Impacts Analysis towards a Sustainable Urban Public Transport System

Darwin Aldas[1], John Reyes[2], Luis Morales[2], Pilar Pazmiño[3], José Núñez[4] and Bladimir Toaza[2]
[1]*Faculty of Accounting and Auditing, Universidad Técnica de Ambato, Ambato, Tungurahua, Ecuador*
[2]*Faculty of Engineering Systems, Electronics and Industrial, Universidad Técnica de Ambato, Ambato, Tungurahua, Ecuador*
[3]*Faculty of Agricultural Sciences, Universidad Técnica de Ambato, Ambato, Tungurahua, Ecuador*
[4]*Faculty of Agricultural Sciences and Natural Resources, Universidad Técnica de Cotopaxi, La Maná, Cotopaxi, Ecuador*

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Abstract: Nowadays, both big and small cities look to optimize their urban public transport systems through models that allow reduction of transfer time and environmental impacts, to create sustainable cities. Thus, cities of Latin American countries are adapting their public transport systems to energetic sustainability conditions. This study analyzes the impacts of transport models and chooses the best alternative, considering four cities with a high urban mobility index and optimal conditions of sustainable development. A review of scientific literature is conducted and priority criteria, such as traffic, environmental impact, social impact, and economic impact are established and evaluated via the Analytical Hierarchy Process (AHP) decision making method. As a result, the AHP model defines the city of Curitiba as the best sustainable transport alternative, with 31, 8% against 27, 6% of Singapore, 17, 8% of Santiago de Chile and Montreal with 22, 9%. The proposal uses a four-step transport model: trip generation, trip distribution, mode choice and route assignment.

1 INTRODUCTION

Transport constitutes an important factor in the development of society but accelerated urbanization and demographic growth cause vehicle congestion, increase in travel time, irregular operation of the public transport system, among others. Besides, current transport patterns, based on fossil energy sources generate negative social, economic, and environmental impacts (Dalkmann and Sakamoto, 2011).

The traditional focus on the layout of public transport is centered on static models that assume users' instant change of behavior toward changes in public transport. However, this focus does not offer a real description of users' behavior. (Jarboui, et al., 2013). The dynamic focus, on the other hand, considers realistic users' behaviors looking for a change of paradigm oriented at sustainable transport, with efficient transport modes and vehicles, and clean, low-carbon energy sources. This change of paradigm focuses on three strategies: avoiding long and unnecessary motorized trips, changing transport of goods and people to more efficient modes of transport, and improving the technology and operational administration of the transport system (Hidalgo and Huizenga, 2013).

Most developed cities work with the first strategy, while Latin American cities – that are mostly at an intermediate level of development – progress through the third strategy since they still depend on motorized transport. There exist nine options to promote urban public sustainable transport in cities located in developing countries: road infrastructure, track-based public transport, road public transport, support of non-motorized travel modes, technological solutions, sensitivity awareness campaigns, price establishment mechanisms, vehicle access restrictions, and land use control (Pojani and Stead, 2015).

Thus, for example, in a few cities such as Buenos Aires and Sao Paulo there exists the light rail transit (LRT), which construction and operation cost is higher than other alternatives, like conventional buses. (Pojani and Stead, 2015). Cable cars or gondolas – with similar characteristics to small or

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medium-sized trams – have become an attractive proposal of urban public transport in cities like Medellin in Colombia, and Caracas, in Venezuela, due to the fact that they provide adequate transport over mountainous land, rivers, historic and densely residential areas (Bergerhoff and Perschon, 2013).

When it comes to road public transport, bus rapid transit (BRT) has been implemented as a new transport system in cities where the other options are not available. BRT, which was born in Curitiba, has set an example for cities like Quito, Bogotá, Pereira, Sao Paulo, Santiago de Chile, and Guayaquil, showing to be an efficient and sustainable solution in congested cities (Jirón, 2013).

The solution to transport problems, and selection of one or more options – of the nine afore mentioned – can be analyzed through trips or transport models. These models are tools that provide a systematic referential framework to represent how trip demand changes in response to different presumptions, and allow evaluation of advantages and disadvantages of different transport alternatives (Castiglione, et al., 2015).

