The Spatial Distribution of Noise Barriers in Montreal: A Barrier to Achieve Environmental Equity

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Abstract:

Road traffic noise constitutes a major problem for the health of populations exposed to it over extended periods. From a perspective of environmental equity, we focus on the distribution of four segments of the population—children, seniors, low-income individuals and visible minorities—in noise disturbance zones near major traffic routes of the Montreal Metropolitan Community. First, some corridors along these traffic routes with different levels of noise disturbance are defined according to a number of parameters; subsequently, the overrepresentation of the groups studied is assessed with the help of two indices. Next, we attempt to determine whether these groups have access to noise barriers, abatement measures to mitigate the noise. To assess the overrepresentation of the four groups under examination in protected and unprotected noise disturbance zones, multinomial logistic regression models were constructed for the entire territory, and then for six subregions. The results reveal a situation doubly inequitable for low-income persons and, to a lesser extent, for visible minorities. Indeed, these groups more often live close to major traffic routes and are less likely to be protected by noise barriers. In contrast, children are doubly advantaged.

1. Introduction

Road traffic noise is an important component of the quality of life since it constitutes the second most harmful factor for health and well-being, as well as the most prevalent source of noise in the urban environment (WHO, 2011, 2018). In particular, prolonged exposure to road traffic noise may cause physical and mental health problems: sleep disturbance (Basner and McGuire, 2018; Öhrström and Skanberg, 2004); hypertension, risk of stroke, risk of diabetes, and especially ischaemic heart disease (Brown and van Kamp, 2017; van Kempen et al., 2018); and may increase risk of depression, agitation, stress and anxiety (Clark and Paunovic, 2018; Passchier-Vermeer and Passchier, 2000). Some population groups are also more vulnerable to noise. Prolonged exposure to noise may affect children's cognitive development (problems with language, reading, concentration, and hyperactivity) (Evans and Maxwell, 1997; Söderlund et al., 2007). On their side, seniors are more sensitive to the characteristics of their immediate environment, since they are more confined to their residence, due to their reduced mobility (Day, 2010; Muzet, 2007; Phillips et al., 2005; WHO, 2007). Thus, when they reside in places with higher noise levels, they could be exposed to them for longer periods in a day.

Recognizing the harmful effects of noise, a number of organizations and countries have adopted policies and directives aiming to control the harmful effects of road traffic noise (WHO, 1999, 2018). The province of Québec is no exception; in 1998, the Quebec Ministry of Transportation adopted a policy on road traffic noise (MTQ, 1998, 2012). The goal of this policy was to reduce the noise levels in sensitive zones which require an adequate soundscape (residential, institutional and recreational zones) through the implementation of mitigation measures (MTQ, 1998). In most countries, noise barriers "constitute the principal means of reducing noise along highways and provincial routes" due to their considerable efficiency

(Girard, 1996). Therefore, for a number of years, this has generally been the preferred method in Québec. This study is thus interested in both the representation of vulnerable groups in residential noise disturbance zones and their representation in residential zones protected by noise barriers in proximity to major traffic routes.

2. Literature background

2.1. Environmental equity and exposure to noise

Environmental justice is a concept with three overarching dimensions: recognition of all groups in a society (justice as recognition); involvement of these groups in decisional processes (procedural justice); and the distribution of both burdens and risks (Konisky, 2015; Schlosberg, 2007; Walker, 2012), as well as environmental resources or benefits (parks, vegetation, large supermarkets, health facilities, bicycle paths, etc.) amongst various groups of the population (Apparicio et al., 2016b; Boone et al., 2009; Houde et al., 2018; Landry and Chakraborty, 2009; Pham et al., 2012) (environmental equity). Stemming from concern about environmental inequities, analysis of social, political and institutional processes is essential in order to understand the distribution of inequalities (Schlosberg, 2007).

In this article, we are interested only in this last dimension, namely, environmental equity. The field of transportation has been approached from a distributional justice perspective in various ways in the literature. One is to conduct a distributional analysis of the risks arising from the operation of road transport and the groups most likely to be exposed. This is similar to the perspective described by Schweitzer and Valenzuela (2004), examining who gets what kind of environmentally undesirable effects and in order to know " which social groups are more exposed to transport-related externalities" (Feitelson, 2002).

2.2. Mapping road traffic noise areas

There are two principal approaches in environmental equity studies to identifying zones with concentrated road traffic noise. The first, consists of using maps of road traffic noise (also referred to as continuous surface maps) for the entire territory of a given city, then relating these to socio-economic variables (Maantay and Maroko, 2018). These maps are mainly generated according to two methods, either by mathematical modeling (Brainard et al., 2004; Carrier et al., 2016a, b; Havard et al., 2011; Lam and Chan, 2006; Nega et al., 2013), or through land use regression (Dale et al., 2015; Goudreau et al., 2014). In employing this approach, a number of scholars have shown that there is a positive relationship between road traffic noise and the proportions of low-income people and ethnic minorities, notably in Birmingham, England (Brainard et al., 2004), in Montreal, Canada (Carrier et al., 2016a, b), in Hong Kong, China (Lam and Chan, 2006) and in Minneapolis–Saint Paul in the United States (Nega et al., 2013). In contrast, the studies of Havard et al. (2011) in Paris and Bocquier et al. (2012) in Marseille in France, as well as that of Kruize et al. (2007) in the Netherlands, found no environmental inequity related to income level. As for the two age groups which are physiologically more vulnerable to noise (children and seniors), studies have shown that they are not in a situation of environmental inequity, either in Birmingham or in Montreal (Brainard et al., 2004; Carrier et al., 2016a, b).

The second approach, widely used, due to its simplicity, consists of defining buffer zones around major traffic routes, given that noise levels and air pollution are generally higher in these areas (Carrier, 2015; Chakraborty, 2006; Jacobson et al., 2005; Maantay, 2007). We can distinguish a number of methods allowing us to determine the size of these buffer zones (Maantay and Maroko, 2018). There appear to be three main ones: 1) the first, a fixed-distance buffer, consists of defining the buffer zone to include all the territory situated within a fixed distance from the infrastructure which is emitting the noise, a distance determined by the findings in the literature; 2) the second, a multiple-ring buffer, very similar to the first, consists of defining a number of buffer zones situated at various fixed distances from the infrastructure emitting the noise; and 3) the last, a variable line buffer, consists of defining the buffer zone on the basis of certain characteristics of traffic routes, such as traffic flows and maximum speeds allowed (Maantay and Maroko, 2018). Then, it is a matter of determining whether certain groups of the population are overrepresented in these zones. Our study adopts this approach and employs the third method. A number of studies using different versions of this approach have shown that, in the United States, ethnic minorities and low-income individuals reside considerably closer to major traffic routes (Chakraborty, 2006; Chakraborty and Zandbergen, 2007; Jacobson et al., 2005; Maantay, 2007; Rowangould, 2013; Tian et al., 2013).

