# POLITECNICO DI TORINO

Master of science in Civil Engineer

Thesis for master's degree

# Traffic control and simulation for PT priority in urban networks: a case study of BRT

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# 1. Introduction

As the population in the urban areas rise, the mobility problems rise with it, as the demand increase at a considerable high rate and, on the other hand, the offer has a much slower pace in order to increase its capacity. This is due to the complex operations that includes the construction or enhance of transport infrastructure. Nowadays, in the urban areas, one of the proposed ways to control the demand on the road network and to offer to all the citizens a connection to the growing city, was the investment in the mass public transportation and the implementation of new strategies to enhance the service provided, often supported by the telecommunication technologies.

Some of the earliest records of this trends on mass public transportation are the omnibus in Paris or the ferry services at New York. These solutions have been substantially different considering their vehicles, but they have in common their final objective: offer a regular service for a continuously growing population, between their living place and their daily activities. These examples show that these measures can be different depending on various factors, among the most relevant the available capital and the geography of the area. The most typical kinds of systems used in the modern era are the Railway based (tram, subway) and roadway base (bus rapid transit, bus).

Of the most interesting examples mentioned above is the Bus Rapid Transit, as in the recent years it has been one of the most applied solutions, especially in Latin America and Asia. The economy in these regions take the advantages of this system, as a more cost-benefit alternative, in comparison to a more expensive urban rail system. Also, it is a more flexible system because it is a rubber-tiered based system.

To improve the operational regularity and punctuality of Public Transport, researchers and transit agencies have developed advance transit systems during the past decades. Particularly, the Transit Signal Priority (TSP) control has gain recognition as one of the most promising ways to reduce bus travel time at local arterials. TSP control is an operational strategy that facilitates the movement of transit vehicles, through signalized intersections, supported in the infrastructure use for the Intelligent Transport Systems.

It is naive to assume, in a first approach, that any mass public transportation solution with any kind of TSP will represent an enhancement of the service provided, especially neglecting the effects the non-prioritized traffic may undergo. The effect of TSP implementation varies depending on the vehicles prioritized, the configuration of the intersection (geometry and control plan) and the traffic in the intersection.

In a real-life situation, before an indiscriminate decision of which TSP strategy to implement upon a PT system, is necessary to model and analyse the specific result of the alternative considered. The aim of this thesis is to perform this procedure with real information.

## 2. Traffic control for Public Transport

As stated before, the objective of this work is to analyse the effects the Transit Signal Priority strategies may have in a particular Public Transport System, specifically the one used in the city of Santiago De Cali, Colombia, corresponding to a Bus Rapid Transit system.

### 2.1. Bus Rapid Transit (BRT) system

The BRT system was conceived as a solution for the constantly growing cities in the developing countries. It offers a flexible service that accommodates easily to the needs of each specific location, thanks to the nature of the rubber-tyre system is easy to offer a fast service along a dedicated corridor and also account the accessibility to the system using feeder vehicles in charge of the collection and distribution of the passengers outside the bus-way lanes. The idea is presented as a mimic of the high capacity, high performance urban rail systems often referred as a "surface metro" (Cervero, 2013).

#### 2.1.1. Classification

Since the conception of the BRT system the services has been classified in "High-end" and "Low-end" in function of the elements included in the system to allow the rapid transit of the users. In 2013 was adopted the classification according to Olympic medals (gold, silver and bronze ) this tiers are stablished following the score given to the system, evaluated as describe in the BRT standard (ITDP et al., 2013), accounting for the basics of a BRT, the service planning, the infrastructure, the station design, the quality of service and the access to the service. Although this recent classification is more specific and useful to compare different BRT systems, the firsts classification is more intuitive.

*High-end (Gold tier)*

- Exclusive transit lanes.
- Intersection treatments.
- Stations as enhance shelters and temperature-controlled transit centres.
- High frequency service; integrated local and express services.
- Off-vehicle collection; multi door loading.
- Intensive use of technology (Automatic Vehicle Location; vehicle docking).

*Low-end (silver and bronze tier)*

It includes all deviations from the above characteristics.

- Service along mixed traffic.
- No stations but stops, may include shelter, seating, and passenger information.
- Traditional fare media.
- Limited technology application.

### 2.1.2. BRT characteristics

*Operating speed*

One of the most important characteristic of the service is the operating speed, this because it gives a notion of the quality of the service and also is useful to compare the BRT, other public transport systems and private means in terms of the time required to perform a trip. The operating speed varies in function of the infrastructure with the buses interacts (Hidalgo & Graftieaux, 2008), the maximum operational speeds (80-60 km/h) are present in systems with not only dedicated lanes but also grade separation for the intersections.

The absence of any form of grade separation limits the operating speed to about the 20 km/h; these values can be improved by adding to the system the high-end characteristics exposed previously. Off-boar electronic payment, multidoor boarding, level boarding and priority protocols, the last one is interesting as it can be employed in systems already consolidated wit out an important intervention on the infrastructure (Hensher & Golob, 2008).

*Infrastructure and running ways*

The operational speed in the system depends significantly in the ease with which the vehicles can provide the service. The obstacles, interruptions and interactions with other vehicles that affect the performance of the service varies according to the lane configuration in the system. The BRT services are present in four lane configurations:

A. mixed traffic
B. dedicated shoulder lanes
C. dedicated median lanes
D. exclusive bus lanes (busways)

The last 2 configurations use certain highlights in the urban layout such as railroad alignments, arterial medians or freeways, tunnels and elevated infrastructures, to minimize the interruptions in the flow of the service.

*Stations*

The stations for the BRT systems are a crucial part in order to reduce the amount of time the bus spend at each alighting and boarding cycle and their location affect the accessibility to the system. The layouts of the stations vary from system to system as there are architectural and climatic conditions that are unique for every case, in general, it must provide services as disable access, a resting zone and protection from rain and sunrays. Additional services, not of the structure itself, are passenger information real-time dynamic (arriving time) and static (e.g. maps, schedules).

Most of the busways are accommodated in medias of an arterial road (BRTdata, 2020b), the access to the stations is an important matter as pedestrians crossing busy roads is not a safety condition, usually this problem is managed by skyways. Another point in the location of the station is referred to the distance between stations, the BRT standard (ITDP et al., 2013) recommend an spacing of approx. 1.5 km; this reduces the amount of time the users required to reach their final destination outside the system and does not compromise the bus speed, by forcing continuous stops.

#### *Vehicles*

BRT fleet varies significantly between systems and inside a same system, this because the service requires different operational modes in order to offer an integral service, especially for the gold tier BRT systems. In general, the global trend is to use articulated high-floor buses in the dedicated lanes, usually with a left boarding; whenever the system is expected to go outside the dedicate lanes, non-articulated low-floor buses are selected in order to facilitate the boarding at sidewalk level.

Nowadays many manufactures are producing BRT buses, such as Volvo, Mercedes and Scania and according with the modern conception of environmental responsibility permeating all the industries, more and more of their vehicles run on clean fuels that meet the Euro III and Euro IV emission standard (Cervero, 2013) as Compressed Natural Gas (CNG), Liquated Natural Gas (LNG) and clean diesel.

## 2.2. Transit Signal Priority (TSP)

The Transit Signal Priority is a set of protocol followed by the entities in charge on the mobility in a city in order to facilitate the and improve the movement of transit vehicles, either public transport or other private means, usually applied on the public service as a way to increase its appealing against other modes by making it more reliable, faster and cost effective

As the name suggest, the protocols to implement consist in the manipulation of the control characteristics in intersections, usually the variations are in terms of the time given to a certain manoeuvre, changing the duration or interrupting a certain phase.

### 2.2.1. Architecture for the TSP

The TPS protocols require the recollection of data, in some cases in real time, due to this is necessary to implement physical devices and software to manage the information. This architecture is also the one use in the Intelligent Transport Systems (ITS) in its physical part but adds different algorithms and data management focused in the priority problem. The whole system can be divided in 4 systems (Gomez Londoño et al., 2014; Smith et al., 2005):

A. Vehicle detection.
B. Priority Request Generator (PRG).
C. Priority Request Server (PRS).
D. TSP control.

The procedure followed in the TSP protocols (see Figure 1) starts when the detector receives a signal indicating that a vehicle is approaching the intersection. Then the signal is emitted to the traffic manager center, that also receives information from the public transport entity (schedules, vehicle position, occupancy), where the Priority Request Generator (PRG) filter the needs of priority. In case the priority is granted the evaluation of the action to take is calculated by the Priority Request Server (PRS), and the instructions for the priority re transmitted to the controller in the intersection that varies the current control plan.

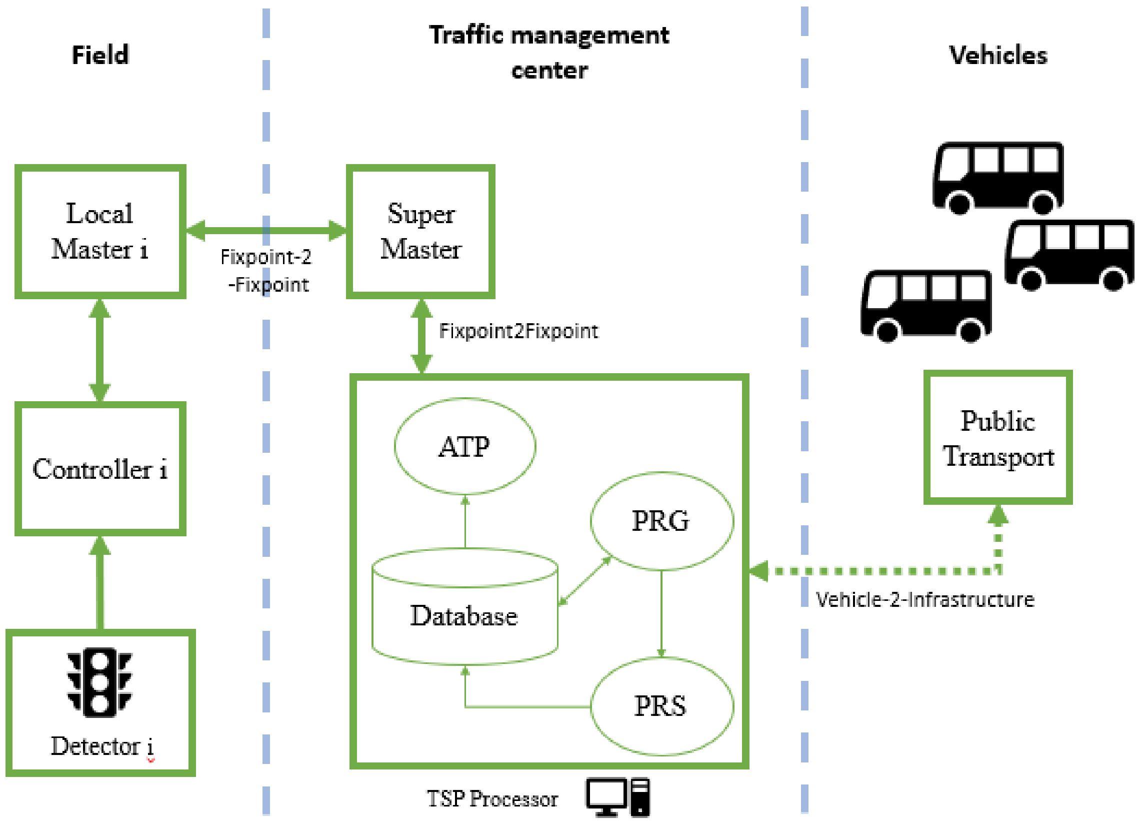



*Figure 1. Typical architecture of TSP (Smith et al., 2005).*

### 2.2.2. TSP strategies

The TSP can be implemented in 3 different approaches: passive, active and adaptative.

*Passive priority*

The passive priority strategies, differs significantly from the active and adaptative strategies as it does not rely in the exitance of the devices clarified in the previous section, meaning there is no detection  or priority request, the strategy is established in advance  on the bas is of  the transit route and ridership patterns. This form of TSP is efficient  when the transit operation is predictable, accounting to passage load, schedule and dwell time.

The benefits of this passive priority reflects on the transit vehicles, but the other traffic can undergo adverse effects such as increase in delays and stops, generating more frustration on those subjects; it possible to account also the parallel traffic to the TSP manoeuvres in the transit signal progression. One of the simplest passive strategies, that include all traffic in the intersection, is to minimize the persons delay, instead of vehicle delay, that is typically employ (Smith et al., 2005).

*Active priority*

The active priority strategies are a set of specific algorithms that change the normal configuration of the control plan after the priority request of a specific vehicle , the aim is to reduce or remove the delay of the approximating vehicle. All these strategies deepen on the estimation of the arrival time of the concerning vehicle to the intersection and in which phase of the pre-established cycle the estimated arrival time window is located.

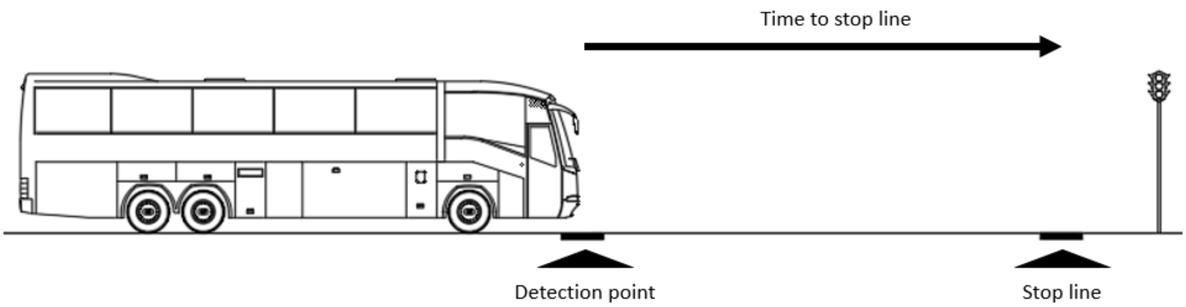



*Figure 2. scheme of active propriety consideration.*

The algorithms included in this classification are the following:

- Green Extension: it comprehends extension of the green time, when the TSP equipped vehicle is detected, and its corresponding signal group is on green; this is an effective algorithm as does not need an additional clearance time to be added to the cycle.
- Early Green: also known as red truncation, the procedure is to shortens the green time in the previous phase, in order to return to green earlier than the program.
- Actuated Transit phases: these protocols consist on the insertion of a new phase in the normal cycle of the intersection, to accommodate a specific manoeuvre, an example of this can be a left turn phase, with a low demand.

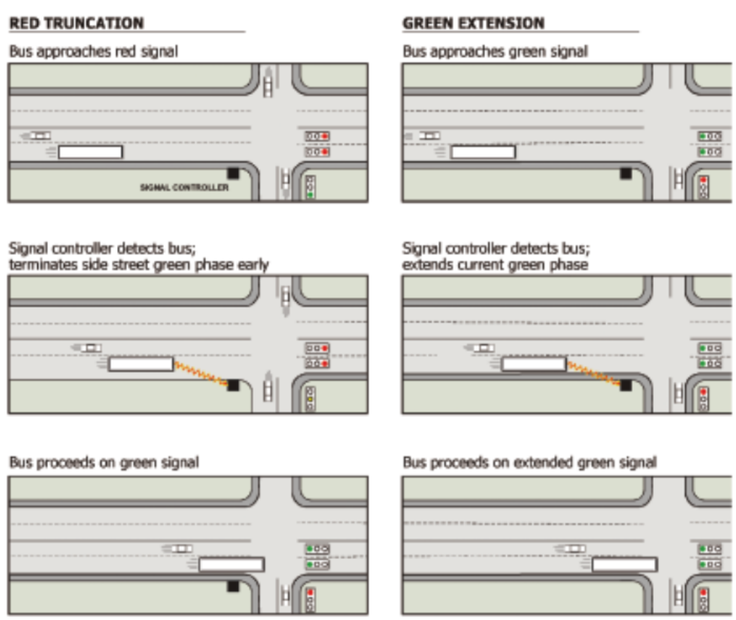



*Figure 3. active signal priority example (Smith et al., 2005)*

*Real-Time priority*

These are the most sophisticated and complex protocols, for this reason are not commonly used. There are two subcategories inside this group, TSP with Adaptative Signal Control Systems and Adaptative Signal Priority, although both consider the algorithms of the active priority there is a difference between the two.

- TSP with Adaptative Signal Control System: this system gives the priority to the transit vehicles while optimizing the cycle with the existing traffic conditions. The optimization therefore requires the monitoring of all approaches to the intersection and a performance criterion, such as person delay, transit delay, vehicle delay or a combination of them.
- Adaptative Signal Priority: the strategy is based o n a compensation between the delays of the transit vehicles and the traffic. The aim is to provide a smooth adjustment to signal times, adapting the prevailing traffic conditions and the behaviour of the prioritized vehicle.

### 2.2.3. Evaluation of TSP strategies

As seen till this point, there are several strategies that can be implemented in order to have prioritisation of certain vehicles in a network. In many cases they can be implemented simultaneously, so is necessary to evaluate what is the better suited for the specific case . The concept of Measures of Effectiveness (MoE), these are derivate from the objectives of the project, can be useful to determine if those goals have been reached or in which measure are fulfilled. The typical MoEs use in the field are (Smith et al., 2005) :

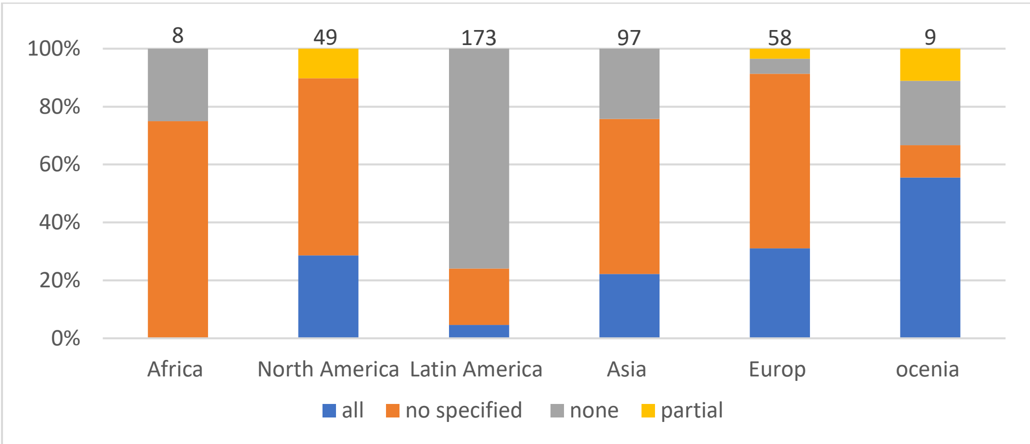
- Reduced travel time of public transport
- Reduced stops and signal delays for public transport
- Fuel savings
- Air quality benefits
- Reduced queue on main line
- Minimal delay for other vehicles
- Reduced accidents

The private traffic can be impacted by the TSP, so define the goal of the strategy is important to avoid overall negative effects .

## 2.3. TSP applied in BRT systems

The use of technologies is a key component for the high-end (gold tier) BRT system, therefore the implementation of the Intelligent Transport System (ITS) concept have a considerable impact , integrating for instance Intelligent Vehicle Initiatives technology, fare collection, passenger information and Vehicle Prioritization. This last one is important as it goes along the original objective in the concept of a BRT system, provide a service similar in capacity and performance of a rail system at a much affordable price, as it is a way of deal with the problem of the interruptions due to intersections avoiding the expenses linked to the procedures in order to give a grade separation (Kulyk & Hardy, n.d.).

With the priority, not only is obtained a reduction in the Bus delay, but also an enhance of the service in terms of a more constant headway and a more reliable schedule. These are important factors that helps the system making it more appealing when a user is deciding which mode use, the ultimate goal pursued by the governments and its mobility policies (Zhu, 2010).




*Graph 1. use of TSP in BRT, world overview (BRTdata, 2020a).*

The BRTdata web site (BRTdata, 2020a) offer an over view of the implementation of TSP in BRT systems around the world; as is shown in the Graph 1,that discretise the coverture of the BRT network than have any kind of TSP (all, partial, none) around the world, the TSP systems are used more frequently in the developed regions of the world, although, they are no the mayor cluster of BRT systems, this being Latin America. In general, only about 20% of the BRT systems counts with some degree of TSP.

### 2.4. Traffic control simulation

At times, it is necessary to perform a digital representation of a system utilizing a simulation model. This approach may be required for three main reasons. First, the system under consideration may be so complex that it is not possible to model it in terms of a set of mathematical equations for which analytic solutions can be derived which predict system behaviour. Second, even though mathematical modelling of the system may be possible, it may not be possible to obtain an analytic solution to the problem, and thus a simulation may be necessary to predict future behaviour of the system. Third, in many cases, it is either physically impossible or economically unfeasible to perform experimental testing and development (Needler, N.D).

These considerations are applicable to the case of new traffic control implementation issue, where the multiple options of configurations for infrastructure and control require digital simulations to compare available alternatives. For example, planners needing to make changes to the road network, it is necessary to forecast the effects on traffic flow; or traffic light sequencing and timing, and placement of road network objects (such as parking bays, bus stops, and access lanes), all have a direct influence on traffic flow and capacity.

As the model is a representation of a real system, it has to count with the relevant components of the system, represented as entities interacting between them as in the real case. The traffic control simulation accounts for the several types of entities, such as vehicles or pedestrians, and infrastructure (roads, intersections and other physical constrains). Also, the control entities are simulated to establish the rules followed to a certain manoeuvre in an intersection.

The simulations can be divided in:

- Microscopic
- Mesoscopic
- Macroscopic
- Hybrid (combining characteristic of the mentioned above)

The difference between the type of models, often related to the size of the area considered for the application, resides in the level of details to modify the state of the entities on the simulation.

The approach of microsimulation is time-based, referring that the new estate of the entities is determined considering a fix time step and the variables assigned to the individual entities (position, velocity, maximum acceleration/deceleration, etc). Mesosimulations are event-based, this indicates that, according to the variable set of the entities the configuration of the model is changed to a new one in a non-fixed time step determined by the following event in the model, for example a vehicle entering or leaving a section or node. Macrosimulations are flow based, there are no individual entities, instead they are aggregated to flows which are assigned to the network to estimate load and journey time of links.

For this thesis the software used was the Aimsun Next software, that provides many tools necessary to perform an analysis of a transport modelling project, importing and editing a transport network; estimating and refining the transport demand; simulating transport movement in static macroscopic assignments or in dynamic mesoscopic, microscopic or hybrid simulation with route paths derived by simple “All or Nothing” methods to complex Dynamic User Equilibrium algorithms. During experiments performed in this study the road network, transit and traffic was modelled using the microscopic approach to compare different control alternatives and estimate relevant traffic indicators.

## 3. Characterization of the case study

### 3.1. Location of the study area

The study is focused on the BRT system in the city of Santiago de Cali, Colombia. This city near the equator has a population of 2,471,474 habitants and an area of 564 km$^2$, is a medium size city, compared with others in the country. Its main public transport system is the MIO (Masivo Integrado de Occidente ), which is a high-end BRT that have been operating since 2009.

The corridor dedicated to the MIO goes along the North-South axis of the city, but the study case proposed in this thesis is limited to the southern part of the network, specifically the corridor between the "Capri" station and "Univerisidades ". This selection is because this is a critical part of the network that connect the university cluster of the city. The section contains 4 intersections in which the public transport and private means interact, allowing the evaluation of the diverse priority protocols being implemented in concatenated intersections.

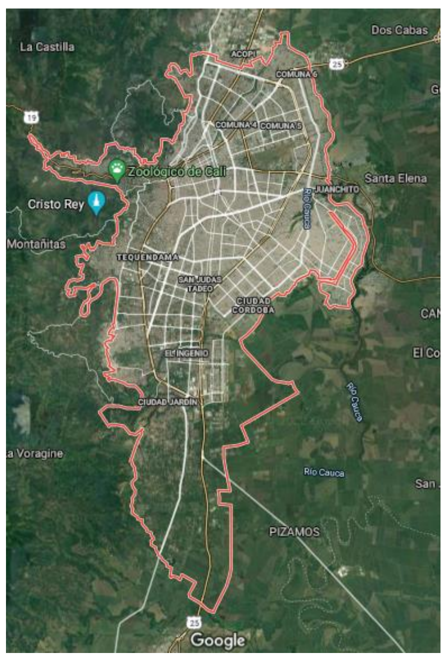



*Figure 4. City of Cali (Google Maps, 2020)*

### 3.2. Road network

The evaluated corridor corresponds to a part of "calle 5" and "Carrera 100", show in the Figure 5 (In yellow "calle 5" and in red "Carrera 100"), limited in the extremes by the "Carrera 80" and the "calle 16". This section has 4 intersections that interrupts the flow of the BRT dedicated lanes, the intersections correspond to the "carreara 80", "Carrera 94", "calle 13" and "calle 16"; all the mentioned intersections are at grade intersections, in which the control for the right of the different manoeuvres is dictated by traffic lights.

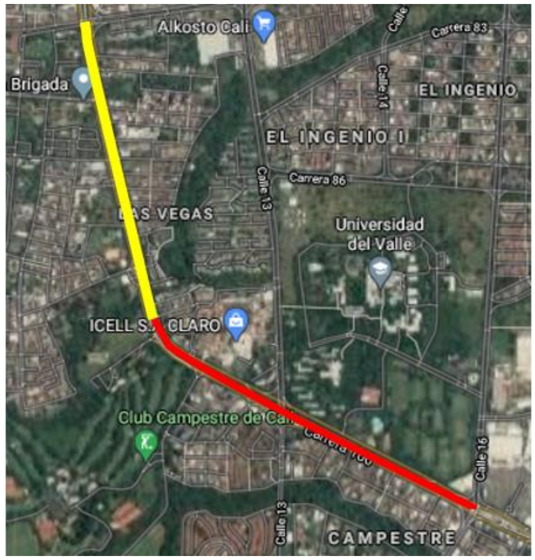



*Figure 5. Selected corridor for the study (Google Maps, 2020)*

As for  the geometry of the corridor of interest,  the road has from 2 to 5 lanes per direction, each one with 3 meter of width, it counts with a physical separation of the streams in the form of a arborized median that varies from its width from 20 meters up to 60 meters; in this median are located the BRT dedicated lanes, 1 to 2 lanes per direction.

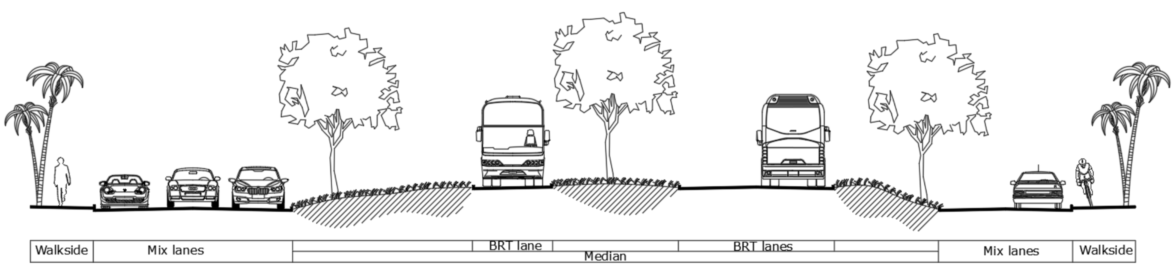



*Figure 6. Scheme of the typical cross section in the studied corridor.*

The principal geometric and operational characteristics of the section are contained in the Table 1.

*Table 1. geometric characteristics of the studied corridor.*

| **Total length [km]** | **3.3** |
|---|---|
| Mix traffic lane width [m] | 3.0 |
| BRT lane width [m] | 3.5 |
| Maximum velocity [km/h] | 60.0 |

To build the road network in the Aimsun software, a software that allows the simulation at various levels of the interactions different type of users (pedestrians, cars, bicycles, buses, etc) on a specific road network, was proceed with the data offered in the Open Street Map catalogue, this information is recollected by the diverse entities employing aerial images, GPS devices, cartographic material and other free data source, it offers not only the geometry of the road but also contains metadata of it (typology, velocity, name); the imported data is the basis to start the modelling of the network, that must be depurated and corrected.

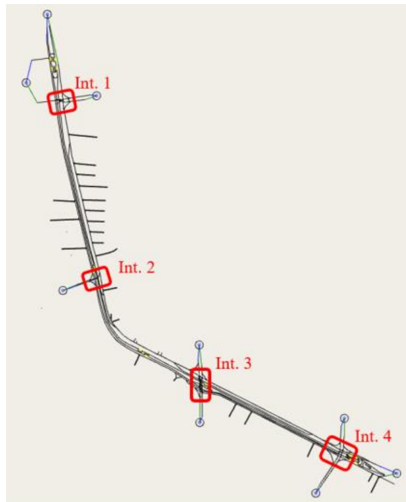



*Figure 7. Model of the road network on Aimsun software.*

*Intersection 1, "calle 5" with "Carrera 80"*

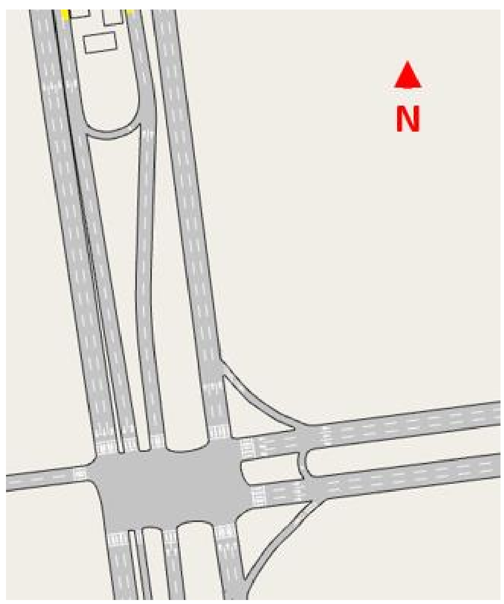



*Figure 8. modelled intersection 1.*

The "calle 5" in this intersection counts with a total of 3 lanes per direction along the North-South axis. The "carrera 80", along the East-West axis, presents an access and exit of 3 lanes each eastwards and a two-lanes exit to the west . In this intersection the TP only lanes are along the North- South axis, one per direction located in the median, except for the north exit with 2 lanes. I t has a length of 56 m and a width of 30 m; and counts with protected right turns form east to north (9(4)) and south to east (9(2)).

*a) North face*

*b) South face*

*c) West face*

*d) East face*

*Figure 9. images of the intersection 1 (Google Street View, 2020).*

*Intersection 2, "calle 5" with "Carrera 94"*

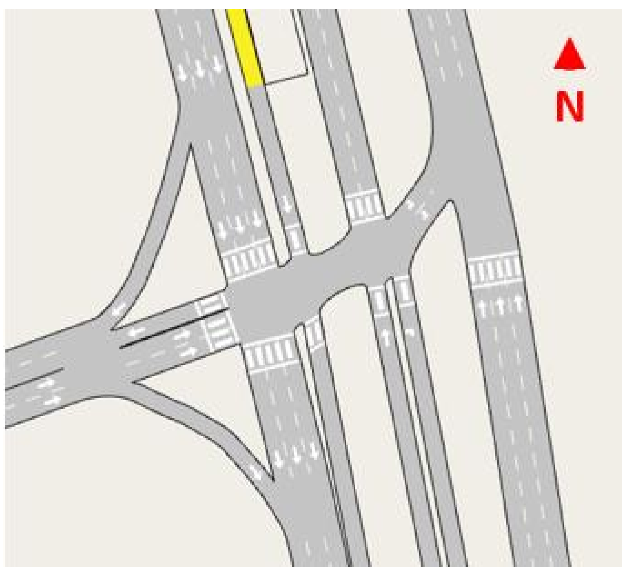



*Figure 10. modelled intersection 2.*

The "calle 5" in this intersection counts with a total of 3 lanes per direction along the North-South axis. The "carrera 94", along the East-West axis, presents an accesses with 2 lanes and an exits with 1 lane westwards. It has a length 66 m of and a width of 20 m; in addition, it counts with the protected right turns form north to west (9(1)) and east to south (9(3)). In this intersection the TP only lanes are along the North- South axis.

*a) North face*

*b) South face*

*c) West face*

*Figure 11. images of the intersection 2 (Google Street View, 2020).*

### *Intersection 3, “Carrera 100” with “calle 13”*

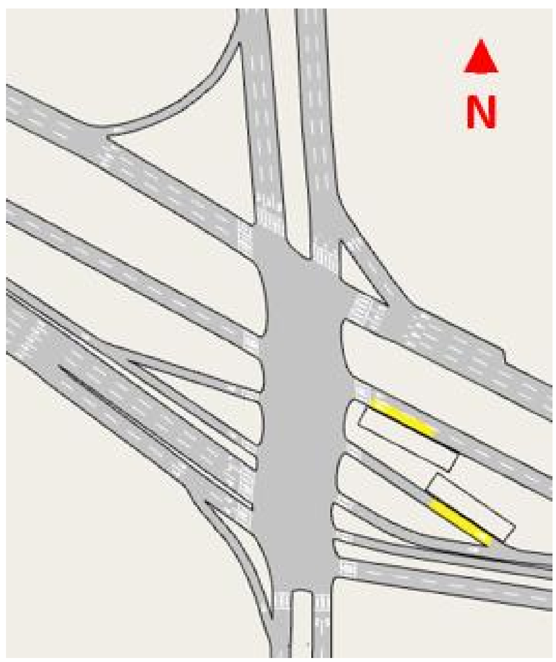



*Figure 12. modelled intersection 3.*

The “calle 13” along the North- South axis, in its northwards counts with an access and exit with 3 lanes each, southwards the access and exit are of 2 lane both. The “carrera 100”, along the East-West axis, has an access from the west with a total of 5 lanes, but to exiting to west 3, the eastward access is formed by 3 lanes, in the exit to east are 2. This intersection has a length 100 m of and a width of 35 m; it counts with the protected right turns form east to north (9(4)), west to south (9(3)) and north to west (9(1)). The TP only lanes are along the East-West axis, with 2 lanes by cense.

*a) North face*

*b) South face*

*c) West face*

*d) East face*

*Figure 13. images of the intersection 3 (Google Street View, 2020).*

*Intersection 4, "Carrera 100" with "calle 16"*

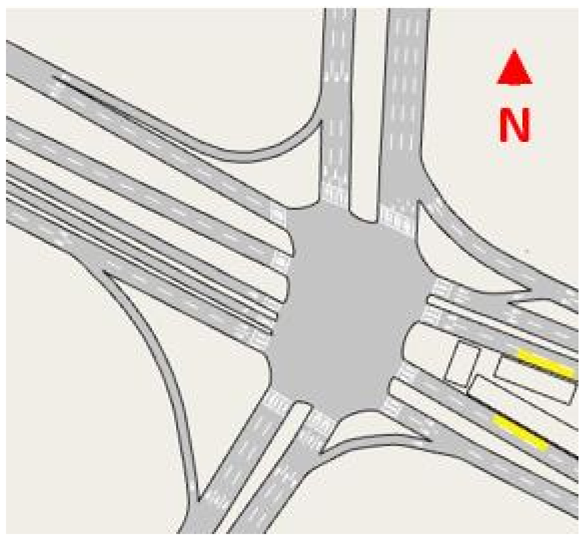



*Figure 14. modelled intersection 4.*

The "calle 16" along the North- South axis, counts with 3 lanes per direction entering and exiting the intersection. The "carrera 100", along the East-West axis, the intersection counts with 2 lanes in al l entrances and exits of the intersection, apart from the westward access that add one more lane dedicated exclusively to the left turn. The intersection has a length 50 m of and a width of 40 m , it counts with the protected right turns form east to north (9(4)), west to south (9(3)), south to east (9(2)) and north to west (9(1)). In this intersection the TP only lanes are along the East-West axis.

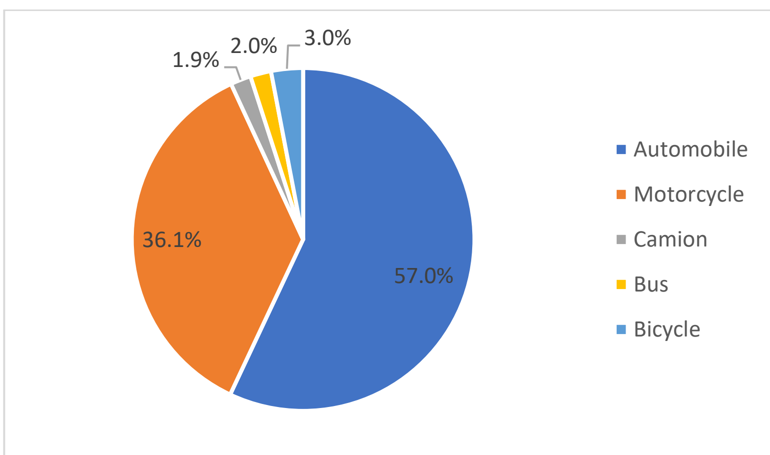
a) North face b) South face

c) West face d) East face

*Figure 15. images of the intersection 4 (Google Street View, 2020).*

## 3.3. Traffic demand

With respect to the private means included in the study, was decided to consider two different types of vehicles, car and motorcycle; this assumption is supported in the traffic restrictions and particular observations of the area, concluding that the load of vehicles such as trucks, buses or vehicles with trailers is minimum, having little impact in the overall behaviour of the traffic. The composition of the traffic in the study area is described in the Graph 2 (Secretaria de movilidad de Cali, 2019)




*Graph 2. Traffic composition in the study area.*

In the simulation model the demand of vehicles is included by the Origin-Destination matrix, constructed based on the information provide by several governmental institutions of the city. The mentioned information and the procedure in order to obtain the O/D matrix for this study are describe in the following sections.

### 3.3.1. Mobility information

The information required to obtain the O/D matrix to use in the model is the daily trip generation and attraction. This data was extracted from the Household mobility survey (Steer Davies Gleave & Centro Nacional de Consulturia, 2015) made in the city on 2015.

*Table 2. Daily trip information in 2015.*

| **Commune** | **Population** | **Daily trips [trips/ day]** | |
|---|---|---|---|
| | | Generated | attracted |
| **1** | 88432 | 17608 | 11250 |
| **2** | 114651 | 139042 | 55175 |
| **3** | 46400 | 62321 | 68364 |
| **4** | 53369 | 67034 | 49796 |
| **5** | 112089 | 50593 | 61429 |
| **6** | 189837 | 45824 | 44551 |
| **7** | 71334 | 33619 | 45688 |
| **8** | 102388 | 78675 | 62806 |
| **9** | 44994 | 31161 | 32333 |
| **10** | 110854 | 63940 | 58311 |
| **11** | 107339 | 103612 | 63382 |
| **12** | 66881 | 22321 | 20493 |
| **13** | 177641 | 53591 | 88700 |
| **14** | 172696 | 47613 | 42423 |
| **15** | 159369 | 41510 | 35733 |
| **16** | 107170 | 28560 | 33996 |
| **17** | 139665 | 172237 | 86350 |
| **18** | 131453 | 60010 | 51665 |
| **19** | 112947 | 196276 | 65678 |
| **20** | 69331 | 23756 | 18591 |
| **21** | 112336 | 44828 | 10971 |
| **22** | 11160 | 30237 | 33779 |

As seen in the Table 2 the data are aggregated at a commune level (communes distribution depicted in the Figure 16), each commune is composed of several neighbourhoods.

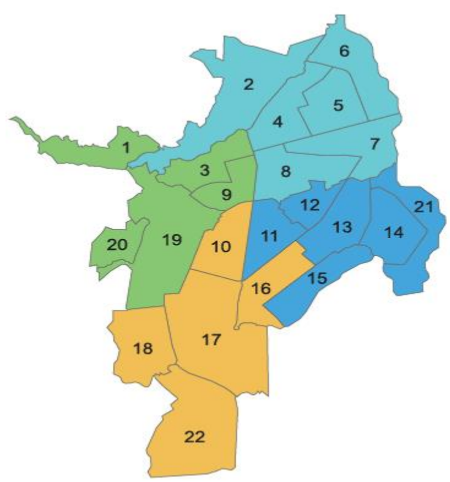



*Figure 16. Commune distribution in the city*

As this information is from 2015 to bring it to 2019, the year set form the model, the actualization process requires information on the increment of the population in the different communes, the city council offers this information (Alcaldia de Cali, 2019a).

*Table 3. City population*

| Commune | Habitants | | | | |
|---|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 | 2019 |
| **1** | 88432 | 91352 | 94335 | 97382 | 100497 |
| **2** | 114651 | 116586 | 118561 | 120577 | 122637 |
| **3** | 46400 | 46517 | 46636 | 46759 | 46887 |
| **4** | 53369 | 53052 | 52740 | 52433 | 52132 |
| **5** | 112089 | 113010 | 113927 | 114842 | 115759 |
| **6** | 189837 | 191529 | 193214 | 194894 | 196573 |
| **7** | 71334 | 70819 | 70305 | 69793 | 69285 |
| **8** | 102388 | 102597 | 102812 | 103034 | 103266 |
| **9** | 44994 | 44645 | 44303 | 43970 | 43646 |
| **10** | 110854 | 111296 | 111741 | 112190 | 112645 |
| **11** | 107339 | 107940 | 108542 | 109146 | 109754 |
| **12** | 66881 | 66712 | 66545 | 66381 | 66221 |
| **13** | 177641 | 178052 | 178475 | 178909 | 179360 |
| **14** | 172696 | 174441 | 176160 | 177856 | 179535 |
| **15** | 159369 | 162439 | 165492 | 168529 | 171556 |
| **16** | 107170 | 108183 | 109191 | 110195 | 111198 |
| **17** | 139665 | 142914 | 146183 | 149475 | 152793 |
| **18** | 131453 | 135199 | 138999 | 142856 | 146773 |
| **19** | 112947 | 113898 | 114849 | 115803 | 116761 |
| **20** | 69331 | 69677 | 70025 | 70375 | 70728 |
| **21** | 112336 | 114270 | 116148 | 117976 | 119763 |
| **22** | 11160 | 11453 | 11748 | 12044 | 12343 |
| **Others** | 30876 | 31675 | 32461 | 33236 | 34002 |

The updated information of generated and attracted trips, as in this study the model considers a limited portion of the real road network of the city, is not possible to use as it is. The procedure to follow is to reduce the aggregation level from the communes to the neighbourhoods compounding each commune, to have information about the trip generation and attraction in the vicinity of the access in the modelled road network, thus obtaining the Origin-Destination Matrix to Implement in the model.

The assignation of the trips generated or attracted by a neighbourhood will be perform following the cadastral information (Alcaldia de Cali, 2019b) of each commune, that specify the amount of commercial lots, industrial lots, institutional lots and habitational lots; contained in the Table 4, Table 5 and Table 6, as “habitational” and “interest /commerce”.

The details and results of the reduction in the aggregation level procedure are discussed in the following section.

*Table 4. Composition Commune 22.*

| Neighbourhood | Distribution of listed state [%] | |
|---|---|---|
| | **Habitational** | **Interest / Commerce** |
| Parcelaciones De Pance | 24.6 | 5.3 |
| Urb. Rio Lili | 13.5 | 28.9 |
| Urb. Ciudad Jardin | 56.3 | 63.4 |
| Club Campestre | 1.1 | 0.4 |
| Ciudad Campestre | 4.5 | 1.9 |

*Table 5.Composition Commune 18.*

| Neighbourhood | Distribution of listed state [%] | |
|---|---|---|
| | **Habitational** | **Interest / Commerce** |
| Polvorines | 4.8 | 6.0 |
| Alto Jordan | 2.3 | 7.3 |
| Napoles | 4.5 | 2.9 |
| Alto De Los Chorros | 2.0 | 6.8 |
| El Jordan | 4.5 | 5.5 |
| Cuarteles De Napoles | 0.7 | 0.6 |
| Mario Correa Rengifo | 3.2 | 5.2 |
| Lourdes | 2.4 | 6.8 |
| Los Chorros | 6.3 | 6.4 |
| Caldas | 10.3 | 4.7 |
| Horizontes | 4.4 | 5.5 |
| Sector Melendez | 1.2 | 2.6 |
| Melendez | 1.0 | 2.6 |
| Buenos Aires | 3.2 | 6.5 |
| Francisco Eladio Ramirez | 6.1 | 8.9 |
| Alferez Real | 29.0 | 5.1 |
| Buenos Aires | 3.6 | 6.3 |
| Los Farallones | 4.5 | 4.5 |
| Colinas Del Sur | 6.1 | 5.9 |

*Table 6.Composition Commune 17.*

| Neighbourhood | Distribution of listed state [%] | |
|---|---|---|
| | **Habitational** | **Interest / Commerce** |
| Valle Del Lili | 8.8 | 5.4 |
| Caney | 5.6 | 3.5 |
| Ciudadela Confandi | 4.1 | 1.4 |
| Urb. San Joaquin | 11.1 | 11.8 |
| Ciudad Universitaria | 2.6 | 6.2 |
| Unicentro Cali | 3.5 | 13.2 |
| La Playa | 4.6 | 0.5 |
| El Ingenio | 5.7 | 5.1 |
| Mayapan | 4.3 | 6.6 |
| Cuiudadela Pasoancho | 2.0 | 4.3 |
| Prados De Limonar | 5.3 | 4.6 |
| Las Quintas De Don Simón | 7.5 | 3.8 |
| Ciudad Capri | 3.2 | 9.7 |

| Neighbourhood | Distribution of listed state [%] | |
|---|---|---|
| | **Habitational** | **Interest / Commerce** |
| El Gran Limonar | 2.8 | 3.3 |
| Cataya | 4.8 | 5.1 |
| Los Portales | 3.9 | 2.7 |
| La Hacienda | 3.2 | 3.1 |
| Bosques De Limonar | 4.5 | 2.4 |
| Cañaverales | 2.1 | 2.5 |
| El Limonar | 4.5 | 1.2 |
| Primero De Mayo | 3.6 | 2.1 |
| Santa Anita | 2.4 | 1.5 |

As the information of the trips is given in a daily base, in order to account only for the peak hour is necessary to determine how much of the traffic operates at this hour, this values was extracted from the "Mobility and Road Safety report" (Secretaria de movilidad de Cali, 2018). In this report the control station near the study area, located as shown in the Figure 17, determines that in average, the peak hour is between 6:30 and 7:30 AM and it accounts for 19.0% of the daily traffic.

