UNIVERSITY OF SÃO PAULO

SÃO CARLOS SCHOOL OF ENGINEERING

DANIELA VANESSA RODRIGUEZ LARA

Community severance and vertical equity assessment with spatially aggregated data

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I dedicate this dissertation to my beloved
parents and sisters who have always supported
me in everything.

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“You cannot hope to build a better world without improving the individual. To that end every person must work for his own improvement, and at the same time he must share a general responsibility for all humanity (…)”

(Curie, 1922, p.5).

ABSTRACT

LARA, D. V. R. (2019). *Community severance and vertical equity assessment with spatially aggregated data*. Thesis (Master). São Carlos School of Engineering, University of São Paulo, São Carlos, 2019.

Transport related urban barriers are often a consequence of the unplanned expansion of transport infrastructures (railways, freeways, roadways and urban streets), housing growth around those infrastructures, and the vehicular traffic itself. This process, also known as "community severance", is a problem that mainly affects vulnerable social groups (the elderly, young children and the physically disabled), and impairs active trips. For this reason, we propose a simple and low-cost analytical approach for the assessment of community severance based on a classification of the quality of pedestrian crossings on two different types of transport infrastructures, railways and urban streets. Furthermore, the approach identifies possible inequities regarding spatially aggregated demographic data in the surroundings of the distinct classification groups. The method for both transport barriers is similar, however, due to their different characteristics, there are specific procedures for each. In general, the analysis procedures that comprise the method, for both transport infrastructures, include: data collection, characterization of the transport barrier through the evaluation of a set of criteria, classification of the quality of pedestrian crossings, statistical analysis and vertical equity analysis. In addition, we presented two case studies in order to illustrate the method. The case studies comprise a railway and urban streets located in the urban region of the city of São Carlos, which is a medium-sized Brazilian city. Results indicated evidence of association between the variables. In addition, the study showed evidence that the residents nearby the railway and the urban streets that have a low income or are aged up to 19 years old are poorly assisted in relation to pedestrian urban mobility. Hence, even with the limitation of the aggregated data, the research indicates that the assessment of community severance by the analysis of the quality of pedestrian crossings in both railways and urban streets is feasible. Moreover, it also highlights that the distribution of the number of residents surrounding the distinct classes of quality of crossings regarding the railway and urban streets are vertically equitable for vulnerable social groups, except for low-income residents and aged up to 19 years old.

Keywords: Community severance. Transport barriers. Pedestrian crossings. Equity. Geographic Information System - GIS. Census data.

RESUMO

LARA, D. V. R. (2019). *Avaliação do efeito barreira e da equidade vertical por meio de dados agregados espacialmente.* Dissertação (Mestrado). Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2019.

Barreiras urbanas relacionadas com transportes são muitas vezes uma consequência: da expansão não planejada de infraestruturas de transporte (ferrovias, vias expressas, rodovias e ruas urbanas), do crescimento de moradias no entorno dessas infraestruturas e do próprio tráfego de veículos. Esse processo, também conhecido como "efeito barreira", é um problema que afeta principalmente grupos sociais vulneráveis (idosos, crianças pequenas e deficientes físicos), e prejudica os deslocamentos ativos. Por este motivo, uma abordagem analítica simples e de baixo custo é proposta para a avaliação do efeito barreira a partir da classificação da qualidade de travessias de pedestres em dois tipos diferentes de infraestruturas de transporte, ferrovias e vias urbanas. Ademais, a abordagem identifica possíveis iniquidades em relação aos dados demográficos agregados espacialmente no entorno dos distintos grupos de classificação. O método para ambas as barreiras de transporte é semelhante, no entanto, devido às suas diferentes características, existem procedimentos específicos para cada. Em geral, os procedimentos de análise que compõem o método, para ambas as infraestruturas de transporte, incluem: coleta de dados, caracterização da barreira de transporte através da avaliação de um conjunto de critérios, classificação da qualidade das travessias de pedestres, análise estatística e análise da equidade vertical. Além disso, dois estudos de caso são apresentados para ilustrar o método. Os estudos de caso compreendem uma ferrovia e vias urbanas localizadas na região urbana da cidade de São Carlos (cidade brasileira de médio porte). Os resultados indicaram evidências de associação entre as variáveis. Adicionalmente, o estudo mostrou evidências de que os moradores próximos à ferrovia e às vias urbanas que possuem baixa renda ou até 19 anos são mal assistidos em relação à mobilidade urbana para pedestres. Portanto, mesmo com a limitação dos dados agregados, a pesquisa indica que a avaliação do efeito barreira a partir análise da qualidade das travessias de pedestres tanto em ferrovias quanto em vias urbanas é viável. Além disso, destaca também que a distribuição do número de moradores ao redor das distintas classes de qualidade de travessias referentes à ferrovia e às vias urbanas é verticalmente equitativa para grupos sociais vulneráveis, com exceção dos moradores de baixa renda e com idade até 19 anos.

Palavras-chave: Efeito barreira. Barreiras de transportes. Travessias de pedestres. Equidade. Sistema de Informação Geográfica - SIG. Dados censitários.

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1 INTRODUCTION

According to Vasconcellos (2016), an intense and fast urbanization process results in larger urban areas, more trips and longer distances traveled, particularly for those living far from the central area. With longer distances, the dependence on trips by motorized vehicles increases, as well as the need of transport infrastructures to meet the growing demand. This process not only affects the travel patterns of the population, but also negatively impacts different city functions (e.g. land uses, real estate development, etc.) and creates barriers to adjacent communities.

Urban barriers are often a consequence of the unplanned expansion of transport infrastructures (railways, freeways, roadways and urban streets), housing growth around those infrastructures, and the vehicular traffic itself. This process, also known as “community severance”, is a problem that mainly affects vulnerable social groups (the elderly, young children and the physically disabled). It also negatively affects cycling and walking trips. Moreover, it has increasingly attracted the attention of urban and transport planners, in part because of the growing need to replace the use of motorized vehicles with active transport, especially in large urbanized areas. Additionally, the social impact of transport is also a growing area of concern and it can no longer be measured simply in terms of its performance but as an enabler or barrier to improving quality of life (Woodcock, 2018).

Community severance is formally defined as a physical impedance to walking trips (Soguel, 1995; Guo, Black, & Dunne, 2001; Mouette & Waisman, 2004; Anciaes, Boniface, Dhanani, Mindell, & Groce, 2016) and to the access to goods, services and people (Scholes, Boniface, Stockton, & Mindell, 2016; Mindell et al., 2017) due to transport infrastructures, traffic streams and speeds (Guo et al., 2001; Anciaes, 2015; Anciaes et al., 2016; Scholes et al., 2016). In addition, community severance is related to psychological barriers separating local communities (Taylor & Crawford, 2009; Scholes et al., 2016), affecting perceptions, behavior, stress (Appleyard & Lintell, 1972; Hine & Russell, 1993; Hart & Parkhurst, 2011), safety perceptions (Hine, 1996; Davis & Jones, 1997; Timperio et al., 2006; Hart & Parkhurst, 2011), wellbeing (Timperio et al., 2006; Scholes et al., 2016; Foley et al., 2017; Nimegeer et al., 2018; Anciaes, Stockton, Ortegon, & Scholes, 2019), health (Timperio et al., 2006; Mackett & Thoreau, 2015; Scholes et al., 2016; Foley et al., 2017; Nimegeer et al., 2018), social interactions (Appleyard & Lintell, 1972; Davis & Jones, 1997; Hart & Parkhurst, 2011; Scholes et al., 2016; Nimegeer et al., 2018) and intensifying social exclusion (Rajé, 2004; Mackett &

Thoreau, 2015) of people who live or use the surrounding areas or need to make trips along or across that infrastructure or traffic stream (Anciaes, 2015).

Therefore, community severance is a complex and interdisciplinary issue that causes negative impacts to society and transport systems. However, urban and transport planners still have difficulties to understand the variations of community severance caused by distinct transport infrastructures.

1.1 Justification of the study

Community severance has been studied since the 1960s and has already been integrated into the mobility guidelines of some countries. In Brazil, however, the Urban Mobility Plan (or *PlanMob*, which in Portuguese stands for *Plano de Mobilidade Urbana*) proposed by the Ministry of Cities more than a decade ago (Ministry of Cities, 2007), does not approach the impacts of community severance on pedestrians' mobility and on communities' social exclusion.

In addition, given the different types and characteristics of transport infrastructures, the intensity and variability of community severance can be substantially high. Accessible and safe pedestrian crossings, for example, can contribute to reducing the impacts of community severance on walking trips because they regulate the preference of passage of motorized and non-motorized traffic. Regarding road infrastructures, impacts can be high in the case of freeways, and from moderate to low in the case of urban streets with pedestrian crossings, with high variability along any single element of infrastructure. For transport infrastructures with a clear physical segregation (e.g. rivers and railways), the impact can be large and the variability small.

Railways in urban areas are also a cause of community severance, given that the passage of motorized vehicles, pedestrians and cyclists is only possible in the specific points where there are railroad crossings. However, relatively few studies have been conducted on railways (e.g. Sousa, Sousa & Braga 2009; Taylor & Crawford, 2009; Chang, Han, Jung & Kim, 2014; Lee & Sohn, 2014; Lara & Rodrigues da Silva, 2018) whereas there are considerably more studies on urban streets (e.g. Appleyard & Lintell, 1972; Soguel, 1995; Hine, 1996; Mouette et al., 2000; Guo et al., 2001; Mouette & Waisman, 2004; Silva Jr & Ferreira, 2008; Hart & Parkhurst, 2011; Cantillo et al., 2015; Mindell et al., 2017).

Urban and transport planners are also concerned about inequalities in the distribution of different social groups around transport infrastructures, the quality of these transport infrastructures and the exposure to transport-related externalities. Litman (2002) presented two categories of equity: horizontal and vertical. Horizontal equity involves the distribution of resources equally to each individual or group, whereas vertical equity implies in the distribution of resources according to each individual or group special needs, in order to ensure that their situation are not made worse off, and that their needs are accommodated. In this study, we used the vertical equity concept.

In summary, community severance may affect the daily activities and the behavior of people of distinct demographic characteristics and at different levels. The analysis of this interdisciplinary effect involves many variables and tools, which sometimes demands qualified and well-trained professionals (e.g. for specific data collection procedures), commitment from the target population, costly technologies and restricted-access data. The development of simple and efficient methods can help to predict and assess actions and policies to minimize community severance impacts. For this reason, we proposed a combination of census data, open access data and free *Geographic Information System* software, which may save time, effort and financial resources, into a single approach for the analysis of equity issues related to community severance.

The proposed approach can help to answer the following questions: Is it possible to assess community severance by analyzing the quality of pedestrian crossings? Is there evidence of association between the distribution of residents with distinct demographic characteristics around urban barriers and the quality of pedestrian crossings? Is the residents' distribution vertically equitable?

1.2 Purposes of the study

The main objective of this study is to develop a simple and low-cost analytical approach to assess community severance based on a classification of the quality of pedestrian crossings on two different types of transport infrastructures, a railway and a sample of urban streets, and to apply it in a Brazilian medium-sized city.

Furthermore, secondary objectives include: (i) constructing an index capable of estimating the quality of pedestrian crossings on urban streets, and (ii) identifying possible inequities regarding demographic data (income, permanent mobility constraints, gender and age) in the surroundings of the distinct classes of quality of pedestrian crossings for both infrastructures.

1.3 Document structure

The present thesis was divided into seven chapters. The first chapter comprises a brief introduction and contextualization of the problem approached, as well as the justification and the objectives of the research. Subsequently, in Chapter 2, we present the state-of-the-art on community severance with a focus on the concept evolution, study approaches and findings. This Chapter also covers pedestrian preferences for crossing facilities, the functional classification of urban roads and concepts of equity.

Chapter 3 describes the necessary data and the method proposed for assessing community severance caused by two transport barriers, i.e. a railway and urban streets. The presentation of the case studies used to illustrate the method are indicated in Chapter 4.

In Chapter 5, we present and discuss the results obtained from the assessment of community severance and, in Chapter 6, the conclusions are drawn. Finally, in Chapter 7, recommendations for future work are indicated.

2 LITERATURE REVIEW

This Chapter presents, in four Sections, an overview of the literature on the main concepts and findings used to develop this research. The first Section describes a brief background on community severance, focusing on the concepts of definition, approach and impacts. The second Section covers pedestrian preferences for crossing facilities. In the third Section, the functional classification of urban roads is addressed, while the fourth Section presents concepts of equity.

2.1 Community severance

This Section presents a literature review on community severance divided into the following topics: the evolution of the concept since 1960, when the topic became well-known; approaches commonly used in the characterization of transport barriers and community severance and impacts on the most affected social groups.

2.1.1 The concept of community severance

The concept of community severance has undergone changes according to the progress of research in the different fields of knowledge. Based on the synthesis presented in Table 2.1, we propose the following definition of community severance:

Community severance is characterized by physical and psychological barriers that cause impedances to pedestrian movements (limiting the access to goods, services and people) and affects pedestrian networks (with impacts on connectivity, permeability and accessibility of pedestrian pathways); inhibits social interactions; interferes negatively on the behavior, perception, wellbeing, mental and physical health of people who live or use the surrounding areas and separates local communities due to transport infrastructures, traffic streams and speeds.

Table 2.1 - Changes in the *community severance* concept over time

Concept	Author	Country
Undesirable **division of an area** of closely inter-related uses by a road carrying a **heavy traffic flow**	UK MOT (1963)	United Kingdom
Effect of **traffic stream** on the environmental (**concern for safety, stress**, noise and pollution) and social (**social interactions and street activity**) quality of streets	Appleyard and Lintell (1972)	USA
Effects of traffic conditions (**speed and flow**) upon **pedestrian movement**, **crossing behavior and perception of the street** (trip change or suppression)	Hine and Russell (1993)	United Kingdom
Nuisances caused to both movement function and social function (playing and strolling) of the **pedestrian network**	Soguel (1995)	Switzerland
Problems caused to **pedestrian movement** due to *static severance* and *dynamic severance*. Static severance is caused by the introduction of a **new highway** with access control and high embankments where there are existing patterns of social interaction. Dynamic severance is caused by **vehicular traffic** on **urban streets** and imposes problems for pedestrian movement	Guo et al. (2001)	Australia
Restrictions or inhibitions on the free **pedestrian movement** between the two sides of the road caused by the **traffic stream** and by the **road infrastructure** itself	Mouette and Waisman (2004)	Brazil
Restrictions on walking and on proper use of city spaces by the residents of urban areas that are sectioned by **highways**	Silva Jr. and Ferreira (2008)	Brazil
Behavior and perception of residents about the impacts of **motor traffic** on their **homes and streets**, and on individual and community **mental and physical health**	Hart and Parkhurst (2011)	United Kingdom
Variable and cumulative **negative impact** of the presence of **transport infrastructure or motorized traffic** on the **perceptions, behavior, and wellbeing** of people who use the surrounding areas or need to make **trips along or across that infrastructure or traffic stream**	Anciaes (2015)	United Kingdom
The ‘barrier-effect’ of the **speed or the volume of traffic**, or other **transport infrastructure**, on **access to goods, services and people**, which can represent **physical and psychological barriers separating local communities**	Scholes et al. (2016)	United Kingdom
Continuum stemming from the presence of **transport infrastructure** or **motorized traffic** and including chain of effects at the individual or community level, which acts as a **physical or psychological barrier** to the **movement of pedestrians**. In addition, it is related not only to the physical characteristics of the road (such as traffic volume, speed, and composition) but also to the **perceptions of people** living near the road	Anciaes et al. (2016)	United Kingdom

Source: The author

2.1.2 Transport infrastructures as barriers and the community severance approach

Diverse transport infrastructures and their motorized traffic stream act as urban barriers to active trips. This is a problem that has increasingly attracted the attention of urban and transport planners, in part because of the growing need to replace the use of motorized transport with active transport, especially in main urban centers.

Community severance caused by railways in urban areas remarkably segregates communities, inhibits social interactions and hampers the free crossing between both sides of the railway. That is because railways in urban areas are demanded to have physical barriers throughout their entire way, in order to avoid accidents. Thus, the passage of motorized vehicles, pedestrians and cyclists is only eligible where there are railroad crossings. Although railways comprise a notable case of community severance there are still relatively few studies focusing on them (e.g. Sousa, Sousa & Braga, 2009; Taylor & Crawford, 2009; Chang, Han, Jung & Kim, 2014; Lee & Sohn, 2014; Lara & Rodrigues da Silva, 2018).

On the other hand, road infrastructures are part of the urban space and are present in the daily lives of pedestrians. However, the community severance caused by road infrastructures is more difficult to characterize than in the case of railways, given that pedestrians can eventually reach the other side of the road. In other words, depending on the traffic stream volume and road characteristics, pedestrians can cross either on crossing facilities (formal passage) or between car gaps (informal passage). There are considerably more studies on urban streets (e.g. Appleyard & Lintell, 1972; Soguel, 1995; Hine, 1996; Mouette et al., 2000; Guo et al., 2001; Mouette & Waisman, 2004; Silva Jr & Ferreira, 2008; Hart & Parkhurst, 2011; Cantillo et al., 2015; Mindell et al., 2017) than studies on railways.

The data collection instruments and analytical tools commonly used in community severance studies include questionnaires (Davis & Jones, 1997; Mouette, Aidar, & Waisman, 2000; Mouette & Waisman, 2004; Timperio et al., 2006; Scholes et al., 2016; Foley et al., 2017; Mindell et al., 2017; Anciaes et al., 2019), interviews (Soguel, 1995; Hine, 1996; Silva Jr & Ferreira, 2008; Hart & Parkhurst, 2011; Cantillo, Arellana, & Rolong, 2015; Nimegeer et al., 2018), workshops (Taylor & Crawford, 2009; Anciaes et al., 2016), focus groups (Cantillo et al., 2015; Mindell et al., 2017), open data (Mouette & Waisman, 2004; Lee & Sohn, 2014; Lara & Rodrigues da Silva, 2018), empirical data collection (Guo et al., 2001; Mouette & Waisman, 2004; Mindell et al., 2017; Lara & Rodrigues da Silva, 2018; Anciaes et al., 2019), video surveys (Hine, 1996; Mindell et al., 2017; Anciaes et al., 2019), participatory mapping, interdisciplinary analysis (Mindell et al., 2017), spatial analysis (Mindell et al., 2017; Lara & Rodrigues da Silva, 2018; Anciaes et al., 2019) and equity analysis (Litman, 2002; Jang, An, Yi, & Lee, 2017; Lara & Rodrigues da Silva, 2018; Pereira, 2018).

Table 2.2 - Synthesis of approaches used for the study of community severance (continued)

Approach	Author	Country
The report identifies **perceptions** of those who live around city **streets** in San Francisco about the effects of traffic on the **environmental and social quality** of these streets using observation and open response **interview** techniques	Appleyard and Lintell (1972)	USA
The study proposes a contingent valuation survey to predict the bids to infer the annual cost (**willingness to pay**) of removing the community severance caused by a **road** around the city center of Neuchâtel, Switzerland	Soguel (1995)	Switzerland
The paper identifies the role that qualitative techniques (**in-depth interviews, questionnaires and video recordings**) can play in assessing the impact of traffic conditions on pedestrian **behavior and perceptions of safety** on selected high-density, radial mixed-use **streets** in Edinburgh	Hine (1996)	United Kingdom
The study portrays the **changes in the concept** of community severance over time, and defines static and dynamic severance. It proposes a new **model of pedestrian delay** incorporating the bunched characteristics of urban traffic flow caused by traffic signalisation. The model validation was performed through **field measurements** conducted in Sydney	Guo et al. (2001)	Australia
The research proposes a **systemic model** considering influence elements, causative elements and impacts of community severance. The model validation is performed through a **field survey**	Mouette and Waisman (2004)	Brazil
The study proposes the determination of the **degree of variables importance** for characterizing community severance impacts through **questionnaires** (with Likert scale) that evaluate the perceptions of residents nearby an **expressway** in the city of Uberlândia, Brazil	Silva Jr. and Ferreira (2008)	Brazil
The study addresses the **intra-urban structure**, community severance and dynamics of mobility and accessibility in the city of Rio Claro, Brazil, based on the **urban design** (zoning and land use) of city districts	Sousa et al. (2009)	Brazil
The study estimates the benefits (cost savings by the project or by the **willingness** of the public **to pay** for the changes) of **rerouting a railway line as underground tunnels** in Seoul, Korea	Chang et al. (2014)	Korea
The study proposes a **broad definition** for community severance based on the analysis of an extensive collection of definitions found in the literature and on discussions held as part of the "Street Mobility and Network Accessibility" research project	Anciaes (2015)	United Kingdom
The study proposes a **model of pedestrian behavior** and **choice preference crossings** (crossing directly, crossing by using a pedestrian bridge or using a crosswalk at a signalized intersection) on a **street** intersection in Bogota, Colombia, through a **stated preference survey** designed with the help of a **focus group** and **expert opinions**	Cantillo et al. (2015)	Colômbia
The research proposes the **integration** between the different disciplines working separately in the development of **policy solutions** by means of a **cross-disciplinary research** on community severance, built on the reflections obtained in **workshops** attended by local authorities, non-governmental organizations, and consultants	Anciaes et al. (2016)	United Kingdom
The working paper describes a survey **questionnaire** component of the toolkit designed to measure community severance and assess its potential associations with transport and health in two contrasting **roads** in inner London	Scholes et al. (2016)	United Kingdom
The research recommends guidelines for the consolidation of the wide variety of methods found in the literature into a consistent **framework for the integration of severance** at three stages of transport planning: problem identification, option generation, and option appraisal	Anciaes, Jones and Mindell (2016)	United Kingdom

Table 2.2 - Synthesis of approaches used for the study of community severance (conclusion)

The study conducts a **stated preference survey** in the areas surrounding two busy **roads** in the United Kingdom. The survey considers people's preferences regarding **crossing roads** (informally, walking further and crossing where the road is covered over, or avoid crossing altogether) with different characteristics (number of lanes, presence of a median strip, traffic density, and traffic speeds)	Anciaes, Jones and Mindell (2017)	United Kingdom
The study developed an **interdisciplinary suite of tools** to measure and value community severance based on: **participatory mapping, spatial analysis, a video survey, street audits, a health and neighborhood mobility survey, and a stated preference survey**, undertaken as part of the "Street Mobility and Network Accessibility" research project	Mindell et al. (2017)	United Kingdom
The report provides information and guidelines for the development of sustainable integrated transport measures. The distributional impacts caused by transport (noise, air quality, accidents, community severance, security, accessibility and personal affordability) are analyzed regarding their effects on individual social groups, and between the different social groups.	Woodcock (2018)	United Kingdom

Source: The author

2.1.3 Impacts of community severance

The main affected population groups identified in the literature correspond to the elderly, children (Hine, 1996; Mouette & Waisman, 2004), residents who have a long-standing illness (Scholes et al., 2016; Foley et al., 2017), adults who need to accompany another individual with restricted mobility (Mouette & Waisman, 2004), people who have great difficulty or some difficulty in walking or climbing stairs and a particular lower income group (Lara & Rodrigues da Silva, 2018). As community severance mainly affects vulnerable groups (the elderly, very young children and the physically disabled), it is reasonable to consider an area of influence compatible with the walking distances of those groups' conditions in order to analyze the community severance effect caused by specific transport infrastructures.

Walking distances should encompass suitable distances to be covered by most people, especially vulnerable groups, which cannot walk long distances and for long periods. In this respect, the urban design concept proposed by Burton and Mitchell (2006) highlights the importance of considering people's physical constraints when defining walking distances. However, studies about community severance do not seem to have a consensus about walking distances, ranging around 300 and 800 meters. Anciaes et al. (2019) defined a walking distance of 400 meters from busy roads. Rosenlieb, McAndrews, Marshall and Troy (2018) used a 300-meter bandwidth to represent the varying intensity of exposure to traffic with distance and another study by Anciaes (2013) used threshold values of 500 and 800 meters. In addition, Pereira (2018) used catchment area analysis to estimate the number of people from different income groups who can reach relevant locations from their homes within a certain travel time threshold (15, 30, 60 and 90 minutes) using only public transport and walking.

The impacts of community severance are related to trip diversion and suppression (Hine, 1996; Guo et al., 2001; Silva Jr & Ferreira, 2008), poor accessibility and restricted personal mobility in the affected neighborhoods (Guo et al., 2001), affecting pedestrians not only when they cross roads but also when they walk along them (Silva Jr. & Ferreira, 2008; Anciaes et al., 2016; Scholes et al., 2016).

In relation to railways, the impacts on community cohesion due to grade railway crossings could be positive or negative, since lowering the railway reduces community severance by making surface movement easier for pedestrians, cyclists and drivers and in locations where a road overpass has been built. However, community severance may be worsened due to the intrusion of the elevated structure and its approaches (Taylor & Crawford, 2009). In addition, railway grade crossings affect the accessibility of pedestrians with disabilities or wheelchair users, generally due to rough surfaces and physical obstructions causing travel delay (McPherson & Daff, 2005).

Furthermore, the community severance caused by different types of transport infrastructures affects the perceptions, behavior, stress (Appleyard & Lintell, 1972; Hine & Russell, 1993; Hart & Parkhurst, 2011), safety perceptions (Hine, 1996; Davis & Jones, 1997; Timperio et al., 2006; Hart & Parkhurst, 2011), wellbeing (Timperio et al., 2006; Scholes et al., 2016; Foley et al., 2017; Nimegeer et al., 2018; Anciaes, Stockton, Ortegon, & Scholes, 2019), health (Timperio et al., 2006; Mackett & Thoreau, 2015; Scholes et al., 2016; Foley et al., 2017; Nimegeer et al., 2018), social interactions (Appleyard & Lintell, 1972; Davis & Jones, 1997; Hart & Parkhurst, 2011; Scholes et al., 2016; Nimegeer et al., 2018) and intensifies social exclusion (Rajé, 2004; Mackett & Thoreau, 2015) of people who live or use the surrounding areas or need to make trips along or across that infrastructure or traffic stream (Anciaes, 2015).

According to Anciaes, Jones and Metcalfe (2018), the economic value of negative impacts on transport systems are relevant for decisions about pricing policies and investment in transport system. Under this direction, Anciaes, Jones and Mindell (2016), proposed guidelines for the consolidation of the wide variety of methods found in the literature into a consistent framework to identify and monetarize the effects of severance on communities, people's wellbeing and behavior.

