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Analysis of Preferential Treatment for Public Transport at intersections controlled by traffic lights

Análisis de Tratamientos Preferenciales para Transporte Público en intersecciones controladas por semáforo

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ABSTRACT

Context: This work presents the possible optimization of passenger transportation at one intersection in San Jose, Costa Rica through the application of preferential treatments for public bus transportation, with a simulation program compatible with said treatments. The main indicator used corresponds to the average delays per passenger; these delays were obtained at intersections with and without the use of preferential treatments. **Methodology:** The input data correspond to vehicle counts that were carried out with the help of video cameras at intersections; Data were obtained, by vehicle type, for the morning and afternoon peak hours. The intersections were recreated according to the site geometry and modeled; the volumes were entered into the simulation model. To simulate preferential treatment, bus detectors were added to the simulation, whose function is to detect the moment in which the bus passes and with this modify the phases of the traffic light to instantly benefit the bus. The strategies used to give bus phase priority (TSP) are green time extension and red suppression. At intersections, existing bus bays were used to recreate queue jumping. **Results:** In the simulation models created, preferential treatments were determined to reduce average delays per passenger by up to 38 % at the intersection studied. Annual savings in time and fuel of up to 60 thousand dollars were determined. It was determined that the recovery time of the investment corresponds to eight months. **Conclusions:** Calculating delays per person, instead of the traditional calculation per vehicle, can provide a different perspective to the analysis of capacity at intersections. The implementation preferential treatments for transit could be feasible in economic terms.

Keywords: autobuses, delay, transit preferential treatments, signal priority, intersection capacity.

RESUMEN

Contexto: Este trabajo presenta la posible optimización del transporte de pasajeros en una intersección de San José, Costa Rica mediante la aplicación de tratamientos preferenciales para el transporte público en autobús, mediante el uso de un programa de simulación compatible con dichos tratamientos. El principal indicador utilizado corresponde a las demoras promedio por pasajero, dichas demoras se obtuvieron en intersecciones con y sin el uso de los tratamientos preferenciales. **Metodología:** Los datos de entrada corresponden a conteos vehiculares que se realizaron con la ayuda de cámaras de video en las intersecciones; se obtuvieron datos, por tipo de vehículo, para las horas pico de la mañana y de la tarde. Se recrearon las intersecciones de acuerdo con la geometría de sitio y se modelaron, los volúmenes se ingresaron en el modelo de simulación. Con el fin de simular el tratamiento preferencial, se agregaron a la simulación los detectores de autobuses, cuya función es detectar el momento en el que pasa el autobús y con esto modificar las fases del semáforo para beneficiar instantáneamente al autobús. Las estrategias utilizadas para dar prioridad de fase al autobús (TSP) son la extensión del tiempo de verde y la supresión del rojo. En las intersecciones se aprovecharon las bahías de autobuses existentes para poder recrear el salto de cola. **Resultados:** En los modelos de simulación creados, se determinó que los tratamientos preferenciales reducen las demoras promedio por pasajero hasta en un 38 % en la intersección estudiada. Se determinaron ahorros anuales en tiempo y en combustibles de hasta 60 mil dólares. Se determinó que el tiempo de recuperación de la inversión es de aproximadamente 8 meses. **Conclusiones:** El cálculo de las demoras por persona, en vez del tradicional cálculo por vehículo, puede brindar una perspectiva diferente al análisis de capacidad en intersecciones. La implementación de tratamientos preferenciales para transporte público es viable en términos económicos..

Palabras clave: autobuses, demora, tratamientos preferenciales para autobuses, prioridad en semáforos, capacidad intersecciones.

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Introduction

The use of automobiles has been growing in the Greater Metropolitan Area of Costa Rica; However, this type of transportation is considered an alternative with little sustainability, because it is a means of transportation that is considered very high cost, is very individualistic, generates inequality, pollutes more by requiring more units in relation to the passengers it can

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accommodate. (normally only five), take up a lot of city space within an urban area and generate a high level of accidents compared to other alternatives (Pardo, 2005).