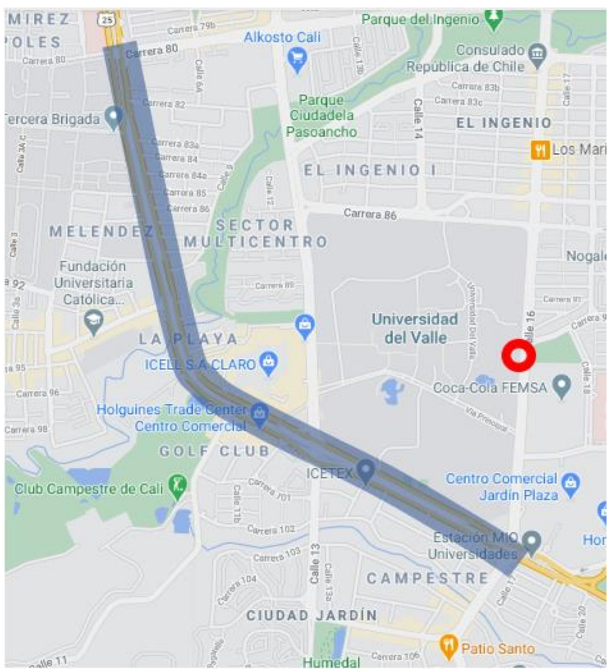



*Figure 17. Position of the control station (red dot).*

### 3.3.2. O/D matrix

Firstly, the information of the daily trips needs to be set in the year of the evaluated scenario (2019), this operation was carried out by considering constant the trip rate per person in each commune, calculated with the data from 2015, and then applying these coefficients to the corresponding population for 2019.

*Table 7. Actualization of daily trips.*

| Commune | trip rate [#Trip / person] | | population 2019 [hab] | Daily trips [trips/ day] | |
|---|---|---|---|---|---|
| | generated | attracted | | generated | attracted |
| 1 | 0.20 | 0.13 | 100497 | 20011 | 12785 |
| 2 | 1.21 | 0.48 | 122637 | 148728 | 59018 |
| 3 | 1.34 | 1.47 | 46887 | 62975 | 69081 |
| 4 | 1.26 | 0.93 | 52132 | 65479 | 48641 |
| 5 | 0.45 | 0.55 | 115759 | 52250 | 63440 |
| 6 | 0.24 | 0.23 | 196573 | 47450 | 46132 |
| 7 | 0.47 | 0.64 | 69285 | 32653 | 44376 |
| 8 | 0.77 | 0.61 | 103266 | 79350 | 63345 |
| 9 | 0.69 | 0.72 | 43646 | 30227 | 31364 |
| 10 | 0.58 | 0.53 | 112645 | 64973 | 59253 |
| 11 | 0.97 | 0.59 | 109754 | 105943 | 64808 |
| 12 | 0.33 | 0.31 | 66221 | 22101 | 20290 |
| 13 | 0.30 | 0.50 | 179360 | 54110 | 89558 |
| 14 | 0.28 | 0.25 | 179535 | 49498 | 44103 |
| 15 | 0.26 | 0.22 | 171556 | 44684 | 38466 |
| 16 | 0.27 | 0.32 | 111198 | 29633 | 35273 |
| 17 | 1.23 | 0.62 | 152793 | 188425 | 94466 |
| 18 | 0.46 | 0.39 | 146773 | 67004 | 57686 |
| 19 | 1.74 | 0.58 | 116761 | 202904 | 67895 |
| 20 | 0.34 | 0.27 | 70728 | 24234 | 18966 |
| 21 | 0.40 | 0.10 | 119763 | 47792 | 11696 |
| 22 | 2.71 | 3.03 | 12343 | 33443 | 37360 |

As the model does not cover the whole city, in order to assess the trips to happen through the selected section was decide to reduce de aggregation level to the neighbourhoods composing the communes; this way the value corresponding to the different nodes in the model will be the trips generated and attracted from/to the neighbourhoods in a 300m radius from the entrance or exit of the sections in the main intersections contained in the study area.

The distribution of the trips of the commune into the neighbourhoods was done by considering the composition of the neighbourhoods describe in the Table 4, Table 5 and Table 6. The trip generation considers the "habitational" proportion and the attraction considers the "commercial / interest" proportion; the disaggregation obtained (see Table 8, Table 9 and Table 10) serves for the procedure previously mention.

*Table 8. Trip distribution in commune 22.*

| Neighbourhood | Daily trips [trips/ day] | |
|---|---|---|
| | **generated** | **attracted** |
| Parcelaciones De Pance | 918500 | 199694 |
| Urb. Rio Lili | 504559 | 1081048 |
| Urb. Ciudad Jardin | 2102393 | 2367368 |
| Club Campestre | 41326 | 15700 |
| Ciudad Campestre | 169247 | 72215 |

*Table 9. Trip distribution in commune 18.*

| Neighbourhood | Daily trips [trips/ day] | |
|---|---|---|
| | generated | attracted |
| Polvorines | 276894 | 346117 |
| Alto Jordan | 132678 | 421109 |
| Napoles | 256920 | 166595 |
| Alto De Los Chorros | 115372 | 392266 |
| El Jordan | 259588 | 317274 |
| Cuarteles De Napoles | 40380 | 34612 |
| Mario Correa Rengifo | 184596 | 299968 |
| Lourdes | 138447 | 392266 |
| Los Chorros | 363423 | 369191 |
| Caldas | 594167 | 271125 |
| Horizontes | 253819 | 317274 |
| Sector Melendez | 70830 | 148345 |
| Melendez | 57855 | 150600 |
| Buenos Aires | 184596 | 374960 |
| Francisco Eladio Ramirez | 351886 | 513407 |
| Alferez Real | 1670671 | 292877 |
| Buenos Aires | 207670 | 363423 |
| Los Farallones | 259588 | 259588 |
| Colinas Del Sur | 351886 | 340348 |

*Table 10.Trip distribution in commune 17.*

| Neighbourhood | Daily trips [trips/ day] | |
|---|---|---|
| | generated | attracted |
| Lili | 831298 | 510115 |
| Caney | 529008 | 330630 |
| Ciudadela Confandi | 387309 | 132252 |
| Urb. San Joaquin | 1043847 | 1117142 |
| Ciudad Universitaria | 246450 | 581276 |
| Unicentro Cali | 327455 | 1244735 |
| La Playa | 434542 | 47233 |
| El Ingenio | 538455 | 481775 |
| Mayapan | 406203 | 620524 |
| Ciudadela Pasoancho | 188931 | 406203 |
| Prados De Limonar | 500668 | 434542 |
| Las Quintas De Don Simón | 708493 | 358970 |
| Ciudad Capri | 299222 | 919471 |
| El Gran Limonar | 264504 | 311737 |
| Cataya | 453435 | 481775 |
| Los Portales | 368416 | 255057 |
| La Hacienda | 302290 | 292844 |
| Bosques De Limonar | 425096 | 226718 |
| Cañaverales | 198378 | 236164 |
| El Limonar | 425096 | 113359 |

| Neighbourhood | Daily trips [trips/ day] | |
|---|---|---|
| | generated | attracted |
| Primero De Mayo | 340077 | 198378 |
| Santa Anita | 226718 | 141699 |

From this information, to re accommodate it to the 9 centroids considered in the model (see Figure 18) is necessary to determine the neighbourhoods related to the production and attraction of the nodes in the model. The corresponding neighbourhoods were selected considering the distance from de access/exit point (300 m) and the physical accessibility, referring to the presence of obstacles that prevent the movement between the access/exit point and the neighbourhood.

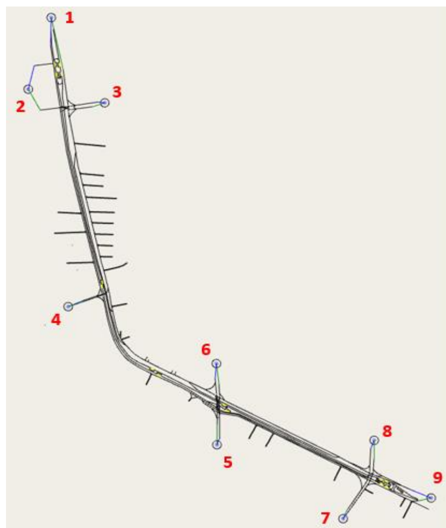



*Figure 18. Node nomenclature and positioning on the model.*

*Table 11. Neighbourhoods corresponding to the nodes in the model.*

| ID | Name | Production | Attraction |
|---|---|---|---|
| 1 | NORTH | Alferez real (commune 18) | Ciudad Capri (commune 17) |
| 2 | NAPOLES | Napoles (commune 17) | Alferez real (commune 18); Napoles (commune 17) |
| 3 | CAPRI | Ciudad Capri (commune 17) | Mayapan (commune 17) |
| 4 | MELENDEZ | Melendez (commune 18); sector Melendez (commune 18) | Melendez (commune 18); sector Melendez (commune 18) |
| 5 | c. JARDIN 13 | Urb. Ciudad Jardin (commune 22); Club Campestre (commune 22); Ciudad Campestre (commune 22) | Urb. Ciudad Jardin (commune 22); Club Campestre (commune 22); Ciudad Campestre (commune 22) |
| 6 | MULTICENTRO | Unicentro Cali (commune 17); Ciudad Universitaria (commune 17) | Unicentro Cali (Commune 17) |
| 7 | c. JARDIN 16 | Urb. Ciudad Jardin (commune 22); Urb. Rio Lili (commune 22) | Urb. Ciudad Jardin (commune 22); Urb. Rio Lili (commune 22) |
| 8 | INGENIO | Ciudad Universitaria (commune 17); Urb. San Joaquin (commune 17) | Ciudad Universitaria (commune 17); Urb. San Joaquin (commune 17) |
| 9 | PANAMERICANA | Urb. San Joaquin (commune 17) | Urb. Rio Lili (commune 22) |

The trips for each node were  assigned as the trips of the corresponding neighbourhoods (see Table 11); whenever a neighbourhood was in more than one node, their trips were distributed equally between the nodes it is account.

*Table 12. model daily trips.*

| ID | Name | Production [trip/day] | Attraction [trip/day] |
|---|---|---|---|
| 1 | NORTH | 19405 | 9195 |
| 2 | NAPOLES | 2984 | 4595 |
| 3 | CAPRI | 5968 | 6205 |
| 4 | MELENDEZ | 1495 | 2989 |
| 5 | c. JARDIN 13 | 11295 | 12716 |
| 6 | MULTICENTRO | 8989 | 12447 |
| 7 | c. JARDIN 16 | 13926 | 17242 |
| 8 | INGENIO | 12868 | 16984 |
| 9 | PANAMERICANA | 10411 | 5405 |

The final form of the data is the hourly production and attraction, obtained by affecting the daily production and attrition by the factor of the peak hour flow of the nearest control traffic station (19.0%), shown in the Table 13.

*Table 13. model trips per hour.*

| ID | Name | Production [trip/hour] | Attraction [trip/ hour] |
|---|---|---|---|
| 1 | NORTH | 3687 | 1747 |
| 2 | NAPOLES | 567 | 873 |
| 3 | CAPRI | 1134 | 1179 |
| 4 | MELENDEZ | 284 | 568 |
| 5 | c. JARDIN 13 | 2146 | 2416 |
| 6 | MULTICENTRO | 1708 | 2365 |
| 7 | c. JARDIN 16 | 2646 | 3276 |
| 8 | INGENIO | 2445 | 3227 |
| 9 | PANAMERICANA | 1978 | 1027 |

The distribution of these trips was carryout by a Gravity distribution model with a doble constrained consideration, in order to assure the consistency with both the production and attractions of each node (Ortuzar & Willumsen, 2011).

This method considers the trips between a pair of nodes equal to the product of the total trips generated and attracted, two balancing factor and a friction function, representing the general cost of the trip.

$$T_{ij} = A_i O_i B_j D_j f(C_{ij})$$

The balancing factors, in order to account the double constrains, are equal to:

$$A_i = 1/\sum_j B_j D_j f(C_{ij})$$

$$B_j = 1/\sum_j A_i O_i f(C_{ij})$$

As can be seen the friction, is an important factor to determine, in this case was selected a power function. The exponent was set in 2, as it is a commonly use value.

$$f(C_{ij}) = C_{ij}^{-2}$$

The generalized costs of the travel between a pair of centroid was calculated in function of the distance and a route choice factor, that is used in order to account if the shortest path between the centroids is out of the modelled network, this method is recommended in the *"Manual for origin destination studies in the municipal areas*" (manual para estudios de origen y destino en áreas municipales) (Ministerio de Transporte de Colombia, 2011).

$$C_{ij} = d_{ij} + d_{max}\left(\frac{5 - RF}{5}\right)$$

The matrix of the distances between the centroids is contained in the Table 14, these values where obtained using the google earth path measurement tool.

*Table 14. distance matrix between centroids.*

| $d_{ij}[km]$ | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 9999.00 | 0.36 | 0.68 | 1.36 | 3.12 | 2.41 | 3.41 | 3.31 | 3.61 |
| **2** | 0.86 | 9999.00 | 0.35 | 1.44 | 2.40 | 2.40 | 3.30 | 3.40 | 3.40 |
| **3** | 0.68 | 0.35 | 9999.00 | 1.43 | 2.39 | 2.39 | 3.29 | 3.39 | 3.39 |
| **4** | 1.36 | 1.44 | 1.43 | 9999.00 | 1.36 | 1.46 | 2.26 | 2.36 | 2.36 |
| **5** | 3.12 | 2.40 | 2.39 | 1.36 | 9999.00 | 0.38 | 1.38 | 1.48 | 2.38 |
| **6** | 2.41 | 2.45 | 2.39 | 1.46 | 0.38 | 9999.00 | 1.48 | 1.58 | 1.58 |
| **7** | 3.41 | 3.30 | 3.29 | 2.26 | 1.38 | 1.48 | 9999.00 | 0.32 | 0.92 |
| **8** | 3.31 | 3.40 | 3.39 | 2.36 | 1.48 | 1.58 | 0.32 | 9999.00 | 0.62 |
| **9** | 3.61 | 3.40 | 3.39 | 2.36 | 2.38 | 1.58 | 1.40 | 0.62 | 9999.00 |

The distance of the trips inside the same zone was set as an extreme value in order to accomplish a null amount of intra zonal trips; form the Table 14 is extracted the $d_{max}$value (3.41 km) used in the cost determination.

*Table 15. Route coefficient for each pair of centroids.*

| **RF [-]** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 1 | 1 | 1 | 4 | 4 | 4 | 4 | 3 | 4 |
| **2** | 1 | 1 | 2 | 4 | 4 | 3 | 4 | 2 | 4 |

| RF [-] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **3** | 1 | 2 | 1 | 5 | 3 | 3 | 4 | 2 | 1 |
| **4** | 5 | 5 | 3 | 1 | 5 | 3 | 2 | 2 | 3 |
| **5** | 4 | 4 | 5 | 5 | 1 | 5 | 1 | 2 | 1 |
| **6** | 3 | 4 | 3 | 4 | 5 | 1 | 3 | 1 | 2 |
| **7** | 4 | 3 | 3 | 5 | 1 | 2 | 1 | 5 | **1** |
| **8** | 2 | 3 | 2 | 4 | 2 | 1 | 5 | 1 | 1 |
| **9** | 2 | 4 | 3 | 5 | 4 | 3 | 1 | 1 | 1 |

The route coefficient values are given according to the information of the fastest route in Google Maps applicative, the criteria are the ones described in the Table 16.

*Table 16, Criteria for the Route Coefficient determination,*

| RF | Criteria |
|---|---|
| **5** | All the routes show in the applicative are through the modelled network. |
| **4** | Most of the routes show in the applicative are through the modelled network. |
| **3** | More than 25% and up to 50% of routes show in the applicative are through the modelled network. |
| **2** | Up to 25%routes show in the applicative are through the modelled network. |
| **1** | No routes show in the applicative are through the modelled network. |

Applying the distribution model, the final origin destination matrix is the one of the Table 17.

*Table 17. hourly O/D matrix.*

| $T_{ij}$ [trip/h] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 171 | 67 | 97 | 867 | 851 | 862 | 260 | 515 | 3690 |
| **2** | 184 | 0 | 14 | 10 | 134 | 59 | 93 | 20 | 58 | 572 |
| **3** | 271 | 39 | 0 | 27 | 120 | 78 | 124 | 26 | 35 | 720 |
| **4** | 156 | 10 | 2 | 0 | 84 | 13 | 10 | 4 | 9 | 288 |
| **5** | 58 | 7 | 5 | 8 | 0 | 2013 | 31 | 14 | 14 | 2150 |
| **6** | 31 | 4 | 2 | 2 | 1620 | 0 | 34 | 6 | 14 | 1713 |
| **7** | 117 | 7 | 3 | 7 | 63 | 55 | 0 | 4630 | 60 | 4942 |
| **8** | 14 | 2 | 1 | 1 | 18 | 8 | 2390 | 0 | 15 | 2449 |
| **9** | 316 | 43 | 15 | 32 | 580 | 408 | 369 | 220 | 0 | 1983 |
| **TOTAL** | 1147 | 283 | 109 | 184 | 3486 | 3485 | 3913 | 5180 | 720 | 18507 |

The individual modal matrixes are obtained by multiplying the whole matrix by the participation coefficient of each mode (61% for automobile; 39% for motorcycle).

## 3.4. BRT

As described before the BRT of the city of Cali is a High-End BRT system, this is a reference to two important aspects, the off-board fare collection and the bus-only corridor, these characteristics are meet in the evaluated corridor. Specifically, the studied corridor counts with 4 stations located along the median of the section," Capri", "Melendez", "Buitrera", "Univalle" and "Universidades".

The service include several lines, differentiated by the station they serve, the type of vehicle and nature of the offer service. In the studied corridor, there are 3 kinds of lines :

- type "P" (from "Pretroncal"), they offer a service that can go outside the exclusive lanes.
- type "T" (from "Troncal"), is a service offered along the exclusive lanes only and stops at every station between two head stations.
- type "E" (from "Expreso"), the express form of the "T" line, the service is offered only in the dedicate lanes, but the amount of stations it stops are reduced.

The information of the lines is contained in the Table 18, the stations and doors of the stops, and the expected frequency of the lines.

*Table 18. operational information of the BRT system.*

| | **CAPRI** | | | | **MELENDEZ** | | **BUITRERA** | | **UNIVALLE** | | **UNIVERSIDADES** | | | | **Frequency [min]** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A1** | **A2** | **B1** | **B2** | **A1** | **B1** | **A1** | **B1** | **A1** | **B1** | **A1** | **A2** | **B1** | **B2** | |
| **E41** | 1 | | 1 | | | | 1 | 1 | | | 1 | | | | 7.00 |
| **E21** | | | | | 1 | 1 | 1 | 1 | | | 1 | | | | 5.50 |
| **E31** | 1 | | 1 | | 1 | 1 | 1 | 1 | | | | | 1 | | 8.00 |
| **T31** | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | | 5.00 |
| **P27C** | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | | | 6.00 |
| **P17** | | 1 | | 1 | 1 | 1 | 1 | 1 | | | | | | | 10.00 |
| **P10A** | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | 1 | 7.50 |
| **P10B** | | | | | | | | | | | | | 1 | | 8.00 |
| **P10D** | | | | | | | | | | | | | 1 | | 10.00 |
| **P12A** | | | | | | | | | | | | | | 1 | 10.00 |
| **P21A** | | | | | | | | | | | | | | 1 | 7.50 |
| **P21B** | | | | | | | | | | | | | | 1 | 6.00 |

"A" refers to the North-South direction, "B" refers to the South-North direction; the number is an indicator if the station counts with more than 1 boarding door.

In "Universidades" station the lines perform 3 different manoeuvres, depicted in the Figure 19.

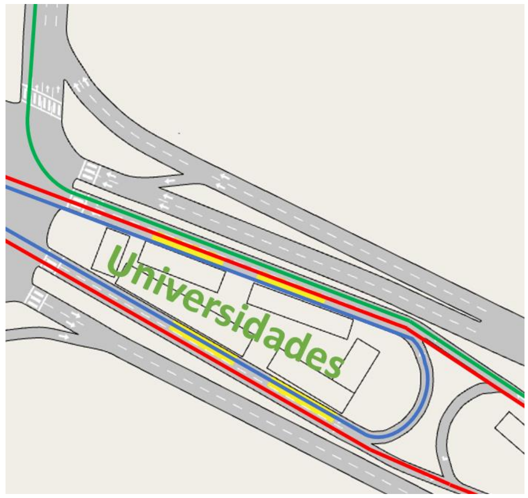



*Figure 19. Scheme of the manoeuvres at the "Universidades" station.*

In blue is the "U" turn, perform by the lines E41, E21, E31, T31, P27C and P10A. In red the path follow by the P17 line. The other lines perform the green path, entering by the south an exiting the dedicated lanes.

The BRT system includes 2 types of vehicles, depending of the ambit of transit expected. For lines only serving along the dedicated corridor an articulated vehicle is use, for lines that require going through mix traffic sections a one body vehicle is employ.

*Table 19. BRT articulated vehicle characteristics.*

| **Length [m]** | **19.75** |
|---|---|
| **Width [m]** | 2.55 |
| **Capacity [passengers]** | 170 |
| **Number boarding doors [-]** | 4 |
| **Potency [kW]** | 265 |
| **Max. Velocity [km/h]** | 60.0 |
| **Length front car[m]** | 9.7 |
| **Length articulation [m]** | 3.5 |

*Table 20. BRT non articulated vehicle characteristics.*

| **Length [m]** | **12.20** |
|---|---|
| **Width [m]** | 2.55 |
| **Capacity [passengers]** | 80 |
| **Number boarding doors [-]** | 2 |
| **Potency [kW]** | 220 |
| **Max. Velocity [km/h]** | 60.0 |

### 3.5. Base Control Plan

For the four intersections the control plan consists of a set of 6 different fixed plans that changes according to the hour of the day. The plan included in the model of the base case is the one stipulated for the morning rush hour, from 5 AM to 8 AM. The control plans are shown below using the RiLSA (FGSV, 2015) nomenclature for manoeuvres, indicating with "A" the mix traffic lanes and with "B" public transport dedicated lanes, when needed.

The general consideration for the cycles is the Ambar time of the transitions, 5 seconds when passing from green to red and 2 seconds passing from red to green. The cycles are of 120 seconds, excepting in the intersection 3 ("Carrera 100" with "calle 13") that has a cycle of 150 seconds.

*Intersection 1, "calle 5" with "Carrera 80"*

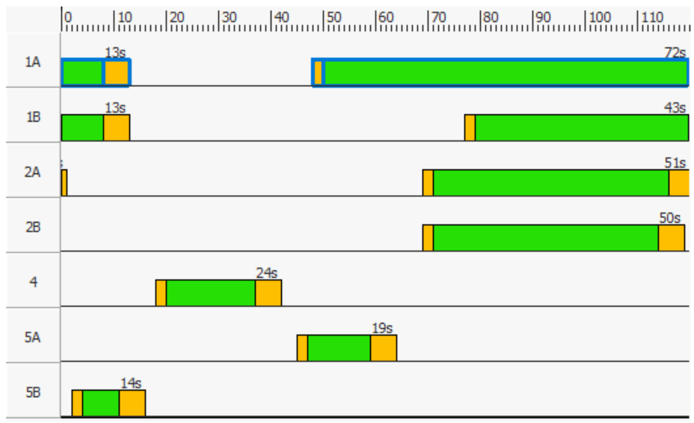



*Figure 20. cycle of the signal groups in the intersection 1, Base Control Plan.*

*Table 21. Control information Intersection 1, Base Control Plan.*

| Movement | Initial time [s] | Duration [s] |
|---|---|---|
| 1a | 50 | 78 |
| 1b | 79 | 49 |
| 2a | 71 | 45 |
| 2b | 71 | 43 |
| 4 | 20 | 17 |
| 5a | 47 | 12 |
| 5b | 4 | 7 |
| 8 | 20 | 17 |

This time configuration results in 13 different phases in the cycle. The manoeuvres in the intersection are depicted in Figure 22.

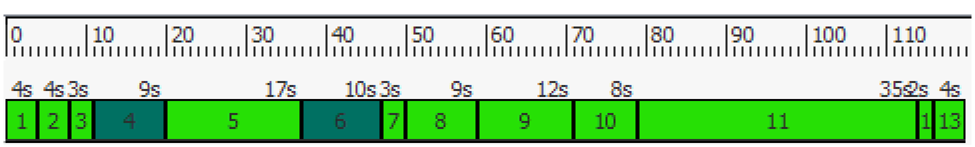



*Figure 21. Timeline of the phases in the cycle, Intersection 1.*

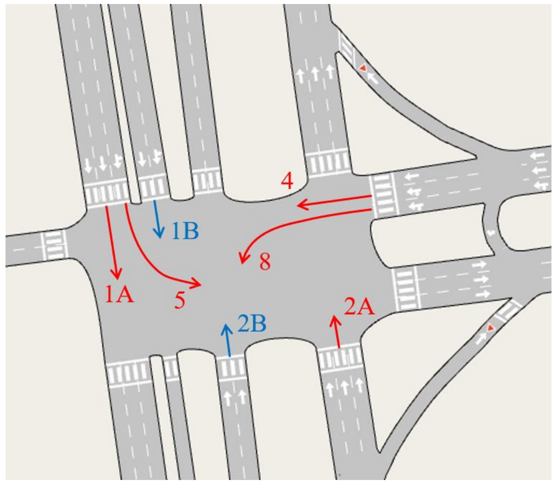



*Figure 22. Scheme of m manoeuvres in Intersection 1*

*Intersection 2, "calle 5" with "Carrera 94"*

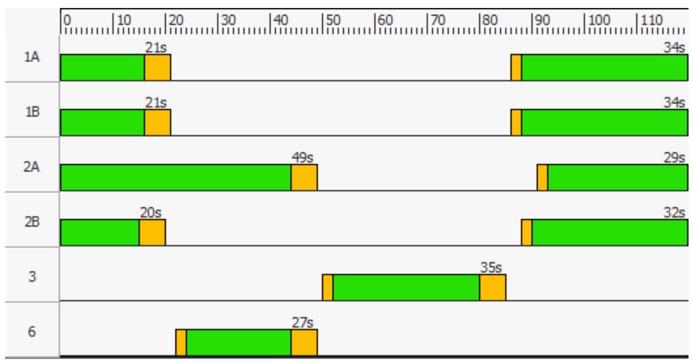



*Figure 23.cycle of the signal groups in the intersection 2, Base Control Plan.*

*Table 22. Control information Intersection 2, Base Control Plan.*

| Movement | Initial time [s] | Duration [s] |
|---|---|---|
| 1a | 88 | 48 |
| 1b | 88 | 48 |
| 2a | 93 | 71 |
| 2b | 90 | 45 |
| 7 | 52 | 28 |
| 6 | 24 | 20 |

This time configuration results in 10 different phases in the cycle. The manoeuvres in the intersection are depicted in Figure 25.

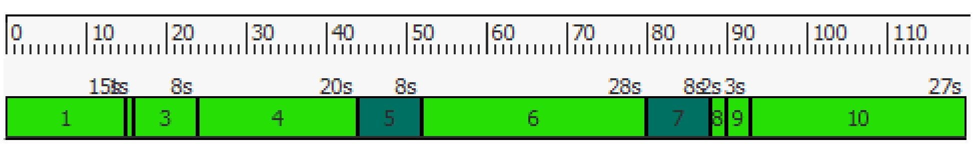



*Figure 24,Timeline of the phases in the cycle, Intersection 2.*

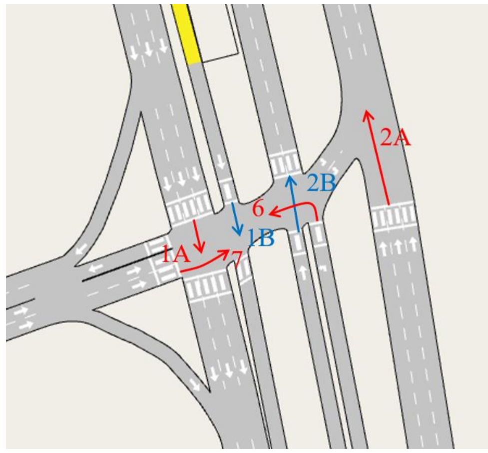



*Figure 25. Scheme of m manoeuvres in Intersection 2.*

### *Intersection 3, "Carrera 100" with "calle 13"*

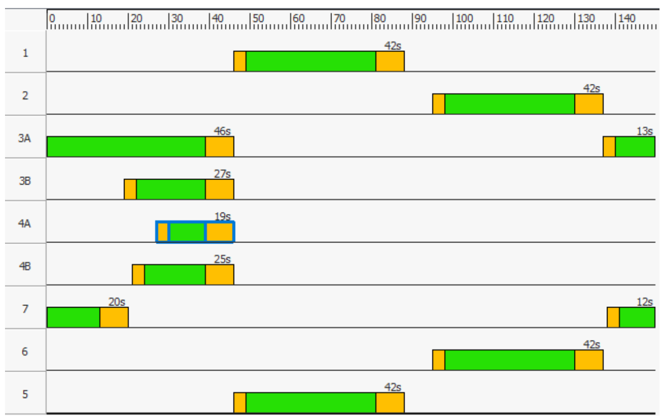



*Figure 26. cycle of the signal groups in the intersection 3, Base Control Plan.*

*Table 23. Control information Intersection 3, Base Control Plan.*

| Movement | Initial time [s] | Duration [s] |
|---|---|---|
| 1 | 49 | 32 |
| 2 | 98 | 32 |
| 3a | 140 | 49 |
| 3b | 22 | 17 |
| 4a | 30 | 9 |
| 4b | 24 | 15 |
| 5 | 49 | 32 |
| 6 | 98 | 32 |
| 7 | 141 | 22 |

This time configuration results in 13 different phases in the cycle. The manoeuvres in the intersection are depicted in Figure 28.

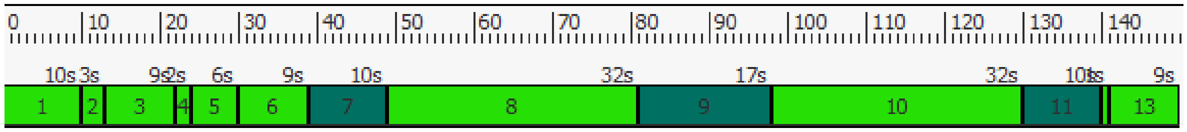



*Figure 27, Timeline of the phases in the cycle, Intersection 3*

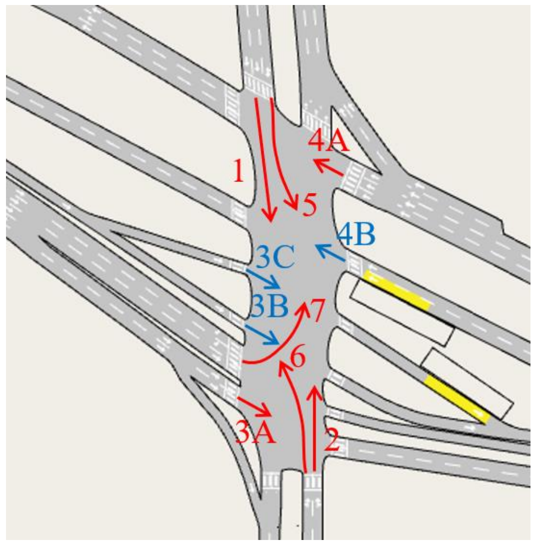



*Figure 28. Scheme of m manoeuvres in Intersection 3*

### *Intersection 4, "Carrera 100" with "calle 16"*

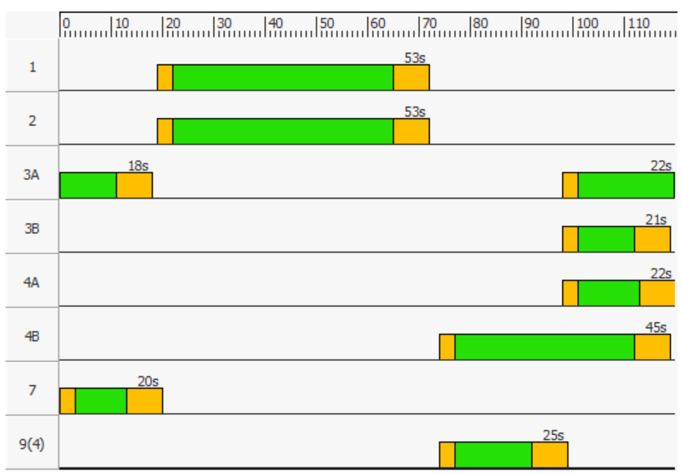



*Figure 29. Cycle of the signal groups in the intersection 4, Base Control Plan.*

*Table 24. Control information Intersection 4, Base Control Plan.*

| Movement | Initial time [s] | Duration [s] |
|---|---|---|
| 1 | 22 | 43 |
| 2 | 22 | 43 |
| 3a | 101 | 30 |

| Movement | Initial time [s] | Duration [s] |
|---|---|---|
| 3b | 101 | 11 |
| 4a | 101 | 12 |
| 4b | 77 | 35 |
| 7 | 3 | 10 |
| 9(4) | 77 | 15 |

This time configuration results in 11 different phases in the cycle. The manoeuvres in the intersection are depicted in Figure 31.

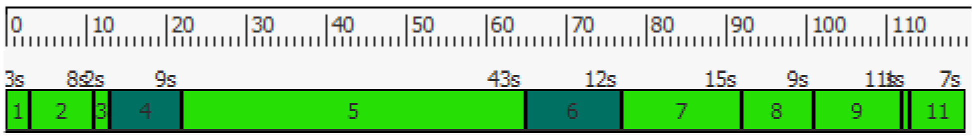



*Figure 30.Timeline of the phases in the cycle, Intersection 4.*

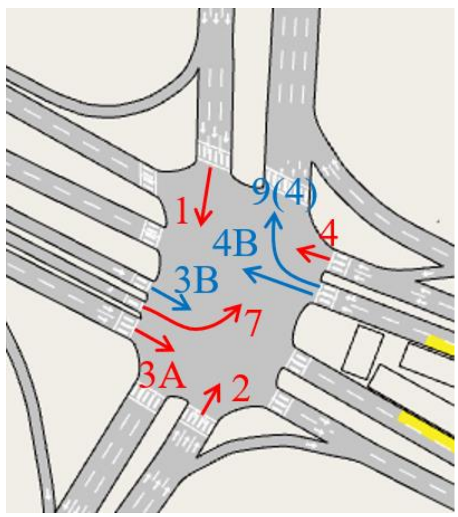



*Figure 31.Scheme of m manoeuvres in Intersection 4.*

# 4. Methodology

## 4.1. Validation process

In order to compare the effects of the different signal priority protocols, as stated in the objective of this study, is necessary to stablish first a base scenario that represents the actual behaviour of the system. This scenario is modelled with the data previously described.

The results of the model are compared with some observations of the actual behaviour of the road network to verify that the model represents the reality correctly. To do so, one of the most commonly use tool is the GEH statistic, propose by George E. Havers in the 70's, is a form of the Chi-squared statistics that incorporates the relative and absolute errors.

$$GEH = \sqrt{\frac{2 * (M - O)^2}{(M + O)}}$$

Where M is the model result and O is the observed value, the design manual for road and bridges of UK (UK Highways Agency, 1996), gives the criteria to accept the model as a valid model, being that in more than the 85% of the evaluated pairs the GEH statistic needs to be less than 5.

## 4.2. Modelling process

The scenarios considered to measure the impacts of the diverse priority strategies are contained in the Table 25.

The se priority strategies are differentiated based on the vehicles given the priority, the intersections in which is applied the priority and the control plan; this last one in order to account the passive priority protocols.

The different scenarios will be coded as "*PX Y ZZ"* where:

1. "X" indicates the prioritized PT lines can be:
    a. 0 when only "E" lines are given priority.
    b. 1 when all PT lines are given priority.
2. "Y" indicates the intersection where the active priority strategies are implemented, can be:
    a. A when the intersection 1 has active priority strategies exclusively.
    b. B when the intersection 2 has active priority strategies exclusively.
    c. C when the intersection 3 has active priority strategies exclusively
    d. D when the intersection 4 has active priority strategies exclusively.
    e. E when all the intersections have active priority strategies.
3. "ZZ" indicates the control plan considered in the system, can be:
    a. BC when the Base Control Plan is used.
    b. MC when the Modified Control Plan is used.

*Table 25. modelled priority strategies.*

| Scenario | Control Plan | Active Priority strategy | Intersection with Active Priority | Passive Priority strategy | Prioritized PT lines |
|---|---|---|---|---|---|
| P0 A BC | Base Control Plan | Green extension and Early Green | 1 | None | “E” lines |
| P0 B BC | Base Control Plan | Green extension and Early Green | 2 | None | “E” lines |
| P0 C BC | Base Control Plan | Green extension and Early Green | 3 | None | “E” lines |
| P0 D BC | Base Control Plan | Green extension and Early Green | 4 | None | “E” lines |
| P0 E BC | Base Control Plan | Green extension and Early Green | All | None | “E” lines |
| P1 A BC | Base Control Plan | Green extension and Early Green | 1 | None | All |
| P1 B BC | Base Control Plan | Green extension and Early Green | 2 | None | All |
| P1 C BC | Base Control Plan | Green extension and Early Green | 3 | None | All |
| P1 D BC | Base Control Plan | Green extension and Early Green | 4 | None | All |
| P1 E BC | Base Control Plan | Green extension and Early Green | All | None | All |
| Modified | Modified Control Plan | None | None | Users Delay | None |
| P0 A MC | Modified Control Plan | Green extension and Early Green | 1 | Users Delay | “E” lines |
| P0 B MC | Modified Control Plan | Green extension and Early Green | 2 | Users Delay | “E” lines |
| P0 C MC | Modified Control Plan | Green extension and Early Green | 3 | Users Delay | “E” lines |
| P0 D MC | Modified Control Plan | Green extension and Early Green | 4 | Users Delay | “E” lines |
| P0 E MC | Modified Control Plan | Green extension and Early Green | All | Users Delay | “E” lines |
| P1 A MC | Modified Control Plan | Green extension and Early Green | 1 | Users Delay | All |
| P1 B MC | Modified Control Plan | Green extension and Early Green | 2 | Users Delay | All |
| P1 C MC | Modified Control Plan | Green extension and Early Green | 3 | Users Delay | All |
| P1 D MC | Modified Control Plan | Green extension and Early Green | 4 | Users Delay | All |
| P1 E MC | Modified Control Plan | Green extension and Early Green | All | Users Delay | All |

### 4.2.1. Priority on Base Control Plan

In this section are contained the specific parameters used and required by the AIMSUN software, to model the active priority protocols (early green and green extension) upon the

Base Control Plan. The indicated variables are discriminated and detailed for every controlled intersection in the network.

The procedure in order to determine the values of the variables required for the priority protocols is depicted in the Figure 32. To clarify there will be 2 different type of phases, the Prioritized and the Non-Prioritized, the prioritized phase is a phase in which is allow the manoeuvre of PT line.

The prioritized phase will conserve its position relative to the other phases but the duration will be set to a minimum whenever no priority request is detected, to avoid a permanent queue for the scenarios with a limited number of prioritized lines; when the priority is granted the duration of the green will vary between a minimum and a maximum value. The Non-Prioritized phases will follow the base control plan but when the priority is granted these phases will change their duration to a set value in order to allocate the Green Extension or the Early Green during the cycle.

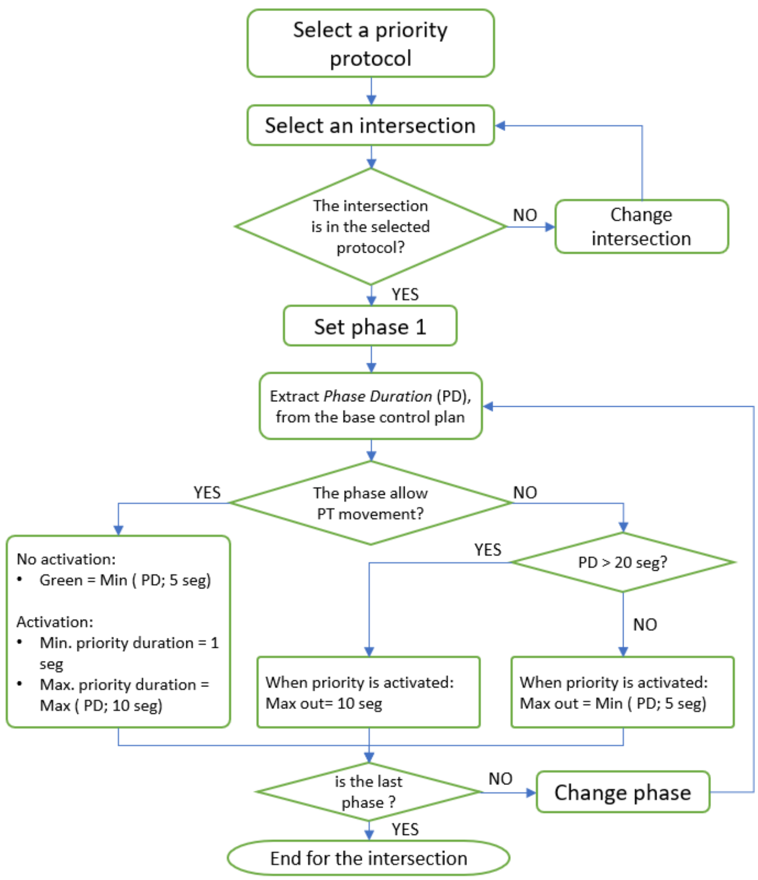



*Figure 32. Flow diagram for priority protocols establishment*

*Intersection 1*

Starting from the Base Control Plan for this intersection, it can be divided in the phases shown in the Figure 33.

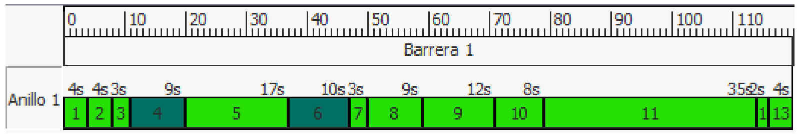



*Figure 33. phases in the Base Control Plan for the intersection 1.*

Applying the algorithm previously stabilised for assign the priority parameter the Table 26 can be constructed.

*Table 26. priority parameters in the Base Control Plan for the intersection 1.*

| **Phase** | **Phase duration [sec]** | **Prioritized** | **Under priority request** | | | **Under no priority request** |
|---|---|---|---|---|---|---|
| | | | Min. Duration [sec] | Max. Duration [sec] | Max out [sec] | Phase duration [sec] |
| 1 | 4 | Yes | 1 | 10 | - | 4 |
| 2 | 4 | Yes | 1 | 10 | - | 4 |
| 3 | 3 | Yes | 1 | 10 | - | 3 |
| 4 | 9 | - | - | - | - | 9 |
| 5 | 17 | No | - | - | 5 | 17 |
| 6 | 10 | - | - | - | - | 10 |
| 7 | 3 | No | - | - | 3 | 3 |
| 8 | 9 | No | - | - | 5 | 9 |
| 9 | 12 | No | - | - | 5 | 12 |
| 10 | 8 | Yes | 1 | 10 | - | 5 |
| 11 | 35 | Yes | 1 | 35 | - | 5 |
| 12 | 2 | Yes | 1 | 10 | - | 2 |
| 13 | 4 | Yes | 1 | 10 | - | 4 |

*Intersection 2*

Starting from the Base Control Plan for this intersection, it can be divided in the phases shown in the Figure 34.

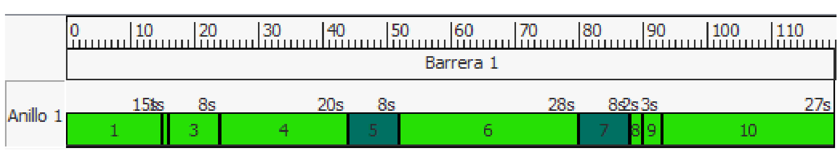



*Figure 34. phases in the Base Control Plan for the intersection 2.*

Applying the algorithm previously stabilised for assign the priority parameter the Table 27 can be constructed.

*Table 27. priority parameters in the Base Control Plan for the intersection 2.*

| Phase | Phase duration [sec] | Prioritized | Under priority request | | | Under no priority request |
|---|---|---|---|---|---|---|
| | | | Min. Duration [sec] | Max. Duration [sec] | Max out [sec] | phase duration [sec] |
| 1 | 15 | Yes | 1 | 15 | - | 5 |
| 2 | 1 | Yes | 1 | 10 | - | 1 |
| 3 | 8 | No | - | - | 5 | 8 |
| 4 | 20 | No | - | - | 5 | 20 |
| 5 | 8 | - | - | - | - | 8 |
| 6 | 28 | No | - | - | 10 | 28 |
| 7 | 8 | - | - | - | - | 8 |
| 8 | 2 | Yes | 1 | 10 | - | 2 |
| 9 | 3 | Yes | 1 | 10 | - | 3 |
| 10 | 27 | Yes | 1 | 27 | - | 5 |

### *Intersection 3*

Starting from the Base Control Plan for this intersection, it can be divided in the phases shown in the Figure 35.

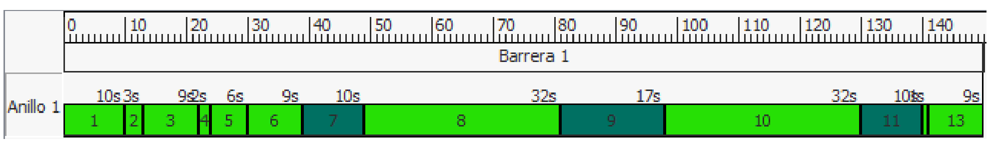



*Figure 35. phases in the Base Control Plan for the intersection 3.*

Applying the algorithm previously stabilised for assign the priority parameter the Table 28 can be constructed.