2.2 Pedestrians and crossing facilities

Crossing facilities in transport infrastructures have the function of ensuring users' (pedestrians, cyclists and drivers) right of way safely. However, they do not always benefit pedestrian movements. Due to the type of crossing facility, its conservation status and location, on-site public lighting, among other factors, there may be pedestrian delays, risks of trampling, robbery or violence. In this case, the crossing comprises a physical and psychological barrier, which can also cause walking trip diversion or suppression. According to Hine and Russell (1993) there is a trade-off between pedestrian mobility and safety which is of direct relevance to the implementation of traffic calming schemes on more heavily trafficked roads.

Based on the guidelines from the National Department of Transport Infrastructure - in Portuguese: *DNIT - Departamento Nacional de Infraestrutura de Transportes* - (DNIT, 2010), pedestrians prefer level crossings and avoid underground passages and footbridges, even though they are well designed and safe. The guidelines also suggest that preferences are due to deviations caused to their natural paths, often increasing travel times, travel distances, and energy expenditures. In addition, underground passages are potential areas of crime, which reduce their use.

Additionally, according to the study conducted by Mindell et al. (2017), crossing is risky and unpleasant due to the exposure of pedestrians to moving traffic, even though there are no physical barriers preventing pedestrians from crossing (such as guard railings, fences, or walls). In general, the presence of a median strip aids pedestrians crossing the road, by splitting the crossing into two stages. However, in many cases, median strips can become an additional barrier, if they have steps or uneven surfaces, making them inaccessible to people with mobility restrictions. Even narrow roads can become barriers to the movement of pedestrians, if they have high traffic densities or speeds, reducing the ability of pedestrians to cross and walk along the road. The study results indicated that participants prefer to avoid crossing roads with no crossing facilities. In addition, the level of the barrier effect of roads on pedestrians was positively related with the road characteristics (number of lanes, traffic density and traffic speed) and the presence of a median strip decreased the barrier effect.

The results from Sisiopiku and Akin's (2003) study support the notion that properly designed and placed pedestrian facilities encourage users to cross at safer proposed locations. Despite the presence of signalized intersections with crosswalks, pedestrians still do not comply with the signal indication (particularly under low traffic demand conditions). Convenience and distance of the crosswalk were also pointed out as important factors for crossing at a designated crossing location.

The findings in the research conducted by Cantillo et al. (2015) suggested that: pedestrians are more prone to using the alternative route involving less walking distance (crossing directly), pedestrian bridges were identified as non-effective crossings, and the probability for pedestrians to choose safer alternatives for crossing diminished with large distances. Furthermore, when traffic flow is high and delay increases, the propensity for direct crossings decreased.

The study developed by Hine (1996) indicated that the elderly, particularly those with health-related mobility constraints, and children were identified as more likely to cross using crossing facilities. In addition, Lee and Sohn (2014) concluded that the land price of areas along at-grade or elevated railways are much less than the areas along underground railways.

2.3 Functional classification of urban roads

The functional classification suggested by DNIT (2010) is based on the process in which roads are hierarchically grouped into subsystems, according to the type of service they offer and the function they carry out within the road system in the traffic flow. Functional classification is usually established according to the mobility (ease of travel) and the accessibility (facility that a road provides to connect the origin of a trip to its destination) that are enabled. Thus, urban roads are classified into four basic systems:

- Primary arterial system: this includes roads that serve mostly direct traffic, usually in continuous routes, but do not have the technical characteristics of an expressway. The system provides a high degree of mobility for longer trips, offering high operating speeds and service levels.
- Secondary arterial system: this includes urban roads that interconnect to the primary arterial system and supplement it, attending travel routes at a service level lower than that provided by the primary arterial roads. This system serves trips with a lower mobility degree and distributes the traffic through smaller areas than the primary system. It provides direct access to properties and the roads can accommodate local bus lines, providing continuity between communities, although avoiding entering these communities.
- Collector system: connects local streets with arterial roads, providing continuity at the level of local communities or urban subdivisions, but at low speeds. It

differs from the arterial system, because the roads from the collector system can penetrate in the residential neighborhoods, distributing the traffic of the arterial roads, through the area, to their final destinations.

- Local system: enables the access to properties that are adjacent to higher order systems, offers the lowest level of mobility and usually does not contain bus routes.

Table 2.3 - Desirable road characteristics from each functional classification

Project and control characteristics	Primary arterial system	Secondary arterial System	Collector System	Local system
Traffic control at intersections	Traffic lights, "Stop" signs on secondary roads	Traffic lights, "Stop" signs on secondary roads	Traffic lights, "Stop" signs on secondary roads	"Stop" signs
Access to adjacent properties	Restricted	Restricted or free	Free	Free
Pedestrian crossings	Different levels or zebra crossing	Different levels or zebra crossing	Zebra crossing	Free
Median	Where possible	Generally, not	No	No
Parking	Controlled	Controlled	Controlled or free	Free
Shoulder	None or parking strip	None	None	None

Source: DNIT (2010)

2.4 Equity in transportation

According to Litman (2002), the concept of equity could be divided into two categories: horizontal and vertical. Horizontal equity involves the distribution of resources equally to each individual or group, whereas vertical equity implies in the distribution of resources according to each individual's or group's special needs in order to ensure they are not worse off, and that their needs are accommodated.

In the study developed by Shirmohammadli, Louen and Vallée (2016), the necessity of mobility equity analyses in transportation systems of societies with an increasing number of non-drivers is highlighted. The study explores the horizontal and vertical mobility equity statuses of various districts and socioeconomic groups in the city of Aachen, Germany. The study indicated that the distribution of mobility between the inhabitants of different districts is overall horizontally equitable, while the vertical equity analysis shows a significant variation between different socioeconomic groups and different transportation modes.

According to Tsou, Hung and Chang (2005), spatial equity means equal spatial separation from or spatial proximity to public facilities among residents. Moreover, spatial equity is often defined and measured by the level of accessibility (Kelobonye et al., 2019).

Jang et al. (2017) developed a methodology for calculating the index of the spatial equity for the public transportation services for the city of Seoul using the Lorenz curve and Gini coefficient based on accessibility to the services. They suggest that equity in public transportation in a city is closely related with horizontal equity, which could arise from the spatial structure in terms of, for example, access to a transit node without much effort. Such equity means public transportation lines and routes are well distributed in consideration of the urban spatial structure of the city. In addition, they pointed out that generally the two types of public transportation equity are observed together in a city without any apparent linkage between them. There could be vertical inequity in a city with high horizontal equity, where the accessibility to public transportation services is good overall, if the city shows severe differences in income levels locally.

Pereira, Schwanen and Banister (2017) defined justice as a broad moral and political ideal that relates to how benefits and burdens are distributed in society (distributive justice); the fairness of processes and procedures of decision and distribution (procedural justice); and the rights and entitlements which should be recognized and enforced. In their study, they reviewed key theories of justice (utilitarianism, libertarianism, intuitionism, Rawls' egalitarianism and capability approaches) and discussed some of their insights and limitations when applied to issues of transport disadvantage, social exclusion, and accessibility. According to the authors, investments in public transport and cycling/walking can be good ways of prioritizing transport modes which are more widely used by low-income classes. To be considered fair, however, these investments should not override the social rights of families (e.g. with eviction of families due to the infrastructure projects). The distributional effects of such investments should be evaluated in terms of the extent to which they reduce inequalities in transport accessibility, particularly by improving the accessibility levels of low-income public transport-dependent groups to key destinations such as employment opportunities, healthcare, and education services. Moreover, this perspective also calls for complementary policies that discourage car use in highly congested and polluted areas to mitigate the negative externalities imposed by drivers on everyone else, particularly on vulnerable populations.

Massive transport investments during preparation for hosting sports mega-events, such as the FIFA World Cup and the Olympic Games, can substantially change the organization of urban space, making it crucial to evaluate whether local governments mobilize these events in a way that redresses or reinforces existing patterns of urban inequality and segregation (Pereira, 2018). In his study, Pereira (2018) reflects on the delimitation of transport legacies and its social impacts in terms of how mega-events in Rio de Janeiro can reshape urban accessibility to opportunities. The study found out that the changes made to the city's transport system have exacerbated socio-spatial inequalities by reducing the ability of the population, particularly of low-income transit-dependent groups, to access medium and high-complexity healthcare facilities. Therefore, the author concluded that the evaluation of mega-events' impacts and transport legacies cannot be disconnected from a critical analysis of equity, that is, a critical analysis of who benefits from such investments, as well as where and how these benefits are realized.

In a micro-scale level, Bereitschaft (2017) qualitatively assessed streetscapes environment and explored possible inequalities among neighborhoods with similar walkability (according to macro-scale indices) but with different social vulnerability. The study suggests that there are disparities at a micro-scale level and that they should be analyzed along with macro-scale elements, such as: density, connectivity, transit accessibility, and land use mix.

In addition, the study developed by Lara and Rodrigues da Silva (2018) introduces the characterization of the community severance caused by a railway in the urbanized area of a medium-sized Brazilian city. Moreover, it also investigates equity issues for residents alongside the railway and nearby the distinct types of crossings regarding the population characteristics, through chi-square tests of independence and descriptive analysis.

The analysis of the community severance caused by transport infrastructures still requires more detailed studies. However, data collection at a disaggregated level is sometimes impractical as it can demand considerable time, financial assistance and the support of qualified and well-trained professionals. In other words, the analysis of the community severance involves a complex process, in which the development of simple and low-cost methods combined with using open data and census data can assist the decision-making of urban and transport planners in order to minimize community severance impacts.

For this reason, in this study we proposed an analytical approach to assess community severance based on the classification of the quality of pedestrian crossings on two different types of transport infrastructures: railway and urban streets. The method also used the concept of vertical equity proposed by Litman in 2002 to identify possible inequities regarding demographic data in the surroundings of the distinct classes of the quality of pedestrian crossings for both transport barriers.

3 METHOD

In this Chapter, we propose an analytical approach to assess community severance based on the classification of the quality of pedestrian crossings on two different types of transport infrastructures: a railway and urban streets. The method is also used to identify possible inequities regarding demographic data in the surroundings of the distinct classes of quality of pedestrian crossings for both infrastructures.

Chapter 3 is divided into four Sections. The first Section indicates the data required by the proposed approach and where they can be obtained. The second Section describes the analysis procedures for the assessment of community severance resulting from two types of transport barriers. In the third Section, we present the statistical analysis techniques used, whereas the final Section contains a summary of the method.

3.1 Data collection

The method developed for the analysis of the community severance caused by transport barriers in a medium-sized city is described in detail in Section 3.2. In general, the analysis procedures that comprise the method, for both transport infrastructures, include: data collection, characterization and classification of transport barriers, delineation of the area of influence, estimate of the population nearby the transport barriers, statistical analysis and vertical equity analysis.

The collected data is used in the analysis procedures related to the characterization of the transport barriers and the estimate of the population nearby them. The characterization of the transport barriers is based on the evaluation of a set of criteria relevant to the particularities of each barrier (detailed in Table 3.2 and Table 3.3). On the other hand, the estimate of the population depends on the availability and level of aggregation of the variables of interest.

Concerning the railway characterization, data on pedestrian infrastructure, safety and maintenance conditions are required, whereas for urban streets characterization, data on geometric design, pedestrian infrastructures, safety, population, maintenance conditions and land use are needed. These data can be obtained by field surveys, internet searches for open data and formal requests to the City Hall or competent bodies. In Table 3.1, we provide a summary of the necessary data for the characterization of the distinct transport barriers, as well as an indication of possible data sources.

Table 3.1 - Summary of the necessary data for the characterization of transport barriers

Data	Railways	Urban streets	Source
Geometric design		x	Field survey or combined images of *Google Street View* and *Google Maps*
Pedestrian infrastructures	x	x	Field survey or combined images of *Google Street View* and *Google Maps*
Safety	x	x	City Hall or competent body
Population		x	Demographic census, questionnaires or interviews
Maintenance conditions	x	x	Field survey or combined images of *Google Street View* and *Google Maps*, City Hall or competent body
Land use		x	City Hall or competent body
Traffic volume	x	x	Field survey, City Hall or competent body

Source: The author

Population data should be as disaggregate as possible, in order to capture a more accurate and actual profile of the inhabitants. This can be obtained through questionnaires or interviews. However, due to unavailability of data, scarcity of financial resources, professional support or time, census data can also be used.

In addition, to locate the railway and create the urban street network, we recommend using open geographic information systems, such as the geographic database from *Open Street Map* or *Google Maps*.

3.2 Analysis procedures

The proposal for the assessment of community severance is based on measuring and classifying the quality of pedestrian crossings on two different types of transport barriers. Afterwards, possible inequities are identified by estimating the number of inhabitants that have particular demographic characteristics in areas close to the railway and urban streets of different classes of quality.

3.2.1 Assessment of community severance caused by a Railway

Railway infrastructures within the urban perimeter of cities comprise physical barriers to pedestrian mobility, since the physical segregation of the infrastructure is practically unavoidable, and passages are only possible in the specific points where there are railroad crossings. Therefore, we propose a concise method for the assessment of the community severance caused by a railway, with the following procedures: data collection (Subsection 3.1), characterization of the railroad crossings and segments without railroad crossings, classification, delineation of the area of influence, estimate of the population nearby the railroad crossings and segments without railroad crossings, statistical analysis and vertical equity analysis.

The characterization of the railway is performed using field surveys, in which the railroad crossings and the segments without railroad crossings are qualitatively analyzed. The field survey must be carried out by a specialist in the area of urban and transportation planning and it does not consider informal crossings.

The qualitative evaluation of the distinct types of railroad crossings and segments without railroad crossings is based on a different and appropriate set of criteria for each facility, as indicated in Table 3.2. Moreover, the criteria selection was based on the Railway Service Instructions of the National Department of Transport Infrastructure (or DNIT, which in Portuguese stands for *Departamento Nacional de Infraestrutura de Transportes*) (DNIT, 2015a, 2015b, 2015c, 2015d, 2015e).

Table 3.2 - Set of criteria assessed for the distinct types of railroad crossings and segments without railroad crossings (continued)

Criterion	Description	Category (score)
Traffic volume	number of railway compositions per hour (in the peak-hour)	low (1.00); regular (0.50); high (0.00)
Level Crossings (LC)		
Pavement conservation conditions	pavement conservation conditions of the urban street segment located within a 40-meters band from the railway line, near the level crossing	regular (1.00); irregular (0.50); nonexistent (0.00)
Rail uniformity	pavement conservation conditions between the rails of the level crossing and rail uniformity conditions	regular (1.00); irregular (0.50); nonexistent (0.00)
Lighting efficiency	lighting near the level crossing stands out from the urban street, emphasizing the existing signs and the LC	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Pedestrian walkway width[1]	a suitable pedestrian walkway width should be equal or greater than 1.50 m	suitable (1.00); unsuitable (0.50); nonexistent (0.00)
Relief conditions	influence of the relief around the railway in the view of the urban street drivers	flat (1.00); corrugated (0.50); mountainous (0.00)
Efficiency of the existing signs	the efficiency of the existing signaling in alerting pedestrians and drivers about the proximity of the LC	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Salubrity	intensity of the presence of garbage and vegetation	good (1.00); regular (0.50); poor (0.00)
Influence limit[2]	level crossing should be outside the limit of influence of other types of crossings	suitable (1.00); unsuitable (0.00)
Underpasses (UP)		
Lighting efficiency during the day	lighting efficiency during the day allows a wide field of vision	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Lighting efficiency at night	lighting efficiency at night allows a wide field of vision	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Pedestrian walkway width[1]	a suitable pedestrian walkway width should be equal or greater than 1.50 m	suitable (1.00); unsuitable (0.50); nonexistent (0.00)

Table 3.2 - Set of criteria assessed for the distinct types of railroad crossings and segments without railroad crossings (conclusion)

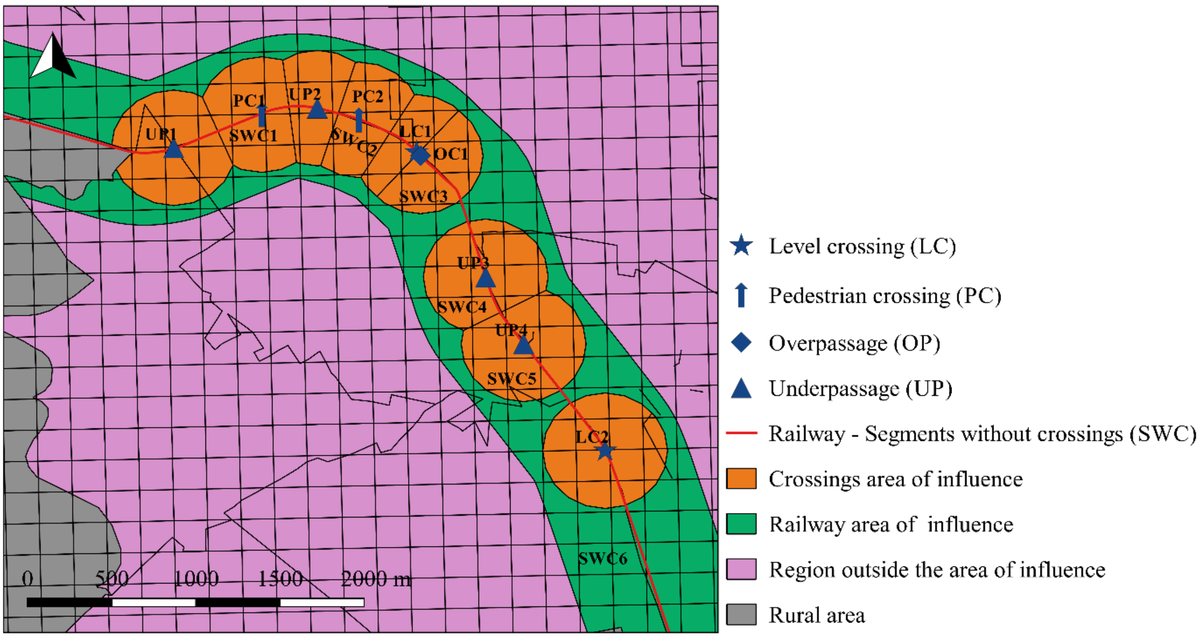
Criterion	Description	Category (score)
	Underpasses (UP)	
Height of Guardrail¹	a suitable height of guardrail should be equal or greater than 1.00 m	suitable (1.00); unsuitable (0.50); nonexistent (0.00)
Salubrity	intensity of the presence of garbage and vegetation	good (1.00); regular (0.50); poor (0.00)
	Overpasses (OP)	
Location attractiveness	the location of the railroad crossing favors the attraction of the main pedestrian flow	suitable (1.00); unsuitable (0.00)
Pedestrian walkway width¹	a suitable pedestrian walkway width should be equal or greater than 1.50 m	suitable (1.00); unsuitable (0.00)
Height of guardrail¹	a suitable height of guardrail should be equal or greater than 1.00 m	suitable (1.00); unsuitable (0.50); nonexistent (0.00)
Existence of coverage	existence of coverage to protect users from adverse weather conditions	existent (1.00); nonexistent (0.00)
Lighting efficiency	the lighting is well distributed along the walkway, allowing a wide field of vision	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Salubrity	intensity of the presence of garbage and vegetation	good (1.00); regular (0.50); poor (0.00)
	Pedestrian Crossings (PC)	
Rail uniformity	pavement conservation conditions between the rails of the level crossing and rail uniformity conditions	regular (1.00); irregular (0.50); nonexistent (0.00)
Lighting efficiency	lighting near the pedestrian crossing stands out from the urban street, emphasizing the existing signaling and the LC	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Crossing width¹	a suitable pedestrian crossing width should be equal or greater than 1.50 m	suitable (1.00); unsuitable (0.00)
Efficiency of the existing signs	the efficiency of the existing signaling in alerting pedestrians and drivers about the proximity of the train	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Salubrity	intensity of the presence of garbage and vegetation	good (1.00); regular (0.50); poor (0.00)
	Segment Without Crossings (SWC)	
Type of barrier material	influence of the permeability of the barrier material on the crossing	facilitates (1.00); hampers (0.50); blocks (0.00)
Barrier height	influence of the barrier height on the crossing	facilitates (1.00); hampers (0.50); blocks (0.00)
Efficiency of the existing signs	efficiency of the existing signaling in alerting pedestrians and drivers about the proximity of the train	efficient (1.00); insufficient (0.50); nonexistent (0.00)
Railway proximity	according to Law No. 10,932/2004, a non-buildable band of 15 meters from both sides of the railway is mandatory	suitable (1.00); unsuitable (0.00)
Salubrity	intensity of the presence of garbage and vegetation	good (1.00); regular (0.50); poor (0.00)
Safety	annual crime rate per 1000 inhabitants combined with the annual death rate per 1000 inhabitants	low (1.00); regular (0.50); high (0.00)

¹ According to ABNT NBR 9050/2004
² According to ABNT NBR 15680/2017, level crossing should be 1500 meters away from another level crossing, 3000 meters away from an overpass and 500 meters away from a pedestrian crossing
Source: The author

As presented in Table 3.2, the criteria evaluation of each type of railroad crossing and segment without railroad crossings receive scores ranging from 0 to 1, in which score 0 is assigned to unfavorable conditions for urban mobility and score 1, to favorable conditions. According to the percentage of conformance for each set of criteria, the classification of the railroad crossings and segments without railroad crossings is performed following an ordinal scale of relevance ranging from A to D. Class A corresponds to the most favorable conditions for pedestrian urban mobility in the area of influence considered, and D, to the most unfavorable conditions.

For the delineation of the area of influence, a band of 500 meters is considered for the railway (highlighted in the example of Figure 3.1, in green). Within the band, the area of influence for each railroad crossing is also delimited, considering a 400 meters radius (highlighted in the example of Figure 3.1, in orange). In the case of overlapping areas of influence of the railroad crossings, Voronoi diagrams can be used, under the assumption that residents will tend to cross the railway through the nearest railway crossing (for details on the Voronoi diagram see Okabe, Boots, Sugihara, & Chiu, 2009). The railway area of influence is slightly larger than the railroad crossings, because it was considered that people who live more than 400 meters away from a railroad crossing are as affected as those who live near the segments without railroad crossings.

Figure 3.1 - Example of areas of influence for the railroad crossings and railway



Source: The author

Based on the population data collected, the characteristics of the railway (layout, railroad crossings and segments without railroad crossings) and the delimited areas of influence, the study area can be georeferenced using, for example, an open source GIS package, such as *Quantum GIS*. We propose the study of variables regarding the range of monthly nominal income, permanent mobility constraints, gender and age, however other variables related to population can also be considered.

If population data are highly aggregated, as in the case of weighting areas and census tracts, the estimate of the number of residents is carried out using adjustment factors. Weighting areas constitute geographical partitions formed by a mutually exclusive group of areas that follow technical restrictions concerning contiguity and size defined by the Brazilian Institute of Geography and Statistics (or IBGE, which in Portuguese stands for *Instituto Brasileiro de Geografia e Estatística*). The adjustment factors will be based on the population distribution provided by the aggregated data, which are multiplied by the number of inhabitants given in the statistical grid (less aggregated data). The statistical grid comprises a system of regular cells arranged in grid form. Urban regions have dimension cells equal to 200 m x 200 m (IBGE, 2016). In the case of the variable gender, this approach is not necessary, since gender is provided directly by the statistical grid.

Each variable has a number of factors equivalent to the number of categories (e.g., permanent mobility constraints have 4 categories - disability, great difficulty, some difficulty and no disability - and, therefore, 4 factors) for each weighting area. Factors are then calculated from the probability of occurrence of the category in the weighting area. Thus, the population is estimated according to its demographic characteristics, for each cell of the statistical grid. Therefore, the variability of the distribution of the estimated population is based on the distribution of the statistical grid, mitigating the limitations resulting from the highly aggregated data.

Hence, through the crossover of the population information (for example, by range of monthly nominal income, self-declared permanent mobility constraints, gender and age range) with the influence areas of the railroad crossings and the railway, the number of residents in the areas of interest can be computed.

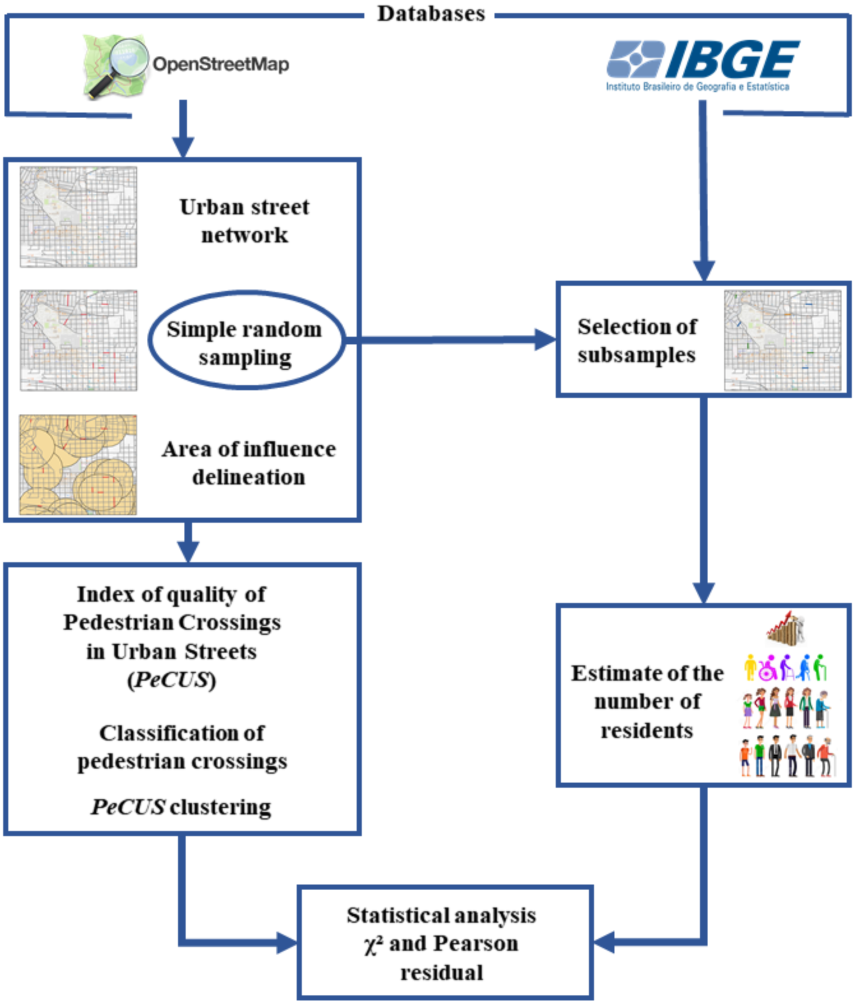
From these values, an exploratory data analysis can show relevant aspects about the residents alongside the railway. Hypotheses regarding the variable of classification can then be formulated and tested with chi-square (χ^2) tests of independence and standardized Pearson residuals (further detailed in Subsection 3.3) in relation to the following variables: *(i) number of residents by range of monthly nominal income; (ii) number of residents with self-declared* *permanent mobility constraints; (iii) number of residents by gender and (iv) number of residents by age range*.

