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Simulation and Optimization of Traffic Lights For Vehicles Flow in High Traffic Areas

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Abstract

In today's world, the increase of the population in the cities cause that the transportation of freight and passenger increase also increasing the number of automobiles and vehicles on the streets, directly impacting traffic on the roads and more in the critical points of the street, the intercessions. To improve mobility at these intersections is necessary to appropriate coordination of signals and traffic lights that regulate traffic in various directions. This research shows the methodology to find the correct time of the lights to reduce the time in traffic of the vehicles on one of the principals and most congested roads in the city of Barranquilla, Colombia, using simulation and optimization techniques, were found the ideal cycle times and the different times of each color of the traffic lights to reduce the time in the line of the vehicles. This paper presents a literature review of similar works, a complete description of the case to be investigated, the construction of the simulation model required for the evaluation of the improvements, the optimization model developed, and the conclusions to which reached in the same way, it proposes a structure that can be replicated in any scenario that handles similar conditions

Keywords: simulation, optimization, traffic light scheduling

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1. Introduction

Simulation refers to the process of designing a real-life situation, imitating all the behaviors of a system into software, developing a model capable of evaluating different tests within, understanding how the system works and how could be improved with all the possible restrictions, depending on how accurate we can be during the modeling process. The correct implementation of a simulation system gives us the opportunity to evaluate how to reduce costs, making some different changes in a system where people want to validate a change.

Around the world, the increase of vehicles quantity to mobilize people is not only affecting how much time they spend driving also affecting people health because of the contamination that all these engines produce lungs illness or affecting the breathing system, for this reason, but researchers on transportation systems are focus to evaluate alternatives that can solve this problem and bring better life quality, as well as other types of fuel, sharing vehicles, improve massive transport, or reducing flow in transit principal purpose of this research. Nowadays, in many places abroad the Colombia territory such as Barranquilla City, one of the principal cities, and where this research is analysed, traffic lights were programmed using fixed time cycles considering the duration of each color, which are precisely coordinated on each intersection to speed up the vehicle flow. The duration time of each color, mainly green and red, depends on the influx of vehicles that reach the traffic light and the other cars that come perpendicularly for the other road. Many of these cycle times change depending on the hours of the day since at peak times there is more influx of vehicles than in regular time, the latest technology traffic lights have sensors that can recognize in real-time the number of cars that pass and based on these measurements and machine learning to regulate their cycles automatically and improving the flow [1]

The techniques to program the duration of the lights of a traffic light optimally have been a subject of considerable study due to the high social impact. The majority of the studies are focused on optimization techniques, sensor management, and machine learning to obtain the best scenarios that reduce traffic. [2] implemented a deep reinforcement learning model to control the traffic light. [3] implemented two kinds of reinforcement learning algorithms: deep policy-gradient and value-function-based agents to reduce vehicle waits. [4] generated an intelligent control system for traffic signal applications, called Fuzzy Intelligent Traffic Signal (FITS) control. [5] patented a system by Pictographic recognition through cameras, mobility sensors and artificial intelligence can program the best way to operate the traffic light. Another focus of study in traffic light control is to reduce the environmental impact caused by keeping cars lit while the light is red. Many investigations try to reduce carbon dioxide (Co2) emissions resulting from these vehicles [6] designed a system called Green Light Optimal Speed Advisory (GLOSA), that can reduce CO_2 emissions, waiting time, and travel time which advises the optimal speed to pass the next traffic light without stopping. Also, [7] proposed to give a high priority to the heavily-loaded vehicle, which consumes and emits a high quantity of fuel and CO_2 due to breaking and stoppage. [4] shows an intelligent traffic light control scheme to reduce vehicle CO_2 emissions based on VANET, real-time traffic information can obtain by wireless communication between the vehicles and the traffic lights. This Vehicular ad hoc network (VANET) is an emerging technology using for future on-the-road applications, based on the roadside unit (RSU) is a computing device located on the roadside that provides connectivity to support Vehicle-to-Infrastructure communication and to increase vehicle-to-vehicle communication connectivity. [8] presents a clear explanation of this and shows the importance of these communications in reducing accidents and traffic. The importance of this connectivity is also observed at a technical level, looking for alternatives such as the 5G connection to guarantee effective connectivity, [9] shows how this type of technology is applied to smart cities and makes traffic more efficient.