*Table 28. priority parameters in the Base Control Plan for the intersection 3.*

| Phase | Phase duration [sec] | Prioritized | Under priority request | | | Under no priority request |
|---|---|---|---|---|---|---|
| | | | Min. Duration [sec] | Max. Duration [sec] | Max out [sec] | phase duration [sec] |
| 1 | 10 | No | - | - | 5 | 10 |
| 2 | 3 | No | - | - | 3 | 3 |
| 3 | 9 | No | - | - | 5 | 9 |
| 4 | 2 | Yes | 1 | 10 | - | 2 |
| 5 | 6 | Yes | 1 | 10 | - | 5 |
| 6 | 9 | Yes | 1 | 10 | - | 5 |
| 7 | 10 | - | - | - | - | 10 |
| 8 | 32 | No | - | - | 10 | 32 |
| 9 | 17 | - | - | - | - | 17 |
| 10 | 32 | No | - | - | 10 | 32 |
| 11 | 10 | - | - | - | - | 10 |
| 12 | 1 | No | - | - | 1 | 1 |
| 13 | 9 | No | - | - | 5 | 9 |

*Intersection 4*

Starting from the Base Control Plan for this intersection, it can be divided in the phases shown in the Figure 36.

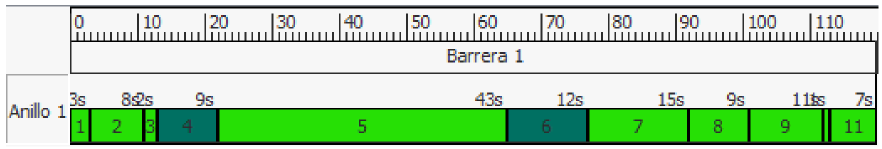



*Figure 36. phases in the Base Control Plan for the intersection 4.*

Applying the algorithm previously stabilised for assign the priority parameter the Table 29 can be constructed.

*Table 29. priority parameters in the Base Control Plan for the intersection 4.*

| **Phase** | **Phase duration [sec]** | **Prioritized** | **Under priority request** | | | **Under no priority request** |
|---|---|---|---|---|---|---|
| | | | Min. Duration [sec] | Max. Duration [sec] | Max out [sec] | phase duration [sec] |
| 1 | 3 | No | - | - | 3 | 3 |
| 2 | 8 | No | - | - | 5 | 8 |
| 3 | 2 | No | - | - | 2 | 2 |
| 4 | 9 | - | - | - | - | 9 |
| 5 | 43 | No | - | - | 10 | 43 |
| 6 | 12 | - | - | - | - | 12 |
| 7 | 15 | Yes | 1 | 15 | - | 5 |
| 8 | 9 | Yes | 1 | 10 | - | 5 |
| 9 | 11 | Yes | 1 | 11 | - | 5 |
| 10 | 1 | No | - | - | 1 | 1 |
| 11 | 7 | No | - | - | 5 | 7 |

### 4.2.2. Modified Control Plan

As exposed in the objectives for this work, the response to different types of Transit Signal Priority are intended to be evaluated, then apart from the scenarios on the previous section where the implementation of Active priority protocols is specified, in this section will be introduced a Passive priority strategy, explained in its respective section (section 2.2.2).

In this case, the Passive priority strategy to implement is the reduction of the Users Delay, because due to the implementation of it is expected a rearrange of the times in the in the control plan for each intersection.

As its name suggest the Users Delay strategy, aims towards a reduction of the average time spend stopped by the transit signal by an individual person in the intersection. Contrary to the usual approach where the subject of interest are the vehicles, in this strategy the occupancy and capacity of the vehicles present a more relevant participation as the amount of people served in a fixed time interval varies importantly depending on those two variables.

The strategy focused on maximize the number of individual users served in the intersection during the duration of the cycle. For the case of this study, having a BRT vehicle with the same capacity to transport the passengers of about 34 familiar vehicles, the High Capacity Vehicle will be prioritized leading to the phases allowing the movement of the PT vehicles have a larger portion of the cycle time.

The average delay per vehicle, in an individual access is defined, for a non-deterministic behaviour, by three components, a deterministic part, a stochastic part and an experimental adjust (F.V. Webster, 1958).

$$d = w_{det} + w_{sto} + w_{exp}$$

$$w_{det} = 0.5 * \frac{c^2}{C} * \frac{\mu}{\mu - \lambda}$$

$$w_{sto} = \frac{\frac{\rho^2}{2}}{(1-\rho) * \lambda}$$

$$w_{exp} = -0.65 * \left(\frac{C}{\lambda^2}\right)^{1/3} * \rho^{2+5*\frac{G}{C}}$$

Where, $\mu$ and $\lambda$ are the service rate and the arrival rate, both measure in vehicles per second; the $R$, $G$ and $C$, respectively are the red time, the green time and the total cycle length, measured in seconds; finally the resting variable is the $\rho$, the saturation degree, it relates the amount of vehicles arriving to the control point and the vehicles effectively passing the control point.

$$\rho = \frac{\lambda * C}{\mu * G}$$

Originally two of the variables discussed above ($\mu$ and $\lambda$) are tough in terms of vehicles per unit time, but for this case they will be considered in users (passengers) per unit time. To do so there are needed some considerations regarding the traffic information, disaggregating the cases by the vehicle type, and regarding the capacity of each access.

To determine the total amount of users hourly passing for each access, the occupancy factor per vehicle needs to be determined (Table 30).

*Table 30. Vehicle occupancy.*

| Vehicle type | Occupancy [per/veh] |
|---|---|
| Cars | 1.5 |
| Motorcycle | 1 |
| Articulated BRT | 128 |
| Non-Articulated BRT | 50 |

The information of the vehicle flows for the mix traffic and the BRT system are obtained from the Table 17 and Table 18 respectively. The respective conversion for the access of the Mix traffic and the BRT access are contained in the Table 31 and Table 32

*Table 31. People flow for mix traffic accesses.*

| Intersection | Turn | Car flow[veh/h] | Motorcycle flow [veh/h] | People flow [per/h] |
|---|---|---|---|---|
| 1 | 1 | 2106 | 1691 | 4504.9 |
| | 2 | 422 | 339 | 903.1 |
| | 4 | 173 | 139 | 369.3 |
| | 5 | 266 | 214 | 569.0 |
| | 8 | 250 | 201 | 535.1 |
| 2 | 1 | 2502 | 2010 | 5353.1 |
| | 2 | 381 | 306 | 815.6 |
| | 6 | 143 | 115 | 305.4 |
| | 7 | 102 | 82 | 219.2 |
| 3 | 1 | 3518 | 2826 | 7525.9 |
| | 2 | 1228 | 986 | 2627.0 |
| | 3 | 1230 | 988 | 2630.9 |
| | 4 | 316 | 254 | 676.0 |
| | 5 | 33 | 26 | 70.5 |
| | 6 | 48 | 38 | 101.8 |
| | 7 | 611 | 490 | 1306.3 |
| 4 | 1 | 1683 | 1352 | 3600.5 |
| | 2 | 2833 | 2276 | 6060.4 |
| | 3 | 403 | 323 | 861.3 |
| | 4 | 850 | 683 | 1819.2 |
| | 7 | 193 | 155 | 412.4 |

*Table 32. Users flow for BRT accesses.*

| Intersection | Turn | Articulated [veh/h] | Non-Articulated [veh/h] | Users flow [per/h] |
|---|---|---|---|---|
| 1 | 1 | 39 | 24 | 6170.0 |
| | 2 | 39 | 24 | 6170.0 |
| 2 | 1 | 39 | 24 | 6170.0 |
| | 2 | 39 | 24 | 6170.0 |
| 3 | 3 | 39 | 24 | 6170.0 |
| | 4 | 39 | 24 | 6170.0 |
| 4 | 3 | 39 | 24 | 6170.0 |
| | 4 | 39 | 24 | 6170.0 |
| | 9(4) | 0 | 38 | 1875.0 |

For the users capacity, first is needed to determine the capacity of the access in vehicles per hour and then transforming into users terms, the capacity is calculated according to the Webters criteria (Victor Gabriel Valencia, 2000).

$$\mu = 525 * access\ width$$

As the equation results are thought in terms of family vehicles (cars), the maximum capacity, in users per vehicle, of the vehicles is used to convert the capacity.

*Table 33. Persons capacity.*

| Intersection | Turn | Lane s [-] | Lane width [m] | Veh. Capacity [veh/h] | Persons Capacity [per/h] |
|---|---|---|---|---|---|
| 1 | 1 | 3 | 3.0 | 4725 | 18900.0 |
| | 2 | 3 | 3.0 | 4725 | 18900.0 |
| | 1 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 2 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 4 | 3 | 3.0 | 4725 | 18900.0 |
| | 5 | 1 | 3.0 | 1575 | 6300.0 |
| | 8 | 2 | 3.0 | 3150 | 12600.0 |
| 2 | 1 | 3 | 3.0 | 4725 | 18900.0 |
| | 2 | 3 | 3.0 | 4725 | 18900.0 |
| | 1 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 2 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 6 | 1 | 3.0 | 1575 | 6300.0 |
| | 7 | 2 | 3.0 | 3150 | 12600.0 |
| 3 | 1 | 4 | 3.0 | 6300 | 25200.0 |
| | 2 | 3 | 3.0 | 4725 | 18900.0 |
| | 3 | 3 | 3.0 | 4725 | 18900.0 |
| | 4 | 3 | 3.0 | 4725 | 18900.0 |
| | 3 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 4 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 5 | 1 | 3.0 | 1575 | 6300.0 |
| | 6 | 1 | 3.0 | 1575 | 6300.0 |
| | 7 | 3 | 3.0 | 4725 | 18900.0 |
| 4 | 1 | 3 | 3.0 | 4725 | 18900.0 |
| | 2 | 3 | 3.0 | 4725 | 18900.0 |
| | 3 | 2 | 3.0 | 3150 | 12600.0 |
| | 4 | 3 | 3.0 | 4725 | 18900.0 |
| | 3 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 4 PT | 2 | 3.5 | 3675 | 14700.0 |
| | 7 | 2 | 3.0 | 3150 | 12600.0 |
| | 9(4) PT | 1 | 3.5 | 1837.5 | 7350.0 |

With these values is now possible to evaluate a new control plan for each intersection, optimising the users delay.

### *Intersection 1*

For the intersection 1, the turns are distributed in 3 phases of the cycle, using the delay function for the individual turns is possible to obtain the optimum green values. They are then adjusted to accommodate better the cycles according to the last part of this section (Traffic light coordination).

*Table 34. Phase distribution, intersection 1.*

| Phase | Activated turn | Optimum Green [sec] | Selected Green [sec] |
|---|---|---|---|
| 1 | 1 | 21.8 | 23 |
| | 2 | | |
| | 1 PT | | |
| | 2 PT | | |
| 2 | 5 | 9.1 | 9 |
| | [1] * | | |
| 3 | 4 | 7.0 | 8 |
| | 8 | | |

**The turn enclosed in brackets are activated in more than one phase*

Specifically, the information about each turn  is contained in the Table 35.

*Table 35. Modified turn information, intersection 1.*

| Turn | Persons flow, λ [per/h] | Person capacity, μ [per/h] | Demand pressure [%] | Lost time [sec] | Green time [sec] | Effective Green [sec] | Saturation [%] | Delay [sec] |
|---|---|---|---|---|---|---|---|---|
| 1 | 4504.9 | 18900.0 | 24% | 5 | 32.0 | 27 | 35% | 0.2 |
| 2 | 903.1 | 18900.0 | 5% | 5 | 23 | 18 | 11% | 1.9 |
| 1 PT | 6170.0 | 14700.0 | 42% | 5 | 23 | 18 | 93% | 3.3 |
| 2 PT | 6170.0 | 14700.0 | 42% | 5 | 23 | 18 | 93% | 3.3 |
| 5 | 569.0 | 6300.0 | 9% | 5 | 9 | 4 | 90% | 9.7 |
| 4 | 369.3 | 18900.0 | 2% | 5 | 8 | 3 | 26% | 9.3 |
| 8 | 535.1 | 12600.0 | 4% | 5 | 8 | 3 | 57% | 9.6 |

Then the whole cycle is distributed following the lineaments of the Table 36.

*Table 36. Modified Control information, intersection 1.*

| Movement | Initial time [s] | Duration [s] |
|---|---|---|
| 1a | 0 | 27 |
| 1b | 0 | 18 |
| 2a | 0 | 18 |
| 2b | 0 | 18 |
| 4 | 32 | 3 |
| 5a | 23 | 4 |
| 5b | 23 | 4 |
| 8 | 32 | 3 |

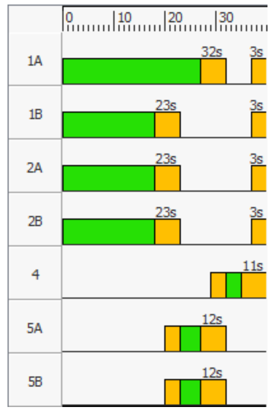



*Figure 37. Cycle of the signal groups in the intersection 1, Modified Control Plan.*

The control plan differentiates 6 phases, depicted in the Figure 38.

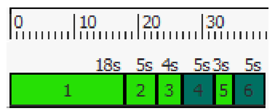



*Figure 38. Phases in the Modified Control Plan for the intersection 1.*

Applying the same algorithm used in the previous section (see Figure 32) to stablish the priority variables, the Table 37 is obtained for the intersection.

*Table 37. Priority parameters in the Base Control Plan for the intersection 1.*

| **Phase** | **Phase duration [sec]** | **Prioritized** | **priority request** | | | **no priority request** |
|---|---|---|---|---|---|---|
| | | | min. Duration [sec] | max. Duration [sec] | Max out[sec] | phase duration [sec] |
| 1 | 18 | Yes | 1 | 18 | - | 5 |
| 2 | 5 | No | - | - | 5 | 5 |
| 3 | 4 | No | - | - | 4 | 4 |
| 4 | 5 | No | - | - | 5 | 5 |
| 5 | 3 | No | - | - | 3 | 3 |
| 6 | 5 | No | - | - | 5 | 5 |

*Intersection 2*

In the intersection 2, the turns are distributed in 3 phases of the cycle, following the procedure in for the interaction 1, the green times for the phases are determined.

*Table 38. Phase distribution, intersection 2.*

| **Phase** | **Activated turn** | **Optimum Green [sec]** | **Selected Green [sec]** |
|---|---|---|---|
| 1 | 1 | 21.5 | 24 |
| | 2 | | |
| | 1 PT | | |
| | 2 PT | | |

| Phase | Activated turn | Optimum Green [sec] | Selected Green [sec] |
|---|---|---|---|
| 2 | 6<br>*[2] | 9.2 | 8 |
| 3 | 7 | 8.6 | 8 |

**The turn enclosed in brackets are activated in more than one phase*

Specifically, the information about each turn are contained in the Table 39.

*Table 39. Modified turn information, intersection 2.*

| Turn | Persons flow, λ [per/h] | Person capacity, μ [per/h] | Demand pressure [%] | Lost time [sec] | Green time [sec] | Effective Green [sec] | Saturation [%] | Delay [sec] |
|---|---|---|---|---|---|---|---|---|
| 1 | 5353.1 | 18900.0 | 28% | 5 | 24 | 19 | 60% | 2.2 |
| 2 | 815.6 | 18900.0 | 4% | 5 | 32 | 27 | 6% | 0.1 |
| 1 PT | 6170.0 | 14700.0 | 42% | 5 | 24 | 19 | 88% | 2.8 |
| 2 PT | 6170.0 | 14700.0 | 42% | 5 | 24 | 19 | 88% | 2.8 |
| 6 | 305.4 | 6300.0 | 5% | 5 | 8 | 3 | 65% | 9.9 |
| 7 | 219.2 | 12600.0 | 2% | 5 | 8 | 3 | 23% | 9.3 |

Then the hole cycle is distributed following the lineaments of the Table 40.

*Table 40. Modified Control information, intersection 2.*

| Movement | Initial time [sec] | Duration [sec] |
|---|---|---|
| 1a | 0 | 19 |
| 1b | 0 | 19 |
| 2a | 0 | 27 |
| 2b | 0 | 19 |
| 7 | 32 | 3 |
| 6 | 24 | 3 |

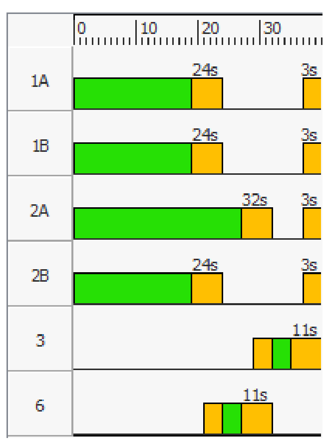



*Figure 39. Cycle of the signal groups in the intersection 2, Modified Control Plan.*

The control plan includes 6 phases, depicted in the Figure 40.

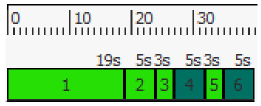



*Figure 40. Phases in the Modified Control Plan for the intersection 2.*

Applying the same algorithm used in the previous section (see Figure 32) to stablish the priority variables; the Table 41 is obtained for the intersection.

*Table 41. Priority parameters in the Base Control Plan for the intersection 2.*

| Phase | Phase duration [sec] | Prioritized | priority request | | | no priority request |
|---|---|---|---|---|---|---|
| | | | min. Duration [sec] | max. Duration [sec] | Max out[sec] | phase duration [sec] |
| 1 | 19 | Yes | 1 | 19 | - | 5 |
| 2 | 5 | No | - | - | 5 | 5 |
| 3 | 3 | No | - | - | 3 | 3 |
| 4 | 5 | No | - | - | 5 | 5 |
| 5 | 3 | No | - | - | 3 | 3 |
| 6 | 5 | No | - | - | 5 | 5 |

### *Intersection 3*

In the intersection 3, the turns are distributed in 4 phases of the cycle, following the procedure in for the interaction 1, the green times for the phases are determined.

*Table 42. Phases distribution, intersection 3.*

| Phase | Activated turn | Optimum Green [sec] | Selected Green [sec] |
|---|---|---|---|
| 1 | 3 | 52.5 | 57 |
| | 4 | | |
| | 3 PT | | |
| | 4 PT | | |
| 2 | 1 | 37.3 | 40 |
| | 2 | | |
| 3 | 5 | 7.4 | 8 |
| | 6 | | |
| 4 | 7 | 12.8 | 15 |

**The turn enclosed in brackets are activated in more than one phase*

Specifically, the information about each turn are contained in the Table 43.

*Table 43. Modified turn information, intersection 3.*

| Turn | Persons flow, λ [per/h] | Person capacity, µ [per/h] | Demand pressure [%] | Lost time [sec] | Green time [sec] | Effective Green [sec] | Saturation [%] | Delay [sec] |
|---|---|---|---|---|---|---|---|---|
| 3 | 2630.9 | 18900.0 | 14% | 4 | 57 | 53 | 32% | 16.9 |
| 4 | 676.0 | 18900.0 | 4% | 4 | 57 | 53 | 8% | 15.1 |
| 3 PT | 6170.0 | 14700.0 | 42% | 4 | 57 | 53 | 95% | 25.7 |
| 4 PT | 6170.0 | 14700.0 | 42% | 4 | 57 | 53 | 95% | 25.7 |
| 1 | 7525.9 | 25200.0 | 30% | 4 | 40 | 36 | 100% | 34.8 |
| 2 | 2627.0 | 18900.0 | 14% | 4 | 40 | 36 | 46% | 28.0 |

| Turn | Persons flow, λ [per/h] | Person capacity, μ [per/h] | Demand pressure [%] | Lost time [sec] | Green time [sec] | Effective Green [sec] | Saturation [%] | Delay [sec] |
|---|---|---|---|---|---|---|---|---|
| 5 | 70.5 | 6300.0 | 1% | 4 | 8 | 4 | 34% | 49.3 |
| 6 | 101.8 | 6300.0 | 2% | 4 | 8 | 4 | 48% | 49.5 |
| 7 | 1306.3 | 18900.0 | 7% | 6 | 15 | 9 | 92% | 43.5 |

Then the hole cycle is distributed following the lineaments of the Table 44.

*Table 44. Modified Control information, intersection 3.*

| Movement | Initial time [sec] | Duration [sec] |
|---|---|---|
| 1 | 57 | 36 |
| 2 | 57 | 36 |
| 3a | 0 | 53 |
| 3b | 0 | 53 |
| 4a | 0 | 53 |
| 4b | 0 | 53 |
| 5 | 97 | 4 |
| 6 | 97 | 4 |
| 7 | 105 | 9 |

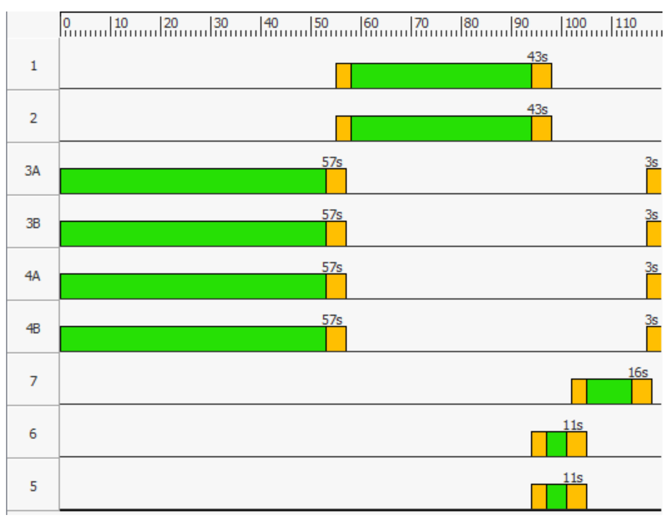



*Figure 41. Cycle of the signal groups in the intersection 3, Modified Control Plan.*

The control plan includes 8 phases, depicted in the Figure 42.

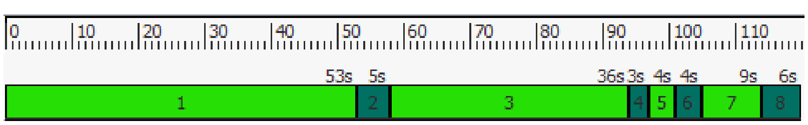



*Figure 42. Phases in the Modified Control Plan for the intersection 3.*

Applying the same algorithm used in the previous section (see Figure 32) to stablish the priority variables; the Table 45 is obtained for the intersection.

Table 45. Priority parameters in the Base Control Plan for the intersection 3.

| Phase | Phase duration [sec] | Prioritized | priority request | | | no priority request |
|---|---|---|---|---|---|---|
| | | | min. Duration [sec] | max. Duration [sec] | Max out[sec] | phase duration [sec] |
| 1 | 53 | Yes | 1 | 53 | - | 5 |
| 2 | 5 | No | - | - | 5 | 5 |
| 3 | 36 | No | - | - | 10 | 36 |
| 4 | 3 | No | - | - | 3 | 3 |
| 5 | 4 | No | - | - | 4 | 4 |
| 6 | 4 | No | - | - | 4 | 4 |
| 7 | 9 | No | - | - | 5 | 9 |
| 8 | 6 | No | - | - | 5 | 6 |

*Intersection 4*

In the intersection 4, the turns are distributed in 3phases of the cycle, following the procedure in for the interaction 1, the green times for the phases are determined.

Table 46. Phase distribution, intersection 4.

| Phase | Activated turn | Optimum Green [sec] | Selected Green [sec] |
|---|---|---|---|
| 1 | 3 | 48.3 | 57 |
| | 4 | | |
| | 3 PT | | |
| | 4 PT | | |
| 2 | 2 | 31.8 | 36 |
| | 7 | | |
| | 9(4) PT | | |
| 3 | 1 | 24.6 | 27 |
| | *[2] | | |

**The turn enclosed in brackets are activated in more than one phase*

Specifically, the information about each turn are contained in the Table 47.

Table 47. Modified turn information, intersection 4.

| Turn | Persons flow, λ [per/h] | Person capacity, μ [per/h] | Demand pressure [%] | Lost time [sec] | Green time [sec] | Effective Green [sec] | Saturation [%] | Delay [sec] |
|---|---|---|---|---|---|---|---|---|
| 3 | 861.3 | 12600.0 | 7% | 4 | 57 | 53 | 15% | 15.6 |
| 4 | 1819.2 | 18900.0 | 10% | 4 | 57 | 53 | 22% | 16.1 |
| 3 PT | 6170.0 | 14700.0 | 42% | 4 | 57 | 53 | 95% | 25.7 |
| 4 PT | 6170.0 | 14700.0 | 42% | 4 | 57 | 53 | 95% | 25.7 |
| 7 | 412.4 | 12600.0 | 3% | 4 | 36 | 32 | 12% | 27.6 |
| 9(4) PT | 1875.0 | 7350.0 | 26% | 4 | 36 | 32 | 96% | 37.6 |
| 1 | 3600.5 | 18900.0 | 19% | 4 | 27 | 23 | 99% | 41.2 |
| 2 | 6060.4 | 18900.0 | 32% | 4 | 63 | 59 | 65% | 17.3 |

Then the hole cycle is distributed following the lineaments of the Table 48.

*Table 48. Modified Control information, intersection 4.*

| Movement | Initial time [sec] | Duration [sec] |
|---|---|---|
| 1 | 93 | 23 |
| 2 | 57 | 59 |
| 3a | 0 | 53 |
| 3b | 0 | 53 |
| 4a | 0 | 53 |
| 4b | 0 | 53 |
| 7 | 57 | 32 |
| 9(4) | 57 | 32 |

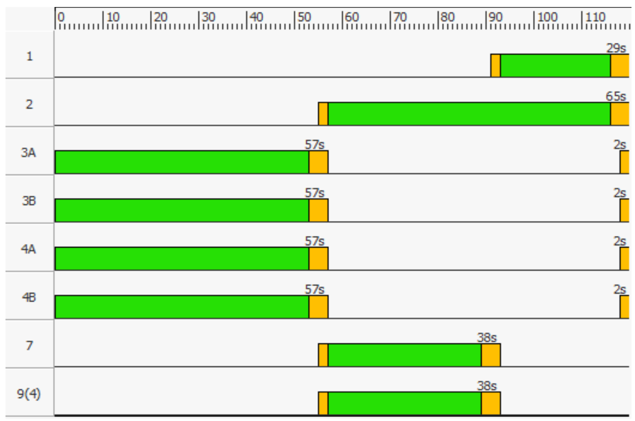



*Figure 43. Cycle of the signal groups in the intersection 4, Modified Control Plan.*

The control plan in the simulation software, then differentiate 6 phases, depicted in the Figure 44.

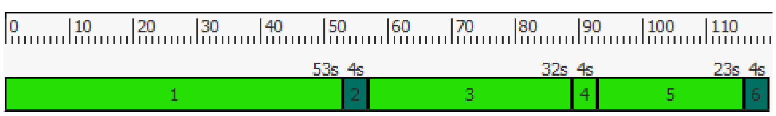



*Figure 44. Phases in the Modified Control Plan for the intersection 4.*

Applying the same algorithm used in the previous section (see Figure 32) to stablish the priority variables; the Table 49 is obtained for the intersection.

*Table 49. Priority parameters in the Base Control Plan for the intersection 4.*

| Phase | Phase duration [sec] | Prioritized | priority request | | | no priority request |
|---|---|---|---|---|---|---|
| | | | min. Duration [sec] | max. Duration [sec] | Max out[sec] | phase duration [sec] |
| 1 | 53 | Yes | 1 | 53 | - | 5 |
| 2 | 4 | No | - | - | 4 | 4 |
| 3 | 32 | Yes | 1 | 32 | - | 5 |
| 4 | 4 | No | - | - | 4 | 4 |
| 5 | 23 | No | - | - | 10 | 23 |
| 6 | 4 | No | - | - | 4 | 4 |

*Traffic light coordination*

As another measure to prioritize the BRT system, along the dedicated corridor the signal lights in the fix control scenario need to be coordinated in order to provide a Green Bandwidth, this means to synchronise the phases of the control plan in such way that the traveling bus encounters always the traffic light in green. As the traffic lights without priority protocols have a pre determine and constant cycle they can be arrange to allow the green bandwidth have a cyclical return, thus the congruency between the cycle length in the various intersection where stablished, all 4 cycles are a multiple of 40 seconds.

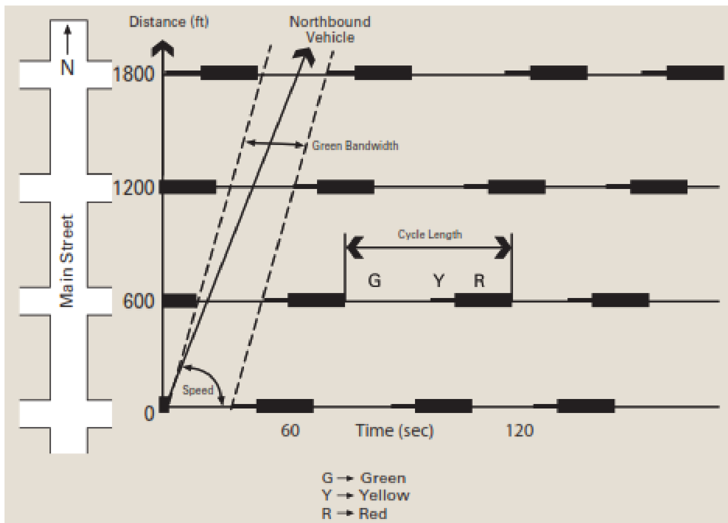



*Figure 45. Green Bandwidth scheme (Smith et al., 2005).*

Supposing the behaviour of a single bus the offset of the deferent control plans can be assessed. To do so it is required to set an average velocity, measure the distance between the intersections and establish the position of the compulsory stops and their duration.

Assuming an average travel speed of 40 km/h and a stop time of 5 seconds in every station, the time set is an estimated average value, compensating the longer durations in the peak hour and the shorter durations in off-peak hours, the itinerary for a bus stopping in all the station will be described in the Table 50.

*Table 50. Expected itinerary of a BRT.*

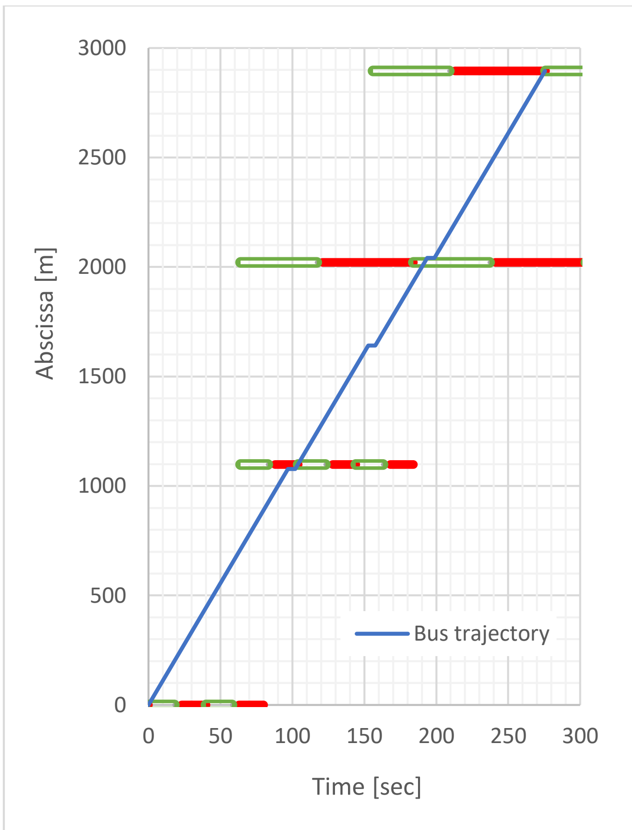
| **Abscissa [m]** | **Point of interest** | **Time [sec]** | |
|---|---|---|---|
| | | Stopped | Ro reach |
| 0 | Intersection 1 | - | 0 |
| 1078 | Melendez station | 5 | 97 |
| 1098 | intersection 2 | - | 104 |
| 1641 | Buitrera station | 5 | 153 |
| 2021 | Intersection 3 | - | 192 |
| 2041 | Univalle station | 5 | 194 |
| 2895 | intersection 4 | - | 276 |

The cycles need to be  set according to how many cycles can be developed prior the bus arriving to the intersection. The  offset calculation is contained in the Table 51.

*Table 51. Defaced time for the cycles in the Modified Control Plan.*

| **Intersection** | **Arrival time [sec]** | **Cycle length, C [sec]** | **Cycles till arrival [-]** Arrival time / C | **offset time [sec]** |
|---|---|---|---|---|
| 1 | 0 | 40 | 0.00 | 0 |
| 2 | 104 | 40 | 2.59 | 24 |
| 3 | 192 | 120 | 1.60 | 24 |
| 4 | 276 | 120 | 2.30 | 36 |

The final trajectory of the bus, and how it is with respect to the control cycles in the intersections is depicted in the Graph 3.




*Graph 3. Bus trajectory, space-time graph.*

## 4.3. Evaluation process

Going along the exposed in the section 2.2.3 “Evaluation of TSP strategies”, the impacts of the strategies modelled in this study are going to be evaluated in terms of the following MoEs.

- Public transport travel time.
- Public transport delay time.
- Public transport average speed.
- Mix traffic Delay.
- Number of stops for Mix traffic.
- Mix Traffic Travel time.

To facilitate the evaluation of the scenarios the MoEs previously mentioned can be aggregate by the type of traffic under evaluation (PT transport and Mix traffic), considering another 2 subdivisions within each one:

- TP transport:
  - "E" lines.
  - Other PT lines.
- Mix traffic:
  - Traffic parallel to the PT corridor.
  - Traffic perpendicular to the PT corridor.

The technique selected to evaluate the alternatives discussed in the previous sections is the "Dimensional Analysis ". This methodology consists in comparing each of the evaluated alternatives with an ideal one, constructed from the values of the alternatives, by a comparison index.

The comparison index reflects how similar the evaluated alternative is to the ideal one, when is value is close to 1 the alternative is close to the ideal one. It is calculated as follows:

$$I_j = \prod_{k=1}^{m} \left[\frac{C_{kj}}{C_{k\,ideal}}\right]^{P_k}$$

Where, $m$ is the total number of variables (factors) in the evaluation; $C_{kj}$ is the value of the variable $k$ for the alternative $j$; $C_{k\,ideal}$ is the ideal value of the variable $k$; finally the las component is the $P_k$, it represent the relative ponderation factor (weight) of the variable $k$. From these components there are 2 that need a deeper explanation.

$C_{k\,ideal}$ is determine for every variable under evaluation, taking the maximum or minimum values of the variable for all the alternatives, the maximum value is choose when the variable is expected to be maximized (the ideal value is the grates value possible), an example of a variable to maximized is the average speed; the other case, are the variables be minimized, the $C_{k\,ideal}$ is the minimum value extracted from the alternatives, an example or this is the average delay.

This maximization and minimization criteria is used also for the ponderation factor ($P_k$) more specifically in its sing, when the variable is to be maximised the ponderation factor assumes a positive sing (+), when is to be minimized the sing is negative (-). With respect of the value itself, it is determined prior the evaluation according to the considerations of the evaluator.

In this evaluation the Ponderation factors ($P_k$) will be set in an scale from 0 to 1, the assignation will depend on how easily the variable is perceived by the user of the respective mean according to the perception of the evaluator, giving more value to the PT related variables, to go with the idea of a TSP project. The factors used in the evaluation, are the ones in the Table 52.

*Table 52. Ponderation factor for the evaluation process.*

| Group | Variable | Unit | Criteria | Sing | Value |
|---|---|---|---|---|---|
| Public transport | Travel time | seconds | minimise | [ - ] | 1 |
| | N. stops | - | minimise | [ - ] | 1 |
| | Speed | km/h | maximise | [ + ] | 0.6 |
| Mix traffic | Travel time | seconds | minimise | [ - ] | 0.6 |
| | Delay | seconds | minimise | [ - ] | 0.4 |
| | N. stops | - | minimise | [ - ] | 0.8 |

The evaluation parameters are depicted in the Table 53.

*Table 53. Evaluation parameters.*

| Group | Variable | Subgroup | Ponderation factor $P_k$ |
|---|---|---|---|
| Public Transport | Travel time [sec] | "E" lines | -1 |
| | | Other lines | -1 |
| | Number of stops [-] | "E" lines | -1 |
| | | Other lines | -1 |
| | Travel speed [km/h] | "E" lines | 0.6 |
| | | Other lines | 0.6 |
| Mix traffic | Travel time [sec] | Parallel traffic | -0.6 |
| | | Perpendicular traffic | -0.6 |
| | Delay [sec] | Parallel traffic | -0.4 |
| | | Perpendicular traffic | -0.4 |
| | Number of stops [-] | Parallel traffic | -0.8 |
| | | Perpendicular traffic | -0.8 |

As the sub groups may have several results in them the value use in the evaluation will be the critical one according to the maximization and minimization criteria, for example, for the case of the Perpendicular traffic in the Mix traffic group the value use in the evaluation of the travel speed will me the minimum registered in the 4 perpendicular paths.

# 5. Results

## 5.1. Validation of the base scenario

As describe in the section 4.1 is necessary to validate the modelled base scenario in order to have a reliable starting point. Using the GEH statistic, that compares the results of the model and the observed flows of the manoeuvres in the intersection 3 (“carrera 100” with “calle 13”) and 4 (“carrera 100” with “calle 13”). The measurements of real vehicle flows obtained from the “documentation for the improvement of mobility in the south of Santiago de Cali” (Secretaria de movilidad de Cali, 2019).

The model results refers to the mean values of 5 replications of the base scenario built in the simulation software.

*Table 54. GEH statistic evaluation.*

| intersection | manoeuvre | Observation [veh/h] | Model [veh/h] | GEH | approbation |
|---|---|---|---|---|---|
| 3 | 1 | 1750 | 1850.4 | 2.37 | TRUE |
| | 2 | 1321 | 1465.0 | 3.86 | TRUE |
| | 3 | 1134 | 1372.8 | 6.75 | FALSE |
| | 4 | 345 | 348.0 | 0.16 | TRUE |
| | 5 | 71 | 69.4 | 0.19 | TRUE |
| | 6 | 132 | 98.0 | 3.17 | TRUE |
| | 7 | 747 | 690.8 | 2.10 | TRUE |
| | 9(1) | 36 | 38.2 | 0.36 | TRUE |
| | 9(2) | 45 | 41.8 | 0.49 | TRUE |
| | 9(3) | 474 | 510.8 | 1.66 | TRUE |
| | 9(4) | 861 | 915.4 | 1.83 | TRUE |
| 4 | 1 | 1984 | 2286.6 | 6.55 | FALSE |
| | 2 | 2453 | 2492.6 | 0.80 | TRUE |
| | 3 | 284 | 363.6 | 4.42 | TRUE |
| | 4 | 1146 | 1008.8 | 4.18 | TRUE |
| | 7 | 233 | 213.2 | 1.33 | TRUE |
| | 9(1) | 289 | 261.8 | 1.64 | TRUE |
| | 9(2) | 66 | 33.4 | 4.62 | TRUE |
| | 9(3) | 798 | 869.0 | 2.46 | TRUE |
| | 9(4) | 414 | 504.4 | 4.22 | TRUE |

As the 90% of the pairs pass the GEH test the model can be considered as reliable. About the pairs that have a GEH value greater than 5, none of them exceeds the GEH of 10 and thus are considered not excessive differences.

## 5.2. Scenarios results

### 5.2.1. Base Condition

At the starting point of the modelling process is necessary to clarify that the scenarios included in the following comparisons are modelled with a reduced demand, the decision of no using the complete demand was taken due to the considerable lengths of the virtual queues encountered when modelling the base scenario at full demand.

Analysing the base scenario at full demand was seen in the sections of entrance from the nodes that the queue of accumulated vehicles exceeds the length of the section. The vehicles stopped outside the modelled network are measured in the so-called virtual queue, which is a problem. In fact, the vehicles located outside the road network are not included in the calculation of the model output variables, such as velocity, delay time and number of stops.

Although the modelled base scenario with the whole demand pass the validation process, these long queues of vehicles are not experience in real live. This has its explanation in the values used to perform the validation, the data set used in the validation process corresponds to the flows of the different manoeuvres in the intersections 3 and 4, the results against they are compared are the flows allowed to pass by the control plan.

In the case the access is in a oversaturated condition the amount of vehicles allowed to pass through the access has already reach its peak of serviceability and the value will no vary significantly despite any increment in the arrival rate, once reached the saturation level of an access with an specific control plan, increasing the demand will not change the amount of vehicles capable of pass through the access creatin a permanent queue.

In the reality the presence of the queue is not so extended, probably due to the existence of alternative  paths the drivers may use to go from one point to another, that is not accounted in the model as it is a simplification of the real road network.

The reduced demand  used was of 50% of the calculated demand  (Table 55). .

*Table 55 general variables for the modelled base scenario.*

| Variable | Base scenario | Base scenario (50%) | difference [%] |
|---|---|---|---|
| density [veh/km] | 44.3 | 9.0 | -79.61 |
| flow [veh/h] | 10801.0 | 8756.0 | -18.93 |
| delay time [sec/km] | 441.7 | 121.9 | -72.40 |
| mean queue [veh] | 1864.6 | 144.4 | -92.26 |
| mean virtual queue [veh] | 2866.6 | 0.0 | -100.00 |

As exposed in the Table 55, there is a significant reduction of the characteristic variables of the system using a reduce demand, the one to highlight the most is the total reduction of the virtual queue. The variable with less variation is flow in the system, this is because it does not refer to the entering flow to the system (sum of the production of each node) that is the one reduced, but refers to the average flow of the sections in the network.

Going into more detailed results of the reduction of the demand is possible to see the impact on the intersections.

*Table 56. effects on intersections of the demand reduction.*

| Intersection | Delay [sec/veh] | | Delay relative difference [%] | Level of Service | |
|---|---|---|---|---|---|
| | Base scenario | Base scenario (50%) | | Base scenario | Base scenario (50%) |
| 1 | 82.7 | 23.9 | -71.14 | F | C |
| 2 | 11.7 | 12.6 | 8.35 | B | B |
| 3 | 111.4 | 45.1 | -59.57 | F | D |
| 4 | 59.2 | 21.9 | -62.91 | E | C |

In the Table 56 it is evident that the reduction on the demand improves the behaviour of the intersections, the delay is significantly reduced in the congestion intersections allowing, seen also the level of service increasing from F to C or E in the intersections 1 and 3.

The other relevant component in the model is the behaviour of the public transport, and thus, it is also affected by the reduction of the demand (see Table 57).

*Table 57. effects on Public Transport lanes of the demand reduction.*

| PT line | Flow [veh/h] | | | Delay time [se c/veh] | | | Travel time [sec] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Base scenario | Base scenario (50%) | Relative difference [%] | Base scenario | Base scenario (50%) | Relative difference [%] | Base scenario | Base scenario (50%) | Relative difference [%] |
| E21 | 9.0 | 9.0 | 0.00 | 404.5 | 339.8 | -16.00 | 8924.0 | 8238.9 | -7.68 |
| E31 | 6.0 | 5.2 | -13.33 | 453.4 | 393.5 | -13.21 | 6230.4 | 5126.5 | -17.72 |
| E41 | 8.0 | 6.0 | -25.00 | 369.3 | 347.9 | -5.79 | 7579.3 | 5551.1 | -26.76 |
| P10A | 7.0 | 6.2 | -11.43 | 394.3 | 330.2 | -16.24 | 7115.4 | 5783.0 | -18.73 |
| P10B | 7.0 | 7.0 | 0.00 | 89.7 | 49.4 | -44.97 | 1123.2 | 828.9 | -26.20 |
| P10D | 6.0 | 6.0 | 0.00 | 81.3 | 45.3 | -44.29 | 905.2 | 685.7 | -24.25 |
| P12A | 6.0 | 6.0 | 0.00 | 86.4 | 42.8 | -50.52 | 982.6 | 719.3 | -26.79 |
| P17-A | 6.0 | 6.0 | 0.00 | 168.3 | 155.5 | -7.62 | 2907.6 | 2853.3 | -1.87 |
| P17-B | 1.0 | 2.0 | 100.00 | 323.8 | 120.3 | -62.85 | 612.8 | 805.4 | 31.44 |
| P21A | 8.0 | 8.0 | 0.00 | 110.9 | 52.9 | -52.27 | 1461.0 | 1033.3 | -29.27 |
| P21B | 9.8 | 9.6 | -2.04 | 90.7 | 43.2 | -52.37 | 1639.5 | 1180.0 | -28.03 |
| P27C | 8.0 | 7.2 | -10.00 | 452.1 | 386.2 | -14.59 | 8737.6 | 7362.2 | -15.74 |
| T31 | 11.0 | 9.0 | -18.18 | 350.6 | 336.0 | -4.17 | 11315.0 | 8748.3 | -22.68 |

The public transport then, has no significant variation in the majority of the lines when the flow is evaluated, varying in 1 or 2 vehicles, probably effect of the variance included in the parameters of the behaviour of the lines (dwell time, frequency, velocity, etc). More important are the effects on the delay and the travel time specially for the lines that go outside the dedicated lanes (P lines).

The reduction in the traffic demand allows an overall reduction on the time spend for the travel, in average 16%. The only atypical value is the one corresponding to the P17-B, it exhibits an unexpected increase of the travel time. After analysing the scenario with the reduced demand the particular increase of travel time in the P17-B line may occur by the increase of the demand of the gates “B” of “Universidades” station, hindering the flow of this line that does not need to stop in the station. The reduction on the total travel time may be in its majority reason the reduction of the delay due to congestion, seen the P lines with a reduction on average of 35% of the delay when the other lanes have a reduction on average less than 10%.

### 5.2.2. Priority on Base Control Plan

*Intersection response*

As an initial point, the delay on the intersection is useful to have a general perspective of the impacts of the priority protocols used in the models, as its main variable is the time each manoeuvre in the intersection is allow to be perform. In the Table 58 and in the Table 59 are shown the results in terms of the delay per vehicle, private and public, in the intersection and the level of service according to the HCM criteria.

