Effective speed in a big city of Brazil — computing the best modal to invest

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ABSTRACT

Effective speed allows comparing travel time and the time spent working to pay the trip cost. This method is important to sustain public policies in mobility that would in fact be useful for most populations. Such studies are even more important in developing countries, such as Brazil, where a considerable amount of the population is not able to pay for public transport and only a minority have access to cars. To estimate the indicator we considered income levels, costs and travel times related to different means of transport, hence: to walk, bicycle, motorcycle, public transport by bus, metro and private car. The study was applied in one of Brazil's main cities, Recife, considering data from three time sections 2012, 2013 and 2014. Recife's municipality invests in favour of car users but it is not sensible to invest hundreds of dollars per year in a mode of transport that is not necessarily faster and that can only be afforded by 20% of the city's population. Results point toward the need of public investment in non-motorized modes; since an important part of the population can't afford public transport services fares.

1. Introduction

Urban transport is a political rather than a technical issue. Founding to provide infrastructure is affected by the way society evaluates the different transport modes and plays an important role in the political agenda of the 21st Century. Overall, supply of new transport infrastructure has increased markedly since the end of the twentieth century, with international financial institutions playing a key role in funding transport infrastructures in developing countries. Throughout 1983-1993 a major part of World Bank loans were directed to intercity transportation, such as highways. In the same period, the World Bank funded approximately US $ 2.5 trillion urban transport projects around the world being: 60% to road construction and maintenance, 17% to bus systems and trains, 10% to traffic management and 14% to technical assistance (Whitelleg, 2003).

Brazil has a leading investment position in transport with private participation totals reaching US $ 21.98 billion (World Bank, 2015). The country follows the same rules as it's development peer countries, even though they have 1/3 or, some times, 1/6 of the industrialized countries motorizing rate, most of the expenditure in infrastructure founding is due to road transport (Peñalosa, 2003).

It is not only a matter of governments favouring automobiles, according to Tranter and Ker (2014) people tent to overestimate financial and time costs of public transport and under-estimate those of car driving. Namely, perception of automobile velocity greatly exceeds its real performance; also a study driven by the RAC (Royal Automobile Club) in the UK established that drivers undervalue the costs of motoring, estimating their expenditure at a level of less than 40% of the real cost. That cost might be even higher since RAC calculations do not consider costs such as fines and car accessories (Leite e Ferreira, 2014).

For its capacity of providing individuals with easily comparable data on the different transport modes, effective speed could be an exceptional decision tool, making it easier for the citizens to allocate consciously their resources. Aiming public policies to improve social inclusion and alleviation of poverty, the governments could also use such tools to decide upon which investment in infrastructure to undertake.

2. Theory

The idea of effective speed was first mentioned by Henry David Thoreau in 1854, when he decided to live alone in the woods as an experiment. According to Thoreau, he would reach his destination by walking much faster than a worker aiming the same destination using the train, for the worker would have to work to obtain the money to use the train, whereas he would not. He would start walking in the morning and reach the destination by noon, while the worker would still be working to be able to use the train (Thoreau, 1862).

The notion was complemented by the thoughts of Ivan Illich in his book *Energy and Equity*, published in 1973. According to the author, citizens of non motorized societies spend between 3% and 8% of their time and energy in transportation and the necessary maintenance of transport, whereas US citizens spend about 25% of their social time for the same purpose (Ilich, 1973).

Since these primary concepts, not much literature has been written about effective speed. Some of the main sources are Kifer (2002), Tranter (2004) and Tranter and May (2005a, 2005b). These authors point out that external costs such as pollution, accidents, health implications due to a sedentary lifestyle, all relate to car traffic and are neglected by most drivers. Their concern is whether policy makers should also neglect these external costs.

Kifer (2002) has estimated several concepts of 'net effective automobile speed' comprising different cost levels borne by the individual traveller, by other travellers or by the community – the externality costs of transport. Tranter and May (2005a) used effective speed to introduce analyses from the traveller's perspective of Transit Oriented Development.

The model proposed by Tranter (2004) differs from the usual formula for computing the average speed of travel - dividing the travelled space by the travel time. For him, the time spent travelling should comprise the time spent to be able to 'buy' the trip, namely Effective Speed or Social Speed formula:

$$Effective\ speed\ = \frac{distance\ travelled}{work\ time\ +transport\ time} \tag{1}$$

where:

- Distance travelled is the total kilometers;
- Work time is the total time spent to pay the transport costs;
- Transport time is the time spent between the origin and destination.

