2010 IEEE Intelligent Vehicles Symposium
University of California, San Diego, CA, USA
June 21-24, 2010

A Policy-Based Multi-Agent management approach for Intelligent Traffic-Light Control

A. Guerrero-Ibáñez, J. Contreras-Castillo, R. Buenrostro, A. Barba Marti, and A. Reyes Muñoz.

Abstract—**In this paper we propose the application of intelligent agents in traffic-lights, for the road control of urban transit in the city of Colima, México; using a multi-agent approach for dynamic urban traffic-lights system coordination that relies on locally available traffic data and the traffic condition of the neighboring intersections. According to this approach, our system consists of agents distributed into a hierarchical architecture. Each agent is responsible for one activity, for example, traffic data collection, preprocessing of these data and decision making of reconfiguration of the traffic-lights controllers. An intelligent algorithm based on the policy management model is defined and used as an auxiliary element for the coordination mechanism in order to form an adaptive control system with learning capabilities that allows a more fluid traffic and reduce some of the problems that the society face such as the average wait time and trip travel time and the average size queue per intersection. We define a model based on configuration profiles that are used as initial configurations and new configuration profiles are created as the traffic conditions change. Our approach is experimented with traffic control of a few connected junctions and the result obtained is promising; it can reduce the average delayed time of each car at each traffic-light near an intersection rather substantially when compared with the current traffic-lights control approach.**

I. Introduction

DURING long time the traffic congestion problems has been related to big cities. The technical report of the United Nations Population Fund showed that for the first time, more than half of the world's population (around 3.3 billion people) lives in urban areas and the balance of people continue shifting to the cities [1]. This evolution has generated a fast development of small cities, and caused an exponential growth of their traffic congestion problems.

The main problem in small cities is that they were not built thinking in the current traffic demands. Building additional or extended roads due to their geographical limitations cannot solve their traffic congestion problems. According to a study carried out by "Melgar Asociados" the number of vehicles in Mexico reached the 20 millions in 2006 and the increment in the last years has been up to 7.81% [2]. In particular, in the last years, Colima, one of the Mexico's smallest states, located in west-central Mexico, has begun to face serious problems caused by the high traffic congestion. The current traffic-lights control system based on fixed-time does not solve the traffic congestion problems of the city. Due to the latter, it is necessary to develop intelligent and adaptive traffic-light systems that satisfy the rising traffic demands.

The present paper proposes a new adaptive multi-agent approach based on the policy model for traffic-lights management in the city of Colima, Mexico. This work is part of a current project of College of Telematics of the University of Colima. The project is focused in improving the operation of the traffic-lights system, reducing the traffic average wait time, queue size and average journey trip.

The rest of the paper is organized as follows: a brief description of related work is discussed in section 2. Section 3 describes in detail our dynamic traffic-lights management approach. An evaluation of the performance of the dynamic traffic-light management approach is presented in the section 4. Finally, section 5 shows the conclusions of our work.

II. Related Work

According to National Electrical Manufacturers Association (NEMA) the traffic-lights controllers are classified into two categories: fixed-time controllers and traffic-response controllers [4]. Fixed-time controllers consider a given time of a specific day and apply the predefined green lights duration and the cycle time. The main problem of these controllers is that their efficiency can be extremely poor when the traffic flow is not stable.

Traffic-response controllers can vary the phase duration and sometimes even the phase sequence. This kind of controllers can extend the phase duration based on the

J. A. Guerrero-Ibáñez is with the College of Telematics, University of Colima, PO 28040 MEXICO (e-mail: antonio_guerrero@ucol.mx).

R. Buenrostro-Mariscal is with the College of Telematics, University of Colima, PO 28040 MEXICO (e-mail: raymundo@ucol.mx).

J. Contreras-Castillo is with the Universidad Autónoma del Estado de México and is a professor in sabbatical visit from the University of Colima, PO 52166 MEXICO (e-mail: juancont@uaemex.mx).

A. Barba Marti, is with the Telematics Engineering Department at Technical University of Catalonia, Barcelona, PO 08034, SPAIN. (e-mail: telabm@entel.upc.edu).

A. Reyes Muñoz is with the Computers Architecture Department at Technical University of Catalonia, Barcelona, PO 08034, SPAIN (e-mail: mreyes@ac.upc.edu).

978-1-4244-7868-2/10/$26.00 ©2010 IEEE

number of waiting cars detected on each phase.