*Table 58. Intersection delay, priority on Base Control Plan*

| Intersection | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 1 | 25.7 | 17.8 | 31.1 | 24.4 | 24.9 | 24.2 | 24.2 | 25.4 | 25.3 | 42.0 | 42.7 |
| 2 | 12.5 | 12.3 | 12.3 | 14.2 | 12.0 | 11.5 | 11.6 | 15.4 | 14.7 | 18.3 | 15.3 |
| 3 | 45.3 | 45.8 | 45.3 | 45.8 | 45.5 | 95.3 | 133.1 | 79.3 | 88.4 | 104.4 | 117.6 |
| 4 | 22.2 | 23.2 | 22.6 | 22.4 | 22.4 | 21.8 | 21.8 | 34.0 | 25.5 | 59.8 | 60.7 |

*Table 59. Level of Service of the intersections, priority on Base Control Plan*

| Intersection | LOS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 1 | C | B | C | C | C | C | C | C | C | D | D |
| 2 | B | B | B | B | B | B | B | B | B | B | B |
| 3 | D | D | D | D | D | F | F | E | F | F | F |
| 4 | C | C | C | C | C | C | C | C | C | E | E |

The priority protocols affect the intersection delay mainly in the intersection it is implemented, only in the protocols considered in the intersection 4 exclusively (P0-D BC and P1-D BC) the delay of the intersections 2, 3 and 4 have a relevant variation.

Specifically talking about the increase or decrease of the intersection delay, with respect to the base condition, in general terms the majority of the protocols result in an increase of the delay, expressed also in the modification of the level of service, where the level stays constant (intersection 2 and 4) or reduced (intersection 3) when the priority protocol are considered. The only relevant reduction in the intersection delay is present for the scenario P0-A BC, reflected also in an improvement on the LOS.

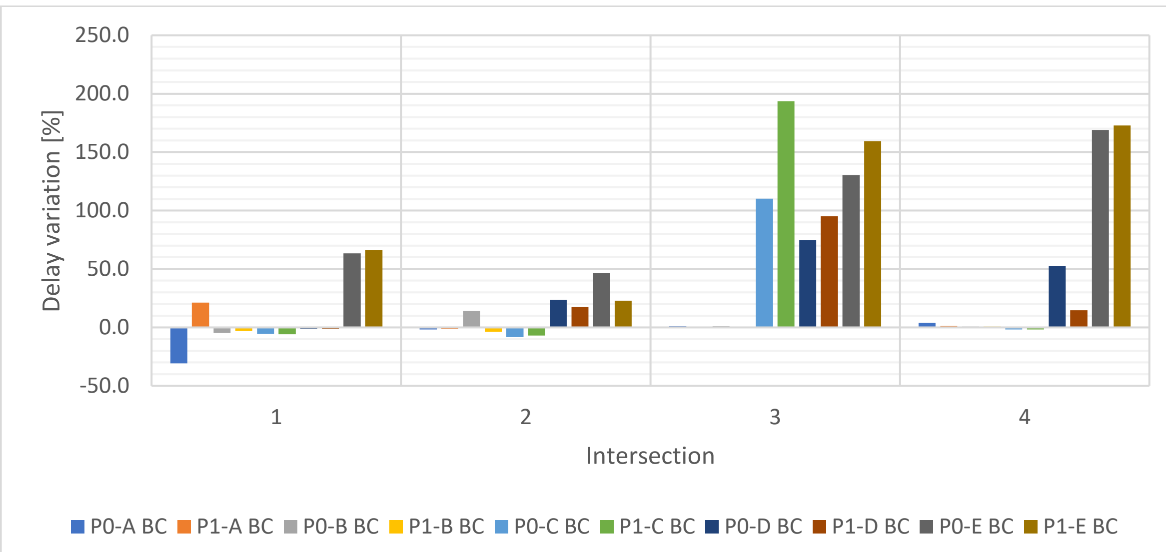
*Table 60. Variation of intersection delay in percentage, priority on Base Control Plan.*

| Intersection | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **P0-A BC** | **P1-A BC** | **P0-B BC** | **P1-B BC** | **P0-C BC** | **P1-C BC** | **P0-D BC** | **P1-D BC** | **P0-E BC** | **P1-E BC** |
| 1 | -30.8 | 21.3 | -4.8 | -3.0 | -5.7 | -5.8 | -1.2 | -1.5 | 63.4 | 66.3 |

| Intersection | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 2 | -1.7 | -1.5 | 14.0 | -3.6 | -8.2 | -6.9 | 23.7 | 17.4 | 46.4 | 22.7 |
| 3 | 1.0 | -0.1 | 1.1 | 0.4 | 110.2 | 193.7 | 75.0 | 95.0 | 130.3 | 159.6 |
| 4 | 4.1 | 1.4 | 0.8 | 0.8 | -1.9 | -1.9 | 52.7 | 14.6 | 169.0 | 172.9 |

The most penalising results are the ones obtained in the scenarios with priority protocols located on intersections 3 and 4. For the protocols in the intersection 3 exclusively, the “all lines” and “E” lines priority scenarios, result in a high increase on the intersection delay, 194% and 110 % correspondently. The other protocols reaching a variation above 100, are the “E” scenarios, where all intersections have prioritization protocols.

Furthermore, an interesting behaviour occurs for scenarios including priority protocols for intersection 4. In these, it appears that the greatest impact occurs at neighbouring intersections: increase in delay of about 80% for intersection 3 and about 20% for intersection 2 (Graph 4), this is in contrast to the other scenarios where the most penalised intersection is the one where priority is implemented.




*Graph 4. relative difference of the delay for the intersections, priority on Base Control Plan.*

The  scenarios P0 E BC and P1 E BC in an overall impact to the network resulting not only in an increment of the delay for all intersections but with a high magnitude, contrasting with the other protocols in the same intersections, especially in the intersection 3 and 4, with average increments for  these protocols of 145% and 171% correspondingly.

*Accesses response*

To look in depth of the previously results about the delay of each intersection, is important to analyse the values of the delay of each access composing each intersection.

For the intersection 1, the accesses delay and the relative variation with respect to the base scenario information is contained in the Table 61 and Table 62.

In Figure 46 the names of the accesses are shown.

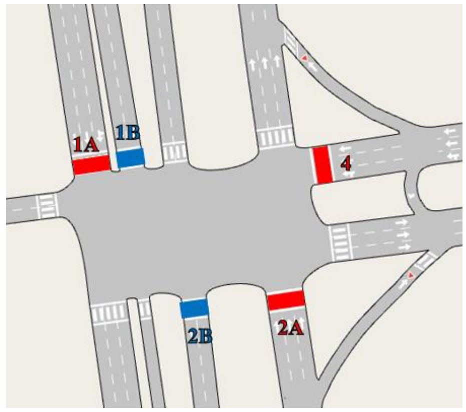



*Figure 46. Access denomination, intersection 1.*

*Table 61. Delay for the accesses of the intersection 1, priority on Base Control Plan.*

| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 2B (PT) | 5.2 | 13.4 | 3.4 | 26.1 | 22.2 | 3.8 | 2.1 | 6.2 | 6.8 | 10.7 | 11.5 |
| 1B (PT) | 29.2 | 10.9 | 3.9 | 26.6 | 28.1 | 26.5 | 27.5 | 28.3 | 27.3 | 13.3 | 13.2 |
| 1A | 21.7 | 15.1 | 34.4 | 19.7 | 20.6 | 20.1 | 19.9 | 21.4 | 21.3 | 45.7 | 47.2 |
| 2A | 24.3 | 25.9 | 22.2 | 23.7 | 21.5 | 23.0 | 23.2 | 22.9 | 23.5 | 25.2 | 27.0 |
| 4 | 45.1 | 18.7 | 20.8 | 45.1 | 45.9 | 44.9 | 46.5 | 45.2 | 46.3 | 30.9 | 30.6 |

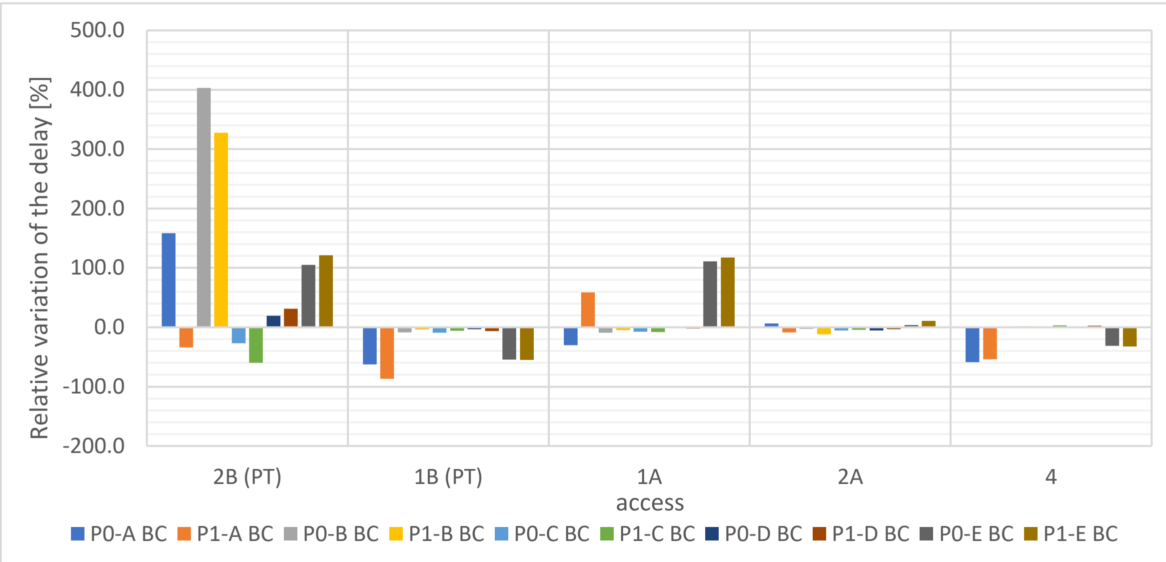
*Table 62. Variation of delay for the accesses of the intersection 1, priority on Base Control Plan.*

| Access | Relative variation of the delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 2B (PT) | 158.7 | -34.0 | 403.0 | 327.8 | -27.1 | -60.0 | 19.2 | 31.4 | 105.2 | 121.3 |
| 1B (PT) | -62.6 | -86.5 | -8.9 | -3.7 | -9.4 | -5.8 | -3.1 | -6.5 | -54.5 | -54.8 |
| 1A | -30.2 | 58.6 | -9.1 | -5.0 | -7.4 | -8.1 | -1.2 | -2.0 | 110.8 | 117.4 |
| 2A | 6.5 | -8.8 | -2.6 | -11.7 | -5.3 | -4.4 | -5.7 | -3.4 | 3.5 | 10.9 |
| 4 | -58.5 | -54.0 | -0.1 | 1.7 | -0.4 | 3.0 | 0.2 | 2.8 | -31.4 | -32.2 |

In the intersection 1 the access 2B, which corresponds to the south access of the public transport, is the one more affected by all the priority protocols, even the ones imposed on other intersections. The Priority protocols in the intersection 2 (P0 B BC and P1 B BC) result in an increment of 403% and 327% on the delay of the access 2B, this behaviour is to be expected as it is an access connected to other intersections, thus capable to exhibit the effects of the protocols outside the intersection 1.

For the scenarios with the protocols implemented in the intersection 1 (P0 A BC and P1 A BC), they modified considerably the delay in almost every access, excepting the 2A (see blue and orange bars Graph 5).

The P0 A BC protocol exhibits an increase of the delay of 159%, less than the effects of the protocols imposed in the intersection 2. For the other access the result is a reduction of the delay, especially in the access 1B (-62%). The P1 A BC protocol also has its mayor reduction of delay in the access 1B (-86%), but the increment is now present in the access 1A (58%).




*Graph 5. Relative variation of the delay for the accesses in the intersection 1, Priority on Base Control Plan*

In the case of the intersection 2, the results of the delay in the accesses (name explained in Figure 47) are displayed in the Table 63 and Table 64.

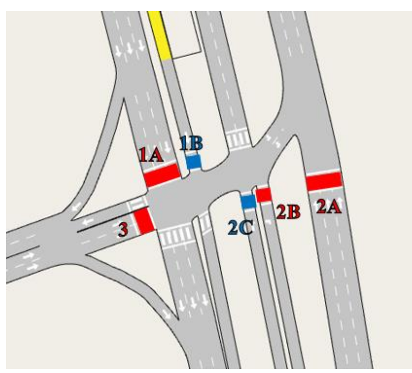



*Figure 47. Access denomination, intersection 2.*

*Table 63. Delay for the accesses of the intersection 2, priority on Base Control Plan.*

| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 1B (PT) | 27.5 | 19.3 | 20.3 | 17.8 | 6.5 | 27.0 | 27.0 | 27.3 | 26.3 | 16.6 | 7.0 |

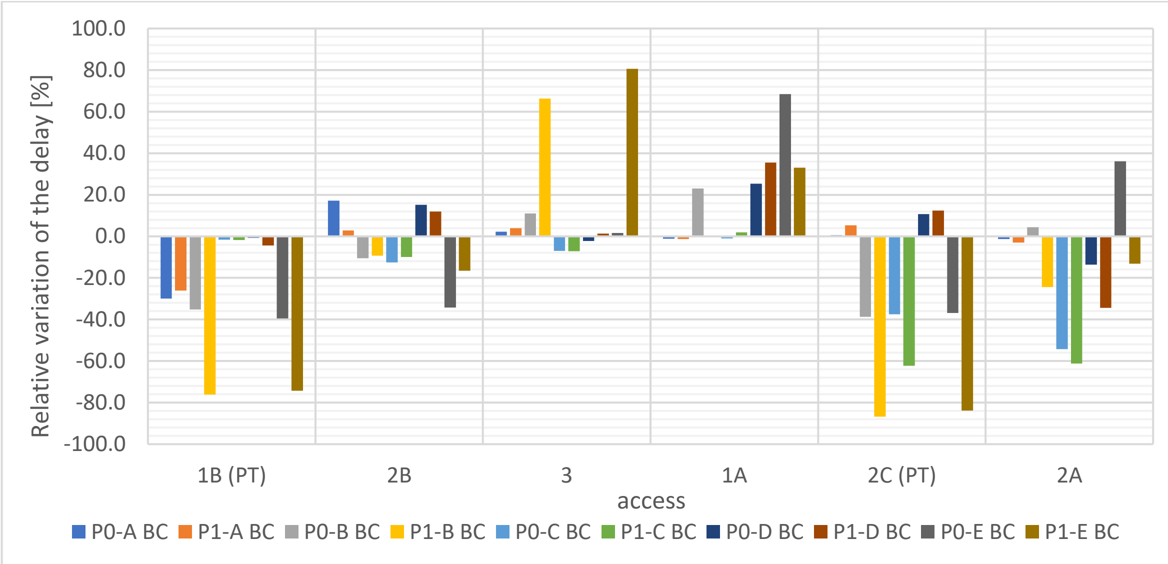
| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Base (50%)** | **P0-A BC** | **P1-A BC** | **P0-B BC** | **P1-B BC** | **P0-C BC** | **P1-C BC** | **P0-D BC** | **P1-D BC** | **P0-E BC** | **P1-E BC** |
| 2B | 34.9 | 40.9 | 35.9 | 31.2 | 31.7 | 30.5 | 31.4 | 40.2 | 39.1 | 22.9 | 29.1 |
| 3 | 34.2 | 35.0 | 35.6 | 38.0 | 56.9 | 31.8 | 31.8 | 33.5 | 34.7 | 34.8 | 61.8 |
| 1A | 11.0 | 10.8 | 10.8 | 13.5 | 11.0 | 10.9 | 11.2 | 13.7 | 14.8 | 18.5 | 14.6 |
| 2C (PT) | 23.7 | 23.8 | 25.0 | 14.5 | 3.1 | 14.8 | 8.9 | 26.2 | 26.6 | 15.0 | 3.8 |
| 2A | 8.8 | 8.7 | 8.5 | 9.2 | 6.6 | 4.0 | 3.4 | 7.6 | 5.8 | 11.9 | 7.6 |

*Table 64.Variation of delay for the accesses of the intersection 2, priority on Base Control Plan*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 1B (PT) | -29.9 | -26.1 | -35.2 | -76.2 | -1.7 | -1.8 | -0.7 | -4.4 | -39.5 | -74.4 |
| 2B | 17.2 | 2.8 | -10.6 | -9.4 | -12.6 | -10.0 | 15.1 | 11.9 | -34.3 | -16.6 |
| 3 | 2.2 | 4.0 | 11.0 | 66.4 | -7.0 | -7.1 | -2.2 | 1.3 | 1.6 | 80.7 |
| 1A | -1.2 | -1.2 | 23.0 | 0.0 | -1.0 | 2.0 | 25.4 | 35.5 | 68.5 | 33.1 |
| 2C (PT) | 0.5 | 5.4 | -38.8 | -86.7 | -37.5 | -62.4 | 10.7 | 12.4 | -36.8 | -83.8 |
| 2A | -1.2 | -3.0 | 4.4 | -24.3 | -54.2 | -61.2 | -13.6 | -34.4 | 36.0 | -13.1 |

In this second intersection (Table 64), there are no extreme variations compared to the base scenario (over 150%), as was observed in the intersection 1. The reduction on the delay expected in the PT accesses due to the implementation of priority protocols is more evident, as shown in the Graph 6. The accesses 1B and 2C, corresponding to the public transport lanes, exhibit an improvement, although not for every priority protocol, in both accesses the mayor reduction is present for the P1 B BC protocol (yellow bar Graph 6), for the access 1B is -76% and for the 2C is -87%.

Another feature to highlight in this access is the reductions of the delay present when the intersection prior to the access is affected by a priority protocol. I n the case of the aces 1B reductions are present for the protocols P0 A BC and P1 A BC with a reductions of about 28%; for the access 2C the reductions correspond to the protocols P0 C BC and P1 C BC respectively 38% and 62%.




*Graph 6. Relative variation of the delay for the accesses in the intersection 2, Priority on Base Control Plan*

Another access affected positively with the reduction of the delay in the protocols P0 A BC and P1 A BC are the 2A, where the priority protocols implemented in the intersection 3 result in the major reduction (about 57%). The protocols implemented in the same intersection have diverse results, an increase for the only "E" lines protocol, less than 5% (0.4 seconds) and for the protocol giving priority to all lines the reductions exceed the 20%.

For this intersection the access with the highest increase of the delay is the 3, with a variation of 66%, a normal result as it is the only access perpendicular to the priority lanes in addition to the protocol it corresponds, P1 B BC, is expected to restrict more the green time for the no parallel lanes and thus increasing the delay due to the control. Also is clear in the Graph 6, the protocols affecting the most in negative way to this intersection are the ones in which the priority is impose in the intersection 4 (P0 D BC and P1 D BC), resulting in a detriment for the behaviour in the accesses 2B, 2C and 1A, this last one although is not directly connected to the intersection 4.

For the intersection 3, the results of the delay in the access (named in Figure 48) are displayed in the Table 65 and Table 66.

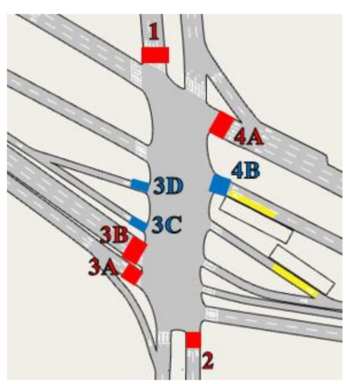



*Figure 48. Access denomination, intersection 3.*

*Table 65. Delay for the accesses of the intersection 3, priority on Base Control Plan.*

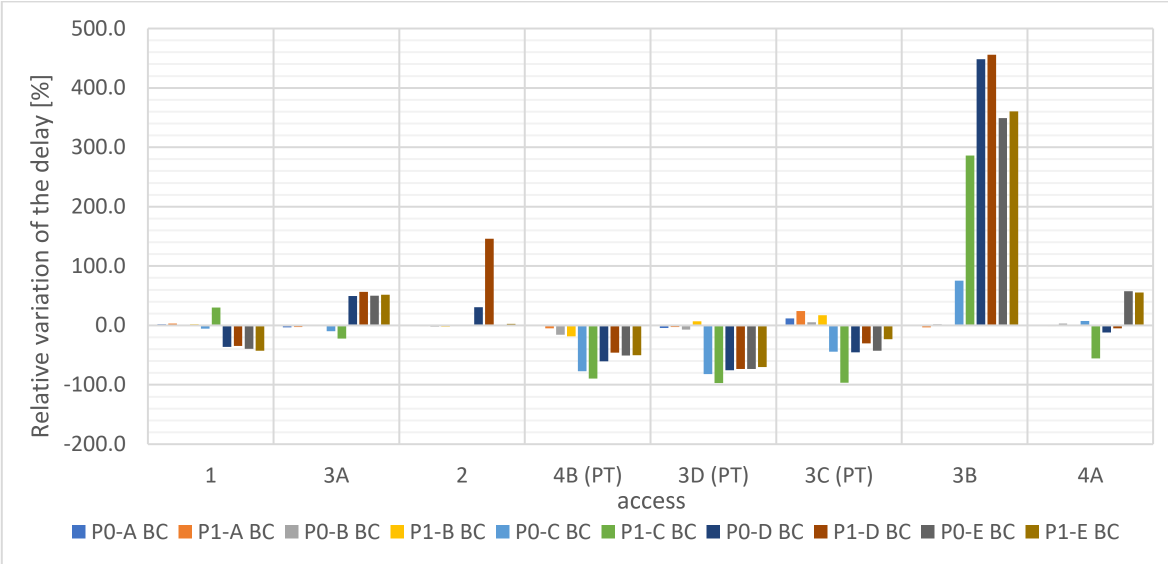
| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 1 | 49.9 | 50.8 | 51.4 | 50.4 | 51.0 | 47.2 | 64.9 | 31.8 | 32.7 | 30.1 | 28.5 |
| 3A | 10.9 | 10.5 | 10.5 | 11.0 | 10.8 | 9.8 | 8.5 | 16.2 | 17.0 | 16.3 | 16.5 |
| 2 | 17.5 | 17.4 | 17.3 | 17.1 | 17.2 | 17.5 | 17.8 | 22.9 | 43.2 | 17.4 | 18.0 |
| 4B (PT) | 60.3 | 61.3 | 57.4 | 50.7 | 49.2 | 13.8 | 6.2 | 23.9 | 32.6 | 29.7 | 29.9 |
| 3D (PT) | 53.6 | 51.2 | 52.2 | 49.9 | 57.4 | 9.7 | 1.5 | 13.2 | 14.4 | 14.3 | 16.1 |
| 3C (PT) | 50.7 | 56.7 | 62.9 | 53.2 | 59.3 | 28.4 | 1.6 | 27.6 | 35.2 | 29.1 | 39.0 |
| 3B | 55.6 | 55.6 | 53.9 | 56.8 | 56.0 | 97.5 | 214.8 | 305.1 | 309.3 | 250.0 | 256.3 |
| 4A | 31.5 | 32.0 | 31.2 | 32.4 | 31.6 | 33.8 | 14.0 | 27.8 | 30.0 | 49.6 | 49.1 |

*Table 66. Variation of delay for the accesses of the intersection 3, priority on Base Control Plan*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 1 | 1.9 | 3.1 | 1.1 | 2.2 | -5.4 | 30.1 | -36.2 | -34.5 | -39.6 | -42.8 |
| 3A | -3.5 | -2.9 | 1.7 | -0.2 | -9.8 | -22.0 | 49.4 | 56.4 | 49.8 | 51.9 |
| 2 | -0.8 | -1.4 | -2.3 | -2.1 | -0.5 | 1.6 | 30.7 | 145.9 | -0.6 | 2.4 |
| 4B (PT) | 1.8 | -4.7 | -15.8 | -18.4 | -77.1 | -89.7 | -60.3 | -45.8 | -50.7 | -50.3 |
| 3D (PT) | -4.4 | -2.6 | -6.9 | 7.1 | -82.0 | -97.3 | -75.4 | -73.2 | -73.4 | -69.9 |
| 3C (PT) | 11.9 | 24.2 | 5.1 | 17.0 | -44.0 | -96.8 | -45.5 | -30.5 | -42.6 | -23.0 |
| 3B | -0.2 | -3.1 | 2.0 | 0.6 | 75.2 | 286.1 | 448.3 | 455.9 | 349.3 | 360.7 |
| 4A | 1.7 | -1.1 | 3.0 | 0.3 | 7.3 | -55.4 | -11.8 | -4.7 | 57.6 | 55.7 |

In this intersection the variations of the delay present extreme values (see Graph 7) as in the intersection 1. In this case in the access 3B, reaching an increase of 456% and 448% for the protocols imposing priority in the intersection 4 exclusively (P1 D BC, P0 D BC). Other protocol resulting in a high increase in the delay is the P1 C BC, expected as the access 3B in the one that allow the left turn from west to north, thus been highly affected by the time the crossing movements in the west-east axis are in green.

The accesses corresponding to the dedicated PT lanes (3C, 3D and 4B) exhibit considerable reductions for the protocols in the intersection 3 and 4. More notable is the fact that the accesses 3C and 3D depicts an impact due to the priority given in the intersection 4, when this accesses are not feed by this intersection. More logical would be for the protocols in the intersection 2 to impact the behaviour of these accesses.




*Graph 7. Relative variation of the delay for the accesses in the intersection 3, Priority on Base Control Plan*

The other accesses have a no significant  variation for specific protocols, . The access 1 undergoes an increase in the P1 C BC of 30% for the protocols in the intersection 4, the delay was reduced in average by 35%. The access 3A inverts the results of the access 1 for the same protocols, the increase corresponds to the protocols P0 D BC and P1 D BC about the 52%, for the reduction of the reduction is 22%. the access 2 only is affected considerably by the protocol P1 D BC, going beyond the bobble of the delay comparing to the base scenario (145%).

Finally, for the intersection 4, the results of the delay in the access (named in Figure 49) are displayed in the Table 67 ad Table 68.

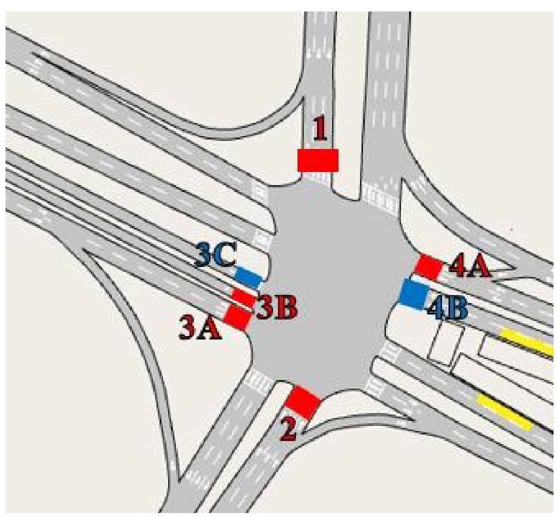



*Figure 49. Access denomination, intersection 4.*

*Table 67. Delay in seconds for the accesses of the intersection 4, priority on Base Control Plan.*

| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Base (50%)** | **P0-A BC** | **P1-A BC** | **P0-B BC** | **P1-B BC** | **P0-C BC** | **P1-C BC** | **P0-D BC** | **P1-D BC** | **P0-E BC** | **P1-E BC** |
| 3A | 34.6 | 35.7 | 36.6 | 33.8 | 33.0 | 27.3 | 24.8 | 17.1 | 10.9 | 19.9 | 23.4 |
| 4A | 51.8 | 57.0 | 54.4 | 53.6 | 53.9 | 53.6 | 52.7 | 52.2 | 30.0 | 385.2 | 381.0 |
| 4B (PT) | 40.6 | 39.4 | 37.2 | 37.4 | 37.4 | 39.9 | 42.3 | 28.7 | 9.6 | 24.9 | 23.9 |
| 3C (PT) | 59.7 | 56.5 | 55.3 | 48.7 | 49.1 | 76.4 | 90.4 | 18.6 | 11.2 | 62.3 | 58.0 |
| 1 | 53.2 | 54.0 | 52.8 | 53.7 | 52.9 | 247.7 | 344.9 | 134.4 | 93.6 | 196.8 | 242.4 |
| 3B | 64.4 | 66.3 | 64.5 | 70.2 | 68.4 | 49.9 | 46.9 | 38.6 | 83.5 | 38.1 | 40.7 |
| 2 | 7.1 | 7.3 | 7.3 | 7.2 | 7.2 | 7.2 | 7.3 | 12.5 | 23.0 | 9.6 | 9.8 |

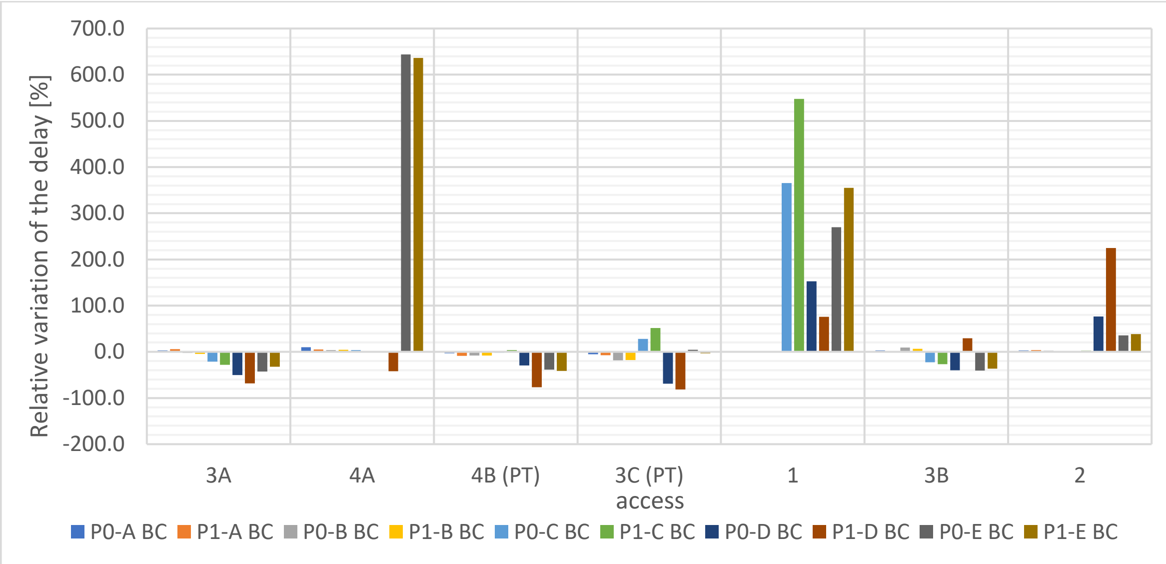
*Table 68. Variation of delay for the accesses of the intersection 3, priority on Base Control Plan*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| 3A | 3.0 | 5.7 | -2.4 | -4.8 | -21.2 | -28.5 | -50.6 | -68.4 | -42.5 | -32.5 |
| 4A | 10.1 | 5.2 | 3.6 | 4.1 | 3.5 | 1.8 | 0.8 | -42.1 | 644.3 | 636.3 |
| 4B (PT) | -2.9 | -8.4 | -7.9 | -8.0 | -1.7 | 4.0 | -29.3 | -76.3 | -38.6 | -41.1 |
| 3C (PT) | -5.4 | -7.4 | -18.5 | -17.8 | 28.0 | 51.5 | -68.8 | -81.2 | 4.3 | -2.9 |
| 1 | 1.4 | -0.9 | 0.9 | -0.6 | 365.2 | 547.8 | 152.4 | 75.8 | 269.6 | 355.2 |
| 3B | 2.9 | 0.1 | 9.0 | 6.2 | -22.5 | -27.1 | -40.0 | 29.6 | -40.9 | -36.8 |
| 2 | 3.1 | 3.5 | 2.0 | 1.3 | 0.9 | 2.5 | 76.4 | 225.1 | 35.6 | 38.3 |

From the results is possible to see mainly 3 features, the first one is the major impact of the protocols imposing priority exclusively in the intersection 3 (P0 C BC and P1 C BC) in the access 1 the delay increase by 365% and 548% respectably. Having this high impact in an access perpendicular to the priority lanes, is remarkable see the minimum impact in the other perpendicular access (access 2), where for the same protocols the variation does not exceeds 3%.

The other feature to highlight is about the impact of the protocols imposed in the same intersection 4, (P0 C BC and P1 C BC), in general terms the ones affecting the most the different accesses, excepting the access 1 exposed before (see light blue and green bars in Graph 8), these protocol follow what is expected for the priority protocols, giving a reduction for the access parallel to the priority lanes, the only exception to this is the increase in the access 3B for the protocol P1 D BC.

The final feature to remark for this intersection is the results of the scenarios P0 E BC and P1 E BC ( dark grey and brown bars in the Graph 8). These scenarios generate the highest increase in the delay in the intersection, corresponding to the access 4A, reaching values higher than 600% in both cases. The access 4A was expected to be affected by the protocol prioritizing all PT lines because the right turn of the PT will block it, but the protocol P1 D BC actually produce a reduction (-42%).




*Graph 8. Relative variation of the delay for the accesses in the intersection 4, Priority on Base Control Plan*

From the information provided by modelling the priority protocol is possible to extract several important observations. One of the most important is the effect that a priority strategy applied at one intersection can have on the others. In general terms is evident the effect occurring in the accesses connected to other intersections, as a clear example of this is the behaviour of the intersection 1 and 4 (see Graph 5 and Graph 8), the extremes of the modelled network, where the protocols implemented outside the specific intersection only have an impact in the accesses coming from the inside the network, in the intersection 1the access 2B and for the intersection 4 the access 3C. In the other two intersections the phenomenon is similar but accounting not for only one access but 2, because the intersection is connected to two other intersections of the network.

Although this is a general behaviour, the results show exceptions, in this case all occurring when implementing the protocols P0 D BC and P1 D BC, corresponding to the intersection 4. In the intersection 2 these protocols lead to an increase of the delay in the access 1A and in the intersection 3 the impact was in the access 3A. This e is remarkable because not only the access does not receive traffic coming from the intersection 4, but also the intersection 2 is not adjacent to the control plan modified in these protocols.

Another observation on the behaviour of the access is how the scenarios where the priority protocols are imposed in every intersection (P0 E BC and P1 E BC) have different result depending on the position of the intersection. In the middle intersections (2 and 3) these protocols follow the expected result of replicating the behaviour of the scenarios considering active priority individually in these intersections, obtaining similar numerical results. At the extremes of the network (intersections 1 and 4) this tendency is not present, clearly shown in the already discussed case of the access 4A on the intersection 4 or in the access 1A for the intersection 1.

Focusing now on the impacts on the BRT system, all the protocols, in general terms, conclude with a reduction of the delay for the access corresponding to the dedicated lanes, being the intersection 2 and 3 the ones more beneficiated. The generalized improve has its exceptions, the more  significant being the access 2B on the intersection 1 where 7 of the 10 protocols result in an increase of the delay, 5 of them duplicating it. Another example of exception can be found in the intersection 4, access 3C, where the protocols P0 C BC and P1 C BC result in an increment of 30% and 50%, probably explained due to the, already discussed, increase on the arrival rate.

*Path response*

Going again into a more global picture of the network, is important to analyse the behaviour of the main paths within it (see Figure 50), this in order to look at important variables for the comfort of the users of the mix traffic lanes. The variables studied in this case are the average spatial speed along the path (average speed) and stop time and number of stops.

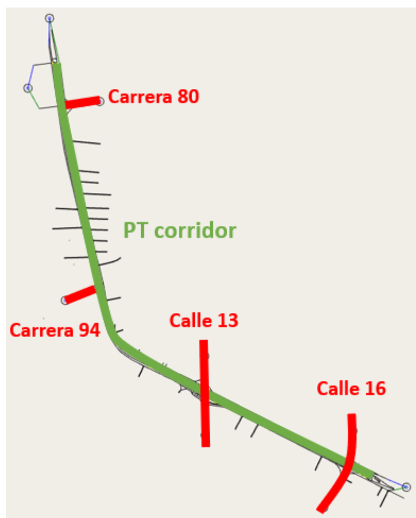



*Figure 50. Path denomination.*

Starting from the average speed, it refers to the average speed reached by every vehicle moving through the specific path, this variable account the variation of the velocity due to the congestion and stops caused by the control devices. Ideally the speed is expected to be near the maximum velocity allowed, in this case 60 km/h, this is behaviour is likely to be exhibit in the corridor along the PT dedicated lines, as the constriction due to the control devices is projected to be fairly reduced.

*Table 69. Average speed in the principal paths, Priority on Base Control Plan.*

| Path | Average speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | **P0-A BC** | **P1-A BC** | **P0-B BC** | **P1-B BC** | **P0-C BC** | **P1-C BC** | **P0-D BC** | **P1-D BC** | **P0-E BC** | **P1-E BC** |
| PT corridor N-S | 31.20 | 31.92 | 31.66 | 30.74 | 31.66 | 34.51 | 34.05 | 21.98 | 20.79 | 16.56 | 21.47 |

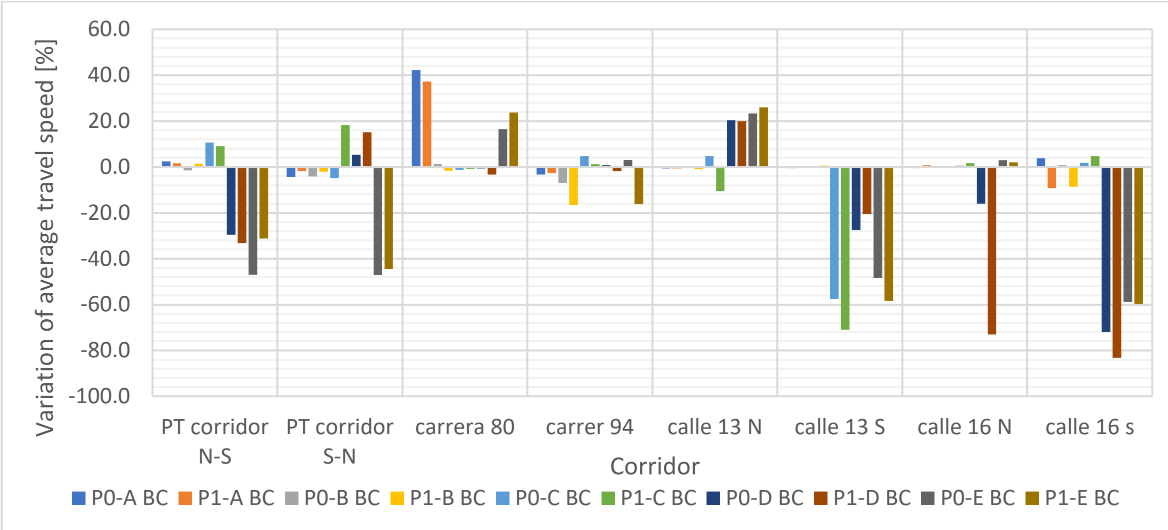
| Path | Average speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor S-N | 30.14 | 28.82 | 29.61 | 28.90 | 29.51 | 28.67 | 35.66 | 31.75 | 34.70 | 15.93 | 16.74 |
| carrera 80 | 18.62 | 26.48 | 25.55 | 18.84 | 18.30 | 18.39 | 18.47 | 18.49 | 18.01 | 21.69 | 23.04 |
| carrera 94 | 26.51 | 25.64 | 25.82 | 24.66 | 22.11 | 27.77 | 26.85 | 26.68 | 26.02 | 27.33 | 22.17 |
| calle 13 N | 29.75 | 29.53 | 29.54 | 29.83 | 29.45 | 31.18 | 26.60 | 35.81 | 35.69 | 36.69 | 37.46 |
| calle 13 S | 30.65 | 30.47 | 30.68 | 30.55 | 30.81 | 13.03 | 8.92 | 22.24 | 24.32 | 15.82 | 12.75 |
| calle 16 N | 35.28 | 35.09 | 35.54 | 35.35 | 35.21 | 35.47 | 35.88 | 29.61 | 9.52 | 36.31 | 35.95 |
| calle 16 S | 27.59 | 28.63 | 25.02 | 27.77 | 25.23 | 28.10 | 28.90 | 7.72 | 4.65 | 11.36 | 11.14 |

From the results contained in the Table 69, firstly is shown that the ideal condition mentioned above does not occurred in none of the modelled situations. Unexpectedly, the maximum value registered, around 40 km/h, does not occur in the PT corridor but for one of the transversal paths. In general, the average speed for the PT corridors does not show a significant variation, but in some particular cases, the scenarios including the intersection 4 with active priority protocols, the variation is a reduction of more than 5 km/h, for the N-S sense the P0 D BC, P1 D BC, P0 E BC and P1 E BC; for the S-N sense only the P0 E BC and P1 E BC protocols. This result demonstrates the high impact on the network response by implementation of priority on the intersection 4 have.

*Table 70. Variation of average speed in the principal paths, Priority on Base Control Plan.*

| Path | Relative variation of the average speed [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor N-S | 2.3 | 1.5 | -1.5 | 1.5 | 10.6 | 9.2 | -29.5 | -33.3 | -46.9 | -31.2 |
| PT corridor S-N | -4.4 | -1.8 | -4.1 | -2.1 | -4.9 | 18.3 | 5.3 | 15.1 | -47.2 | -44.5 |
| carrera 80 | 42.3 | 37.2 | 1.2 | -1.7 | -1.2 | -0.8 | -0.7 | -3.3 | 16.5 | 23.8 |
| carrera 94 | -3.3 | -2.6 | -7.0 | -16.6 | 4.8 | 1.3 | 0.7 | -1.9 | 3.1 | -16.4 |
| calle 13 N | -0.7 | -0.7 | 0.3 | -1.0 | 4.8 | -10.6 | 20.4 | 20.0 | 23.3 | 25.9 |
| calle 13 S | -0.6 | 0.1 | -0.3 | 0.5 | -57.5 | -70.9 | -27.5 | -20.7 | -48.4 | -58.4 |
| calle 16 N | -0.5 | 0.8 | 0.2 | -0.2 | 0.5 | 1.7 | -16.1 | -73.0 | 2.9 | 1.9 |
| calle 16 S | 3.8 | -9.3 | 0.7 | -8.6 | 1.8 | 4.8 | -72.0 | -83.2 | -58.8 | -59.6 |

For the other paths is possible see how the tendency established when individual intersections have active priority protocols, is reflected in the protocols considering active priority in all the intersections. As shown in Graph 9 in the path called "carrera 80" there is an increase in average speed for the protocols affecting the intersection 1 exclusively P0 A BC and P1 A BC (blue and orange bars).

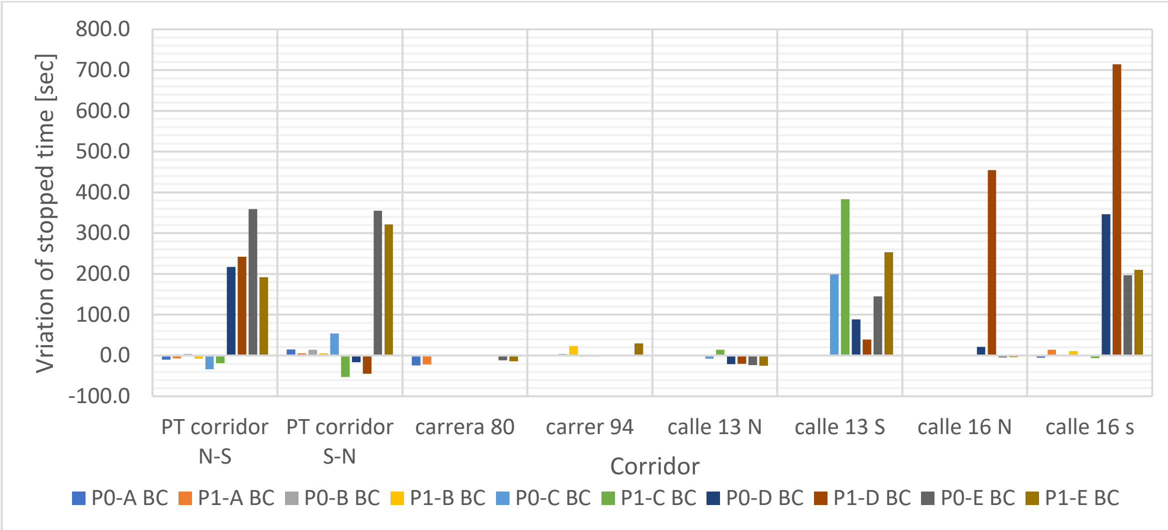



*Graph 9. variation of average in speed in the paths, Priority on Base Control Plan.*

Another variable of interest considered is the stop time along the routes already considered, as it can have economic and psychological impacts on the user, is expected it is reduced or at least maintained within a limit. The behaviour of this variable is reported in an absolute form in the Table 71 and relative to the total travel time in the Table 72, important to referee also to the relative measure as it accounts to the length of the followed path.

*Table 71. average stop time in the principal paths, Priority on Base Control Plan.*

| Path | Stop time [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor N-S | 133.4 | 123.4 | 126.3 | 137.2 | 125.9 | 99.3 | 114.7 | 350.4 | 376.1 | 492.9 | 325.3 |
| PT corridor S-N | 137.8 | 153.1 | 143.6 | 151.6 | 143.5 | 191.6 | 85.2 | 121.4 | 93.2 | 493.1 | 459.0 |
| carrera 80 | 44.2 | 20.3 | 21.9 | 43.1 | 45.1 | 43.7 | 45.1 | 43.3 | 45.8 | 32.3 | 30.2 |
| carrera 94 | 33.6 | 34.4 | 34.9 | 37.4 | 56.7 | 31.2 | 31.1 | 32.8 | 34.0 | 34.2 | 63.4 |
| calle 13 N | 52.5 | 53.2 | 53.6 | 52.1 | 53.3 | 44.7 | 66.4 | 31.2 | 31.8 | 29.1 | 27.5 |
| calle 13 S | 50.1 | 51.2 | 50.1 | 50.8 | 49.9 | 249.6 | 433.8 | 138.7 | 89.3 | 195.2 | 303.5 |
| calle 16 N | 27.2 | 27.3 | 26.2 | 26.3 | 27.0 | 26.4 | 26.0 | 48.7 | 481.8 | 22.4 | 23.1 |
| calle 16 S | 50.6 | 45.1 | 65.1 | 49.9 | 61.5 | 50.8 | 44.3 | 396.8 | 764.9 | 247.2 | 260.7 |




*Graph 10. Variation of the stopped time in the paths, Priority on Base Control Plan*

Relative to the variation of the stopped time there are some extreme variations, being the most dramatical located in the paths perpendicular to the PT corridor, as this paths are the shortest, the response marks the supposed negative effect expected due to the priority protocol implementation.