Acknowledging the concept of effective speed and the context of Recife's metropolitan area this paper intends to estimate the effective speed for different transport modes for a determined path in this region. This infers which modal would be the most effective to each income stratum and what modes should public policies promote in order to benefit the majority of the population. Some of our limitations include the amount of data available, only three years, and the fact that it has only been measured in the evening peak hour, meaning results for other times of the day might be very different. However peak hour is when the traffic is worse and when most traffic related issues happen.

3 Material and Methods

In a effort to measure the effective speed for the city of Recife, a methodology has been created based on the one proposed by Tranter (2004) to the city of Canberra, Australia that has enhanced aspects such as: inhabitants level of income and travel data from several transport means. The social data needed to supply the model was obtained from the latest Brazilian Census (IBGE, 2010); travel times were obtained from three intermodal challenges placed in 2012, 2013 and 2014. The challenges were settled at 6pm peak hour at the controlled area.

The following procedures were adopted. First, we analysed transport by determining the means adopted and the fixed and variable costs per kilometre of each mode. Second, we determined the average speed for each mode of transport. At last we collected socioeconomic data and analysed it to the extent of determining the effective speeds for each mode.

In the beginning, the most used means of transport in Recife have been sorted: (i) bicycle normal speed, (ii) bicycle fast speed, (iii) bicycle and boat, (iv) bicycle and metro, (v) bike sharing, (vi) electric bicycle, (vii) automobile, (viii) metro and skate, (ix) metro, (x) motorcycle, (xi) bus, (xii) roller-skate, (xiii) pedestrian walking, (xiv) pedestrian running, and (xv) taxi.

The costs were estimated regarding each mode. They were divided into: fixed annual cost and variable costs according to the amount of kilometre travelled. Fixed costs include transport taxes that do not depend on whether the vehicle has been used or not, such as: IPVA (Tax over the Possession of Automotive Vehicles), assurance, instalments, etc. Variable costs per kilometre are the ones that vary with the distance reached, for example: gasoline, oil, maintenance, etc.

Subsequently the average travel speeds for each transport mode to the city of Recife was collected. The speeds were estimated through three commuter's challenges placed in the years of 2012, 2013 and 2014.

3.1 Commuter Challenges

Commuter's challenges are popular in several international cities such as New York (Press, 2008), Bristol (Sager, 2014) and Manchester (CMFT, 2005) and 15 Brazilian cities including Curitiba, Rio de Janeiro and Sao Paulo (UCB, 2015).

The goal of a commuter's challenge is to evaluate the efficacy of different transport means (walking, biking, motorcycle, automobile, bus, etc.) based on characteristics relating to travel time and costs and gas emissions. The challenges in Recife were organized by the Metropolitan Biking Association (AMECICLO) and Observatório das Metrópoles, a national NGO whose mission is to finance research concerning urban issues.

The proposal of Commuter's Challenges is to compare different displacement modals, trying to portrait the actual mobility conditions in a city, while considering the advantages and disadvantages which they bring in individual, social and environmental conditions. The evaluation in each parameters group followed objective and subjective criteria.

The objective indicators evaluated in Recife were: time, calories spent, cost and emissions, all relative to the displacement. The subjective indicators were calculated by a survey in the end of the challenge approaching questions about comfort, security, usability, infrastructure and traffic conditions. Each parameter had its own ranking and the modals could win in various rankings, allowing a personal evaluation of each modal. However, in this study only the travel time will be used to balance the model.

