Impact of the Charitas-Cafubá tunnel on vehicle travel time

https://doi.org/10.56238/sevened2024.004-014

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ABSTRACT

One of the objectives of the Charitas-Cafubá Tunnel is to reduce travel time on the way to the city center of Niterói or the city of Rio de Janeiro. To measure the impact of the tunnel, a comparison of the travel time and vehicle flow of the current two existing routes after the construction of the tunnel with the single previous route was conducted. The results indicated that the travel time between the two alternatives after the construction of the tunnel approaches an equilibrium, both with a shorter travel time than the previous one. However, there was an increase in the total number of vehicles at the point of convergence between the routes. By analyzing the section after the convergence point, it is concluded that the reduction in the initial travel time provided by the Tunnel is counterbalanced by the increase in travel time in the segment after the convergence of the current routes.

Keywords: Urban mobility, Traffic engineering, Transport planning.

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INTRODUCTION

One of the main challenges of large cities is to provide conditions for the safe and efficient movement of people and vehicles. It is the job of public agencies to implement measures to mitigate congestion. Among the solutions indicated by the experts are the investment in public transport so that there is an increase in supply and operates with a level of service that meets the demand of the population. In this way, investing in quality public transport implies improving urban mobility.

However, there is a thought that one of the solutions adopted to solve the problems of congestion is the creation of new roads or the expansion of existing ones. However, studies highlight (Hansen and Huang, 1997; *Surface Transportation Policy Project*, 1998) that these actions do not reduce traffic, on the contrary, in the long run they tend to increase it. Stanley and Spivak (1993) indicate that there is an existing demand (on average 30% of the current traffic on the road) restricted by the fact that drivers do not use the vehicles due to congestion, such that adding a new lane will induce these drivers to use the automobile.

Therefore, before choosing the creation of a new road as a solution, extensive studies are needed to evaluate the characteristics of the current road system, because with the reduction of travel time, the motivation to use private transport is greater and travel time can increase again. If the studies are superficial, the scenario may still arise where the expected demand is not reached, leaving the road underutilized and not generating the expected benefits of the investment.

The objective of this work is to evaluate the impacts of the construction of the Charitas – Cafubá Tunnel on traffic in the region of the city of Niterói. Travel times and flows of vehicles found to travel two different routes from the same place of departure and arriving at the same point at the destination will be analysed. The first route, already in existence before the construction of the tunnel, starts at the place called "Trevo do Cafubá" to the Raul Veigas Tunnel, where drivers can choose between going to the center of Niterói or to Rio de Janeiro. The second, between the same "Clover", but now following the new Charitas – Cafubá Tunnel, bound for the same end point as the previous route, the Raul Veigas Tunnel.

The data prior to the construction of the tunnel were obtained from a technical feasibility study carried out by the city of Niterói, where, among other information, there are vehicle counts at certain points and the travel time required to travel specific stretches on some roads. Traffic volume data after the construction of the tunnel were collected through field research, at the same points used in the feasibility study, while travel time data were obtained through the tool available on Google *Maps*.

WARDROP EQUILIBRIUM THEORY

Techniques for distributing the flow of vehicles in a transport network emerged in the 1950s. In general, these techniques basically seek to follow two principles defined by Wardrop (1952). In the first of them, the author points out that in road networks in which the user can choose between two or more different routes to make a trip of common origin and destination, the travel time for all routes converges to the same value, lower than that of any other route not commonly used. In his publication, he argues that this principle is close to what has been tried in practice by assuming that traffic tends to settle into a situation of equilibrium in which the user always tries to reduce the cost and travel time by choosing a new route. This theory became known as the 1st Principle of Wardrop.

The Second Principle, also known as the Optimal System or altruistic Wardrop equilibrium, is based on the idea that car drivers would choose the route to their destination that would be best for all drivers in order to optimize the flow of the available road system in such a way that the overall average travel time of all drivers is minimal.

When dealing with the relationship between the Wardrop Principles and user behavior, Holden (1989) highlighted the possibility that in the future, electronic devices would provide information in real time, and this would affect route choices and consequently the entire behavior of the road system. The author indicates that one of the possible changes suffered in the transport network would be the occurrence of the *rat-runs phenomenon,* used to describe when drivers start to use roads with less capacity to avoid the congestion of the main roads.