Transport modeling includes instruments, strategies, and solutions that have an influence on the results of vehicle congestion, times and trip speeds, which makes it difficult to determine which the best option is; just focusing on one criterion limits taking advantage of all these instruments. Conversely, evaluation of transport model variables, using multi-criteria decision analysis (MCDA) helps to find the best option that suit the goal (Nosal and Solecka, 2014). One of the most known MCDA is analytic hierarchy process (AHP).

The number of researches using AHP has increased over the last decade, especially in mathematical methods, computer science and management studies. Furthermore, AHP has been successfully applied in the management of limited resources, the transportation sector, strategic planning and in the area of logistics (Emrouznejad and Marra, 2017). In optimization of the public transport net, multifactor analysis through AHP adjusts better since more reasonable and practical results are attained (Xiaowei, et al., 2010).

The future view is the search of sustainable transport, which is essential to achieve most – if not all – of the goals set by the United Nations Organization for Sustainable Development. However, climate change debate concentrates on energy and industrial activity, setting aside transport, without considering that the latter is responsible of a fourth of greenhouse gas emissions per year, globally (United Nations, 2015). In Latin America, the amount of CO_2 emissions is around 357 thousand tons per day, being individual transport vehicles, the ones producing higher amounts than public transport vehicles (CAF, 2016).

This study proposes selecting a sustainable transport methodology for an Ecuadorian city, considering the variables travel time, waiting time, pollutants emission and noise, technology, system costs, among others; part of the search for sustainable transport as an applied case in the city of Ambato.

2 METHODOLOGY

Conventional multi-criteria decision making considers both quantitative and qualitative criteria; there exist methods for the quantitative approaches and other for the qualitative ones. However, the problem of this study, about selecting a sustainable transport methodology, combines quantitative and qualitative criteria for valuation of the best option. For this reason, AHP method is used, which allows handling both approaches. This method, developed by Thomas L. Saaty in 1980, makes paired comparisons at a scale implemented by himself. In the AHP solution, the problem is modeled with a hierarchy; first, the object is defined, becoming the highest. Then, the criteria and sub criteria are established, locating these in the intermediate level. Afterwards, the alternatives are identified in the lower level, to finally establish the priorities of each alternative and choose the best option. (Saaty, 1980).

After the alternatives are compared with each other in terms of each one of the decision criteria, the method evaluates each alternative with respect to each criterion and then multiples that evaluation by the importance of the criterion. This product is summed over all the criteria for the particular alternative to generate the rank of the alternative. Mathematically:

$$R_i = \sum_{j=1}^{N} a_{ij} w_j \tag{1}$$

Where R_i is the rank of the i^{th} alternative, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight or importance of the j^{th} criterion (Nguyen, 2014).

The proposed objective in the AHP model of this research is the selection of the best model of sustainable urban public transport, based on results and experiences of other cities.

2.1 Criteria

The used criteria for evaluation are gathered through a review of studies and researches that have similarities with the use of AHP in urban public transport. The criteria are grouped into four categories that are directly related with the objective: traffic, environmental impact, social impact and economic impact.

2.1.1 Traffic

This criterion refers to the project variables, based on passenger demand and operation parameters of the vehicles. These parameters must look for optimization of transport service operation. Five sub criteria are included in this criterion: travel time, operational speed, waiting time, passenger per kilometre rate and vehicle occupation rate.

Travel time is the average travel time of a passenger on public transport (Solecka, 2013). Operational speed is the average speed between an origin stop and another destination, including all the intermediate stops (Soltani, et al., 2013). Waiting time is the interval between the arrival of a passenger at the stop, and the moment at which they get on a bus (Cepeda, 2006). The passenger per kilometer rate is the relation between transported passengers and the total number of traveled kilometers (Soltani, et al., 2013). Vehicle occupation is the average amount of passengers per vehicle at a specific period and section (CTS EMBARQ, 2015) .