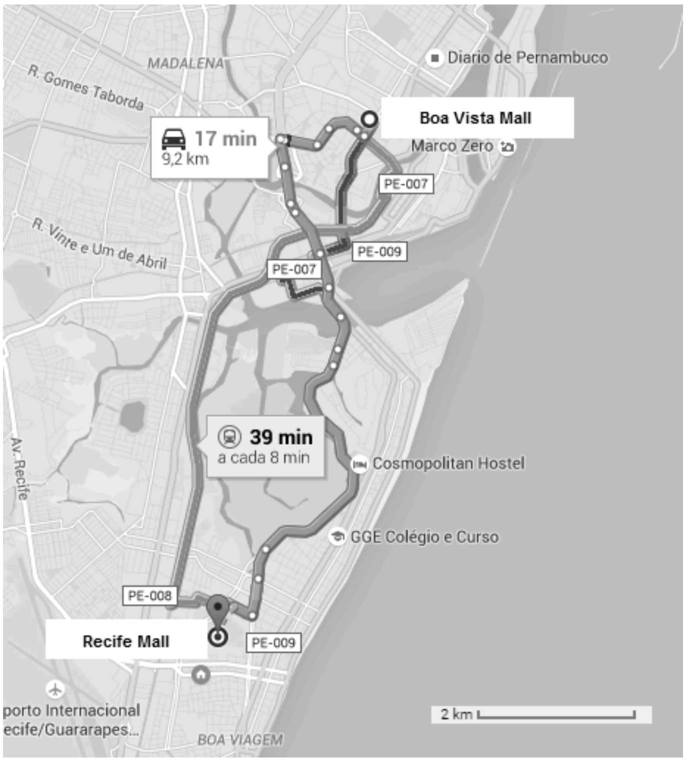

Figure 1: Map showing the starting and ending points, and some possible paths.
Source: Google Maps

The rule is that all participants must meet at the origin point at the appointed time (6 PM), all participants shall behave in the way they do daily and everyone must follow traffic laws. They all leave at the same time towards a common destination. Whoever arrives first, wins the race, but not necessarily the challenge, since other subjective variables also apply.

3.1 Social Economic Analysis

An income pattern was searched throughout the local population. The data base was IBGE (Brazilian Geographical Statistics Bureau) Census Inquiry from 2010 (IBGEcidades, 2014). The dataset of Recife's workers average nominal income has been classified by income levels. Taking the minimum wage as a base, the resident's incomes have been classified into six representative levels. The levels and percentages can be seen in the table below:

Level	# of minimun wages	Percentage
1	0 - 1/2	8,50%
2	1/2 - 1	11,44%
3	1- 2	21,27%
4	2-5	29,02%
5	5 - 10	13,81%
6	> 10	15,97%

Table 1: Income levels, city of Recife

The total annual costs are defined by Equation (2):

$$Total\ Annual\ Costs\ =\ Fixed\ Costs +\ Variable\ Costs \quad (2)$$

Then variable costs are estimated according to Equation (3):

$$Variable\ costs = cost\ per\ Km\ \times Km\ travelled\ by\ year \quad (3)$$

Thereby, it is possible to estimate the Total Annual Cost to each transport mode. As shown in Equation (4), by taking the costs and the average income the relation Cost/income can be obtained:

$$Transport\ Cost/Income = \frac{Total\ Annual\ Transportation\ Costs}{Total\ Annual\ Income} \quad (4)$$

If the Cost/Income ratio is 1, the workers in that class shall dispense 100% of their income, or all their working hours, to pay for transportation. If it is higher than 1, it means that they cannot afford it even if they intended to spend all their income on transportation, which obviously is not a legitimate decision either. A 0.1 result means that the workers provide 10% of their time to pay for transportation. By means of this relation it's possible to follow Equation (5) to have estimation on how long shall an individual worker be able to pay the daily cost of the trip, considering his working hours being 8 hours a day.

$$Work\ time\ to\ pay\ for\ transportation = \frac{Relation\ Cost}{Income\ \times 8h} \quad (5)$$

The total displacement time (Equation 6) can be calculated once the working time to buy a single trip and the travel time to work have been acquired.

$$Total\ Displacement\ Time = Travel\ Time + Working\ Time\ to\ Pay\ for\ Transport \quad (6)$$

Finally, the ratio between the travelled distance until work per day and the total displacement time in this trip is the effective speed or social speed by work means, as in Equation (7):

$$Effective\ Speed = \frac{Distance\ between\ home\ and\ work}{Work\ time + Displacement\ Time} \quad (7)$$

4. Results

The city analysed in this study is Recife, in the state of Pernambuco, located in poorer Northeast of Brazil. Its population is estimated at 1,608,488 inhabitants, but as in most metropolises, people from all metropolitan areas and further are influenced by its centrality, being vital to over 4 million people. The total area of the municipality is 218.435 km2 and its density is 7,039.64 inhabitants/km2 (IBGEcidades, 2014).