Due to the population growth, many Latin American countries have carried out multiple investigations into how to improve the mobilization of people within the city, optimize the resources used there, and improve air quality on mobilization, some of these are: [10]–[12]. In some of these countries, use mass transit systems to improve the mobilization, these types of models were designed to reduce traffic through the correct programming of times and traffic light programming considering the number of passengers moving on buses so that your objective is applied to reduce the average waiting time of people, regardless of the number of vehicles [13], [14] even models whose objective is to give priority to people who have some disability, contemplating radiofrequency devices to be able to recognize it.

2. Problem Description

To carry out this research, it was necessary to find a segment that had the specific conditions analyzed, the model proposed in this research was evaluated in a high mobility sector of the city of Barranquilla, Colombia. The choose area has a particularly high rate of movement of vehicles caused by the proximity to banks, restaurants, shopping centers, and a university. Pedestrian flow is not analyzed as pedestrian bridges are expected soon at these interceptions. The roads analyzed are transited by four bus routes and two lines of the massive transportation system of the city. The segment with the highest vehicular congestion and object of the study consists of the main street of the city that has two lanes in each direction and two interceptions with traffic lights, as shown in Figure 1.

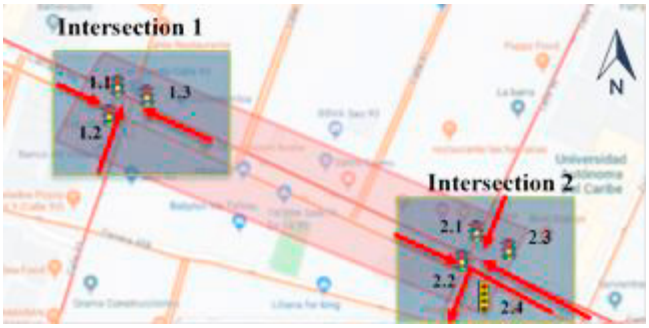

Figure 1. Section to analyze.

Interception number one has traditional three-color traffic lights because vehicles can only go forward and to the right when the light is green and enters a road in the same direction. While at interception number two, the traffic light on the west direction is a four-light traffic light, which contemplates an option to turn right, crossing the road that comes in the opposite direction to take the north-south route. To do this turn, only the lane you are coming from must remain active. Also, along the road that goes in the west-east direction, there is a pair of streets which can be taken by turning to the right in that same direction, the number of vehicles that travel through these streets is not much to enter or get off the main road.

3. Simulation Model Description and Validation

To represent this system as close to reality, it was first necessary to compile data to evaluate how the system is currently for this was necessary to do a data collection and data analysis process, some provided by the secretary of mobility (department associated with traffic in this region) and data shown by google maps, we proceeded to collect and validate all the information relevant to the arrival and vehicles in that area finding the best probability distribution of the data according to the type of vehicle and route where it entered, was found that the strip with the larger vehicular congestion is between 5:30 p.m. and 7:00 p.m., at which time most people return to their homes. For the simulation of the system to be analysed, a model discrete stochastic simulation was created contemplating the four inputs of the system, when they meet with a traffic light there are two different types of decision; the first one is associated with whether the vehicle incurs a wait not according to the colour that the traffic light is currently taking; wait if the traffic light is red and yellow and if it is green you can continue. The second decision is associated with the direction that the vehicle can take once they pass the traffic light, these can be turned to the right, continue forward, or turn left, this is given depending on where the vehicle has arrived and the traffic light where be found.