The more recent developments are focused on traffic-responsive control of large-scale urban networks. These works are based on fluid-dynamic model [5], queue size or the gaps between arriving vehicles [6] or agents [7].

Traffic parameters estimation has been an active research area for the development of Intelligent Transportation Systems [8]-[9]. Commonly, the conventional traffic information measurement used intrusive sensors, including inductive loop detectors, micro-loop probes and pneumatic road tubes. Some published works propose that "image tracking systems" as a method for traffic flow monitoring or radars [10][11]. Even though this method provides quantitative information of traffic flow, it has many limitations: 1) does not work properly for gathering real-time traffic condition information to large scale; 2) presence of the False Acceptance Rate (FAR) and False Rejection Rate (FRR), which generally produce erroneous identification of the number of vehicles.

One alternative that is becoming popular for monitoring is the Radio Frequency IDentification (RFID) technology [12],[13]. RFID offers an advanced system of individual identification without line of sight, without detection problems FAR or FRR, large storage capacity, simultaneous reading, the lowest level of maintenance, among other advantages.

III. Traffic-Lights Management Approach

In this section we describe in detail our traffic-lights control approach. Some assumptions are considered for the proposed approach. We consider that the 100% of the vehicles is equipped with a RFID tag. We assume that at least two RFID readers are installed in each line.

A. Model description

In this section, we describe the model of our approach. As mentioned before, it is based on a multi-intersection model (Fig. 1). In our system we uses the typical phase model used in the city in order to analyze the performance of our proposed approach (Fig. 1c).

B. Traffic Control Profiles

As mentioned before, our approach defines a set of profiles for the traffic-lights configuration one for each traffic-light controller. Additionally, new profiles could be created if the traffic demand conditions change.

Figure 2 displays the elements of the *traffic control profile*. As shown, the profile is composed of:

- *ID_Profile* is the profile identifier.
- *IP_TrafficController* represents the IP address of the Traffic controller for a specific intersection.
- *CycleTime* describes the maximum and minimum values for the cycle time of the intersection.

No_TrafficLights expresses the number of traffic-lights into the intersection.

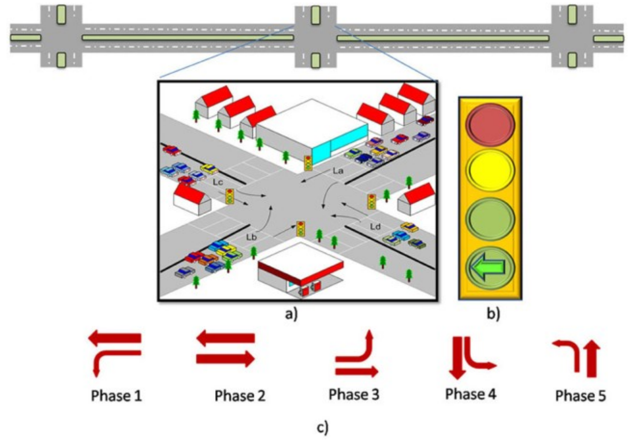


Fig. 1. Model description. Our approach is based on a multi-intersection scenario with four traffic-lights. a) Model of an isolate intersection. b) traffic-light used in our model. c) phase model.

We define a sub-profile for each road of the intersection. This sub-profile contains information about traffic-light identifier, the throughput of the road which represents the average traffic demand of the road that the profile can be support, the traffic controller which the traffic-lights belongs, and the configuration of the green duration of the traffic signal.

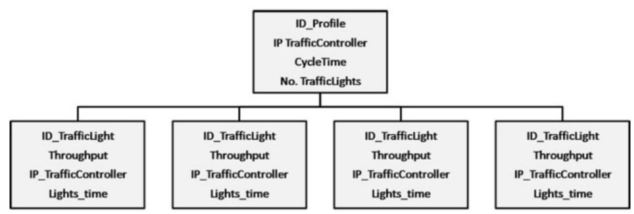


Fig. 2. Global structure of the traffic control profile.

Current model applied to control the traffic-lights uses a peak and an off-peak signal plan. Based on the current model we define main two profiles, an initial profile (profile 0) as the default configuration applied when the system starts and a second profile (profile 1) for peak hours. The main difference between our approach and the current approach is that we generate new profiles as the traffic demand conditions change.

C. Architecture

The dynamic traffic-lights management approach is based on a centralized management model. This model consists of three components: the Traffic-light Controllers (TLC), the Traffic Control Center (TCC) and the traffic data collectors (TDC).