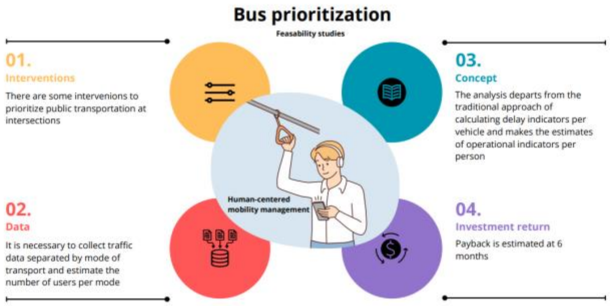

Figure 1. Bus priorization.
Source: self-authorship

The Greater Metropolitan Area (GAM) of Costa Rica, in recent years, has been characterized by a lack of road infrastructure and inefficient public transportation, this is aggravated because the GAM houses 57% of the population so only 4 % of the national territory. The low density and high dispersion of the population generates a large number of trips in the GAM. All the above causes a very serious phenomenon called congestion, which increases the social and economic costs related to transportation. Congestion in the GAM has caused a deterioration in the quality of life of Costa Ricans and has affected performance and competitiveness at the business level (Otoya, 2009).

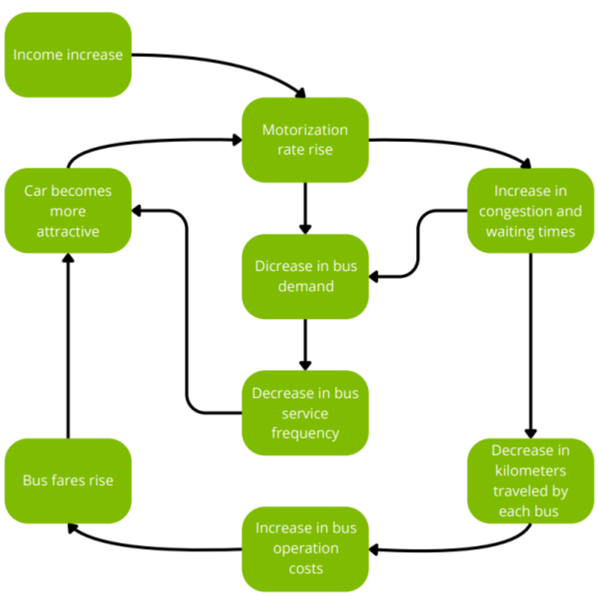

Figure 2. Vicious circle of public transport and the automobile.
Source: adapted from (Ortúzar, 2000)

On the other hand, the bus is the most important means of public transportation in Costa Rica, since, according to PRUGAM data, approximately 50% of trips in the GAM are made by bus (L.C.R. Logística S.A., 2007). It can be said that the transportation situation in Costa Rica is experiencing a vicious circle, since, due to the increase in congestion, a deterioration in the operational characteristics of the public transportation service is generated, which causes more people to opt for transportation. private, which causes more congestion to be generated, so the problem is not solved, but rather it becomes more serious (Sabatini & Arenas, 2000) (Figueroa, 2005) (Figueroa & Orellana, 2007).

Due to the above, it is imperative to look for options to provide public transportation not only with good infrastructure, but also to carry out technical-scientific studies to promote its use in the most effective way possible. This study seeks to analyze an option that can give more priority to the bus and thus increasingly make it a more attractive means of transportation for users.

Regarding the vicious circle between bus and car use, there are ways to counteract it, turning it into a virtuous circle. One of the most effective ways is to give priority to public transport (the central theme of this study) to make public bus transport more attractive by reducing delays and thereby increasing demand for this means of transport (Ortúzar, 2000).