With the simulation model developed, proceed to find the data required for its operation. The first goal was to find the best random distribution associated with the time between the arrival of the vehicles in the rush hour segment of analysis using the goodness of fit test. This methodology was used according to the data collected in each one of the four inputs of the model. These were made in three types, depending on the type of vehicle: cars, taxis, and buses. in the same way, size affects the results to a small extent. In the same way, information associated with the probability that an entering vehicle was going to make any type of crossing at a traffic light was collected. Finally, data were collected on the average time of a vehicle waiting at the traffic light and the average number of cars in a line, this information served as support to validate the correct operation of the simulation.

As the traffic lights in intersection number one and intersection number two are synchronized, the first group of scenarios were used to evaluate how the system would behave if the green phase is change. Considering a complete phase in a traffic light (green-yellow-red-yellow) is fixed at 120 seconds included two times of 5 seconds are required in the yellow phase to change from green to red and vice versa. These scenarios were analyzed contemplated the duration of the green phase are between 10 to 90 seconds, each scenario with 10 seconds of

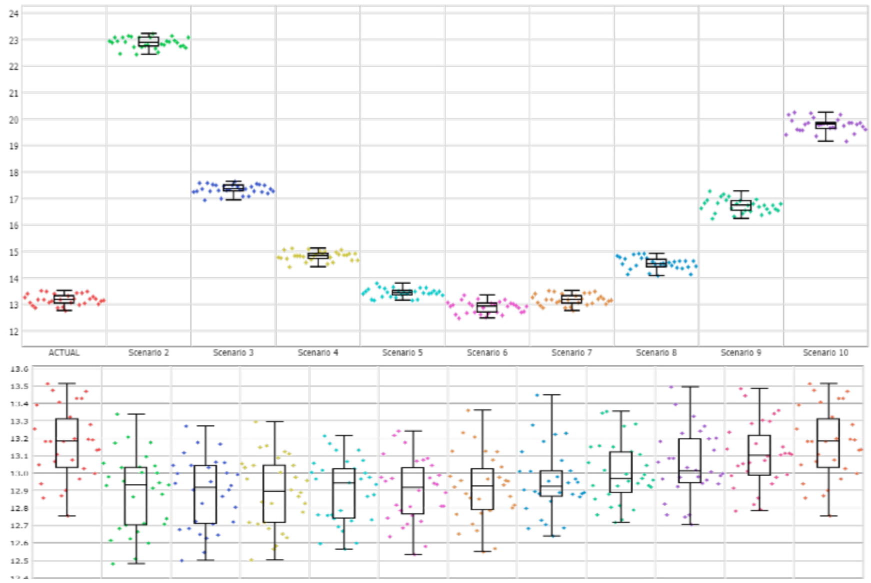

Figure 2. Simulation results by scenarios (scenarios vs waiting time avg in seconds).

difference apart from the other, for a total of 9 different scenarios measuring the average time vehicles waiting at the traffic light (Figure 2) and, subsequently, second by second was analyzed in the best range to review if the changes improve results. For the creation of the simulation model, the flexsim program used running each model 40 times per scenario.

With these parameters in these values of the length of the green phase in both traffic lights, improvements of 5% would be achieved in the waiting time of vehicles in line, however, this proposal does not contemplate an analysis that entails different and desynchronized cycle times in each traffic light. For this solution, an optimization model was carried out which would consider all these possible points since there are many options to analyse.

4. Optimization Model and Results

To perform the optimization and find the ideal values of the time that each colour should last in the traffic lights to reduce the time in the queue of the vehicles in all the analysed systems, the optimization tool from Flexsim was used for this. First, it was necessary identify all the possible variable to be considered to find the ideal value that allows optimizing the model and all the constraints associated with each one of the processes and limitations that they had in them, also considering, in turn, a variable time of a fixed cycle time actually corresponding to 100 seconds of which 10 were to be given by the changes of the colours 5 seconds when it goes from green to red and 5 more when it goes from red to green. The main goal to achieve was the duration of the vehicles in line with the entire system. Figure 3: Traffic light variables and constrains represents the complete variables and their restrictions associated with the process.