The internal elements of each component are shown in fig. 3. TLC controls the traffic-lights located in the intersection and processes all information that TDC gathered in each cycle time. The traffic status data processor module processes information. The communication with the TCC and the configuration of the different traffic-lights of the intersection is controlled by the coordinator module.

Additionally, TLC uses a knowledge base to stores information about the Intelligent Decision Engine (IDE) decisions according to the traffic status.

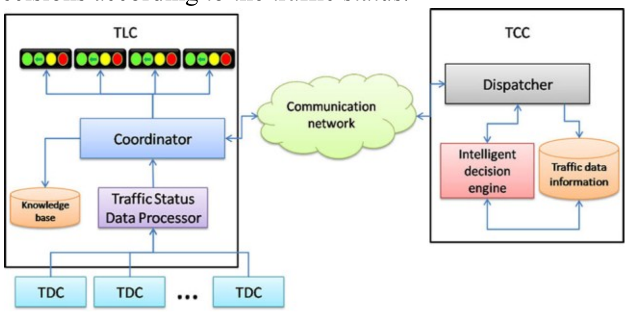


Fig. 3. Architecture and internal components of our approach.

An example of the knowledge base is shown in table I. The knowledge base component keeps a copy of the profiles (This concept is explained in detail later). that have been applied by the TCC for this TLC. This database is used as a configuration model when the communication with the Traffic Control Center is broken. The purpose of this registry is to allow the system taking a profile previously configured, according to the traffic conditions and time of the day. TLC sends to TCC all collected information via a communication network. The communication network consists of wireless access points (802.11) and a set of routers that connect all access point to the TCC via the Internet.

TABLE I
KNOWLEDGE BASE INFORMATION

ID	DAY	START TIME	END TIME	PROFILE
1	Monday	6:00	9:00	Profile 0
2	Monday	9:01	10:00	Profile 1
3	Monday	10:01	15:00	Profile 2
4	Monday	15:01	24:00	Profile 1

The traffic data collector module (TDC) is based on a set of RFID readers that gather information about traffic condition for each road of the intersection. The readers capture the time-in for each vehicle passing within its reading range. As mentioned before, a set of two RFID readers are placed at each lane. The readers are classified as incoming readers and outcome readers according to the place where they are located. These RFID readers can help to calculate the queue length of each traffic flow to be serviced by a traffic-light. This value can be calculated from the discrepancy between the number of cars getting into and the cars leaving the queue of each lane.

We define a traffic data repository, which stores all information collected by RFID readers in a tag reference table. Each RFID-tag reader placed at each lane collects information about the tag ID, and the time when the tag crossed its reading range. The data engine is responsible for analyzing the stored data and generating a report of the traffic information. The information that the data engine sends TCC is the number of cars that passed during the defined green time, the queue length, and the average time between the different cars. In order to avoid a congestion problem in the network, the report is sent at the end of each cycle time.

Finally, TCC analyzes all information and sends suitable configurations to TLC. TCC manages all control processes for the traffic-light management. It is responsible for initializing, monitoring, analyzing, evaluating and taking decisions for each TLC, in order to make a reconfiguration, after performing a cycle time. TCC is composed of two modules (*IDE* and *dispatcher*) and a repository (*Traffic data information*). IDE is the component where the decisions of traffic control are taken. IDE retrieves *condition-action* rules from traffic data information base and tries to match the traffic conditions with the rules' condition parts. If any of these succeed, the actions parts of the eligible rules will be fired. The dispatcher module controls of all TLC connected. Finally, the traffic data information base stores all information regarded by each TDC and the configuration profiles defined for each TLC.

D. *Traffic Control Algorithm*

In this section we explain the developed algorithm for the dynamic traffic control in order to facilitate the efficient traffic control at certain intersection. Our algorithm is based on a policy based management model, which allows defining a set of rules for intelligent selection of adequate times for the different traffic-lights in a multilane traffic flow of an intersection. We define two stages for our algorithm: fixed cycle and dynamic cycle. There is a common cycle time for all intersections that allow for coordination of different signalized intersections. Moreover, we specify a maximum cycle time as limit to variation.

In the first stage the time allocated to the cycle time is fixed at the beginning and it is kept during all time of execution of our model. The algorithm tries to adapt the traffic-lights green time according to the cycle time and traffic conditions for each intersection. This means that the duration of the signals is modified without affecting the cycle time. If the traffic congestion problems cannot be solved, we apply the second stage, which considers a dynamic cycle time based on the manipulation under demand of the duration of the signals on each road.