2.3. Distribution of mitigation measures

The inequities are not solely observable at the level of the distribution of burdens; they may also be manifest in terms of the distribution of mitigation measures against these burdens (Konisky, 2009, 2015). The first study to investigate questions of protection from these environmental nuisances is that of Lavelle and Coyle (1992). This demonstrated that decontamination of toxic waste sites near which significant proportions of ethnic minorities and low-income individuals were living was handled differently. For these sites: 1) it took longer to be placed on the priority list for decontamination and to be decontaminated; 2) the decontamination methods were often less effective; and 3) fewer penalties for violations toward regulated facilities are given to owners of these contaminated sites (Lavelle and Coyle, 1992). The research of Lee (1997) also had similar findings on a smaller scale. This author refers to the four and a half kilometre extension of Long Beach Freeway in eastern Los Angeles, crossing El Sereno, a primarily Hispanic neighbourhood, and then the cities of Pasadena and South Pasadena, which are mostly white. For this project, the state agencies concerned proposed a discriminatory distribution of mitigation measures, recommending that the section of highway going through Pasadena and 80% of that passing through South Pasadena be built underground (thus diminishing atmospheric, sound and visual problems created by the highway), and the major part of the section passing through El Sereno on ground level.

These studies served to highlight a dimension of environmental equity, largely neglected until this point, that of the distribution of measures designed to mitigate the burdens (Konisky, 2009). In the United States, subsequent research has focuses on disparities in policy implementation, such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Clean Air Act (CAA), the Clean Water Act (CWA) and the Resource Conservation and Recovery Act (RCRA). These studies concluded that ethnic minorities (African Americans and Hispanics) and low-income individuals are generally exposed to disproportionate environmental risks, notably because fewer protective measures are located in areas where these groups are overrepresented (Anderton et al., 1997; Hird, 1993; Konisky, 2009). Konisky (2009) observed this same relationship for the entire United States, but only for low-income individuals. Despite the relevance of these studies, this rather recently developed field needs further research to deepen our knowledge (Konisky, 2009, 2015), especially in the Canadian context, in particular that of Montreal.

2.4. Protection from road traffic noise and mitigation measures

In reaction to the multiplication of studies and the greater awareness of the harmful effects of noise, a number of works and planning guides have focussed on various protective measures, more specifically on different types of noise barriers allowing for the limitation of the spread of noise (Girard, 1996; Kotzen and English, 2009; Singal, 2005). Indeed, noise barriers would allow for the reduction of noise by approximately 5 to15 dB(A), depending on the materials used and their height (Girard, 1996). In short, the ability to protect residential areas from road noise by creating noise barriers largely depends on the urban environment's characteristics, such as density, road elevation and the height of residential buildings. In this sense, the more imposing these characteristics, the greater the costs and difficulties of planning. Indeed, low buildings can be protected more easily, simply by the height of the barrier (Girard, 1996; Kang, 2007; Kotzen and English, 2009). This is especially the case in suburbs where the built environment generally takes the form of single-family homes of one or two stories (Figure 1.a). In contrast, the greater the number of stories, the more difficult it is to erect barriers to protect the upper floors (Figure 1.b) (Kang, 2007; Kotzen and English, 2009). Also, the elevation of major traffic routes (road in cutting or elevated road) is especially present in the City of Montreal. This is notably the case of Highway 15, cutting through the Côte-des-Neiges sector of Montreal (Figure 1.c), and Highway 40, elevated in the Villeray–Saint-Michel sector of Montreal (Figure 1.d) while, in the suburban milieu, the vast majority of the network is at ground level. That being said, the studies and planning manuals on noise barriers have concentrated mostly on the physical characteristics (design, forms, materials, etc.) allowing them to improve their acoustic performance (Chih-Fang and Der-Lin, 2003; Ekici and Bougdah, 2003; Ishizuka and Fujiwara, 2004; Kang, 2007; Kotzen and English, 2009; Watts, 1995; Watts and Godfrey, 1999; Watts et al., 2001). However, to our knowledge, no study has yet seemed interested in the spatial distribution of protective measures against road traffic noise from a perspective of environmental equity.

<Insert Figure 1 about here>

In Québec, the policy on road traffic noise, intended to legislate the implementation of mitigation measures, foresees two types of approach to protecting sensitive zones, notably residential areas. The first, that of integrated planning, requires municipalities hoping to pursue their urbanization after the policy on road traffic noise came into effect, in March 1998, "to provide for [the implementation of] mitigation measures for noise impacts" in residential zones so as to keep the level of exposure to road traffic noise below the threshold of 55 dB(A), a level of noise acceptable for the population concerned (MTQ, 1998). The second, the corrective approach, concerns the residential zones urbanized before the adoption of the policy, that is, before March 1998. The corrective approach of the policy on road traffic noise allows municipalities wishing to protect already built sensitive zones from noise, the level of which is equal or superior to 65 dB(A) $L_{eq,\ 24\ hours}$ (a high acoustic disturbance level), to share equally the costs related to establishing measures to mitigate the noise. This cost sharing is between the municipality concerned and the MTQ. The mitigation measures established should reduce the sound level by 7 to 12 dB(A) for the first row of buildings. This is equivalent to halving the level of noise (FHWA, 2018). In this study, we distinguish two thresholds, that of 55-64 dB(A) and that of 65 dB(A) and more.