Thereby, we identify deficits and excesses of residents in the surrounding regions of the railroad crossings and segments without railroad crossings, thus identifying equity issues in the distribution of the number of residents along the railway and in the distinct types of railroad crossings.

3.2.2 Assessment of community severance caused by Urban Streets

Urban streets constitute physical barriers to pedestrian urban mobility, not only because of the street infrastructure but also because of their traffic stream volume and speeds. The characterizations of these barriers are performed using open and census data, combined images of *Google Street View* and *Google Maps*, *Quantum GIS v.3.4.6 software* and *IBM SPSS Statistics v.25 software*. The procedures of the proposed method are summarized in Figure 3.2.

Figure 3.2 - Overview of the method

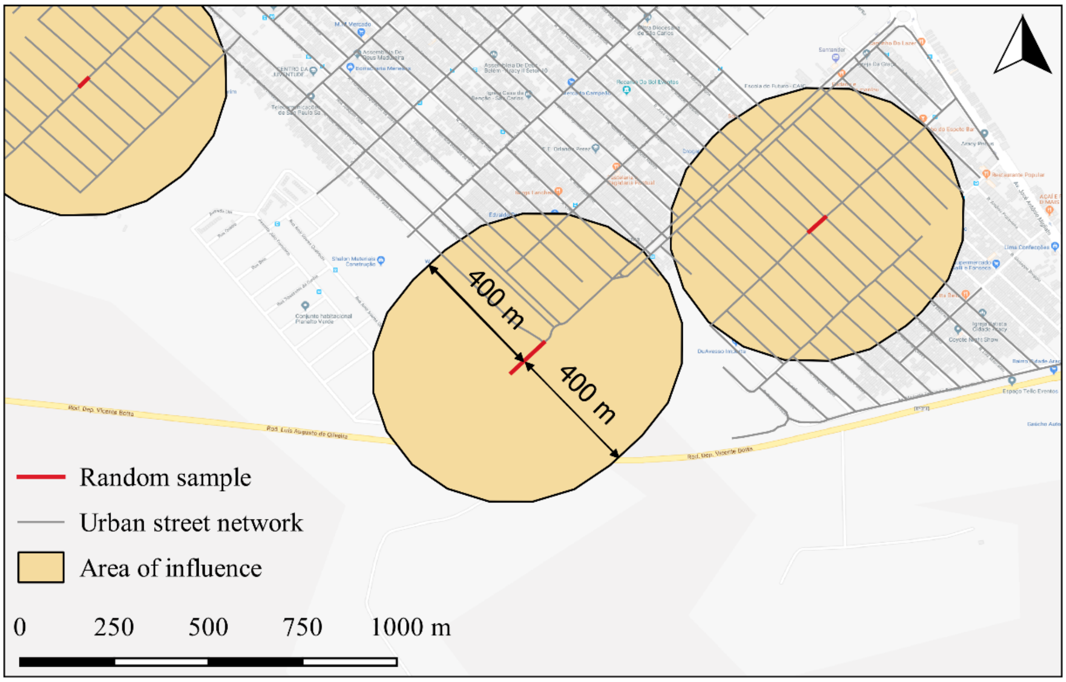


Source: The author

The urban street network map can be generated using the *Open Street Map (OSM)* database and the free software package *Quantum GIS*. Unpaved streets, private streets, parking lots, railways and streams are not included in the map. Then, with the urban street network map containing only public urban streets, we selected a sample of urban streets by simple random sampling. The sample size must be determined considering a confidence level and a margin of error that ensure the statistical representation of the analysis.

A band of 400 meters is defined as the area of influence nearby the selected streets (Figure 3.3). The band area is used for classifying pedestrian crossings on urban streets (e.g. number of crimes and deaths, number of inhabitants) and for estimating the demographic characteristics of residents in the streets' surroundings.

Figure 3.3 - Example of area of influence for the randomly selected urban streets



Source: The author

The classification of pedestrian crossings is based on fourteen criteria (Table 3.3) related to: the geometric design of the streets, available pedestrian infrastructures, population within the selected 400-meter band, safety and maintenance conditions, as well as land use. For each criterion, score values ranging from 0 to 1 are assigned. Score 0 corresponds to the worst mobility conditions for pedestrians and score 1 to the best conditions, as indicated in Table 3.3.

Table 3.3 - Summary of the criteria assessed for classifying pedestrian crossings on urban streets

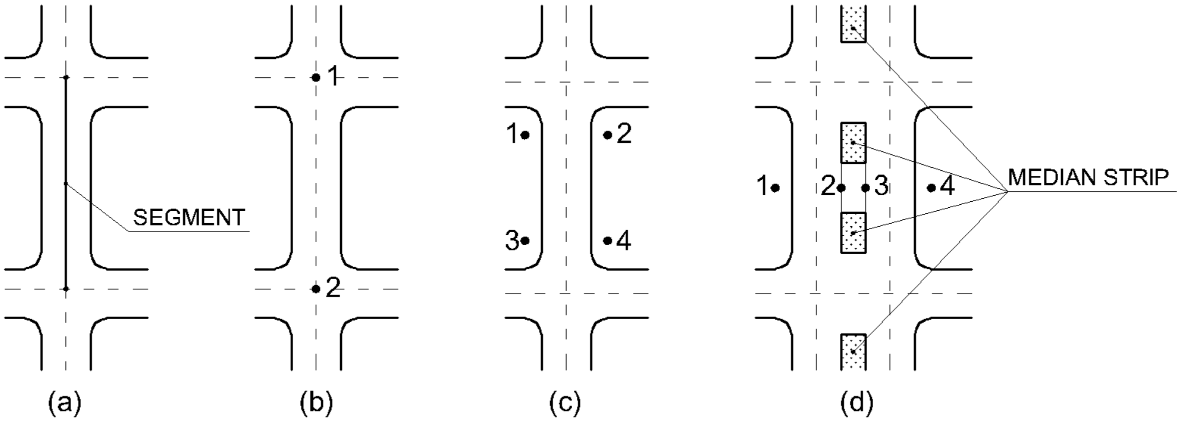
	Criterion	Description	Category (score)
Traffic volume		number of vehicles (passenger car equivalent - pce) per hour (in the peak-hour)	very low (1.00); low (0.75); regular (0.50); high (0.25); very high (0.00)
Geometric design	Functional classification	urban street functional classification (DNIT 2010)	local (1.00); collector (0.67); secondary arterial (0.33); primary arterial (0.00)
	Traffic direction	one-way or two-way direction	one-way (1.00); two-way (0.00)
	Number of lanes	number of lanes per direction	1 (1.00); 2 (0.67); 3 (0.33); 4 or more (0.00)
Pedestrian infrastructure	Zebra crossing	presence and type of zebra crossing	raised (1.00); at level (0.50); absence (0.00)
	Zebra crossing location	attractiveness of the zebra crossing location	very attractive (1.00); attractive (0.67); not attractive (0.33); absence of zebra crossing (0.00)
	Pedestrian visibility	driver's pedestrian visibility at intersections	total (1.00); moderate (0.75); regular (0.50); poor (0.25); none (0.00)
	Mandatory stop	presence of vertical and/or horizontal "STOP" signs at intersections or presence of traffic lights	two-phase traffic light (1.00); three-phase traffic light (0.80); vertical and horizontal "STOP" signs (0.60); vertical "STOP" signs (0.40); horizontal "STOP" signs (0.20); absence (0.00)
	Median	presence of median strip and pedestrian accommodation possibility in the median strip	allow pedestrian accommodation (1.00); do not allow pedestrian accommodation (0.50); absence (0.00)
	Accessibility	presence and maintenance conditions of curb ramps on both sides of the pedestrian crossing	excellent (1.00); good (0.80); regular (0.60); poor (0.40); very poor (0.20); absence (0.00)
Safety	Number of crimes and deaths	annual crime rate per 1000 inhabitants combined with the annual death rate per 1000 inhabitants	very low (1.00); low (0.75); regular (0.50); high (0.25); very high (0.00)
Popu-lation	Number of inhabitants	number of inhabitants within the 400-meter band	regular (1.00); high (0.75); very high (0.5); low (0.25); very low (0.00)
Maintenance	Public lighting	quality of public lampposts[1]	excellent (1.00); good (0.80); regular (0.60); poor (0.40); very poor (0.20); absence (0.00)
	Salubrity	intensity of the presence of garbage and vegetation	excellent (1.00); good (0.75); regular (0.50); poor (0.25); very poor (0.00)
Land use	Land use	land use[1] around the selected urban street	commercial (1.00); mixed land use - commercial and residential (0.75); residential (0.50); institutional (0.25); industrial (0.00)

[1] Provided by the City Hall or competent body
Source: The author

Criteria related to geometric design, pedestrian infrastructure, and maintenance conditions are evaluated by analyzing the combined images of *Google Street View* and *Google Maps*. The assessment of the criterion: functional classification, traffic direction, number of lanes, zebra crossings, zebra crossings location, pedestrian visibility, median and salubrity are described in Table 3.3. However, the criteria: mandatory stop, accessibility and public lighting needs more explanation.

Segments of urban streets correspond to the stretches between intersections, as shown in Figure 3.4(a). For the calculation of the mandatory stop criterion, we evaluate two points that correspond to the two intersections of the segment, as indicated in Figure 3.4(b). In this criterion the presence of vertical and/or horizontal "STOP" signs or presence of traffic lights at the intersections are scored according to Table 3.3. The final score corresponds to the average of the scores for the two points.

Figure 3.4 - Schematic drawing of the reference points analyzed in the segments of urban streets



Source: The author

Concerning the accessibility criterion, four points near the intersections of the segment are evaluated, as illustrated in Figure 3.4(c), in the case of the presence of a median strip the reference points are considered according to the schematic drawing in Figure 3.4(d). We considered that an accessible crossing occurs when the sidewalks have curb ramps on both sides of the crossing. Thus, if only one side of the sidewalk has a curb ramp, score 0 is assigned for the pair of points. If both sides have curb ramps, their scores are assigned according to their maintenance conditions, as indicated in Table 3.3. Therefore, the final score corresponds to the average of the scores for the pair of points.

The public lighting criterion is assessed through the quality of the lampposts surrounding the segments. The location plan of the city lampposts and its specifications ought to be provided by the City Hall or competent body. The specifications detail the bracket type (short, long or medium), lamp-type (fluorescent, halogen, incandescent, led, mixed, Mercury vapors or Sodium vapor or metallic vapor), lamp power (70W, 80W, 100W, 125W, 150W, 250W or 400W) and luminaire type (open, closed, integrated or ornamental) of the city lampposts. Therefore, the final score corresponds to the combination of the lamppost specifications, as presented in Table 3.3.

On the other hand, the evaluation of the criterion concerning safety is carried out based on the annual crime and death rates per 1000 inhabitants within the area of influence of the urban street segments sampled, during a specified period.

Regarding the criterion related to population, the number of inhabitants from the area of influence is estimated and categorized into five levels. The scores assigned to the five levels of number of inhabitants (very high to very low) follow the concept that a neighborhood with an intermediary (regular) number of inhabitants favors pedestrian urban mobility. A high number of inhabitants in the neighborhood mostly attracts local trips, whereas a low number of inhabitants, may attract a greater number of trips (motorized or not), because generally in these places there are trip generation centers.

In addition, the scores assigned for the land use criterion are also analyzed considering the number of trips generated. Moreover, land use brings information about commercial, residential, mixed land use (commercial and residential), institutional and industrial zones, which enables a reading on the number of inhabitants, as well. Commercial zones have a higher number of attracted trips than residential zones, which encourages active trips, however this number reduces overnight. In residential, institutional and industrial zones the number of attracted trips is low. Besides that, institutional and industrial zones have a very low number of inhabitants and generally in these places there are no trip generation centers, which could inhibit active trips.

Thus, from the assessment of the criteria detailed, the classification of pedestrian crossings on urban streets is carried out. For the classification, each street is considered as an independent case. Therefore, the overlapping areas of influence do not affect the results.

The combination of criteria is defined as the *PeCUS* (Pedestrian Crossings on Urban Streets) index. As the total sum of scores varies according to the quality of crossings for pedestrians, the *PeCUS* index also reflects, but inversely, the variation of trip impedances and the access of pedestrians to goods and services (and by extension, the level of community severance).

As indicated in Figure 3.2, a cluster analysis is conducted (detailed in Subsection 3.3) to group the *PeCUS* index results into six classes ranging from A to F, using the *IBM SPSS Statistics v.25* software. Class A corresponds to the best quality of pedestrian crossings and F corresponds to the worst evaluation.

The sampled streets are then classified (from A to F) regarding the quality of pedestrian crossings. Next, the demographic characteristics of the residents in the streets' surroundings are examined. However, in order to look for evidence of associations between the variables through a chi-square (χ^2) test of independence, each unit of the sample must be counted only once, that is, each observed element must be allocated in only one cell of the contingency table. For this reason, overlapping areas of influence must be avoided and a selection of subsamples without overlapping areas of influence become necessary.

Three subsamples are randomly selected from the original sample in such a way that only the segments that have bands that do not overlap with the bands of the segments already chosen are kept in the subsample. The new subsamples are then used to estimate the number of residents within non-overlapping 400-meter bands regarding the variables of interest. As in the railway, in this method we propose the study of the variables regarding range of monthly nominal income, permanent mobility constraints, gender and age, however other variables related to the population could also be used.

If the population data are highly aggregated, as in the case of weighting areas and census tracts, the estimate of the number of residents is carried out using adjustment factors. These factors are based on the population distribution provided by the aggregated data, which are multiplied by the number of inhabitants given in the statistical grid (less aggregated data). Finally, in order to accept or reject the null hypothesis of independence between the variables (H_0) and to verify the degree of dependence between them, we use the chi-square (χ^2) test of independence and the squared Pearson residuals, as detailed in Subsection 3.3.

Thus, we identify deficits and excesses of residents' distribution in the surrounding regions of the urban streets, which may help to understand important equity issues.

3.3 Statistical analysis

The method presented for the assessment of the community severance caused by two different transport barriers uses statistical analysis techniques, such as: cluster analysis, chi-square (χ^2) test of independence and standardized Pearson residuals. In this Section, we briefly describe these statistical analysis techniques.

The cluster analysis is used to group the *PeCUS* index results into classes of quality, using the *IBM SPSS Statistics v.25* software. In addition, the chi-square (χ^2) test of independence and standardized Pearson residuals are used to investigate evidence of associations and the degree of dependence between the variables studied for both transport barriers.

3.3.1 Cluster analysis

Cluster analysis classifies objects (e.g., respondents, products, or other entities) on a set of user selected characteristics. The resulting clusters should exhibit high internal (within-cluster) homogeneity and high external (between-cluster) heterogeneity. Thus, if the classification is successful, the objects within clusters will be close together when plotted geometrically, and different clusters will be far apart (Hair, Black, Babin, & Anderson, 2010).

According to Hair et al. (2010), nonhierarchical clustering procedures assign objects into clusters once the number of clusters is specified. The nonhierarchical cluster software programs usually proceed through two steps:

a) Specify cluster seeds: the first step is to identify initial values or starting points, known as cluster seeds, for each cluster. In this study, cluster analysis is used for the urban street analysis. For the cluster seed identification, we based the number of classes on the six pedestrian levels of service (LOS) from the Highway Capacity Manual (2010), therefore we adopted a cluster seed equal to 6.
b) Assignment: with the cluster seeds defined, the next step is to assign each observation to one of the cluster seeds based on similarity. In this study, the most appropriate approach to do this assignment corresponds to the *k-means* algorithm.

K-means algorithms work by portioning the data into a user-specified number of clusters and then iteratively reassigning observations to clusters until some numerical criterion is met. The criterion specifies a goal related to minimizing the distance of observations from one another in a cluster and maximizing the distance between clusters (Hair et al., 2010).

3.3.2 Chi-square (χ^2) test of independence and standardized Pearson residuals

The chi-square (χ^2) test of independence is used in contingency tables built from the variables studied in order to accept or reject the hypothesis of independence between the variables (H_0). The value of the chi-square (χ^2) is calculated from the sum of the squared Pearson residual (PR^2) values, according to Equation 3.1. Therefore, the squared Pearson residual corresponds to the individual contribution of each cell to the chi-square (χ^2) value.

$$\chi^2 = \sum PR^2 = \frac{(Observed - Expected)^2}{Expected} \tag{3.1}$$

where χ^2 corresponds to the chi-square value, $\sum PR^2$ indicates the summation of squared Pearson residuals, *Observed* corresponds to the observed count and *Expected*, corresponds to the expected count.

In addition to calculating the chi-square (χ^2) value and its corresponding p-value, we compute the standardized Pearson residuals (Equation 3.2), which allows a direct comparison between each cell of the contingency table. Thus, the chi-square (χ^2) test of independence is used to assess the evidence of association between the variables, whereas the standardized Pearson residuals are used to better understand the nature and the degree of dependence between the variables.

$$SPR = \frac{Observed - Expected}{\sqrt{Expected \cdot \left(1 - \frac{row_{total}}{Total}\right) \cdot \left(1 - \frac{column_{total}}{Total}\right)}} \tag{3.2}$$

where *SPR* corresponds to the standardized Pearson residual, row_{total} indicates the sum of the observed counts in the row, and $column_{total}$ indicates the sum of the observed counts in the column and *Total* indicates the sum of all observed counts.

A standardized Pearson residual that exceeds about 2 indicates that the cell greatly contributes to the chi-square (χ^2) value and does not fit the H_0. Larger values are more relevant when the degrees of freedom are larger, and it becomes more likely that at least one is larger simply by chance (Agresti, 2018).

3.4 Summary of the proposed method

The method proposed for the assessment of community severance caused by a railway and urban streets is summarized in Table 3.4.

As presented in Table 3.4, there are some differences between the classification criteria and scale of the railway and urban streets. For the railway, the criteria are not equal for all railway crossings and segments without railway crossings, because those facilities have different characteristics that must be differently and properly evaluated. However, urban streets have similar characteristics that allow a unified evaluation, and for this reason, the creation of an index, capable of measuring the variation of the quality of pedestrian crossings on urban streets (*PeCUS* index) is possible.

Table 3.4 - Summary of the method applied for the assessment of community severance caused by both transport barriers

		Railway	Urban streets
Databases		open data, population data as disaggregated as possible, however highly aggregated data (census data) can also be used	open data, population data as disaggregated as possible, however highly aggregated data (census data) can also be used
Classification	Criteria	different for each type of crossing	equal for all crossings
		number of criteria evaluated ranges from 5 to 6	number of criteria evaluated corresponds to 14
		scores range from 1 to 3	scores range from 0 to 1
		related to pedestrian infrastructure and maintenance	related to geometric design, pedestrian infrastructure, safety, population, maintenance and land use
			creation of the index of quality of Pedestrian Crossings on Urban Streets (*PeCUS* index)
	Scale	groups were divided by % of conformance	groups were divided by cluster analysis
Area of influence		band of 500 meters for the railway line and 400 meters radius for the railroad crossings	band of 400 meters nearby the selected urban streets
		overlapping areas of influence are avoided by computing a Voronoi diagram	overlapping areas of influence are avoided by selecting three new subsamples
Estimate of the number of residents	Income Permanent mobility constraints Age range Gender	preferably computed in a disaggregated level, but the use of census data (highly aggregated) is also possible. In this case, factors based on the population distribution provided by the aggregated data are multiplied by the number of inhabitants given in the statistical grid	preferably computed in a disaggregated level, but the use of census data (highly aggregated) is also possible. In this case, factors based on the population distribution provided by the aggregated data are multiplied by the number of inhabitants given in the statistical grid
Exploratory data analysis		outline conjectures about the residents alongside the railway regarding the variables studied	outline conjectures about the residents alongside the urban streets regarding the variables studied
Chi-square (χ^2) test of independence		used to investigate evidence of associations between the variables studied	used to investigate evidence of associations between the variables studied
Standardized Pearson residuals		used to investigate the degree of dependence between the variables studied	used to investigate the degree of dependence between the variables studied
Vertical equity		deficits and excesses of residents regarding the variables studied are identified in the surrounding regions of the railroad crossings and segments without railroad crossings	deficits and excesses of residents regarding the variables studied are identified in the surrounding regions of the crossings

Source: The author

The area of influence regarding the railway line and urban streets is defined as a band of 400 meters. The railway area of influence is slightly larger than the railroad crossings, because it was considered that people who live more than 400 meters away from a railroad crossing are as affected as those who live near the segments without railroad crossings.

In relation to the estimate of the number of residents for both infrastructures, it is preferable to be computed at a disaggregated level, but the use of census data (spatially aggregated) is also possible. In this case, factors based on the population distribution provided by the aggregated data are multiplied by the number of inhabitants given in the statistical grid.

Concerning the exploratory data analysis, chi-square (χ^2) test of independence, standardized Pearson residuals and vertical equity, the method used for both transport barriers has no difference.

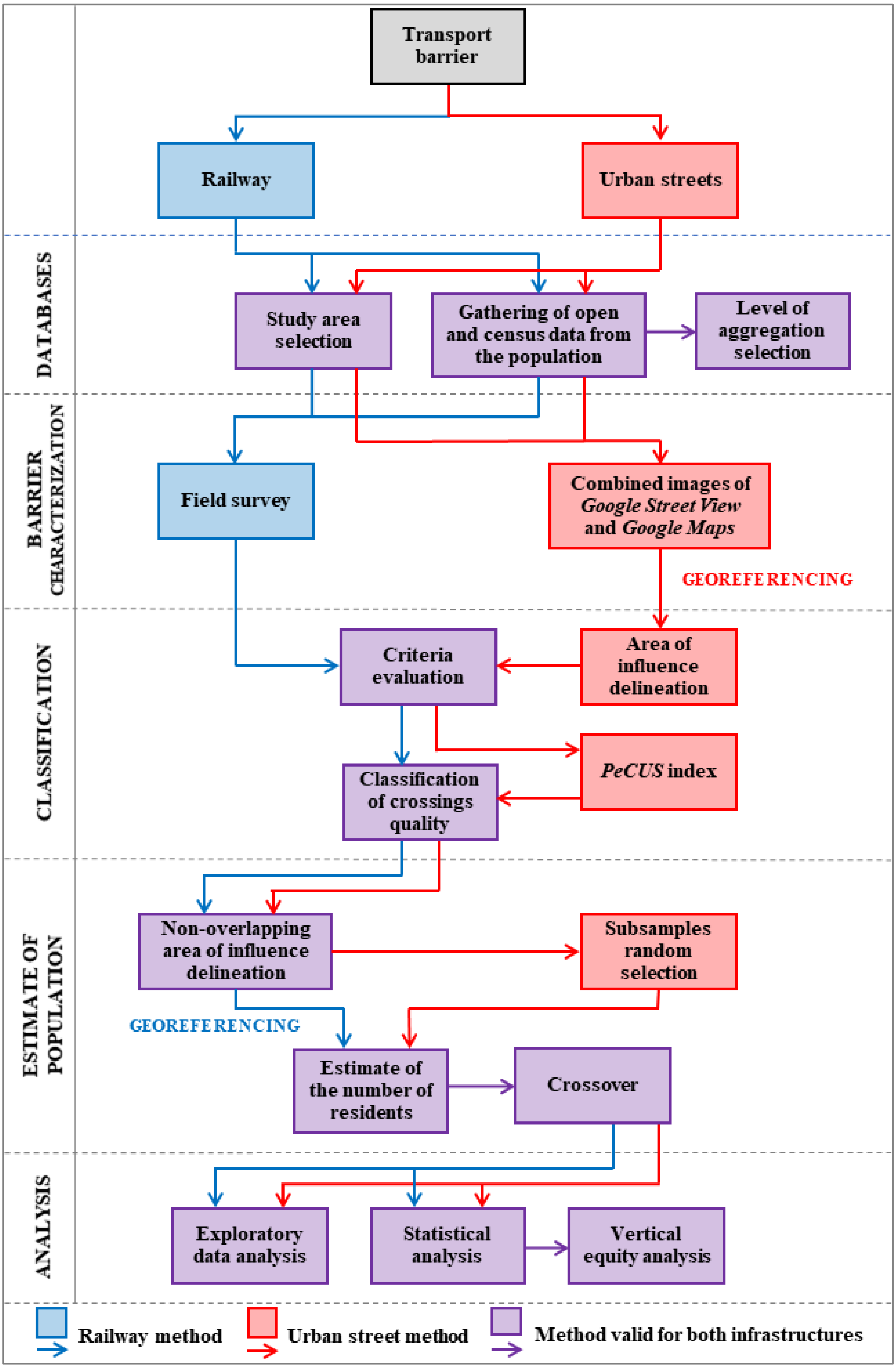
From the summary and the comparison of the method proposed for both railway and urban streets, we prepared a concise description of the analytical procedures that constitute the method, as indicated in Table 3.5 and illustrated in the flow diagram of Figure 3.5.