The algorithm considers a set of parameters for the dynamic configuration of the traffic-lights. These parameters consist of:

- Threshold of cars per road. Defines the minimum and maximum number of cars that should pass in each road according to the defined time.
- Threshold of headway. Represents the average time between cars that the sensor detects.
- Occurrence frequency (*OF*). Defines the maximum number of occurrences of a traffic congestion problem in a road that will trigger a reconfiguration. This parameter defines the threshold to detect a real congestion problem.
- Cycle time base. It is the default cycle time for an intersection.
- Cycle time max. Represents the maximum value that cycle time can get without affect other intersections

and it is used in the scenario where the cycle time can be modified dynamically.

The algorithm examines all parameters and decides the adequate times for the different traffic-lights of the intersection.

The rules for traffic-lights control are in the form of *condition* → *action*, where *condition* and *action* are a conjunction of sentences. Some of the traffic-lights conditions applied to our approach are defined as follow:

First, our algorithm checks if there is a traffic congestion problem in any road of the intersection. To do this, we compare the average number of vehicles that should pass during the green time and the average time between vehicles, which are defined in the traffic control profile, with the respective parameters of the current traffic conditions getting by the data traffic monitoring system. We analyze if the problem was a sporadic situation or it is a real traffic congestion problem. To do this, we define an incidence counter (P_L), which defines the maximum number of incidences of a traffic congestion problem. If the number of incidences is more than P_L, we analyze the traffic conditions in order to select the new configuration for the traffic-lights. We check the parameters in order to avoid affecting the other roads with the change. If the other roads do not have problems, we calculate the maximum time that can be allocated to the green light of the road with the traffic congestion problem without change the cycle time. We create a new profile with the new configuration parameters, the new profile is stored in the database of the TCC and it is sent to TLC.

If the problem cannot be solved with defined cycle time we apply the dynamic cycle time scenario which modifies the cycle time duration according to cycle time max value. A new cycle time is calculated and a new time distribution for the different traffic-lights is allocated. We create a new profile with the new configuration parameters, the new profile is stored in the database of the TCC and it is sent to TLC. A pseudo-code of the algorithm is shown as follow:

RULE: If *queue_lenght(La,Lb,Lc,Ld) = 0 and light(green)* ***then***
Change next_phase
RULE: If *current_car(La,Lb,Lc,Ld) ≥ Profile (current_car, La,Lb,Lc,Ld) and space_time()* ***then***
{
increase counter for road;
}
RULE: If *counter(La,Lb) >* P_L and *current_car(Lc,Ld) ≥ Profile (current_car, Lc,Ld) and space_time() >* S_{min} ***then***
{
find_max_time(La,Lb);
create_new_profile(La,Lb,Lc,Ld);
send_new_profile;
}
RULE: If *counter(La,Lb) >* P_L and *current_car(Lc,Ld) ≤ Profile (current_car, Lc,Ld) and space_time() <* S_{min} ***then***
{
find_max_time(La,Lb, CT_{max}*);*
create_new_profile(La,Lb,Lc,Ld);
send_new_profile;
}
RULE: If *counter(Lc,Ld) >* P_L *and current_car(La,Lb) ≥ Profile (current_car, La, Lb) and space_time() >* S_{min} ***then***
{
find_max_time(Lc,Ld);
create_new_profile(La,Lb,Lc,Ld);
send_new_profile;
}
RULE: If *counter(Lc,Ld) >* P_L *and current_car(La,Lb) ≤ Profile (current_car, La, Lb) and space_time() <* S_{min} ***then***
{
find_max_time(Lc,Ld, CT_{max}*);*
create_new_profile(La,Lb,Lc,Ld);
send_new_profile;
}

IV. Evaluation and Results

behavior of the proposed approach, we compare our proposed approach with the fixed time approach used in the city. To evaluate the performance of our proposed approach, we carried out some simulations in a multi-agent programmable modeling environment software. The traffic simulator employed in this research was developed in NetLogo [15].

The rest of the section describes the simulation setup; the traffic scenarios used in the conducted simulation study; and the obtained results.

A. Simulation setup

The arterial road network consists of three intersections located over 0.5Km distance along an arterial road. Each intersection is composed of two roads. Horizontal road is three lanes wide, central lane for go-forward, right lane for go-forward or right-turn and left lane for left-turn, while vertical roads are one lane roads.

