

**Impact of the Barrier Effect of Urban Highways on Mobility and  
Accessibility**

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## **SUMMARY**

Highways in urban areas, while facilitating traffic flow, can also pose a barrier to people's mobility in peripheral zones. Even though they expedite traffic, they can segment communities and distance them from areas with more opportunities and services. This phenomenon is known as the "barrier effect." Most current research focuses on the impacts of this barrier on mobility, especially concerning non-motorized transportation. Thus, the purpose of this study was to analyze how the barrier effect of an urban highway influences the transportation choices of the population living nearby, as well as the consequences for urban mobility and accessibility. The investigation relied on local household survey data, addressing travel patterns and socioeconomic aspects. Additionally, it included census information, thematic map production, and correlational analysis. Findings revealed that areas with multiple urban crossings tend to foster more travel, especially in higher-income areas where private motor vehicles prevail. In contrast, areas with limited crossings typically house lower-income communities with fewer trips. These areas, being further away from employment centers and services, have shorter trips, often made on foot or by bicycle, or with heavy use of public transportation, such as buses.

**KEYWORDS:** Community Severance. Travel Patterns. GIS in Transportation. Transport Mode Choice.

## **1 THE HIGHWAY BARRIER EFFECT IN CITIES**

The barrier effect is a broad concept that encompasses issues such as accessibility and population mobility. It can be caused by various elements related to transportation systems, such as vehicle traffic, road infrastructure, and user characteristics. Common in many cities, urban highway sections often cut through established neighborhoods and hinder crossing from one side to the other, primarily due to heavy and dense vehicle traffic or due to barriers, level differences, walls, and other types of physical obstacles.

A widely propagated understanding of the barrier effect caused by road structures primarily refers to the difficulties in accessibility and mobility for non-motorized modes of transport, especially pedestrians (LITMAN, 2011; MACIOROWSKI; SOUZA, 2018; MOUETTE; WAISMAN, 2004; SILVA JÚNIOR; FERREIRA, 2008).

Other authors, aiming for a broader understanding of the problem, use the term "Community Severance." In this context, the definitions encompass aspects such as the reduction of a population's potential to interact with a set of destinations that cannot be accessed without crossing the barrier (ANCIAES, 2013); changes in people's travel patterns, leading to the separation of the affected population from facilities, services, and social networks within a community (GRISOLÍA; LÓPEZ; DE DIOS ORTÚZAR, 2015); physical or psychological barriers that hinder and negatively affect movement, connectivity, accessibility, social interactions, well-being, and perceptions of people living or traveling in the vicinity, separating local communities due to infrastructure, traffic flow, and speed (LARA; DA SILVA, 2019).

Therefore, it is important to remember that the barrier effect and the community severance are phenomena that can affect all modes of urban transportation. These effects can be caused by road infrastructure or the vehicle traffic that utilizes it. Furthermore, they can have negative impacts not only on the people who transit or inhabit these areas but also on land use and the environment, such as noise and air pollution.

Para Ancaies, Jones e Mindell (2016) the assessment of impacts resulting from the barrier effect caused by road infrastructures should consider the relationships between

transportation, social environment, and built environment, which will involve multiple areas. This assessment is useful not only for transportation planning but also for urban planning, social policies, and health policies. These authors further argue that to evaluate the impacts of community severance on the population, individuals living in these areas may have very different mobility and accessibility experiences, restrictions, and needs. These barriers can have a significant impact on populations considered more vulnerable to mobility and accessibility challenges, such as people with disabilities, the elderly, and children. Other limitations include available modes of transportation, destinations, unemployment, low income, and ethnic minorities.

To structure the variety of impacts, Van Eldjk, Gil e Marcus (2022), based on previous studies, categorized the impacts of the barrier effect into: direct impacts, characterized by additional efforts in travel; indirect impacts, linked to changes in travel patterns; and broad impacts, encompassing attitudinal, individual, or collective aspects. These categories emerge from determining factors such as land use, personal needs, transportation resources, individual competencies, and ease of crossing.

In the search for indicators to assess the impacts of duplicating an urban highway segment, it was observed that conventional design approaches compromise the mobility and accessibility of residents and visitors in adjacent areas. Moreover, the strategies currently adopted to mitigate such effects, such as overpasses, for example, are not suitable for local demands. Among the most notable impacts on mobility and accessibility are: road and flow interruptions; spatial segregation; unplanned urban sprawl; prolonged travel times for the affected population; and pedestrians' reluctance to use overpasses due to safety concerns. (DE ANDRADE; TAVARES, 2017). These findings indicate the need to incorporate the concerns of residents and passersby from the outset of highway duplication and/or construction projects to reduce the mentioned adverse effects.