3. Question and objectives

As indicated in the literature review, a number of authors have shown that socio-economically vulnerable groups, especially low-income individuals and visible minorities, have, on one hand, a greater tendency to live near highway network and, on the other hand, increased probability of living in areas characterized by problematic noise levels (55-60 dB(A)—low levels of discomfort, 60-64 dB(A)—moderate discomfort, and 65 dB(A) and more—high levels of discomfort) (MTQ, 1998). Thus, it is appropriate to verify whether the groups studied are more concentrated all along the highway network and whether the setting up of noise barriers allows for a certain improvement in this adverse situation for these groups. This study contributes to the scientific knowledge in three main ways. First, we have already addressed the fact that the distribution of mitigation measures against some burdens remains a recently developed—and therefore limited—field. Second, we also broached the fact that studies interested in noise barriers mostly investigate their efficiency. Indeed, to our knowledge, no study has to date examined the distribution of noise barriers. Third, we are carrying out an assessment of double environmental equity by looking at both the distribution of the burden and the protection developed to mitigate it, which has rarely been done.

This study intends to respond to the following research question: does the distribution of protection measures against road traffic noise reinforce or attenuate the situations of environmental inequities for socioeconomically vulnerable groups (low-income individuals and visible minorities) and does it generate situations of environmental inequities for physiologically vulnerable groups (people aged sixty-five and over, and young people under fifteen years old)? The study has two objectives. The first consists of determining whether or not the four vulnerable groups are overrepresented in proximity to major traffic routes compared to the rest of the territory. The second objective is to determine whether or not the four groups are protected from road traffic noise by noise barriers when they reside near major traffic routes. Thus, a group which is overrepresented in zones near major traffic routes (Objective 1) and is not protected by the presence of noise barriers (Objective 2) would be suffering from a situation of double inequity.

4. Methodology

4.1. Study area

The study area is the Montreal Metropolitan Community (MMC). The MMC has a total population of 3.9 million inhabitants, that is nearly 48% of the population of Québec, spread over an area of 4,000 square kilometres (MMC, 2016a). This vast territory includes 82 municipalities and 14 regional county municipalities (RCM). It encompasses a number of sections which have been urbanized for a very long time, as well as others which were developed after March 1998, when the policy on road traffic noise was adopted. Some are more densely populated than others. In this way, the central city, Montreal, is the most densely populated administrative entity, with a population constituting 45% of the MMC and more heavily concentrated in the central neighbourhoods of the city. In contrast, population density is considerably less in the suburbs of the North and South Shores, of Laval and of the territory of independent municipalities of the Island of Montreal (Figure 2).

<Insert Figure 2 about here>

In addition to density, the social geography of the Montreal Metropolitan Community, in particular, residential dynamics, also vary from one sector to another. Indeed, families with children are more likely to live on local streets perceived as safer due to lower road traffic (Carrier et al., 2016b; Fortin et al., 2011; Lam, 2001; Mullan, 2003) and in the suburbs, because the proportion of under-15-year-olds has substantially declined in the central boroughs of the Island of Montreal (Apparicio et al., 2010). As for older adults, over the past few decades, we have witnessed a gradual dispersion of this group within the Greater Montréal area (Apparicio et al., 2010; Séguin et al., 2013). As a result, seniors are more likely to be spread across the territory. However, low-income people are more concentrated in the central neighborhoods of the

City of Montreal and in the old neighborhoods of the first ring of suburbs, although they are present throughout the MMC (Apparicio et al., 2007; Charbonneau and Germain, 2002; Heisz and McLeod, 2004). As a result, the spatial concentration of visible minorities is a factor underpinning the growth of concentrated urban poverty even if, in the MMC, visible minorities do not end up in a situation of segregation (Deslauriers, 2013; Statistics Canada, 2001).

This territory is even more interesting to study because automobile congestion is a major problem in the MMC since the modal share of public transport has remained stagnant while the fleet of automobiles, at 2.5 million vehicles, is constantly growing (MMC, 2016a). Indeed, number of vehicles showed an increase of 11.4% from 2008 to 2013 (AMT, 2013). Moreover, growth is much greater in the suburban areas of Laval and the North and South Shores (including Longueuil) (respectively 13%, 18% and 13%) compared to the Island of Montreal (6%) (AMT, 2013). That being said, highways on the Island of Montreal and in Laval are characterized by greater traffic flows than those of the North and South Shores. For example, on Highway15, the highest summer average daily traffic (SADT) is only of 15,839 on the North Shore while it increases to 164,000 on the Island of Laval and reach 201,000 in the center of the Island of Montreal, thus, making Montreal and its downtown area a magnet for commuting on the metropolitan level. Inevitably, the increasing road traffic within the MMC has repercussions for noise levels near the highway network.

Since there are major variations within sectors of the MMC due to the development period, density and traffic flow, it is appropriate to subdivide the study area into geographical subregions. We divided the territory into five subregions: the City of Montreal; the independent municipalities of the Island of Montreal; the City of Laval; the North Shore; and the South Shore. Rather than consider the Island of Montreal as a single subregion, we have chosen to distinguish the City of Montreal from other independent municipalities on the Island of Montreal, given the considerable size of the former compared to other municipalities and since a significant portion of the territory of the City of Montreal was urbanized well before the rest of the island.

4.2. Data and noise indicator

4.2.1. Population groups and scale of analysis

This study is interested in four groups: low-income individuals, visible minorities[1], children under 15, and individuals aged 65 and over. The data on these populations are extracted from the 2016 Statistics Canada (2016a) at the level of the dissemination area (DA), namely, a small geographic unit composed of adjacent dissemination blocks with an average population of 400 to 700 people (Statistics Canada, 2016b). Those data are disaggregated to city blocks, which is the smallest geographical unit. In order to better take into account the distribution of the population within a city block, we retained only the residential portion of each block by using the 2016 land use map (MMC, 2016b). Thus, this allows us to obtain a more precise location of population data, which is useful since the propagation of noise may vary within only a few metres (Hokanson et al., 1981). That being said, given the small size of the city block, only data on the total population and the number of dwellings are available. Consequently, to overcome this obstacle, following the example of a number of authors (Carrier et al., 2016a, b; Pham et al., 2012), the data for four population groups available at the level of DA are disaggregated to the level of blocks in the following manner:

$$G_b = G_d \times \frac{T_b}{T_d}$$

[1] Visible minorities refers to individuals, except Aboriginal people, who are non-Caucasian in race or non-white in colour, and mainly to the following groups: South Asian, Chinese, Black, Filipino, Latin American, Arab, Southeast Asian, West Asian, Korean and Japanese (Statistics Canada, 2017).