In general terms the protocols having the most detrimental results are the ones providing priority in all 4 intersections (P0 E BC and P1 E BC), the impact of these can be seen in the PT corridor in both senses; the “calle 13” coming from the south and the “calle 16” coming from the south (see Graph 10). Second to these protocols, the P0 D BC and P1 D BC also have a high impact specially in the “calle 16” where the protocol P1 D BC reach an increase of 714 seconds in the path coming from south, and 454 seconds coming from north.

Looking to the reductions present in this set of protocols, they do not exceed 50 seconds, the major reductions are present in the PT corridor. For the N-S path have a greater proportion of protocols resulting in reductions (6 out of 1), in the S-N path the proportion is less( 3 out of 10), but here the protocol P1 C BC results in the grater reduction for all cases.

Observing now to the stopped time in relative terms with respect to the total travel time, it is comprehended between a minimum value of 23% and a maximum value of 86%, these extreme values correspond to the paths perpendicular to the PT dedicated lanes, increasing the discordancy with respect to the with the expectations upon the improvement of the behaviour of the PT corridor, for which the time spend stopped with the priority protocols implemented should be reduced.

*Table 72. percentage of time stopped in the principal paths, Priority on Base Control Plan.*

| **Path** | **Proportion of stopped time [%]** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor N-S | 33.7 | 31.8 | 32.4 | 34.0 | 32.3 | 27.6 | 30.3 | 55.9 | 57.4 | 62.7 | 53.5 |

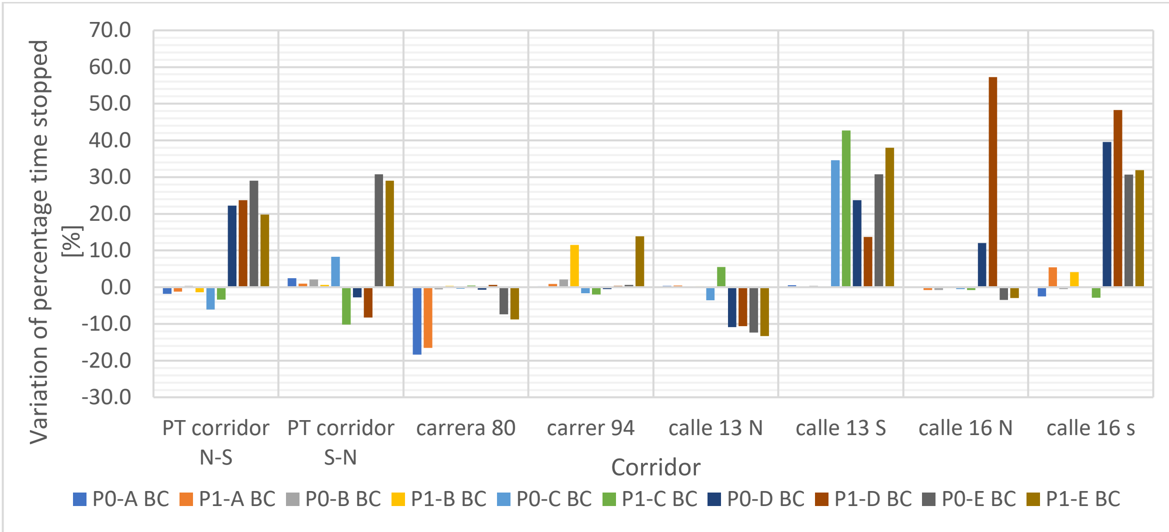
| Path | Proportion of stopped time [%] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor S-N | 36.5 | 38.9 | 37.5 | 38.5 | 37.1 | 44.8 | 26.3 | 33.7 | 28.2 | 67.3 | 65.5 |
| carrera 80 | 63.8 | 45.4 | 47.2 | 63.2 | 64.2 | 63.4 | 64.2 | 63.1 | 64.5 | 56.4 | 55.0 |
| carrera 94 | 58.6 | 58.9 | 59.5 | 60.7 | 70.2 | 57.0 | 56.6 | 58.1 | 58.9 | 59.2 | 72.5 |
| calle 13 N | 39.6 | 40.0 | 40.1 | 39.4 | 39.9 | 36.1 | 45.2 | 28.7 | 29.0 | 27.3 | 26.3 |
| calle 13 S | 39.4 | 39.9 | 39.5 | 39.8 | 39.3 | 74.0 | 82.1 | 63.1 | 53.1 | 70.2 | 77.4 |
| calle 16 N | 26.2 | 26.1 | 25.5 | 25.4 | 26.0 | 25.7 | 25.4 | 38.2 | 83.5 | 22.7 | 23.2 |
| calle 16 S | 37.9 | 35.4 | 43.3 | 37.4 | 42.0 | 38.0 | 35.0 | 77.5 | 86.2 | 68.6 | 69.8 |

In general, is seeing a congruence with the features highlighted when looking to the absolute values of the stop time, referring to the tendencies of increase or reduction, the general impact to the mix traffic occurs in the scenarios P0 D BC, P1 D BC, P0 E BC and P1 E BC.

Furthermore, the relative terms allow a better measure of the impact and the most important feature to highlight are the two extreme values (86.2% and 22.7%), located in the same path (calle 16 ). The major impact is for the protocol P1 D BC in the path "calle 16" coming from north, increasing the percentage of time stopped by 57%, and the path coming from south increase in 48%, meaning that although the absolute variation is higher in the south path, the mayor impact is actually in the north path.

*Table 73. variation of the percentage of time stopped in the principal paths, Priority on Base Control Plan.*

| Path | Total variation of proportion of stopped time [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor N-S | -1.9 | -1.2 | 0.3 | -1.4 | -6.1 | -3.4 | 22.2 | 23.7 | 29.0 | 19.8 |
| PT corridor S-N | 2.4 | 1.0 | 2.1 | 0.6 | 8.3 | -10.2 | -2.8 | -8.2 | 30.8 | 29.1 |
| carrera 80 | -18.4 | -16.6 | -0.6 | 0.4 | -0.4 | 0.4 | -0.7 | 0.7 | -7.4 | -8.8 |
| carrera 94 | 0.3 | 0.9 | 2.1 | 11.6 | -1.6 | -2.0 | -0.5 | 0.3 | 0.6 | 13.9 |
| calle 13 N | 0.4 | 0.5 | -0.2 | 0.3 | -3.5 | 5.5 | -10.9 | -10.6 | -12.4 | -13.3 |
| calle 13 S | 0.5 | 0.0 | 0.4 | -0.1 | 34.6 | 42.7 | 23.7 | 13.7 | 30.8 | 38.0 |
| calle 16 N | 0.0 | -0.7 | -0.8 | -0.2 | -0.5 | -0.8 | 12.0 | 57.3 | -3.5 | -3.0 |
| calle 16 S | -2.5 | 5.4 | -0.5 | 4.1 | 0.1 | -2.9 | 39.6 | 48.3 | 30.7 | 31.9 |




*Graph 11. total variation of the percentage of time stopped in the paths, Priority on Base Control Plan*

Revising the last of the three variables discussed for the path analysis, the number of stops (Table 74 and Table 75) performed along a path in average for each vehicle is also associated to the comfort of the users performing that travel and the wear of their vehicles.

*Table 74. number of stops in the principal paths, Priority on Base Control Plan.*

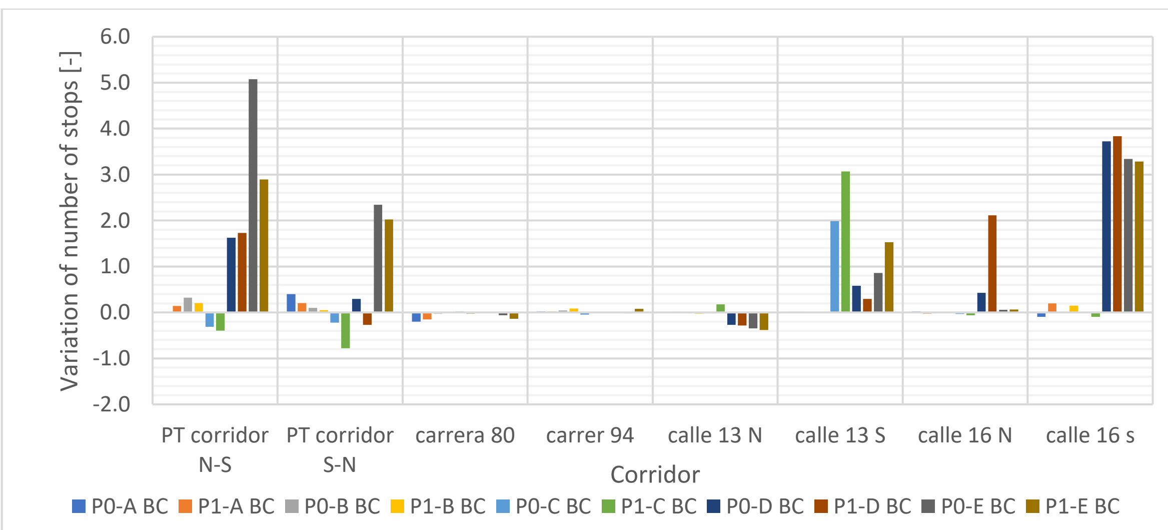
| path | Number of stops [-] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor N-S | 3.2 | 3.2 | 3.3 | 3.5 | 3.4 | 2.9 | 2.8 | 4.8 | 4.9 | 8.3 | 6.1 |
| PT corridor S-N | 2.7 | 3.1 | 3.0 | 2.9 | 2.8 | 2.5 | 2.0 | 3.0 | 2.5 | 5.1 | 4.8 |
| carrera 80 | 1.0 | 0.8 | 0.8 | 0.9 | 1.0 | 1.0 | 0.9 | 0.9 | 1.0 | 0.9 | 0.8 |
| carrera 94 | 0.7 | 0.8 | 0.7 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 |
| calle 13 N | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.5 | 1.0 | 1.0 | 1.0 | 0.9 |
| calle 13 S | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 2.9 | 4.0 | 1.5 | 1.2 | 1.7 | 2.4 |
| calle 16 N | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 1.2 | 2.9 | 0.9 | 0.9 |
| calle 16 S | 1.2 | 1.1 | 1.4 | 1.2 | 1.4 | 1.2 | 1.1 | 4.9 | 5.0 | 4.5 | 4.5 |

The lines of thinking of this variable are similar to those of the time spend stopped when were analysed the absolute terms, the paths along PT corridor are expected to have the highest values because of it contains several intersections, this is effectively obtained in the major of the cases studied, clearly depicted in the base scenario. Looking into the scenarios with priority protocols there are some that does not follow these lineaments, the protocols implementing priority in the intersection 4 (P0 D BC and P1 D BC) where the "calle 16" coming from the south is the path with the grates number of stops about 5 stops in average, slightly more than the ones fort the PT corridor coming from the north.

Due to the priority protocols the number of stops in the paths along the PT corridor is projected to be reduced, as the time in green for these are expected to be grater. The perpendicular corridors are likely to have a more restrain flow of vehicles, resulting in more stops. The mentioned behaviour is not accomplished for all the scenarios (see the Table 75 and Graph 12), the PT corridor exhibits in general terms an increase of the number of stops, the obtained reductions are concentrated in the protocol implementing priority in the intersection 3 exclusively. The other paths have, as predicted, a marked increase, except for the "calle 13" coming from the north for which the tendency is to have no variation or a reduction.

*Table 75. variation on the number of stops in the principal paths, Priority on Base Control Plan.*

| Path | Variation of the number of stops [-] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| PT corridor N-S | 0.0 | 0.1 | 0.3 | 0.2 | -0.3 | -0.4 | 1.6 | 1.7 | 5.1 | 2.9 |
| PT corridor S-N | 0.4 | 0.2 | 0.1 | 0.1 | -0.2 | -0.8 | 0.3 | -0.3 | 2.3 | 2.0 |
| carrera 80 | -0.2 | -0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 |
| carrera 94 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| calle 13 N | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | -0.3 | -0.3 | -0.3 | -0.4 |
| calle 13 S | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 3.1 | 0.6 | 0.3 | 0.9 | 1.5 |
| calle 16 N | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | 0.4 | 2.1 | 0.1 | 0.1 |
| calle 16 S | -0.1 | 0.2 | 0.0 | 0.1 | 0.0 | -0.1 | 3.7 | 3.8 | 3.3 | 3.3 |




*Graph 12. total variation on the number of stops in the paths, Priority on Base Control Plan.*

Looking to the results corresponding to the mix traffic, we obtain a general detriment of the mobility when the Transit Signal Priority (TSP) is employed. Although the projected results in many cases are no achieved, this fact most significantly seen in the path analysis where, along the PT corridor, the affectation due to the priority protocols leads to worsen the conditions instead of the improvement expected when applying the TSP. Furthermore, the results for certain protocols, those involving the intersection 4, have a drastic response in most of the paths, for every variable considered.

Going to the intersection and accesses analysis, continuing focus in the mix traffic, the impact to the system of the intervention with priority protocols of the intersection 4, continues to stand above the other protocols evaluated to this point. As can be seen in the specific sections for the accesses of each intersection these protocols affect the access far away of the intersection 4, and even those not accessible to the vehicles coming from this intersection.

*BRT response*

Now, the discussion will be centred in the analysis of the results of the priority protocols applied upon the Base Control Plan with resect of the BRT system, as stated before the central component for the evaluation of the implementation of a Transit Signal Priority system in this case.

The first variable to study the BRT performance will be the average speed registered by each PT line in the system, similar to the stated in the path analysis the limit velocity is 60 km/h. Considering that the BRT vehicles are required stop at specific stations, the ideal scenario of the vehicles traveling at maximum speed is likely to not occur, The Table 76 and Table 77 contain the average speed for the PT lines and it relative variation compared to the base condition.

*Table 76. Average speed of the PT lines, Priority on Base Control Plan.*

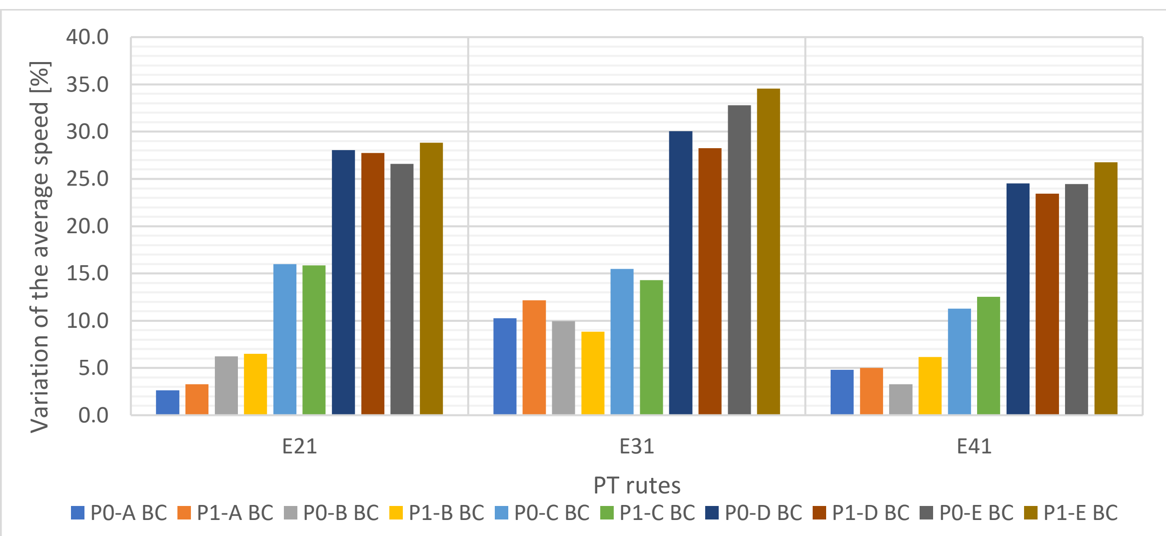
| Name | Average speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | 27.7 | 28.4 | 28.6 | 29.4 | 29.4 | 32.1 | 32.0 | 35.4 | 35.3 | 35.0 | 35.6 |
| E31 | 25.4 | 28.0 | 28.5 | 27.9 | 27.6 | 29.3 | 29.0 | 33.0 | 32.6 | 33.7 | 34.2 |
| E41 | 27.7 | 29.0 | 29.1 | 28.6 | 29.4 | 30.8 | 31.1 | 34.4 | 34.1 | 34.4 | 35.1 |
| P10A | 27.1 | 26.7 | 27.4 | 27.2 | 28.2 | 29.5 | 30.6 | 30.4 | 30.8 | 29.5 | 30.2 |
| P10B | 24.0 | 22.9 | 24.2 | 25.4 | 24.1 | 25.2 | 24.8 | 23.6 | 33.1 | 26.5 | 27.0 |
| P10D | 24.4 | 24.6 | 24.2 | 24.5 | 24.6 | 24.5 | 23.4 | 27.0 | 34.2 | 26.4 | 26.2 |
| P12A | 24.6 | 24.9 | 24.4 | 24.7 | 24.2 | 25.1 | 24.3 | 23.6 | 32.8 | 25.7 | 23.7 |
| P17-A | 27.8 | 27.9 | 28.3 | 27.6 | 28.4 | 28.2 | 28.0 | 30.6 | 30.6 | 30.2 | 31.0 |
| P17-B | 31.8 | 29.8 | 31.7 | 30.7 | 32.3 | 31.3 | 34.8 | 30.0 | 29.1 | 29.9 | 29.1 |
| P21A | 23.4 | 20.5 | 21.7 | 23.5 | 22.8 | 22.0 | 21.8 | 24.6 | 33.6 | 25.7 | 27.8 |
| P21B | 23.1 | 23.9 | 25.6 | 25.1 | 24.1 | 24.9 | 24.4 | 24.6 | 33.3 | 24.6 | 25.7 |
| P27C | 24.4 | 26.0 | 27.0 | 26.1 | 26.9 | 27.7 | 28.0 | 28.4 | 28.8 | 28.7 | 29.9 |
| T31 | 26.4 | 26.5 | 27.5 | 26.8 | 28.0 | 28.3 | 29.5 | 29.3 | 29.9 | 28.8 | 29.5 |

From the Table 76, the results exhibit a clear difference between the lines going exclusively along the dedicated lanes and the ones using them briefly. The first group (the 3 “Expreso” lines, the T31, the P10A, the P27C and the P17 lanes) have a higher average for all the cases evaluated, about 30 km/h; the highest velocities are concentrated, as forecast in the “E” lines; more specific, in the protocols P0 D BC, P1 D BC, P0 E BC and P1 E BC. The P1 D BC is the one that have the highest results for all the other lines, in this group the minimum value is 32.6 km/h and the maximum is 35,6 km/h. For most of the protocols the line with the greatest average speed is the P17 coming from the south (it is sectioned because the middle part of the route is performed outside the modelled network), the exceptions to this tendency are the protocol already mentioned.

*Table 77. Variation of average speed of the PT lines, Priority on Base Control Plan.*

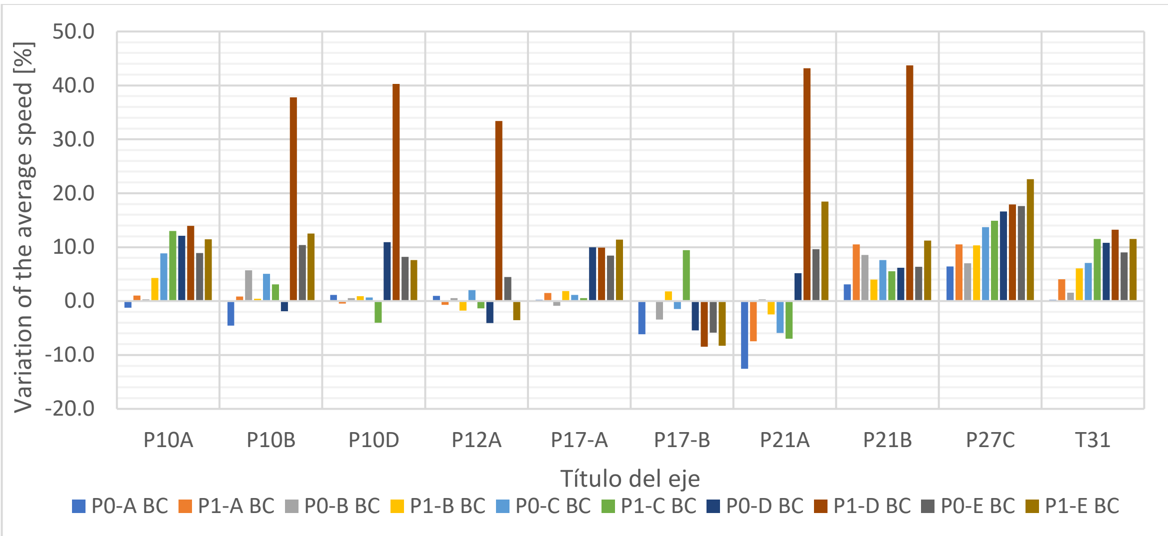
| Name | Relative Variation of the average speed [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | 2.6 | 3.3 | 6.2 | 6.5 | 16.0 | 15.9 | 28.1 | 27.7 | 26.6 | 28.8 |
| E31 | 10.3 | 12.2 | 10.0 | 8.8 | 15.5 | 14.3 | 30.1 | 28.3 | 32.8 | 34.5 |
| E41 | 4.8 | 5.0 | 3.3 | 6.1 | 11.3 | 12.5 | 24.5 | 23.4 | 24.5 | 26.8 |
| P10A | -1.3 | 1.0 | 0.3 | 4.3 | 8.8 | 13.0 | 12.1 | 13.9 | 8.9 | 11.4 |
| P10B | -4.6 | 0.8 | 5.7 | 0.4 | 5.0 | 3.1 | -1.9 | 37.8 | 10.4 | 12.5 |
| P10D | 1.1 | -0.4 | 0.6 | 0.9 | 0.7 | -4.0 | 10.9 | 40.3 | 8.2 | 7.6 |
| P12A | 1.0 | -0.7 | 0.5 | -1.8 | 2.0 | -1.3 | -4.1 | 33.4 | 4.5 | -3.6 |
| P17-A | 0.3 | 1.5 | -0.9 | 1.8 | 1.1 | 0.5 | 9.9 | 9.9 | 8.4 | 11.4 |
| P17-B | -6.1 | -0.1 | -3.4 | 1.8 | -1.4 | 9.4 | -5.4 | -8.5 | -5.9 | -8.3 |
| P21A | -12.6 | -7.5 | 0.3 | -2.5 | -5.9 | -7.0 | 5.2 | 43.2 | 9.6 | 18.5 |
| P21B | 3.1 | 10.5 | 8.5 | 4.0 | 7.6 | 5.5 | 6.2 | 43.7 | 6.3 | 11.2 |
| P27C | 6.4 | 10.5 | 7.0 | 10.3 | 13.7 | 14.9 | 16.6 | 17.9 | 17.6 | 22.6 |
| T31 | 0.2 | 4.0 | 1.6 | 6.0 | 7.1 | 11.5 | 10.8 | 13.3 | 9.0 | 11.5 |

Seeing the variation contained in the Table 77 the general behaviour of the PT lines is to increase the average speed, the P21A line is the only line depicting a general tendency to decrease the speed when the priority protocols are implemented, such as this line has the greatest reduction in the set of protocols evaluated, 12.6%. The protocols resulting in an increase of the speed of the line are the ones involve the intersections 4. As expected, the "E" lines sustain an increase along the intervention of the individual intersections, when all 4 intersections are simultaneously subjected to the priority protocols the results are similar to the results of the intervention on the intersection 4 exclusively (see Graph 13).




*Graph 13. Variation of average speed of the "E" PT lines, Priority on Base Control Plan.*

For the “P” and “T” lines the behaviour varies more with respect the protocols implemented (see Graph 14), as stated before in the majority of cases the result of the priority protocols is to increase the speed of the lines. The “P” lines have the greatest increase of all the pairs line/protocol specifically in the P1 D BC protocol in the lines making the turn 9(4) in the intersection 4 ( lines P10B, P10D, P12A, P21A and P21B), this protocol is the one giving the best results, for the no Expreso lines; excepting for the lines P17-B and the P27C, for the first one the results is a reduction of 8.5% and the second with an increase of 17.8% is overcome by the increase in the protocol P1 E BC of 22.6%.




*Graph 14. Variation of average speed of non “E” lines, Priority on Base Control Plan.*

The variable to be evaluated now is the travel time of the PT lines inside the modelled network, this variable is important as concerns directly in the perception of the service of the BTR system. The results for the travel time and the variation with the priority protocols are contained in the Table 78 and Table 79.

*Table 78. Travel time for the PT lines, Priority on Base Control Plan.*

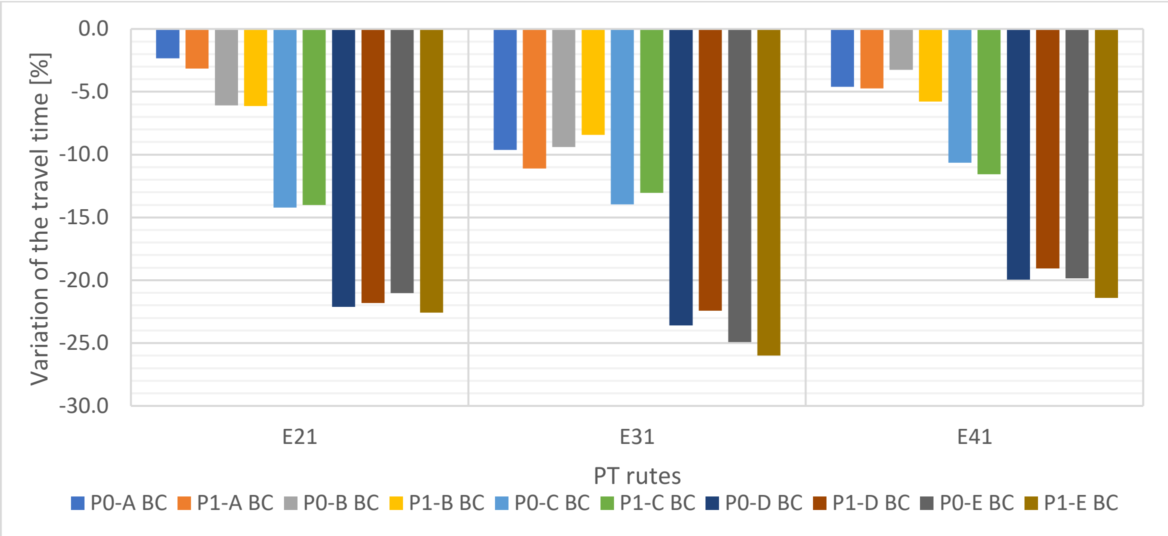
| Name | Travel time [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | 921.0 | 899.4 | 892.0 | 864.9 | 864.5 | 790.1 | 791.9 | 717.3 | 720.1 | 727.5 | 713.1 |
| E31 | 1004.2 | 907.5 | 892.8 | 909.8 | 919.6 | 864.1 | 873.2 | 767.2 | 779.0 | 753.9 | 743.1 |
| E41 | 921.6 | 879.2 | 878.0 | 891.7 | 868.3 | 823.6 | 815.1 | 737.8 | 745.9 | 738.7 | 724.3 |
| P10A | 939.1 | 951.9 | 929.8 | 936.1 | 899.6 | 863.0 | 828.9 | 839.1 | 827.2 | 867.6 | 845.1 |
| P10B | 120.0 | 125.0 | 115.7 | 114.6 | 118.7 | 113.5 | 115.8 | 122.3 | 83.9 | 107.9 | 104.4 |
| P10D | 117.3 | 114.4 | 116.4 | 115.7 | 118.4 | 115.0 | 120.0 | 109.6 | 81.9 | 108.5 | 108.5 |
| P12A | 116.4 | 116.8 | 115.4 | 113.6 | 117.4 | 111.6 | 115.5 | 126.4 | 85.5 | 111.9 | 119.9 |
| P17-A | 478.7 | 477.3 | 471.4 | 483.4 | 470.5 | 473.4 | 476.1 | 439.6 | 439.1 | 447.8 | 435.1 |
| P17-B | 397.9 | 421.1 | 397.3 | 411.8 | 387.8 | 406.5 | 360.9 | 418.6 | 432.1 | 427.7 | 434.5 |
| P21A | 125.2 | 140.8 | 135.1 | 129.4 | 128.3 | 133.4 | 133.4 | 116.9 | 82.9 | 110.3 | 101.7 |
| P21B | 125.7 | 118.4 | 110.7 | 114.6 | 115.9 | 115.5 | 115.8 | 117.9 | 84.3 | 116.5 | 110.9 |
| P27C | 1042.4 | 983.8 | 945.1 | 977.0 | 945.1 | 915.3 | 905.9 | 895.6 | 883.4 | 888.8 | 852.8 |
| T31 | 964.5 | 960.1 | 924.1 | 949.4 | 905.8 | 898.1 | 860.9 | 870.5 | 851.1 | 886.5 | 863.8 |

To remember that the travel time is the result of summing the time spend in movement and the time spend stopped (due to control and the dwell of the bus) in the existing network. The “E” and “T” lines, the P27C and P10A lines, can be grouped according to the path followed by them, the other two groups are the P17 lines and the “P” lines, the paths referred can be seen depicted in Figure 19. This groups are expected to have similar values of the travel time, because the distances and the number of stations required to stop are similar between the lines, this is reflected in the results of the Table 78. The line with the greatest travel time is the P27C, consistent with its long path and the fact that it stops in every station.

*Table 79. Variation of travel time of the PT lines, Priority on Base Control Plan.*

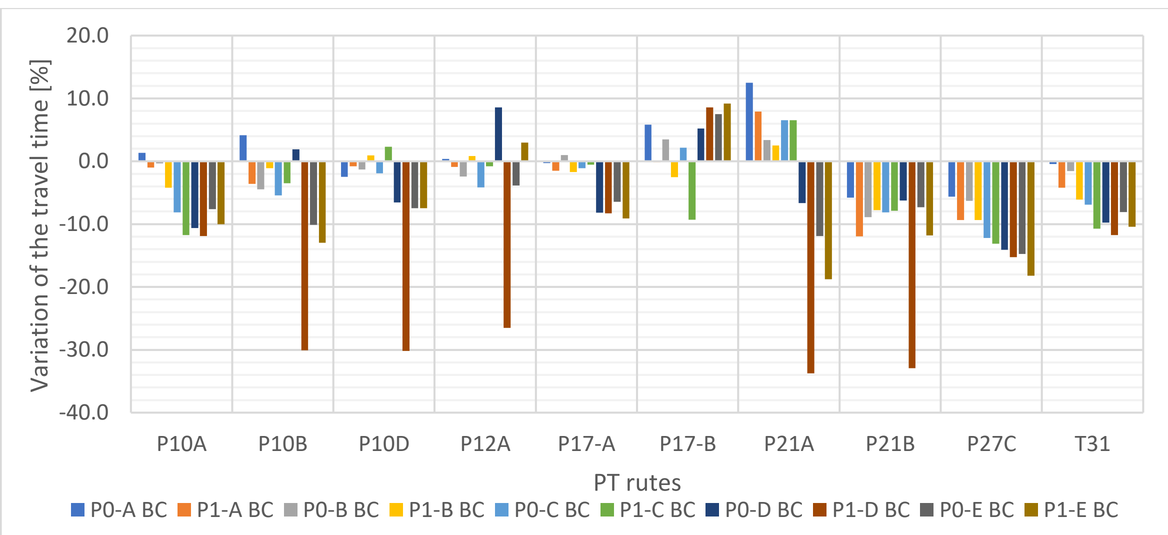
| **Name** | **Relative variation of the travel time [%]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | -2.3 | -3.1 | -6.1 | -6.1 | -14.2 | -14.0 | -22.1 | -21.8 | -21.0 | -22.6 |
| E31 | -9.6 | -11.1 | -9.4 | -8.4 | -14.0 | -13.0 | -23.6 | -22.4 | -24.9 | -26.0 |
| E41 | -4.6 | -4.7 | -3.2 | -5.8 | -10.6 | -11.6 | -19.9 | -19.1 | -19.8 | -21.4 |
| P10A | 1.4 | -1.0 | -0.3 | -4.2 | -8.1 | -11.7 | -10.6 | -11.9 | -7.6 | -10.0 |
| P10B | 4.1 | -3.6 | -4.5 | -1.1 | -5.4 | -3.5 | 1.9 | -30.1 | -10.1 | -13.0 |
| P10D | -2.5 | -0.8 | -1.3 | 0.9 | -1.9 | 2.3 | -6.6 | -30.2 | -7.5 | -7.5 |
| P12A | 0.4 | -0.9 | -2.4 | 0.8 | -4.1 | -0.8 | 8.6 | -26.5 | -3.9 | 3.0 |
| P17-A | -0.3 | -1.5 | 1.0 | -1.7 | -1.1 | -0.5 | -8.2 | -8.3 | -6.4 | -9.1 |
| P17-B | 5.8 | -0.2 | 3.5 | -2.5 | 2.2 | -9.3 | 5.2 | 8.6 | 7.5 | 9.2 |
| P21A | 12.5 | 7.9 | 3.4 | 2.5 | 6.5 | 6.6 | -6.6 | -33.8 | -11.9 | -18.8 |
| P21B | -5.8 | -11.9 | -8.9 | -7.8 | -8.1 | -7.9 | -6.3 | -32.9 | -7.3 | -11.8 |
| P27C | -5.6 | -9.3 | -6.3 | -9.3 | -12.2 | -13.1 | -14.1 | -15.3 | -14.7 | -18.2 |
| T31 | -0.5 | -4.2 | -1.6 | -6.1 | -6.9 | -10.7 | -9.8 | -11.8 | -8.1 | -10.4 |

With respect to the relative variation of the travel time, the results follow the same behaviour as in the average speed. The tendency in the “E” lines is to have a higher reduction of this variable following the intersection affected by the priority protocol (see Graph 15), the protocols involving all 4 intersection have a similar result to the ones only affecting the intersection 4 exclusively, the maximum reduction for this type of line is about 22.6% in the protocol P1 E BC.




*Graph 15. Variation of travel time of "E" lines, Priority on Base Control Plan.*

For the other lines, included in the protocols "P1" (see Graph 16), the results depict a major tendency to decrees the travel time, only the line P17-B and P21A have a negative reaction to a great part of the evaluated cases. The P17-B response is remarkable because the increases are present for the protocols "D" and "E", the ones where for the other lines their highest decreases are exhibit.




*Graph 16.Variation of travel time on non "E" lines, Priority on Base Control Plan.*

To evaluated more specifically the incidence of the TSP on the control behaviour, the analysis is focused in the delay time, the results of his variable are contained in the Table 80 and Table 81.

*Table 80. Delay time for the PT line, Priority on Base Control Plan.*

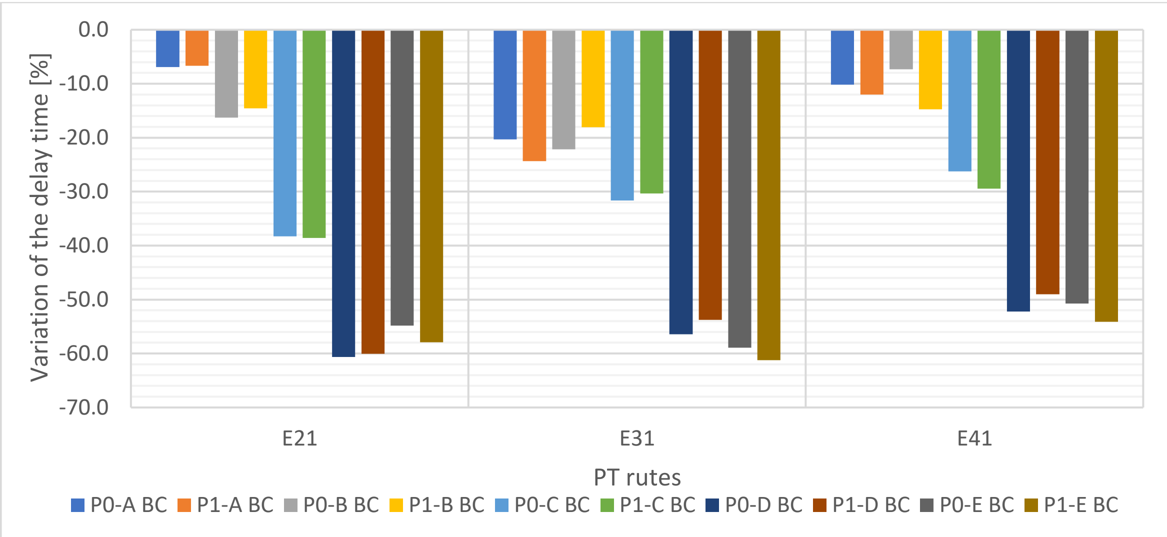
| Name | Delay time [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Base (50%)** | **P0-A BC** | **P1-A BC** | **P0-B BC** | **P1-B BC** | **P0-C BC** | **P1-C BC** | **P0-D BC** | **P1-D BC** | **P0-E BC** | **P1-E BC** |
| E21 | 348.4 | 324.4 | 325.1 | 291.8 | 297.6 | 215.1 | 213.9 | 137.2 | 139.3 | 157.4 | 146.6 |
| E31 | 400.6 | 319.2 | 303.1 | 311.9 | 328.3 | 273.8 | 279.1 | 174.5 | 185.3 | 164.5 | 155.2 |
| E41 | 343.5 | 308.5 | 302.2 | 318.3 | 292.9 | 253.4 | 242.3 | 164.0 | 175.2 | 169.2 | 157.7 |
| P10A | 339.4 | 353.9 | 331.4 | 346.4 | 313.4 | 279.8 | 247.5 | 252.9 | 240.3 | 285.3 | 260.1 |
| P10B | 51.0 | 56.4 | 46.7 | 45.8 | 48.7 | 44.9 | 47.0 | 53.3 | 14.4 | 39.0 | 35.0 |
| P10D | 48.5 | 45.4 | 47.3 | 47.5 | 49.3 | 45.6 | 50.7 | 40.6 | 12.9 | 38.5 | 39.6 |
| P12A | 40.7 | 37.9 | 32.5 | 29.8 | 34.0 | 32.1 | 36.5 | 53.7 | 16.1 | 39.0 | 47.0 |
| P17-A | 161.7 | 159.6 | 159.9 | 173.1 | 170.9 | 156.0 | 157.5 | 125.3 | 116.0 | 141.7 | 137.5 |
| P17-B | 118.8 | 139.0 | 117.0 | 124.7 | 100.4 | 127.3 | 81.8 | 137.5 | 153.3 | 149.3 | 152.7 |
| P21A | 50.3 | 65.6 | 59.6 | 53.8 | 51.2 | 58.5 | 61.4 | 42.9 | 12.7 | 38.3 | 30.1 |
| P21B | 50.7 | 39.3 | 32.0 | 33.3 | 32.4 | 36.2 | 35.2 | 46.6 | 14.6 | 46.3 | 39.9 |
| P27C | 398.9 | 345.3 | 313.9 | 349.5 | 320.0 | 296.7 | 289.9 | 273.4 | 264.7 | 271.4 | 238.5 |
| T31 | 330.9 | 339.1 | 306.1 | 328.0 | 286.8 | 277.0 | 237.6 | 250.6 | 226.6 | 279.3 | 255.7 |

For this variable is expected to be proportional to the intersections each line undergoes along its route. The "E" lines, the T31, P10A and P27C lines cross 8 times an intersection; the P17 lines take 4 each and the rest of the lines pass only the intersection 4 one time; this is effectively seen in the Table 80, where the specified groups have consistent values inside them.

*Table 81. Variation of Delay time for the PT line, Priority on Base Control Plan.*

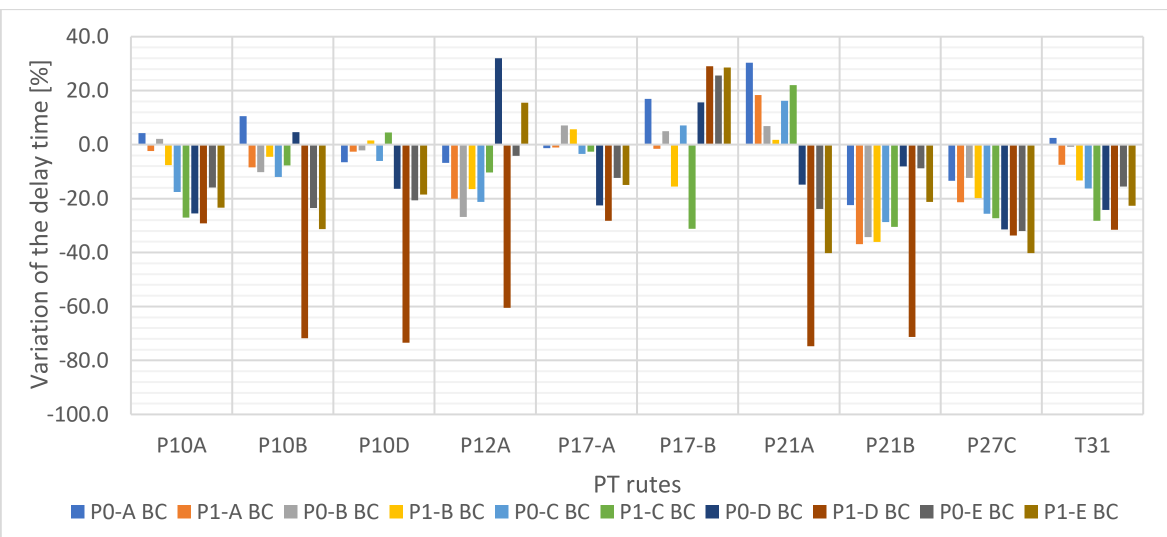
| Name | Relative variation of the delay time [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | -6.9 | -6.7 | -16.3 | -14.6 | -38.3 | -38.6 | -60.6 | -60.0 | -54.8 | -57.9 |
| E31 | -20.3 | -24.3 | -22.1 | -18.0 | -31.6 | -30.3 | -56.4 | -53.7 | -58.9 | -61.2 |
| E41 | -10.2 | -12.0 | -7.3 | -14.7 | -26.2 | -29.4 | -52.2 | -49.0 | -50.7 | -54.1 |
| P10A | 4.3 | -2.3 | 2.1 | -7.6 | -17.6 | -27.1 | -25.5 | -29.2 | -15.9 | -23.4 |
| P10B | 10.6 | -8.4 | -10.2 | -4.5 | -12.0 | -7.7 | 4.7 | -71.7 | -23.5 | -31.3 |
| P10D | -6.5 | -2.6 | -2.1 | 1.5 | -6.1 | 4.5 | -16.4 | -73.4 | -20.6 | -18.5 |
| P12A | -6.8 | -20.1 | -26.8 | -16.4 | -21.2 | -10.4 | 32.0 | -60.5 | -4.1 | 15.5 |
| P17-A | -1.3 | -1.1 | 7.1 | 5.7 | -3.5 | -2.6 | -22.5 | -28.2 | -12.3 | -14.9 |
| P17-B | 17.0 | -1.6 | 4.9 | -15.5 | 7.1 | -31.2 | 15.7 | 29.0 | 25.6 | 28.5 |
| P21A | 30.4 | 18.3 | 6.9 | 1.8 | 16.2 | 22.0 | -14.8 | -74.7 | -23.9 | -40.3 |
| P21B | -22.5 | -36.9 | -34.3 | -36.1 | -28.7 | -30.5 | -8.1 | -71.3 | -8.8 | -21.3 |
| P27C | -13.4 | -21.3 | -12.4 | -19.8 | -25.6 | -27.3 | -31.5 | -33.6 | -32.0 | -40.2 |
| T31 | 2.5 | -7.5 | -0.9 | -13.3 | -16.3 | -28.2 | -24.3 | -31.5 | -15.6 | -22.7 |

Following the behaviour of the delay for the lines depending on the evaluated cases, the tendency to a reduction. For the "E" lines the reduction is marked following the increase of the intersection indicator and with similar results for the protocols involving the intersection 4 (protocols "D" and "E"), phenomenon clearly shown in the Graph 17, the variation in these protocols exceeds 15% with respect the following grater reduction ( Protocols P0 C BC and P1 C BC).




*Graph 17. Variation of delay time on "E" lines, Priority on Base Control Plan.*

For the other lines, as in the variables previously studied, the behaviour does not follow the tendency as in the "E" lines, but the results are a general reduction on the delay, the P17-B and P21B concentrate most of the increase of all the cases evaluated, but the grates increase is for the line P21A with the protocol P0 D BC. On the reduction side the protocol with the better impact in the BRT system is the P1 D BC although for the P17-B line result in an increase of the delay of 29%.




*Graph 18. Variation of delay time on non "E" lines, Priority on Base Control Plan.*

Finally, the last variable under consideration when evaluating the impacts of the STP on the BRT system is the average number of stops, directly affected by the control configuration and important as it affects the perception the users have of the system in great manner, the results for this variable and its variation are contained in the Table 82 and the Table 83. To clarify that although the number of stops is an integer, the evaluation is performed about the average number of stops for each line, then the results will not be necessary integers.