2.1.2 Environmental Impact

It refers to the impact that the transport project has on the environment, considering the requirements to minimize the damaging effects on it, in respect to nitrogen oxides, sulfur dioxides, hydrocarbons, carbon oxides. It has four sub criteria: type of fuel, air contaminant emission, noise emission and fuel economy.

Type of fuel refers to the source of energy that public transport uses for functioning, currently existing five types: gasoline, diesel, natural gas, hybrid and entirely electric (CTS EMBARQ, 2015). Air contaminant emissions are produced by public transport, mostly regulated by the Euro Standards environmental norm, in respect to the level of carbon monoxide, hydrocarbons, nitrogen oxide, and particulate matter (CTS EMBARQ, 2015). Noise emission produced by transport happens because of engines and propulsion systems, road coating, tires and aerodynamic noise of speed that, together, produce sonorous pollution (Ceballos and Palacio, 2015). Fuel economy is the relation that exists between the number of traveled kilometers by the vehicle and the amount of fuel or energy (CTS EMBARQ, 2015).

2.1.3 Social Impact

It takes into consideration the impact that a project causes, from a social benefit point of view. In social impact are included safety and comfort offered by the transport system, accessibility to people with

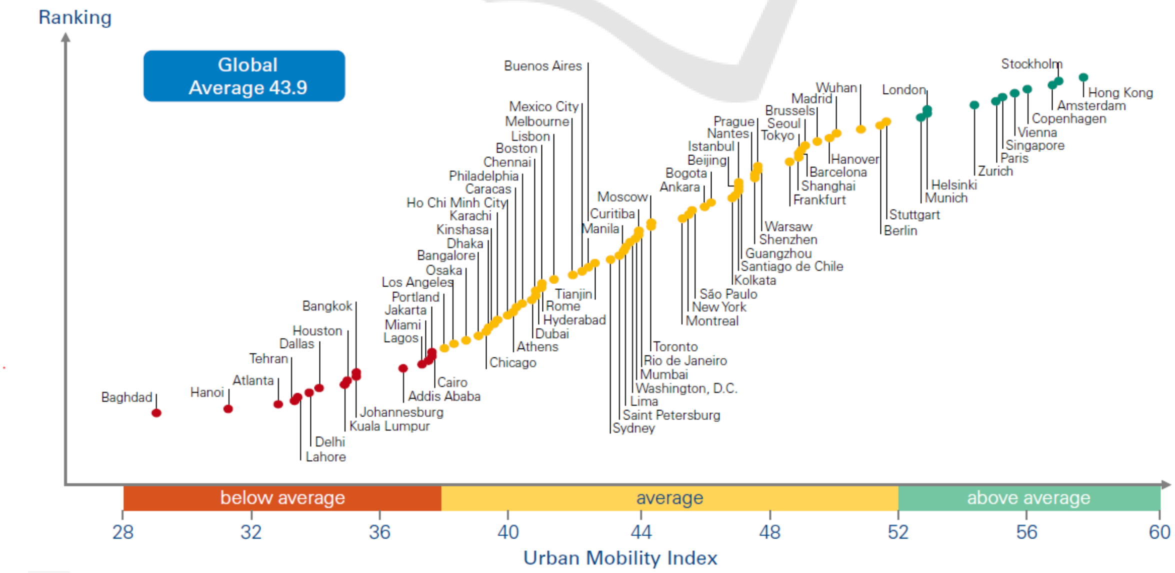

Figure 1: Arthur D. Little’ Urban Mobility Index 2.0 (Van Audenhove, et al., 2014).

reduced mobility, fare payment, type of bus stop and the technology inside the fleet.

Safety and comfort refer to the assessment that users make in relation to the public transport system (Soltani, et al., 2013). Passenger accessibility is the combination of elements of the built space that allow access, movement, and use by disabled people, existing four cases: stair access, low floor access, wheelchair ramp access and automatic elevator. Fare payment refers to charging mechanisms, validation and distribution of public transport fees, being the most common access through a token or ticket, fee-free access, smart card, and direct collection by operator. The stations or stops are the physically delimited spaces, where users go on and off, which can be the center of the road or the sidewalk. Technology refers to the technological service on board the vehicle, such as video surveillance cameras, GPS location, type of information for the user, Wi-Fi service and others. (CTS EMBARQ, 2015).