Another impact of travel time and real-time traffic conditions tools, such as *Global Positioning System* (GPS) devices, mobile applications such as *Waze* or Google *Maps*, the time for Wardrop balancing to happen tends to be shorter. By instantly showing the fastest route between the source and the destination desired by the user, such tools shorten the time that would be spent by the user for system recognition with the availability of a new route. According to Holden (1989), this process could take up to months to define which route is faster and more convenient to your destination.

CHARACTERIZATION OF THE REGION

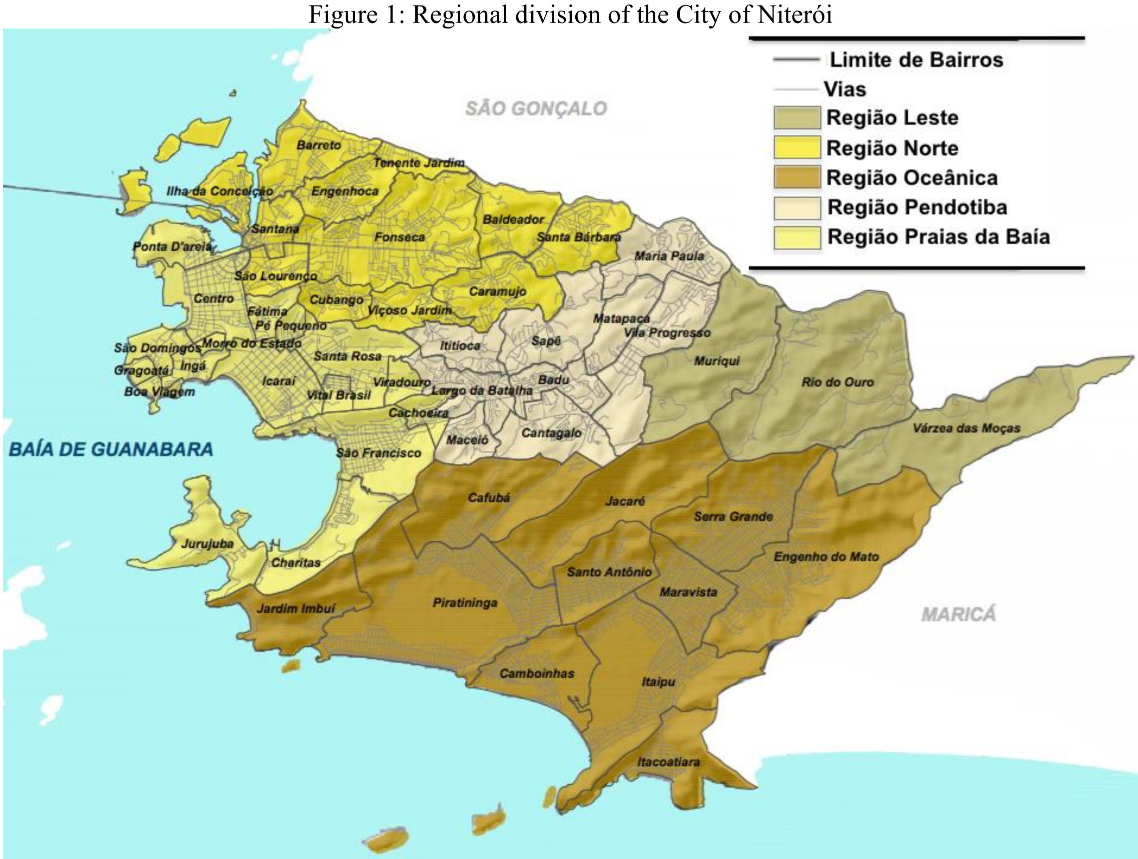
The city of Niterói is located to the east of Guanabara Bay, which along with 21 other municipalities, makes up the Metropolitan Region of Rio de Janeiro. Data from the Brazilian Institute of Geography and Statistics (IBGE, 2018) show that the population increased from 487,562 in 2010 to 499,028 inhabitants in 2017.