*Table 82. Number of stops for the PT lines, Priority on Base Control Plan.*

| Name | Number of stops [-] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base (50%) | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | 12.3 | 12.4 | 11.8 | 12.4 | 11.6 | 10.7 | 10.3 | 11.3 | 11.0 | 11.9 | 11.3 |
| E31 | 15.1 | 14.0 | 14.4 | 14.9 | 15.3 | 12.6 | 12.9 | 12.9 | 13.0 | 14.4 | 13.7 |
| E41 | 13.7 | 12.0 | 12.0 | 12.7 | 12.2 | 11.9 | 11.8 | 12.2 | 11.5 | 12.3 | 11.9 |
| P10A | 15.6 | 15.7 | 15.4 | 15.2 | 14.9 | 14.7 | 13.4 | 14.8 | 14.3 | 14.5 | 14.2 |
| P10B | 2.0 | 2.0 | 2.0 | 1.9 | 1.9 | 2.0 | 1.9 | 2.0 | 1.5 | 1.9 | 1.9 |
| P10D | 2.0 | 2.1 | 2.1 | 2.1 | 2.0 | 2.0 | 2.1 | 1.9 | 1.5 | 1.9 | 2.1 |
| P12A | 2.3 | 2.6 | 2.3 | 2.4 | 2.2 | 2.6 | 2.5 | 2.3 | 1.8 | 2.1 | 2.3 |
| P17-A | 8.2 | 7.5 | 6.7 | 8.2 | 7.9 | 7.7 | 7.3 | 7.4 | 7.9 | 6.9 | 7.1 |
| P17-B | 6.2 | 7.0 | 6.6 | 7.4 | 6.8 | 5.8 | 4.8 | 6.8 | 7.6 | 6.6 | 7.2 |
| P21A | 1.9 | 2.0 | 2.1 | 1.8 | 1.9 | 2.0 | 2.0 | 2.0 | 1.6 | 2.0 | 1.9 |
| P21B | 2.3 | 2.2 | 2.0 | 1.9 | 2.1 | 2.0 | 2.0 | 2.0 | 1.6 | 2.0 | 2.0 |
| P27C | 18.8 | 18.3 | 17.2 | 18.6 | 17.8 | 16.5 | 16.3 | 16.7 | 16.7 | 17.8 | 16.1 |
| T31 | 17.8 | 17.2 | 16.8 | 17.7 | 16.9 | 16.8 | 15.8 | 16.6 | 16.1 | 16.3 | 16.1 |

The supposition for this variable, as in the delay time, is that the magnitude for the number of stops must be proportional to the number of intersections the line goes through and the stations the lines is required to stop, in an ideal scenario the result should be equal to the previous summation. In the Table 82 the different groups according to the ideal number of estops criteria can be easily distinguished. The line with the greater number of stops is the P27C (about 17), this line pass 8 times an intersections and the itinerary (see Table 18) stablish stops at 9 stations, then the result goes along the ideal conditions established for the no cases where the line is not prioritized (P0), the scenarios of P1 the behaviour does not follow the foreseen lineaments, as the reduction is only about 1 stop when it should be of 2.

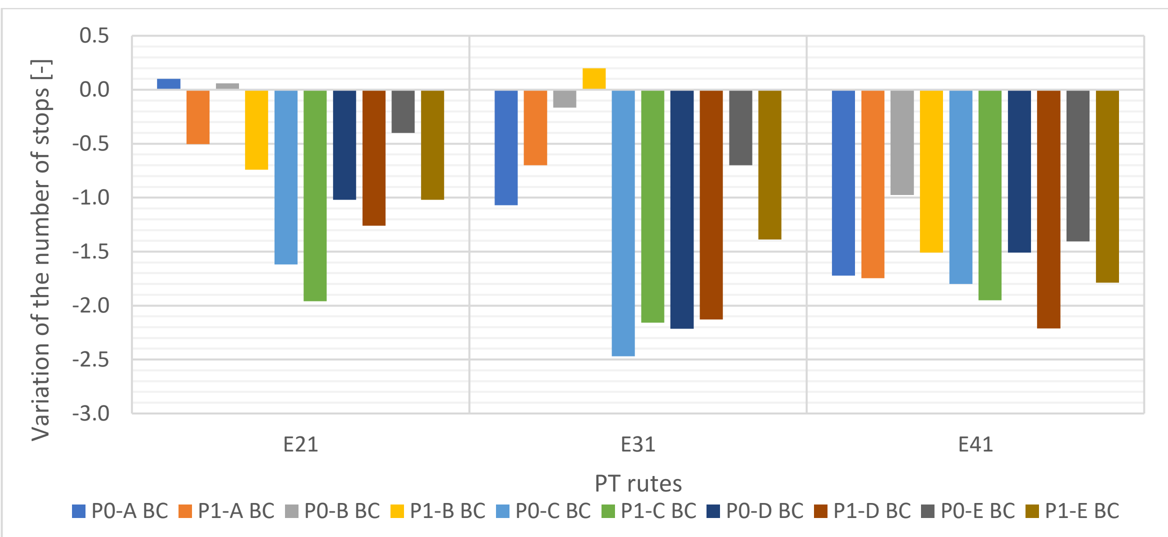
The difference between the protocols P0 and P1 in the scenarios evaluated present some discrepancies with the expected results, as exposed previously for the case of the P27C line. More significant is the fact that the "E" protocols follow the tendency of the other 4 protocols, when they should have a major reduction due to them implementing TSP in all 4 intersections simultaneously.

*Table 83. Variation of the Number of stops for the PT lines, Priority on Base Control Plan.*

| Name | Absolute variation of the number of stops [-] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A BC | P1-A BC | P0-B BC | P1-B BC | P0-C BC | P1-C BC | P0-D BC | P1-D BC | P0-E BC | P1-E BC |
| E21 | 0.1 | -0.5 | 0.1 | -0.7 | -1.6 | -2.0 | -1.0 | -1.3 | -0.4 | -1.0 |
| E31 | -1.1 | -0.7 | -0.2 | 0.2 | -2.5 | -2.2 | -2.2 | -2.1 | -0.7 | -1.4 |
| E41 | -1.7 | -1.7 | -1.0 | -1.5 | -1.8 | -2.0 | -1.5 | -2.2 | -1.4 | -1.8 |
| P10A | 0.1 | -0.2 | -0.4 | -0.7 | -0.9 | -2.2 | -0.8 | -1.3 | -1.1 | -1.4 |
| P10B | 0.0 | 0.0 | 0.0 | -0.1 | 0.0 | -0.1 | 0.0 | -0.5 | 0.0 | 0.0 |
| P10D | 0.0 | 0.1 | 0.1 | 0.0 | -0.1 | 0.0 | -0.2 | -0.6 | -0.1 | 0.0 |

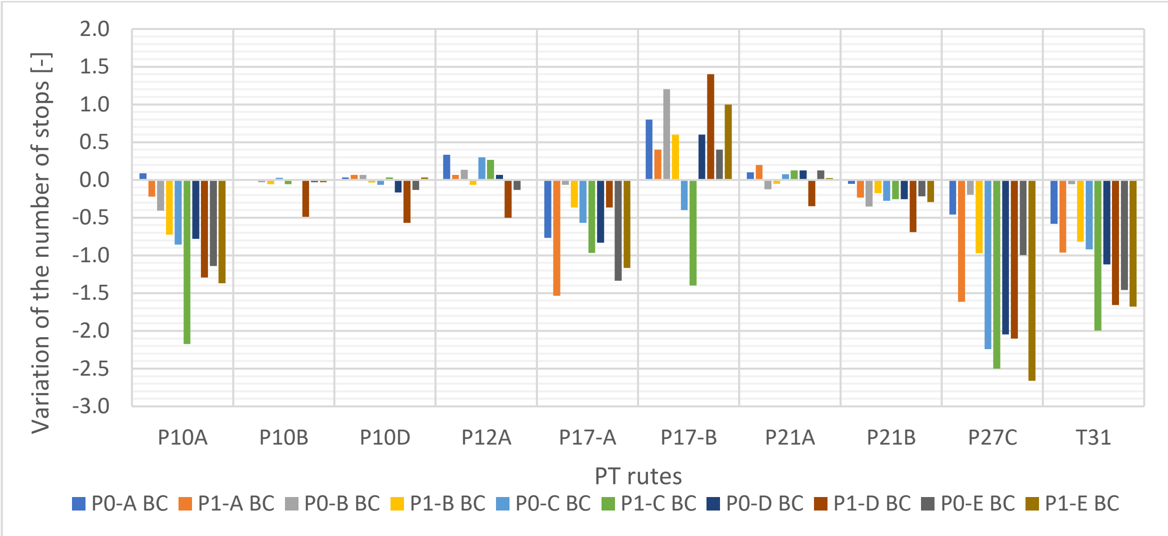
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| P12A | 0.3 | 0.1 | 0.1 | -0.1 | 0.3 | 0.3 | 0.1 | -0.5 | -0.1 | 0.0 |
| P17-A | -0.8 | -1.5 | -0.1 | -0.4 | -0.6 | -1.0 | -0.8 | -0.4 | -1.3 | -1.2 |
| P17-B | 0.8 | 0.4 | 1.2 | 0.6 | -0.4 | -1.4 | 0.6 | 1.4 | 0.4 | 1.0 |
| P21A | 0.1 | 0.2 | -0.1 | 0.0 | 0.1 | 0.1 | 0.1 | -0.4 | 0.1 | 0.0 |
| P21B | -0.1 | -0.2 | -0.4 | -0.2 | -0.3 | -0.3 | -0.3 | -0.7 | -0.2 | -0.3 |
| P27C | -0.5 | -1.6 | -0.2 | -1.0 | -2.2 | -2.5 | -2.0 | -2.1 | -1.0 | -2.7 |
| T31 | -0.6 | -1.0 | -0.1 | -0.8 | -0.9 | -2.0 | -1.1 | -1.7 | -1.5 | -1.7 |

Looking to the variation with respect to the base scenario, most of the cases does not reduce one unit the number of stops. The P27C line is the line obtaining the better results, the protocols evaluated result in a reduction of 1 stop in 5 of them, even reaching the threshold of 2 stops (see Table 83). Focusing in the "E" lines the results are satisfactory as the general tendency is a reduction in the number of stops, there are 3 light increases, but are no relevant because the maximum increase for this group is of 0.2 stops (see Graph 19), probably due to the randomness employed by the software; the reduction present in the group are more pronounced generally in the protocols that applied TSP in the intersection 3 exclusively ( P0 C BC and P1 C BC), the protocols including all 4 intersections does not have a remarkable result.




*Graph 19. Variation of number of stops on "E" lines, Priority on Base Control Plan.*

In the case of the other lines, there are some increments of the number of stops, the largest ones concentrated in the P17-B line (see Graph 20), for this line the only reduction is present in the protocols P0 C BC and P1 C BC, reaching about 1 stop for the last protocol. In this group a protocol that stand out is the protocol P1 C BC, that in many lines result in the larger reduction, 4 of the 10 lines. Among the lines making the turn 9(4) in the intersection 4, as expected the major reduction corresponds to the P1 D BC protocol.




*Graph 20. Variation of number of stops on non "E" lines, Priority on Base Control Plan.*

This variable at the end, does not varies considerably enough to be perceived as an improvement or a detriment of the service by the users of the BRT system. Going the other way of the expected solution, the protocols affecting al 4 intersections simultaneously does not offer the greatest reductions but intervening the intersection 3 exclusively does.

All the protocols on this section have a high variation in their results, having a good response for certain variables and a bad response for others, this hider the evaluation of the protocols. The only aspect to be highlighted is the general good effect obtained for the BRT system when the intersection 4 is accounted in the priority protocols (protocols "D" and "E") but, as stated before, the evaluation of the different solutions not only considers the BRT system performance, but the mix traffic results are also a fundamental criterion.

### 5.2.3. Modified Control Plan

The inspection of the Modified Control Plan starts comparing its results with the Base Control Plan, retrieving that the last scenario refers to the one with the reduced demand. The general variables of the system and the relative variation are contained in the Table 84.

*Table 84. System results for the Modified Control Plan.*

| Scenario | Base | Modified | Relative variation [%] |
|---|---|---|---|
| Density [veh/km] | 9.7 | 11.3 | 16.5% |
| Flow [veh/h] | 9307.8 | 8979.6 | -3.5% |
| Delay time [sec/km] | 123.4 | 141.5 | 14.7% |
| Mean queue [veh] | 157.5 | 243.9 | 54.8% |
| Mean virtual queue [veh] | 0.03 | 0.03 | 2.4% |

Looking at the results at the system level there is a detriment of the behaviour of the traffic, although the only variable having a remarkable variation is the Mean queue, that increments above 50%. This behaviour is expected due to the criteria followed to generate the new control plan, that favours the users delay instead the vehicle delay and the variables computed by the software only accounts to the number of vehicles. The control variables, flow and virtual queue, have variations but in a more reduced scale, neither exceeds the 5% threshold; this is good as the virtual queue result indicates that it is an useful scenario to make the comparisons when the priority protocols are to be implemented.

*Intersection response*

To understand better what happens in the system is preferable to analyse the intersections individually, in the Table 85 are contained the delay and the Level of Service (LOS) according to the HCM.

*Table 85. Delay and LOS for the intersections with the Modified Control Plan.*

| **Intersection** | **Delay [sec]** | | **Relative variation [%]** | **LOS** | |
|---|---|---|---|---|---|
| | Base | Modified | | Base | Modified |
| 1 | 25.7 | 8.3 | -67.6 | C | A |
| 2 | 12.5 | 5.8 | -53.9 | B | A |
| 3 | 45.3 | 53.8 | 18.7 | D | D |
| 4 | 22.2 | 20.4 | -8.4 | C | C |

Now, on the contrary to the initial observations, the general response of the intersections of interest to the Modified Control Plan is a reduction on the delay, for the smaller intersections (1 and 2) the reduction is considerably high passing the 50%; the intersection 4 has a reduction of about 10 %. The only increment is present in the intersection 3, about 9 seconds (19%), but despite it the LOS remain in the same level D. For the first two intersections the improvement is such that the LOS is increased to A.

*Accesses response*

Focusing on intersection 3, the only one with an increment, analysing the individual accesses can provide specific information about where the problem emerge. The delay of the individual accesses in the intersection 3 for the Modified Control Plan are contained in the Table 86.

*Table 86. Delay for the accesses I the intersection 3 for the Modified Control Plan.*

| **Access** | **Delay [sec]** | | **Delay variation [%]** |
|---|---|---|---|
| | Base | Modified | |
| 1 | 4.0 | 2.9 | -29.4 |
| 3A | 1.3 | 0.9 | -26.0 |
| 2 | 2.2 | 3.8 | 75.3 |
| 4B (PT) | 0.6 | 0.2 | -71.2 |
| 3D (PT) | 0.5 | 0.2 | -62.1 |
| 3C (PT) | 0.4 | 0.1 | -70.6 |
| 3B | 3.5 | 10.2 | 194.4 |
| 4A | 0.8 | 0.3 | -60.3 |

The intersection 3, only in 2 of its accesses presents an increment, this are considerably high specially for the access 3B, almost four times the initial value of the delay, the increments are consistent with the access containing the manoeuvres with the third and fourth greatest vehicle flows. The results then are not surprising as in the Users Delay criteria these access where not prioritized, the overall delay on the intersection 3 shown in the Table 85, has sense because in the calculation of the intersection delay the access delay is weighted by the access flow, all referring to vehicles and not to users (passengers), thus the priorization due to the Modified Control Plan can be reflected in a detriment in the behaviour on the accesses with high vehicular flows and low occupancy.

*Paths response*

Having seen the effects in the general system and for specific particular intersections, it is important to analyse the travel along the network for the mix traffic users. The variables under consideration are the average speed (Table 87), the travel time (Table 88), the percentage of time stopped (Table 89) and the number of stops (Table 90).

*Table 87. average speed for the Modified Control Plan.*

| **Path** | **Average Speed [km/h]** | | **Relative Variation [%]** |
|---|---|---|---|
| | Base | Modified | |
| PT corridor N-S | 31.2 | 37.4 | 19.9 |
| PT corridor S-N | 30.1 | 39.1 | 29.6 |
| carrera 80 | 18.6 | 26.1 | 40.4 |
| carrera 94 | 26.5 | 31.8 | 20.1 |
| calle 13 N | 29.7 | 34.3 | 15.2 |
| calle 13 S | 30.7 | 34.8 | 13.5 |
| calle 16 N | 35.3 | 14.2 | -59.8 |
| calle 16 S | 27.6 | 32.2 | 16.8 |

For the velocity the major positive impact is on the perpendicular path of the "Carrera 80", increasing the average speed in 40%, the rest of paths exhibits a general tendency to increment its values with the exception of the "calle 16" coming from north were a drastical reduction is spotted, 60%, this is more stands more having seen in previous analysis that the intersection 4 for which this paths pass through, have a positive response to the Modified Control Plan.

*Table 88. Travel time for the Modified Control Plan.*

| **Path** | **Travel time [sec]** | | **Relative Variation [%]** |
|---|---|---|---|
| | **Base** | **Modified** | |
| PT corridor N-S | 396.2 | 330.6 | -16.5 |
| PT corridor S-N | 377.9 | 288.4 | -23.7 |
| carrera 80 | 69.3 | 40.7 | -41.2 |
| carrera 94 | 57.3 | 37.4 | -34.6 |
| calle 13 N | 132.6 | 111.9 | -15.6 |
| calle 13 S | 127.1 | 110.0 | -13.5 |

| Path | Travel time [sec] | | Relative Variation [%] |
|---|---|---|---|
| | **Base** | **Modified** | |
| calle 16 N | 103.8 | 303.3 | 192.3 |
| calle 16 S | 133.5 | 113.6 | -14.9 |

*Table 89. Percentage of time stopped for the Modified Control Plan.*

| Path | % of time stopped [%] | | Variation [%] |
|---|---|---|---|
| | Base | Modified | |
| PT corridor N-S | 33.7 | 22.2 | -11.5 |
| PT corridor S-N | 36.5 | 17.4 | -19.1 |
| carrera 80 | 63.8 | 38.9 | -24.9 |
| carrera 94 | 58.6 | 35.8 | -22.8 |
| calle 13 N | 39.6 | 30.0 | -9.7 |
| calle 13 S | 39.4 | 31.1 | -8.3 |
| calle 16 N | 26.2 | 70.8 | 44.6 |
| calle 16 S | 37.9 | 25.8 | -12.1 |

The behaviour in the travel time and percentage of time stopped, the results is similar to the average speed, in terms of the ponderation of the paths, where the better results are the ones of the "carrera 80" path, with a reduction of 40%; in the travel time and a reduction of 25 percentual points in the percentage of time stopped. The worst results are both in the "calle 16" path coming from north.

*Table 90. Number of stops for the Modified Control Plan.*

| Path | Number of Stops [-] | | Variation [-] |
|---|---|---|---|
| | Base | Modified | |
| PT corridor N-S | 3.2 | 2.6 | -0.6 |
| PT corridor S-N | 2.7 | 2.3 | -0.4 |
| carrera 80 | 1.0 | 0.9 | -0.1 |
| carrera 94 | 0.7 | 0.7 | 0.0 |
| calle 13 N | 1.3 | 1.1 | -0.2 |
| calle 13 S | 0.9 | 0.8 | -0.1 |
| calle 16 N | 0.8 | 2.5 | 1.7 |
| calle 16 S | 1.2 | 1.1 | -0.1 |

The number of stops observed is in contrast with the previous tendency in the corridor that exhibits the better result. This time the PT corridor in the north-south sense is the one with the grated reduction; even where the majority on paths have a reduction, it is not significant enough and provably the variation occurs due to the randomness induced in the software. Where the variation is more significant is for the negative impact, again in the "Calle 16" coming from the north where almost 2 stops are added.

*BRT response*

Looking now to the impacts on the BRT system the variables to analyse are similar to the ones in the mix traffic analysis with the exception of the percentage of time stopped, replaced with the delay time, the results are contained in the Table 91, the Table 92, the Table 93 and the Table 94.

*Table 91. Average speed in the BRT for the Modified Control Plan.*

| Name | Average speed [km/h] | | Relative variation [%] |
|---|---|---|---|
| | Base | Modified | |
| E21 | 27.7 | 35.7 | 29.0 |
| E31 | 25.4 | 33.8 | 33.1 |
| E41 | 27.7 | 33.9 | 22.6 |
| P10A | 27.1 | 33.8 | 24.9 |
| P10B | 24.0 | 24.8 | 3.3 |
| P10D | 24.4 | 24.4 | 0.3 |
| P12A | 24.6 | 22.7 | -8.0 |
| P17-A | 27.8 | 32.5 | 16.8 |
| P17-B | 31.8 | 41.1 | 29.4 |
| P21A | 23.4 | 24.3 | 3.9 |
| P21B | 23.1 | 24.0 | 3.8 |
| P27C | 24.4 | 31.9 | 30.7 |
| T31 | 26.4 | 32.5 | 23.0 |

*Table 92. Delay time in the BRT for the Modified Control Plan.*

| Name | Delay time [sec] | | Relative variation [%] |
|---|---|---|---|
| | Base | Modified | |
| E21 | 348.4 | 147.4 | -57.7 |
| E31 | 400.6 | 163.2 | -59.3 |
| E41 | 343.5 | 177.4 | -48.3 |
| P10A | 339.4 | 174.7 | -48.5 |
| P10B | 51.0 | 45.6 | -10.5 |
| P10D | 48.5 | 47.6 | -2.0 |
| P12A | 40.7 | 47.7 | 17.2 |
| P17-A | 161.7 | 113.9 | -29.5 |
| P17-B | 118.8 | 26.3 | -77.9 |
| P21A | 50.3 | 43.9 | -12.7 |
| P21B | 50.7 | 44.8 | -11.6 |
| P27C | 398.9 | 185.0 | -53.6 |
| T31 | 330.9 | 174.9 | -47.1 |

*Table 93. Travel time in the BRT for the Modified Control Plan.*

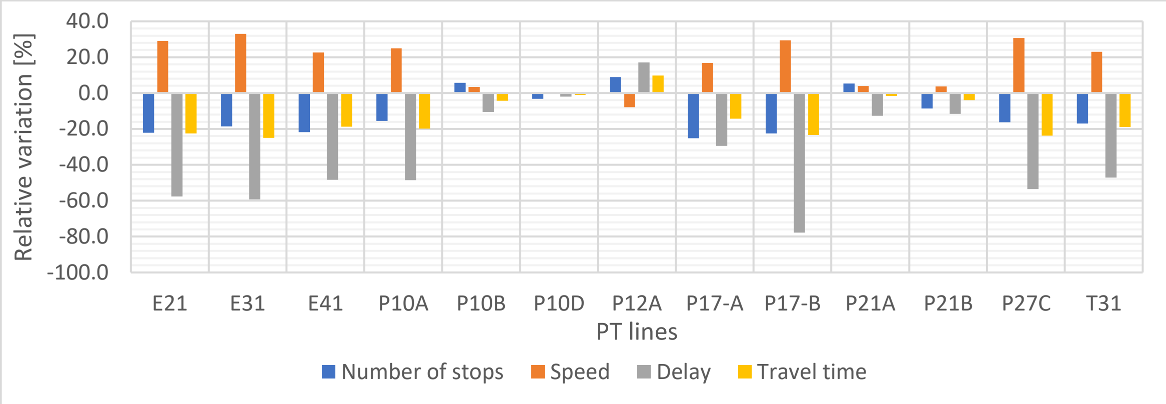
| Name | Travel time [sec] | | Relative variation [%] |
|---|---|---|---|
| | **Base** | **Modified** | |
| E21 | 921.0 | 713.6 | -22.5 |
| E31 | 1004.2 | 753.2 | -25.0 |
| E41 | 921.6 | 748.3 | -18.8 |

| Name | Travel time [sec] | | Relative variation [%] |
|---|---|---|---|
| | **Base** | **Modified** | |
| P10A | 939.1 | 752.7 | -19.9 |
| P10B | 120.0 | 114.8 | -4.3 |
| P10D | 117.3 | 116.0 | -1.1 |
| P12A | 116.4 | 127.9 | 9.9 |
| P17-A | 478.7 | 410.0 | -14.3 |
| P17-B | 397.9 | 305.0 | -23.3 |
| P21A | 125.2 | 123.1 | -1.6 |
| P21B | 125.7 | 120.7 | -4.0 |
| P27C | 1042.4 | 795.7 | -23.7 |
| T31 | 964.5 | 781.4 | -19.0 |

*Table 94. Number of stops in the BRT for the Modified Control Plan.*

| Name | Number of stops [-] | | Relative variation [%] |
|---|---|---|---|
| | Base | Modified | |
| E21 | 12.3 | 9.6 | -22.1 |
| E31 | 15.1 | 12.3 | -18.6 |
| E41 | 13.7 | 10.7 | -21.8 |
| P10A | 15.6 | 13.2 | -15.5 |
| P10B | 2.0 | 2.1 | 5.8 |
| P10D | 2.0 | 2.0 | -3.3 |
| P12A | 2.3 | 2.5 | 8.8 |
| P17-A | 8.2 | 6.2 | -25.1 |
| P17-B | 6.2 | 4.8 | -22.6 |
| P21A | 1.9 | 2.0 | 5.3 |
| P21B | 2.3 | 2.1 | -8.7 |
| P27C | 18.8 | 15.7 | -16.3 |
| T31 | 17.8 | 14.7 | -17.0 |

In the case of the BRT system the results depict a good response to the Modified Control Plan, in general terms the average speed tends to increase and the delay time, travel time and number of stops have a marked decrease. The only line going against  this general tendency in the four variables is the P12A line, as can be seen in the Graph 21; in the number of stops two other lines (P10B and P21A) have an increase but the absolute difference is low, the difference probably is due to the random variation induce by the software.




*Graph 21. relative variation of the BRT variables for the Modified Control Plan.*

The implementation of the Modified Control Plan,  results in an overall improvement in the mix traffic and the BTR system, this being more meritorious due to the fact that the new control plan was obtain using the persons delay as prioritizing criteria, then having reduction in the vehicle delay in the general system and a reduction on the travel time in almost all the paths in the system reflects the deficient present in the original control plan.

The intersection 3 specifically the access 2 and the intersection 4 access 1 are the two critical points obtained in this analysis, both are expected as they are accesses perpendicular to the PT corridor. The results, discussed previously, serves to expose how the persons delay protocol can affect the intersections of two principal roads that have a high  traffic flow of low capacity vehicles.

#### 5.2.4. Priority on Modified Control Plan

Having seen the effects of the implementation of the Modified Control Plan, it is necessary now explore the impacts the different priority protocols exposed in the section 4.2.2 in the new control plan, to do so the structure will be similar to the one used in the analysis for the priority protocols applied on the Base Control Plan. For this specific section the variation on the variables will be done considering the scenario of the Modified Control Plan (Modified) as the initial condition.

##### *Intersection response*

Starting the inspection, the initial point to evaluate is the behaviour of the 4 major intersection in the modelled network, the analysis is done upon the delay and therefore the Level Of Service of the intersection, the results of the priority protocols re contained in Table 95.

*Table 95. Intersection delay, priority on Modified Control Plan*

| **Intersection** | **Delay [sec]** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 1 | 8.3 | 7.4 | 8.0 | 7.9 | 8.2 | 8.0 | 8.1 | 8.8 | 8.3 | 8.1 | 7.7 |
| 2 | 5.8 | 5.8 | 5.8 | 14.4 | 12.3 | 8.8 | 10.0 | 5.8 | 5.8 | 15.2 | 16.3 |
| 3 | 53.8 | 54.2 | 53.9 | 51.7 | 53.3 | 47.3 | 72.8 | 55.4 | 53.5 | 43.4 | 84.0 |
| 4 | 20.4 | 19.8 | 20.3 | 19.6 | 20.5 | 19.8 | 20.2 | 12.3 | 12.2 | 11.8 | 48.2 |

The delay in the nodes offers a clear distinction between the two length cycles used in the new control plan, where the first two intersections with a cycle of 40 seconds does not excides the 20 seconds of delay, in the case of the intersections 3 and 4, the cycles is of 120 seconds have a more variable results, this due to the implementation of the priority protocols. This feature is consistent with the theory of the optimisation of transit signal lights, where is stablish that shorter cycles leads to less delay than longer cycles.

*Table 96. Level of Service for the intersections, Priority on Modified Control Plan.*

| **Intersection** | **LOS** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | **P0-A MC** | **P1-A MC** | **P0-B MC** | **P1-B MC** | **P0-C MC** | **P1-C MC** | **P0-D MC** | **P1-D MC** | **P0-E MC** | **P1-E MC** |
| 1 | A | A | A | A | A | A | A | A | A | A | A |
| 2 | A | A | A | B | B | A | B | A | A | B | B |
| 3 | D | D | D | D | D | D | E | E | D | D | F |
| 4 | C | B | C | B | C | B | C | B | B | B | D |

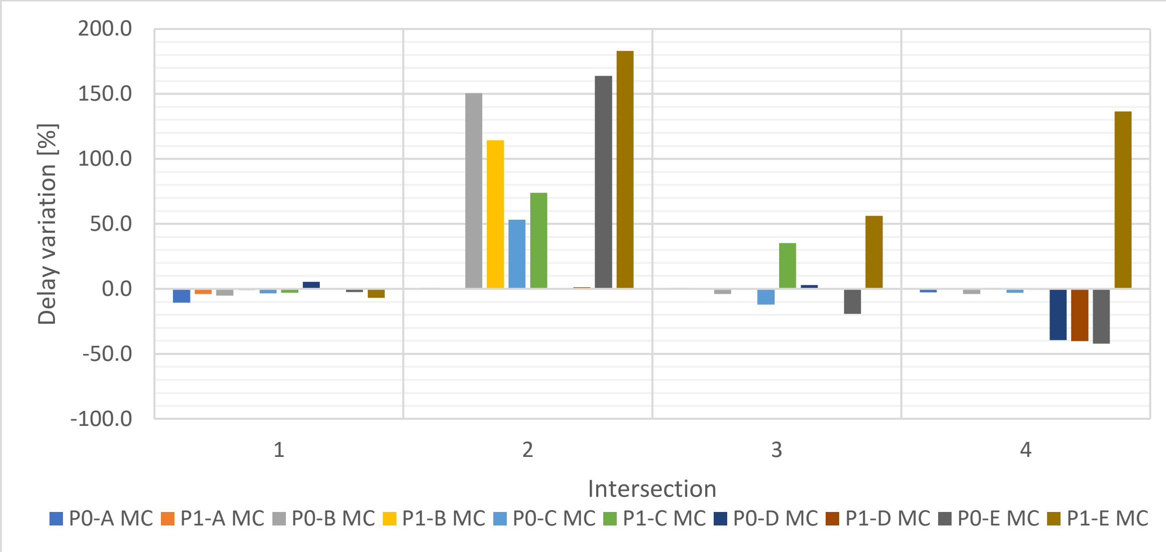
Looking to the Level of Service (LOS) according to the HCM (see Table 96), all the intersections behave different. The intersection 1 conserves the maximum grade through all the modelled scenarios, the intersection 2 have a decrees in its level of service when the priority protocols intervene the intersection 2, the intersection 3 have a more inconsistent behaviour because the protocols resulting in a detriment of the LOS have no particular link, the worst scenario for this intersection is the P1 E MC, where it reach a LOS grade F; the final intersection, on the contrary of the other two previous intersections, depicts an improvement from its original stated increasing to level B generally in the protocols granting priority solely to the "E" lines.

*Table 97. Variation of intersection delay in percentage, priority on Modified Control Plan.*

| Intersection | **Relative variation of delay [%]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 1 | -10.7 | -4.0 | -5.2 | -1.1 | -3.6 | -2.9 | 5.4 | 0.2 | -2.4 | -7.0 |
| 2 | 0.7 | 0.1 | 150.7 | 114.2 | 53.3 | 74.0 | 0.0 | 1.2 | 164.0 | 183.1 |
| 3 | 0.8 | 0.1 | -3.9 | -0.9 | -12.2 | 35.3 | 2.9 | -0.5 | -19.3 | 56.2 |
| 4 | -2.7 | -0.4 | -3.8 | 0.7 | -2.9 | -0.7 | -39.4 | -40.3 | -42.2 | 136.6 |

To support the analysis on the Level of Service, the relative variation of the delay is exposed in the Table 97, from in the greatest variations can be located in the intersection 2 where 6 of the 10 cases evaluated results in an increase and with a 4 of those being grater tan 100%. Specifically analysing the increases, the P1 E MC that results for 3 of the 4 intersections in a considerable increase.

For the side of the reductions the most beneficiated intersection is the number 4 where 3 of the evaluated scenarios are about the 40% of reduction. The other cases evaluated does not have a major variation with respect the base scenario.




*Graph 22. Relative variation of the intersection delay, priority on Modified Control Plan.*

### *Accesses response*

To go deeper into the exploration of the effects of the implementation of the TSP protocols in the individual intersections, now the analysis will be in the delay of the specific access in each intersection, the nomenclature uses to name the accesses is the same us in the section 5.2.2.

For the intersection 1 the evaluation of the delay in the accesses is contained in the Table 98.

*Table 98. Delay for the accesses of the intersection 1, priority on Modified Control Plan.*

| **Access** | **Delay [sec]** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 2B (PT) | 4.7 | 5.2 | 2.5 | 4.3 | 4.0 | 3.9 | 3.5 | 5.7 | 6.4 | 7.5 | 7.8 |
| 1B (PT) | 4.1 | 5.2 | 2.9 | 4.3 | 4.6 | 4.6 | 4.7 | 4.8 | 5.0 | 7.2 | 6.5 |
| 1A | 6.2 | 5.5 | 5.6 | 5.7 | 6.3 | 6.0 | 5.9 | 6.8 | 6.1 | 6.8 | 6.3 |
| 2A | 5.5 | 6.4 | 5.5 | 4.5 | 4.3 | 5.3 | 5.0 | 5.8 | 5.5 | 6.9 | 6.8 |
| 4 | 16.7 | 11.4 | 18.1 | 16.5 | 16.3 | 16.1 | 17.2 | 16.4 | 16.9 | 7.9 | 8.0 |

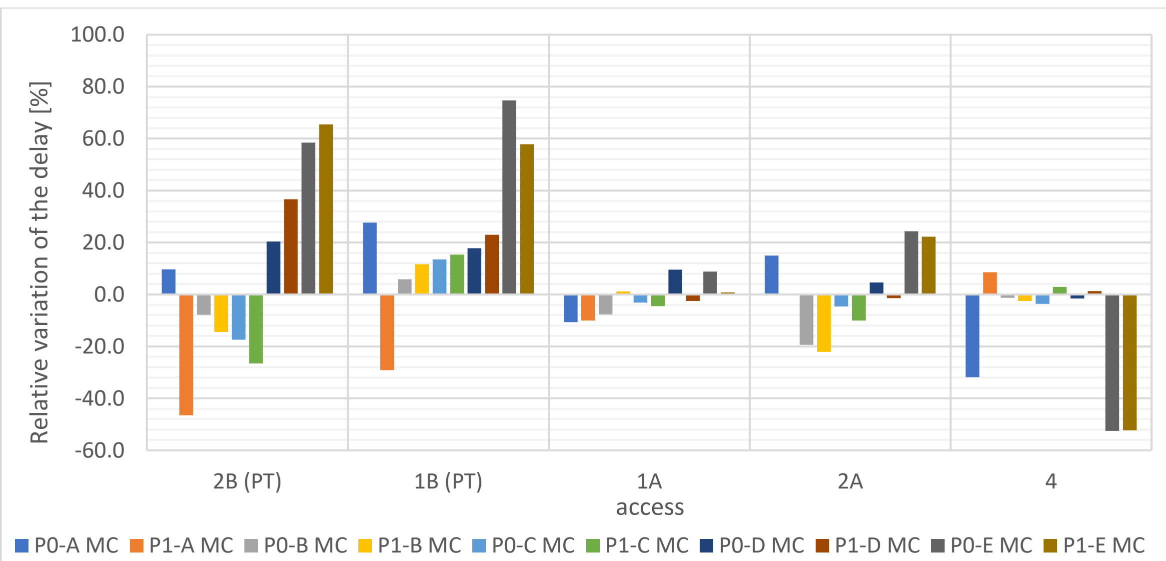
The results in this intersection chows than the biggest delay is always un the access 4, consistent with the established in the new control plan, that gives the less green time to this access. In the access 4 the lower delay is obtained when the intersection 1 is included in the priority protocol, the exemption is the protocol P1 A MC, that result in the biggest delay of the access among all the scenarios. This result stands out as the access 4 is perpendicular to the BRT dedicated lanes and thus the priority protocols are expected to reduce the amount of time the access is allowed to flow.

*Table 99. Variation of delay for the accesses of the intersection 1, priority on Modified Control Plan.*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 2B (PT) | 9.7 | -46.5 | -7.8 | -14.4 | -17.4 | -26.6 | 20.4 | 36.6 | 58.4 | 65.5 |
| 1B (PT) | 27.7 | -29.2 | 5.8 | 11.6 | 13.5 | 15.4 | 17.8 | 23.0 | 74.8 | 57.9 |
| 1A | -10.7 | -10.1 | -7.8 | 1.1 | -3.2 | -4.5 | 9.6 | -2.6 | 8.8 | 0.8 |
| 2A | 15.0 | -0.1 | -19.4 | -22.1 | -4.6 | -10.1 | 4.7 | -1.4 | 24.3 | 22.3 |
| 4 | -31.8 | 8.5 | -1.3 | -2.5 | -3.6 | 2.9 | -1.5 | 1.3 | -52.5 | -52.3 |

Observing the variation of the delay, the accesses with a mark increase of the delay are the PT accesses, 1B and 2B, especially for the protocols considering TSP in all 4 intersections simultaneously (see Graph 23), where are obtained increases of about 60%. The other important feature concerning one of these accesses is the impacts of the protocols implemented in other intersections, the access 1B only receiving vehicular load according to the PT schedule and no interactions with other intersections, have always an increase in the delay, excepting for the protocol P1 A MC, where the access reduces its delay in 29%, expected for the implementation of the priority.

The highest reduction in the delay is present in the access 4, for the protocols P0 E MC and P1 E MC, about 52%; for the other protocols this access only have a notable response to the protocol P0 A MC that although the priority protocol is supposed to restrain the flow in this access the result is a reduction of 31%.




*Graph 23. Relative variation of the delay for the accesses in the intersection 1, priority on modified Control Plan.*

Following the order of the intersections, now are presented the results of the delay evaluation for the implementation of the TSP protocols in the intersection 2 and how is the variation with respect to the reference scenario, these are contained in the Table 100 and the Table 101.

*Table 100. Delay for the accesses of the intersection 2, priority on Modified Control Plan.*

| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 1B (PT) | 10.2 | 6.5 | 6.7 | 8.3 | 5.2 | 10.2 | 9.7 | 10.3 | 9.7 | 7.3 | 5.0 |
| 2B | 17.1 | 14.7 | 16.2 | 11.2 | 11.4 | 17.6 | 17.9 | 17.2 | 16.4 | 10.0 | 10.6 |
| 3 | 14.1 | 14.1 | 14.4 | 11.1 | 15.9 | 14.2 | 14.1 | 14.3 | 14.1 | 9.7 | 13.8 |
| 1A | 5.2 | 5.3 | 5.2 | 16.4 | 13.5 | 9.0 | 10.6 | 5.2 | 5.3 | 17.9 | 18.9 |
| 2C (PT) | 1.6 | 2.0 | 2.3 | 5.2 | 2.4 | 2.4 | 3.0 | 2.1 | 2.6 | 5.7 | 2.5 |
| 2A | 2.4 | 2.6 | 2.5 | 2.4 | 2.0 | 2.2 | 2.2 | 2.2 | 2.2 | 2.3 | 2.1 |

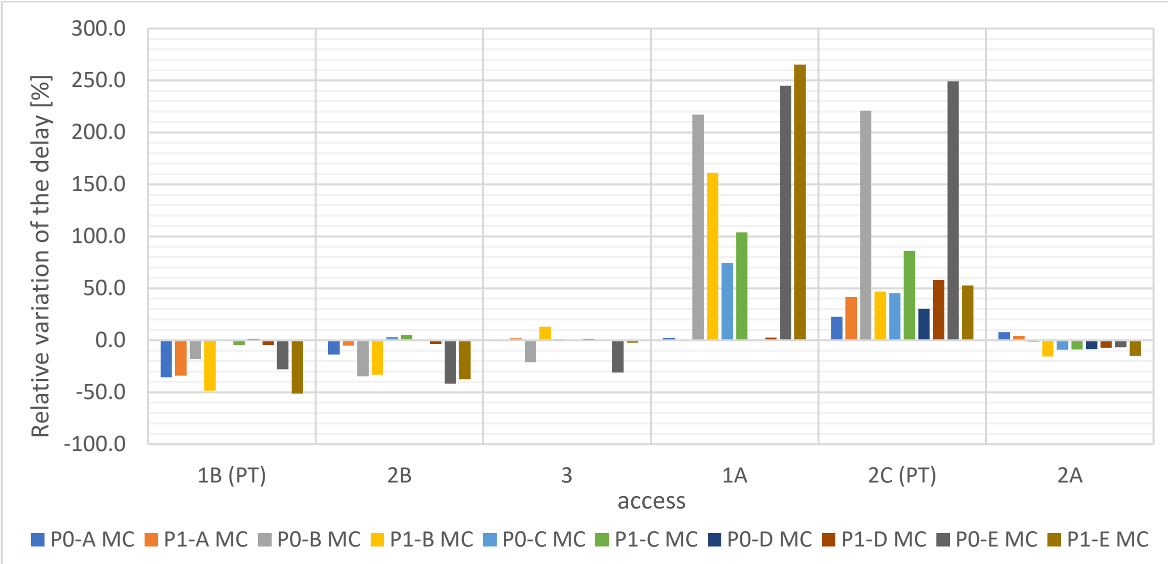
In this intersection the results in general terms are consistent with the expectation of the delay in the individual accesses, the ones with the lowest delay are the accesses that allow movements parallel to the PT corridor, the accesses 2B and 3 have the major delay. This behaviour is preserved in all but 3 particular protocols, the P0 B MC, the P0 E MC and the P1 E MC, in these scenarios the access with the highest delay is the 1A, contradictory with the assumptions previously mentioned; the common characteristic for the three protocols is the inclusion of the interreacting 2 for priority. For the side of the lowest delay, it corresponds in all the cases for the accesses 2A and 2C, this result is expected due to the almost constant flow allowed in the new control plan.

*Table 101. Variation of delay for the accesses of the intersection 2, priority on Modified Control Plan.*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 1B (PT) | -35.6 | -34.2 | -18.1 | -48.5 | 0.4 | -4.6 | 1.3 | -4.4 | -28.0 | -51.2 |
| 2B | -13.7 | -5.1 | -34.7 | -33.3 | 3.3 | 5.0 | 0.6 | -3.6 | -41.7 | -37.6 |
| 3 | 0.0 | 2.0 | -21.3 | 12.9 | 0.9 | -0.3 | 1.3 | -0.3 | -31.1 | -2.5 |
| 1A | 2.3 | 0.8 | 217.2 | 161.0 | 74.4 | 103.8 | 0.5 | 2.5 | 245.0 | 265.1 |
| 2C (PT) | 22.5 | 41.5 | 220.9 | 46.8 | 45.2 | 85.9 | 30.1 | 58.1 | 249.2 | 52.7 |
| 2A | 7.7 | 4.1 | -1.3 | -15.7 | -9.2 | -8.9 | -8.5 | -7.2 | -6.7 | -14.9 |

Inspecting the variations there are some extreme increases in the accesses 1A and 2C, the maximum increase is located in the access 1A for the protocol P1 E MC, 265%. The protocols P0 B MC and P0 E MC have increases in the access 2C, correspondently 218% and 249%. In the other accesses the main tendency is to have a reduction in the delay, an example of this is the access 1B where reductions reach values of about 50%.

The increases in accesses leading movements parallel to the PT corridor may have an explanation in the way the control plan is set when there is no priority request, the green time for the se phases is reduced to about 5 seconds, explaining why this phenomenon is present for the protocols that grant priority exclusively to the "E" lines, restricting the amount of vehicles to detect and grant priority reduces the amount of requests received and thus more time the access is functioning with the minimum green value.




*Graph 24. Relative variation of the delay for the accesses in the intersection 2, priority on modified Control Plan.*

For the accesses in the intersection 3 the results for the delay are exposed in the Table 102 and Table 103.