2.1.4 Economic Impact

It implies knowing the financial model before the investment is made, that is, to consider the costs that the transport system generates and if the expected annual profitability could be achieved, inside the expectations. This criterion contains two sub criteria: operational cost and travel cost.

The operational cost refers to the implementation and operation cost of public transport, including new road sections, new stations, purchase and maintenance of vehicles. Travel cost, on the other hand, is the fee that the user pays for using public transport. *(Nosal and Solecka, 2014)*.

2.2 Alternatives

The considered alternatives are from the study “Future of Urban Mobility” (Van Audenhove, et al., 2014), that evaluates 84 cities around the world, classified intro three representative groups; first,

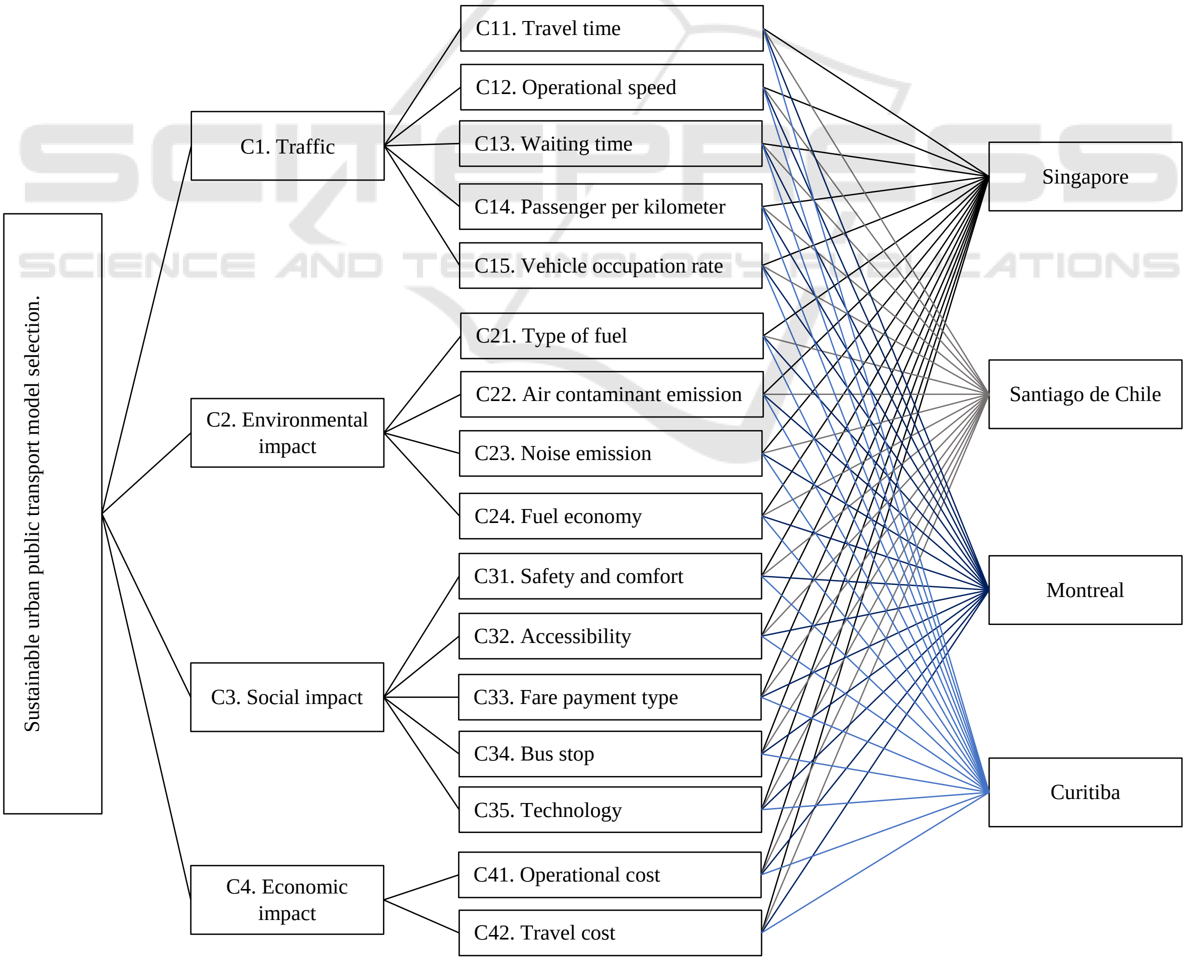

Figure 2: Hierarchy tree.