In the 1990s, in Mexico there was already talk about some preferential treatments for public transportation, such as reserved lanes, exclusive side lanes, exclusive contraflow lanes, central exclusive lanes, exclusive streets and preferential treatments at intersections with and without traffic light (Molinero & Sánchez, 1996).

In the preferential treatments of transit in buses and trains in mixed traffic, some preferential treatments for public transport standout such as queue jump or queue-jumping lane, Transit Signal Priority or phase priority for public transport, special signal phasing or special signal of passage and the modification of bus stop sites (Danaher, 2010). In addition, there are other treatments such as allowing some maneuvers prohibited to buses, restricting maneuvers for private vehicles, giving way to the bus (yield to bus), traffic signal shadowing, among other forms of preferential treatment (Transit Cooperative Research Program, 2016).

Preferential treatment for public bus transportation can be applied both in a segment of a corridor and occasionally at an intersection. Within these preferential treatments for public transport, there are the following (Danaher, 2010):

- Segments of a corridor:
  - Median lane on a road
  - Exclusive lanes without medians
  - Relocation of bus stops
- Intersections:
  - Phase priority for public transport
  - Exclusive signs for public transport
  - Queue jumping
  - Extension of bus stops

TSP (Transit Signal Priority or PFA in spanish) is a type of preferential treatment that is applied at intersections with the presence of traffic lights. TSP is a way to improve the quality of service for public bus transportation, thus making it easier for the bus to pass through intersections. The TSP preferential treatment system is an alteration in the phases of the traffic light cycle, with the aim of giving priority to public transport. This alteration can be the extension of the green time, the suppression of part of the red time, among other forms. However, for this alteration to occur, there must be a request from the public transportation unit, this request can be both manually and automatically (Danaher, 2010) (Koonce, 2008).

Commonly, since the TSP method has been used, it has been confused in the United States with the phase perception method for transportation (Transit Signal Preemption). The difference between these two methods is that TSP refers to priority for public transport over other means of transport, while the Transit Signal Preemption method refers to the perception of any type of transport (not necessarily public) and that must alter the common operation of the traffic light cycle, it is widely used for the passage of trains, emergency vehicles, boats, among other types of transportation (Koonce, 2008) (Smith, Hemily & Ivanovic, 2005).

The benefits of applying TSP to public transportation have been very significant in the cities where it has been applied. Studies have shown that in the city of Tacoma, Washington, USA, public transportation delays have been up to 40% shorter in two corridors where TSP was applied. Portland TriMet saved the placement of an additional bus, improved travel times by 10%, and reduced travel time variability by 19% thanks to the application of TSP. Another Chicago bus service called Pace averaged a 15% improvement in travel time (Smith, Hemily & Ivanovic, 2005).

There are negative impacts on private transportation with the implementation of TSP, however, the delays generated are minimal, since the seconds that the TSP takes in any phase to operate are negligible compared to the total cycle of the traffic light (Smith, Hemily & Ivanovic, 2005).

The costs when implementing the use of TSP, in the case in which the traffic light controller is modern, are very low. However, for cases where the traffic light controller is old, costs may be high due to changing the traffic light controller, but installing updated traffic lights is an investment that is justified in a city (Smith, Hemily & Ivanovic, 2005).

By using treatments such as queue jumping, TSP, and bus stop relocation, delays for public transportation are reduced (Cesme, 2014).

TSP-type preferential treatment for public transportation can work through three different control strategies (Transit Cooperative Research Program, 2016) (Smith, Hemily & Ivanovic, 2005):

Passive priority: This type of strategy does not require any public transport detection system, rather the traffic light phases are programmed based on knowledge based on public transport routes and passenger usage patterns. Passive priority works well in cities where public transportation schedules and other arrival times are very predictable, when the duration of a run, passenger boarding times, and bus departure times can be calculated. In this type of priority, we must not leave aside analyzing the flow of private vehicles parallel to public transport, to avoid unnecessary delays for private vehicles. Since there is good periodic control of traffic in general, adjustments can be made to the traffic light cycle.