In a study analyzing pedestrians' choices in crossing urban highways, Cantillo; Arellana; Rolong (2015) noted that longer distances reduce the likelihood of a safe crossing, exemplified in the study by the use of overpasses. Additionally, it was observed that men are more prone to taking risks when crossing. Following a similar line of reasoning, Mindell e Anciaes (2020) explain that due to detours for crossings or a decline in urban environment quality, there is a reduction in non-motorized trips, as these modes are directly affected by travel time. All of this can result in the loss of mobility and accessibility to goods, services, social contacts, as well as some degree of isolation for this population.

In a national approach dedicated to determining the importance of impacts resulting from the barrier effect caused by a highway in an urban stretch, Silva Júnior e Ferreira (2008) concluded that insecurity, difficulty in crossings, and discouragement from using overpasses, along with changes in the number of trips and environmental quality, were the most relevant impacts (variables) in this study.

In their endeavor to assess the impacts on mobility and accessibility, as well as the potential consequences of this on family budgets, Neri e Silva Junior (2023) concluded that income and crossing opportunities influence displacements. Generally, the most valued areas are occupied by high-income families, which have greater mobility and accessibility, reinforced

by the greater ease in acquiring and maintaining individual motorized vehicles, facilitating and expediting displacements even in areas affected by urban barriers.

The same authors further argue that low-income individuals reside in areas with fewer crossing options, which are generally more distant, further complicating their mobility and contributing to limited access to services. In the quest to improve transportation conditions, primarily due to existing barriers, distance, and potential deficiencies in public transportation, this population ends up compromising a significant portion of their income on acquiring individual motorized vehicles. Such inequalities are reinforced by the devaluation of land along areas with fewer crossing points, meaning they are less accessible.

Thus, it was possible to briefly observe that there are various types of approaches being carried out regarding the barrier effect. However, it is necessary to include research that analyzes the impacts on population accessibility and mobility together with characteristics such as travel patterns, population, household size, ownership of motorized vehicles, and their possible relationships with the object causing the separation or barrier in the local community.

An important point to remember is that a significant portion of research on the barrier effect, both in Brazil and in other countries, has focused on understanding these effects arising from transportation infrastructures on pedestrians and to a lesser extent cyclists. Research utilizing transportation databases, which are increasingly available in medium and large cities in Brazil, can contribute to more effectively enabling the inclusion of other modes of transportation (public transportation users, drivers, and motorcyclists). All individuals and different modes of transportation are somehow impacted by the barrier effect caused by highways in urban areas. Non-motorized transportation and certain population groups, as previously noted, are the most affected, but it is necessary to broaden the understanding of this common urban phenomenon in Brazilian cities.

## **2 OBJECTIVE**

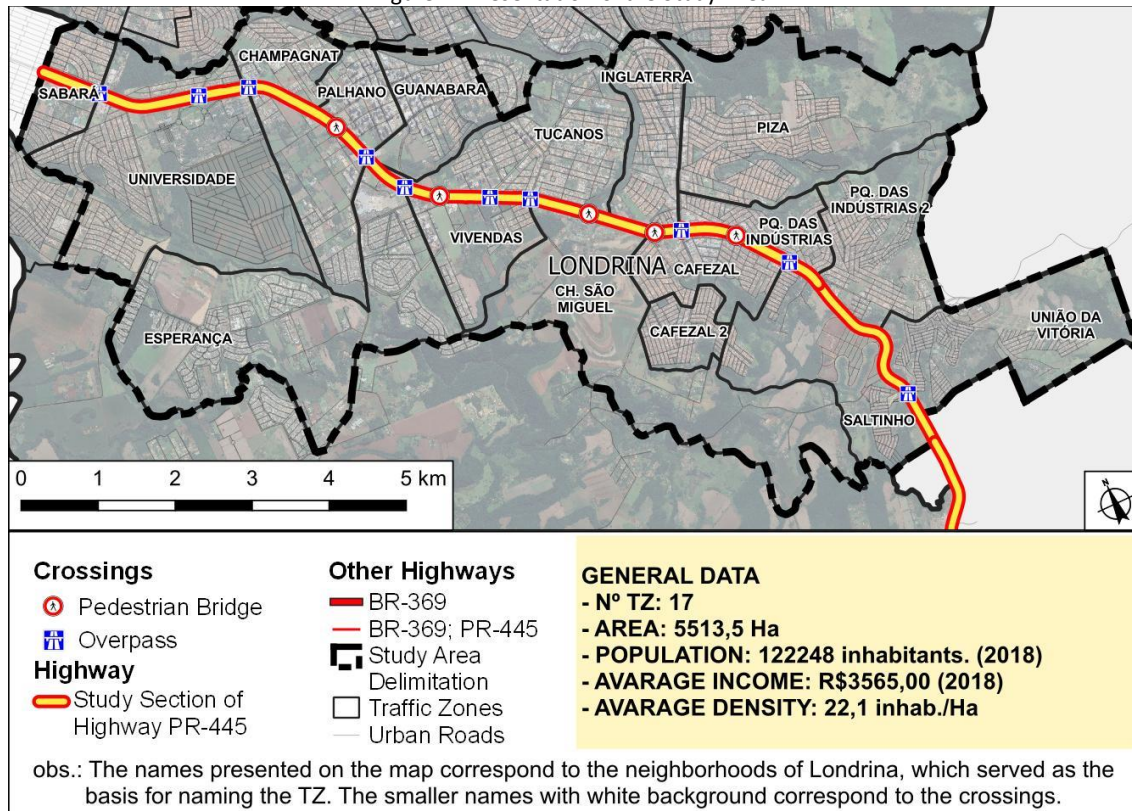
Identifying the impacts of the Barrier Effect of an urban highway on the modal split of the population in areas adjacent to the road infrastructure and its possible consequences on urban mobility and accessibility.