megacities (40), secondly, big metropolises with a high gross domestic product (GDP) (24), and the group of small cities with good environmental practices (20) via the urban mobility index that scores, in a 0 to 100 scale, 19 aspects related to the city's maturity in terms of its infrastructure, public transport, performance, pollutant gas emissions, among others. Hong Kong has the highest score, 58,2 and the lowest belongs to Bagdad with 28,6, resulting in a global average of 43,9. Nine of the 84 cities are Latin American, as shown Figure 1.

The criteria to be considered for a preliminary selection of possible alternatives are: the urban mobility index must be inside the average or above and the cities must be in the third group. Hence, 19 cities meet the prerequisites, among them Stockholm at 57,4 and Portland with 37,8 as shown in Table 1.

Table 1: Filtered cities for selection.

Group	Ranking	City	Mobility Index
Above average	2	Stockholm	57,4
	3	Amsterdam	57,2
	4	Copenhagen	56,4
	5	Vienna	56,0
	6	Singapore	55,6
	8	Zurich	54,7
	10	Helsinki	53,2
	11	Munich	53,0
Average	12	Stuttgart	51,9
	16	Hanover	50,1
	17	Brussels	49,7
	22	Frankfurt	48,8
	23	Prague	47,8
	25	Nantes	47,7
	30	Santiago de Chile	47,1
	36	Montreal	45,4
	39	Curitiba	44,0
	56	Dubai	40,6
	68	Portland	37,8

Table 2: Selected cities.

Group	Ranking	City	Mobility Index
Above average	6	Singapore	55,6
Average	30	Santiago de Chile	47,1
	36	Montreal	45,4
	39	Curitiba	44,0

Out of the 19 cities, four with are selected. The selected cities are: Singapore, Santiago de Chile, Montreal and Curitiba, as shown in Table 2.

Out of the four cities, three are American and one is Asian, two are in South America and one in North America. Singapore is a state city, Santiago is the capital of Chile, Montreal is a Canadian city and Curitiba belongs to Brazil.

2.3 The Evaluation Model

The hierarchy built for this study has four levels: in the first level is the decision objective, in the second one, the four evaluation criteria, in the third one, the sub criteria of each criterion – that add up to 16 in total – and in the last level, the four alternatives. Figure 2 shows the structure of the hierarchy tree of this study.

2.4 Prioritization

Prioritization of criteria, in relation to the objective, is done via paired comparisons based on Saaty's table, considering as value judgments the goals established on the mobility master plan of the city of Ambato. Likewise, prioritizations of sub criteria, in relation to each criterion, are done via paired comparisons based on Saaty's table, considering as value judgements the policies set out by the mobility master plan. The weights of the alternatives, in relation to each sub criterion, are done via paired comparisons for qualitative ones, and addition normalization, for quantitative ones; they have value judgements according to the reports presented by transport authorities in each city, such as the Land Transport Authority (LTA, 2014; 2015a; 2015b; 2016) in Singapore, the Metropolitan Public Transport Directory (DTPM, 2014; 2015a; 2015b; 2016) in Santiago, the Société de Transport (STM, 2014; 2015) of Montreal and the Urbanização de Curitiba (URBS, 2015a; 2015b; 2015c; URBS, 2015d) as shown in Table 3.

3 RESULTS

Synthesis of the hierarchical model, done over SuperDecisions software determines prioritizations of each criterion, in respect of each alternative, as shown in Table 4.

The results show that Singapore has 27,6% priority of being selected, Santiago keeps 17,8%, Montreal 22,9% and Curitiba 31,8%, becoming the last one the highest percentage, as shown in Figure 3.