Table 3.5 - Steps of the analytical procedures that constitute the method

1	Definition of the study area
2	Gathering and selection of the population information available for the study area, as open and census data
3	Selection of the level of aggregation of the selected data
4a	Characterization of the railway barrier through a field survey
4b	Characterization of urban street barriers using combined images of Google Street View and Google Maps
5b	Delineation of the area of influence of urban streets considering overlapping areas, since for the classification step (Step 9) each street was considered as an independent case
6	Georeferencing of the study area using the open software *Quantum GIS v.3.4.6*
7	Qualitative evaluation of the distinct types of crossings based on an appropriate set of criteria for each facility
8b	Creation of the *PeCUS* index from the sum of the criteria scores
9	Classification of the quality of the transport barriers crossings based on the criteria assessed
10	Delineation of the area of influence avoiding overlapping areas
11b	Random selection of three subsamples from the original sample of urban streets without overlapping areas of influence
12	Estimate of the number of residents regarding the variables selected (using factors based on the population distribution provided by the weighting areas multiplied by the number of inhabitants given in the statistical grid and directly extracted from the statistical grid)
13	Crossover of the estimated population within the areas of influence
14	Exploratory data analysis to characterize relevant aspects and outline conjectures about the residents alongside the railway
15	Statistical analysis using the chi-square (χ^2) tests of independence and the calculation of the standardized Pearson residuals
16	Analysis of vertical equity through the calculation of deficits and excesses of residents in the surrounding regions of the railroad crossings and segments without railroad crossings

a. Step corresponds to the railway
b. Step corresponds to the urban streets
Source: The author

Figure 3.5 - Flow diagram of the analytical procedures that constitute the method



Source: The author

4 CASE STUDIES

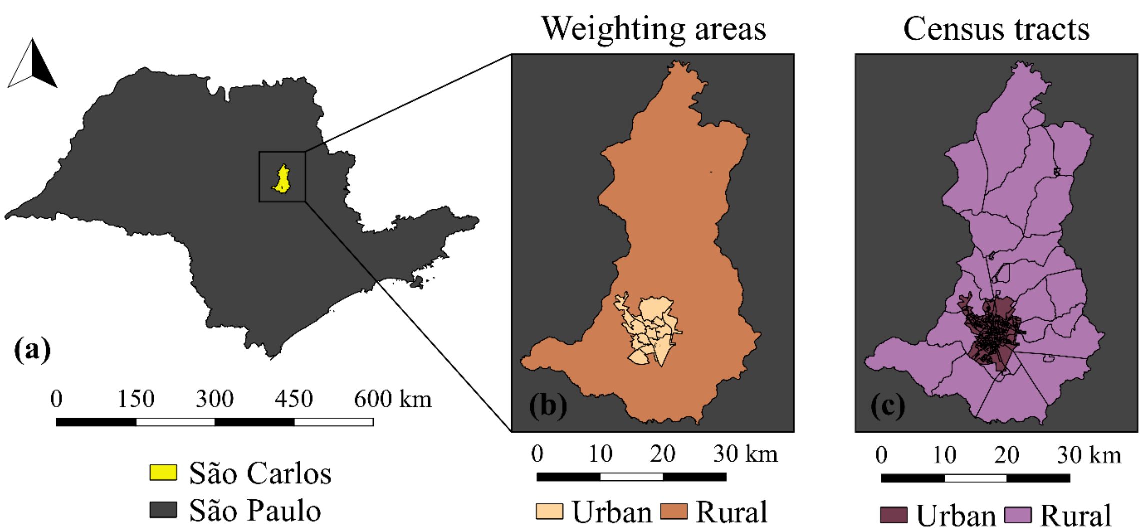
In this Chapter, we present the case studies used to illustrate the method created for the assessment of the community severance caused by a railway inserted in an urban perimeter, and by urban streets of a medium-sized Brazilian city.

Chapter 4 is divided into three Sections, in which the first Section has an overview of the study area. Sections 4.2 and 4.3 contain details of the railway and of the urban streets, respectively.

4.1 Study area

The case studies addressed in this research comprise a railway and urban streets located in a significant part of the urban region of the city of São Carlos. São Carlos is a medium-sized Brazilian city located in the state of São Paulo, as indicated in Figure 4.1(a). The population considered for this study included 213,010 inhabitants (IBGE, 2010) distributed over 83.5 km², 13 weighting areas (Figure 4.1(b)) and 295 census tracts (Figure 4.1(c)). Weighting areas constitute geographical partitions formed by a mutually exclusive group of areas that follow technical restrictions concerning contiguity and size defined by the Brazilian Institute of Geography and Statistics (or IBGE, which in Portuguese stands for *Instituto Brasileiro de Geografia e Estatística*).

Figure 4.1 - Location of the city of São Carlos in the state of São Paulo (a). São Carlos subdivisions into weighting areas (b) and census tracts (c)



Source: The author

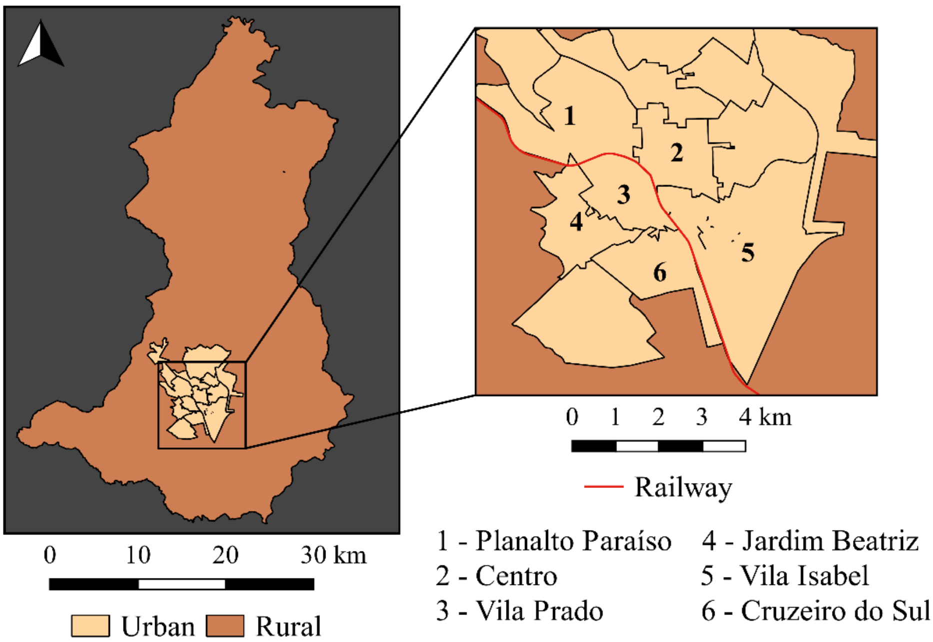
Relevant demographic characteristics of the study area are: average monthly nominal income of R$ 1,601.71, 36,000 inhabitants with some level of self-declared disability (13,213 of which with permanent mobility constraints), 108,795 female residents (with an average age of 38.0 years old) and 104,215 male residents (with an average age of 35.8 years old) (IBGE 2010).

4.2 Case study 01: Railway within the urban perimeter

For a better understanding of community severance and how it affects the distribution of the population in its surroundings, we first selected a transport barrier whose impact on pedestrian mobility is large, but its variability is small. That is the case of railways within the urban perimeter of cities, since the physical segregation of the infrastructure is practically unavoidable and the passage of pedestrians, cyclists and motorized vehicles, is only possible in the specific points where there are railroad crossings.

The urban perimeter of São Carlos city is cut by the *Itirapina - Colômbia* trunk railway line, operated by the concessionaire ALL (*América Latina Logística Malha Paulista S.A.*). The railway is at grade virtually throughout its entire way, has an average capacity of 11 railway compositions per day and a maximum traffic speed of 10 km/h (maximum speed allowed in urban perimeter). Figure 4.2 shows the city of São Carlos, highlighting the weighting areas sectioned by the railway.

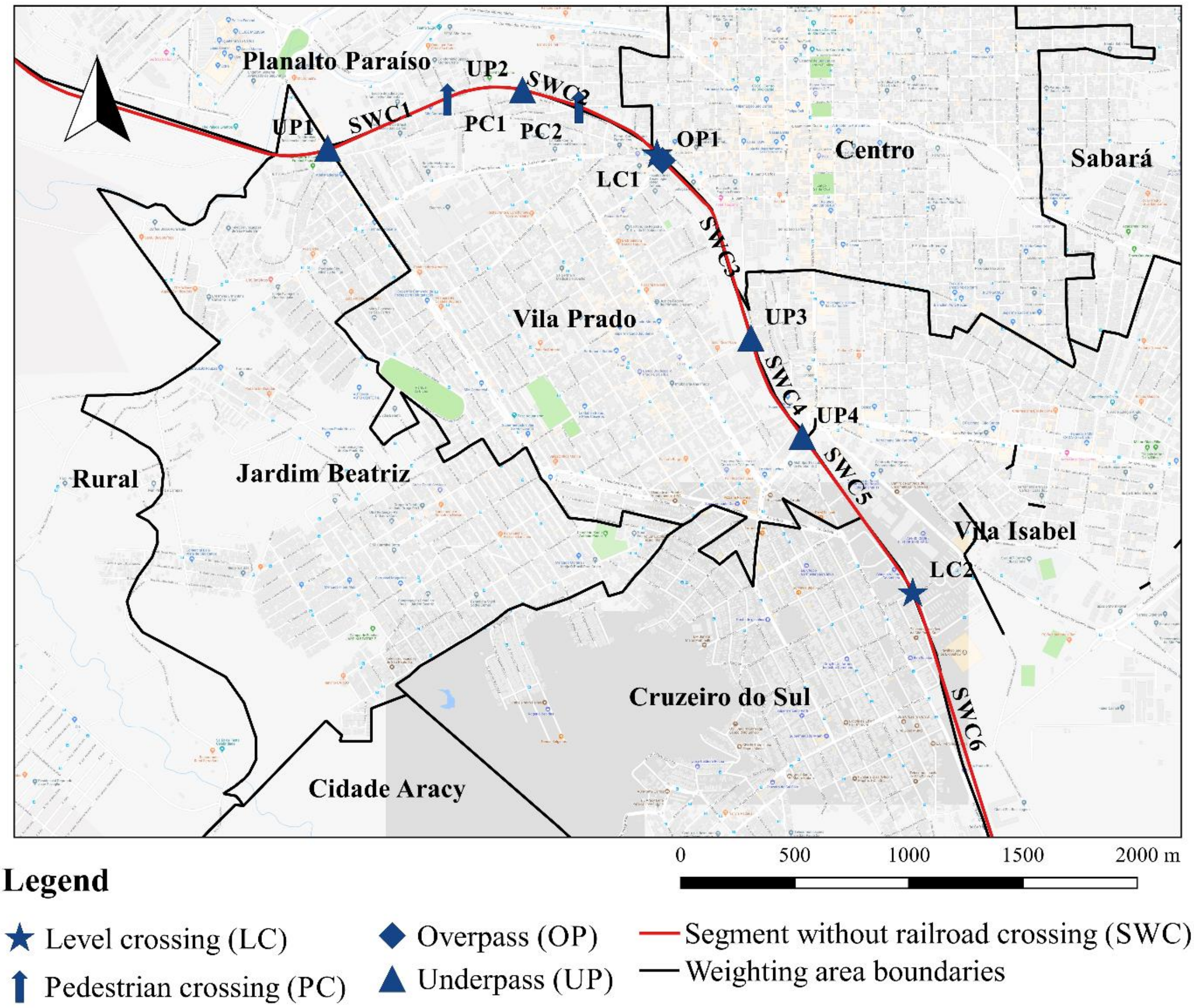
Figure 4.2 - Weighting areas sectioned by the railway in the city of São Carlos, SP, Brazil



Source: The author

The city growth was strongly influenced by the railway in the past. As a consequence, the population distribution along the railway within the urbanized region is quite homogeneous. The railway throughout the urban region includes the following types of crossings: level crossings (LC), pedestrian crossings (PC), overpasses (OP), underpasses (UP) and segments without railroad crossings (SWC), as shown in Figure 4.3.

Figure 4.3 - Location of railroad crossings and segments without railroad crossings in the city of São Carlos, SP, Brazil



Source: The author

Some examples of types of railroad crossings along the railway and the segments without railroad crossings, within the urban perimeter, are illustrated in Figure 4.4. The segments without railroad crossings (SWC) have physical barriers preventing the passage of pedestrians, motorized and non-motorized vehicles along the whole way, however the material and the height of the barriers vary among segments.

Figure 4.4 - Examples of types of crossings and segments without railroad crossings. From top left to bottom right: OP1, PC2, UP4 and SWC6

Note: OP - Overpass; PC - Pedestrian crossing; UP - Underpass e SWC - Segment without railroad crossing.
Source: The author

4.3 Case study 02: Urban streets

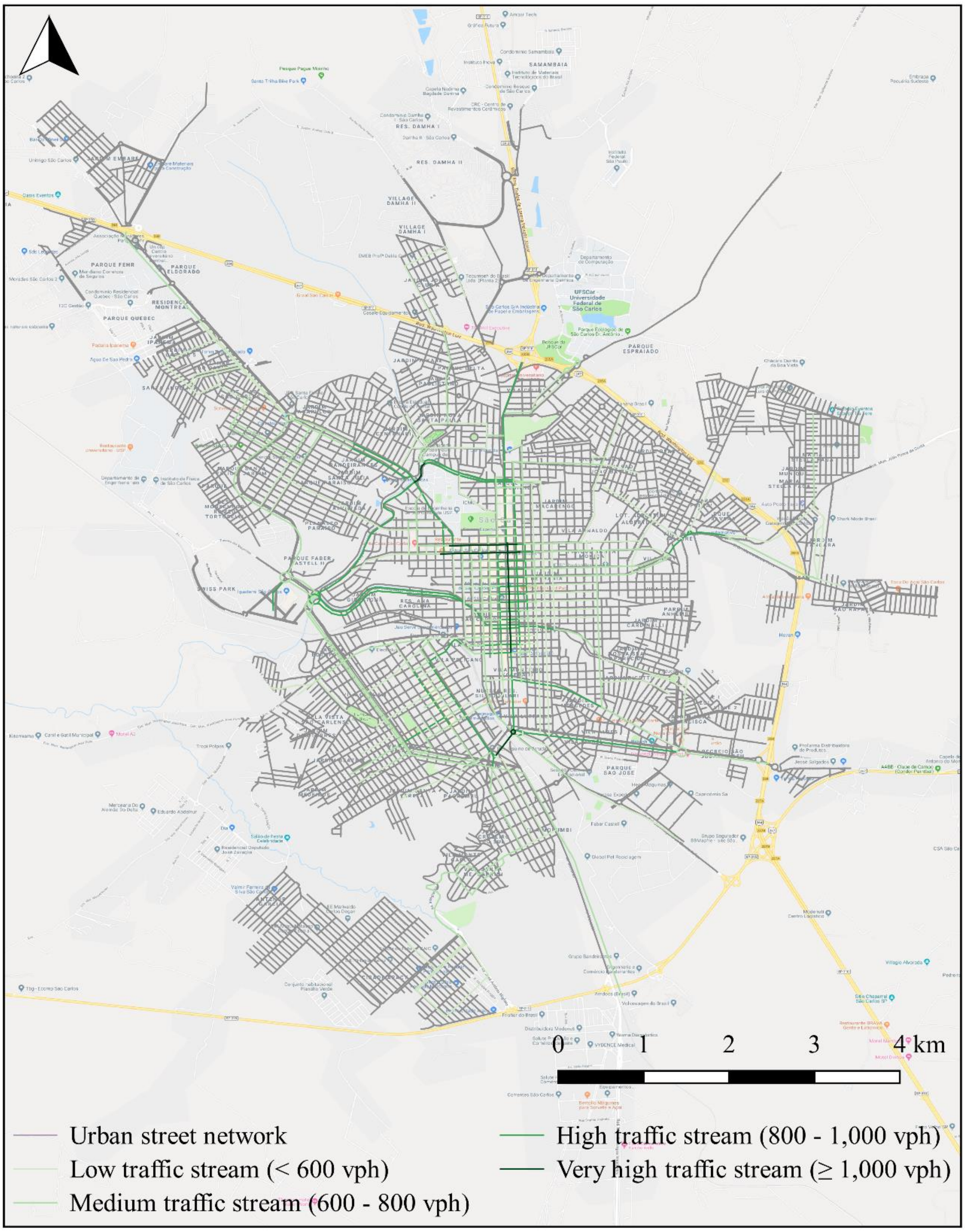
The study case carried out for a railway located in the urban perimeter of a medium-sized city helped to understand the impact of community severance on the distribution of the nearby population. Thus, we developed a second case study in a transport barrier whose impacts can range from moderate to low, but their variability is considerably large throughout the entire barrier. That is the case of urban streets, given that pedestrians, depending on the traffic stream volume and road characteristics, can cross either on crossing facilities (formal passage) or between car gaps (informal passage). However, informal passages were not considered in this study.

The urban street network of São Carlos is typically laid out in a grid pattern comprising local streets, collector streets and arterial streets (primary and secondary). This functional classification of urban roads follows guidelines defined by the National Department of

Transport Infrastructure (or DNIT, which in Portuguese stands for *Departamento Nacional de Infraestrutura de Transportes*) from 2010.

As São Carlos is a medium-sized city, its traffic stream ranges between low (below 600 vph (vehicles per hour)) and very high (above 1,000 vph), as presented in Figure 4.5.

Figure 4.5 - Overview of traffic volumes in the city of São Carlos, SP, Brazil



Source: Adapted from the map of roads hierarchy provided by the Municipal Housing and Urban Development Secretariat of São Carlos (in Portuguese: *Secretaria Municipal de Habitação e Desenvolvimento Urbano*), 2002

In addition, pedestrian crossing facilities on urban streets are limited to raised or at level zebra crossings, with the occasionally presence of traffic lights or vertical/horizontal "STOP" signs. Some examples of pedestrian crossings on urban streets are illustrated in Figure 4.6.

Figure 4.6 - Examples of pedestrian crossings on urban streets

Note: From top left to bottom right: at level zebra crossing and traffic lights; at level zebra crossing, vertical and horizontal "STOP" signs; raised zebra crossing; at level zebra crossing; vertical and horizontal "STOP" signs; vertical "STOP" sign; absence of zebra crossing and signs.
Source: The author

5 RESULTS

In this Chapter, we present and discuss the results from the implementation of the methods created for the assessment of the community severance caused by a railway inserted in an urban perimeter, and by urban streets. In addition, the vertical equity analysis regarding residents' distribution around the distinct classes of quality of pedestrian crossings for both infrastructures is carried out.

Chapter 5 is divided into four Sections. The first Section presents the data used, the second and third Sections describe the assessment of community severance for two case studies. Lastly, the final section presents a summary of the main results.

5.1 Data collection

The data collection for the assessment of community severance varies according to the transport barrier analyzed, as presented in Section 3.1. Moreover, the data collection is required for the characterization of the transport barriers and to estimate the population around them. The characterization of the transport barriers is carried out according to the evaluation of a set of criteria relevant to the particularities of each barrier (detailed in Table 3.2 and Table 3.3). On the other hand, population estimates depend on the availability and level of aggregation of the variables of interest.

Concerning the railway characterization, the data collection was carried out through field surveys. Databases were only needed for the estimate of the population around the railway crossings and segments without railway crossings, therefore population databases were gathered. However, data on safety and traffic volume were not available.

On the other hand, for the characterization of the urban streets, we collected data on the number of registered occurrences of crimes and deaths between 2010 and 2017, maps of location of lampposts (and its specifications) and land use, and disaggregated population data. In addition, for the estimate of the population around the urban streets, census data were gathered. However, data on traffic volume were not available.

The assessment of the vertical equity among residents within the specific areas of influence (railway and urban streets) was based on the estimate of the population nearby the transport barriers. For this purpose, we collected the following data from the 2010 Demographic Census: classes of monthly nominal income, groups of permanent mobility constraints, gender and age. However, the databases used for each transport barrier had different levels of aggregation.

Concerning the railway, the databases of the population by classes of monthly nominal income, the population with self-declared permanent mobility constraints, i.e. those who have difficulty walking or climbing stairs without the help of another person, and by age range were used by weighting areas. On the other hand, the gender data of the inhabitants were obtained from the database of the statistical grid.

In relation to the urban streets, monthly nominal income and permanent mobility constraints data were obtained by weighting areas, whereas data on gender and age were used at census tract level.

In addition, the spatial distribution of the urban population was based on the statistical grid from the 2010 Demographic Census and it was applied for both transport barriers. The statistical grid is available online in shapefile format.

In summary, besides the data used for the characterization of the transport barriers, five 2010 census databases combined with the spatial distribution of the population were used, as presented in Table 5.1. In addition to the demographic data, we used the geographic database from the Open Street Map (OSM) to locate the railway and create the urban street network.

Table 5.1 - Summary of the databases used and their corresponding level of aggregation per transport barrier

Database	Railway	Urban streets	Aggregation level	Source
Income	x	x	Weighting areas	2010 Demographic Census (IBGE)
Permanent mobility constraints	x	x	Weighting areas	2010 Demographic Census (IBGE)
Gender	x		Statistical grid	2010 Demographic Census (IBGE)
Age	x		Weighting areas	2010 Demographic Census (IBGE)
Gender and age		x	Census tracts	2010 Demographic Census (IBGE)
Occurrences of crimes and deaths		x	Disaggregated	Public Security Secretariat of São Paulo[1]
Location plan of lampposts and its specifications		x	Disaggregated	Municipal Secretariat of Public Services of São Carlos[2]
Land use map		x	Disaggregated	Municipal Secretariat of Housing and Urban Development of São Carlos[3]
Geometric Information System	x	x	Disaggregated	Open Street Map (OSM)

[1] in Portuguese stands for Secretaria de Segurança Pública de São Paulo - SSP/SP
[2] in Portuguese stands for Secretaria Municipal de Serviços Públicos
[3] in Portuguese stands for Secretaria Municipal de Habitação e Desenvolvimento Urbano
Source: The author

5.2 Case study 01: Assessment of the community severance caused by a Railway

Based on the data collected and the delimited areas of influence, we classified the railroad crossings and segments without railroad crossings, carried out the exploratory data analysis and chi-square (χ^2) tests of independence, and evaluated the standardized Pearson residuals, as detailed in the subsequent Subsections.

5.2.1 Classification of the types of railroad crossings and the segments without railroad crossings

The characterization of each type of railroad crossing (LC, UP, OP and PC) and segment without railroad crossing (SWC) was performed according to the evaluation of a set of criteria (Subsection 3.2.1). The criteria were evaluated through a field survey, in which it is worth noting that only one of the level crossings “LC1” had a segregated pedestrian walkway, but it was not fully accessible and had no handrails. In the regions without railroad crossings, where the barrier was made of metal or chain-link fencing, there were many segments in bad and flawed conditions, which enabled an informal passage of passers-by. However, informal crossings were not considered in this study. Moreover, garbage and high vegetation was found alongside almost the whole length of the railway, except for the railroad crossings OP1, UP1, UP3 and UP4.

The classification of the railroad crossings and segments without railroad crossings was performed according to the percentage of conformance of the qualitative assessments based on a set of criteria. The railroad crossings and segments that met from 90.0% to 100.0% of the established criteria were associated with class A. Those attending from 80.0% to 90.0% were associated with class B, from 70.0% to 80.0%, class C and from 33.0% to 70%, class D. Thus, the different types of railroad crossings and segments were classified, as shown in Table 5.2.

Table 5.2 - Classification of types of railroad crossings and segments without railroad crossings (as shown in Figure 4.3) according to the percentage of conformance to the analyzed criteria

Type of railroad crossings	LC		OP	UP				PC		SWC					
	1	2	1	1	2	3	4	1	2	1	2	3	4	5	6
% of conformance	86	71	100	83	83	73	73	80	80	60	63	47	55	50	53
Class	B	C	A	B	B	C	C	B	B	D	D	D	D	D	D

Note: LC - Level crossing; OP - Overpass; UP - Underpass; PC - Pedestrian crossing and SWC - Segment without railroad crossings.
Source: The author

Therefore, according to the proposed classification, based on the National Department of Transport Infrastructure (or DNIT, which in Portuguese stands for *Departamento Nacional de Infraestrutura de Transportes*) Railway Service Instructions (ISF - DNIT), only the overpass (OP1) was categorized as class A. The pedestrian crossings (PC1 and PC2), underpasses (UP1, UP2) and level crossing (LC1) located in the Centro, Jardim Beatriz, Planalto Paraíso and Vila Prado were categorized as class B. Underpasses (UP3, UP4) and level crossings (LC2) located in Vila Isabel and Cruzeiro do Sul were categorized as class C, while all segments without railroad crossings (SWC) were categorized as class D.

5.2.2 Exploratory data analysis

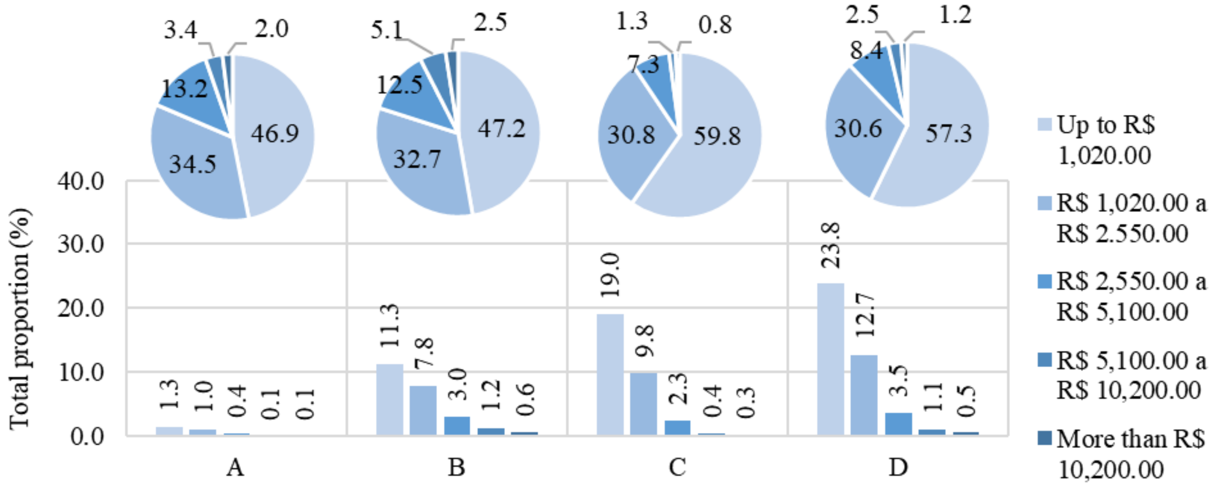
The exploratory data analysis of the variables of the different databases studied enabled us to describe aspects and make conjectures about the equity in the distribution of the number of residents along the railway and around the different types of railroad crossings.