Until December 2017, Niterói's fleet was estimated at 290,824 vehicles (Detran-RJ, 2018), of which 207,668 are automobiles, 33,920 motorcycles and 2,799 buses. Relating these values to the population of the municipality, the Motorization Rate is 482 cars per 1000 inhabitants, higher than the rate of the southeast region, which has 363 vehicles per 1000 inhabitants (Observatório das Metrópolis, 2015). The average salary income of the municipality estimated by the census carried out in 2010 by the IBGE (2018) is R$2,303.46, which places the city at the top of the list of per capita income among Brazilian cities in that year's study.

The city has 51 neighborhoods, subdivided into 5 regions: Beaches of the Bay, North, East, Oceanic and Pendotiba, as shown in the map in Figure 1, and has municipal and intercity bus systems, ferries that connect Niterói to the city of Rio de Janeiro, through the stations of Araribóia, located in the center of Niterói and the catamaran station in Charitas, located in the Beaches of the Bay Region.

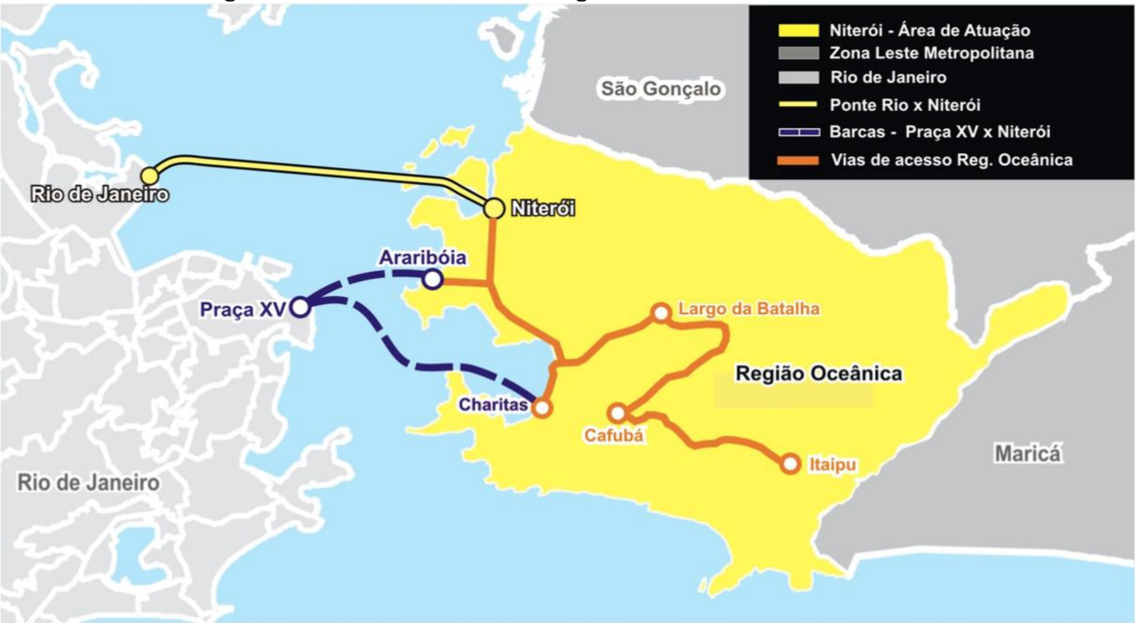
With facilities that facilitate access to Rio de Janeiro through ferries and the Presidente Costa e Silva bridge, a significant portion of the population of Niterói works in the State Capital (PDTU, 2015). However, residents of neighboring municipalities who work in Rio de Janeiro also use these alternatives to reach the capital, through the access roads to the bridge, and to the Barcas station at Praça Araribóia in downtown Niterói. Figure 2 marks the territory of Niterói, highlighting the main routes between the Oceanic Region and the city of Rio de Janeiro available to users before the construction of the Charitas-Cafubá Tunnel.