The methodological characteristics of the transportation of the city of Curitiba applied in the city of Ambato-Ecuador, allow to estimate the traffic of public transport and also to evaluate the level of the service of the complete transport network.

Table 3: Weight of the sub criteria for each city.

Sub criteria	Singapore	Santiago de Chile	Montreal	Curitiba
C11. Travel time (min)	19,93	59,2	90	39
C12. Operational speed (km/h)	28,9	20,84	17,9	19,75
C13. Waiting time (min)	9 min	7,5	4	6
C14. Passenger per kilometer (pas/km)	3,601	2,1	3,4	2,19
C15. Vehicle occupation (%)	63,21	95,5	97,6	71,023
C21. Type of fuel	Diesel	Diesel	Natural gas, Hybrid Biodiesel	Biodiesel B100, Hybrids
C22. Air contaminants emission	EURO V	EURO III	EURO V	EURO V
C23. Noise emission dB(A)	76	80	72	77
C24. Fuel economy (km/lit)	2,35	2,4	2,22	2,43
C31. Safety and comfort	9,0	4,3	8,0	5,4
C32. Accessibility	Low floor	Access ramps Low floor Braille signs	Access ramps Fee exemption Door-to-door buses for people with limited mobility	Access ramps Low floor Braille signs Fee exemption Electric lifting platforms Door-to-door buses for people with limited mobility
C33. Fare payment type	Onboard, Smartcard	Onboard, Smartcard	Onboard, Smartcard	Smartcard, payment at stop
C34. Bus stop	At the center of the road and sidewalk	At sidewalk, with shelter	At sidewalk, with shelter	At sidewalk, with shelter, at the center of the road
C35. Technology	GPS location Wi-Fi	Not allowed to travel with open doors Surveillance cameras GPS location	Surveillance cameras GPS location	Surveillance cameras Internet access USB chargers GPS location
C41. Operational cost (USD millions)	1,4	23	1,4	25,9
C42. Travel cost (USD)	0,95	0,98	2,42	1,06

Table 4: Final scores.

Sub criteria	Singapore	Santiago	Montreal	Curitiba
C11	0,092	0,031	0,02	0,047
C12	0,022	0,016	0,014	0,015
C13	0,014	0,016	0,031	0,020
C14	0,007	0,004	0,006	0,004
C15	0,008	0,012	0,013	0,009
C21	0,002	0,002	0,006	0,013
C22	0,029	0,006	0,029	0,029
C23	0,02	0,019	0,021	0,02
C24	0,003	0,003	0,003	0,003
C31	0,03	0,014	0,027	0,018
C32	0,009	0,029	0,023	0,088
C33	0,005	0,005	0,005	0,014
C34	0,004	0,002	0,001	0,005
C35	0,004	0,014	0,006	0,029
C41	0,024	0,001	0,024	0,001
C42	0,003	0,003	0,001	0,003
∑	0,276	0,178	0,229	0,318

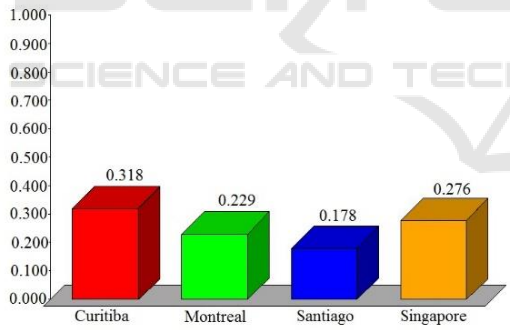

Figure 3: Synthesis of the hierarchical model.

3.1 The Curitiba Model

Curitiba is the capital of Paraná, state of the south region in Brazil, located at 945 MASL; it has an extension of 434,967 km^2 and a population of 3.261.168 inhabitants. During the last 30 years, it has concentrated on urban planning through its Directive Plan, made up by six sectorial plans in areas of social development, transport and mobility, housing, security and social defense, economic development and environment.