Active priority: this strategy is the one that is accompanied by the detection of public transport and with this the activation of priority, this priority request modifies the phases of the traffic light in several ways. It has five different strategies, which are strategically chosen depending on several factors (National Cooperative Highway Research Program, 2015):

- Traffic signal cycle length
- Complexity of the phases
- Amount of traffic in parallel accesses
- Compliance with pedestrian phase times
- Compliance with the minimum times of the other phases
- Capacity of traffic light signal control centers

The main strategies when implementing a TSP correspond to green time extension, early green (or red suppression), phase insertion, sequence change and phase omission.

The main objective of the study is to evaluate the impacts of using the preferential treatments queue jump lane (Queue Jump) and bus phase priority (TSP or TSP) through a simulation model in some intersections of the Greater Metropolitan Area of San José Costa Rica.

Methodology

The intersection modeling study with TSP and queue jumping was carried out in Curridabat (one intersection) of San José, Costa Rica. The intersections that were selected have a high volume of buses. In addition, they have the necessary infrastructure (traffic light and space to generate an exclusive lane for buses) to develop preferential treatments, since the idea is to evaluate possible improvements at intersections with a minimum investment for the state.

The data to be taken at the intersection as part of the geometric survey must be summarized graphically in a site diagram, which has at least:

- Width of the lanes of all accesses and bus bays.
- Width and thickness of all sidewalks.
- Location of horizontal and vertical traffic signs.
- Location and height of traffic light heads.
- Existing distance to borders of neighboring properties.
- Distance between the intersection and the bus stops.
- Location of trees or vegetation present.
- Location of advertising signs

In addition to the geometric survey, during the field visit a survey of the traffic light phases was also carried out, in which, with the help of a stopwatch, the green, yellow and red times and the intervals of change of the phases were measured. In this part, it was necessary to document the way in which the movements are distributed within the traffic light phases.

Additionally, the vehicle volume was gauged by vehicle type at the selected intersections. From the gauged data, the peak hours and peak hour factors for each intersection were determined.

The peak hour factor must be calculated for each movement at each access, according to Equation (1) (Transportation Research Board, 2010):

$$FHP = \frac{V_T}{4 \cdot V_{m15}} \qquad (1)$$

Where VT is the hourly volume for the movement and Vm15 is the maximum volume of all quarter-hour intervals for the specific movement.

Once the previous steps have been completed, we proceed with the simulation of the current situation. with current volume data and without the use of TSP and queue jumping, with current traffic light times and with bus stops as they currently exist. Subsequently, the same simulation is performed for the 5- and 10-year scenarios, varying all input data, traffic light times, and the use of TSP and queue jumping.

With the data obtained from the simulation model, analysis graphs can be built, such as the delay versus the V/C ratio (volume to capacity) for buses. This can be done for the extension of the green time or the red time suppression. Graphs such as delay versus r/c ratio (red between cycle) for buses can also be analyzed. Finally, the results of the current situation are compared against those of the application of TSP and Queue Jump.

Results

Specifically, the analysis was carried out at the intersection of the national routes 2 and 221, in the canton of Curridabat. This is a point with a high flow of light vehicles and buses, mainly from east to west and vice versa. At this intersection, it can be said that there is enough space to build an additional lane that can be used as an exclusive approach lane for buses, and with this facilitate the passage of the bus when the traffic light is green for the eastern access, In addition to the construction of this lane, phase priority for buses can also be applied.

At the intersection, the traffic light phases were collected, the vehicle gauges were carried out, as shown in Figure 3. In addition, the approximate number of people passing through the intersection was estimated, this calculation was carried out by multiplying the number of vehicles by type by the average occupancy in each type of vehicle, finally obtaining the volumes of people, as shown in Figure 4.