Figure 1: Regional division of the City of Niterói



Source: Department of Urbanism and Mobility of Niterói (2018)

Figure 2: Access roads between Região Oceânica and Rio de Janeiro



Source: Sinergia (2013)

THE CHARITAS – CAFUBÁ TUNNEL

The Charitas – Cafubá tunnel is part of the Transoceanic Road Corridor project, which is 11.2 km long, of which 1.35 km correspond to the tunnel. According to the Environmental Impact Report of the Transoceanic Road Corridor (2013), the main objective of the Transoceanic Highway project in Niterói is to improve the mobility of citizens and the connection with the center of Rio de Janeiro. To enable the integration of the Transoceanic Road Corridor with the Charitas Waterway Terminal, the Charitas-Cafubá Tunnel was built, allowing the reduction of travel time between the Oceanic Region and the center of Rio de Janeiro.

Due to the mountainous relief that separates the Oceanic Region from the Beaches of the Bay Region, the construction of the tunnel was the solution found to connect the neighborhoods of Charitas (Beaches of the Bay Region) to Cafubá (Oceanic Region), as shown in Figure 3.

Figure 3: Location of the Charitas – Cafubá Tunnel

Source: Google *Maps* (2018)

The tunnel has two galleries with a length of 1350 meters. Each with two asphalt pavement lanes, a concrete lane for the bus systems and a bike lane that will use an auxiliary lane. One of the factors for choosing the location of the tunnel is the proximity of the Charitas landslide to the Charitas Waterway Station (Transoceânica Niterói, 2018), as shown in Figure 4.

The operation of the tunnel is carried out through 40 cameras, 6 variable message panels, 6 control panels, 80 emergency telephones and an exhaust system with 16 high-capacity fans according to Transoceânica Niterói (2018).

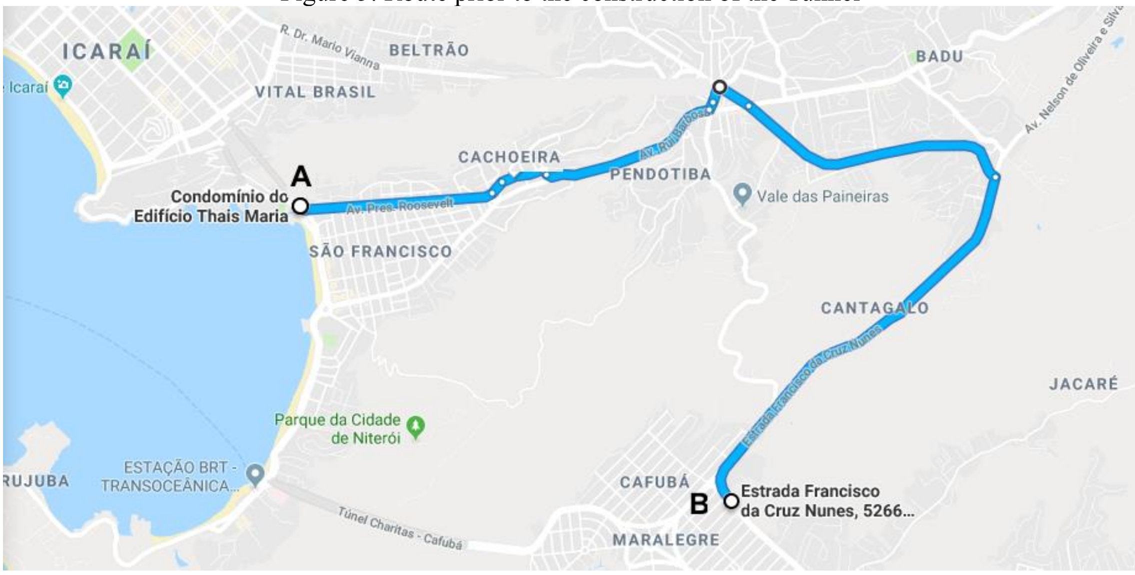
Figure 4: Entrance to the Tunnel through the Charitas neighborhood

Source: Google *Maps* (2018)

TRAFFIC CONDITIONS PRIOR TO TUNNEL CONSTRUCTION

Before the completion of the Charitas-Cafubá Tunnel, the path commonly used by users moving from the Oceanic Region towards the Bay Beaches Region was using the Francisco da Cruz Nunes Road (Point "B" of Figure 5), following until reaching Presidente Roosevelt Avenue (Point "A" of Figure 5). In this place, the user can go to the neighborhood of Charitas to have access to the center of Rio de Janeiro through the Catamaran station, or head towards the center of Niterói, through the Raul Veigas Tunnel, having access to the neighborhoods of the Bay Beaches Region, the commercial area in the center, the Presidente Costa e Silva Bridge, and the ferry station located in Araribóia square, in the city center.