For this reason, we produced graphs showing the total and partial proportions for each database, as shown in Figure 5.1 to Figure 5.4. Total proportions correspond to the analysis including the whole population on the database studied, whereas partial proportions indicate the analysis including only the population of a particular class of railway crossings. Therefore, from Figure 5.1 to Figure 5.4 (in percentage values), the distribution of the number of residents along the different types of railroad crossings and segments without railroad crossings regarding residents' demographic characteristics can be observed.

In relation to income distribution (Figure 5.1), most of the total number of residents (86.6%) has a monthly nominal income of less than R$ 2,550.00, and more than half of the total (55.4%) has a maximum income of R$ 1,020.00, nearly 36.3% below the average monthly nominal income of the city (excluding the rural area). The distribution of residents with income over R$ 2,550.00 have greater differences among classes A, B and classes C, D. There is a substantially reduced number of residents (1.4%) with a monthly nominal income greater than R$ 10,200.00. Classes C and D have residents predominantly with incomes lower than R$ 1,020.00 (59.8% and 57.3%, respectively) and in considerably higher proportions than in the other classes. Meanwhile, classes A and B have the higher portions of residents with income over R$ 10,200.00 (2.0% and 2.5%, respectively) and these proportions are almost twice the proportions in classes C and D.

In the case of income distribution, it is expected that residents with lower incomes will be substantial along the best classified crossings, since these groups tend to do more active trips and are also part of vulnerable social groups. However, it is observed that the distribution of the population along the railway is predominantly comprised of residents with low-income. This could be explained by the anecdotal evidence showing that land prices along the railway are around 4 times less than land prices in the central area of the city. Thus, this pattern of residents' distribution could be an indicative that the railway tends to cause urban segregation and marginalization.

Figure 5.1 - Total (bar graph) and partial (sector graph) proportions of the number of residents with income as a function of the different classes of railroad crossings and segments without railroad crossings

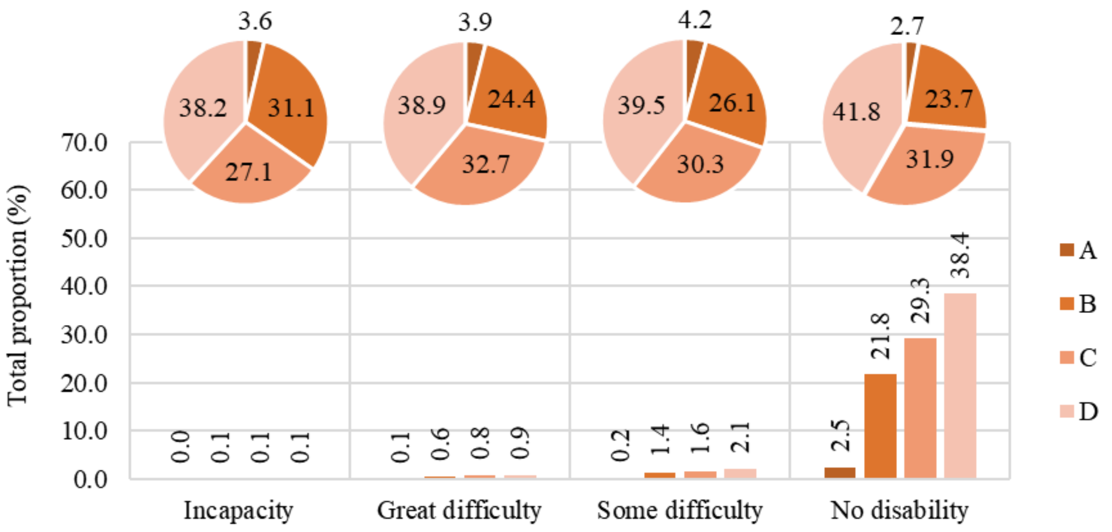


Source: The author

With respect to residents with permanent mobility constraints (Figure 5.2), the largest portion (31.1%) of residents who live near class B railroad crossings are self-declared incapable of walking or climbing stairs without the help of another person, whereas the largest portions of residents with great difficulty or some difficulty or no disability (38.9%, 39.5% and 41.8%, respectively) live near the segments without railroad crossings (class D). Inversely, the smallest portions of residents in this database were observed living around class A railroad crossings, in which the highest portion occurs among residents with some difficulty (4.2%). In addition, once the total proportions are analyzed, it can be observed that a small part of the residents distributed alongside the railway has permanent mobility constraints (8.0%), in which 0.3% are incapable, 2.3% have great difficulty and 5.3% some difficulty.

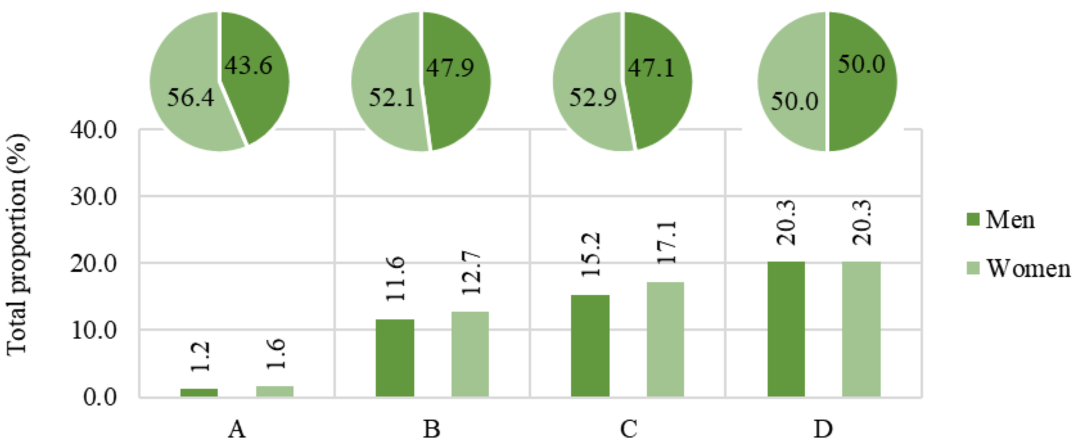
Even though a minority of the population lives close to the railroad that has some degree of mobility constraints, it is expected that the distribution of these vulnerable groups will be preferred along the best classified crossings. However, it is observed that the distribution of the population along the railway is similar for all groups, except for the self-declared incapable residents whose distribution is significant around class B railroad crossings.

Figure 5.2 - Total (bar graph) and partial (sector graph) proportions of the number of residents per class of types of railroad crossings (A is the best and D the worst) and segments without railroad crossings as a function of permanent mobility constraints



Source: The author

Figure 5.3 - Total (bar graph) and partial (sector graph) proportions of the number of residents by gender as a function of the different classes of railroad crossings and segments without railroad crossings



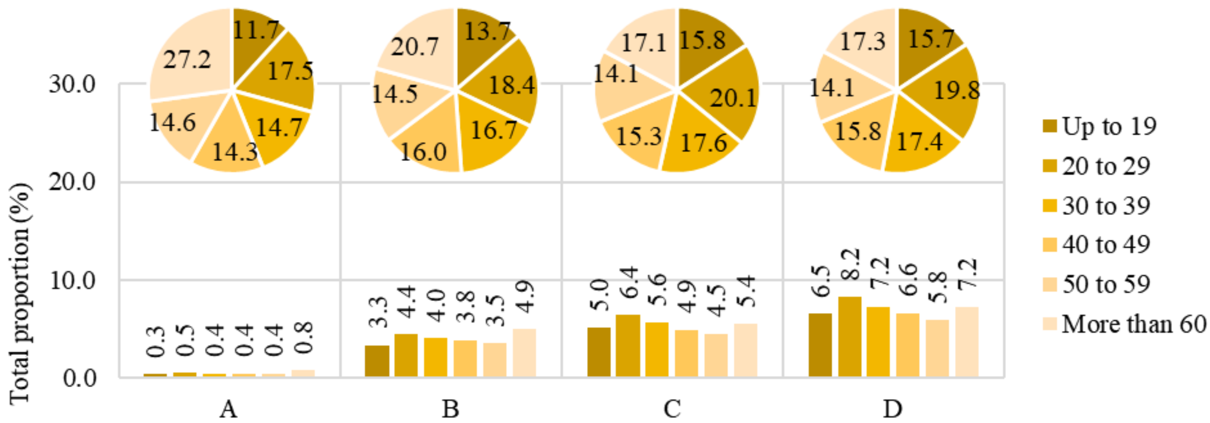
Source: The author

The number of women is proportionally higher surrounding class A railroad crossings (56.4%), while in the other classes of railroad crossings there is a slightly higher distribution for female residents (52.1% and 52.9%), as presented in Figure 5.3. It can also be observed that gender distribution along the segments without railroad crossings are balanced (50%, class D). In addition, almost half of the population (20.3% + 20.3%) lives in regions without any railroad crossings (class D), indicating that there may be a need for implementing more railroad crossings.

The distribution of residents who live close to class A and B railroad crossings is slightly higher for the residents aged over 60 years old (27.2% and 20.7%, respectively), as illustrated in Figure 5.4 . While in classes C and D, the age ranges from 20 to 29 years old are slightly greater than the other categories (20.1% and 19.8%, respectively). It can also be observed that the age range corresponding to up to 19 years old presents the lowest values for class A and B railroad crossings (11.7% and 13.7%, respectively).

In relation to age, it is expected that children and the elderly will be preferably distributed along the best classified crossings, since these vulnerable groups cannot walk long distances and for long periods. However, our data is aggregated for children and young adults (age range up to 19 years old), thus the results for children are unclear. For the elderly, it is observed that their distribution is considerably higher in the best classified railroad crossings.

Figure 5.4 - Total (bar graph) and partial (sector graph) proportions of the number of residents by age range as a function of the different classes of railroad crossings and segments without railroad crossings



Source: The author

5.2.3 Chi-square (χ^2) test of independence and standardized Pearson residuals

The exploratory data analysis (Subsection 5.2.2) showed relevant aspects between the variables but it did not validate the hypothesis of association among them, therefore the chi-square (χ^2) test of independence was used as a hypothesis test in contingency tables built from values of the variables of the different databases studied. Thus, the chi-square (χ^2) test is used to accept or reject the hypothesis of independence between the variables (H_0).

The calculations of the squared Pearson residual, the standardized Pearson residuals and the chi-square (χ^2) test of independence for the database concerning the variables of *classification* of railroad crossings and segments without railroad crossings and *(i) number of residents by range of monthly nominal income* are indicated in Table 5.3. The chi-square (χ^2)

value obtained was equal to 403.8902 and it corresponds to a p-value of 5.6777×10^{-79} (which is smaller than 0.0250). Hence, hypothesis H_0 is rejected at a level of significance of less than 0.0250, then a possible association between the variables of *classification* and (i) *number of residents by range of monthly nominal income* cannot be ruled out.

Table 5.3 - Squared Pearson residuals (PR^2), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *classification* (of the types of railroad crossings and segments without railroad crossings) and *number of residents by range of monthly nominal income*

Class	Calculations	Range of monthly nominal income (number of residents)					Total
		Up to R$ 1,020.00	R$ 1,020.00 to R$ 2,550.00	R$ 2,550.00 to R$ 5,100.00	R$ 5,100.00 to R$ 10,200.00	More than R$ 10,200.00	
A	Observed	266	196	75	19	11	567
	Expected	314	177	52	16	8	567
	PR^2	7.4426	1.9674	10.0331	0.7709	1.4011	
	SPR	-4.14	+1.72	+3.37	+0.90	+1.21	
B	Observed	2,270	1,573	603	243	119	4,808
	Expected	2,664	1,503	443	133	67	4,808
	PR^2	58.0327	3.2852	58.3111	92.0336	40.0690	
	SPR	-13.07	+2.50	+9.18	+11.15	+7.30	
C	Observed	3,836	1,972	470	81	53	6,413
	Expected	3,552	2,004	590	177	89	6,413
	PR^2	22.7015	0.5101	24.4532	52.1301	14.3965	
	SPR	+8.64	-1.04	-6.28	-8.87	-4.63	
D	Observed	4,804	2,564	708	213	97	8,387
	Expected	4,646	2,621	772	231	117	8,387
	PR^2	5.3414	1.2377	5.2050	1.3895	3.1787	
	SPR	+4.53	-1.76	-3.13	-1.56	-2.35	
Total	Observed	11,176	6,305	1,857	557	281	20,175
	Expected	11,176	6,305	1,857	557	281	20,175
$\chi^2 = \sum PR^2$		403.8902					
p-value		5.6777×10^{-79} (12 degrees of freedom)					

Note: PR^2 - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

In addition, based on the standardized Pearson residuals shown in Table 5.3, it was observed that there is a smaller than expected count of population that has an income less than R$ 1,020.00 who lives near classes A and B, that is, there is a deficit of residents as can be seen through the values -4.14 and -13.07, respectively, (in absolute values is higher than 2) and the negative signs. For the same social group presented previously, there is a larger than expected count of inhabitants that lives near classes C and D, that is, an excess of residents as can be perceived by the values +8.64 and +4.53, respectively, (in absolute values is higher than 2) and the positive signs. There are excesses of residents with an income greater than R$ 5,100.00 that live near class B railroad crossings, and deficits of residents of the same social groups living along classes C and D. Additionally, there is an excess of residents' distribution of the social group with an income between R$ 1,020.00 and R$ 2,550.00 that live near class B railroad crossings, an excess of residents with an income between R$ 2,550.00 and R$ 5,100.00 living around classes A and B and a deficit of residents with the later income range that live around classes C and D.

Analogously, we conducted the determination of the squared Pearson residuals, the standardized Pearson residuals and the chi-square (χ^2) test of independence for the databases regarding the variables of classification and for the other variables of: *(ii) number of residents with self-declared permanent mobility constraints; (iii) number of residents by gender and (iv) number of residents by age range*.

The standardized Pearson residuals and the chi-square (χ^2) test of independence for the database concerning the variables of *classification* of railroad crossings and segments without railroad crossings and the *number of residents with self-declared permanent mobility constraints* are indicated in Table 5.4. The chi-square (χ^2) test of independence presented only 6.3% of the total expected counts below 5.0. As the test permits up to 20% of the expected counts less than 5.0, the application of the test in the database was possible. Since the chi-square (χ^2) value (18.0581) matched a p-value of 0.0345 (which is smaller than 0.0500), we reject the hypothesis H_0 with a significance level of 0.05. Therefore, we cannot rule out the possibility of an association between the variables of *classification* and *(ii) number of residents with self-declared permanent mobility constraints*.

In addition, based on the standardized Pearson residuals shown in Table 5.4, it was observed that there is a larger than expected (excess) count of inhabitants that is self-declared with some difficulty living near the class A railroad crossings. For residents with no disability that live in the class A surroundings, there is a smaller than expected count (deficit) of population. In addition, the standardized Pearson residuals found for all permanent mobility constraints categories in classes B, C and D, and residents self-declared incapable or with great difficulty in class A are less than 2 (in absolute values). Therefore, the squared Pearson residuals (PR^2) values of those categories contribute little to the chi-square (χ^2) calculation and are consequently poorly associated with the permanent mobility constraints of the residents who live near the railroad crossings of those classes.

Table 5.4 - Squared Pearson residuals (PR²), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *classification* (types of railroad crossings and segments without railroad crossings) and *number of residents with self-declared permanent mobility constraints*

Class	Calculations	Permanent mobility constraints (number of residents)			No disability	Total
		Incapacity	Great difficulty	Some difficulty		
A	Observed	2	19	44	501	567
	Expected	2	13	30	522	567
	PR²	0.1691	2.1932	7.0385	0.8044	
	SPR	+0.42	+1.52	+2.77	-3.22	
B	Observed	21	116	278	4,396	4,812
	Expected	16	113	254	4,428	4,812
	PR²	1.5245	0.0716	2.2928	0.2308	
	SPR	+1.42	+0.31	+1.78	-1.95	
C	Observed	19	155	322	5,920	6,416
	Expected	22	151	339	5,905	6,416
	PR²	0.4819	0.1252	0.7753	0.0386	
	SPR	-0.84	+0.43	-1.10	+0.84	
D	Observed	26	184	420	7,757	8,388
	Expected	29	197	443	7,720	8,388
	PR²	0.1892	0.8049	1.1374	0.1807	
	SPR	-0.57	-1.19	-1.43	+1.97	
Total	Observed	69	474	1,065	18,574	20,182
	Expected	69	474	1,065	18,574	20,182
$\chi^2 = \sum PR^2$		18.0581				
p-value		0.0345 (9 degrees of freedom)				

Note: PR² - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

For the database related to the variables of *classification* and *(iii) number of residents by gender*, considering the result equivalent to 22.7977 and a p-value equal to 4.4500 x 10^{-5} (which is smaller than 0.0250), hypothesis H_0 is rejected with a significance level of 0.0250 (Table 5.5). Thus, also in this case the test shows evidence of association between the variables.

Regarding the standardized Pearson residuals shown in Table 5.5, it can be observed that there is a deficit of men who live around classes A and C railroad crossings, while there is an excess of men living near classes B and D. Inversely, for women there is an excess living near classes A and C railroad crossings, whereas there is a deficit living around classes B and D.

Table 5.5 - Squared Pearson residuals (PR^2), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *classification* (of the types of railroad crossings and segments without railroad crossings) and *number of residents by gender*

Class	Calculations	Population (number of residents)		Total
		Men	Women	
A	Observed	247	320	567
	Expected	278	289	567
	PR^2	-1.8469	1.8111	
	SPR	-2.62	+2.62	
B	Observed	4,016	4,016	8,031
	Expected	3,937	4,094	8,031
	PR^2	1.2521	-1.2278	
	SPR	+2.17	-2.17	
C	Observed	3,019	3,397	6,416
	Expected	3,145	3,271	6,416
	PR^2	-2.2528	2.2092	
	SPR	-3.71	+3.71	
D	Observed	4,016	4,016	8,031
	Expected	3,937	4,094	8,031
	PR^2	1.2521	-1.2278	
	SPR	+2.17	-2.17	
Total	Observed	11,297	11,748	23,045
	Expected	11,297	11,748	23,045
$\chi^2 = \sum PR^2$		22.7977		
p-value		4.4500×10^{-5} (3 degrees of freedom)		

Note: PR^2 - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

Furthermore, the chi-square (χ^2) test of independence obtained for the database regarding the variables of *classification* and *number of residents by age range* was equivalent to 74.7030 and it corresponds to a p-value of 6.4062 x 10-10 (which is smaller than 0.0250), as indicated in Table 5.6. Hence, the hypothesis H_0 is rejected at a level of significance of less than 0.0250, then we cannot rule out a possible association between the variables of *classification* and *(iv) number of residents by age*.

Regarding the standardized Pearson residuals shown in Table 5.6, it was noted that there is a portion of the population aged up to 19 who live near classes A and B, that is smaller than the expected (deficit). For the population aged between 20 and 29 years, there is a deficit of people living near the regions of class B railroad crossings. For the population over 60 years of age, there is an excess of residents near classes A and B railroad crossings and a deficit of residents near classes C and D.

Table 5.6 - Squared Pearson residuals (PR²), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *classification* (of the types of railroad crossings and segments without railroad crossings) and *number of residents by age range*

Class	Calculations	Age ranges (number of residents)						Total
		Up to 19	20 to 29	30 to 39	40 to 49	50 to 59	More than 60	
A	Observed	67	99	83	81	83	154	567
	Expected	86	110	98	89	80	104	567
	PR²	4.3932	1.1399	2.1188	0.6137	0.0615	24.2560	
	SPR	-2.31	-1.21	-1.62	-0.87	+0.27	+5.53	
B	Observed	661	886	806	769	697	997	4,815
	Expected	730	938	829	754	683	882	4,815
	PR²	6.5473	2.8875	0.6448	0.3005	0.2958	15.0029	
	SPR	-3.18	-2.17	-1.01	+0.68	+0.67	+4.91	
C	Observed	1,016	1,288	1,128	984	903	1,099	6,416
	Expected	973	1,250	1,105	1,004	910	1,175	6,416
	PR²	1.9015	1.1546	0.4677	0.3931	0.0593	4.9812	
	SPR	+1.81	+1.45	+0.91	-0.83	-0.32	-2.99	
D	Observed	1,316	1,658	1,458	1,324	1,180	1,447	8,384
	Expected	1,271	1,633	1,444	1,312	1,189	1,536	8,384
	PR²	1.6331	0.3912	0.1512	0.1135	0.0695	5.1253	
	SPR	+1.81	+0.91	+0.56	+0.48	-0.37	-3.28	
Total	Observed	3,059	3,931	3,475	3,159	2,862	3,697	20,183
	Expected	3,059	3,931	3,475	3,159	2,862	3,697	20,183
$\chi^2 = \sum PR^2$		74.7030						
p-value		6.4062×10^{-10} (15 degrees of freedom)						

Note: PR² - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

Table 5.7 presents a summary of excesses and deficits of residents with different demographic characteristics that live surrounding the distinct classes of railroad crossings and segments without railroad crossings. It also brings information about the positive (+) or negative (-) effect of the excess/deficit to the vertical equity in the residents' distribution along the railway. This happens because excesses/deficits of residents living near a determined class of railroad crossing or segment without crossings could denote a positive or negative effect to vertical equity depending on which social group it is related to.

In relation to the variable monthly nominal income, the deficit of residents with income less than R$ 1,020.00 living in classes A and B surroundings, and the excess of the same social group that lives near classes C and D denote a negative effect to the vertical equity. As in the excess of residents with an income greater than R$ 5,100.00 that live near class B railroad crossings, and the deficit of residents of the same social groups living along classes C and D indicate a negative effect to the vertical equity. On the contrary, a positive effect to the vertical equity corresponds to the excess of residents' distribution of the social group with an income between R$ 1,020.00 and R$ 2,550.00 that live near class B railroad crossings, an excess of residents' distribution of the social group with an income between R$ 2,550.00 and R$ 5,100.00 living around classes A and B and a deficit of residents with the later income range that live around classes C and D. This is because regarding the vertical equity, it is expected that residents with lower incomes (less than R$ 2,550.00) will be preferred along the best classified crossings, since these groups tend to do more active trips and are also considered vulnerable social groups. We also assumed that the excess of residents with an intermediary income (from R$ 2,550.00 to R$ 5,100.00) is positive.

Table 5.7 - Summary of excesses and deficits for the variables of classification (of the types of railroad crossings and segments without railroad crossings) regarding *income, permanent mobility constraints, gender and age*

		Class			
		A	B	C	D
Range of monthly nominal income	Up to R$1,020.00	Deficit (-)	Deficit (-)	Excess (-)	Excess (-)
	R$ 1,020.00 to R$ 2,550.00	NR[1]	Excess (+)	NR[1]	NR[1]
	R$ 2,550.00 to R$ 5,100.00	Excess (+)	Excess (+)	Deficit (+)	Deficit (+)
	R$ 5,100.00 to R$ 10,200.00	NR[1]	Excess (-)	Deficit (-)	NR[1]
	More than R$10,200.00	NR[1]	Excess (-)	Deficit (-)	Deficit (-)
Permanent mobility constraints	Incapacity	NR[1]	NR[1]	NR[1]	NR[1]
	Great difficulty	NR[1]	NR[1]	NR[1]	NR[1]
	Some difficulty	Excess (+)	NR[1]	NR[1]	NR[1]
	No disability	Deficit (+)	NR[1]	NR[1]	NR[1]
Gender	Male	Deficit (-)	Excess (+)	Deficit (+)	Excess (-)
	Female	Excess (+)	Deficit (-)	Excess (-)	Deficit (+)
Age range	Up to 19	Deficit (-)	Deficit (-)	NR[1]	NR[1]
	20 to 29	NR[1]	Deficit (+)	NR[1]	NR[1]
	30 to 39	NR[1]	NR[1]	NR[1]	NR[1]
	40 to 49	NR[1]	NR[1]	NR[1]	NR[1]
	50 to 59	NR[1]	NR[1]	NR[1]	NR[1]
	More than 60	Excess (+)	Excess (+)	Deficit (+)	Deficit (+)

[1] Not relevant. The standardized Pearson residual has a small contribution to the chi-square (χ^2) value
(+) Positive effect related to equity in the distribution of the number of residents
(-) Negative effect related to equity in the distribution of the number of residents
Source: The author

Concerning the variable permanent mobility constraints, the excess of residents with some difficulty of walking or climbing stairs that live in the class A railway crossing surroundings is a positive effect to the vertical equity, since it corresponds to a vulnerable group which cannot walk long distances and for long periods. Therefore, it is expected that this social group distribution will be preferred along the best classified crossings. On the other hand, the deficit of residents with no disability that live around the class A railway crossings is also a positive effect to the vertical equity, since individuals from this group do not have any mobility constraints and can walk greater distances.

Regarding residents' gender distribution, for a positive effect to the vertical equity, an excess of men or women living around classes A and B railroad crossings or a deficit of men or women living around classes C and D is desired, and the contrary for a negative effect. Thus, an excess of women in class A, an excess of men around class B, a deficit of men in class C and a deficit of women around class D indicate a positive effect to the vertical equity. On the other hand, a deficit of men in class A, a deficit of women around class B, an excess of women in class C and an excess of men around class D indicate a negative effect to the vertical equity.

Similarly, a positive effect to the vertical equity regarding age involves an excess of residents up to 19 years old or more than 60 years old around classes A and B railroad crossings, or a deficit of residents up to 19 years old or more than 60 years old around classes C and D. Thus, the deficit of residents up to 19 years old in classes A and B indicate a negative effect. On the other hand, the deficit of residents aged between 20 and 29 in class B, the excess of residents aged more than 60 around classes A and B and the deficit of residents aged more than 60 in classes C and D indicate a positive effect to the vertical equity.