As part of the transport and mobility sectorial plan, the Urban Mobility and Integrated Transport Plan, *Planmob,* was prepared to establish policies and guidelines related to urban mobility, with a projected scenario in 2020; first a diagnosis and analysis are done, then, structuring of scenarios and alternatives to, afterwards, set up a preliminary proposal and lastly, introduce a final proposal. The estimated demand calculation bases for future scenarios during plan elaboration were done using the transport model based on trips, or four-step model: generation, distribution, assignment and application.

Generation and travel attraction is the starting point, for which it is necessary to compile and possess enough information through investigation and surveys, for example, the Origin-Destination survey. Travel distribution is defined through assembly of Origin-Destination arrays, based on surveys, which allows adjusting the model to the observed volumes. In travel assignment, the arrays are located on a simulation net, to evaluate the effects of vehicle occupancy, travel delays, road sections, among others; the arrays must be calibrated in case they do not adjust to reality. Finally, the proposed future scenarios model is applied.

4 DISCUSSION

Figure 4 shows that in the criterion traffic, the alternative with higher prioritization is Singapore, at 36% and below is Curitiba, with 24%, due to the fact that its public transport system maintains better circulation frequencies and lower travel time, which allows satisfying its passenger demand. In the environmental criterion, the city with higher priority is Curitiba, at 31%, since its master mobility plan focuses on sustainability. The social criterion also predominates for Curitiba, at 46% due to the fact it looks for integration of disabled people, for which technology is also required, but it is evident that the more technology is sought after, a greater investment is needed. Therefore, in the economic criterion, Curitiba is in the last place, at 7%, and Singapore in the first at 45%, since the Singapore fleet does not have much technology; even the majority is not disabled people friendly.

Curitiba is the selected alternative; even though its public transport system is expensive, its transport model has had good results. Considering the social criterion, it would dominate over other alternatives, hence, the idea would be to apply this transport model in the city of Ambato. As a second option, the Singapore transport model could be adapted since it is the one that offers a greater priority to the criterion traffic and, also, is in second place in respect to the objective.

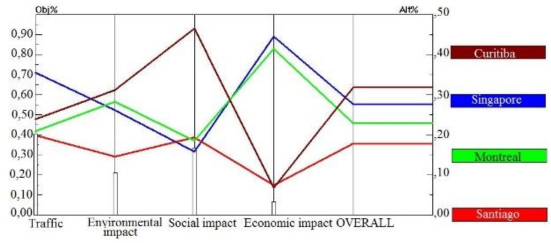

Figure 4: Sensitivity analysis.

5 CONCLUSIONS AND FURTHER DEVELOPMENT

The methodologies analyzed in this study demonstrate that most cities look for progress of mobility in the environmental field, promoting in their strategic plans the use of electric massive transport systems, or with reduced emission of contaminants. Developed cities such as Copenhagen, Vienna or Amsterdam even look to apply non-motorized mobility and, in the worst scenario, they encourage the use of massive public transport and reduction of individual motorized transport. On the other hand, developing cities such as Santiago de Chile, Curitiba, where this paradigm shift is difficult, improvement of public transport is sought after through modeling.

Evaluation of the methodologies of the four chosen cities through AHP method, considers traffic, environmental, social and economic criteria, determining that the best city is Curitiba, getting 31,8%, before Singapore with 27,6%, Santiago with 17,8% and Montreal with 22,9%, even though the cost of its system is the highest when compared to the other cities. However, this cost is reflected in its high social development, in relation to accessibility of people with reduced mobility to the transport system. The Curitiba model is four-step, multimodal, structured by travel generation, travel distribution, selection of mode of travel, and assignment of routes in the transport network.

The decision to select the sustainable transport of this research is the basis for future work in which it is intended to experiment these results using the software VISUM 16.0 and VISSIM 10.0. These systems will allow a complete simulation of the urban transport network under study to model and analyze the operation of urban traffic in various conditions. This includes environmental aspects that reduce the emission of pollutants that are emitted into the atmosphere, such as carbon dioxide.

This study considers the different variables involved in a public transport sustainable system. Especially in a complex urban topographies such as the city of Ambato, which is located in the Andes mountains range when will be of proposing a possible infrastructure in the development of the system.

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