Where G_b represents the estimated population of the group G in the city block b, G_d is the group's population in the dissemination area d, T_b and T_d are the total population in the block and the dissemination area respectively.

4.2.2. Noise indicator

Sound is measured in decibels (dB), that is, "a logarithmic unit which expresses the ratio of the sound pressure level being measured to a standard reference level" (FHWA, 2018). Now, since the human ear can only perceive the sounds of certain frequencies, we apply an A-scale on a sound-level meter (dB(A)). This unit allows to determine the sound level by using a measure which accentuates the components of average frequency, thus imitating the reaction of the human ear (FHWA, 2018). According to the scale of Corrales et al. (2000), the effects of noise on health may be felt starting from a noise level of 55 dB(A) and intensify significantly at a level of 65 dB(A). Moreover, a noise whose intensity is reduced by 10 dB(A) is perceived as being half as strong (FHWA, 2018).

The study area includes only certain routes of the MTQ network, that is, along sections of highway and certain major roads, the numbered provincial routes on the territory of Montreal Metropolitan Community (MMC) (Figure 3). That being said, to simplify the designation of the network used (highways and major roads), we will refer to "major traffic routes" in the rest of the text.

<Insert Figure 3 about here>

With the goal of identifying residential areas near major traffic routes where the noise level is harmful for health, we delineated noise disturbance zones around each section of major traffic routes managed by the MTQ, based on the formula below for estimating noise level. Two noise disturbance zones were created, following two approaches prescribed by the noise policy, an initial zone of strong disturbance where the noise level is at least 65 dB(A), and then a second, larger zone of average disturbance, where the noise level is at least 55 dB(A). These zones were determined at 1.5 metres from the ground. The noise assessment formula allows us to determine at which distance from the highway (y), the exposure reach these two levels of noise:

$$y = 10\log(m \times \log(SADT) + b)$$

where SADT represents the summer average daily traffic (SADT) and the constants *m* and *b* are adjusted as a function of the maximum speed permitted on the route (70, 90 and 100 km/h), and the zone of noise disturbance to be determined (55 dB(A) or 65dB(A) and higher) (Table 1). The constants *m* and *b* are parameters which stem from basic equations contained in the TNM (Traffic Noise Prediction Model) software used to model sound level. Summer traffic flows are used since it is during this period of the year that people are most likely to open their windows and, thus, be exposed to road traffic noise. The SADT comes from the 2016 traffic flow map in the interactive atlas of the MTQ (2016). When the SADT was not available in the atlas, we used data from the Schémas d'Aménagement et de Développement (SAD [Planning and Development Plans]) of RCM [regional county municipalities]). In summary, based on the formula above and parameters from Table 1, the size of noise disturbance zones varies from 6 to 217 metres from the centre of the road infrastructure for the buffer for higher levels of noise (65 dB(A)), and then from 28 to 864 metres for the buffer for average noise (55 dB(A)).

<Insert Table 1 about here>

4.2.3. Geolocation of noise barriers

In order to distinguish the protected residential zones exposed to average or high levels of noise from those which are not protected, we proceeded in two stages. First, an initial tracking was done using images from *Google Street View* and *Google Earth*. Next, the entire road network of the MTQ was travelled by car and the noise barriers were recorded precisely with the help of a GPS watch (*Garmin 920XT*). Thus, surveys on the ground allowed us to validate the location of noise barriers. In the end, this database was updated in October 2017. In total, 88.4 kilometres of noise barriers were present on MMC territory, of which 34.4 km were on the South Shore, 21.2 km were in Laval, 18.8 km were on the territory of the City of Montreal (central city), 11.9 km were on the North Shore and only 2.2 km were in the independent municipalities of the Island of Montreal (Figure 3). Amongst these noise barriers, we find earth mound barriers, anti-noise concrete walls, rows of willows, sheet metal walls and mixed barriers (for example, earth mound barrier topped by an anti-noise concrete wall), all with a similar degree of efficiency in terms of acoustic performance (Figure 4). We only considered noise barriers of a height at least equal to the first floor of a building. Considering that all the noise barriers in the database are approved by the Quebec Ministry of Transportation, we are assuming that their efficiency enables them to reduce the noise level to an acceptable threshold that is under 55 dB(A).

<Insert Figure 4 about here>

Once the precise location of noise barriers was confirmed, it was possible to determine which city blocks, situated within residential zones with noise exceeding the two thresholds chosen, were protected from the noise. This distinction permits us to divide the different segments of city blocks into three categories:

A. Part of the block in the zone with an average disturbance level of 55 to 64 dB(A), not protected by noise barriers;

B. Part of the block in the zone with a high disturbance level of 65 dB(A) and more, not protected by noise barriers; and

C. Part of the block protected by noise barriers (regardless of whether it is in the zone with an average level of disturbance of 55-64 or one with a higher level of 65 dB(A) or greater).

Thus, Type A represents the parts of city blocks affected by an moderate noise level (55 to 64 dB(A)); Type B represents the parts of blocks affected by a high noise level (65 dB(A) and more); and, finally, Type C represents the protected parts of blocks, those situated in one or the other of the noise disturbance zones, as defined by the noise indicator, but which are behind a noise barrier (Figure 5a).

Considering that a city block may be found in more than one type of zone at a time, we have recalculated the numbers of the four population groups as a function of the proportion of the block in each of the different types, illustrated by the following formula:

$$G_{bt} = G_b \times \frac{A_{bt}}{A_b}$$

where G_{bt} is the estimated population of the group in Type *t* (A or B and C, defined above) of block *b*, A_{bt} is the area of the block comprised in Type *t* and A_b is the total area of block *b*. The estimation of these populations for the different types is illustrated in Figure 5.b.