*Table 102. Delay for the accesses of the intersection 3, priority on Modified Control Plan.*

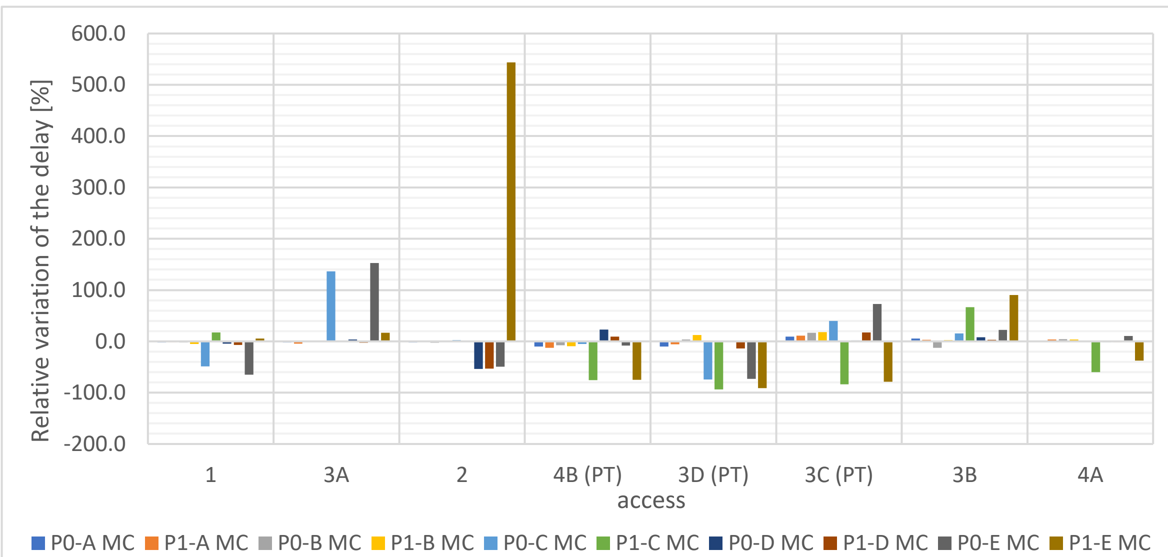
| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 1 | 36.8 | 36.0 | 36.3 | 36.1 | 34.8 | 18.8 | 43.2 | 35.0 | 34.3 | 12.8 | 38.7 |
| 3A | 8.7 | 8.5 | 8.3 | 8.8 | 8.7 | 20.5 | 8.7 | 9.0 | 8.4 | 21.9 | 10.1 |
| 2 | 33.1 | 32.5 | 33.0 | 32.3 | 33.1 | 33.9 | 33.2 | 15.2 | 15.5 | 16.7 | 213.2 |
| 4B (PT) | 16.8 | 15.1 | 14.6 | 15.5 | 15.1 | 16.0 | 4.1 | 20.6 | 18.3 | 15.4 | 4.2 |
| 3D (PT) | 21.4 | 19.2 | 20.2 | 22.2 | 24.1 | 5.4 | 1.4 | 21.5 | 18.5 | 5.8 | 1.9 |
| 3C (PT) | 15.4 | 16.8 | 17.1 | 17.9 | 18.1 | 21.5 | 2.6 | 15.6 | 18.0 | 26.6 | 3.3 |
| 3B | 196.6 | 207.0 | 202.0 | 172.0 | 200.8 | 227.4 | 328.0 | 213.0 | 202.7 | 240.8 | 373.7 |
| 4A | 14.2 | 14.1 | 14.7 | 14.8 | 14.8 | 14.4 | 5.7 | 14.0 | 14.0 | 15.7 | 8.9 |

*Table 103. Variation of delay for the accesses of the intersection 3 priority on Modified Control Plan.*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 1 | -2.1 | -1.3 | -1.7 | -5.3 | -48.8 | 17.4 | -4.7 | -6.8 | -65.1 | 5.3 |
| 3A | -2.0 | -4.7 | 1.2 | 0.1 | 136.2 | 0.3 | 3.9 | -2.8 | 152.9 | 16.8 |
| 2 | -1.8 | -0.3 | -2.4 | -0.1 | 2.4 | 0.2 | -54.0 | -53.2 | -49.5 | 543.8 |
| 4B (PT) | -9.9 | -12.7 | -7.6 | -9.7 | -4.8 | -75.6 | 22.8 | 9.2 | -8.1 | -74.7 |
| 3D (PT) | -10.3 | -5.5 | 3.8 | 12.5 | -74.6 | -93.4 | 0.2 | -13.7 | -72.9 | -91.2 |
| 3C (PT) | 9.5 | 11.5 | 16.5 | 17.7 | 39.8 | -83.3 | 1.5 | 17.1 | 72.9 | -78.6 |
| 3B | 5.3 | 2.7 | -12.5 | 2.1 | 15.7 | 66.8 | 8.3 | 3.1 | 22.5 | 90.1 |
| 4A | -0.9 | 3.6 | 4.1 | 3.8 | 1.4 | -59.8 | -1.4 | -1.6 | 10.5 | -37.7 |

From the absolute values of the delay,  the total opposite form the previous intersection is seen. The smaller values of delay in the accesses allowing movements parallel to the PT corridor, corresponds to the cases where the activated protocols included the intersection under investigation, intersection 3 this time, protocols C and E; especially when all the lines are granted priority. The access with the grates delay is the 3B for all the scenarios, having always values in the order of magnitude if the hundreds, this is consistent with the priority criteria implemented as the access allows mainly the left turn that encounter prioritized movements.

Looking to the variations of these values, the first feature that is notice is  the high increase in the access 2 for the protocol P1 E MC, of about 543%; especially because in this access the other protocols produce a reduction. The other values above 100% are concentrated in the access 3A specifically for the protocols P0 C MC and P0 E MC. In the access 3C, for the PT, only 2 of the evaluated protocols results in a reduction, P1 C MC and P0 E MC; both reducing about 80%.




*Graph 25. Relative variation of the delay for the accesses in the intersection 3, priority on modified Control Plan*

Looking to the other PT access the same P1 C MC and P1 E MC protocols are the ones leading the bests results, 75% for the access 4B and 92% for the access 3D; in this last access the protocols P0 C MC and P0 E MC have also a considerably decrees of about 74%. Other protocols have smaller impacts on the accesses, for them the major variation corresponds to 23% increase in the access 4B.

For the last intersection the delay results and the variation with respect to the scenario implementation exclusively the Modified control plan are contained in the Table 104 and Table 105.

*Table 104. Delay for the accesses of the intersection 4, priority on Modified Control Plan.*

| Access | Delay [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Modified** | **P0-A MC** | **P1-A MC** | **P0-B MC** | **P1-B MC** | **P0-C MC** | **P1-C MC** | **P0-D MC** | **P1-D MC** | **P0-E MC** | **P1-E MC** |
| 3A | 38.7 | 37.7 | 39.2 | 38.5 | 39.8 | 18.3 | 16.9 | 20.8 | 20.2 | 17.2 | 8.8 |
| 4A | 19.8 | 19.6 | 20.1 | 20.2 | 20.5 | 20.7 | 19.8 | 24.9 | 24.5 | 22.8 | 33.9 |
| 4B (PT) | 32.4 | 32.1 | 30.7 | 32.7 | 32.0 | 35.4 | 33.2 | 17.2 | 16.9 | 17.3 | 27.4 |
| 3C (PT) | 47.0 | 47.4 | 46.9 | 48.1 | 48.7 | 18.2 | 17.6 | 13.8 | 12.9 | 16.0 | 6.5 |
| 1 | 40.6 | 39.9 | 42.1 | 44.8 | 41.5 | 18.2 | 71.6 | 40.7 | 39.8 | 12.8 | 100.0 |
| 3B | 31.4 | 29.1 | 27.8 | 22.6 | 32.1 | 40.2 | 49.9 | 23.1 | 21.1 | 17.9 | 461.7 |
| 2 | 5.6 | 5.4 | 5.6 | 5.3 | 5.6 | 6.0 | 6.1 | 2.0 | 1.9 | 2.0 | 12.3 |

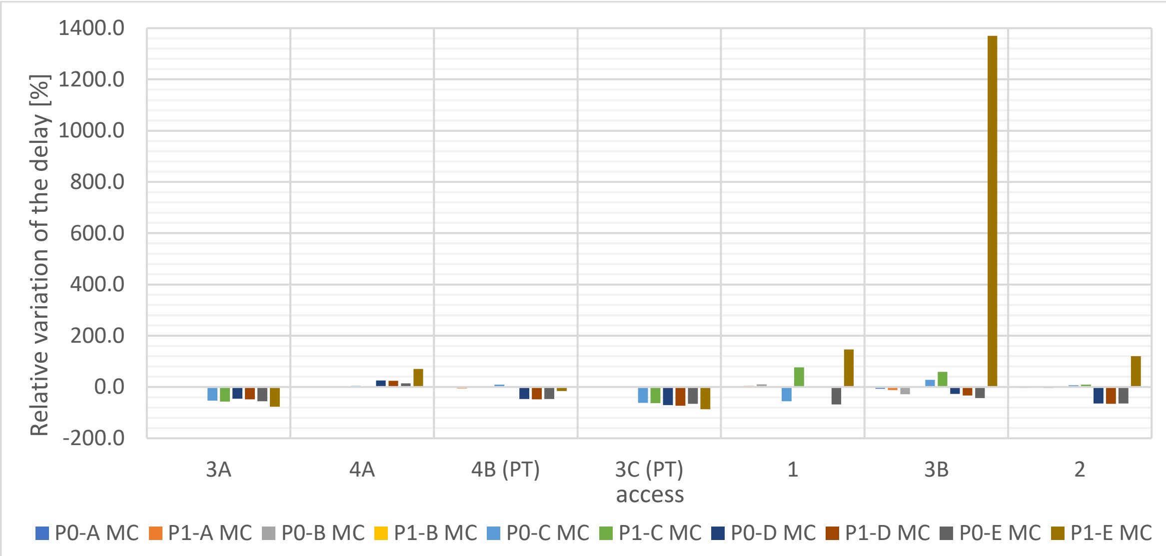
In this intersection the delay among all the accesses results is in the same order of magnitude, only the access 2 have a considerable low value along all the modelled scenarios. Another exception is present for the Protocol P1 E MC, the access 3B has the highest value of the delay in this intersection, this result stands out as this access is allowed to flow simultaneously with the right turn of the PT lines, movement 9(4), manoeuvre considered is prioritized in the protocols implemented in the intersection 4 considering all TP lines.

*Table 105. Variation of delay for the accesses of the intersection 4, priority on Modified Control Plan.*

| Access | Relative variation of delay [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| 3A | -2.5 | 1.4 | -0.4 | 2.8 | -52.8 | -56.3 | -46.1 | -47.8 | -55.7 | -77.3 |
| 4A | -1.2 | 1.1 | 1.9 | 3.2 | 4.3 | -0.4 | 25.7 | 23.7 | 14.8 | 71.0 |
| 4B (PT) | -1.1 | -5.4 | 0.8 | -1.4 | 9.2 | 2.5 | -47.0 | -47.9 | -46.6 | -15.5 |
| 3C (PT) | 0.8 | -0.3 | 2.2 | 3.6 | -61.4 | -62.5 | -70.6 | -72.6 | -66.0 | -86.2 |
| 1 | -1.6 | 3.9 | 10.3 | 2.3 | -55.1 | 76.4 | 0.4 | -1.9 | -68.4 | 146.5 |
| 3B | -7.4 | -11.5 | -28.0 | 2.2 | 27.9 | 58.9 | -26.4 | -32.8 | -43.0 | 1370.3 |
| 2 | -3.2 | 0.5 | -4.3 | -0.4 | 7.1 | 9.1 | -64.8 | -66.0 | -64.9 | 120.3 |

Focusing in to the variation there is a clear tendency to increase the reduction of the delay as the priority protocols are activated in the intersections, this tendency has is exception in the last case (protocol P1 E MC), that have for some access an extreme increases, the major example of this corresponds to the access 3B 1370 % (see Graph 26). In the same protocol the accesses 1 and 2 have increases above the 100%. Other protocol having an increase, although not as significant as the previous one, is the P1 C MC, that for the accesses 1 (76%) and 3B (58%).

The PT accesses have a more pronounce tendency to a reduction than for than increase; the increases does not go over 10% where the decreases reach values of 86%. The accesses 4B and 3C shares a good response to the protocols P0 D MC, P 1 MC and P0 E MC, the only feature consistent between these protocols is the consideration of the intersection.




*Graph 26. Relative variation of the delay for the accesses in the intersection 4, priority on modified Control Plan*

From the observation of the particular accesses in the individual intersections in terms of the delay, is possible spot in every intersection are notorious increase values, mainly for the protocol P1 E MC, in the majority of cases it goes beyond doubling the initial delay. Another important feature standing out is the location of the extreme increases that although if obtained in accesses that allow movements conflicting with the PT manoeuvres, although not for all of this type of access in the same intersection, only one exhibits the discussed extreme behaviour.

*Paths response*

The next step to analyse the impact of the priority implementations is to see the behaviour of the main paths followed by the private means in the modelled network, as was carryout in or the Base Control Plan the variables considered in the analysis will be Speed, travel time, percentage of time stopped and number of stops.

The first variable to analyse the principal paths is the average speed, applying the priority protocols is expected to have an increase in the velocity in the corridors of the PT dedicated line. For the other paths the expected result is a decrease on the variables as the priority protocol is expected to restring the allowed green time in them.

*Table 106. Average speed in the principal paths, priority on Modified Control Plan.*

| Path | Average speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N - S | 37.4 | 36.7 | 37.8 | 26.6 | 32.2 | 18.6 | 29.7 | 39.2 | 39.6 | 16.1 | 29.4 |
| PT corridor S -N | 39.1 | 39.3 | 39.6 | 39.5 | 39.7 | 40.0 | 42.7 | 39.3 | 39.5 | 40.1 | 41.2 |
| carrera 80 | 26.1 | 29.4 | 25.7 | 26.0 | 26.3 | 26.8 | 25.8 | 26.1 | 25.9 | 31.5 | 31.5 |
| carrera 94 | 31.8 | 31.5 | 31.3 | 34.6 | 31.9 | 31.6 | 31.8 | 31.7 | 32.0 | 35.8 | 33.0 |
| calle 13 N | 34.3 | 34.4 | 34.3 | 34.6 | 35.0 | 43.0 | 35.2 | 34.3 | 34.4 | 44.7 | 38.4 |
| calle 13 S | 34.8 | 34.8 | 34.6 | 34.6 | 35.0 | 43.4 | 31.6 | 34.6 | 35.0 | 45.1 | 34.2 |

| Path | Average speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Modified** | **P0-A MC** | **P1-A MC** | **P0-B MC** | **P1-B MC** | **P0-C MC** | **P1-C MC** | **P0-D MC** | **P1-D MC** | **P0-E MC** | **P1-E MC** |
| calle 16 N | 14.2 | 15.9 | 13.6 | 15.6 | 13.2 | 11.2 | 14.0 | 37.8 | 37.6 | 36.4 | 3.6 |
| calle 16 S | 32.2 | 33.0 | 31.4 | 33.4 | 31.6 | 29.2 | 29.9 | 45.2 | 45.0 | 44.9 | 13.1 |

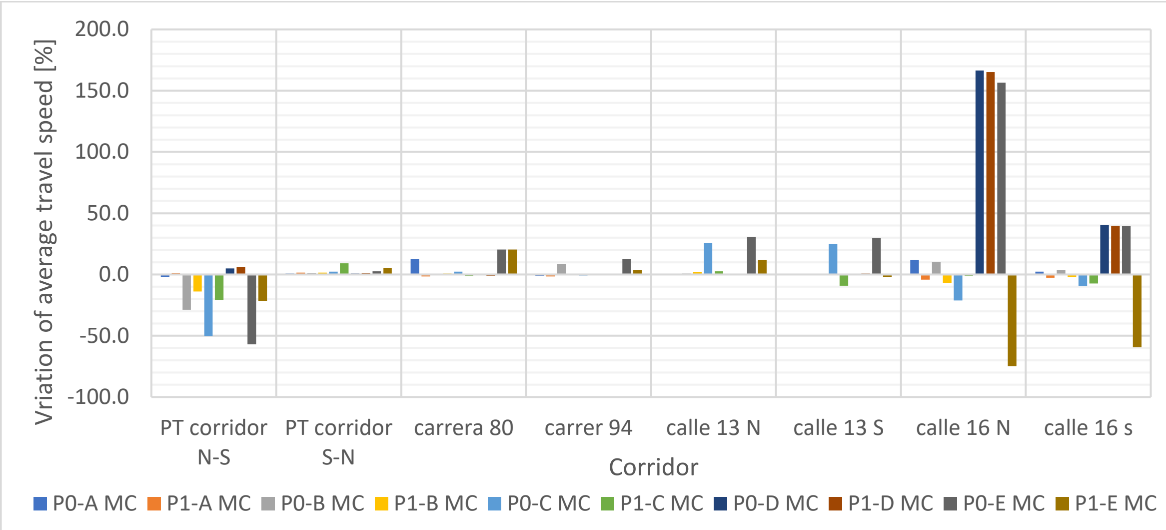
From the Table 106 some features can be spotted, in general the greatest speeds correspond for the PT corridor paths, this goes with the expected results although the highest values for all the cases does not occur in them but for the “calle 13” paths when the protocols P0 C MC and P0 E MC are activated, and for the “Calle 16” coming from south path with the protocols P0 D MC, P1 D MC and P0 E MC. The “calle 16” coming from north in general is the worst path, the only variation of this behaviour corresponds to the implementation of the protocols P0 D MC, P1 D MC and P0 E MC, where the velocity overcome the 40 km/h.

Another feature standing out from the average speed is the discrepancy between the behaviour of the paths for the protocols P0 E MC and P1 E MC, in the other pairs of protocols the behaviour is similar when the same intersections are considered in the priority protocol. In the particular case of the discussed “E” protocols, they account all four intersections, but the results varied considerably, the most dramatic of the differences is in the “calle 16” coming from north, when the priority protocol only account or the “E” lines the speed reach 36 km/h, in the other scenario, all PT lines are prioritized and the speed decrees to less than 4 km/h.

*Table 107. Variation of average speed in the principal paths, priority on Modified Control Plan.*

| Path | Relative variation of average speed [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | -2.0 | 1.0 | -28.9 | -13.9 | -50.3 | -20.7 | 4.9 | 6.0 | -56.9 | -21.6 |
| PT corridor S-N | 0.7 | 1.5 | 1.1 | 1.5 | 2.3 | 9.2 | 0.7 | 1.0 | 2.6 | 5.3 |
| carrera 80 | 12.6 | -1.6 | -0.5 | 0.8 | 2.4 | -1.3 | -0.1 | -1.1 | 20.5 | 20.4 |
| carrera 94 | -1.1 | -1.7 | 8.7 | 0.1 | -0.9 | -0.1 | -0.4 | 0.5 | 12.5 | 3.7 |
| calle 13 N | 0.4 | 0.2 | 0.8 | 2.1 | 25.6 | 2.6 | 0.0 | 0.3 | 30.5 | 12.0 |
| calle 13 S | 0.1 | -0.6 | -0.6 | 0.6 | 24.9 | -9.3 | -0.6 | 0.7 | 29.7 | -1.8 |
| calle 16 N | 11.9 | -4.2 | 10.2 | -6.8 | -21.1 | -1.2 | 166.5 | 165.1 | 156.7 | -74.7 |
| calle 16 S | 2.3 | -2.7 | 3.7 | -2.0 | -9.5 | -7.3 | 40.2 | 39.7 | 39.4 | -59.2 |

Analysing the relative variations of the speed with the reference scenario, the maximum increase is located in the in the “calle 16” coming from north path, for the protocols P0 D MC, P1 D MC and P0 E MC, increase of 166%, 165% and 157% correspondingly. Between the mentioned protocols the constant is the inclusion of the intersection 4, although the protocol P1 E MC that share the same characteristic, goes the other way and results in the greatest decrees of the velocity, 79%. In general, the results of the implementation of priority protocols is an increase on the average speed, the corridor that does not follow this general tendency is the PT corridor in the north-south, 7 of the 10 protocols evaluated resulting in decreases (see Graph 27).




*Graph 27. Relative variation of average in speed, Priority on Modified Control Plan*

The next variable to analyse is the travel time sped in average by the users of the network through the principal paths of the modelled network, the results are contained in the Table 108 and the Table 109.

*Table 108. Travel time in the principal paths, Priority on Modified Control Plan.*

| Path | Travel time [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | 330.6 | 338.9 | 325.2 | 479.6 | 386.9 | 709.0 | 490.0 | 322.8 | 313.6 | 813.8 | 493.3 |
| PT corridor S-N | 288.4 | 286.8 | 283.9 | 285.3 | 284.4 | 284.1 | 265.6 | 287.9 | 286.5 | 281.6 | 285.6 |
| carrera 80 | 40.7 | 36.1 | 43.6 | 40.8 | 40.4 | 39.7 | 41.0 | 40.5 | 41.2 | 32.8 | 32.7 |
| carrera 94 | 37.4 | 37.5 | 37.9 | 34.4 | 39.1 | 37.7 | 37.3 | 37.6 | 37.2 | 32.7 | 36.9 |
| calle 13 N | 111.9 | 111.8 | 111.9 | 111.0 | 110.0 | 87.7 | 112.3 | 112.1 | 111.9 | 82.8 | 109.4 |
| calle 13 S | 110.0 | 110.1 | 110.4 | 110.7 | 109.4 | 86.2 | 132.3 | 110.5 | 109.5 | 81.5 | 163.9 |
| calle 16 N | 303.3 | 270.2 | 316.6 | 259.2 | 319.9 | 380.5 | 323.3 | 96.5 | 97.0 | 101.0 | 1511.9 |
| calle 16 S | 113.6 | 111.1 | 119.6 | 109.0 | 118.4 | 133.2 | 133.5 | 78.2 | 78.4 | 78.8 | 440.0 |

From the travel time results, the first feature to notice is the highest value, located in the "calle 16" coming from north path when the protocol P1 E MC is activated, in this particular case the travel time is more than 4 times greater than the travel time of the paths along the PT corridor although those are the longest paths, the detrimental response was expected as it corresponds to a perpendicular path to the PT corridor. This response marks how critical can be the effects of the implementation of any TSP strategy.

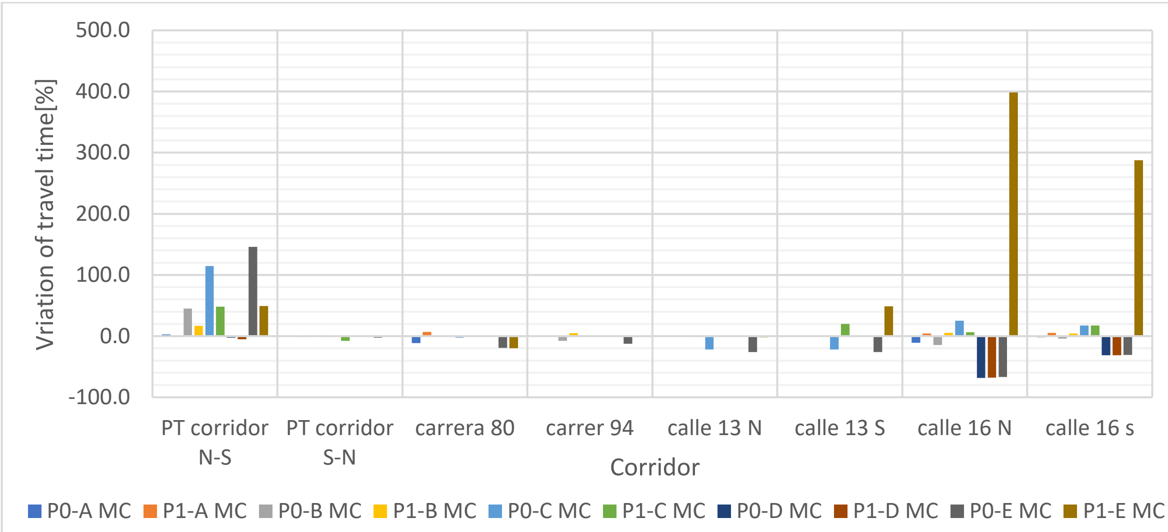
Another feature to highlight is the sporadic inconsistency of the travel time of the two paths in the PT corridor, when generally the difference of the time between the senses is less than 2 minutes, in the protocols containing the intersection 3 this is not follow; the difference is more pronounce when only the "E" lines are given priority, the increase on the average travel time in the “0” protocols have is due to the less priority given, and thus less green time given to the manoeuvres parallel to the BRT system.

*Table 109. Variation of travel time in the principal paths, Priority on Modified Control Plan.*

| Path | Relative variation of time travel [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | 2.5 | -1.7 | 45.1 | 17.0 | 114.4 | 48.2 | -2.4 | -5.2 | 146.1 | 49.2 |
| PT corridor S-N | -0.6 | -1.6 | -1.1 | -1.4 | -1.5 | -7.9 | -0.2 | -0.7 | -2.4 | -1.0 |
| carrera 80 | -11.3 | 7.2 | 0.3 | -0.7 | -2.5 | 0.7 | -0.4 | 1.2 | -19.4 | -19.6 |
| carrera 94 | 0.3 | 1.3 | -8.0 | 4.6 | 0.7 | -0.4 | 0.6 | -0.5 | -12.5 | -1.3 |
| calle 13 N | 0.0 | 0.1 | -0.8 | -1.6 | -21.6 | 0.4 | 0.3 | 0.1 | -25.9 | -2.2 |
| calle 13 S | 0.1 | 0.4 | 0.7 | -0.5 | -21.7 | 20.2 | 0.4 | -0.5 | -25.9 | 48.9 |
| calle 16 N | -10.9 | 4.4 | -14.5 | 5.5 | 25.5 | 6.6 | -68.2 | -68.0 | -66.7 | 398.5 |
| calle 16 S | -2.2 | 5.3 | -4.0 | 4.3 | 17.3 | 17.6 | -31.1 | -31.0 | -30.6 | 287.5 |

Looking to the variation with respect to the initial scenario, the tendency is to have small variation, less than 20%. In particular cases this tendency is disrupted, among them the PT corridor in the north-south direction, where the majority of protocols results in increases, 7 of 10, 3 reaching values about 48% and other 2 overcoming an increase of 100%. The las 2 protocols in this category are the protocols P0 C MC and P0 E MC, protocols discussed previously when analysing the absolute values of the travel time. The greatest increases correspond to the protocol P1 E MC in the “calle 16” paths, coming from the north the increase is of 398 % and coming from the south the increase is about 287%.

For the side of the reduction of the travel time, considered the better response, the only relevant reductions correspond to the “calle 16” paths, for the same 3 protocols in both directions, P0 D MC, P1 D MC and P0 E MC, in the north-south direction the average reduction is about 67% and for the south-north sense is about 30%. The difference in the two paths resides in that although corresponds to the same street according to the control plan of the intersection 4 the have the north access of the “calle 16” is activated for only one phase que int south access is activated in 2, one of them included as prioritized. The reduction being a good response, for the North-south sense, was no expected as belongs to a manoeuvre perpendicular to the PT corridor and is not include in any prioritized phase.




*Graph 28.Relative variation of Travel time for paths, Priority on Modified Control Plan.*

The next step in the analysis of the behaviour it the paths, derives into the analysis of the percentage of the time the users are obligated to be stopped of the total travel time, analysed previously; the results are contained in the Table 110 and the Table 111.

*Table 110. Percentage of time spend stopped in the principal paths, Priority on Modified Control Plan.*

| Path | % of time stopped [%] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | 22.2 | 23.2 | 21.7 | 46.9 | 32.4 | 61.5 | 44.6 | 20.7 | 17.7 | 66.3 | 44.1 |
| PT corridor S-N | 17.4 | 16.9 | 16.4 | 16.9 | 16.5 | 16.3 | 11.6 | 17.5 | 17.6 | 16.7 | 18.3 |
| carrera 80 | 38.9 | 32.1 | 43.3 | 39.2 | 38.7 | 38.1 | 39.5 | 38.7 | 39.6 | 25.2 | 25.5 |
| carrera 94 | 35.8 | 35.7 | 36.2 | 30.4 | 39.1 | 35.9 | 35.9 | 36.1 | 35.9 | 27.6 | 35.2 |
| calle 13 N | 30.0 | 30.0 | 29.8 | 29.7 | 29.3 | 14.3 | 30.9 | 30.0 | 29.9 | 9.4 | 30.2 |
| calle 13 S | 31.1 | 31.2 | 31.6 | 31.7 | 30.8 | 14.0 | 41.9 | 31.2 | 30.8 | 9.4 | 52.6 |
| calle 16 N | 70.8 | 68.1 | 71.9 | 66.7 | 72.2 | 76.2 | 72.8 | 21.6 | 22.1 | 24.8 | 94.0 |
| calle 16 S | 25.8 | 24.8 | 29.1 | 24.1 | 28.3 | 34.8 | 34.9 | 3.4 | 3.1 | 3.4 | 76.7 |

The percentage of time stopped is expected to be higher in the non-prioritized paths, this is confirmed in the results of the Table 110 where the PT corridors, in general, corresponds to the lower values, especially in the south-north sense; for the north-south sense some high peaks are spotted in the protocols P0 C MC (61%) and P0 E MC (66%), behaviour not followed by the corresponding "1" protocols, due to the increment of priority request granted.

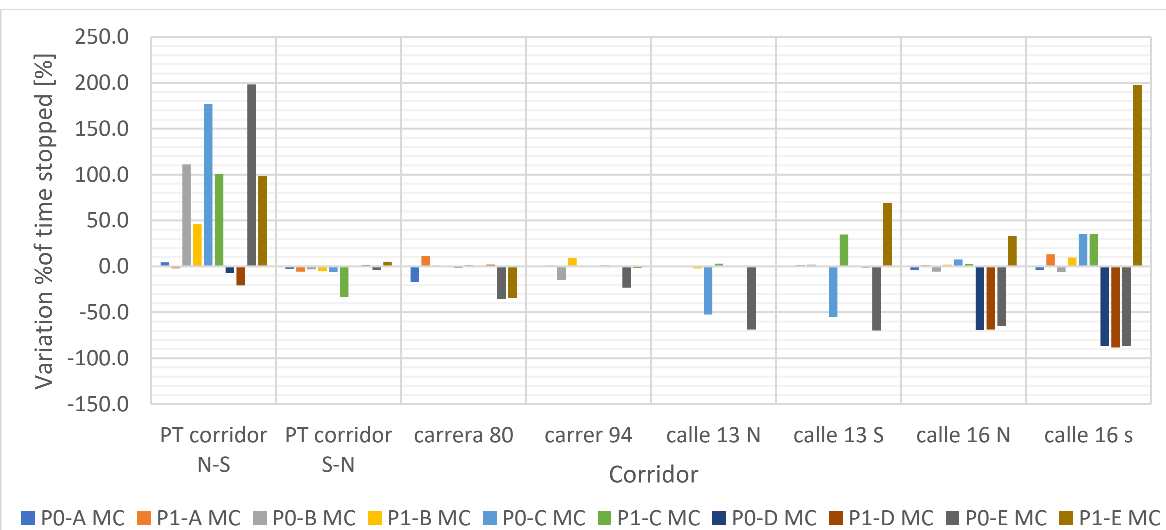
Looking for the worst path, the "calle 16" coming from north, have the major concentration of values are 50%, containing the highest values of percentage of time stopped for the protocol P1 E MC (94%), in this paths only the protocols P0 D MC, P1 D MC and P0 E MC does not follow the exposed tendency resulting in 22%, 22% and 25% correspondingly. The low values in these protocols are consistent for the other path of the "calle 16", although in this case generally the results are below 50% and for the particular protocols, the time stopped is lower than 5%

*Table 111. Variation of percentage of time spend stopped in the principal paths, Priority on Modified Control Plan.*

| Path | Absolute variation of % of time stopped [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | 4.5 | -2.2 | 111.0 | 45.8 | 176.8 | 100.7 | -7.0 | -20.5 | 198.2 | 98.6 |
| PT corridor S-N | -2.8 | -5.8 | -3.1 | -5.2 | -6.5 | -33.3 | 0.3 | 1.3 | -4.1 | 5.1 |
| carrera 80 | -17.3 | 11.4 | 0.8 | -0.6 | -2.0 | 1.7 | -0.4 | 1.9 | -35.3 | -34.3 |
| carrera 94 | -0.4 | 1.0 | -15.1 | 9.1 | 0.4 | 0.2 | 0.9 | 0.1 | -23.0 | -1.7 |
| calle 13 N | 0.0 | -0.4 | -0.8 | -2.1 | -52.3 | 3.0 | 0.0 | -0.1 | -68.8 | 0.7 |
| calle 13 S | 0.4 | 1.5 | 2.0 | -0.8 | -55.0 | 34.7 | 0.4 | -1.0 | -69.8 | 69.0 |
| calle 16 N | -3.8 | 1.5 | -5.8 | 2.0 | 7.7 | 2.8 | -69.4 | -68.8 | -65.0 | 32.9 |
| calle 16 S | -3.9 | 13.0 | -6.5 | 9.8 | 35.0 | 35.4 | -87.0 | -88.1 | -86.8 | 197.7 |

Looking in the variations of the variable, the results contradicts the expectation, where the PT corridor is supposed to have a reduction on the time the users are stopped due to the TSP.

As can be seen in the Graph 29, the PT corridor in the North-South direction have 6 of the 10 evaluated protocols resulting in considerable increases, only the “A” and “D” protocols are not included in them. The increases correspond to the pair of protocols determine by the intersection considered having the “0” ones a higher increase than the “1”, the reason of this have been already discussed. For the other PT corridor path the tendency is a slightly reduction, the difference is considered due to the presence of the right turns in the intersections, having a total of 3 in the north-south and only 1 in the other direction; this manoeuvres are prejudicated by the priority protocols leading to a retention of vehicles in the corresponding access that influence in the flow of the other manoeuvres in the same access.




*Graph 29. Absolute variation of percentage of time stopped in the principal path, priority on Modified Control Plan.*

The higher reductions are for the side of the reduction the best results are for the “calle 16” paths for the previously exposed protocols, P0 D MC, P1 D MC and P0 E MC. The remain P1 E MC protocol, results in an increase of the percentage of time the vehicles are stopped as was expected, although the greatest impact is in the path coming from south, an increase of 197%; standing out because this particular path is accounted in the priority plan of the intersection 4 in the second phase.

The last variable to analyse for the paths in the network is the number of stops performed by the users along the travel, important as it is perceived directly by the user and can influence in great manner the evaluation of the trip, the results are contained in the Table 112 and the Table 113.

*Table 112. Number of stops in the principal path, Priority on Modified Controls Plan.*

| Path | Number of stops [-] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | 2.6 | 2.8 | 2.6 | 5.2 | 4.4 | 5.4 | 3.7 | 2.6 | 2.6 | 8.6 | 5.2 |
| PT corridor S-N | 2.3 | 2.3 | 2.2 | 2.1 | 2.0 | 2.1 | 1.7 | 2.3 | 2.4 | 2.6 | 2.0 |
| carrera 80 | 0.9 | 0.8 | 0.9 | 0.9 | 0.9 | 0.8 | 0.9 | 0.9 | 0.9 | 0.7 | 0.7 |
| carrera 94 | 0.8 | 0.8 | 0.8 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 |
| calle 13 N | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.7 | 1.2 | 1.1 | 1.1 | 0.6 | 1.0 |
| calle 13 S | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.5 | 1.1 | 0.8 | 0.8 | 0.5 | 1.2 |
| calle 16 N | 2.5 | 2.3 | 2.6 | 2.3 | 2.7 | 2.9 | 2.5 | 0.8 | 0.8 | 0.9 | 3.3 |
| calle 16 S | 1.1 | 1.1 | 1.2 | 1.0 | 1.2 | 1.4 | 1.4 | 0.3 | 0.3 | 0.3 | 3.4 |

The number of stops, as discussed for the evaluation of the priority on the Base Control Plan, ideally must be one stop per intersection or less. The results show that generally the perpendicular paths follow this behaviour, with the exception of the “calle 16” coming from north, where 7 of 11 scenarios have more than 2 stops; the “calle 16” coming from south path have a particular case where not respected this tendency for the protocol P1 E MC resulting in 3.4 stops in average. The results or the “calle 16” are consistent with the analysis of the previous variables where the protocols P0 D MC, P1 D MC and P0 E MC results in a benefit for the paths, although the priority protocols are considered to be detrimental for the perpendicular paths.

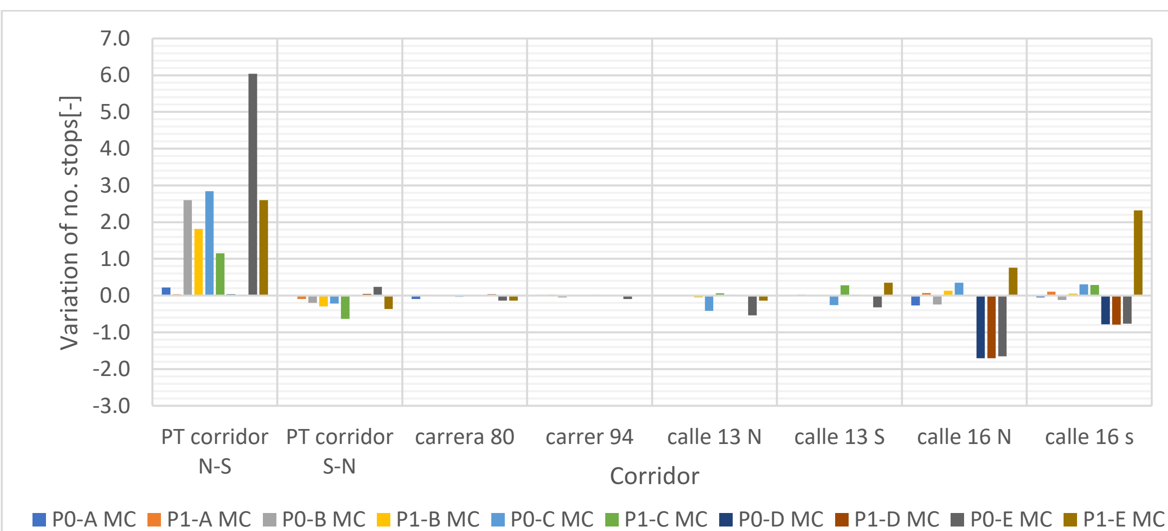
Focusing in the PT corridor, that is expected to have always less than 5 stops, this is accomplished in the south-north sense in all the protocols evaluated, for the other direction the protocols P0 B MC, P0 C MC, P0 E MC and P1 E MC result in more than 5 stops, being the P0 E MC the most critical case, where a value of 8 is reached, as if the vehicle have to stops twice per intersection.

*Table 113. Variation of Number of stops in the principal path, Priority on Modified Controls Plan.*

| Path | Absolute variation of number of stops [-] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| PT corridor N-S | 0.2 | 0.0 | 2.6 | 1.8 | 2.8 | 1.2 | 0.0 | 0.0 | 6.0 | 2.6 |
| PT corridor S-N | 0.0 | -0.1 | -0.2 | -0.3 | -0.2 | -0.6 | 0.0 | 0.0 | 0.2 | -0.4 |
| carrera 80 | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 |
| carrera 94 | 0.0 | 0.0 | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | 0.0 |
| calle 13 N | 0.0 | 0.0 | 0.0 | -0.1 | -0.4 | 0.1 | 0.0 | 0.0 | -0.5 | -0.1 |
| calle 13 S | 0.0 | 0.0 | 0.0 | 0.0 | -0.3 | 0.3 | 0.0 | 0.0 | -0.3 | 0.4 |
| calle 16 N | -0.3 | 0.1 | -0.2 | 0.1 | 0.4 | 0.0 | -1.7 | -1.7 | -1.7 | 0.8 |
| calle 16 S | -0.1 | 0.1 | -0.1 | 0.1 | 0.3 | 0.3 | -0.8 | -0.8 | -0.8 | 2.3 |

With respect to the variation due to the implementation of the priority protocols, the number of stops is expected to be reduced in the PT corridor as an effect of the prioritization of the manoeuvres along it, for the perpendicular paths the expected behaviour is to increase. In the results of the evaluated protocols the variation in general are not significant enough and can be derived of the variation of the experiments. The relevant variation corresponds for the PT corridor in the North-South direction and both paths of the "calle 16" (see Graph 30). In the case of the PT path due to the implementation of TSP the general result is an increase, generally of about 2.5 stops, the greatest increase is for the protocol P0 E MC with 6 stops more than in the base case; the only protocols without an increase are the P1 A MC, P0 D MC and P1 D MC.

For the "calle 16" paths, as in the other evaluated variables have a no expected, beneficial behaviour due to the protocolsP0 D MC, P1 D MC and P0 EMC, in the case of the Protocol P1 E MC the behaviours go along the initial suppositions, having an increase of the number of stops. The other protocols have a varying behaviour but not being relevant enough.




*Graph 30. Absolute variation of the Number of stops in the principal paths, Priority on Modified Control Plan.*

From the analysis of the paths in the network when applying the various priority protocols upon the Modified Control Plan, is possible to observe that going against the expected results, the active TSP protocols considered where detrimental to the mix traffic in the PT corridor in the north-south direction, most likely due to the presence of right turs in the intersections. The 2 paths of the "calle 16" also have an unexpected response to the protocols reacting positively for 3 specific protocols.

*BRT response*

The final component in the model to analyse is the PT, in order to have an overall looking of the response to the different priority protocols three variables are considered, the average speed, average travel time and number of stops, variables that are accounted by the user of the BTR system in order to judge the service.

The results for the velocity exhibit by the different busses in the BRT system under the different priority protocols upon the Modified Control Plan are contained in the Table 114 and the Table 115.

*Table 114. Average speed of the PT lines, Priority on Modified Control Plan.*

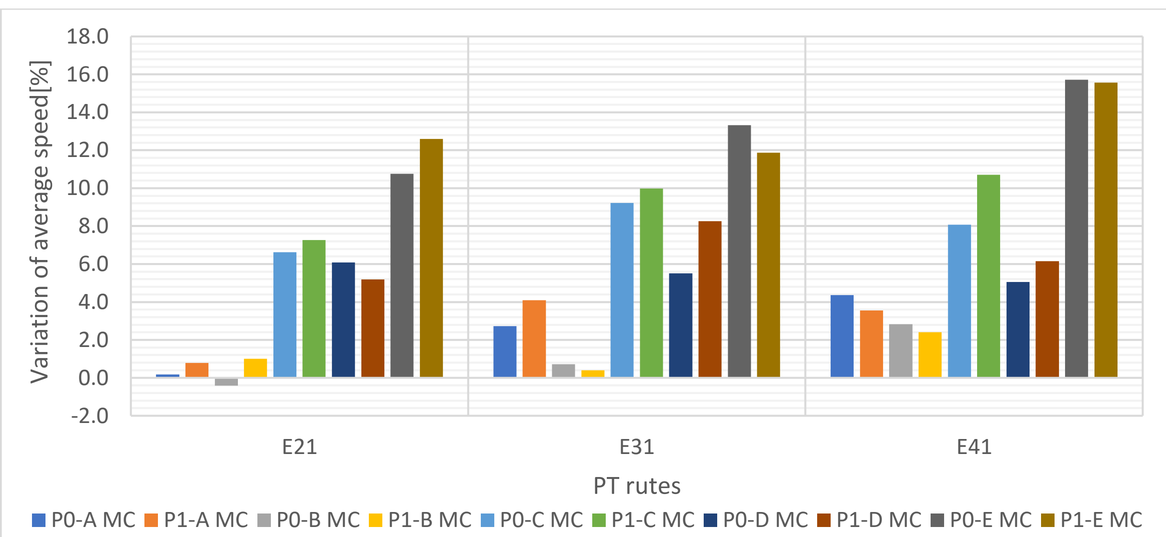
| Name | Average speed [km/h] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| E21 | 35.7 | 35.8 | 36.0 | 35.5 | 36.0 | 38.0 | 38.3 | 37.9 | 37.5 | 39.5 | 40.2 |
| E31 | 33.8 | 34.7 | 35.2 | 34.0 | 33.9 | 36.9 | 37.2 | 35.7 | 36.6 | 38.3 | 37.8 |
| E41 | 33.9 | 35.4 | 35.1 | 34.9 | 34.7 | 36.6 | 37.5 | 35.6 | 36.0 | 39.2 | 39.2 |
| P10A | 33.8 | 33.5 | 34.5 | 33.3 | 34.0 | 35.3 | 37.6 | 36.3 | 35.9 | 34.1 | 38.8 |
| P10B | 24.8 | 21.7 | 23.8 | 23.3 | 21.8 | 23.4 | 22.7 | 31.0 | 32.0 | 30.5 | 23.3 |
| P10D | 24.4 | 23.6 | 23.2 | 24.4 | 23.3 | 20.8 | 23.0 | 29.1 | 28.6 | 31.2 | 24.9 |
| P12A | 22.7 | 21.8 | 22.1 | 21.4 | 20.6 | 22.3 | 22.0 | 27.9 | 27.8 | 28.9 | 22.9 |
| P17-A | 32.5 | 32.8 | 32.7 | 32.7 | 32.4 | 37.1 | 38.3 | 36.3 | 36.7 | 36.7 | 40.5 |
| P17-B | 41.1 | 40.6 | 41.4 | 40.6 | 41.4 | 35.8 | 39.5 | 35.1 | 34.4 | 34.8 | 38.3 |
| P21A | 24.3 | 23.1 | 22.4 | 23.4 | 23.3 | 23.7 | 23.0 | 29.1 | 29.4 | 30.8 | 24.1 |
| P21B | 24.0 | 24.1 | 22.7 | 23.4 | 22.4 | 23.7 | 23.4 | 30.1 | 30.2 | 28.7 | 24.8 |
| P27C | 31.9 | 32.4 | 33.1 | 32.1 | 32.7 | 32.8 | 35.3 | 34.6 | 34.4 | 32.9 | 36.9 |
| T31 | 32.5 | 32.2 | 33.1 | 32.1 | 32.5 | 33.1 | 35.2 | 34.7 | 34.6 | 32.6 | 36.6 |

From the previous results is possible to see a homogeneous behaviour between the lines that follows the dedicated PT lanes and the lines exiting them, the only line depicting an abnormal behaviour is the P17 line, which have an increase of about 10 km/h when evaluating the B part of the route. With the differentiation of the 2 major groups is possible to notice a reduction of the speed of the lines exiting the PT dedicated corridor, whenever the lines along the PT corridor exhibit an increases, this is followed in all the evaluated cases, although the expected result for all the lines in the "0" protocols is to have an increase of the speed.