4.1 Transport Mode Analysis

The transportation means considered in this study were: (i) automobile, (ii) motorcycle, (iii) bicycle, (iv) bus, (v) metro, (vi) taxi, and, (vii) walking.

To illustrate the calculation of the fixed and variable costs to each mode the automobile will be set as the example, being the most complete. The automobile mostly sold in Brazil in 2014 was Fiat Palio (FENABRAVE, 2015); therefore it will be used to represent the automobile costs in our set. Table 2 shows the transportation means considered in this study. The first step is to estimate the fixed costs compounded by the yearly depreciation to a 10 year product life, followed by an insurance quota (4% p.a.), motor vehicle property tax (IPVA -2,5% p.a.) and Opportunity Cost of Capital (OCC – 11% p.a.). The values, originally in Brazilian Reais, will be shown in the equivalent amount in US dollars (1 U$ = R$ 3,12, 10/06/2015).

Table 2: Fixed Costs Automobile

OCC	U$ 944.55
IPVA	U$ 214.74
Assurance	U$ 343.60
Depreciation	U$ 1,433.97
TOTAL	U$ 2,936.86

Source: Author

The variable costs per kilometer have been obtained in the literature (Leite and Ferreira, 2014; Ameciclo, 2014), considering oil, fuel, and maintenance, as being for each mode:

Table 3: Transport costs of each mode

Modalities	Fixed	Variable
Automobile	U$ 2,936.86	U$ 0.10
Motorcycle	U$ 937.11	U$ 0.03
Bicycle	U$ 51.23	U$ -
Bus	U$ -	U$ -
Metro	U$ -	U$ -
Taxi	U$ -	U$ 0.85
Walking	U$ -	U$ -

Source: Ferreira and Leite (2014) and Ameciclo (2013)

The values paid on the respective public transport (bus and metro) and taxi trips were used to fill the model. The bus ticket was R$ 2.45 (U$ 0.79) and the metro ticket was R$ 1.60 (U$ 0.51). The taxi cost varies by distance, so the value used was the trip cost divided by the kilometres (R$ 2.65 = U$ 0.85).

4.2 Determining average speed

Data from the three commuter's challenge contest held in Recife where used to estimate the average speed to each transport mode.

Table 4: Average speeds and standard deviation to each transport mode

Mode:	Average Speed (km/h)	Standard deviation (km/h)
Automobile	14,4	6,6
Motorcycle	19,8	4,3
Bicycle	20	3,3
Bus	10,6	4,5
Metro	11,6	1,2
Taxi	13	13,4
Walking	6,1	0,7

Source: Ameciclo (2013) & Authors

Regarding table 4, it is easy to acknowledge that the fastest ways of transport with the chosen path are bicycle, motorcycle and taxi. The slowest ones are walking (which was already expected being a long distance, in a straight line 6.7 km) and taking the bus. Due to the lack of serious investments in infrastructure towards public transportation, buses and metro lines are becoming scrapped.

4.3 Effective Speed Computation

Since effective speed accounts travel time and working time to pay transport costs it varies according to travel time and income. Table 5 shows Recife's inhabitants monthly income level by salary range (minimum wage at R$ 720.00 or U$ 230.77).

Table 5: Income level by wage range

Level	Minimum Wages	Monthly value		Year value		Percentage
Level 1	0.25	$	57.69	$	692.31	8.50%
Level 2	0.75	$	173.08	$	2,076.92	11.44%
Level 3	1.5	$	346.15	$	4,153.85	21.27%
Level 4	3.5	$	807.69	$	9,692.31	29.02%
Level 5	7.5	$	1,730.77	$	20,769.23	13.81%
Level 6	10	$	2,307.69	$	27,692.31	15.97%

Source: Censo IBGE (2010)

The kilometres travelled by each commuter are the first feature to define when calculating effective speed. Assuming that each commuter makes two trips a day: residence-work and work-residence. The average distance travelled by the participants of the challenge was 10.24 km; 5,406.72 km would have been travelled by the end of the year. In table 6, fixed and variable costs are estimated to each transport mode, obtaining the total cost by mode.