<Insert Figure 5 about here>

4.3. Statistical analyses

In the literature, various quantitative methods have been proposed to address the need to readily evaluate the environmental equity impacts of transportation projects, notably by Forkenbrock and Schweitzer (1999) and Chakraborty (2006) for highway projects, by Harner et al. (2002) in areas around polluting industries and by Carrier et al. (2016) for noise and air pollution. Nonetheless, there is also an increasing need for a single quantitative EJ measurement method to help federal and state policymakers to determine who gets what kind of environmentally undesirable effects (Schweitzer and Valenzuela, 2004). For the first objective, assessing whether or not the groups selected are overrepresented near major traffic routes, we chose to retain two indexes, the BCI and ACI (with different labels depending on the study) (Chakraborty, 2006; Harner et al., 2002). In accordance with Harner et al. (2002) we consider BCI and ACI most appropriate for a preliminary environmental equity diagnosis because they are simple to calculate and easily interpretable, since they are based on proportions of a population group in at-risk areas versus non at-risk areas. On one hand, the BCI evaluates whether a population group have a greater tendency to live near major traffic routes (in the noise buffer zone) compared to the rest of the population while, on the other hand, the ACI evaluates whether this same population group is more likely to live in proximity to the major traffic routes (in the noise buffer zone) than in the rest of the territory ~~(Chakraborty, 2006)~~. Thus, the first index compares the proportion of a group relative to the proportion of the rest of the population in the buffer zone. As for the second index, it compares the proportion of a group in the buffer zone to the proportion of this same group outside the buffer zone. Despite their different interpretations, these two indices both measure inequities. Therefore, we chose to use them both instead of only one. That allows us a broader perspective and greater confidence in pointing out the presence of inequity if the results of the two indexes are consistent.

In more detail, the first index, the BCI, allows us to determine whether the four groups have a greater tendency to live near major traffic routes. To do so, we calculate the ratio of the proportion of the group in the entire territory residing in the affected zone (numerator) and the same proportion applied to the population not belonging to the group (denominator):

$$BCI = \frac{G_{bz}/G}{(P_{bz} - G_{bz})/(P - G)}$$

where P_{bz} G_{bz} are respectively the total population and the population of group G in the buffer zone bz; P and G are, respectively, the total population and that of group G in the entire study area (i.e., the Montreal Metropolitan Community).

The second index (ACI) allows us to determine whether these same groups are more likely to live in proximity to the major traffic routes than in the rest of the territory. It represents the ratio of the proportion of the group of the overall population residing in the zone affected (numerator) and the proportion of the group of the total population residing outside the affected zone (denominator):

$$ACI = \frac{G_{bz}/P_{bz}}{(G - G_{bz}) - (P - P_{bz})}$$

Those indexes are interpreted in the same way. If the value of the index is greater than one, the group studied is overrepresented. Inversely, if the value of the index is smaller than one, the group studied is underrepresented.

4.4. Multinomial logistic regression models

To reach our second objective, determining whether or not the groups selected residing in the zones with a disturbance level of 55 dB(A) or more near major routes are protected from road traffic noise by the presence of noise barriers, six multinomial regression models were developed for the entire MMC and its different subregions (the North Shore, the South Shore, the City of Laval, the City of Montreal and the independent municipalities of the Island of Montreal).

In these six models, the classification of parts of city blocks described above (A. 55-64 dB(A), B. 65 dB(A) and more, and C, exposed to 55 dB(A) and more but protected by a noise barrier) is introduced as a dependent variable while the percentages of the four population groups in the study are independent variables. All the statistical analyses were done in R (R Core Team, 2017). It should be noted that we did not weight the observations by the total population size of each block.

5. Results

5.1. The presence of vulnerable groups in the noise disturbance zones

Concerning proximity to major traffic routes, if we compare the two indices (BCI and ACI) for each group studied, we observe the same tendencies in the whole of the MMC as in each of the subregions (Table 2). Thus, the two indexes are consistent so it allows us a greater confidence in pointing out the presence of inequity. If we now compare the groups, for the entire MMC, only children are underrepresented in the noise disturbance zones near major traffic routes while seniors, low-income individuals and visible minorities are overrepresented. This finding also applies to the three subregions of the South and North Shore and the independent municipalities of the Island of Montreal. However, the situation differs in Montreal and Laval. In the City of Montreal, the four groups are overrepresented in proximity to major routes. In Laval, only children and visible minorities are overrepresented while seniors and low-income individuals are underrepresented. In addition, regardless of the subregion, the group of visible minorities is always overrepresented in the noise disturbance zones and presents the strongest BCI and ACI values, except for the independent municipalities of the Island of Montreal where low-income individuals have even higher overrepresentation indices.

<Insert Table 2 about here>

5.2. Noise protection for vulnerable population groups

Logistic regressions models were built with Type A, that is, those in zones with an average level of noise disturbance of 55 - 64 dB(A), as the reference category since in this zone there is less disturbance. The models measure the probability of inhabiting a zone with a high level of disturbance or a zone protected from the noise according to one's population group, for the entire territory, as well as for the five subregions. Therefore, the odds ratios can be interpreted as follows: compared to the reference category (A), adding a percentage point to one of the groups studied makes the probability of living in a portion of the block situated in a zone of great disturbance (B) or a protected zone (C) increase or decrease X times.

For all of the MMC (Table 3), only low-income individuals are disadvantaged in terms of their protection from road traffic noise since they constitute the sole group whose probability of living in a zone protected by a noise barrier diminishes significantly (Type C, OR=0.944). In contrast, for the three other groups—children, visible minorities and seniors—, the probability of living in a protected zone increases (Type C, OR=1.035, 1.025 and 1.007). The situation is even more advantageous for seniors and children since their probability of living in an unprotected zone with considerable noise disturbance (65 dB(A) and more) diminishes (Type B, OR=0.957 and 0.984). Nevertheless, with the exception of children, these findings for the entire study area are not applicable to each of the five subregions which comprise the MMC. Indeed, for all the subregions, children have a greater probability of living in a protected zone (Type C) and/or a reduced probability of living in a zone with considerable noise disturbance (Type B).

As for those with low-income (Table 3), they are in an unfavourable situation, both in the City of Montreal, and on the North and South Shores, with reduced probability of living in a protected zone (Type C, OR=0.944, 0.921 and 0.915). However, the situation of this group is distinctive on the South Shore since there is a lesser probability of them residing in a zone with considerable noise disturbance (Type B, OR=0.975), which leads us to believe that they are more present in a zone with an average level of noise disturbance (Type A: from 55 to 64 dB(A)).

As for visible minorities (Table 3), the City of Montreal is the only territory where they are disadvantaged since they are very likely to live in a zone with a high level of noise disturbance (Type B, OR=1.009) and they are unlikely to live in a protected zone (Type C, OR=0.972). In contrast, their situation is more favourable on the North and South Shores, with a greater probability of living in a protected zone (Type C, OR=1.062 and 1.053) and a lesser chance of living in a zone with considerable noise disturbance (Type B, OR=0.957 and 0.990).