Traffic Light number (intersection, light)	Variable	Definition	Condition
2,1	X1	Red light	$\leq$ X3, X7, X2
	X2	Green light	-
2,3	X3	Red light	$\geq$ X2
			$\leq$ X1, X5, X7
	X4	Green light	-
2,4	X5	Red light	$\geq$ X1,X2,X3,X4,X6,X7,X8
	X6	Green light	-
2,2	X7	Red light	= X6+X3+X8
			$\leq$ X5,X1
	X8	Green light	-
1,2	X9	Redlight	= X12, X14
	X10	Green light	= X11, X13
1,3	X11	Redlight	= X10
	X12	Green light	= X9
1,1	X13	Redlight	= X10
	X14	Green light	= X9

Figure 3: Traffic light variables and constrains

In the same way, were considered the set of variables C like the phase time of colours red and green without a fixed time of 8 seconds for the yellow phase (twice 4 seconds, once after finishing each colour used in countries like Colombia) to find his best phase length, were analysed like a different pair of variables C according to the intersection to analyse (C1 and C2). A minimum value of 10 seconds (5 seconds by colour red plus 5 to colour green) and a maximum of 120 seconds was estimated for each C variable assuming possible limits of the variable limiting the times of each colour. The variables and constraints on the following final model were possible to group which aims to reduce the vehicle's average waiting time: $X1 \geqslant 5$, $X1 \geqslant X3$, $X1 \geqslant X7$, $X3 \geqslant (C1-X1)$, $X3 \leqslant X5$, $X3 \leqslant X7$, $X5 \geqslant X1$, $X5 \geqslant X7$, $X7 = (C1-X5) + X3+5$, $X9 \geqslant 5$, $X11= (C2-X9)$, $X13= (C2-X9)$.

Once the goals and restrictions were defined, proceeded to execute it in the optimizer of the Flexsim software where, after analysing more than 250 solutions, the best result reached, which could be a reduction in waiting time of more than 30 % of current system time. According to this result, it is better to handle two cycle times according to the intersection be analysed, on the intersection where there is no left turn, the cycle time will be shorter since it allows greater flow while the intersection does allow the left to turn the duration of the phase will be longer but not as high as the current one

5. Conclusions

The most important contribution from this research is the importance of analysing these types of mobility systems and combine different tools to find ways to improve, the presented in this work were simulation and optimization. Many investigations are turning towards the topic of the management of industry 4.0 in these systems, advancing intelligent traffic lights that allow evaluating the flow and finding what are the best cycle times according to the current state, being very useful in actuals times in which due to confinement the mobilization of people has changed at a very high rate.

With the models developed in this work, it was possible to improve the dwell time of the waiting vehicles at the different traffic lights of the two analysed intersections. The simulation model has an improvement of approximately 10% that could be found simply by changing the times that the red and green colours of the traffic lights lasted, keeping the total cycle time (return to its initial colour) the same for all traffic light classes at each interception. With the optimization model, improvements reduced by more than 30% the duration that vehicles wait at the traffic-light, occurred because this model helps to found solutions considering cycle times between the two different intersections, otherwise, one interception may take longer to change all the colours of the traffic light than another, being able to improve the flows and adapt to the best condition presented.

Complementing a simulation model with an optimization model makes it easier to find the optimal conditions for handling a system and makes it able to model mathematically complex systems such as traffic lights. This work did not consider the pedestrian crossing at traffic lights, adjust it would not be difficult since there is a built simulation system that could be adapted to any other instance. In the same way, the model structure and methodology proposed in this paper could be replicated in a different system with similar conditions if the steps are developing is a follow: analysed the flow, the analysis of input data, select the time section to be analysed, analyse scenarios with different times in each traffic light, analyse traffic light restrictions and make the optimization.

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