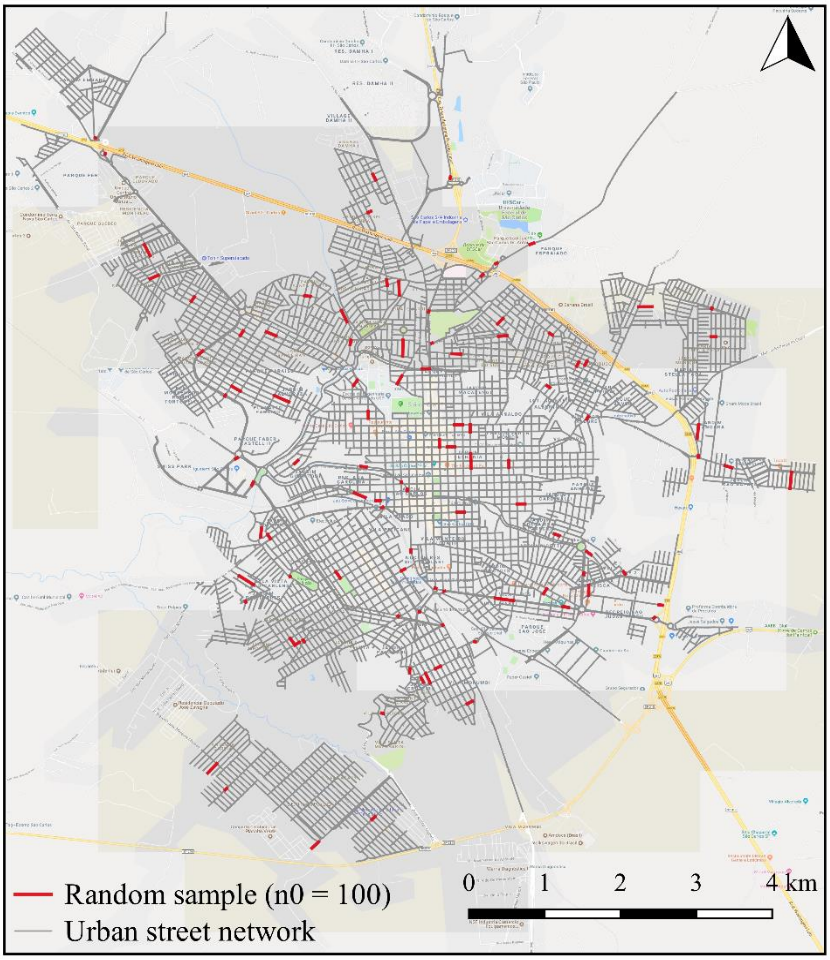
5.3 Case study 02: Assessment of the community severance caused by Urban Streets

Based on the data collected, the urban street network created and the delimited areas of influence, we selected a sample of urban streets and classified them. We also carried out the exploratory data analysis and chi-square (χ^2) tests of independence, and evaluated the standardized Pearson residuals, as detailed in the subsequent Subsections.

5.3.1 Classification of the urban streets

The urban street network of the study area was generated using the *Open Street Map (OSM)* database and the free software package *Quantum GIS v.3.4.6*. The resulting map comprised 13,329 segments of public urban streets, as represented in gray in Figure 5.5. Based on the resulting map, we selected a sample of segments of urban streets by simple random sampling. The sample size corresponded to n_0 = 100 segments of urban streets (at a 95% confidence level and with a 10% margin of error), as highlighted in red in Figure 5.5.

Figure 5.5 - Urban street network, in gray, and random sample (n_0 = 100 segments), highlighted in red

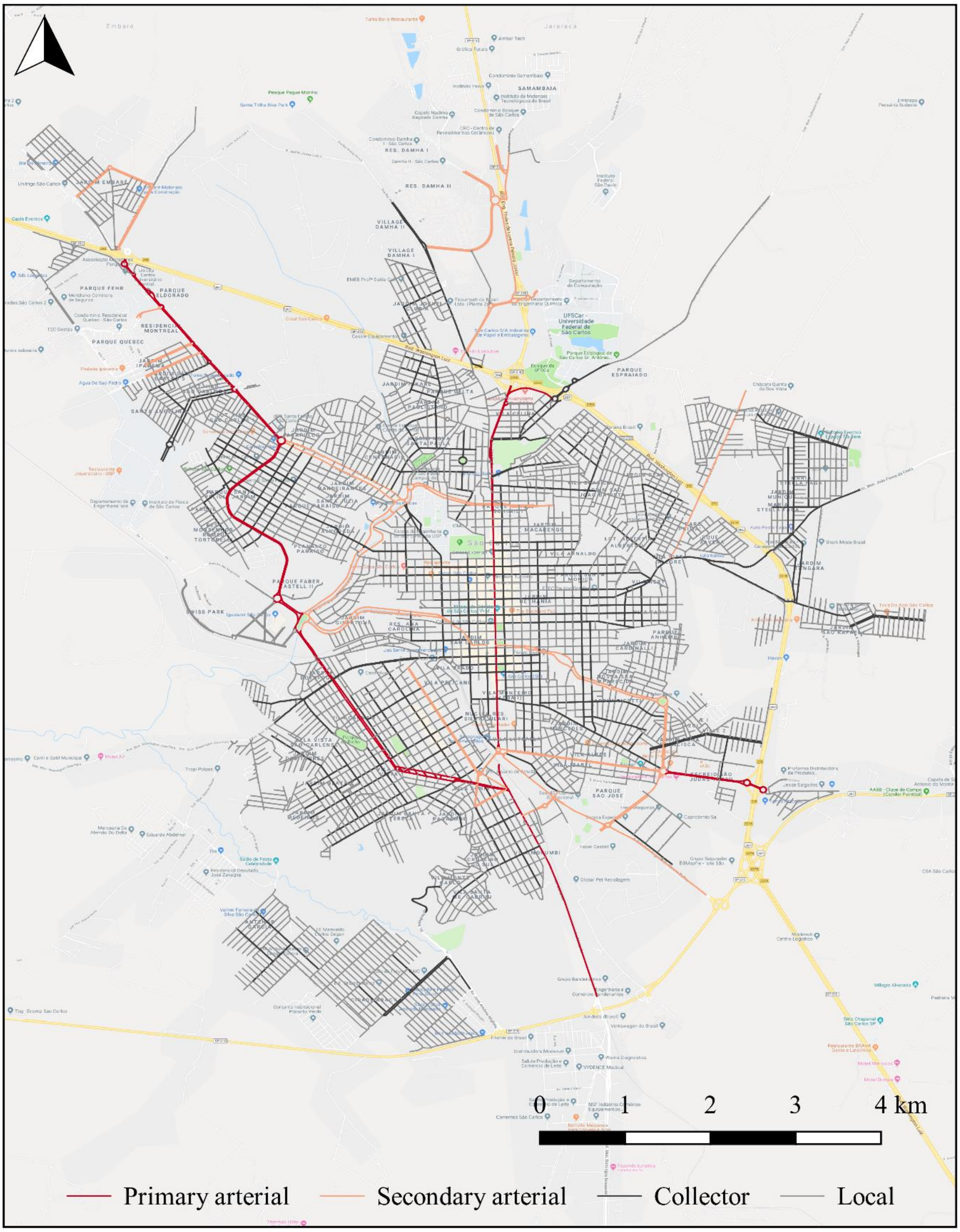


Source: The author

Thereby, considering the sample of segments of urban streets selected and the area of influence defined as a band of 400 meters, the segments were classified. The classification was carried out according to a qualitative assessment of the fourteen criteria described in Table 3.3 (Subsection 3.2.2). For each criterion, score values ranging from 0 to 1 were assigned. Score 0 corresponds to the worst mobility conditions for pedestrians and score 1 to the best conditions.

Criteria related to geometric design, pedestrian infrastructures, and maintenance conditions were evaluated through the analysis of the combined images of *Google Street View* and *Google Maps*. Although there is a limitation in this analysis, because some *Google Street View* images are from 2011, that is, some images are not current and may not represent the precise reality of the analyzed segments, the saving of time and financial resources, due to the great number of urban roads analyzed, and the ease of access to data justify the use of these image resources. The functional classification of the urban streets, which is another evaluation criterion, was also carried out with the help from the *Google Maps* images (and following the guidelines defined by DNIT (2010)), as shown in Figure 5.6.

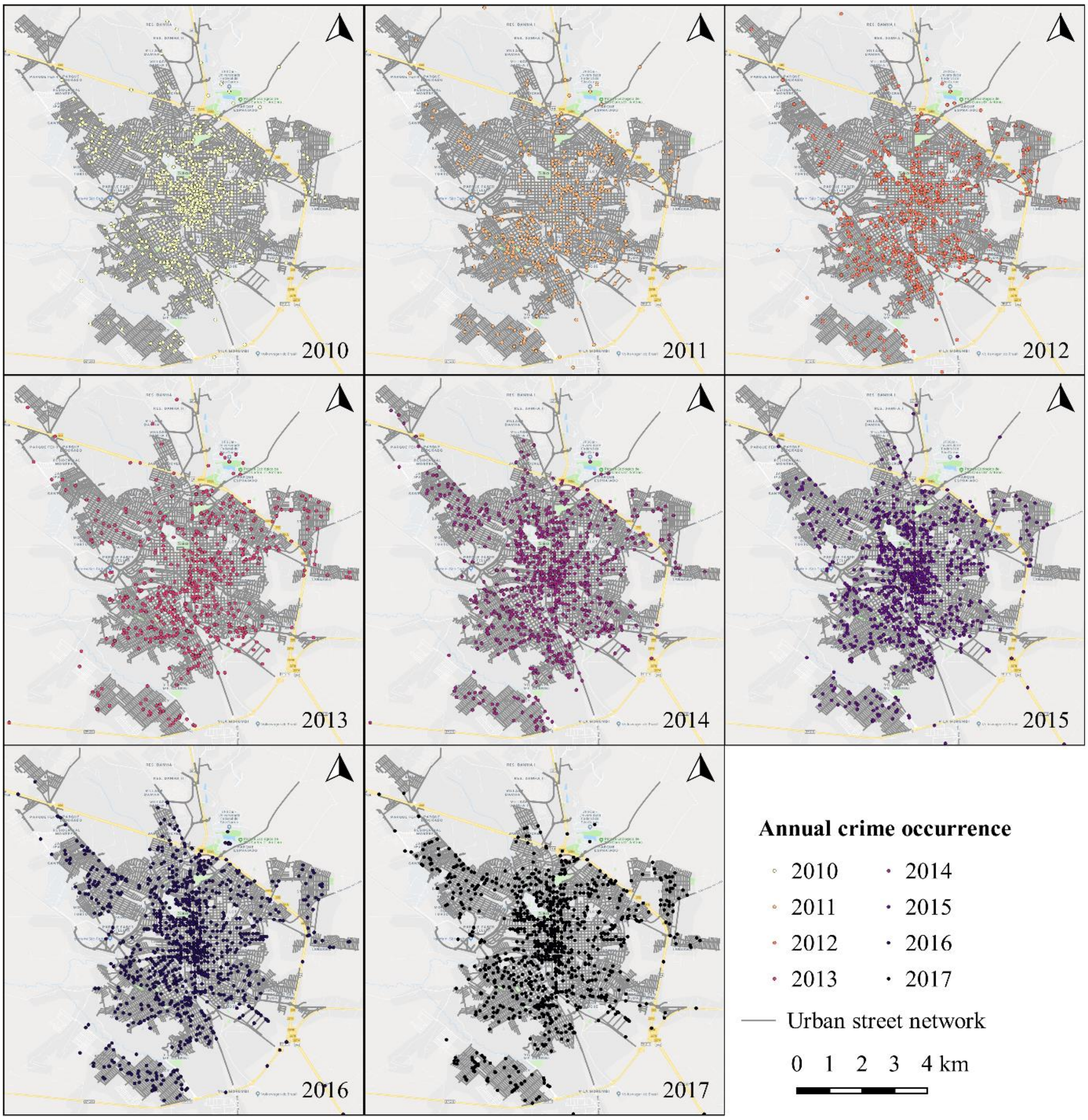
Figure 5.6 - Functional classification of the urban streets of São Carlos



Source: The author

The public lighting criterion, which is also related to maintenance conditions was assessed by the quality of the lampposts surrounding the segments. The location plan of the city lampposts and its specifications was provided by the Municipal Secretariat of Public Services of São Carlos.

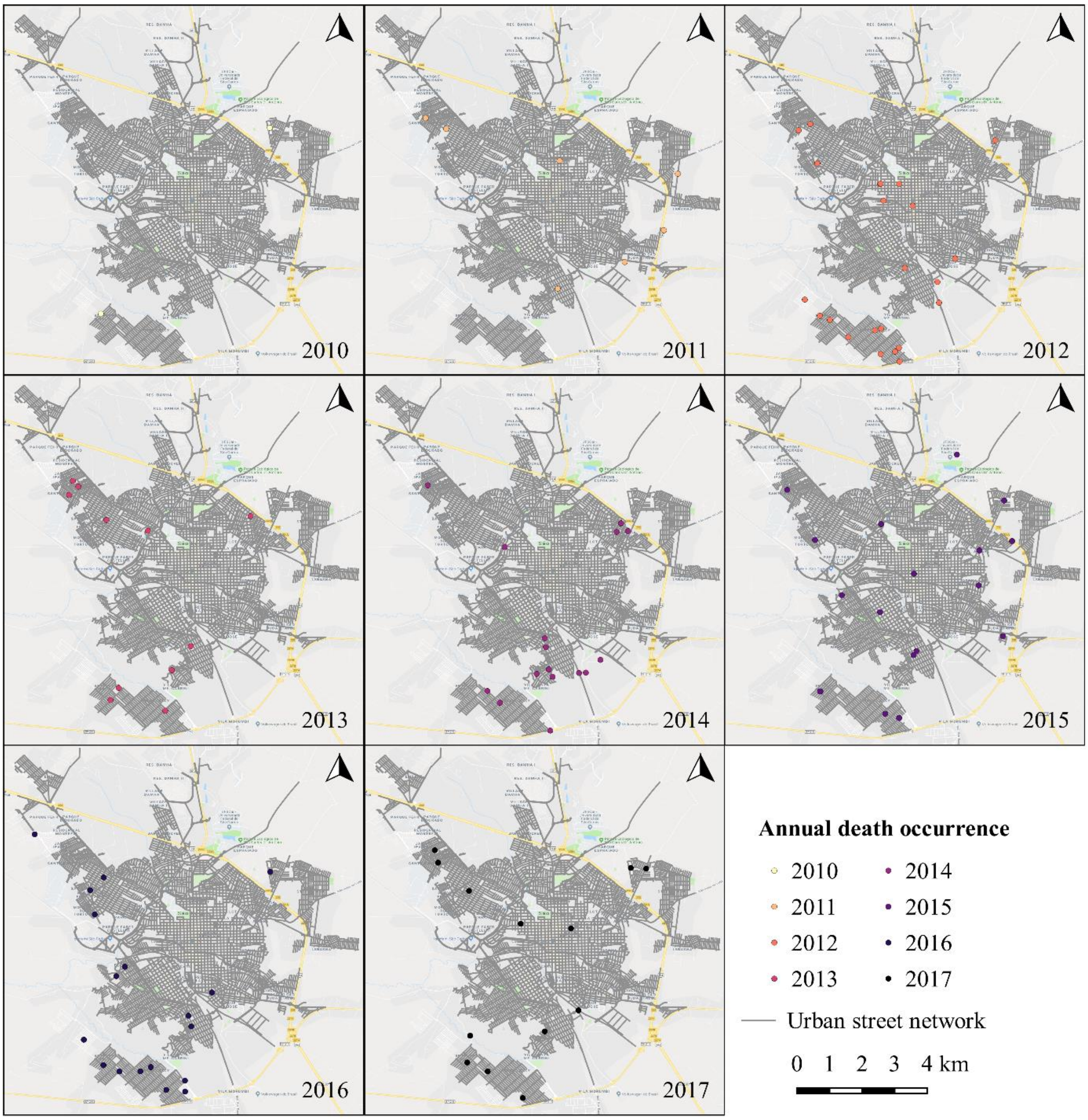
Figure 5.7 - Crime occurrence per year (from 2010 to 2017)



Source: Open data website of the Public Security Secretariat of São Paulo (in Portuguese: *Secretaria de Segurança Pública de São Paulo - SSP/SP*)

The evaluation of the criterion concerning safety was carried out based on the annual crime and death rates per 1000 inhabitants within the area of influence of the urban street segments sampled ($n_0 = 100$). In order to do so, we used data regarding the number of registered occurrences of crimes and deaths extracted from the open data website of the Public Security Secretariat of São Paulo. Part of the registered data presented the location by coordinates (longitude and latitude), another part presented only the address, or the intersecting streets, and another part of the data did not present any information of the location of the occurrence. Georeferencing of data by address or intersecting streets was conducted using the batch geocoding from the *Google Earth Pro software*. However, even using the *Google Earth Pro software* tools, the georeferencing of some of these occurrences was not achieved. Thus, we discarded part of the data due to the lack of location information and the impossibility of georeferencing the occurrences. Therefore, we created maps of registered occurrences of crimes and deaths whose georeferencing was reachable, as illustrated in Figure 5.7 and Figure 5.8.

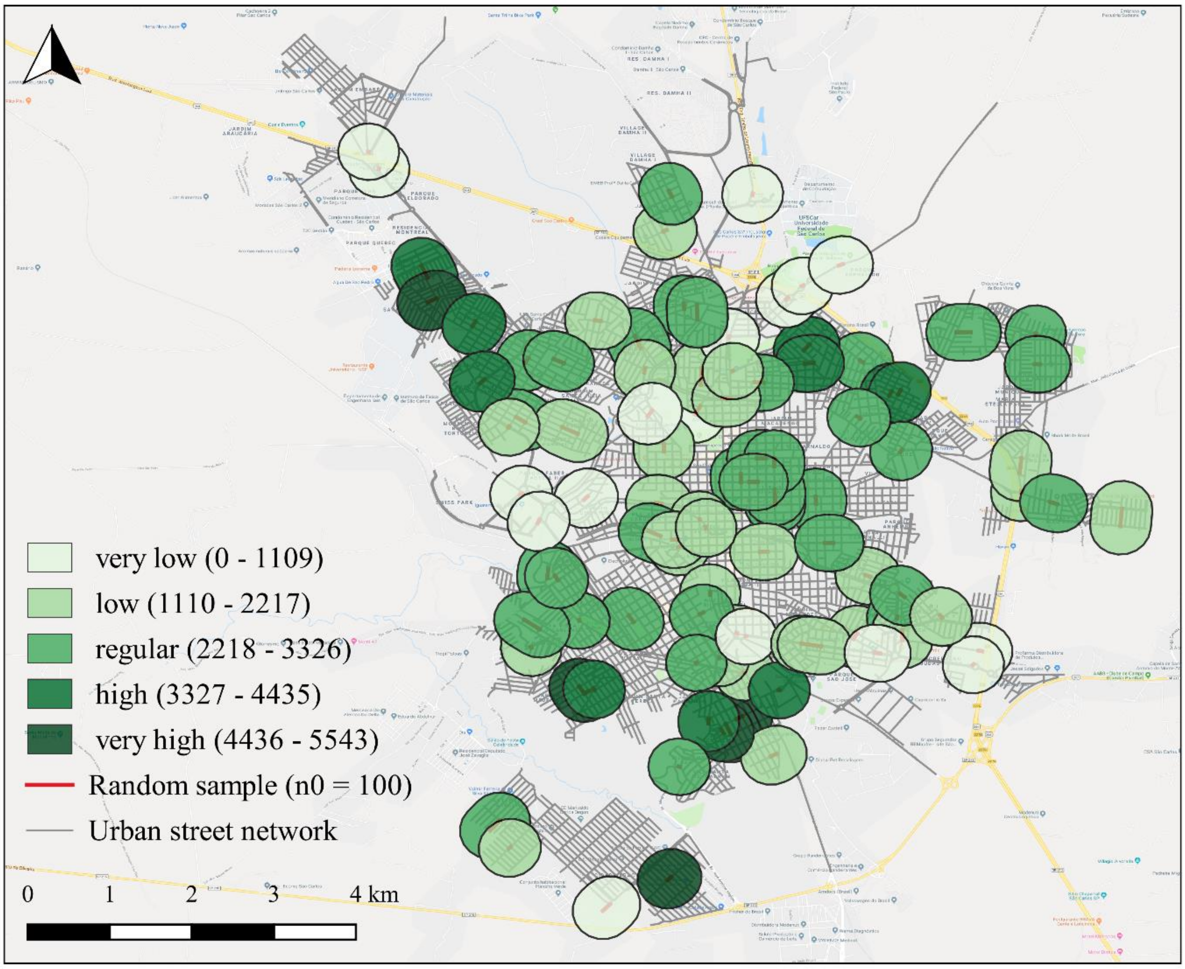
Figure 5.8 - Death occurrence per year (from 2010 to 2017)



Source: Open data website of the Public Security Secretariat of São Paulo (in Portuguese: *Secretaria de Segurança Pública de São Paulo - SSP/SP*)

Regarding the criterion related to population, we estimated the number of inhabitants from the area of influence using the statistical grid database. The scores assigned to the five levels of number of inhabitants were categorized into equal ranges, as indicated in Figure 5.9.

Figure 5.9 - Number of inhabitants within the areas of influence

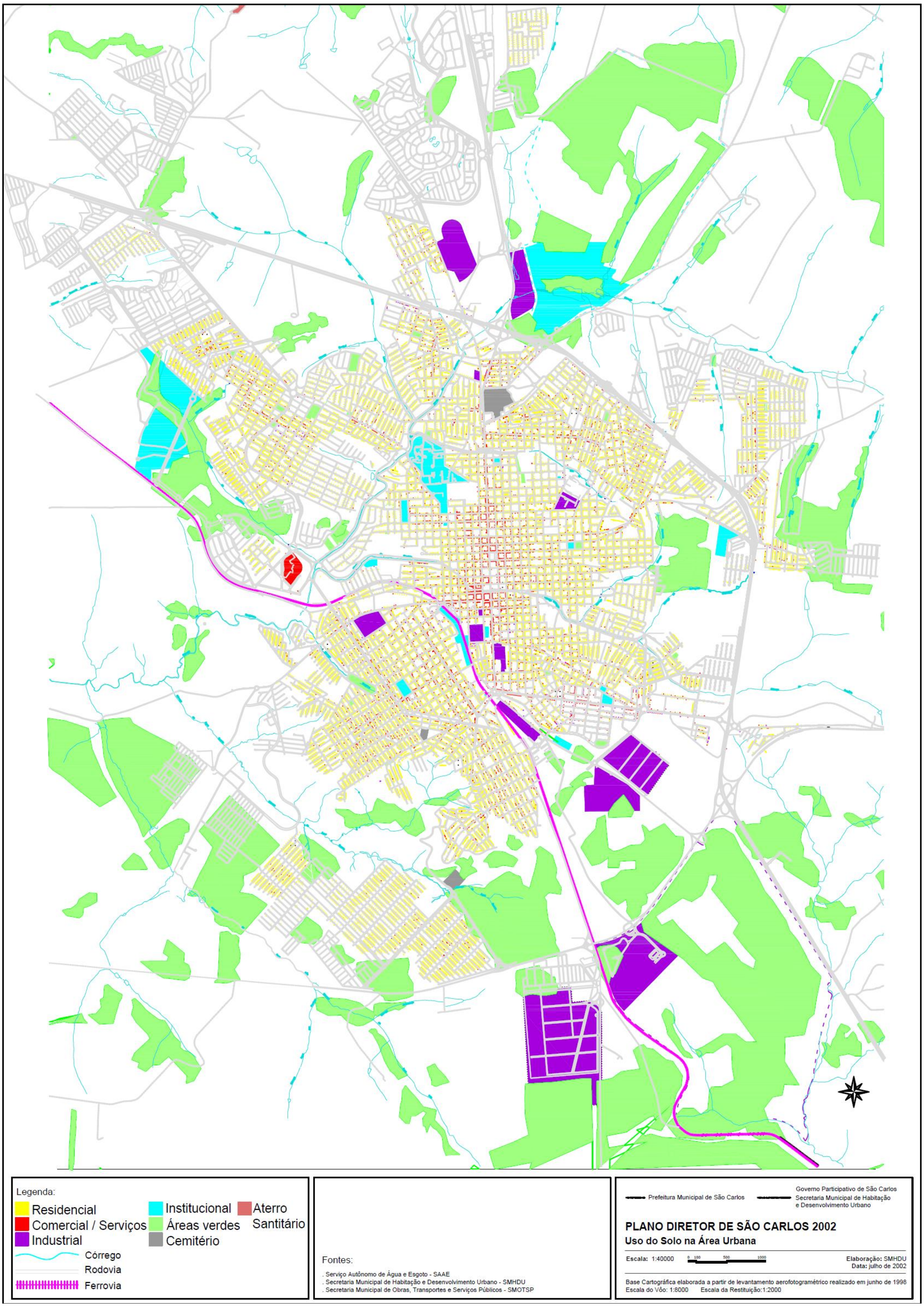


Source: The author

On the other hand, land use criterion was analyzed according to the land use map from the city Master Plan of 2002 provided by the Municipal Secretariat of Housing and Urban Development of São Carlos, as presented in Figure 5.10.

Having analyzed and calculated the criteria, we conducted the sum of all fourteen criteria and this sum resulted in the *PeCUS* index value for each segment of urban street. The value of the *PeCUS* index varies according to the quality of the conditions available for pedestrians to cross the segments of urban streets. Therefore, the *PeCUS* index also reflects, but inversely, the variation of community severance.

Figure 5.10 - Land use map in the urban area of São Carlos



Source: Municipal Secretariat of Housing and Urban Development of São Carlos (in Portuguese: Secretaria Municipal de Habitação e Desenvolvimento Urbano), 2002

Additionally, we conducted a cluster analysis to group the *PeCUS* index results into six classes, ranging from A to F, using the *k-means* clustering algorithm from the *IBM SPSS Statistics v.25* software. Class A corresponds to the best quality of pedestrian crossings and F corresponds to the worst evaluation. The number of segments grouped in each class of the *PeCUS* index is presented in Table 5.8. In addition, Table 5.9 contains the results for the highest and lowest *PeCUS* index per class, as well as their respective scores for each criterion assessed.