Vehicles are generated according to a uniform distribution trying to simulate the current traffic of the city. When created, vehicles receive different features such as speed and turn probability. Vehicles are created to reach a cruising velocity of 14 m/s. Their acceleration is 2 m/s, which mean that they reach their cruising speed in 7 seconds. Their deceleration is 4 m/s^2. Each vehicle is driven by a basic controller that keeps a safe distance and reacts automatically to change traffic-lights.

For roads where vehicles can choose between two lanes, the controller chooses a lane randomly at the beginning of its course according to the turn probability. Traffic-lights are located at the two roads intersection. The signal plans we use are composed of five phases which were explained in section II. During their travel, vehicles are delayed if they encounter red lights. As soon as a vehicle stops due to a traffic-light, it starts to compute wait time in the intersection. We used the current configuration of the traffic-lights duration, which is shown in Table III.

TABLE II
Traffic-light Configuration

Phase	DURATION (seconds)
Phase 1	10
Phase 2	30
Phase 3	10
Phase 4	16
Phase 5	16

B. *Simulation scenarios*

The proposed approach was evaluated on two different scenarios that represent real scenarios of low traffic demand (scenario 1) and traffic demand in peak hours (scenario 2). The information of the traffic demands for both scenarios is shown in Table III. We programmed the cars to record their delayed time while they are in a queue, their speed when the car is moving and their trip waiting time (TWT). We use this information from every car to find out the average delayed time, the average trip waiting time and the average speed of all cars during the traffic simulation in real-time whenever required.

In order to evaluate the performance of our proposed approach we analyzed four parameters: average delayed time, average speed, average queue size for each direction and the average trip waiting time. We compared our proposed and the current traffic control approaches. The results are shown in the following subsection.

C. *Simulation results*

We show the results obtained by the simulation process. First part presents the results for the scenario 1 when we have a few traffic demands.

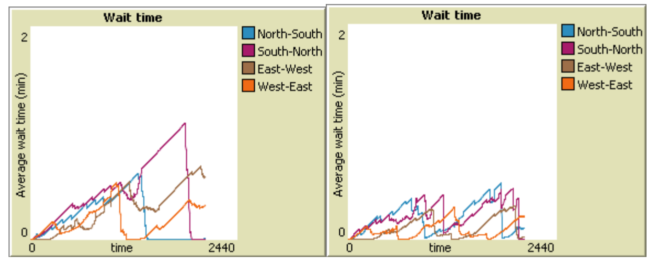
TABLE III
PERCENTAGE OF DISTRIBUTION OF VEHICLES PER

DIRECTION	TRAFFIC DEMAND (SCENARIO 1)	TRAFFIC DEMAND (SCENARIO 2)
Horizontal / vertical	80% - 20%	70% - 30%
Left-turn probability	20%	20%
Right-turn probability	15%	15%
Simulation time	2 hrs.	2 hrs.
Average number of cars per intersection	50	200

Figure 4 shows the average wait time for the scenario 1 obtained by both traffic-lights control mechanisms. As can be noted, the results show that our approach reduces the wait time in both directions compared to current approach. This delay is due to the cars must wait that all phases be completed. However, our model can manipulate the duration and sequence of the traffic-lights, when a road does not have wait cars, our model change to the next phase.

According to the results shown in the figure 4, the wait times for north-south direction is reduced 16%, for south-north 59%, for east-west 57% and for west-east up 33% regarding current traffic control approach.

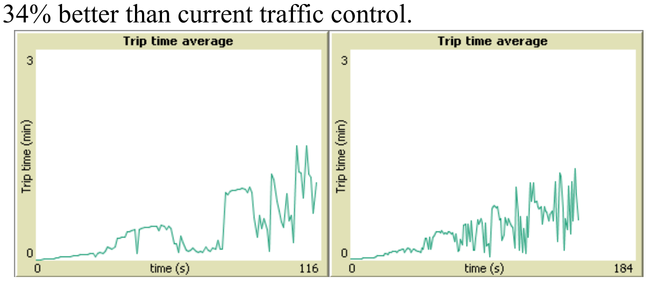
The next parameter evaluated was the trip wait time. Average trip wait time is considered from the car enters to the road network to the car leaves the road network by an exit gate.



a) b)

Fig. 4. Average wait time obtained by a) current approach and b) proposed approach for situations of low traffic demand.