*Table 115. Variation of average speed of the PT lines, Priority on Modified Control Plan.*

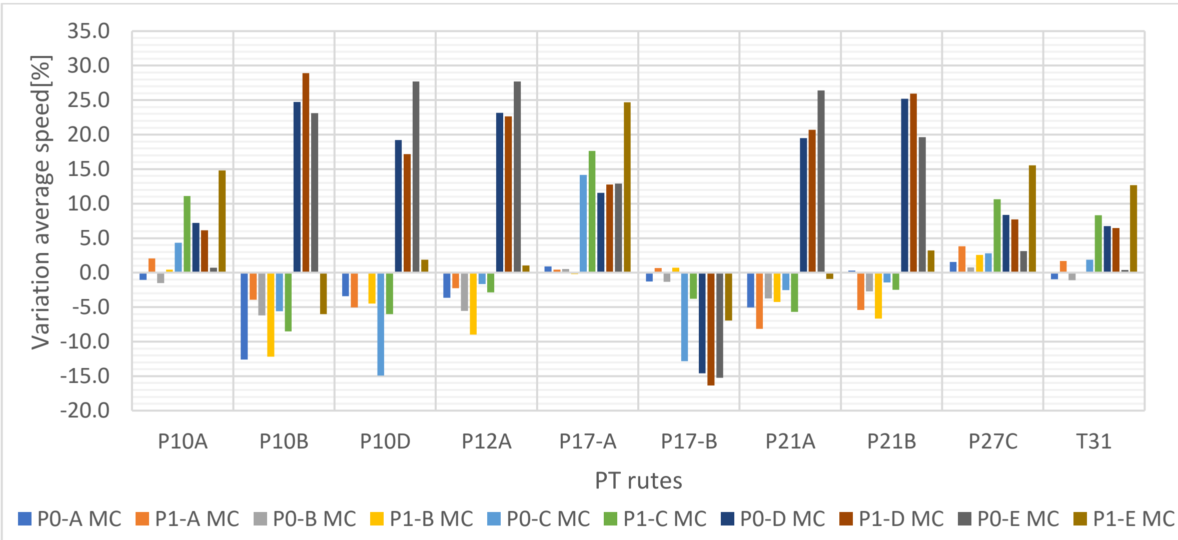
| Name | Relative variation of the average speed [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| E21 | 0.2 | 0.8 | -0.4 | 1.0 | 6.6 | 7.3 | 6.1 | 5.2 | 10.8 | 12.6 |
| E31 | 2.7 | 4.1 | 0.7 | 0.4 | 9.2 | 10.0 | 5.5 | 8.3 | 13.3 | 11.9 |
| E41 | 4.4 | 3.6 | 2.8 | 2.4 | 8.1 | 10.7 | 5.1 | 6.1 | 15.7 | 15.6 |
| P10A | -1.1 | 2.1 | -1.5 | 0.4 | 4.3 | 11.1 | 7.2 | 6.1 | 0.7 | 14.8 |
| P10B | -12.6 | -3.9 | -6.2 | -12.2 | -5.6 | -8.5 | 24.7 | 28.9 | 23.1 | -6.0 |
| P10D | -3.4 | -5.0 | 0.0 | -4.5 | -14.9 | -6.0 | 19.2 | 17.2 | 27.7 | 1.9 |
| P12A | -3.7 | -2.2 | -5.6 | -9.0 | -1.6 | -2.8 | 23.2 | 22.7 | 27.7 | 1.0 |
| P17-A | 0.9 | 0.4 | 0.5 | -0.2 | 14.1 | 17.6 | 11.6 | 12.8 | 12.9 | 24.7 |
| P17-B | -1.3 | 0.7 | -1.3 | 0.7 | -12.8 | -3.8 | -14.6 | -16.4 | -15.3 | -6.9 |
| P21A | -5.0 | -8.2 | -3.7 | -4.2 | -2.5 | -5.7 | 19.5 | 20.7 | 26.4 | -0.9 |
| P21B | 0.3 | -5.4 | -2.7 | -6.7 | -1.4 | -2.5 | 25.2 | 25.9 | 19.6 | 3.2 |
| P27C | 1.5 | 3.8 | 0.7 | 2.6 | 2.8 | 10.6 | 8.4 | 7.7 | 3.1 | 15.6 |
| T31 | -0.9 | 1.7 | -1.1 | 0.1 | 1.9 | 8.3 | 6.7 | 6.5 | 0.4 | 12.7 |

With respect to the variation of the speed along the diverse scenarios evaluated, is possible to spot a tendency towards an increase in almost all the lines, along the increment of the intersection indicator. This way the greatest increments are located in the protocols P0 D MC, P1 D MC and P0 E MC, all accounting for the intersection 4, with increments of about 27% for the lines exiting the dedicated PT lanes (see Graph 32); this tendency are no followed by the P17 line coming from the south (B) when the effect is the contrary of the mentioned and for this protocols there is a mark reduction of the speed.




*Graph 31. Variation of average speed of "E" lines, Priority on Modified Control Plan.*

Specifically for the "E" lines in every case the response to the priority protocols is an increase in the speed, although not exceeding the 16 % in any case, the better responses for all 3 lines correspond to the "E" protocols, this effect can be primarily granted to the intervention of the intersection 3, explained due to the response depicted for the "C" protocols ( see Graph 31),the second greatest increase of the speed; the protocols given priority in in the intersections 1 and 2 exclusively does not have a significant variation from the base scenario.




*Graph 32. Variation of average speed of non "E" lines, Priority on Modified Control Plan.*

The next variable is the travel time of the different PT travel time, expected to be positively impacted by the priority protocols, as more green time is given in more intersections, this way the expected protocol to have the best result is the P1 E CM that gives priority to all lines in every intersection. In this case best result referees exclusively to the PT service, as the mix traffic have been already disused and analysed. The result of the travel time is contained in the Table 116, the Table 117 show the behaviour with respect the initial condition.

*Table 116. Travel time of the PT lines, Priority on Modified Control Plan.*

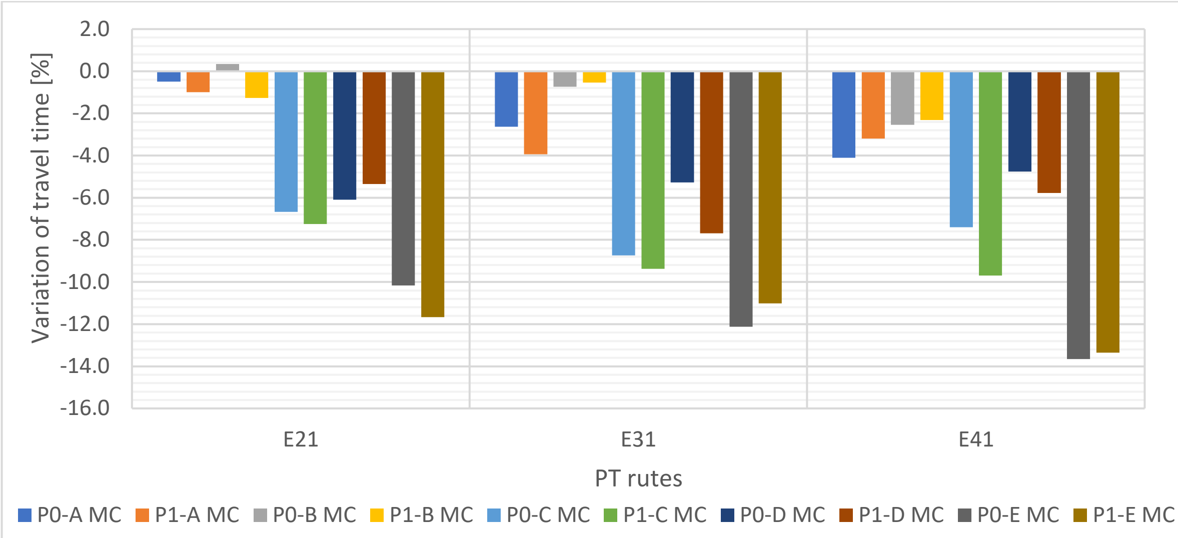
| Name | Travel time [sec] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| E21 | 713.6 | 710.1 | 706.5 | 716.1 | 704.5 | 665.9 | 661.9 | 670.1 | 675.3 | 641.0 | 630.3 |
| E31 | 753.2 | 733.4 | 723.5 | 747.6 | 749.1 | 687.3 | 682.5 | 713.5 | 695.3 | 661.9 | 670.2 |
| E41 | 748.3 | 717.6 | 724.4 | 729.3 | 731.0 | 692.9 | 675.8 | 712.8 | 705.1 | 646.1 | 648.4 |
| P10A | 752.7 | 760.5 | 737.6 | 764.1 | 750.0 | 719.0 | 674.3 | 698.8 | 707.2 | 745.2 | 652.3 |
| P10B | 114.8 | 129.9 | 119.5 | 124.6 | 128.3 | 123.5 | 124.2 | 91.6 | 87.4 | 91.3 | 138.6 |
| P10D | 116.0 | 119.8 | 122.1 | 115.5 | 121.7 | 134.7 | 123.4 | 96.9 | 98.2 | 90.3 | 127.2 |
| P12A | 127.9 | 132.6 | 128.4 | 132.1 | 138.7 | 129.0 | 129.6 | 104.7 | 102.8 | 98.2 | 136.7 |
| P17-A | 410.0 | 407.3 | 408.5 | 408.2 | 410.9 | 362.6 | 351.1 | 368.2 | 364.3 | 364.8 | 328.7 |
| P17-B | 305.0 | 309.3 | 303.3 | 309.2 | 302.9 | 352.6 | 318.7 | 358.3 | 365.3 | 361.3 | 328.6 |
| P21A | 123.1 | 129.1 | 131.7 | 124.7 | 126.1 | 126.9 | 129.0 | 98.9 | 95.3 | 91.8 | 139.1 |
| P21B | 120.7 | 117.7 | 126.5 | 122.5 | 126.3 | 120.8 | 121.3 | 94.7 | 92.6 | 100.1 | 122.3 |
| P27C | 795.7 | 784.9 | 769.2 | 791.5 | 777.5 | 775.4 | 718.5 | 734.6 | 740.1 | 771.2 | 687.2 |
| T31 | 781.4 | 788.9 | 768.8 | 790.6 | 780.3 | 767.1 | 719.7 | 730.6 | 732.6 | 778.3 | 692.5 |

The Table 116 allows a clear distinction of the lines according to the movements performed in the “Universidades” station (see Figure 19), thus the travel time can be divided in three groups, the lines making an “U” turn in the station, accounting the “E” liens, T31, the P10A and P27C; the second group contains the P17 lines, that pass through the station; the las group corresponds to the lines exiting the dedicated line in the intersection 4, including in it the remaining “P” lines.

Two main features can be extracted from the behaviours of the differed groups, the first is the relation between the P17 lines and the lines making the “U” turn, summing up the time employ in the 2 senses of the P17 lines, logically, result in a similar time to the whole trip performed by the other group. The second feature concern exclusively to the group including the “E” lines; is that in this group is expected a distinction in the travel time of the “E” lines and the other three lines, due to the different priority protocols given priority exclusively to the “Expreso” lines, then, when activated these protocols, the non-prioritized lines are expected to have a greater travel time; the results show no distinction and the time for the non “E” lines between the protocols “0” and “1” are similar when affecting the same intersection.

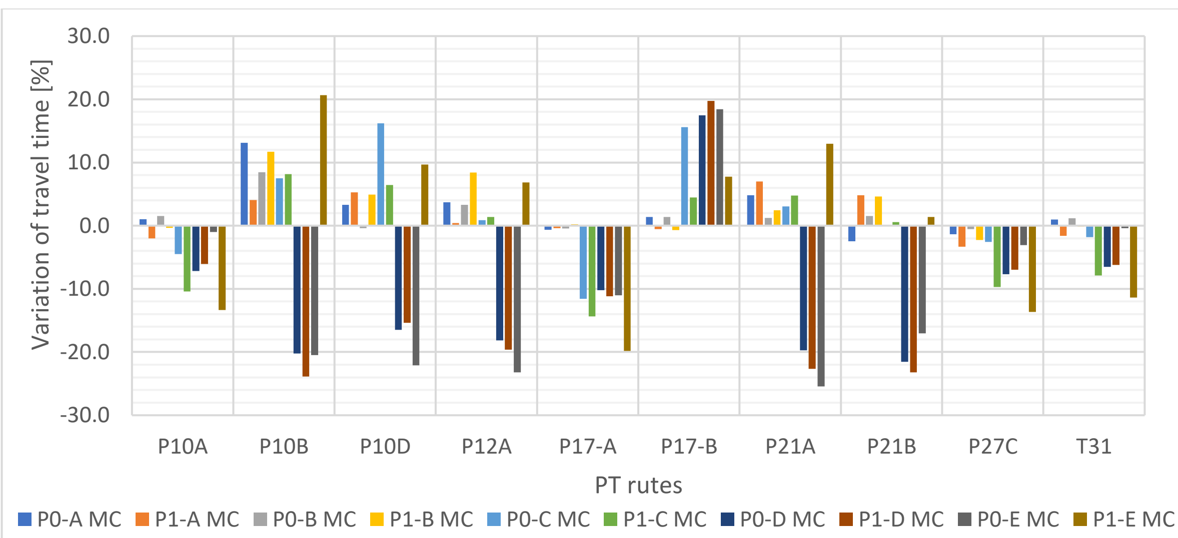
*Table 117. Variation of travel time of the PT lines, Priority on Modified Control Plan.*

| **Name** | **Relative Variation of the travel time [%]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| E21 | -0.5 | -1.0 | 0.4 | -1.3 | -6.7 | -7.2 | -6.1 | -5.4 | -10.2 | -11.7 |
| E31 | -2.6 | -3.9 | -0.7 | -0.5 | -8.7 | -9.4 | -5.3 | -7.7 | -12.1 | -11.0 |
| E41 | -4.1 | -3.2 | -2.5 | -2.3 | -7.4 | -9.7 | -4.8 | -5.8 | -13.7 | -13.4 |
| P10A | 1.0 | -2.0 | 1.5 | -0.4 | -4.5 | -10.4 | -7.2 | -6.0 | -1.0 | -13.3 |
| P10B | 13.1 | 4.0 | 8.5 | 11.7 | 7.5 | 8.2 | -20.2 | -23.9 | -20.5 | 20.7 |
| P10D | 3.3 | 5.3 | -0.4 | 4.9 | 16.2 | 6.4 | -16.5 | -15.4 | -22.1 | 9.7 |
| P12A | 3.7 | 0.4 | 3.3 | 8.4 | 0.9 | 1.4 | -18.1 | -19.6 | -23.2 | 6.9 |
| P17-A | -0.7 | -0.4 | -0.4 | 0.2 | -11.6 | -14.4 | -10.2 | -11.2 | -11.0 | -19.8 |
| P17-B | 1.4 | -0.6 | 1.4 | -0.7 | 15.6 | 4.5 | 17.5 | 19.7 | 18.4 | 7.7 |
| P21A | 4.8 | 7.0 | 1.2 | 2.4 | 3.1 | 4.8 | -19.7 | -22.6 | -25.5 | 13.0 |
| P21B | -2.5 | 4.8 | 1.5 | 4.6 | 0.1 | 0.6 | -21.5 | -23.2 | -17.0 | 1.4 |
| P27C | -1.4 | -3.3 | -0.5 | -2.3 | -2.6 | -9.7 | -7.7 | -7.0 | -3.1 | -13.6 |
| T31 | 1.0 | -1.6 | 1.2 | -0.1 | -1.8 | -7.9 | -6.5 | -6.2 | -0.4 | -11.4 |




*Graph 33. Variation of travel time of "E" lines, Priority on Modified Control Plan.*

In terms of the variation with respect to the scenario of the Modified Control Plan, is important to highlight the good response of the "E" lines in all the cases evaluated, the better results correspond to the protocols including all the intersection, a reduction of about 12%. For the other protocols, the results for the "E" protocols may be mainly due to the intervention of the intersection 3, the one with the greatest overall delay.




*Graph 34. Variation of travel time of non "E" lines, Priority on Modified Control Plan.*

For the non "E" lines the variations do not present any general tendency. The line P17 coming from the south is the only line having mainly an increment of the travel time, 8 of the 10 evaluated scenarios result in an increase four of them resulting in an increase of about 15%. The grates increase corresponds to the protocol P1 E MC, contrary as the expected results mentioned previously, for the P10B line, reaching a value of 21%. On the other end, the reduction in the majority of the lines is obtained for the protocol P0 D MC, P1 D MC and

P0 E MC, for the lines exiting the dedicated corridor the reduction is of about 20%, being the greatest ones for the P21A lines in the protocol P0 E MC, 25%.

The last variable to evaluate in the PT analysis of the Modified control plan is the number of stops, important as is directly perceived by the users and affect the perception of the comfort of the service. The results and the behaviour of this variable are contained in the Table 118 and the Table 119

*Table 118. Number of stops for the PT lines, Priority on Modified Control Plan.*

| Name | Number of stops [-] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modified | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| E21 | 9.6 | 9.5 | 9.2 | 10.0 | 9.4 | 9.0 | 8.9 | 9.8 | 9.6 | 10.1 | 8.9 |
| E31 | 12.3 | 12.1 | 11.3 | 12.3 | 12.0 | 11.4 | 10.7 | 12.3 | 11.8 | 11.8 | 11.6 |
| E41 | 10.7 | 9.5 | 9.4 | 10.0 | 10.5 | 10.3 | 9.2 | 10.6 | 10.5 | 10.0 | 9.4 |
| P10A | 13.2 | 13.5 | 12.4 | 13.9 | 13.2 | 12.2 | 10.8 | 12.3 | 12.9 | 14.3 | 11.7 |
| P10B | 2.1 | 2.2 | 2.2 | 2.2 | 2.2 | 2.1 | 2.2 | 1.8 | 1.6 | 1.9 | 2.1 |
| P10D | 2.0 | 2.0 | 2.1 | 2.0 | 2.1 | 2.4 | 2.0 | 1.9 | 2.0 | 1.7 | 2.0 |
| P12A | 2.5 | 2.1 | 2.4 | 2.3 | 2.3 | 2.5 | 2.2 | 2.3 | 2.3 | 2.1 | 2.5 |
| P17-A | 6.2 | 6.3 | 6.3 | 6.0 | 5.8 | 5.7 | 5.1 | 6.1 | 6.1 | 6.2 | 5.1 |
| P17-B | 4.8 | 4.6 | 4.6 | 5.0 | 5.0 | 5.4 | 4.6 | 5.6 | 5.8 | 6.6 | 5.4 |
| P21A | 2.0 | 1.9 | 2.2 | 2.1 | 2.0 | 2.1 | 2.1 | 1.8 | 2.0 | 1.8 | 1.9 |
| P21B | 2.1 | 2.0 | 2.0 | 2.1 | 2.3 | 2.3 | 2.3 | 2.0 | 1.9 | 2.2 | 2.2 |
| P27C | 15.7 | 15.2 | 14.9 | 15.7 | 15.2 | 15.3 | 14.2 | 14.3 | 14.6 | 16.0 | 14.0 |
| T31 | 14.7 | 14.8 | 13.9 | 15.4 | 14.7 | 14.8 | 14.0 | 14.4 | 14.5 | 15.6 | 13.6 |

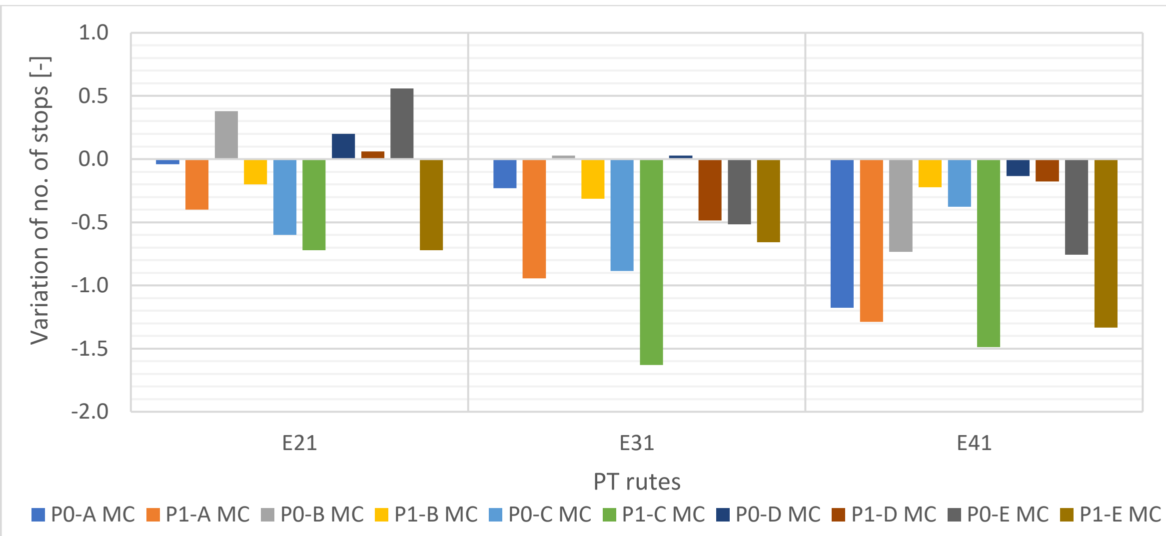
This variable ideally should be equal or less than the sum of the intersection the line goes through and the stations it stops, this is no accomplish in the lines exiting the dedicated PT lines, where in the number of stops are slightly greater than the ideal condition, having stated it, the difference is in the order of decimals, accounted in the analysis because the analysis is upon the average number of stops. For the lines having the ideal condition all are about 3 stops below the stablished limit, with this result the benefit of the passive priority strategy implemented when determining the Modified Control Plan is highlighted.

*Table 119. Variation of the number of stops for the PT lines, Priority on Modified Control Plan.*

| Name | Absolute variation of the number of stops [-] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **P0-A MC** | **P1-A MC** | **P0-B MC** | **P1-B MC** | **P0-C MC** | **P1-C MC** | **P0-D MC** | **P1-D MC** | **P0-E MC** | **P1-E MC** |
| E21 | 0.0 | -0.4 | 0.8 | -0.6 | -0.4 | -0.1 | 0.9 | -0.1 | 0.5 | -1.3 |
| E31 | 2.5 | 1.8 | 3.1 | 2.0 | 2.0 | 1.7 | 3.5 | 2.0 | 2.1 | 1.5 |
| E41 | 0.0 | -0.1 | 0.8 | 0.5 | 1.0 | 0.2 | 1.7 | 0.8 | 0.3 | -0.8 |
| P10A | 3.9 | 2.9 | 4.7 | 3.2 | 2.8 | 1.8 | 3.4 | 3.1 | 4.6 | 1.6 |
| P10B | -7.4 | -7.4 | -7.0 | -7.8 | -7.3 | -6.8 | -7.1 | -8.2 | -7.7 | -8.1 |
| P10D | -7.5 | -7.5 | -7.2 | -7.9 | -6.9 | -7.0 | -6.9 | -7.8 | -7.9 | -8.1 |
| P12A | -7.5 | -7.1 | -6.9 | -7.7 | -6.9 | -6.7 | -6.6 | -7.5 | -7.6 | -7.6 |
| P17-A | -3.3 | -3.3 | -3.2 | -4.1 | -3.6 | -3.9 | -2.8 | -3.7 | -3.5 | -5.1 |
| P17-B | -5.0 | -4.9 | -4.2 | -5.0 | -4.0 | -4.4 | -3.3 | -4.0 | -3.0 | -4.7 |
| P21A | -7.7 | -7.3 | -7.1 | -8.0 | -7.3 | -6.9 | -7.0 | -7.8 | -7.8 | -8.2 |
| P21B | -7.6 | -7.5 | -7.0 | -7.6 | -7.1 | -6.7 | -6.8 | -7.9 | -7.5 | -7.9 |

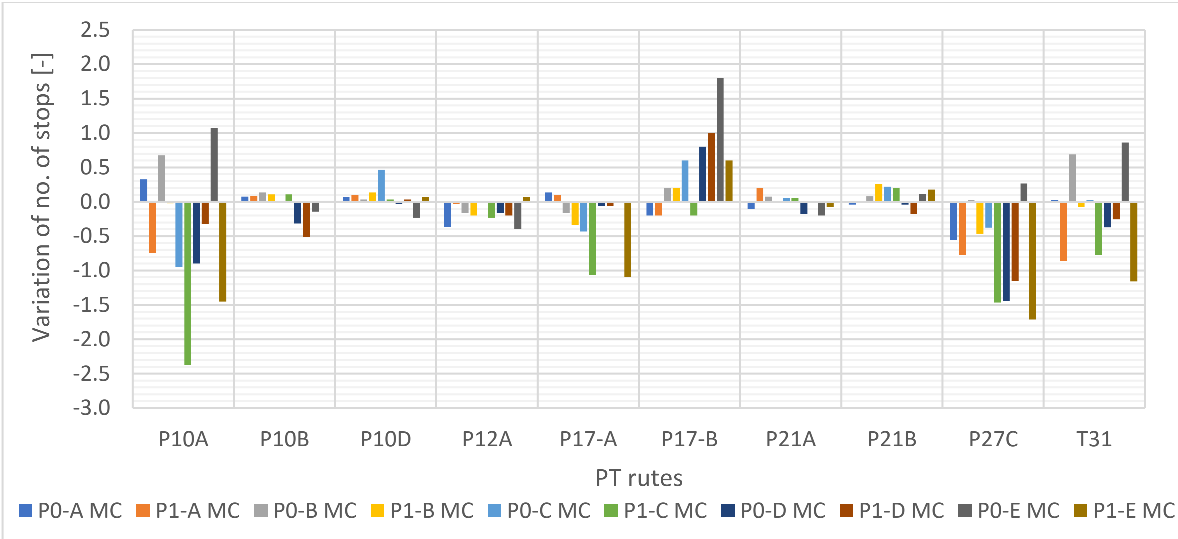
| Name | Absolute variation of the number of stops [-] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P0-A MC | P1-A MC | P0-B MC | P1-B MC | P0-C MC | P1-C MC | P0-D MC | P1-D MC | P0-E MC | P1-E MC |
| P27C | 5.6 | 5.4 | 6.6 | 5.3 | 6.0 | 5.3 | 5.4 | 4.8 | 6.3 | 3.9 |
| T31 | 5.2 | 4.3 | 6.3 | 4.7 | 5.4 | 5.0 | 5.5 | 4.7 | 6.0 | 3.4 |

Focusing in the variation with respect to the base scenario, in the “E” lines is possible to see a tendency to decrease the number of stops, especially in the E31 and E41 lines, where the majority of the evaluated scenarios results in a reduction, in this two lines the protocols P1 A MC and P1 C MC are constant with the reduction having about 1 and 1.5 respectively. For the E31 the other protocols having a significant reduction is the P0 C MC and for the line E41 the other relevant protocols are the P0 A MC and the P1 E MC. The line E21 have a more mixed response, with 4 cases resulting in increases and 7 in reductions, although in this line the variation only exceeds the 0.5 threshold un the case of the reductions.




*Graph 35. Variation of number of stops of "E" lines, Priority on Modified Control Plan.*

For the other lines, as can be seen in the Graph 36, the major impact occurred for the lines following the PT dedicated corridor; the lines exiting have a minor variation not exceeding 0.5 stops in any of the cases. The P27C is the line with major number of positive responses, with 8 out of 10; although the grates reduction is in the P10A line for the protocol P1 C MC reducing more than 2 stops in average. The line having the worst response to the implementation of the priority protocols is the P17 coming from the south (B), with 7 of the 10 scenarios resulting in an increase of the number of stops and containing among them for the protocol P0 E MC almost reaching the increment of 2 stops. In general terms, the protocols across all the lines traveling along the PT corridor having the better response are the P1 C MC and P1 E MC.




*Graph 36. Variation of number of stops of "E" lines, Priority on Modified Control Plan.*

From the analysis of the BRT system response is clear the benefit for the PT service when the intersection 3 is intervene, as in the variables considered the protocol P1 C MC stand above the other protocols and remain as a scenario of good results, this is support by the fact show in the section dedicated to the analysis of the results of the Modified Control Plan, where the intersection 3 is the most critical on in terms of the delay.

### 5.3. Alternatives comparison and ranking

Having analysed the different components of the model in various levels, in order to determine the better scenario among all the proposed is necessary to implement a multicriteria selection, following the parameter established in the section 4.3, dedicated of the evaluation process. The values of the variables necessary to perform the evaluation is contained in Table 120, in which the ideal scenario is in the last row.

*Table 120. Evaluation variables.*

| **Group** | **Public Transport** | | | | | | **Mix traffic** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Travel time [sec]** | | **Number of stops [-]** | | **Travel speed [km/h]** | | **Travel time [sec]** | | **Delay [sec]** | | **Number of stops [-]** | |
| **Sub-group** | **"E" lines** | **Other lines** | **"E" lines** | **Other lines** | **"E" lines** | **Other lines** | **Par. traffic** | **Perp. traffic** | **Par. traffic** | **Perp. traffic** | **Par. traffic** | **Perp. traffic** |
| Base (50%) | 1004.2 | 1042.4 | 15.1 | 18.8 | 25.4 | 23.1 | 396.2 | 133.5 | 175.4 | 65.2 | 3.2 | 1.3 |
| P0-A BC | 907.5 | 983.8 | 14.0 | 18.3 | 28.0 | 20.5 | 393.4 | 133.0 | 174.6 | 65.3 | 3.2 | 1.3 |
| P1-A BC | 892.8 | 945.1 | 14.4 | 17.2 | 28.5 | 21.7 | 389.2 | 150.2 | 170.0 | 81.8 | 3.3 | 1.4 |
| P0-B BC | 909.8 | 977.0 | 14.9 | 18.6 | 27.9 | 23.5 | 403.4 | 133.3 | 183.3 | 64.8 | 3.5 | 1.3 |
| P1-B BC | 919.6 | 945.1 | 15.3 | 17.8 | 27.6 | 22.8 | 390.4 | 146.4 | 171.4 | 77.9 | 3.4 | 1.4 |
| P0-C BC | 864.1 | 915.3 | 12.6 | 16.8 | 29.3 | 22.0 | 427.6 | 337.3 | 210.6 | 268.2 | 2.9 | 2.9 |
| P1-C BC | 873.2 | 905.9 | 12.9 | 16.3 | 29.0 | 21.8 | 378.8 | 528.2 | 157.4 | 459.2 | 2.8 | 4.0 |
| P0-D BC | 767.2 | 895.6 | 12.9 | 16.7 | 33.0 | 23.6 | 626.6 | 512.3 | 403.2 | 443.7 | 4.8 | 4.9 |
| P1-D BC | 779.0 | 883.4 | 13.0 | 16.7 | 32.6 | **28.8** | 655.6 | 887.1 | 431.9 | 818.5 | 4.9 | 5.0 |
| P0-E BC | 753.9 | 888.8 | 14.4 | 17.8 | 33.7 | 24.6 | 786.2 | 360.2 | 564.4 | 291.7 | 8.3 | 4.5 |
| P1-E BC | 743.1 | 863.8 | 13.7 | 16.1 | 34.2 | 23.7 | 700.3 | 392.1 | 478.2 | 322.8 | 6.1 | 4.5 |
| Modified | 753.2 | 795.7 | 12.3 | 15.7 | 33.8 | 22.7 | 330.6 | 303.3 | 110.5 | 235.5 | **2.6** | 2.5 |
| P0-A MC | 733.4 | 788.9 | 12.1 | 15.2 | 34.7 | 21.7 | 338.9 | 270.2 | 117.5 | 202.2 | 2.8 | 2.3 |

| Group | Public Transport | | | | | | Mix traffic | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Travel time [sec] | | Number of stops [-] | | Travel speed [km/h] | | Travel time [sec] | | Delay [sec] | | Number of stops [-] | |
| Sub-group | "E" lines | Other lines | "E" lines | Other lines | "E" lines | Other lines | Par. traffic | Perp. traffic | Par. traffic | Perp. traffic | Par. traffic | Perp. traffic |
| P1-A MC | 724.4 | 769.2 | 11.3 | 14.9 | 35.1 | 22.1 | 325.2 | 316.6 | 107.4 | 248.5 | **2.6** | 2.6 |
| P0-B MC | 747.6 | 791.5 | 12.3 | 15.7 | 34.0 | 21.4 | 479.6 | 259.2 | 260.8 | 191.3 | 5.2 | 2.3 |
| P1-B MC | 749.1 | 780.3 | 12.0 | 15.2 | 33.9 | 20.6 | 386.9 | 319.9 | 166.8 | 252.5 | 4.4 | 2.7 |
| P0-C MC | 692.9 | 775.4 | 11.4 | 15.3 | 36.6 | 20.8 | 709.0 | 380.5 | 482.0 | 312.4 | 5.4 | 2.9 |
| P1-C MC | 682.5 | 719.7 | **10.7** | 14.2 | 37.2 | 22.0 | 490.0 | 323.3 | 265.4 | 255.4 | 3.7 | 2.5 |
| P0-D MC | 713.5 | 734.6 | 12.3 | 14.4 | 35.6 | 27.9 | 322.8 | 112.1 | 103.3 | 44.6 | **2.6** | 1.1 |
| P1-D MC | 705.1 | 740.1 | 11.8 | 14.6 | 36.0 | 27.8 | **313.6** | 111.9 | **93.7** | 44.0 | **2.6** | 1.1 |
| P0-E MC | **661.9** | 778.3 | 11.8 | 16.0 | **38.3** | 28.7 | 813.8 | **101.0** | 586.7 | **33.2** | 8.6 | **0.9** |
| P1-E MC | 670.2 | **692.5** | 11.6 | **14.0** | 37.8 | 22.9 | 493.3 | 1511.9 | 271.5 | 1443.3 | 5.2 | 3.4 |
| **IDEAL** | **661.9** | **692.5** | **10.7** | **14.0** | **38.3** | **28.8** | **313.6** | **101.0** | **93.7** | **33.2** | **2.6** | **0.9** |

Looking for the values of the ideal alternative among the evaluated alternatives, they are mainly concentrated in the scenario with the Modified Control Plan, the only exception to this tendency is the travel speed in the non "E" lines, for which the ideal value corresponds to the scenario P1 D BC; the majority of the ideal values are located in the alternative P0 E MC, accounting for 5 of the 9 variables evaluated.

From these values is possible to start the evaluation of the different variables, the partial results of the similitude index are in Table 121.

*Table 121. Partial results of the similitude index.*

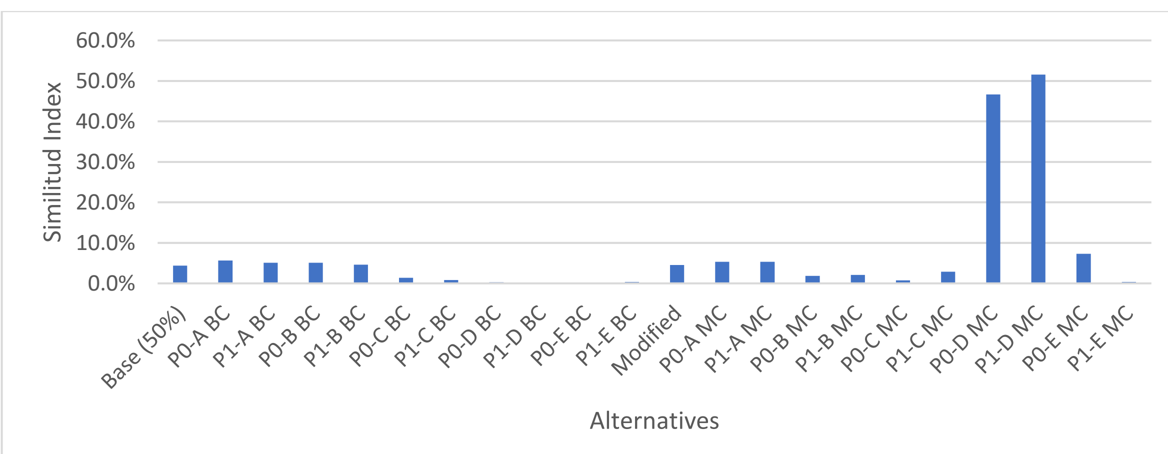
| Group | Public Transport | | | | | | Mix traffic | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Travel time | | Number of stops | | Travel speed | | Travel time | | Delay | | Number of stops | |
| Sub-group | "E" lines | Other lines | "E" lines | Other lines | "E" lines | Other lines | Par. traffic | Perp. traffic | Par. traffic | Perp. traffic | Par. traffic | Perp. traffic |
| Base (50%) | 66% | 66% | 71% | 74% | 78% | 88% | 87% | 85% | 78% | 76% | 85% | 75% |
| P0-A BC | 73% | 70% | 76% | 77% | 83% | 82% | 87% | 85% | 78% | 76% | 85% | 75% |
| P1-A BC | 74% | 73% | 74% | 81% | 84% | 84% | 88% | 79% | 79% | 70% | 83% | 70% |
| P0-B BC | 73% | 71% | 72% | 75% | 83% | 89% | 86% | 85% | 76% | 77% | 79% | 75% |
| P1-B BC | 72% | 73% | 70% | 79% | 82% | 87% | 88% | 80% | 79% | 71% | 81% | 70% |
| P0-C BC | 77% | 76% | 85% | 83% | 85% | 85% | 83% | 49% | 72% | 43% | 92% | 39% |
| P1-C BC | 76% | 76% | 83% | 86% | 85% | 85% | 89% | 37% | 81% | 35% | 94% | 30% |
| P0-D BC | 86% | 77% | 83% | 84% | 91% | 89% | 66% | 38% | 56% | 35% | 61% | 26% |
| P1-D BC | 85% | 78% | 82% | 84% | 91% | **100%** | 64% | 27% | 54% | 28% | 60% | 25% |
| P0-E BC | 88% | 78% | 74% | 79% | 93% | 91% | 58% | 47% | 49% | 42% | 40% | 28% |
| P1-E BC | 89% | 80% | 78% | 87% | 93% | 89% | 62% | 44% | 52% | 40% | 51% | 28% |
| Modified | 88% | 87% | 87% | 89% | 93% | 87% | 97% | 52% | 94% | 46% | **100%** | 44% |
| P0-A MC | 90% | 88% | 88% | 92% | 94% | 84% | 95% | 55% | 91% | 49% | 94% | 47% |
| P1-A MC | 91% | 90% | 95% | 94% | 95% | 85% | 98% | 50% | 95% | 45% | **100%** | 43% |
| P0-B MC | 89% | 87% | 87% | 89% | 93% | 84% | 77% | 57% | 66% | 50% | 57% | 47% |
| P1-B MC | 88% | 89% | 89% | 92% | 93% | 82% | 88% | 50% | 79% | 44% | 66% | 42% |
| P0-C MC | 96% | 89% | 94% | 92% | 97% | 82% | 61% | 45% | 52% | 41% | 56% | 39% |
| P1-C MC | 97% | 96% | **100%** | 99% | 98% | 85% | 77% | 50% | 66% | 44% | 75% | 44% |
| P0-D MC | 93% | 94% | 87% | 97% | 96% | 98% | 98% | 94% | 96% | 89% | **100%** | 85% |
| P1-D MC | 94% | 94% | 91% | 96% | 96% | 98% | **100%** | 94% | **100%** | 89% | **100%** | 85% |

| Group | Public Transport | | | | | | Mix traffic | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Travel time | | Number of stops | | Travel speed | | Travel time | | Delay | | Number of stops | |
| Sub-group | "E" lines | Other lines | "E" lines | Other lines | "E" lines | Other lines | Par. traffic | Perp. traffic | Par. traffic | Perp. traffic | Par. traffic | Perp. traffic |
| P0-E MC | **100%** | 89% | 91% | 88% | **100%** | 100% | 56% | **100 %** | 48% | **100%** | 38% | **100%** |
| P1-E MC | 99% | **100%** | 92% | **100%** | 99% | 87% | 76% | 20% | 65% | 22% | 57% | 35% |

From these values is possible to perform the complete dimensional analysis to obtain the comparison index, contained in the Table 122.

*Table 122. Evaluation results.*

| Scenario | Index |
|---|---|
| Base (50%) | 4.4% |
| P0-A BC | 5.6% |
| P1-A BC | 5.1% |
| P0-B BC | 5.1% |
| P1-B BC | 4.6% |
| P0-C BC | 1.3% |
| P1-C BC | 0.8% |
| P0-D BC | 0.3% |
| P1-D BC | 0.2% |
| P0-E BC | 0.2% |
| P1-E BC | 0.3% |
| Modified | 4.5% |
| P0-A MC | 5.4% |
| P1-A MC | 5.3% |
| P0-B MC | 1.8% |
| P1-B MC | 2.1% |
| P0-C MC | 0.8% |
| P1-C MC | 2.8% |
| P0-D MC | 46.7% |
| P1-D MC | 51.6% |
| P0-E MC | 7.3% |
| P1-E MC | 0.3% |




*Graph 37. Similitude index for the evaluated scenarios.*

The alternative with the higher similitude index is the P1 D MC scenario, with 51.6%. In this alternative the evaluated variables are in 95% of the ideal ones, the variables lowering the final grade of the alternative where the delay of the mix traffic parallel to the PT corridor (89% of partial similitude index) and the Number of stops of the mix traffic perpendicular to the PT corridor ( 85% of partial similitude index).

The second scenario most similar to the ideal case is the P0 D MC, reaching a similitude index of 46.7%, differing significantly from the previously alternative in the partial result for the Number of stops of the "E" lines.

Every other alternative present a considerably low similitude index, not passing the threshold of 10%. The lowest alternatives correspond to the scenarios including prioritization protocols in the intersections 3 and 4. The scenarios P0 E MC and P1 E MC, although, as appointed previously, have the majority of the ideal values due to the nature of the protocols are expected to be the best solutions, are highly affected by the response of the mix traffic, where in the case of the scenario giving priority only to the "E" lines the parallel mix traffic are affecting the most the total similitude index. In the scenario with all PT lines with priority the more dramatic partial results correspond to the perpendicular mix traffic.

The alternatives P0 D MC and P1 D MC, beaning the top of the rank, share the control plan affected by the priority protocol, in this case the Modified Control Plan; and the intersections in which the priority protocols are activated, exclusively the intersection 4. The major benefit of these alternatives is in the BRT system, being the intersection 4 the only intersection where the public transport exits the dedicated lanes. On the other hand, these protocols result in increases in the delay for the other three intersections, balanced for the great reduction on the delay of the intersection 4, than in the evaluation of the whole system marks the difference with respect the other alternatives.

## 6. Conclusions

The effect of the implementation of diverse Transit Signal Priority (TSP) protocols were evaluated and analysed in a section of Bus Rapid Transit system, specifically in the city of Santiago de Cali, Colombia. This work was carryout by modelling the selected corridor with a micro-simulation software accounting the real conditions of geometry, traffic and public transport schedule. Alternative scenarios are explored by varying the control plans of intersections according different TSP protocols.

The aim of this work is the evaluation of the impacts due to the implementation of the TSP in the BRT corridor in a realistic traffic demand and not to estimate how the demand can change in case of TSP. Thus the demand is assumed constant through all the simulated scenarios for comparison.

The priority protocols used in this work can be classified according to the intersections where the Active Priority is applied and the Public Transport lines prioritized.

For the first classification one of the most important features to highlight is the effects the intervention of the some of the major intersections by the priority protocols have. The inclusion of the two greater intersections in terms of dimension and input flow (the intersections 3 and 4) in the TSP protocols leads to the greatest variations with respect to the base scenario, in both the service travelling along roads in mixed traffic and those reserved to the public transport

In the cases of exclusive intervention in the intersection 3, the most beneficiated component of the model is the BRT system, contrasting with the negative impact in terms of time spend stopped experimented by the mix traffic . This response probably is associated to the high demand of the left turn coming from the west (turn 7) in the intersection 3, its green time is greatly limited by the prioritization of the movements parallel to the PT corridor, this generates queue, long enough to restrict the arriving of vehicles that perform another manoeuvres in access . The priority protocols involving exclusively the intersection 4 has good effects on public transport less than the previously scenarios, but consistent with the expectations upon the TSP implementation. The reaction of the mix traffic is a detriment of the studied variables with respect the scenarios of comparison.

In the scenarios with all intersections with priority protocols , are expected to have a sum of the effects of the protocol considering individual intersections and this happens for the BRT system which achieves the best results. Looking for the response of the mix traffic, the results are no consistent with the assumptions probably due to the high variation of the flows of vehicles arriving to the different accesses, or the restriction of the manoeuvres perpendicular to the PT corridor, that to a variation of the saturation degree of access along the paths parallel to the PT corridor.

In the second type of categorization according to the prioritized lines, is possible to measure the direct impact on the model when different PT lines are given priority. In a general view the variation of the evaluated variables is not significant when comparing the scenario sharing the same Control Plan and the intersections included in the priority protocol. The only relevant difference can be observed when the scenario establish the active priority strategy in the intersection 4, where the results for only prioritizing the “E” lines are significantly higher than the protocols prioritizing all PT lines.

One of the key points of this study was the implementation of the Users Delay protocol, a passive priority strategy, meaning that it does not change constantly the durations of the phases in a control plan as is needed in the Active priority strategies such as Early green or Red truncation. This solution is investigated to obtain a new Control Plan that accounts the high capacity of the buses use in the BRT system. The Modified Control Plan obtained is easier than the Base Control Plan, in fact the number of phases of the cycles of all intersection is greatly reduce and the order of the sequency is more congruent with the movements allowed in the phases. The implementation of the new Control Plan results in an overall improvement in every aspect of the model, compared with the base scenario, presenting only bad response in the “calle 16” coming from north path and some of the “P” lines.

The general good response of the Modified Control Plan is probably due not only to the Users Delay criteria implemented but also to the simplification of the cycles themselves. The simplicity of the cycles to intervene by the active priority strategies, reflected in the reduced number of phases and better coordination of manoeuvres, is important in order to allow every manoeuvre to be performed within every cycle . I n the Base Control Plan implementing the Early Green or Green Extension strategy, depending in the request generated by the PT, can cause the total loss of a phase or manoeuvre, especially in this particular case where the cycles have many phases with less than 5 seconds that can be totally skipped. Having less phases, more consistent between them and with more duration within the cycles, as in the Modified Control Plan reduces greatly the possibility of cancelling a manoeuvre by the active priority strategy, reducing the negative impact on the mix traffic.

The results for the two categories described above summed with the effect of the Passive Priority, that prioritize the high capacity vehicles of the BRT , concludes with the results exposed in the section of alternative comparison . The scenarios P0 D MC and P1 D MC where the two alternatives with the higher grade among all the considered in this study, they offer a balance between the benefits the BRT and the negative impacts on the mix traffic. The other alternatives are greatly inferior considering the criteria used to evaluate the alternatives.

Contrary of what could be presumable in a first approach to transit a Transit Signal Priority application on a Bus Rapid Transit system, where is expected to be better prioritize every intersection for all the PT lines, this study showed that the benefits of implementing a TSP in system such as the BRT, should be carefully evaluated. Indeed, in the case study examined, the best option is not to implement the priority in all the intersections and all the TP lines but focusing in the critical points of the network. Moreover, maintaining a simple Control Plan based on a passive priority strategy generated the best results. The ideal results among all the alternatives considered in the study concentrated in the ones with the Modified Control Plan and the ones affecting the intersection 4; the only variable contrary to this is the travel speed in the non “E” lines for which the best result is for the P1 D BC scenario.

The model and the validation of the scenario representing the actual behaviour of the BRT corridor present an important problem: the initial demand estimated for the Origin-Destination matrix was reduced because the virtual queues generated may derivate in a wrong estimation of the variables to evaluated. Indeed, the software was used with educational license and  limitations on the number of intersections and the total length of the streets in the model impacts directly on the behaviour. To reduce the road network only to the principal streets were modelled and not all the possible paths to go from/to each pair of centroids were available. This problem was reflected in the long queues observed in the model of the scenario with the Base Control Plan and full traffic demand. In case secondary streets were included, more alternative routes could be used to the access of the main intersections reducing extreme queues. However, this problem has been mitigated exploring scenarios with a reduced demand.

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