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Experiments simulation and design to set traffic lights' operation rules

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A B S T R A C T

This empirical study aims to minimize the travel time of motor vehicles on one of the most important avenues in Celaya City, Guanajuato, Mexico, by means of the optimal synchronization of existing traffic lights. In the optimization process, the following three factors are considered with 3 evaluation levels each: traffic light cycle times; the synchrony defined as staggered, parallel and actual; and the speed limit. The response variables to consider were the average time in the system, the fuel consumption and the greenhouse effect gas (CO2) emissions. Different experiments were performed using the simulation model developed in the PTV-VISSIM software, which represents the vehicle traffic system. The obtained results for the different proposed scenarios allow proper levels to be determined for vehicle traffic system operation to improve mobility, reduce contamination rates and decrease fuel consumption for different motor vehicles using the avenue. As a result, it was possible to establish a methodology that combines microsimulation and design of experiments to program traffic lights and define the operating conditions of a complex vehicular flow system.

1. Introduction

In Celaya City, Guanajuato 873,111 tons of CO_2 are released every year (Aranda et al., 2013) due to the increasing demand of vehicles that use routes throughout the city. Blvd. Adolfo López Mateos is the busiest route, thus, it is convenient to reduce the travel time of vehicles that use this road system. During idle periods, engines will consume more fuel and release more CO_2 emissions than during in travel periods (Barth and Boriboonsomsin, 2009). However, another study reported that acceleration and deceleration had emission rates greater than at idle periods (Frey et al., 2003). The relationship between speed and duration in the system (Blvd. ALM.) as well as acceleration and deceleration of vehicles affects the carbon dioxide emission and fuel consumption. Helbing (2001) found that the increase of vehicle speed from 10 to 40 leads to a 2- to 4-fold increase in fuel consumption; therefore, the carbon dioxide emission would similarly increase. Long et al. (2012) carried out an investigation to analyze the idea that the drivers have to implement variable speed limit systems, but may people are not in agreement with this concept. Chunxiao and Shimamoto (2012) reported that trip duration, trip distance and speed variation are the main factors that affect the vehicle carbon dioxide emissions. Oh et al. (2016) found that driving behavior from vehicle interactions, such as acceleration, deceleration, and stop-and-go, are highly associated with traffic environment and, more specifically, with vehicle emissions.

Henein et al. (2000) studied the effect of start transients in the fuel consumption and emissions of HC and NOx using direct injection diesel engines and determined that stopping the engine reduces the fuel consumption. They also demonstrated that shutdown time had an important influence on NOx emissions. The aim of this paper is to reduce the average time in vehicle systems that use the road Blvd. Adolfo López Mateos, applying design of experiment (DoE) and simulation techniques. The experiment can be considered as part of scientific process and a way to understand the operation of systems and processes (Montgomery, 2004). The simulation is the process to design and develop a computer model of a system or model and to perform experiments using this model with the purpose to understand the system behavior or assess several strategies that can be used to operate the system (Shannon, 1988).

With regards to DoE, there were 27 proposed treatments (scenarios obtained when considering three factors, every factor with three levels). According to the DoE methodology, this design is called 33, where the base 3 are the levels of every factor and the potency 3 means the number of the factors. These factors were chosen because they can be manipulated and are also suspects that can influence the response variables. The factors were cycle time, the synchronization of the traffic lights, and the speed limits. The levels of each factor were values that could be manipulated. In this case, three feasible values were chosen and were easy to implement in the real system. The levels for the cycle time were defined as 100, 120 and 140 s. The levels for synchronization were defined as

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current state (where it is possible that each intersection with a traffic light automatically varies in several ways), parallel (where all traffic lights have the same indication of time) and staggered (where the traffic lights of near intersections, grouped, show alternating indications throughout the route). Finally, the speed limits were defined considering the transit regulations in 40, 50 and 60 km/h zones. The aim was to minimize the vehicle average time in the system, the CO2 emissions and fuel consumption.

Cal and Mayor (1994) report that there are coordination systems of fixed time type for 4 traffic lights; although, only the following three systems were used herein: 1. simultaneous or parallel systems in which all traffic lights have the same time indication; 2. alternating or step systems, in which the traffic lights of near intersections are grouped and show alternating indications throughout the route, thereby improving the vehicle circulation compared with the first system; and 3. flexible progressive system in which each intersection with a traffic light automatically varies in several ways, setting several schedules to subdivide the cycle, with the predefined time to give preference in hours of maximum demand.

Medina et al., 2009 proposed a brilliant methodology based on metaheuristic genetic algorithms to control the vehicular flow of an intersection. The results were very promising; however, for larger instances with several intersections, its methodology becomes very complicated and it becomes necessary to use more suitable techniques for the treatment of vehicular flow. For this reason, it was decided to use microsimulation.

