, the operator uses the eq. (2).

$$V_Q = \left(V_L - \left[\frac{tg_i}{D} * n \right]_{t_0} \right) \quad V_Q = \begin{cases} 0 & : V_Q < 0 \\ V_Q & : V_Q \geq 0 \end{cases} \quad (2)$$

Retain - After revision, if the operator considers that this action achieves at least the 51% of performance (it means that 51% of the vehicles have already left the lane) the studied problem and the proposed solution have to be indexed in the cases-base in order to use it in future operations.

IV. EXPERIMENTS AND RESULTS

In this section, experiments are performed to simulate the likely mobility and environmental benefits of the intelligent control concept IC compared to traditional control approach TC. Two test cases are considered: 1) a connection between two four-way intersections and 2) a multiple interconnected intersection. The simulations are given in four demand levels fixed in 50%, 100%, 150% and 200% according to a usual arrival of vehicles per second. The emissions are calculated based on information provided by the INEGI (www.inegi.org.mx). From the data obtained in the performed simulations, some preliminary results have been obtained in order to evaluate the usefulness of the methodology proposed in this paper.

Test case 1. Two interconnected four-way junction are simulated in the developed system with the traditional preprogramming control showed in Fig. 2 and the incoming vehicle data provided in Table 1.

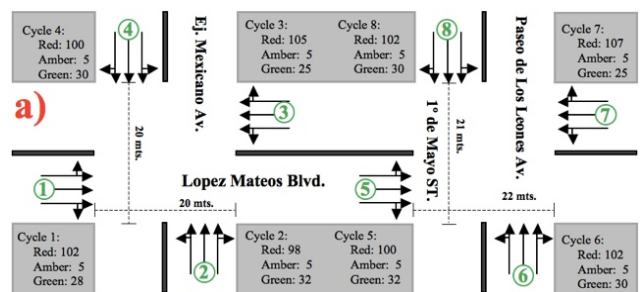


Fig. 2. General scheme of the test bed 1.

Table 1. Observed data from the real study count.

INTERSECTION ₁				INTERSECTION ₂			
Demand Level	r	μ	σ	Demand Level	r	μ	σ
50%	[0-1]	2.5	1.8	50%	[0-1]	2.6	1.7
100%	[0-3]			100%	[0-2]		
150%	[1-4]			150%	[1-3]		
200%	[2-4]			200%	[2-4]		

In particular, Fig. 3 presents a comparison where IC reduces in almost 16% the fuel consumption in TC approaches. Focusing on the average service increasing, as shown in Fig. 4, the proposed methodology appears to be capable of improving substantially the service level of a particular intersection.

For instance, the performance of the service using the IC is better than TC around 23% with a demand level of 100%.

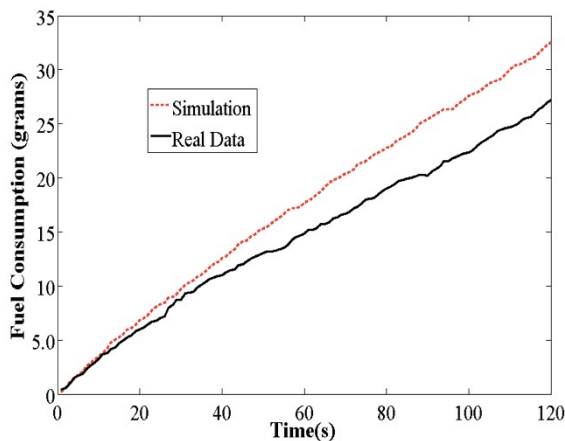


Fig. 3. Resume of the Fuel consumption.

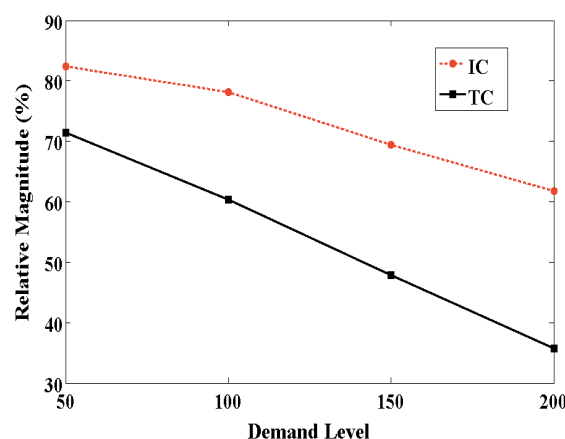


Fig. 4. Average of the served vehicles in the test case 1.