The results for average trip wait time (expressed in minutes) are compiled in figure 5. As the number of vehicles traveling on the road network is increased, the average journey time begins to increase noticeably as the system becomes congested. We can observe a better performance of our proposed traffic control approach regarding current traffic control approach. Our proposed approach performs 34% better than current traffic control.



a) b)

Fig. 5. Average trip wait time obtained by a) current traffic control and b) proposed traffic control approach for situations of low traffic demand.

Second part of the results presents the performance of both traffic control approaches in situations of high traffic demand. Figure 6 shows the average wait time obtained by both traffic-lights control mechanisms in situations of high traffic demand. As can be noted, the results show that our approach reduces the wait time in both directions compared to current approach. According to the results shown in the figure 9, the wait times for north-south direction is reduced 16%, for south-north 40%, for east-west 42% and for west-east up 35% regarding current traffic control approach.

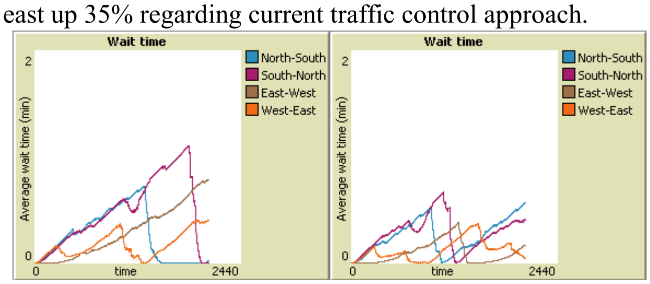


Fig. 6. Average wait time obtained by a) current traffic control mechanism and b) proposed traffic control approach for situations of high demand.

Finally, we present the results of the average trip wait time for high traffic demand situations. Figure 7 show the performance of both traffic control approaches. As can be observed, our proposed approach reduces the average trip wait time up 29% regarding current traffic control approach.

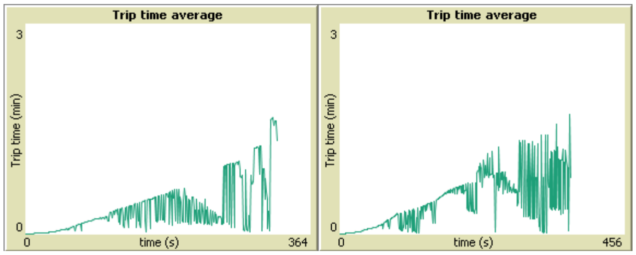


Fig. 7. Average trip wait time obtained by a) current traffic control and b) proposed traffic control approach for situations of high traffic demands.

Table IV shows the average queue size obtained for each traffic-lights control mechanism. When the traffic demand is low, queue size for east direction is reduced up 14%, for west direction up 26%, for south 41%, east turn left 6%, west turn left 46% and for north direction up 8% regarding current traffic control approach. However when the traffic demand increases, queue size for east direction is reduced up 29%, for west direction up 39%, for south 69%, east turn left 65%, west turn left 64% and for north direction up 34% regarding current traffic control approach.

TABLE IV
AVERAGE QUEUE SIZE FOR LOW TRAFFIC DEMAND

DIRECTION	Current traffic control approach		Proposed traffic control approach	
	Low traffic	High traffic	Low traffic	High traffic
East	4.2	5.8	3.9	4.1
East (turn left)	5.98	9.66	3.5	3.3
West	2.89	12.75	2.5	7.8
West (turn left)	2.01	10.98	1.9	3.9
North	5.67	10.91	4.2	7.2
South	5.93	13.93	3.2	4.3

V. CONCLUSION

We designed a policy-based intelligent traffic-lights control approach which efficiently manages the traffic according to the current traffic conditions. A real-time traffic information system based on RFID is used as the main source for the decision process. We defined a centralized system that takes decisions about the best configuration for the intersection according to traffic conditions. One of its main features is the ability to take decision of configuration from head-quarters to any traffic controller in the system via an existing communication infrastructure. A simulation study investigated the benefits of our approach. Compared to current traffic-lights control mechanism queues size, and average trip wait time could be reduced while the average wait time could be improved slightly.

The system gathers details of traffic information, which provides valuable information to traffic systems planners. This approach can enhance the transportation systems helping to reduce the traffic congestion problems and improve the management of traffic systems in Colima city.

ACKNOWLEDGMENT

We gratefully acknowledge the financial support by Ramon Alvarez Buylla Research Fund in the University of Colima, México.

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