The situation of seniors varies from one subregion to another (Table 3). In the Cities of Montreal and Laval, it is rather favourable, with a greater probability of living in a protected zone (Type C, 1.020, 1.019). However, their situation is more unfavourable on the South Shore with a reduced probability of living in a protected zone (Type C, OR=0.974). Finally, let us draw attention to the particular cases of the models of independent municipalities of the Island of Montreal and Laval for which very few of the modalities are significant.

< Insert Table 3 about here>

5.3. Situations of single and double inequity

The analyses allow us to combine the two dimensions of environmental equity relative to exposure to road traffic noise: the probability of living near major traffic routes in noise disturbance zones and the likelihood of being protected by the presence of noise barriers when one resides near a major route. Analysis of the spatial distribution of the four population groups and of the location of noise barriers has enabled us to reveal three main cases in point: a doubly advantageous situation where the group is underrepresented in proximity to major routes and more present in zones protected by the presence of noise barriers (Situation 1); a corrective situation when the group is overrepresented in proximity to major traffic routes, but also more present in zones protected by a noise barrier (Situation 2); and, finally, a doubly disadvantaged situation wherein the group is not only overrepresented near major traffic routes, but is also underrepresented in zones protected by a noise barrier (Situation 3).

What are the situations in which the four groups analyzed find themselves and do they vary within the study area (Table 4)? Concerning children, when they live in the independent municipalities of the Island of Montreal and on the South or North Shore, they are doubly advantaged (Situation 1), while those who live in the City of Montreal are in a corrective situation (Situation 2). In contrast, low-income individuals, regardless of their place of residence, are doubly disadvantaged (Situation 3). In turn, visible minorities are also doubly disadvantaged in Montreal (Situation 3), but in a corrective situation on the North and South Shores (Situation 2). Finally, the situation of seniors is more ambiguous because it varies greatly from one subregion to another. They are in a corrective situation in the City of Montreal, doubly advantaged in Laval, doubly disadvantaged on the South Shore and in a neutral situation on the North Shore since they are overrepresented there in proximity to major routes but they are also underrepresented in the zone with a disturbance level of 55-64 dB(A). Also, let us recall that the models of independent municipalities on the Island of Montreal and of the City of Laval do not conform to this type of situation since very few of those modalities are significant.

<Insert Table 4 about here>

The results show that some groups are less likely to be protected by noise barriers and that these same groups are also more likely than others to live within noise buffer zones along major traffic routes. When interpreting these results, one must remember that the built environment can complicate the development of noise barriers. Indeed, in our review of the literature, we have already addressed the additional difficulties posed by the height and density of some buildings, as well as road elevation, especially in the City of Montreal. In this sense, the City of Montreal is, from the outset, a sub-region where it is more difficult to protect the various population groups from road noise. That said, the situation of certain groups does not seem to be affected by geographical determinants and the built environment of the territory. This is particularly the case for children and low-income people. Indeed, children are generally in a favorable situation, regardless of the sub-region where they live. As we have discussed in the literature review, the fact that they are more likely to live on local streets and in suburban areas can be an explanation. Therefore, we may suppose that, as much as possible, families with children will avoid living near a major traffic route, to reduce problems such as noise, atmospheric pollution and road insecurity. Also, we may suggest that when they do reside near such a route, they will be inclined to either choose a zone protected from noise by a barrier or work together to obtain one.

Conversely, the situation is much more worrisome for low-income people, who are generally at a disadvantage in most subregions. It is possible to believe that, due to limited financial resources restricting their residential choices, they are more likely to live in urban environments with a number of problems (for example, proximity to major traffic routes, higher levels of atmospheric pollution and more noise) which lowers the value of housing, thus the acquisition cost (Kim et al., 2007; Levkovich et al., 2016; Sénécal et al., 2000). For this purpose, a study in the City of Montreal (Sénécal et al., 2000) revealed a larger number of low-rent lodgings and more social housing in a state of deterioration near Highways A-15 and A-40. It is possible that this situation also applies to visible minorities living in the City of Montreal.

Nonetheless, it must be remembered that the doubly disadvantaged situation of visible minorities is only observed in the City of Montreal and not in other subregions, contrary to that of low-income individuals. As for the suburbs, visible minorities are in a corrective situation (that is, near major routes but protected by the presence of noise barriers). Indeed, while poor immigrants have been living in central Montreal for a long time, this phenomenon is relatively recent in the inner-ring suburbs (Charbonneau and Germain, 2002). As a result, it is probable that in these suburbs, the noise barriers were erected before the appearance of these phenomena of the suburbanization of poverty and of immigration. In this sense, since poor immigration does not yet appear in the more remote suburban subregions (mainly the North and South Shore), it is possible to believe that the visible minorities living there do not necessarily have low incomes.

Finally, it should be noted that the results obtained for seniors are rarely significant. This situation can be attributed to the fact that they are rather dispersed within the Montréal metropolitan area (Apparicio et al., 2010; Séguin et al., 2013). However, as with visible minorities, this group also seems to be more sensitive to geographical factors since their situation varies widely from one sub-region to another.

6. Discussion

Thus, these explanatory factors allow us, in part, to understand why the distribution of noise barriers in the MMC is unequal for some vulnerable groups. However, an unequal distribution of environmental “bads” by itself may not necessarily be unjust. Instead, it is the “fairness” of the processes by which the distribution has occurred and the possibilities which individuals and communities have to avoid or ameliorate risk, which are important (Walker et al., 2005). That is why it is relevant, not only to measure inequities, but also to study why and how they are created. Nevertheless, we are unable to determine whether this is "procedural unfairness" considering that we did not investigate possible contributing factors to that end. To do so, in a future study, individual surveys should be carried out to understand the presence of these groups near major traffic routes and discover their motivations for living there. Finally, according to the environmental perception, as discussed by Hamersma et al. (2015); Hamersma et al. (2014), people with higher levels of income and education are more aware of the negative aspects of their environment (Kollmuss and Agyeman, 2002). This could provide a possible explanation. Thus, all citizens are not equal when faced with municipal administrations, which introduces a potential procedural injustice. Following Hird and Reese (1998), we might formulate the hypothesis that property owners would be more likely to mobilize to reduce the nuisances, while renters would tend to tolerate environmental burdens since they cannot always afford a more expensive dwelling away from nuisance (Bryson, 2013).