For example, in Fig. 5 the magnitude of CO₂ emission under the control of rational operators shows a better performance than the one controlled by traditional methods around 35% under 100% of demand.

The fuel consumption (in units of grams per second, generated by stopped cars while the red light is on) and the emission level of three of the pollutants (also in units of grams per second) under the IC and the TC for different demand level is compared in Fig. 6.

In particular, the implementation of such operators based on past decisions and by coordinating the length of the cycles, appears to have reduced the emission significantly. As the demand level has increased all the emissions, and the fuel consumption, the IC manages to reduce or maintain both all the emissions, and the fuel consumption.

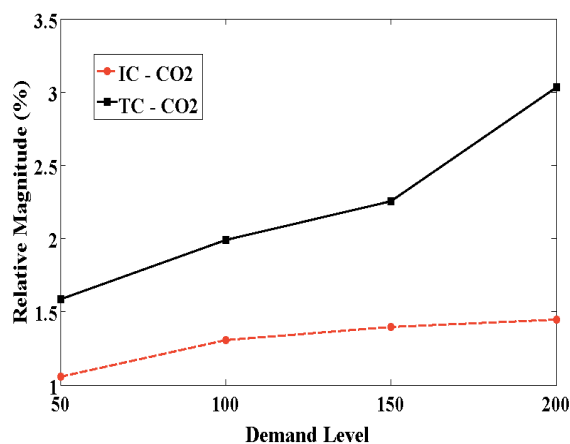


Fig. 5. Resume of the CO₂ generation in the test case 1.

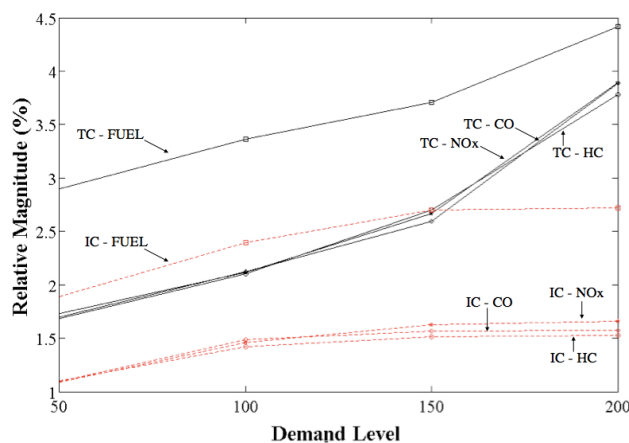


Fig. 6. Relative magnitude of emissions and fuel consumption in the test case 1.

Test Case II. The second test involves data of a real-world intersection, taking into account one of the most important roads in Tampico City, MX (Hidalgo Ave) with multiple intersections. The data used in the experiments has been obtained in real traffic study dated from Oct. 2011 to Mar. 2012. To evaluate the decision-making process of the Intelligent Control IC approach proposed in this work, the Fig. 7 depicts how the IC reaches a suitable behavior after 100 decisions along 1000 trials. This effect emphasizes the ability of rational operators to make sure decisions that carry a better performance when they resort to information from previous situations solved in a suitable way. The performance does not improve significantly beyond 100 intents. Such number of trials is therefore used initially to confirm the decision performance. In particular, there is an improvement rate of around 21% reached by IC over the TC approach.

Selecting a suitable case (or cases) from the cases-base is another interesting question to assess. In this sense, the Fig. 8 confronts the sensitivity of selecting an effective case to solve any given situation versus the specificity of taking a wrong case. For the proposal of this approach, this analysis permit to argue that the selected method for the retrieve phase (see Section 3) is appropriated and trustworthy for the intentions of this work. The complete analyzing results are summarized in Table 2.

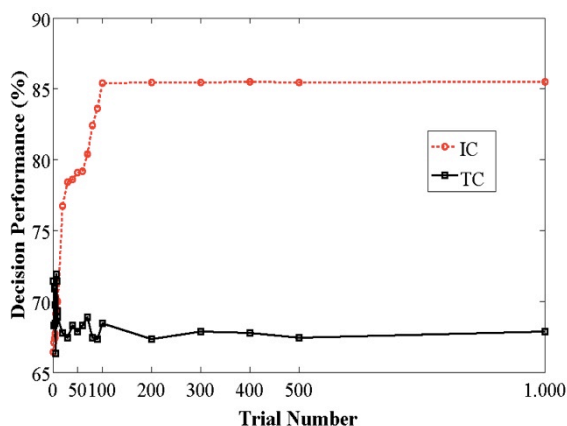


Fig. 7. Improving decision performance.