## **3 METHODOLOGY**

The study area (Figure 1) comprises 17 Traffic Zones (TZs) adjacent to the urban stretch of the PR-445 highway in Londrina/PR, with a length of 12.1 km. This stretch begins at the intersection with Arthur Thomas Avenue in Jd. Sabará (near the border with Cambé/PR) and ends at the access to the neighborhood called Conjunto Jamile Dequech (to the south). The road infrastructure is duplicated, with two lanes of travel, shoulders, and a concrete barrier separating the lanes. Marginal roads are present along almost the entire stretch (10.0 km). The traffic volume is high, and speeds are elevated (70 km/h). The highway features ten grade-separated crossings for vehicles and pedestrians (overpasses) and an additional four pedestrian overpasses, totaling 14 crossing opportunities.

This study is a continuation of the work carried out by Neri and Silva Junior (2023) entitled "The Barrier Effect of Urban Highways and its Impacts on Mobility and Transportation Expenses," conducted in the same area. However, it utilizes different variables related to mobility and accessibility to the city compared to the previous study.

Figure 1 - Presentation of the Study Area.



Source: Own authorship.

The material used as the basis was the household survey data from Londrina, conducted in 2018 to support the development of the Mobility Plan. This survey collected data on travel patterns and socioeconomic aspects from a representative sample of households, families, individuals, and trips. The data is available in spreadsheet format on the website of the Planning and Research of Londrina Institute (IPPUL). The survey was conducted in 91 Traffic Zones (TZs), which were established by dividing the 717 census tracts of the municipality of Londrina. The sociodemographic data of these TZ were updated for the year 2018 (IPPUL, 2018). The following procedures were carried out based on this data:

- Utilization of trip generation data from the 17 traffic zones adjacent to the urban stretch of the PR-445 highway in Londrina/PR;
- Selection of sociodemographic variables and travel patterns of the population in the study traffic zones: Average Income/household; Population; Trip Generation; Modal Split (walking; cars; motorcycles; buses; bicycles; and others); Number of People/household; Motorized Vehicles/household; Number of Trips/person/day; and Internal Trips;

- Construction of a statistical correlation matrix among the eight delimited variables in order to select the variables that obtained at least some correlation with one of their pairs;
- Construction of thematic maps in a Geographic Information System (GIS) based on variables relating: Modal Split/TZ and Average Income/household/TZ with Trip Generation/TZ, Number of Trips/person/day/TZ; Motorized Vehicles/household/TZ and Internal Trips/TZ.

To obtain information about the coverage of bus lines serving the research area and its population, the routes traversing the study area were mapped, and their corresponding frequencies on a typical day were added to the database. Using the QGIS software, the density of the bus lines was obtained by interpolating them within a radius of 300 meters, based on the number of schedules on a typical day for a 24-hour period. This data was provided by the companies providing the service, the Municipal Urban Transport Company (CMTU), and urban mobility applications.

#### 4 RESULTS AND DISCUSSION

In this section, the linear correlation between the thirteen studied variables will be initially presented, highlighting those that obtained the following results: very strong positive correlation (between 0.9 and 1.0 - dark green color); strong positive correlation (between 0.7 and 0.9 - intermediate green color); moderate positive correlation (between 0.5 and 0.7 - light green color); moderate negative correlation (between -0.5 and -0.7 - orange color); and strong negative correlation (between -0.7 and -0.9 - red color), as shown in Table 1.