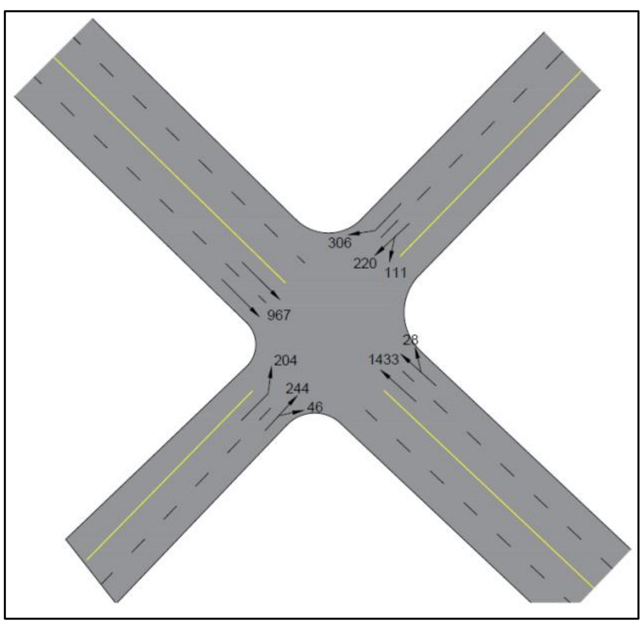

Figure 3. Detail of vehicle volumes for the morning peak hour at the intersection of national routes 2 and 221.
Note: National Route 2 is the one with four lanes in the diagram.

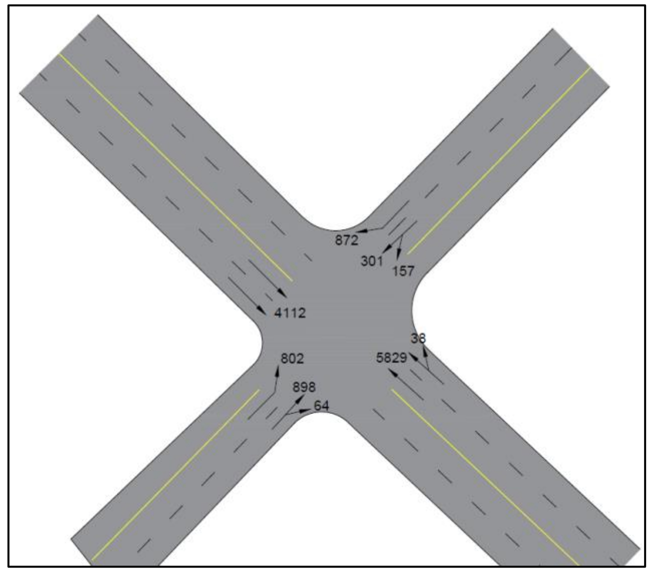

Figure 4. Detail of volumes of people for the morning peak hour at the intersection of national routes 2 and 221.
Note: National Route 2 is the one with four lanes in the diagram.

It is observed that the highest flow of people per hour is in the eastern access, for a total of 5,829 people traveling in the Cartago direction towards San José, which is why it can be thought that this access is the one that needs the most priority of passage in the case of the morning.

The way to implement the priority improvement in the traffic light phases with the Vissim program is by placing a detector in the access from which the bus comes. When the bus passes by the detector, if its phase is green, a signal is sent to the traffic light, which, through logic programmed in the VisVap extension of Vissim, modifies the phases in such a way that there is an extension of the green time of ten seconds of the phase involving the bus. If the bus approaches when its phase is red, the time of the other phases is reduced, generally by five seconds, so that the bus phase starts earlier than normal. A bus detector was also placed at the exit of the intersection, which has the function of deactivating the configuration of prioritized phases for buses, so that the traffic light times continue as usual.