Table 5.8 - Number of segments of urban street assigned per class

Class	A	B	C	D	E	F
Number of cases	4	9	21	31	26	9

Source: The author

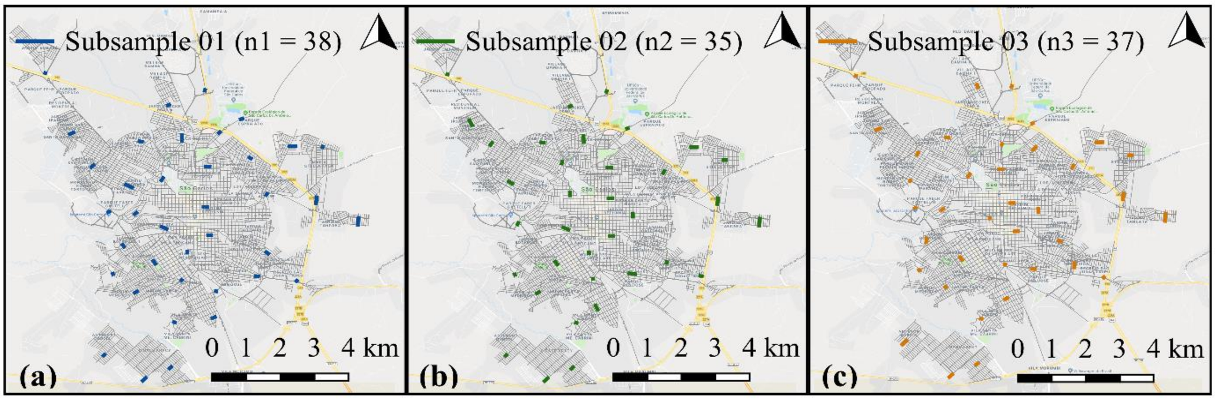
Table 5.9 - Results of the highest and lowest values for the *PeCUS* index and their corresponding scores for each criterion assessed (indicated by segment's ID)

Criterion	ID[1]											
	13062	332	335	12917	8235	1087	2969	9867	2422	5321	145	4546
Class	A	A	B	B	C	C	D	D	E	E	F	F
PeCUS index	11.86	10.71	10.14	8.89	8.27	7.14	7.07	6.17	5.92	5.02	4.92	3.62
Functional classification	0.67	0.67	0.67	0.67	0.33	0.67	1.00	1.00	1.00	1.00	0.00	1.00
Stream direction	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Number of lanes	0.67	0.67	1.00	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Zebra crossing	0.50	0.50	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zebra crossing location	0.67	0.67	0.67	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pedestrian visibility	1.00	0.50	0.50	0.50	1.00	1.00	0.50	0.00	0.00	0.00	1.00	0.00
Mandatory stop	1.00	0.60	0.00	0.60	0.20	0.00	0.20	0.60	0.20	0.40	0.00	0.00
Median	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Accessibility	0.80	0.80	1.00	0.40	0.60	0.00	0.00	0.40	0.00	0.00	0.00	0.00
Number of crimes and deaths	0.75	0.75	0.50	0.50	0.75	0.50	1.00	0.50	0.75	0.25	0.25	0.50
Number of inhabitants	1.00	1.00	1.00	1.00	0.25	1.00	1.00	1.00	0.25	0.25	0.00	0.00
Public lighting	0.80	0.80	0.80	0.80	0.80	0.80	0.20	0.00	0.80	0.20	0.00	0.20
Salubrity	1.00	1.00	0.75	0.50	1.00	1.00	1.00	0.50	0.75	0.75	1.00	0.25
Land use	1.00	0.75	0.75	0.75	1.00	0.50	0.50	0.50	0.50	0.50	0.00	0.00

[1] Identification number of the segments of urban streets
Source: The author

In order to estimate the number of residents within the area of influence of 400 meters, three subsamples were randomly selected from the original sample ($n_0 = 100$). The subsamples resulted in $n_1 = 38$ segments, highlighted in blue in Figure 5.11(a), $n_2 = 35$ segments, highlighted in green in Figure 5.11(b) and $n_3 = 37$ segments, highlighted in orange in Figure 5.11(c). This was done to avoid overlapping areas of influence in the sample units. The number of residents within the area of influence was estimated for each subsample, regarding the variables of *range of monthly nominal income*, *permanent mobility constraints*, *gender and age*.

Figure 5.11 - Subsample 01 ($n_1 = 38$ segments), highlighted in blue (a). Subsample 02 ($n_2 = 35$ segments), highlighted in green (b). Subsample 03 ($n_3 = 37$ segments), highlighted in orange (c)



Source: The author

The size of each subsample should be greater than 57,555 inhabitants, at a 95% confidence level and with a 10% margin of error. Therefore, for each subsample the number of residents within the area of influence was estimated regarding the aforementioned variables. Table 5.10 presents the total population of the three subsamples regarding each variable.

Table 5.10 - Subsamples population per variable

Variable	Subsample 01 ($n_1 = 38$)	Subsample 02 ($n_2 = 35$)	Subsample 03 ($n_3 = 37$)
Range of monthly nominal income	78,938	78,595	81,508
Permanent mobility constraints	78,938	78,600	81,514
Female age range[1]	40,686	40,393	41,999
Male age range[1]	38,449	38,453	39,848

[1] The combined population for female and male age ranges should be greater than 57,555
Source: The author

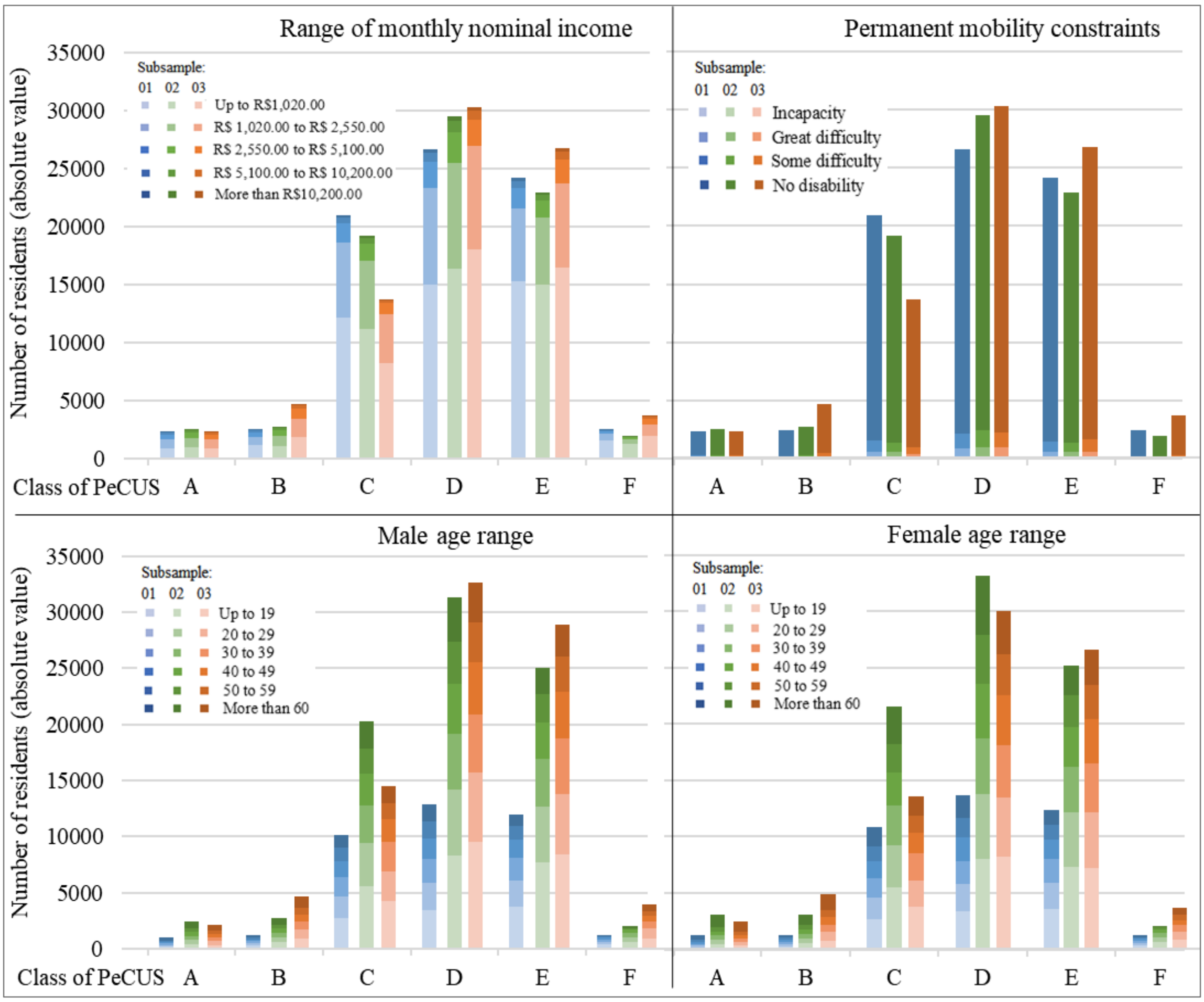
5.3.2 Exploratory data analysis

The exploratory data analysis of the variables of the different databases studied enabled us to describe aspects and make inferences about the equity in the distribution of the number of residents in the urban streets surroundings.

For this reason, using the free software package *Quantum GIS v.3.4.6*, we calculated the distribution of inhabitants according to the class of the *PeCUS* index regarding residents' demographic characteristics, per subsample, as shown in Figure 5.12 to Figure 5.16.

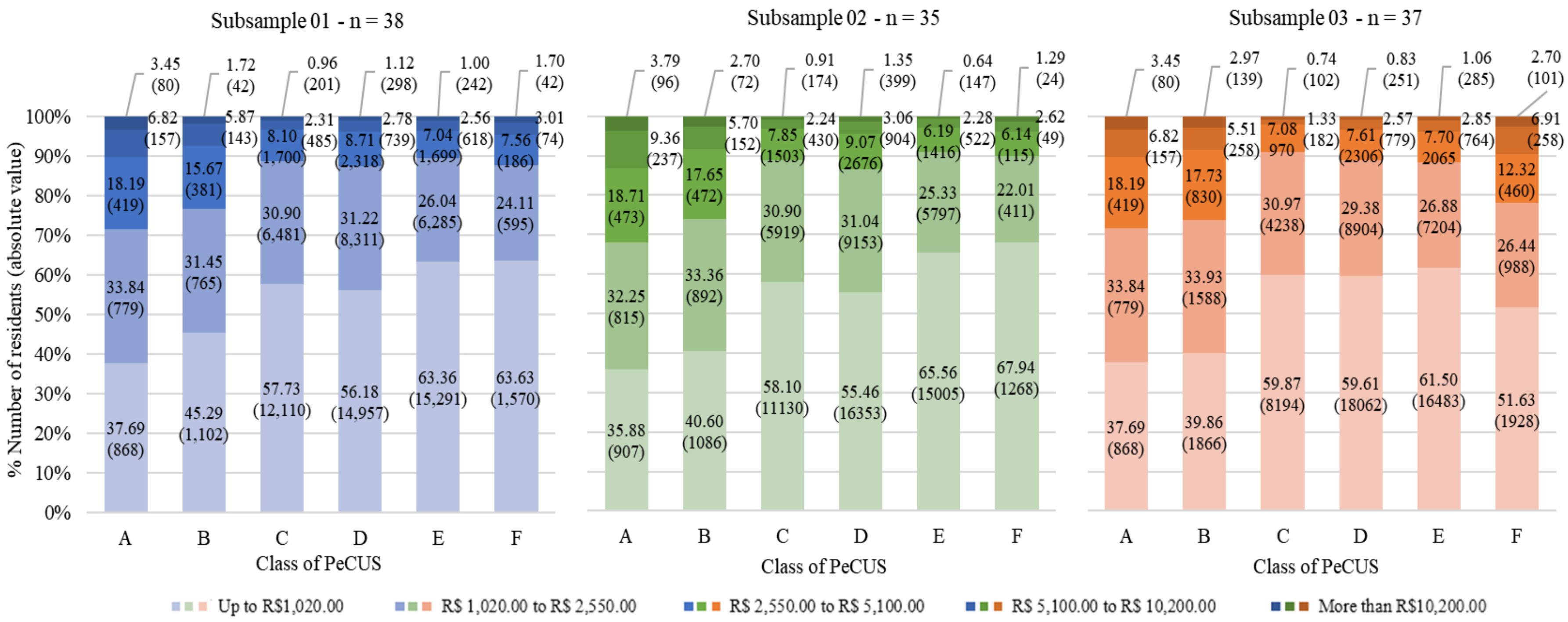
Figure 5.12 indicates an overview of the distribution of the residents for each variable per class of the *PeCUS* index and by subsample, in absolute values. Figure 5.13 to Figure 5.16 provide an overview of the main categories in the classes of the *PeCUS* index, per variable and per subsample, in percentage values.

Figure 5.12 - Graph of the number of residents distributed by class of *PeCUS* index, for each subsample and for each variable



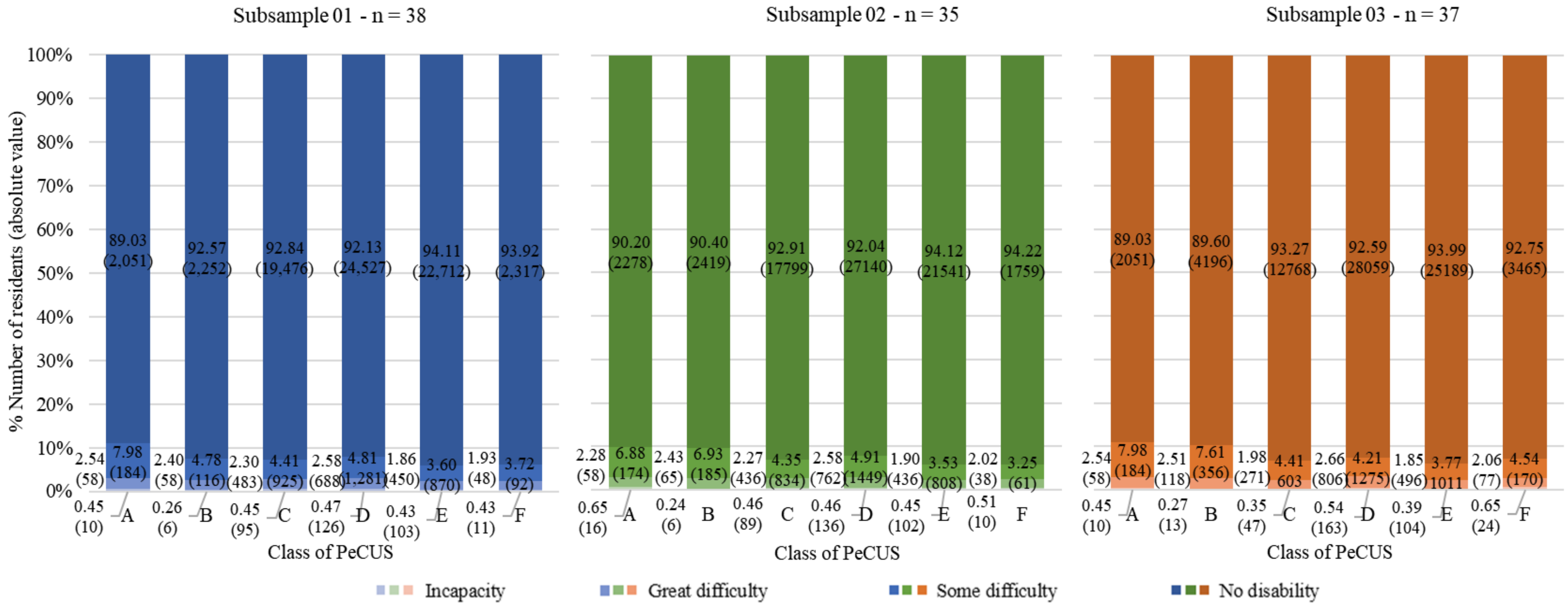
Source: The author

Figure 5.13 - Number of residents by range of monthly nominal income distributed by class of the *PeCUS* index, for the three subsamples



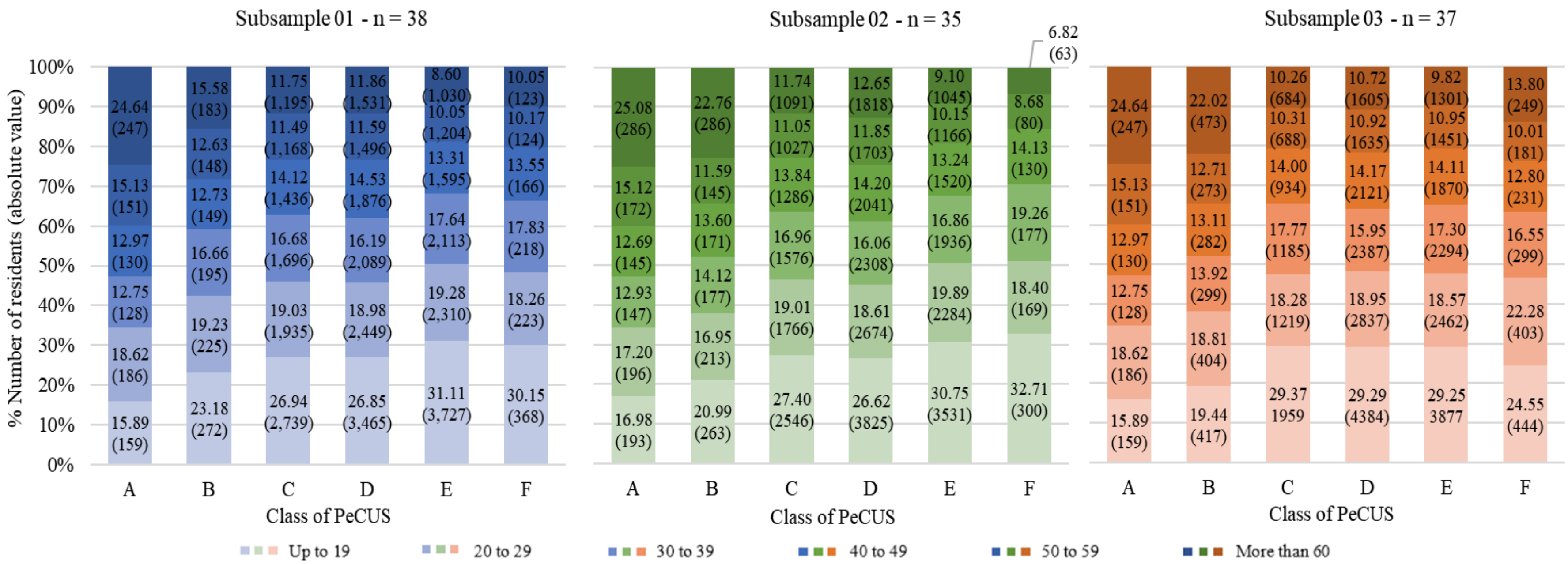
Source: The author

Figure 5.14 - Number of residents by permanent mobility constraints distributed by class of the *PeCUS* index, for the three subsamples



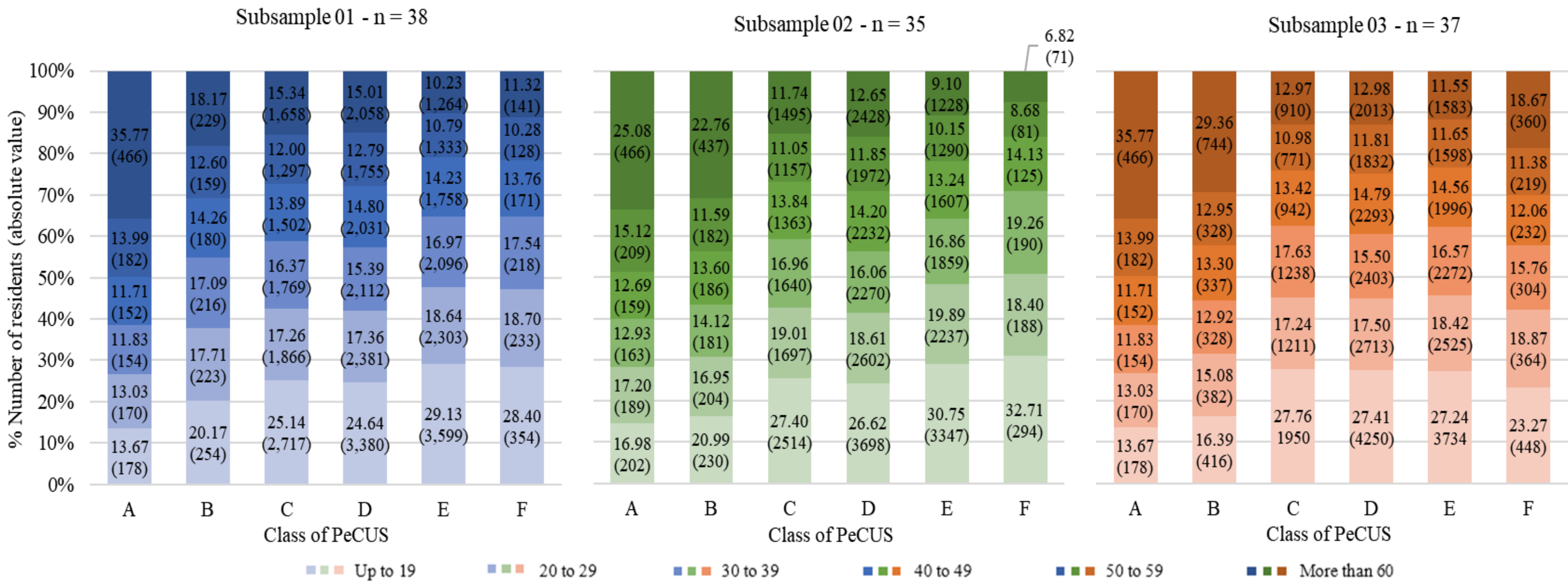
Source: The author

Figure 5.15 - Number of male residents by age distributed by class of the *PeCUS* index, for the three subsamples



Source: The author

Figure 5.16 - Number of female residents by age distributed by class of the *PeCUS* index, for the three subsamples



Source: The author

Figure 5.13 indicates that more than half of the residents in classes C, D, E and F have a monthly income below R$ 1,020.00, whereas the portion of the population with an income greater than R$ 5,100.00 that lives near classes A and B is about twice as large as the portion that lives in classes C, D, E and F. In Figure 5.14, it can be observed that around 11.0% of the population has some level of self-declared permanent mobility constraints. Furthermore, the proportion of residents with some difficulty in walking or climbing stairs without the help of another person is higher among the residents that live near class A. Moreover, most of the population that lives near class A streets are over 60 years old, and this proportion is higher among women (about 1/3) than among men (about 1/4) (as shown in Figure 5.16 and Figure 5.15, respectively). In addition, we can see in Figure 5.15 and Figure 5.16 that most residents in class E are aged up to 19 years old.

5.3.3 Chi-square (χ^2) test of independence and standardized Pearson residuals

The exploratory data analysis of the variables enabled us to describe aspects between the variables and make assumptions about the vertical equity in the distribution of the number of residents according to the distinct classes of the *PeCUS* index. However, it is not enough to validate the hypothesis of association between the variables or to identify the nature and the degree of dependence between the variables.

Thus, chi-square (χ^2) values were calculated for all subsamples by looking at the number of residents observed and expected in each of *the classes of the PeCUS* index when combined with the variables: *(i) number of residents by range of monthly nominal income; (ii) number of residents with self-declared permanent mobility constraints; (iii) number of male residents by age range and (iv) number of female residents by age range*, as indicated in Table 5.11 to Table 5.14.

All values calculated for the chi-square (χ^2) resulted in higher than the critical values of the chi-square (χ^2) distribution, considering their respective degrees of freedom, with a p-value less than 0.0250 (Table 5.11 to Table 5.14). Hence, the null hypothesis (H_0) was rejected at a level of significance of less than 0.0250 for all subsamples regarding each variable. Therefore, a possible association between the variables of *classification* and *(i) number of residents by range of monthly nominal income; (ii) number of residents with self-declared permanent mobility constraints; (iii) number of male residents by age range and (iv) number of female residents by age range* cannot be ruled out.

Additionally, we calculated the standardized Pearson residuals (Table 5.11 to Table 5.14) and found cells of the cross-classification tables with population values higher than expected, indicating excesses of residents with certain demographic characteristics living in the surroundings of specific classes of the *PeCUS* index. Analogously, we also found cells with less residents than expected, indicating deficits of residents.