Table 1 - Linear Correlation Matrix between the Analyzed Variables

Variables/traffic zone	OF	CA	MO	BU	BI	OU	PO	IH	TG	PH	TP	IT	MV
On Foot (OF)	1,0												
Cars (CA)	-0,8	1,0											
Motorcycles (MO)	0,1	-0,6	1,0										
Bus (BU)	-0,1	-0,5	0,5	1,0									
Bicycle (BI)	0,4	-0,4	0,3	-0,1	1,0								
Outthers (OU)	0,2	-0,2	0,0	-0,1	-0,3	1,0							
Population (PO)	0,2	-0,2	0,2	0,0	0,3	-0,2	1,0						
Avg. income/hh. (IH)	-0,6	0,9	-0,6	-0,5	-0,3	-0,3	0,0	1,0					
Trip generation (TG)	-0,1	0,4	-0,4	-0,4	0,2	-0,4	0,5	0,5	1,0				
People/hh. (PH)	0,3	-0,3	0,1	0,2	0,4	-0,2	0,0	-0,1	-0,1	1,0			
Trips/person/day (TP)	-0,4	0,7	-0,7	-0,5	0,0	-0,4	-0,1	0,8	0,4	0,1	1,0		
Internal trips (IT)	0,5	-0,2	0,0	-0,4	0,7	-0,2	0,6	0,0	0,6	0,2	0,1	1,0	
Motorized vehicles/Hh. (MV)	-0,7	0,8	-0,5	-0,4	-0,1	-0,3	-0,3	0,8	0,3	0,0	0,7	-0,1	1,0

hh.: household

Source: Own authorship.

Table 1 presents the linear correlation between the study variables. It highlights: the very strong linear correlation between average income and the participation of cars in trips

made by TZs; the strong positive correlation between income and the average number of motorized vehicles/household and the quantity of trips generated/person/day. These data provide evidence that the higher the income of a family or individual, the greater their ability to generate trips and access a private vehicle, especially a car.

It was also possible to observe a strong correlation between the quantity of internal trips/TZ generated by the populations and the participation of bicycles in trips. This indicates that this mode of transportation is suitable for medium or short-distance trips, which in this case mostly occur within the TZs themselves.

On the other hand, it is worth highlighting the inversely proportional relationships between the average number of motorized vehicles/household/TZ and the participation of cars in trips generated by the TZs, both in relation to the use of walking mode in trips. In other words, the higher its participation in the transport modal choice of the TZ, the mentioned variables decrease. Although moderate, average income had a negative relationship with walking, bus, and motorcycle modes of transportation. This data is important because it helps to understand that, in general, higher family incomes tend to use non-motorized, collective, and motorcycle modes less, with the latter gaining some prominence in low-income communities as they are more economically accessible than cars. The variables "number of people/household/TZ" and "population/TZ", due to their weak linear correlations with the others, were not selected for spatial analysis.

#### **4.1 Trip Generation Around the Highway and Mode Choice**

Although trip generation is also linked to the size of the population and the demographic density of a region, factors such as income and modal split can help explain this phenomenon, especially in areas influenced by a Trip Generating Developments (TGD) or a barrier caused by transportation infrastructure, such as urban highways.

Along the highway section within the research area, urban crossings are unevenly distributed. In locations where these crossings are closer together (averaging around 500 meters), the TZs that generate the most trips are found, such as TZ Palhano and TZ Guanabara. These two TZs are advantageously positioned relative to the highway as it is not necessary for the population to cross the highway when traveling to other trip-attracting areas of Londrina. The map in Figure 2 also shows that these TZs, followed by two neighboring ones (TZ Esperança and TZ Vivendas) on the other side of the highway, are characterized by high average household incomes (above R\$ 6,000.00), which may partly explain the high trip generation.