From a regulatory point of view, the operating mechanism of the policy on road traffic noise requires local mobilization so that the process of discussion with the Government of Quebec can be triggered. For this purpose, the first step in the process is for a municipality to request it from the Quebec Ministry of Transport after citizens have reported a problem. In terms of regulations, in Québec, the policy on noise is the only legal document on noise management and it does not require the municipalities to erect noise barriers because it does not have the force of law. Thus, this regulatory context means that there is an even more important role for public participation since municipalities could be inclined to wait for citizens to actively mobilize to that end before erecting noise barriers. The capacity for public participation and citizen mobilization may, thus, constitute an explanatory dimension since social, political and institutional processes are inevitably intertwined with environmental injustices (Schlosberg, 2007). Nonetheless, participation requires informational resources (knowledge of the harmful effects of noise on physical and mental health, and knowledge of administrative and municipal mechanisms), as well as financial resources (residents' ability to pay for the erection of barriers by the municipality, if necessary through higher property taxes). However, if no complaints are forwarded to City Council, the cities will not carry the file given the financial costs associated with such a request. The question to ask is therefore the following: Are the existing processes unfair to certain population groups with respect to road noise mitigation?

6.1. Limitations of the study

This study constitutes a first step in the analysis of spatial distribution of noise barriers on Montreal territory and it is based on a noise indicator which could be improved. Indeed, the technique used to delineate noise disturbance zones is an estimated proxy based on two main variables (speed permitted and average daily summer traffic with an average proportion of heavy vehicles at 10%). It does not allow us to consider a number of other elements which also have an impact on the level of noise, such as meteorological conditions, topography, and the presence of obstacles to noise on the territory. Indeed, it is very probable that after the first 2-3 rows of buildings, the level of noise diminishes more rapidly. The same is true for the presence of noise barriers, that is, that we were unable to consider their actual acoustic performance and their level of protection as a function of their characteristics (for example, height, materials, etc.). In this article, we are interested in the concentration of noise in residential environments, a place where people spend a certain number of hours of their day. Moreover, there may be a floating population, individuals who work near major axes for example, which is not taken into account in the study. Obviously, by focusing on noise exposure at the place of residence, we do not capture the real exposure of individuals as they move around cities. However, several recent articles dealing with nuisances such as noise have focused on exposure in several types of environments (Apparicio et al., 2016a; Boogaard et al., 2009; Kraus et al., 2015). Finally, it would have been interesting to study subgroups that combine physiological vulnerability and socio-economic vulnerabilities (e.g. children from poor families or poor elderly) if only to confirm the hypothesis of the differentiated income of immigrants in the suburbs. Unfortunately, there are not enough census data available at the dissemination area (DA) level to allow us to identify these doubly vulnerable groups.

7. Conclusion

This study has allowed us to observe that there are situations of inequity in terms of exposure to road traffic noise and the distribution of noise barriers for certain groups in subregions of the Montreal Metropolitan Community. Indeed, low-income individuals are doubly disadvantaged, both in Montreal and on the North and South Shores since, not only they are overrepresented in proximity to major traffic routes, but they also have a tendency to be less protected by the presence of noise barriers. As for visible minorities, they are doubly disadvantaged in the central city, while on the North and South Shores they are overrepresented in proximity to major traffic routes, but are more protected by the presence of noise barriers. Then, children are in a favourable situation in the central city and doubly advantaged on the North and South Shore, and in the independent municipalities of the Island of Montreal. Finally, the situation of seniors is more ambiguous since they are in a corrective situation in the City of Montreal, in a favourable situation in Laval, and disadvantaged on the South Shore. Thus, seniors are faced with situations which vary from one subregion to another. It is noteworthy that very few spatial patterns could be discerned for the independent municipalities of the Island of Montreal and the City of Laval since only children and seniors displayed significant modalities.

Also considering some challenges of erecting barriers in certain situations that are found in the City of Montreal, the question of the efficiency of barriers must be examined. Given the current regulatory situation which, at least partially, leaves the issue of erecting noise barriers up to citizen mobilization, the procedural dimension of environmental justice becomes central. As a consequence, there is a need for two types of further research: studies in the field of acoustics to evaluate the performance of noise barriers present on the territory of the MMC; and studies exploring the dimensions of procedural justice with respect to decisions concerning the erection of noise barriers.