The type of detector that would be supposed to implement these improvements is optical technology, similar to those used in "quickpass" type tolls. In this way the traffic light cycle would change to a variable type. This type of adaptive traffic light technology is quite efficient, as it makes the phases adapt to the traffic in real time and works very well for intersections where there are different behaviors throughout the day, thus avoiding unnecessary delays outside of traffic. peak hours. The placement of the two detectors at the intersection of national routes 2 and 221 (known as the Figueres crossing) can be seen in Figure 5, with Detector 1 being the access one and Detector 2 being the exit one.

The results that were collected in the simulations were delays and queue lengths. Delays were obtained separately for light vehicles, buses and all vehicles in general; With this, the improvement in delays for buses was seen, but also the increase in delays in private vehicles, to see its impact. These separate delays allow the delay per person to be calculated, based on the average occupancy by vehicle type.

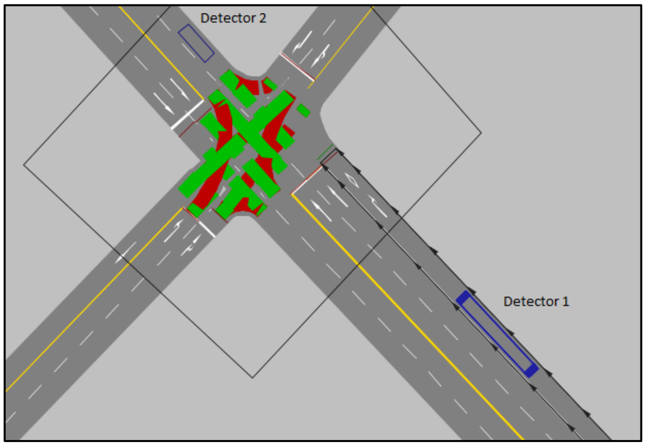

Figure 5. Location of the proposed detectors for the configuration of a traffic light with an exclusive phase for buses at the intersec-tion of national routes 2 and 221.
Note: National Route 2 is the one with 4 lanes in the diagram.

An image of the ongoing simulation of the intersection with the configuration proposed can be seen in Figure 6. The red bus is jumping the queue and passing through the intersection first than the other vehicles, as it has its exclusive access lane on the right that is proposed to be mandatory for all vehicles with the exception of buses that can continue directly at this point.

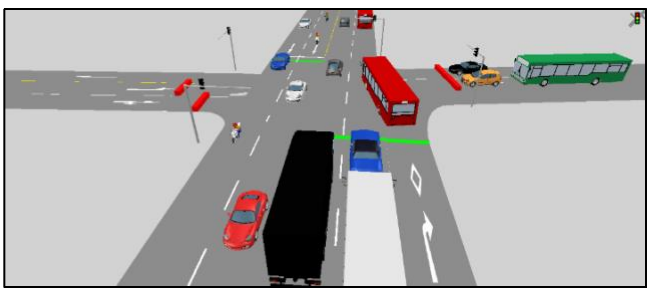

Figure 6. Simulation of the proposed configuration at the intersection of national routes 2 and 221.
Note: National Route 2 is the one with four lanes in the diagram.

Table 1. Current situation data

Access	Maneuver	Queue length (m)	Bus delay (s)	Vehicle delay (s)
North	Left turn	27,4	-	23
	Straight	27,4	-	40
	Right turn	27,4	65	36
South	Left turn	14,8	13	30
	Straight	14,8	48	33
	Right turn	14,8	-	12
East	Straight	53,9	35	32
	Right turn	53,9	-	31
West	Straight	31,5	37	27

Table 1 shows the data corresponding to the initial situation for the intersection of national routes 2 and 221. In this table, and with the indicators of Table 2 it can be seen that the delays for all accesses are relatively similar, so it can be said that the levels service is distributed in relation to vehicle delays. The highest delays observed are for buses on the north and south entrances; However, the number of buses for these accesses is very low.

Table 2. Current situation indicators.