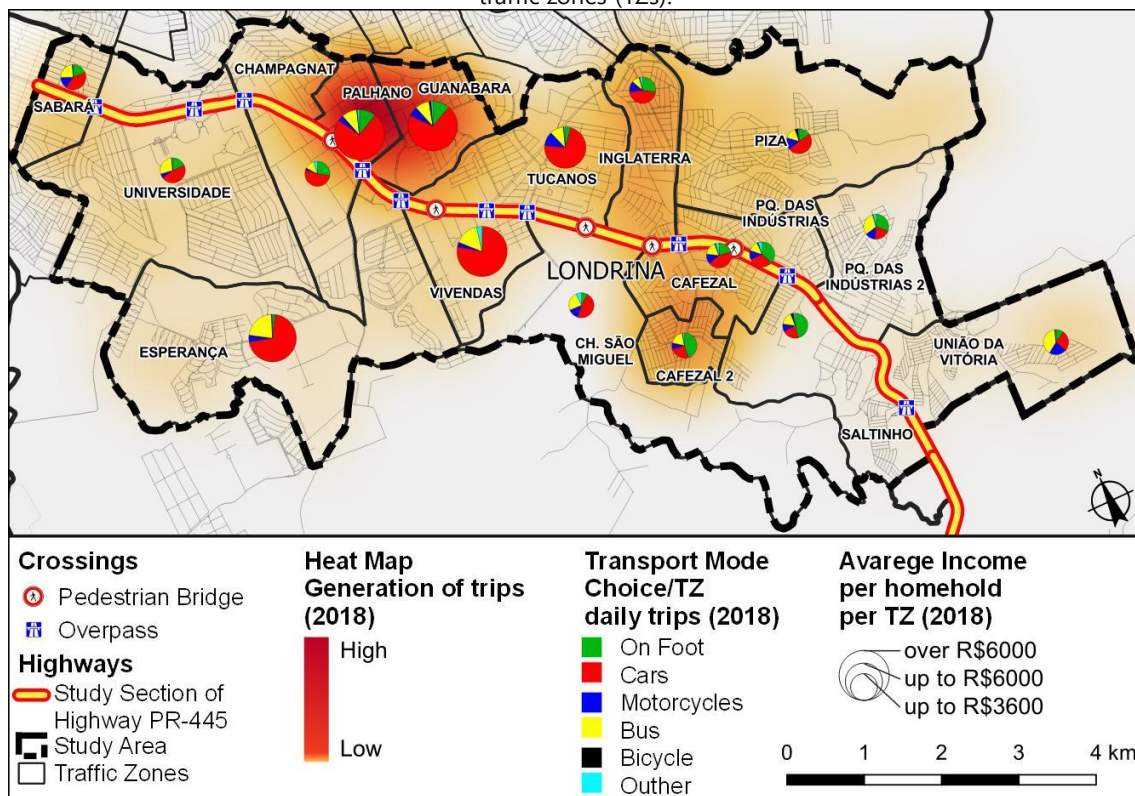
It is worth noting that these four TZs share a significant predominance of car use in their daily trips. Specifically, TZ Vivendas and TZ Esperança have car usage rates of 78% and 71%, respectively. Characterized by recent urban development and predominantly horizontal residential condominiums, these areas have little land use diversity, with few commercial and service options and low population densities. Additionally, the long distances to other trip-attracting areas, urban voids, and the limitations imposed by the urban crossings of PR-445 contribute to this phenomenon. Favorable economic conditions, combined with the need to improve access to urban services and mobility, explain the high dependence on cars among this population, to the detriment of other modes of transport, which are often not viable.

In this case, it is possible to affirm that the locations with a greater presence of highway crossing devices (footbridges or overpasses, as shown in Figure 2) coincide with the TZs of higher average household income and higher trip production, as the high use of automobiles drives more trips. Additionally, areas that are more accessible and connected tend to be valued higher in the real estate market, making them more economically accessible to higher-income families.

Another noteworthy factor is that near this region of the study area, where more highway crossing points are located, there are two major Trip Generating Developments (TGD): a shopping center and a public university with a student population of over 20,000 people.

On the other hand, in the section of the highway that borders TZs Cafezal 1 and Parque das Indústrias 1, there are four crossings with an average distance of 460 meters between them (similar to what occurs between TZs Palhano, Vivendas, Guanabara, and Esperança). Their average household incomes are low; however, in the case of Cafezal 1, individual motorized modes account for more than half of the trips (44% cars and 13% motorcycles). This situation may be exacerbated because this TZ is positioned in a way that the highway acts as a barrier to the mobility of this population, especially for collective or non-motorized modes, which end up being less viable than cars and motorcycles, for example.

Figure 2 - Trip generation, transport modal choice, and average household income among the analyzed traffic zones (TZs).



Source: Own authorship.

Other TZs that generated considerable volumes of trips (as shown in the heat map in Figure 2) also have the characteristic of higher use of individual motorized modes in the population's daily trips (TZs Cafezal 1, Inglaterra, and Parque das Indústrias 1). Another



important point is that these TZs are located near the largest concentrations of highway crossings. The exception was TZ Cafezal 2, located in the same position as TZ Cafezal 1 in relation to the highway but farther away from it. In this TZ, pedestrian trips accounted for 45%, followed by 26% by cars, 18% by buses, and 8% by motorcycles. This predominance of walking mode can be explained by being a consolidated and predominantly residential neighborhood, where many of these trips are short distances for local services or commerce purposes and occur within the TZ itself (see map 3 in Figure 3). Additionally, the lower average income and consequently greater economic difficulty in owning individual motorized vehicles, coupled with the lower viability of using bicycles and a likely deficit in bus public transportation services, are other factors that may have contributed to this characteristic.