Table 6: Transport mode costs

Modes:	Fixed Costs		Variable Costs		Total	
Automobile	$	2,936.60	$	554.54	$	3,491.13
Motorcycle	$	937.12	$	173.29	$	1,110.41
Bicycle	$	51.23	$ -		$	51.23
Bus	$ -		$	456.92	$	456.92
Metro	$ -		$	270.77	$	270.77
Taxi	$ -		$	4,592.25	$	4,592.25
Walking	$ -		$ -		$ -	

Source: Authors

Furthermore, the calculation will differ by income level. To depict this step estimation will be shown for income level 3, the major level regarding Recife’s population. This level represents the inhabitants who earn in between one and two minimum wages a month (approximately from U$ 270 to U$ 550). To make an average the calculation takes as if that level earned 1.5 minimum wages a month, meaning a yearly income of R$ 12,960.00, about U$ 4,984.60. The relation Cost/Income is calculated by taking the labourers’ yearly income and then comparing it with the different transport modes costs.

The income’s share that a worker shall give to pay for transportation in a determined mode is shown by the Cost/Income ratio. A worker won’t be able to pay for a determined transport mode if the value overpasses 1. Working Time is the figure obtained by multiplying that ratio by the quantity of hours worked in a day. It is an estimation on the amount of hours that have to be spent working for paying for the commuter’s trip using that mode.

The Travel Time to work can be inferred by knowing the values of every journey’s Working Time. Total Time for each mode of transport is obtained by adding Travel Time and Working Time. In some cases the sum will be greater than 8 hours meaning that the person cannot afford that mean of transportation. Effective Speed is finally obtained by dividing the Total Displacement by the Total Time.

Table 8: Effective Speed estimation for income level 3

Modes:	Ratio (C/I)	Work Time	Travel Time	Total Time	Normal Speed	Effective Speed	Ranking
Small car	0.84	6.72	1.60	8.32	14.40	2.46	6
Motorcycle	0.27	2.14	1.07	3.21	19.79	6.39	5
Bicycle	0.01	0.10	1.04	1.14	19.97	17.92	1
Bus	0.11	0.88	2.13	3.01	10.61	6.80	4
Metro	0.07	0.52	1.78	2.30	11.60	8.91	2
Taxi	1.11	8.84	0.81	9.66	13.00	2.12	7
Walking	0.00	0.00	3.39	3.39	6.10	6.04	3

Source: Authors

Reproducing the same calculations to all modalities and income levels the following matrix is obtained:

Table 9: Effective Speeds

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Small car	0.00	0.00	2.46	4.57	6.95	7.85
Motorcycle	0.00	3.83	6.39	10.33	13.70	14.76
Bicycle	12.51	16.49	17.92	18.85	19.24	19.33
Bus	2.76	5.26	6.80	8.16	8.87	9.04
Metro	4.17	7.26	8.91	10.23	10.88	11.03
Taxi	0.00	0.00	0.00	4.45	7.94	9.58
Walking	6.04	6.04	6.04	6.04	6.04	6.04

Source: Authors

The lowest income level (representing 8.5% of the population in the capital area, approximately 137,000 people) cannot afford to use any of the motorized private modes; therefore these modes are represented as being '0.00'. It is an even bigger issue considering that the population in the metropolitan area has much lower incomes, making the exclusion share notably bigger.

The bicycle had the best effective speed, adding travel time plus time spent to working to pay for the travel, it was the fastest, for all levels of income, varying between (12.51km/h and 19.33 km/h). It is reasonable, since it has won the first two commuter challenges, has done well in the ultimate exercise and is a very cheap way to commute. The motorcycle has also presented good effective speed, especially in the highest levels of income, ranking second position in Table 10. It develops good speed even in the intense traffic present in the studied city, but its costs are considerably high and include a large amount of the poorest income.

Automobiles made a terrible campaign, being last (2,3,4,5,6) or second to last (1) for all levels of income, since they are very expensive to maintain and were unable to develop good speeds in the peak hour time period. Metro has done quite well to maintain a second or third place in all levels for being cheap for a motorized mode (R$ 1.60 or U$ 0.51) and developing good speed.