Table 5.11 - Squared Pearson residuals (PR^2), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *class of the PeCUS* index and *number of residents by range of monthly nominal income*

	Range of monthly nominal income		Class of *PeCUS* A	B	C	D	E	F	$\chi^2 = \sum PR^2$
			PR^2 / SPR	PR^2 / SPR	PR^2 / SPR	PR^2 / SPR	PR^2 / SPR	PR^2 / SPR	
Sample 01	Up to R$1,020.00	PR²	165.5966	69.1635	0.6196	17.6514	112.7593	12.7704	1,398.3285 p-value = 0.0000 (20 degrees of freedom)
		SPR	-20.19	-13.06	-1.42	-7.98	+19.70	+5.61	
	R$ 1,020.00 to R$ 2,550.00	PR²	15.3687	3.4558	15.7304	29.5281	93.2165	23.5339	
		SPR	+4.74	+2.25	+5.51	+7.94	-13.79	-5.87	
	R$ 2,550.00 to R$ 5,100.00	PR²	254.9171	147.4206	3.7270	1.4601	59.9809	2.5504	
		SPR	+16.94	+12.89	-2.36	+1.55	-9.72	-1.70	
	R$ 5,100.00 to R$ 10,200.00	PR²	132.1241	81.4288	18.3493	0.0905	5.2623	0.3471	
		SPR	+11.83	+9.30	-5.07	-0.37	-2.79	+0.61	
	More than R$10,200.00	PR²	107.0355	6.9890	6.3769	0.1772	4.2129	6.4847	
		SPR	+10.56	+2.70	-2.96	-0.52	-2.48	+2.60	
Sample 02	Up to R$1,020.00	PR²	216.3650	142.3730	0.0377	38.1682	212.6371	30.3739	2,394.4367 p-value = 0.0000 (20 degrees of freedom)
		SPR	-23.13	-18.78	-0.35	-12.09	+26.79	+8.63	
	R$ 1,020.00 to R$ 2,550.00	PR²	7.7861	15.4338	17.8766	32.5031	120.0926	33.4140	
		SPR	+3.37	+4.75	+5.78	+8.57	-15.47	-6.96	
	R$ 2,550.00 to R$ 5,100.00	PR²	313.2668	266.1581	8.6695	12.8815	140.4435	11.9326	
		SPR	+18.80	+17.35	-3.54	+4.75	-14.71	-3.65	
	R$ 5,100.00 to R$ 10,200.00	PR²	359.5715	70.7999	29.7629	2.1820	31.8836	0.5693	
		SPR	+19.56	+8.69	-6.37	+1.90	-6.81	-0.78	
	More than R$10,200.00	PR²	151.1753	54.4155	10.5549	9.5947	53.2490	0.2648	
		SPR	+12.57	+7.55	-3.76	+3.94	-8.72	+0.52	
Sample 03	Up to R$1,020.00	PR²	154.0448	141.6954	0.0109	36.8381	215.6863	30.7090	3,384.0618 p-value = 0.0000 (20 degrees of freedom)
		SPR	-19.27	-18.72	-0.19	-11.87	+26.97	+8.67	
	R$ 1,020.00 to R$ 2,550.00	PR²	13.3330	159.6305	98.6148	20.0949	13.2221	6.0747	
		SPR	+4.42	+15.45	-13.31	+6.67	-5.25	+3.00	
	R$ 2,550.00 to R$ 5,100.00	PR²	228.2192	683.2526	169.3245	18.9873	13.1801	131.0956	
		SPR	+16.06	+28.07	-15.32	-5.70	-4.60	+12.23	
	R$ 5,100.00 to R$ 10,200.00	PR²	111.5908	169.1201	201.4427	7.5114	0.0125	297.5580	
		SPR	+10.88	+13.54	-16.20	-3.47	+0.14	+17.86	
	More than R$10,200.00	PR²	97.5429	181.0307	47.7966	24.4732	1.1420	110.8272	
		SPR	+10.08	+13.88	-7.82	-6.21	-1.30	+10.80	

Note: PR^2 - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

Table 5.12 - Squared Pearson residuals (PR²), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *class of the PeCUS* index and *number of residents with self-declared permanent mobility constraints*

	Permanent mobility constraints	Class of *PeCUS*						$\chi^2 = \sum PR^2$
		A	B	C	D	E	F	
		PR² SPR	PR² SPR	PR² SPR	PR² SPR	PR² SPR	PR² SPR	
Sample 01	Incapacity	0.0009 +0.03	1.8407 -1.38	0.0305 +0.20	0.4806 +0.85	0.1861 -0.52	0.0141 -0.12	159.4212 p-value = 0.0000 (15 degrees of freedom)
	Great difficulty	0.7906 +0.91	0.1936 +0.45	0.1610 +0.47	12.2227 +4.34	16.8825 -4.99	1.2089 -1.13	
	Some difficulty	67.5376 +8.53	0.8200 +0.94	0.0115 +0.13	10.7127 +4.11	34.2594 -7.18	2.5530 -1.66	
	No disability	3.7166 -7.34	0.0295 -0.65	0.0096 -0.43	1.7033 -6.02	3.7779 +8.76	0.2779 +2.01	
Sample 02	Incapacity	1.9515 +1.42	2.7080 -1.68	0.0203 +0.16	0.0155 +0.16	0.0745 -0.33	0.1221 +0.35	176.2151 p-value = 0.0000 (15 degrees of freedom)
	Great difficulty	0.0002 -0.01	0.2639 +0.53	0.0055 -0.09	11.8494 +4.41	14.3898 -4.56	0.5774 -0.78	
	Some difficulty	32.9237 +5.97	36.3061 +6.27	0.5554 -0.88	13.2354 +4.71	44.9493 -8.15	6.1785 -2.57	
	No disability	1.8353 -5.13	1.6560 -4.88	0.0273 +0.71	1.8136 -6.35	4.3468 +9.23	0.4095 +2.41	
Sample 03	Incapacity	0.0015 +0.04	3.1429 -1.83	2.9160 -1.88	6.1694 +3.14	1.9148 -1.69	3.4407 +1.90	282.6249 p-value = 0.0000 (15 degrees of freedom)
	Great difficulty	0.9224 +0.99	1.5718 +1.31	4.1892 -2.27	23.8044 +6.23	18.1616 -5.26	0.5199 -0.75	
	Some difficulty	66.3249 +8.45	108.2797 +10.96	0.0027 -0.06	2.9854 -2.23	25.0145 -6.24	0.1387 +0.39	
	No disability	3.7151 -7.34	5.4802 -9.05	0.1999 +1.84	0.3052 -2.62	3.4144 +8.46	0.0095 -0.37	

Note: PR² - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

Table 5.13 - Squared Pearson residuals (PR²), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *class of the PeCUS* index and *number of male residents by age range*

Sample	Male age range	A PR²	A SPR	B PR²	B SPR	C PR²	C SPR	D PR²	D SPR	E PR²	E SPR	F PR²	F SPR	$\chi^2 = \sum PR^2$
Sample 01	Up to 19	51.8167	-8.59	9.3942	-3.67	3.4365	-2.55	5.1964	-3.29	44.0890	+9.43	2.2003	+1.78	440.9800 p-value = 0.0000 (25 degrees of freedom)
	20 to 29	0.1024	-0.36	0.0186	+0.15	0.0058	-0.10	0.0488	-0.30	0.3080	+0.74	0.4161	-0.73	
	30 to 39	9.5290	-3.43	0.0057	-0.08	0.0279	-0.21	2.4011	-2.08	5.6742	+3.15	0.8591	+1.03	
	40 to 49	0.6462	-0.88	1.1869	-1.19	0.2962	+0.68	3.5293	+2.48	3.1252	-2.30	0.1195	-0.38	
	50 to 59	14.1266	+4.04	2.2480	+1.62	0.9603	+1.21	2.1168	+1.89	13.2168	-4.65	1.0874	-1.12	
	More than 60	161.1612	+13.65	19.9674	+4.82	2.7021	+2.03	4.9905	+2.91	72.5139	-10.89	1.4559	-1.30	
Sample 02	Up to 19	47.3952	-8.22	20.5191	-5.42	0.3371	-0.78	6.2204	-3.71	38.0352	+8.66	8.2382	+3.42	588.50284 p-value = 0.0000 (25 degrees of freedom)
	20 to 29	1.9176	-1.56	2.7568	-1.88	0.0019	+0.06	1.0955	-1.47	4.9793	+2.96	0.1658	-0.46	
	30 to 39	8.5415	-3.25	4.1114	-2.26	1.5247	+1.55	1.2323	-1.53	1.2686	+1.47	4.4422	2.33	
	40 to 49	0.9495	-1.07	0.0241	-0.17	0.0409	+0.25	2.0383	+1.94	2.2643	-1.93	0.0886	+0.32	
	50 to 59	15.9664	+4.30	0.2025	+0.49	0.1034	-0.39	6.1118	+3.31	10.5461	-4.11	5.0672	-2.42	
	More than 60	165.1911	+13.90	123.4563	+12.04	0.2769	-0.64	6.2512	+3.37	77.0939	-11.17	20.0476	-4.83	
Sample 03	Up to 19	53.8531	-8.77	58.5371	-9.28	3.2164	+2.32	6.2199	3.73	5.0905	+3.26	8.5828	-3.54	626.8240 p-value = 0.0000 (25 degrees of freedom)
	20 to 29	0.0277	-0.19	0.0019	-0.05	1.1242	-1.29	0.0825	+0.40	0.5368	-1.00	11.3247	+3.82	
	30 to 39	8.6794	-3.27	8.9539	-3.37	6.0903	+2.96	3.1882	-2.47	4.6529	+2.89	0.0001	+0.01	
	40 to 49	0.7225	-0.93	1.1442	-1.19	0.0037	+0.07	0.4146	+0.88	0.1830	+0.56	1.7688	-1.47	
	50 to 59	15.6313	+4.24	5.7830	+2.62	2.7615	-1.93	0.0645	-0.34	0.0207	-0.19	1.5662	-1.36	
	More than 60	152.3309	+13.28	209.9936	+15.83	8.1858	-3.33	6.7603	-3.50	30.5486	-7.19	8.7784	+3.22	

Note: PR² - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

Table 5.14 - Squared Pearson residuals (PR^2), standardized Pearson residuals (SPR) and chi-square (χ^2) test of independence between the variables of *class of the PeCUS* index and *number of female residents by age range*

Sample	Female age range		Class of *PeCUS* A	B	C	D	E	F	$\chi^2 = \sum PR^2$
			PR² / SPR	PR² / SPR	PR² / SPR	PR² / SPR	PR² / SPR	PR² / SPR	
Sample 01	Up to 19	PR²	73.8875	15.3145	1.6469	6.6851	54.5348	3.3552	844.7090 p-value = 0.0000 (25 degrees of freedom)
		SPR	-10.14	-4.61	-1.74	-3.69	+10.27	+2.16	
	20 to 29	PR²	15.6468	0.0037	0.8517	0.5958	7.0622	0.8002	
		SPR	-4.43	+0.07	-1.19	-1.04	+3.51	+1.00	
	30 to 39	PR²	14.9543	0.7173	0.3545	4.6669	5.3528	1.5153	
		SPR	-4.29	+0.94	+0.76	-2.90	+3.03	+1.37	
	40 to 49	PR²	5.8717	0.0003	0.9128	3.0665	0.0008	0.1980	
		SPR	-2.66	+0.02	-1.20	+2.32	-0.04	-0.49	
	50 to 59	PR²	4.6462	0.4710	0.0429	8.5816	13.4258	2.8487	
		SPR	+2.33	+0.74	+0.26	+3.83	-4.68	-1.83	
	More than 60	PR²	419.8737	13.2649	8.2918	4.8379	142.7315	7.6972	
		SPR	+22.50	+4.00	+3.63	+2.92	-15.46	-3.04	
Sample 02	Up to 19	PR²	64.9696	47.8639	0.0011	7.7309	54.7619	11.5313	1070.4551 p-value = 0.0000 (25 degrees of freedom)
		SPR	-9.50	-8.16	+0.04	-4.08	+10.15	+3.98	
	20 to 29	PR²	12.5372	8.4009	0.9784	2.2106	19.3764	2.5572	
		SPR	-3.97	-3.25	-1.25	-2.07	+5.74	+1.78	
	30 to 39	PR²	13.1887	7.4773	6.5595	4.4116	1.6154	11.8788	
		SPR	-4.02	-3.03	+3.21	-2.90	+1.64	+3.80	
	40 to 49	PR²	6.5938	0.9658	0.3551	4.4629	0.1911	0.4919	
		SPR	-2.82	-1.08	-0.74	+2.89	-0.56	-0.77	
	50 to 59	PR²	9.9111	0.6319	1.1926	9.4005	8.7599	10.2106	
		SPR	+3.42	+0.86	-1.34	+4.14	-3.74	-3.45	
	More than 60	PR²	309.8895	227.9703	0.0006	6.5728	157.7142	37.0898	
		SPR	+19.45	+16.69	-0.03	+3.52	-16.14	-6.69	
Sample 03	Up to 19	PR²	77.3669	91.9794	7.1519	9.6728	6.4328	6.0594	1246.5370 p-value = 0.0000 (25 degrees of freedom)
		SPR	-10.40	-11.51	+3.41	+4.56	+3.60	-2.93	
	20 to 29	PR²	15.0530	8.7113	0.3405	0.0112	6.1085	1.9489	
		SPR	-4.34	-3.35	-0.70	-0.15	+3.32	+1.57	
	30 to 39	PR²	13.8508	14.5605	12.4432	1.9515	3.3333	0.0421	
		SPR	-4.12	-4.29	+4.22	-1.92	+2.43	-0.23	
	40 to 49	PR²	5.6030	1.3786	2.8472	4.1249	1.4619	6.1097	
		SPR	-2.60	-1.31	-2.00	+2.76	+1.59	-2.73	
	50 to 59	PR²	5.6421	3.1498	3.4516	0.0767	0.0823	0.2130	
		SPR	+2.57	+1.95	-2.17	+0.37	-0.37	-0.50	
	More than 60	PR²	408.1721	388.4165	10.9669	23.5842	80.7261	23.5125	
		SPR	+22.19	+21.98	-3.92	-6.61	-11.84	+5.37	

Note: PR² - Squared Pearson residual; SPR - Standardized Pearson residual
Source: The author

Table 5.15 presents a summary of the excesses and deficits found for each class of the *PeCUS* index regarding each variable. They also provide information about the positive (+), negative (-) or unclear (+/-) effect of the excess/deficit to the vertical equity, since the effect varies depending on which social group it is related to.

Table 5.15 - Summary of excesses and deficits for each class of the *PeCUS* index per variable for the three subsamples

		Class of *PeCUS*					
		A	B	C	D	E	F
Range of monthly nominal income	Up to R$1,020.00	Deficit (-)	Deficit (-)	NR[1]	Deficit (+/-)	Excess (-)	Excess (-)
	R$ 1,020.00 to R$ 2,550.00	Excess (+)	Excess (+)	NR[1]	Excess (+/-)	Deficit (+)	NR[1]
	R$ 2,550.00 to R$ 5,100.00	Excess (+)	Excess (+)	Deficit (+/-)	NR[1]	Deficit (+)	NR[1]
	R$ 5,100.00 to R$ 10,200.00	Excess (-)	Excess (-)	Deficit (+/-)	NR[1]	NR[1]	NR[1]
	More than R$10,200.00	Excess (-)	Excess (-)	Deficit (+/-)	NR[1]	NR[1]	NR[1]
Permanent mobility constraints	Incapacity	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	Great difficulty	NR[1]	NR[1]	NR[1]	Excess (+/-)	Deficit (+)	NR[1]
	Some difficulty	Excess (+)	NR[1]	NR[1]	NR[1]	Deficit (+)	NR[1]
	No disability	Deficit (+)	NR[1]	NR[1]	Deficit (+/-)	Excess (+)	NR[1]
Male age range	Up to 19	Deficit (-)	Deficit (-)	NR[1]	NR[1]	Excess (-)	NR[1]
	20 to 29	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	30 to 39	Deficit (-)	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	40 to 49	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	50 to 59	Excess (+)	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	More than 60	Excess (+)	Excess (+)	NR[1]	NR[1]	Deficit (+)	NR[1]
Female age range	Up to 19	Deficit (-)	Deficit (-)	NR[1]	NR[1]	Excess (-)	NR[1]
	20 to 29	Deficit (-)	NR[1]	NR[1]	NR[1]	Excess (-)	NR[1]
	30 to 39	Deficit (-)	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	40 to 49	Deficit (-)	NR[1]	NR[1]	Excess (+/-)	NR[1]	NR[1]
	50 to 59	Excess (+)	NR[1]	NR[1]	NR[1]	NR[1]	NR[1]
	More than 60	Excess (+)	Excess (+)	NR[1]	NR[1]	Deficit (+)	NR[1]

[1] Not relevant. The standardized Pearson residual has a small contribution to the chi-square (χ^2) value
(+) Positive effect related to vertical equity in the distribution of the number of residents
(+/-) Unclear effect related to vertical equity in the distribution of the number of residents
(-) Negative effect related to vertical equity in the distribution of the number of residents
Source: The author

According to Table 5.15, there is a deficit of residents with an income less than R$ 1,020.00 and an excess of residents with an income greater than R$ 5,100.00 living near the best quality classes of the *PeCUS* index (classes A and B). In addition, there is an excess of people with an income less than R$ 1,020.00 living near the worst quality classes of the *PeCUS* index (classes E and F). As, in terms of vertical equity, it is expected that low-income residents will be preferably distributed throughout the best quality classes, the distributions mentioned above represent negative effects to the vertical equity. In contrast, the excess of residents with an income range between R$ 1,020.00 and R$ 5,100.00 that live nearby the best classes (A and B) and the deficit of inhabitants from the same income range that live close to one of the worst classes (class E) indicate positive effects to the vertical equity.

Regarding permanent mobility constraints, Table 5.15 shows an excess of people with some difficulty and a deficit of people with no disability living near one of the best classes of the *PeCUS* index (class A), which indicate positive effects to the vertical equity of residents' distribution. In addition, the deficit of people with great difficulty and some difficulty, and the excess of people with no disability living near one of the worst classes (class E) also indicate positive effects.

Concerning men's age, Table 5.15 points out deficits of men aged up to 19 and between 30 and 39 who live near the best classes of the *PeCUS* index, and excess of men up to 19 years old who live near one of the worst classes (class E), which represent negative effects to the vertical equity of residents' distribution. On the other hand, the excess of men aged more than 50 living near the best classes and the deficit of men aged more than 60 living near one of the worst classes (class E) indicate positive effects.

Regarding women's age, Table 5.15 presents deficits of women up to 49 years old who live near one of the best classes (class A) of the *PeCUS* index and excesses of women up to 29 years old that live around one of the worst classes (class E), which indicates negative effects to the vertical equity. In contrast, excesses of women aged more than 50 who live near the best classes and the deficit of women aged more than 60 living near one of the worst classes (class E) indicates positive effects.

5.4 Summary of the assessment of the community severance caused by transport barriers

The main results from the assessment of community severance caused by a railway and urban streets are summarized in Table 5.16.

Table 5.16 - Summary of the main results from the assessment of community severance regarding railway and urban streets (continues)

		Railway	Urban streets
Classification	Criteria	scores range from 1 to 3	scores range from 0 to 1
			the sum of all criteria resulted in the *PeCUS* index
	Scale	ranges from A to D	ranges from A to F
		the higher the quality of the pedestrian crossing the lower the severity of the barrier effect	the higher the quality of the pedestrian crossing the lower the severity of the barrier effect
Exploratory data analysis	Income	Classes A and B have the higher portions of residents with income over R$ 10,200.00, while classes C and D have residents predominantly with incomes lower than R$ 1,020.00	The population with an income greater than R$ 5,100.00 that lives near classes A and B is about twice as large as the portion that lives in other classes. More than half of the residents in classes C, D, E and F have a monthly income below R$ 1,020.00
	Permanent mobility constraints	Population distribution is similar for all social groups, except for the self-declared incapable residents whose distribution is significant around class B	The proportion of residents with some difficulty is higher among the residents that live near class A
	Gender	The number of women is proportionally higher surrounding class A, while in the other classes B and C there is a slightly higher distribution for female and in class D, the gender distribution is balanced	The majority of the population (male and female) that lives near class A streets are over 60 years old, and this proportion is higher among women (about 1/3) than among men (about 1/4).
	Age range	The distribution of residents who live close to class A and B railroad crossings is slightly higher for the residents aged over 60 years old. While in classes C and D, the age ranges from 20 to 29 years old are slightly greater than the other age ranges	
Chi-square (χ^2) test of independence		Evidence of association between the variables *classification* and: *(i) number of residents by range of monthly nominal income, (ii) number of residents with self-declared permanent mobility constraints, (iii) number of residents by gender and (iv) number of residents by age range.*	Evidence of association between the variables *classification* and: *(i) number of residents by range of monthly nominal income, (ii) number of residents with self-declared permanent mobility constraints, (iii) number of female residents by age range and (iv) number of male residents by age range.*
Standardized Pearson residuals	Income	There is an excess of residents with an income greater than R$ 5,100.00 that live near class B and an excess of residents with income less than R$ 1,020.00 who lives near classes C and D	There is an excess of residents with an income greater than R$ 5,100.00 living near classes A and B. In addition, there is an excess of people with an income greater than R$ 1,020.00 living near the classes E and F
	Permanent mobility constraints	There is an excess of residents with some difficulty that live near class A	There is an excess of people with some difficulty living near class A, a deficit of people with great difficulty and some difficulty living near class E

Table 5.16 - Summary of the main results from the assessment of community severance regarding railway and urban streets (conclusion)

<table>
<tr><td rowspan="2">Standardized Pearson residuals</td><td>Gender</td><td>There is deficit of women who live around classes A and C, while there is an excess of women living near classes B and D. Inversely, for men there is an excess living near classes A and C, whereas there is a deficit living around classes B and D</td><td rowspan="2">There is an excess of men up to 19 years old who live near class E, an excess of men aged more than 60 living near classes A and B. There are deficits of women up to 49 years old who live near the class A, and excesses of women up to 29 years old that live around class E. In contrast, there are excesses of women aged more than 50 who live near class A</td></tr>
<tr><td>Age range</td><td>There is a deficit of residents aged up to 19 in classes A and B, an excess of residents aged more than 60 around classes A and B</td></tr>
<tr><td rowspan="4">Vertical equity</td><td>Income</td><td>The distribution of residents concerning income is vertically equitable, except for residents with income less than R$ 1,020.00 and more than R$ 5.100.00</td><td>The distribution of residents concerning income is vertically equitable, except for residents with income less than R$ 1,020.00 and more than R$ 5.100.00</td></tr>
<tr><td>Permanent mobility constraints</td><td>The distribution of residents with permanent mobility constraints is vertically equitable</td><td>The distribution of residents with permanent mobility constraints is vertically equitable</td></tr>
<tr><td>Gender</td><td>The distribution of female or male residents is vertically equitable</td><td rowspan="2">The distribution of male or female residents is vertically equitable for residents aged more than 50 years old. In contrast, for the other female or male age ranges, the distribution is not vertically equitable</td></tr>
<tr><td>Age range</td><td>The distribution of residents regarding age is vertically equitable, except for residents aged up to 19 years</td></tr>
</table>

Source: The author

As presented in Table 5.16, the classification criteria and scale from the railway and urban streets were suitable for the different transport infrastructures. Therefore, in the case of the urban streets, in which their similar characteristics allowed a unified evaluation, the creation of an index (*PeCUS* index) was possible.

The exploratory data analysis for both infrastructures had similar results, while the results from the chi-square (χ^2) test of independence were the same. On the other hand, the standardized Pearson residual results for gender slightly diverged, while for the other variables they were similar. Finally, regarding the vertical equity, the results for gender and age differed slightly, while for the other variables they were the same.

6 CONCLUSIONS

This study presented a simple and low-cost analytical approach for the assessment of community severance based on the classification of the quality of pedestrian crossings on two different types of transport infrastructures of a medium-sized city: railway and urban streets. The quality of the railroad crossings was based in the evaluation of a set criteria suitable for each type of railroad crossing. On the other hand, the quality of Pedestrian Crossings on Urban Streets (*PeCUS*) was performed through an index. The *PeCUS* index was used to identify variations in the quality of crossings in a random sample (n_0 = 100) of urban streets. Additionally, the approach was used to identify possible inequities in the surroundings of the distinct classification groups for both transport infrastructures. This can be seen as an indirect assessment of community severance.

The analysis of the chi-square (χ^2) tests of independence and the standardized Pearson residuals carried out in the area of influence of the railroad crossings, segments without railroad crossings and the urban streets subsamples (n_1 = 38, n_2 = 35 e n_3 = 37), suggested an association between the variables of *classification* and the demographic characteristics studied. Furthermore, the standardized Pearson residuals were also used to indicate deficits and excesses of residents regarding *monthly nominal income*, *permanent mobility constraints*, *gender* and *age* surrounding the railway and the urban streets. Additionally, it pointed out that the conditions for pedestrian urban mobility of some population strata may be impaired.

Concerning the railway, the study found evidence that low-income (less than R$ 1,020.00) residents tend to live around the worst classes of crossings and segments without crossings, while high-income (greater than R$ 5,100.00) inhabitants tend to live around one of the best classes. Residents with some difficulty in walking or climbing stairs tend to live near the best class crossings, men or women tend to live near the best classes. Residents aged up to 19 tend not to live in the surroundings where the best classes are, and residents aged more than 60 tend to live near the best classes. Particularly, the population who live near the segments without railroad crossings (class D) are prone to traveling longer distances in order to transpose the railway. This could be an indicative that this population is more susceptible to active trip diversion or suppression, thus their health and well-being condition could tend to be more affected.

In relation to the urban streets, we found evidence that residents with an income over R$ 1,020.00, have some difficulty in walking or climbing stairs, or are over 50 years old tend to live near the best quality of *PeCUS* index. In contrast, residents with an income less than R$ 1,020.00, no disability or aged up to 19 tend to live near the worst quality of *PeCUS* index.

In summary, the inhabitants that live in the railway surroundings and have a high income, have permanent mobility constraints, are men or women, or are aged above 60 years old are well assisted in relation to pedestrian urban mobility. Moreover, residents that have a low income or are aged up to 19 years old are poorly assisted in relation to pedestrian urban mobility. In addition, the inhabitants nearby the urban streets that have an income higher than R$ 1,020.00, permanent mobility constraints or are aged above 50 years old are well assisted in relation to pedestrian urban mobility. Moreover, low-income residents (nearby urban streets) or aged up to 19 are poorly assisted in relation to pedestrian urban mobility conditions.

Hence, even with the limitation of aggregated data, the research responds to the questions formulated in Chapter 1, indicating that the assessment of community severance by the analysis of the quality of pedestrian crossings on railways and urban streets is feasible. In addition, the study proposed an index capable of estimating the quality of pedestrian crossings on urban streets, the *PeCUS* index. Furthermore, the study shows evidence of an association between the distribution of residents with distinct demographic characteristics around transport barriers and the quality of pedestrian crossings. Moreover, it also highlights that the distribution of the number of residents surrounding the distinct classes of railroad crossings and segments without railroad crossings is vertically equitable for vulnerable social groups, except for residents with a low income and aged up to 19 years old. Besides that, the distribution of the number of residents surrounding the distinct classes of the *PeCUS* index is vertically equitable for vulnerable social groups (e.g. residents with permanent mobility constraints and elderly), except for low-income residents and for male/female residents aged up to 19 years old.

7 RECOMMENDATIONS

Particularly in Brazil, the analysis of the community severance caused by transport infrastructures still requires more detailed studies. The main contributions of this study include the methodology developed and tested, and the index of quality of Pedestrian Crossings on Urban Streets (the *PeCUS* index) created and tested here as well.

This study showed evidence that the community severance caused by different transport infrastructures has a distribution of the number of residents surrounding the distinct classes of quality of pedestrian crossings, substantially similar. This could be a consequence of the aggregated data used.

For further research, we recommend incorporating the land use criterion for railway assessment. We also suggest using this study in other medium-sized cities and comparing the results in order to identify patterns regarding the different classes of quality of pedestrian facilities to transpose transport barriers and the demographic characteristics of its surrounding population. In addition, we recommend using disaggregated data for the analysis, which could be collected through questionnaires or interviews. Using disaggregated data helps to capture the perception of residents living in the transport barriers surroundings and track the variability of the distribution of the population. The analysis of residents' perceptions could be an important contribution, because it may identify the suppression of trips by active modes, impacts on social interactions and impacts on the well-being of the inhabitants, which are also important factors to characterize community severance.

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[1] According to the American Psychological Association (APA) style.

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