At the southernmost and most isolated end of the research area compared to the other TZs (see Figure 2), in TZ Saltinho, it is noticeable that trip generation is significantly lower than in the neighboring areas to the north. Another important point is that there is only one highway crossing device in this area, in this case, an overpass, connecting it to the neighboring União da Vitória neighborhood. The long distances and socio-economic conditions, combined with the isolation from the main road network, are factors that may have contributed to this lower number of trips generated in this region, which is mainly composed of the CJ Hab. Jamile Dequesh neighborhood.

#### **4.2 The Daily Number of Trips per Person, Vehicle Ownership per Household, and Internal Trips in the TZs Surrounding the Highway**

When placed side by side and also compared with the choice of transportation mode, the variables "Motorized Vehicles per Household and Trips per Person per Day" show a strong resemblance across the TZs. Furthermore, these two variables are also linked to average household income, which in turn impacts the choice of transportation mode and the number of trips generated by individuals.

The stretch of highway PR-445 in Londrina with closer crossing facilities borders TZs with the highest average number of trips per person per day (more than two trips - darker purple tones in Map 1 of Figure 3), as well as higher numbers regarding motorized vehicle ownership per household (darker blue tones in Map 2 of Figure 3). These include the TZs: Esperança and Vivendas do Arvoredo, both in an unfavorable position relative to the highway; TZs Palhano and Guanabara on the opposite side. In the case of TZ Esperança specifically, it was the only one with an average of more than two motorized vehicles per household, confirming the notion that, faced with the need to cross the highway, this population has sought to improve their access and mobility conditions by using primarily automobiles (over 78%), facilitated by their high average household incomes.

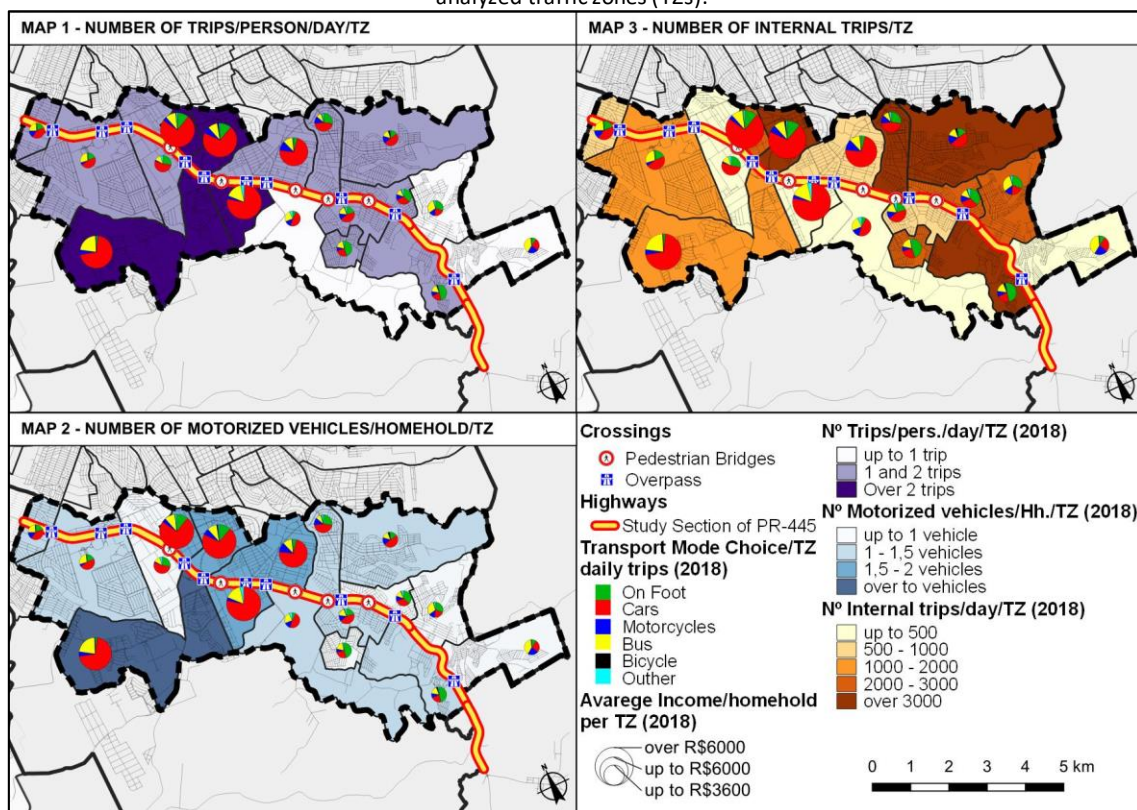
On the other hand, among all TZs with high incomes, TZ Esperança was the only one that showed more than 20% of trips made by bus, which seems paradoxical given the ideas presented so far. However, this can be explained by the presence of Trip Generating Developments (TGD), such as a large shopping center and a bus rapid transit terminal. In the case of the former, as it generates many jobs and comprises a large number of commercial and service establishments, it attracts many trips not only from customers but also from workers. As