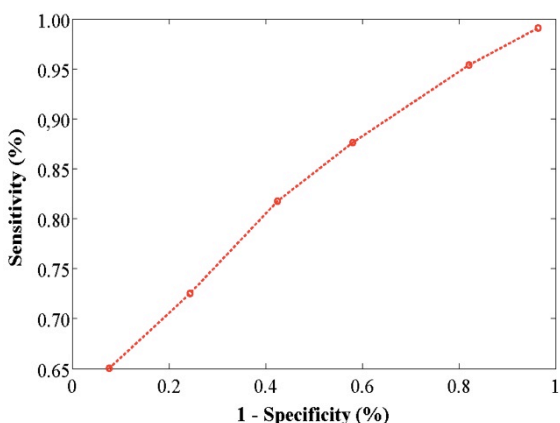


Fig. 8. Sensitivity of selecting a suitable action.

Table 2. Resume of Emissions and Fuel Consumption – Test case 2.

	Demand Level	Intelligent Control (IC)	Traditional Control (TC)	Improvement Rate (IC over TC)
HC (gram/sec)	50%	1.1005	1.6849	34.68%
	100%	1.4230	2.1070	32.46%
	150%	1.5120	2.6990	43.97%
	200%	1.5280	3.7800	59.57%
CO (gram/sec)	50%	1.0975	1.7001	35.44%
	100%	1.4860	2.1210	29.93%
	150%	1.5690	2.5930	39.49%
	200%	1.5740	3.8870	59.50%
CO2 (gram/sec)	50%	1.0912	2.0264	46.15%
	100%	1.4995	2.3984	37.47%
	150%	1.7891	2.8897	38.08%
	200%	1.9919	3.2530	38.76%
NOx (gram/sec)	50%	1.0889	1.7319	37.12%
	100%	1.4630	2.1190	30.95%
	150%	1.6240	2.6640	39.03%
	200%	1.6620	3.8950	57.32%
FUEL (gram/sec)	50%	1.8899	2.9002	34.83%
	100%	2.3980	3.3630	28.69%
	150%	2.6990	3.7080	27.21%
	200%	2.7200	4.4200	38.46%

V. CONCLUSIONS

Road traffic congestion is one of the main causes in low productivity and decrease in modern city standards. In this sense, some recent trends in artificial intelligence suggest that in close future intelligent agents improving some road challenges will operate some vehicles. Based on ubiquitous computing paradigm, the control of the traffic based on

intelligent agents offers an ideal path to operate the vitalities using Internet or other ad-hoc interconnections based on real world time information. The flexibility of the rational agents allows making decisions in similar ways as a human being. For this reason, the paper introduces a novel methodology to manage traditional traffic control using rational agents. Specifically, agents are in-charge of ensuring that at least 51% of vehicles are dispatched during a green light interval. To do this, the agents use an adaptation of the CBR methodology, which is also similar to that of a police officer handling the traffic flow at a typical junction. This human-based process allows agents to be capable of evaluating past decisions from a database built over the time. In this light, an integrated simulator for the design and evaluation of intersection has been developed.

The simulator permits users to configure different aspects of a determined intersection in order to provide results that disclose the behavior of the traffic flow and other relevant information such as pollutant emission and fuel consumption. The simulator also reports the changes of the lights in each traffic signal throughout the experiments. Finally, the studies performed in the integrated simulator were used to evaluate not only the mobility advantages but also the environmental benefits of the new strategy to control traffic lights based on rational agents. Consequently, the results compared the volume of attended vehicles and the fuel consumption and emissions, under the traffic lights control based on intelligent agents, to those under traditional signal control methods. Different configurations have been considered in two experiments, one involving two-connected isolated intersections and another one considering multiple intersected roads. Results have clearly showed the significant mobility benefits of the proposed approach in terms of congestion level after a green light by increasing traffic capacity in a particular lane and important reduction of stopping-time, fuel consumption and the emissions generated because of long-length of red lights. However, future investigation is suggested including the following aspects:

Issues such as acceleration and des-acceleration, collision avoidance and vehicles with different velocities, must be included in the simulator by offering a set of more realistic situation in the virtual instrument proposed here.

This paper has focus on vehicular traffic and on assessing the mobility and environmental benefits. Future research should attempt to evaluate the likely safety benefits of the approach and how pedestrians can be accommodated at such junctions.

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