Microsimulation models can measure different parameters of interest (such as delay time, travel time, average speed, etc.) based on individual vehicles (Koukol and Pribyl, 2013). The software used to build the simulation model that represent the route system of Blvd. Adolfo López Mateos (ALM) was PTV VISSIM (acronyms German, Planung Transport Verkehr, Verkehr In Städten – SIMulation). This software can analyze private and public transport operations under constraints such as lane configuration, vehicle composition, traffic signals, PT stops, etc., making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness (PTV, 2011). With this software, experiments were carried out according to the proposed scenarios (experiments) in order to find the best conditions of the vehicle traffic system.

The main contribution of the paper lies in the use of two powerful tools such as microsimulation and the design of experiments in order to find a very ingenious and economical way to program traffic lights on busy avenues. The appropriate methodology allows several scenarios to be generated and the performance of each scenario analyzed without hindering the continuous flow of vehicles. It is possible to find the best performance at low cost and to reduce waiting times, CO_2 pollution and fuel consumption to impact the environment and economy of road users in this study.

2. Method

The steps suggested by Banks (2005) to perform a successful simulation project were followed. The steps were classified as the system, data collection, data analysis, model construction, model verification and validation and experimentation. The analysis of the results is presented in the third section of this paper.

2.1. Description of system to simulate

The system simulated was defined as the Blvd. Adolfo López Mateos that runs from Plan de Iguala Street to Velázquez Street and vice versa. This system has 14 traffic lights and corresponding intersections, as shown in Fig. 1. These figures define the system to simulate. The figure shows the Blvd. Adolfo López Mateos in red, which intersects with the following 14 numbered streets:

1. Plan de Iguala, 2. Plan de Ayutla, 3. Antonio Plaza, 4. Luis Cortazar, 5. Allende, 6. Benito Juárez, 7. Emeteria Valencia, 8. Chaurand Concha, 9. Javier Mina, 10. Abasolo, 11, Francisco juárez, 12. Ponciano, 13. Piña, 14. Velázquez. Every green circle indicates traffic lights.

2.2. Data collection

Vehicle capacity studies were performed, and these data were collected during intense traffic times from 13:00 to 14:00 h; the number of cars driving on the Boulevard and the cars traveling by each intersection were recorded, as shown in Table 2. Ten cycles were recorded for each intersection. The cycle is the time it takes for the traffic light to change its green, yellow and red lights. The distance between intersections was measured and is shown in Table 1. The cycle time of each traffic light was also observed.

2.3. Data analysis

The obtained data were subjected to a goodness-of-fit test with to define the probability distributions, with the help of STAT:FIT statistics tooling, included in PROMODEL. PROMODEL is software that helps build system models related with production operations that include a large number of elements, such as path networks, locations, resources, entities, and attributes (Yazici, 2006).

The test is based on the fit between the occurrence frequency and the expected frequencies that are obtained from the hypothetical distribution (Walpole et al., 2007). Then, it was determined that the arrivals distribution in each intersection followed the Poisson distribution. This was performed in every lane of Blvd. ALM and its corresponding intersections, but Fig. 2 only shows lane 1 of the Fco. Juárez and Blvd. ALM intersection.

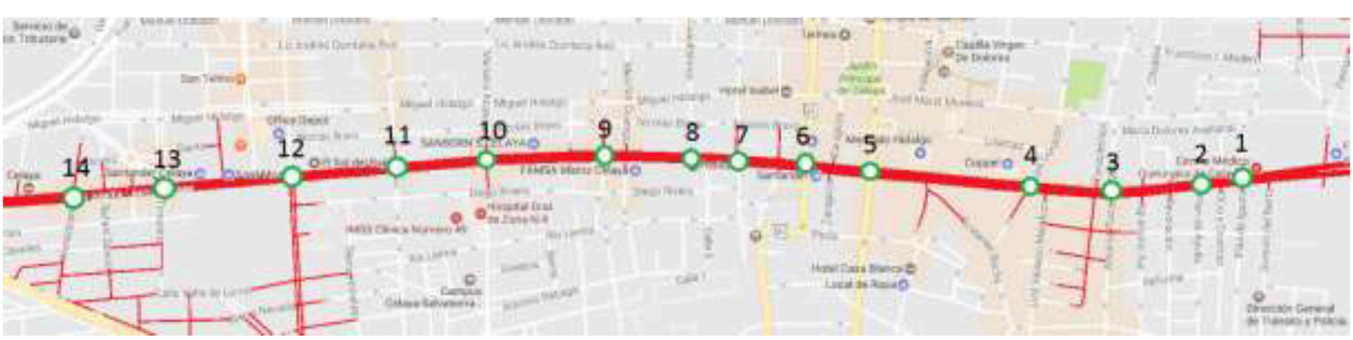

Fig. 1. System to Simulate (Blvd. ALM) and model development.