for the latter, being a nodal point of transportation, it also serves as a hub of attraction, concentrating bus lines arriving from various areas of the city and even the metropolitan region.

Further south in the study area, it was observed that on the maps in Figure 3, the TZs with the lowest averages of trips per person per day and the number of motorized vehicles per household are located, and in this area, lower average incomes prevail. These regions are those with the greatest distances from the city center, as well as less proximity between the urban crossings of the highway, making them more disconnected from the main urban network.

It's also worth mentioning that in the case of TZs Cafezal 2 and Saltinho, the average number of trips per person per day may have been reinforced by the fact that a large portion of their trips are made on foot, as the recorded averages of motorized vehicles per household were low (up to one vehicle in TZ Cafezal 2). This information is confirmed by Map 3 in Figure 3, where these two mentioned TZs appear among those that generated the most internal trips, which in turn are related to walking and shorter trips.

Figure 3 - Number of trips per person per day, transport modal choice, and average household income among the analyzed traffic zones (TZs).



Source: Own authorship.

Another notable observation was that in the TZs with lower incomes and fewer trips per person per day, buses played a significant role in the generated trips, as seen in the cases of TZ União da Vitória and TZ Parque das Indústrias 2. Although these TZs are not directly affected by the barrier effect of the highway, this low average number of trips per person per day is due to their heavy reliance on public bus transportation, which is generally less flexible, prone to low



of urban occupation, or large areas with specific uses, such as the campus of the State University of Londrina (UEL). Although the university is served by several lines, these are concentrated in the area closest to the highway. These gaps are predominantly located in TZs positioned in areas less favorably situated in relation to the highway, with connections to other regions of the city limited to the existing urban crossing points (overpasses or pedestrian walkways) on the PR-445 highway.

Another important piece of information present in the map in Figure 4 relates to the density of the bus lines. This data was obtained using a tool that calculates the density of the lines according to their routes. An additional weight corresponding to the daily frequency of each of these lines on a typical day was added, with their density also weighted by this information. The map shows that near the bus terminals, the darker areas represent regions with a higher accumulation of routes and their frequencies, which explains the black tones. This visual characteristic can also be observed along important road axes in the study area, such as the PR-445 highway itself and some roads that connect with the existing crossing devices.

In summary, the regions with the highest densities correspond to the bus transit routes located near the crossing points, especially where these are closer to each other. In the section of the highway bordering the TZs Vivendas and Esperança, this is enhanced by the presence of important interconnections with the highway, the location of a bus terminal, and a shopping center, which are points of travel attraction. A similar process occurred in the case of TZ Cafezal 1, which, despite not having a shopping center nearby, benefits from the short distance between three urban crossings. This has improved the connections for this TZ and concentrated the bus route itineraries serving this area.

Another high-density area that also deserves attention is the section of the PR-445 highway bordering the TZs Universidade and Champagnat. This can be explained by the presence of a major traffic generator, the State University of Londrina (UEL), along with important connections between both sides of the highway and consequently between these TZs and other regions of the city.

In contrast to the previously mentioned regions, the TZ Saltinho, located in the southern part of the study area, exhibits very light gray tones that are almost imperceptible. This indicates a low density of bus lines and frequency, suggesting a lower quality of public transportation service in this area. This region includes the Conjunto Hab. Jamile Dequed neighborhood, situated at the southern end of the TZ, with only one option for crossing the highway. It is served by only two urban bus lines, both connecting it to the Acapulco Terminal in the TZ Cafezal 1. This means that residents, when traveling to other regions of Londrina that generate employment and concentrate commercial and service activities, will likely need to transfer. Such a situation results in longer travel and waiting times, consequently increasing the total travel time.