Table 10: Ranking

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Automobiles	5	6	6	6	6	6
Motorcycle	5	5	5	2	2	2
Bicycle	1	1	1	1	1	1
Bus	4	4	4	4	4	5
Metro	3	2	2	3	3	3
Taxi	5	6	7	7	5	4
Walking	2	3	3	5	7	7

Source: Authors

5. Discussion

Both the population and the government could benefit from using effective speed as a decision tool to pick the most suitable mode of transport. Considering average income of the city of Recife and average speeds for different modes of transport, it can be recognized that between level 1 (R$ 180.00/U$ 57.69) and level 6 (R$ 7,200.00/U$ 2,307.69), the bicycle's effective speed was superior to any other mode, ranging from 12.51 km/h to 19.33 km/h. Bicycles had an outstanding cost/benefit relation when compared to other modes of transport, explained by its low purchasing and maintenance costs as well as its ability to move constantly even in the traffic jammed peak hours. Literature shows that investments in bicycle infrastructure slow the demand for expensive car infrastructure such as roads, flyovers and parking spaces. These evidences should persuade the city's administration into creating public policies to improve cycling infrastructure and promote the usage of bicycles.

Metro was rated good for lower income levels (from average income between R $ 180.00 or US $ 57.69 to R $ 1,080.00 or US $ 346.15). Metro does well in peak hours for not getting stopped by traffic jams. Also, metro lines from the city of Recife are less expensive than the bus, thus it's good rating. Nevertheless being responsible for commuting 200,000 people a day in 272 trips, the two available metro lines are far from serving the majority of displacements (UrbanaPE, 2014). Many people are deprived from using this mode simply because their paths are not covered by the metro.

To higher income levels the mode with the second best effective speed was the motorcycle. Increased purchase of motorcycles can be credited to a certain degree of incrementing perception of its cost-benefit offered by this mode of transport. Currently about 20% of all vehicles in Recife are motorcycles (DENATRAN, 2015) a big increase considering that in 1990 that share was only 6.7% of the share (Andrade et al, 2014). They outweigh other modes for requiring little road and parking space and for being able to reach longer distances without depending on any time schedule. However a remark should be done about the danger of using a motorcycle, in the district of Pernambuco reaching a mortality level of 3.47/100,000 inhabitants (Silva et al,2010).

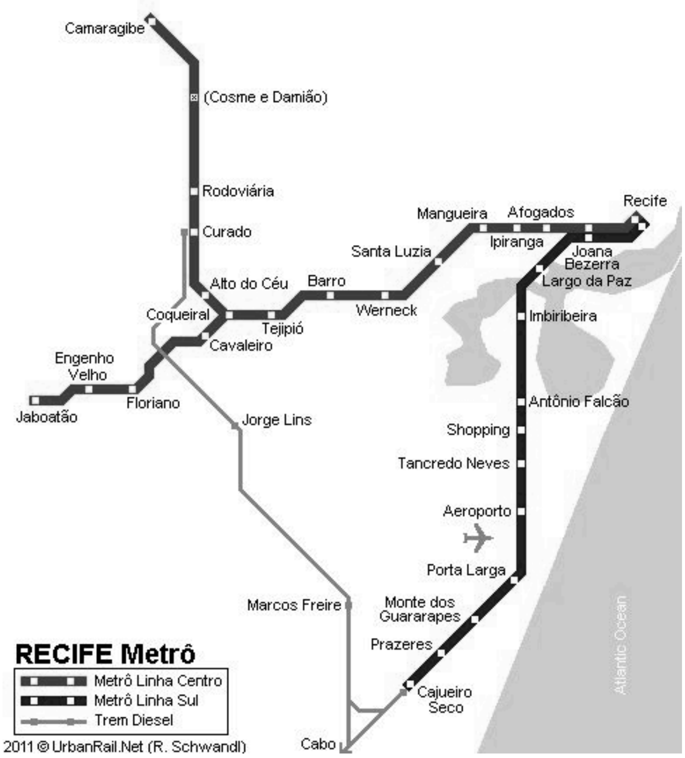

Figure 2 – Recife's Metropolitan Region metro lines

Of course, all results depend on the speed developed in the chosen path by the modes, if the path was longer and outside of peak hour the results would be much different. Probably the bicycles would decrease in effectiveness whereas cars and motorcycles would increase. However it is usual to use peak hour traffic levels to plan transport within a city. For that, the path chosen represents one of the main commuting paths, since it connects one of the most important residential and commercial area (Boa Viagem District) to the most important commercial area (Centro District) within the metropolitan area.

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