Access	Maneuver	General delay (s)	Level of service
North	Left turn	24	C
	Straight	38	D
	Right turn	37	D
South	Left turn	29	C
	Straight	33	D
	Right turn	26	C
East	Straight	33	D
	Right turn	30	C
West	Straight	37	D

Table 3 shows the data for the intersection with the application of the preferential treatments TSP and tail jumping, as well as Table 4 shows the percentages of improvement for the vehicles independently and also for all the vehicles that passed through the intersection.

Table 3. Proposed situation data.

Access	Maneuver	Queue length (m)	Bus delay (s)	Vehicle delay (s)	General delay (s)
North	Left turn	32,6	-	32	37
	Straight	32,6	-	52	53
	Right turn	32,6	94	44	46
South	Left turn	63,4	37	40	40
	Straight	63,4	44	48	46
	Right turn	63,4	-	37	37
East	Straight	31,9	3	27	28
	Right turn	0,3	-	13	13
West	Straight	27,9	13	29	27

Table 4. Proposed situation indicators.

Access	Maneuver	Upgrade rate for bus delay (%)	Upgrade rate for vehicle delay (%)	Upgrade rate for general delay (%)	Level of service
North	Left turn	-	-38	-54	D
	Straight	-	-30	-40	E
	Right turn	-45	-22	-24	E
South	Left turn	-195	-32	-38	D
	Straight	10	-47	-38	E
	Right turn	-	-221	-40	D
East	Straight	90	14	15	C
	Right turn	-	57	55	B
West	Straight	66	-8	27	C

Table 5 shows the data obtained in the field, while Table 6 shows average delays per passenger and the number of people at the intersection for the initial condition.

Table 5. Current situation data at the National Roads 2 and 221 in-tersection

Access	Maneuver	Total delay of bus passengers (s)	Total delay of vehicle passengers (s)
North	Left turn	-	3 536
	Straight	-	10 584
	Right turn	29 070	14 834
South	Left turn	6 831	6 939
	Straight	28 232	8 750
	Right turn	-	667
East	Straight	139 968	45 542
	Right turn	-	1 071
West	Straight	107 078	29 009
Total		311 180	120 931

Table 6. Current situation indicators at the National Roads 2 and 221 intersection.

Access	Maneuver	Total delay of passengers (s)	Average delay per passenger (s)	Number of passengers
North	Left turn	3 536	23	152
	Straight	10 584	40	267
	Right turn	43 904	51	864
South	Left turn	13 770	18	769
	Straight	36 982	43	853
	Right turn	667	12	58
East	Straight	185 510	34	5 479
	Right turn	1 071	31	34
West	Straight	136 087	34	3 956
Total		432 111	-	12 432
		Average for intersection (s)	35	

Table 7 shows total delays by transport mode, while Table 8 shows the average delays per passenger at the intersection once the preferential treatments were applied in the simulation. There are percentages of improvement in the delay per person of up to 71%, this in the case of the east and west accesses, the opposite case is for the north and south accesses, in which the average delay per person increased by 113%.

Table 7. Proposed situation data at the National Roads 2 and 221 intersection

Access	Maneuver	Total delay of bus passengers (s)	Total delay of vehicle passengers (s)
North	Left turn	-	4 896
	Straight	-	13 796
	Right turn	42 102	18 042
South	Left turn	20 120	9 178
	Straight	25 547	12 843
	Right turn	-	2 141
East	Straight	13 973	39 255
	Right turn	-	458
West	Straight	36 058	31 355
Total		137 799	131 963

Table 8. Proposed situation indicators at the National Roads 2 and 221 intersection.