Figure 5: Route prior to the construction of the Tunnel



Source: Google *Maps* (2018)

The route described in Figure 5 has sections with a number of lanes ranging from 1 to 3 per direction. The route has a height variation of 158 meters, making it difficult for heavy vehicles to make the route on a ramp due to the slope. The length of the highlighted section is 8,900 meters.

In the demand study carried out to evaluate the feasibility of the construction of the Transoceanic Way (Sinergia 2013), the results of traffic volumes and travel time on the main roads from Monday to Friday, during the morning (7:00 am to 9:00 am) and afternoon (5:00 pm to 7:00 pm) peak hours, were presented. Table 1 shows the volumetric count in the direction of the highest flow (towards the Praias da Baía region) and the points where the counts were made are marked in Figure 6, where point number 1 marks the point of volumetric counting made on Av. President Roosevelt, and point 2 marks the counting point before the entrance to the Raul Veiga Tunnel.

2782

Point	Local	Direction	Private Vehicles	Bus	Motorcycles	Total
1	Av. Presidente Roosevelt	B to A	1548	73	138	1758
2	Túnel Raul Veiga	B to A	2390	149	243	2782

Source: Sinergia (2013)

Figure 6: Vehicle Counting Points

Source: Google *Maps* (2018)

The average travel time over a period of one week, in the morning (direction from B to A) and afternoon (direction from B to B) peak hours, for the stretch used to connect the Oceanic region to the Bay Beaches Region before the completion of the Charitas-Cafubá Tunnel is shown in Table 2.

10,8

Direction	Travel Time (min)
B to A	18,43
A to B	10,8

Source: Sinergia (2013)

SCENARIO WITH THE TUNNEL

After 1 year and 6 months from the beginning of the work, on May 6, 2017 the tunnel was opened to users, even with the bus system of the Transoceanic Road Corridor still inoperative. With the inauguration, a second option is provided for access to the Oceanic Region, with the aim of alleviating the flow of vehicles on the existing road. According to Transoceânica Niterói (2018), in the first 6 months of operation, more than 5.3 million vehicles crossed the Charitas - Cafubá Tunnel, with an average of 40 thousand vehicles per day and 1600 vehicles per hour.

Figure 7: Available routes for the route

Source: Google *Maps* (2018)

Figure 7 shows the new route section made possible by the Charitas – Cafubá Tunnel (Section 2) and the existing route before the construction of the tunnel (Section 1). Points "A" and "B" mark the places where vehicles to and from the Oceanic Region are divided between the path prior to the construction of the Tunnel and the new route. The connection between the two points through "Section 1" is 8,900m long and the path through "Section 2" is 6,000m.

IMPACT ON TRAVEL TIME

In order to compare the travel time to travel the same route after the construction of the tunnel, data regarding the travel time to complete the route were collected through Google Maps. The method adopted was the same as Sinergia (2013), an average of the 5 days of the week, considering the direction from A to B in the morning peak and from B to A in the afternoon peak. The results are shown in Table 3.

12.8

Direction	Average Travel Time (min)		
	Before Tunnel Construction	After Tunnel Construction	
	Excerpt 1	Excerpt 1	Excerpt
A to B	10.8	10.6	11.4
B to A	18.4	16.0	12.8

The average travel time for private vehicle users from point "B" to point "A" through the tunnel (Section 2) during the morning peak is 12.8 minutes. The average time for "Section 1" is 16 minutes, close to the time indicated by the Synergy report (2013), of 18.4 minutes. These values indicate that in the morning rush hour the flow of vehicles has a greater impact on section 1 than on section 2, in such a way that through the tunnel there is a time gain of 20%.

In the direction from A to B by the new path generated by the tunnel, despite presenting a shorter distance and inclination of the track to be overcome by the automobiles, the travel time was close to that executed before by the old route (Section 1). Even with a difference in the length of the route of 32.5%, the travel time of both is closer. One of the factors for this time to be close is that the flow during the morning peak (from 7 to 9 am) is greater compared to the flow in the afternoon peak hours, as the latter is diluted throughout the end of the day, without forming large retentions in the accesses between the regions studied. In this sense, for the analysis of the increase in flow, the direction of greater flow of vehicles that travel between the regions during the morning peak was considered.