The barrier effect caused by the highway, combined with the greater distance and poor road connectivity of this neighborhood, confirms the idea that the population's access to urban services is compromised. This is because they face greater difficulties in making daily trips, especially those who depend on public bus transportation services. This could be a factor explaining why a large portion of the trips generated by these residents are made on foot, characterized by shorter and quicker routes within the neighborhood itself. Additionally, the

lower average household incomes and the low number of motorized vehicles per household also contribute to these adverse conditions regarding mobility and accessibility.

## **5 CONCLUSIONS**

From the analysis of the heat map, it was concluded that the TZ with the strongest travel generation are located in the vicinity of road sections with closer crossings, and are even composed of populations with higher average household incomes and their percentage of trips by car estimated at 70% of the total. These trips stem from the difficulties that the local population encounters in making their journeys by other modes, such as walking, cycling, and public bus transport. In this way, residents of the region attempt to alleviate the negative impacts that the presence of a highway can cause on their travels, as well as the lack of crossing opportunities exacerbates adverse accessibility conditions.

Based on the opportunities for crossings along the analyzed highway section, it is evident that more crossings generate more trips according to the average household income of each TZ. Thus, in TZs with high average household incomes, there is a predominance of motorized individual trips. On the other hand, in TZs with lower average incomes, there is a predominance of non-motorized trips on foot and trips made by public transport.

On the other hand, in the case of a TZ located in the southern region of the study area, where there are few crossing options across the highway, leaving it more isolated in relation to other regions of the city, the trip generation was lower. Even when compared to other TZs with similar population and income and the same position in relation to PR-445 highway. In these areas, the generated trips predominantly involved non-motorized modes, mainly walking, and possibly shorter trips.

There is evidence that in TZs with higher average household incomes, their populations make more trips per day on average, all of which are located in the stretch of the highway with more crossing opportunities. It is also in these areas that the use of the car as a daily mode of transportation is very high (above 70%), which justifies the fact that this population, which has better economic conditions to acquire motorized vehicles, produces more trips per day per person than the other TZs in the study area. On the other hand, the TZs with lower income, especially those located in less connected regions with fewer crossing opportunities, have, in addition to lower averages of trips per person per day, a higher participation of non-motorized and collective modes in the trips made.

The TZs with more motorized vehicles per household coincided with those with higher average incomes and are bordered by the stretch of the highway with the highest concentrations of crossings. On the other hand, the TZs with lower numbers of motorized vehicles per household and income are located in areas with few crossings over the highway. In the TZs positioned in a way that they are affected by the barrier effect caused by the highway, it was observed that even in areas with lower incomes, the average number of motorized vehicles per household was slightly higher than in TZs with similar economic conditions but located on the opposite side.

These characteristics suggest a pursuit of improvements in mobility and accessibility for this population, who allocate portions of their income to the purchase of motorcycles or

automobiles. In these areas, besides the barrier effect caused by the highway, bus line frequencies are generally scarcer, and there are significant distances to the central areas of the city.

The most isolated areas due to the highway and the limited crossing options are also among those least served by public bus transportation. In the southern region of the research area, where there are fewer crossing opportunities, there are few bus lines serving the area, and their frequency is low compared to other TZs. This further reinforces the idea of isolation in these areas due to the limited connections between the highway banks, resulting in the need for longer routes, increasing the time and distance of these trips. Another important factor is that these are the areas where the population most needs public transportation services, mainly due to their more unfavorable socioeconomic characteristics and the long distances from areas with potential for attracting trips from the city.

In this research, it was possible to conclude that TZs in unfavorable positions relative to the highway are, to some extent, negatively impacted by its presence in terms of accessibility and mobility. However, the greatest impacts tend to occur on populations with lower average incomes, which are generally located in more distant areas with few crossing opportunities. In these cases, transportation costs are possibly more significant relative to the income of these families, who, due to their impaired accessibility and mobility conditions, tend to generate fewer trips, with a higher proportion of their journeys made on foot or by bus, which often proves inadequate in these areas. In pursuit of improvements in these factors, many of these families commit a significant portion of their incomes to acquiring motorized vehicles, which can improve their mobility conditions. In more extreme cases, trips may be suppressed and opportunities lost due to these greater difficulties.

Despite the highway causing a barrier effect on mobility and accessibility conditions for affected individuals, this should not be the only factor to be considered. The implementation of crossings closer to each other will contribute to shorter trips, less extensive bus routes, and even greater connectivity of these neighborhoods with the main urban network. However, more rational land use and zoning policies, the occupation of existing urban voids, transit-oriented urban development, and other urban planning tools need to be promoted so that both uncontrolled urban expansion and the layout of highways too close to urban areas can be mitigated.

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