Access	Maneuver	Total delay of passengers (s)	Average delay per passenger (s)	Upgrade rate of delay per passenger (%)
North	Left turn	4 896	32	-38
	Straight	13 796	52	-30
	Right turn	60 144	70	-37
South	Left turn	29 299	38	-113
	Straight	38 390	45	-4
	Right turn	2 141	37	-221
East	Straight	53 227	10	71
	Right turn	458	13	57
West	Straight	67 412	17	50
Total		269 762	-	-
		Average for intersection (s)	22	38

Discussion

It can be seen in Table 3 and Table 4 that with the proposed situation, at the north and south accesses all delays increased, however, for the east and west accesses the delays improved up to 55% for all vehicles and up to 90% for the buses of the east access, these results are extremely positive, since these accesses mobilize a large number of passengers who go both by bus and in private vehicles.

Table 5 and Table 6 shows that delays are evenly distributed across all accesses, however, the number of passengers is not evenly distributed across all accesses. In the direct movement of the eastern access, a high flow of people passes, a total of 5,479 passengers at rush hour, these are divided between those who go by bus and those who go in private vehicles, but passengers who go on buses experience a much higher total delay.

It can be seen in Table 8 that the total average at the intersection of delay per passenger improved by 38% after applying preferential treatments, this behavior occurs since more passengers pass through the east and west accesses.

Savings from reduced travel time can be quantified in a simplified way, for example, by multiplying the amount of time saved by the value of the minimum wage hour considered and by the fuel savings generated by the proposed intervention. The costs of implementing the preferential treatments studied are mainly composed of the cost of the modifications in the traffic light controller, the implementation of the bus detectors and the communication devices with the control center and the construction of the lane for bus queue jumping. The annual savings were estimated at 61,500 dollars and the costs of implementing the measure at 29,300 dollars, so the recovery of the investment can be presented in approximately eight months. The results from a sensitivity analysis, where the costs and benefits were changed in a range between – 25 % and + 25 % give a recovery of the investment for periods between five and fourteen months.

Although, improved a transport mode shift is expected due to improvements in transit time, the current analysis does not consider possible mode shifts in the models. The effects on the surrounding road network were not considered in this study.

The implementation of detectors requires an upgrade of the traffic signal controller. Also, it is important to consider the lifetime cost (Federal Highway Administration, 2006) therefore, preventive maintenance and regular inspections are necessary to ensure a correct operation of the traffic signal (NZ Transport Agency, 2013).

Proper timing and configuration of detectors is required to establish signal times that allow proper braking distances and a proper transit operation; however, the bus priority lane proposed is not physically separated from traffic, and to prevent private cars to use a lane and a traffic phase dedicated to transit is recommended to use police enforcement regularly. Otherwise, it is recommended to consider technologies different that traditional sensors (video, loops, ultrasonic, etc.) like the use of wayside antennas that reads vehicle-mounted tags (Intelligent Transportation Systems Joint Program, 2013) or equip the transit units with automatic vehicle location systems (AVL) or an intelligent computational devices like vehicle logic units (VLU) (Shalaby, Lee, Greenough, Hung, Bowie, 2006) that allow the traffic signal controller implement the TSP strategy accordingly to the information gathered from the buses.

Conclusions

It was possible to evaluate the impacts of using the preferential treatments Queue Jump and Phase Priority for the bus (TSP or PFA in spanish) through a simulation model at an intersection in the Great Metropolitan Area of Costa Rica.

The delays for people who use bus are reduced with the proposed intervention by 44%, from 311 thousand seconds to 138 thousand seconds; while delays for people traveling by car increased by 9%, from 121 thousand seconds to 132 thousand seconds. This generates an overall reduction in delays at the intersection, a situation that is not reflected when performing the traditional capacity analysis that does not consider the number of people only the number of vehicles. According to the results obtained, the proposed intervention generates a 38% reduction in average delays per person using the intersection.

The decisions made at the state and private level for transportation engineering must be oriented to the needs of passengers regardless of the type of transportation and not be centralized in only moving vehicles without analyzing the number of passengers inside each of the vehicles.

It is also recommended that buses be separated from other vehicles, within the usual classification carried out by the Dirección General de Ingeniería de Tránsito (Traffic Enginering Division) in its ordinary counts.

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