IMPACT ON VEHICLE FLOW

The data regarding the flow of vehicles after the construction of the tunnel were obtained through volumetric counts carried out between April 23 and 27, 2018, during the morning peak (B to A), at the access points of the Oceanic Region to the Beaches of the Bay region. The counting points were chosen because they are the same as the counting made by the company Sinergia in the feasibility study of the Transoceanic Road Corridor. For this, a manual volumetric count of traffic was carried out on Av. President Roosevelt (Point 1 of Figure 6) and the Raúl Veiga Tunnel (Point 2 of Figure 6).

3144

Local	Vehicle Flow (vehicles/hour)	
	Before Tunnel Construction	After Tunnel Construction
Túnel Charitas-Cafubá	-	1348
Av. Presidente Roosevelt	1758	1228
Túnel Raul Veiga	2782	3144

When comparing the total number of vehicles per hour that passed through the Raul Veiga tunnel before and after the construction of the tunnel, it was recorded that the number of vehicles per hour increased by 13%, from 2782 to 3144 vehicles per hour. The data in Table 4 show that the number of vehicles per hour that use the Charitas - Cafubá Tunnel in the direction of downtown Niterói or Rio de Janeiro during the morning rush hour, exceeded the flow of vehicles that arrived at point A through Av. President Roosevelt.

Thus, the travel time from B to A and the division of flows between the two routes after the tunnel is opened to traffic, indicate that the travel times of Sections 1 and 2 are in the process of equilibrium. Therefore, as indicated by Wardrop (1952), the flow of vehicles using the fastest route will continue to grow until the time spent by users in congestion and traffic when using "Stretch 2" will result in a travel time close to that experienced by users on "Stretch 1".

It is possible to see that the travel times of the routes fluctuate according to the different divisions of the flow. According to Wardrop (1952), the variable with the greatest impact on the decision of road users in route choices is the travel time of each one, that is, the driver tends to choose the fastest one, even if it has a longer length. Therefore, users' route choices will oscillate between the two alternative paths until an equilibrium point where the travel time tends towards the same value.

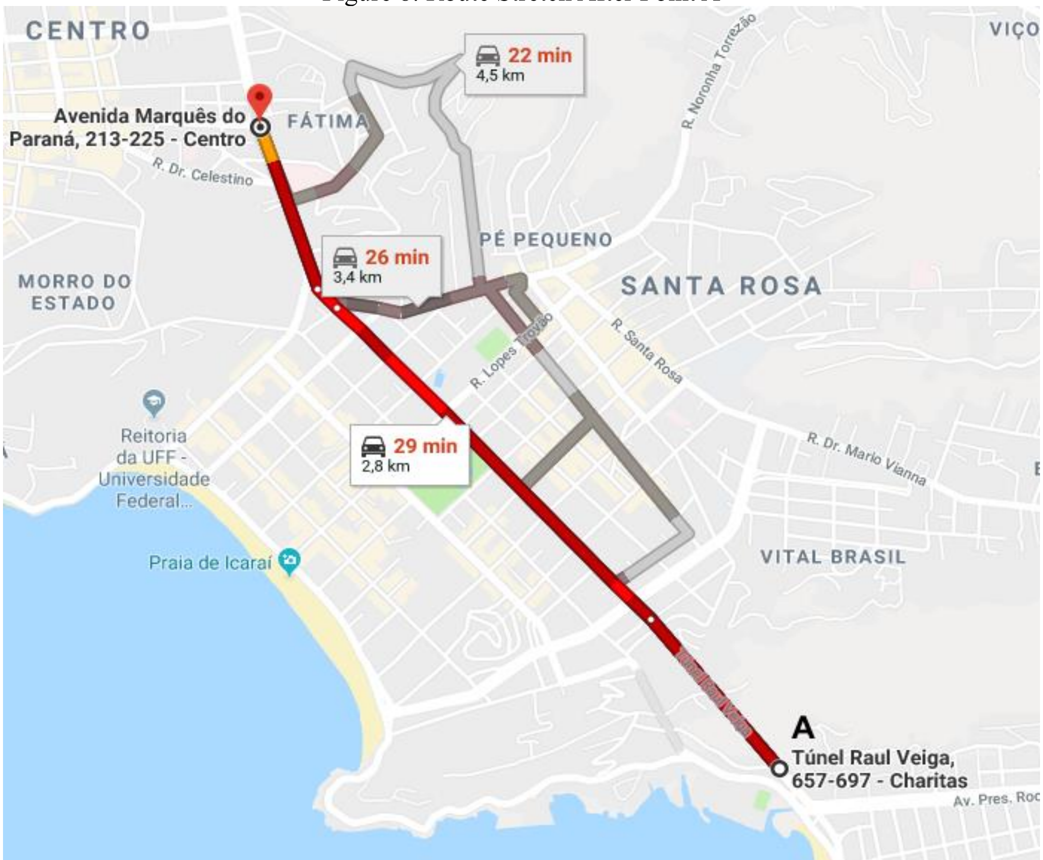
Although the travel time of the two sections is reduced compared to Section 1 in the scenario prior to the construction of the Charitas – Cafubá Tunnel, this gain in travel time may be lost in the section after the convergence of the two paths that occurs at "Point A" (Figure 6), as the flow of vehicles that passed through the two routes join again and this total flow follows the Raul Veiga Tunnel.

IMPACT ON TRACKS AFTER CONVERGENCE

This increase in the number of vehicles accessing the Raul Veiga Tunnel during the morning peak reflects on the flow of adjacent roads, as they have not undergone any intervention such as increasing the number of lanes, changing traffic lights or implementing reversible lanes to increase capacity to accommodate the increase in demand. Therefore, this additional flow of vehicles tends to aggravate traffic on the roads after the convergence of routes and, consequently, increases travel time on this stretch.

Therefore, the reduction in travel time provided by the division of the flow of vehicles from the Oceanic Region between two alternative stretches for the route to the Bay Beaches Region is compensated by the increase in travel time on the stretch following "Point A", on the route to the center of Niterói or Rio – Niterói Bridge. as shown in Figure 8, where to cover a 2.9 km stretch, 29 minutes are needed in the morning peak, while data from Sinergia (2013) for this same stretch indicated 20 minutes. In the same Figure it is possible to observe the *rat-run* phenomenon, where adjacent streets, with characteristics of local roads, are also used by drivers, considering that it takes approximately the same time as the main road to make the journey.

Figure 8: Route Stretch After Point A



Source: Google *Maps* (2018)

CONCLUSIONS

Through the new route generated by the construction of the Charitas Cafubá Tunnel, a new alternative has emerged for drivers to make the trip. The travel time of the available routes converges to the same value, according to the First Principle of Wardrop. The total number of vehicles that started to travel after the implementation of the tunnel increased by 13%, indicating that the increase in capacity implies an increase in traffic.

This increase caused a reflection on the travel time on the roads after the meeting between the flows of Sections 1 and 2 in the direction of the Oceanic Region to the Beaches of the Bay Region. This counterbalanced the reduction in travel time initially provided, at first, by dividing the flow of vehicles from the Oceanic Region between two alternative stretches for the route to the Bay Beaches Region.

The study detected values indicating that just offering a new route does not necessarily imply a gain in travel time as a whole, as there is an increase in the number of vehicles attracted by the initial reduction in the time to complete the route. In this sense, without the migration of users from private transport to public transport, the opening of a new path connecting the Oceanic Region with the Bay Beaches Region, does not reduce the travel time between the main points of attraction (downtown Niterói and the City of Rio de Janeiro), and the reflection caused by the opening of the tunnel can be perceived in a negative way by users of the road system of Niterói. in view of the worsening of traffic on the stretch after the Raul Veiga Tunnel.

The success of the Charitas - Cafubá Tunnel in improving mobility in the transportation system by reducing the flow of vehicles circulating in the region during peak hours will depend on the success of the Transoceanic Road Corridor in promoting integration with the Charitas Waterway Terminal, connecting the region served by the road corridor with downtown Rio de Janeiro and through the implementation of a bus system that uses an exclusive lane within the tunnel.

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