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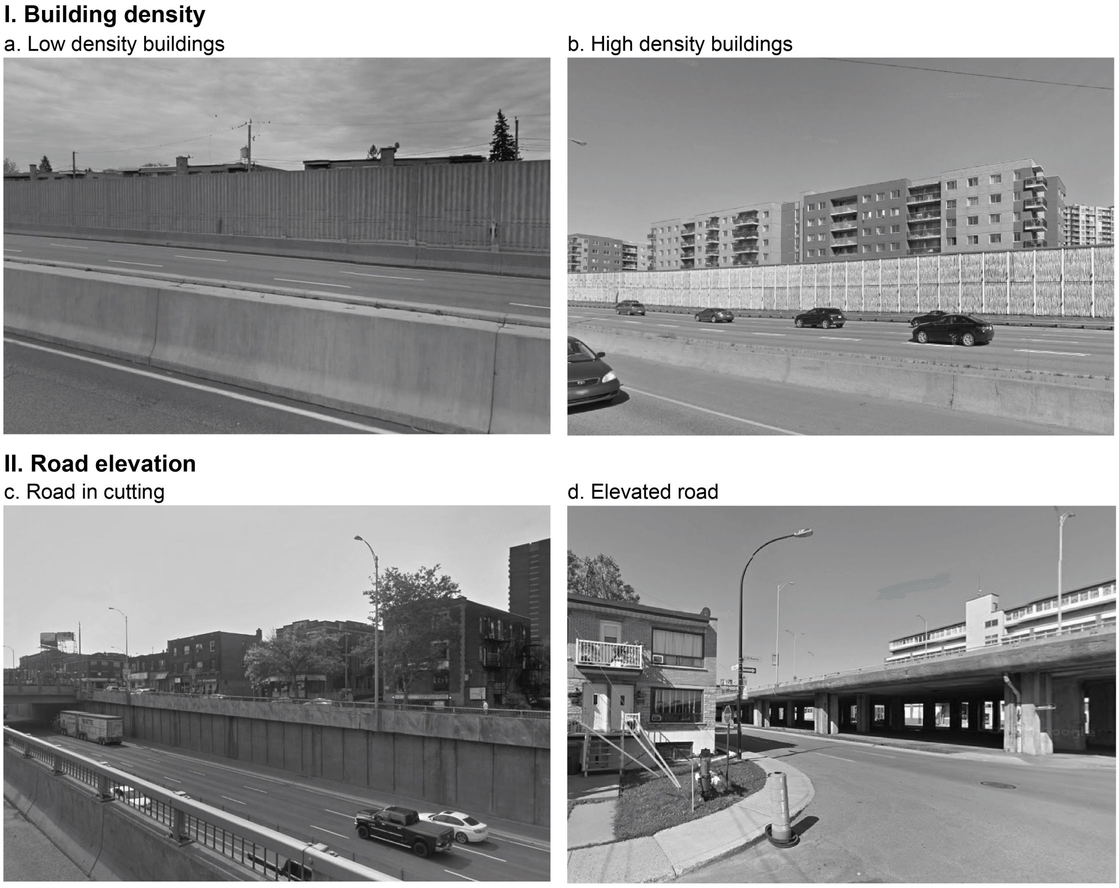
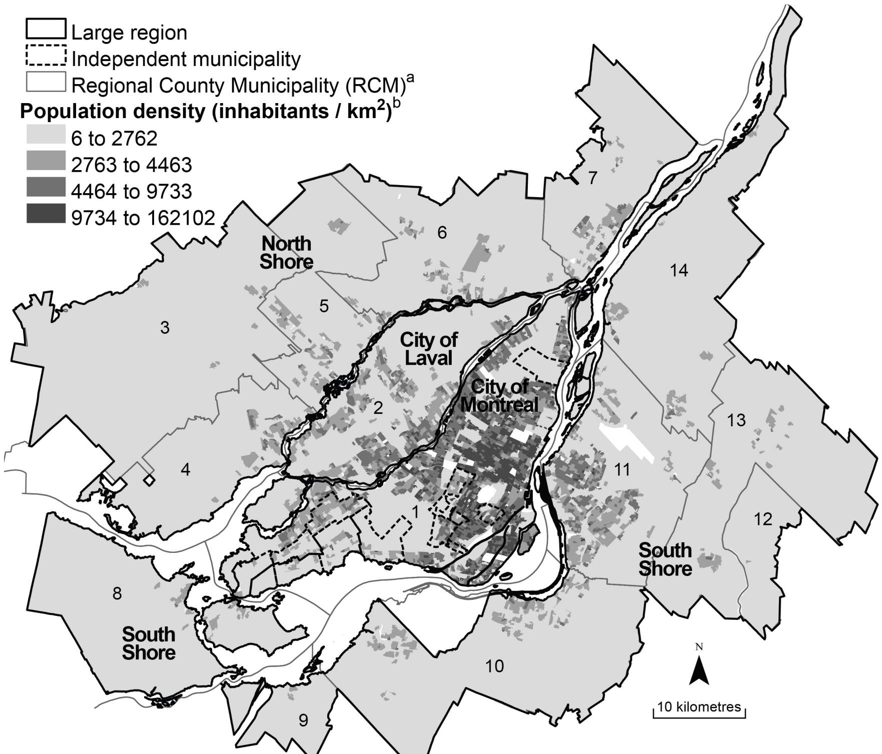


Fig. 1. Examples of noise barriers and elevated highways in Montreal.



List of Regional County Municipalities (RCM)

1. Agglomeration of Montreal
2. Laval

North Shore

3. Mirabel
4. Deux-Montagnes
5. Thérèse-De-Blainville
6. Les Moulins
7. L'Assomption

South Shore

8. Vaudreuil-Soulange
9. Beauharnois-Salaberry
10. Roussillon
11. Agglomeration of Longueuil
12. Rouville
13. La Vallée-du-Richelieu
14. Marguerite-D'Youville

a. Part of the Regional County Municipalities (RCM) included in the Montreal Metropolitain Community (MMC).
b. Classification method by quantiles.

Fig. 2. Population density by dissemination area, 2016.

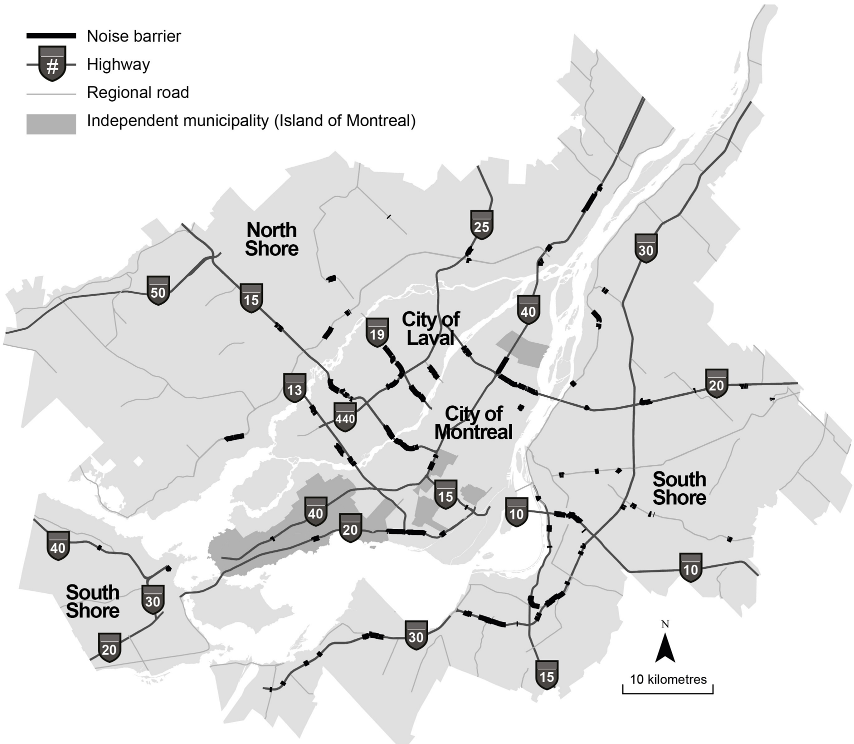


Fig. 3. Study area.

Fig. 4. Types of noise barriers.

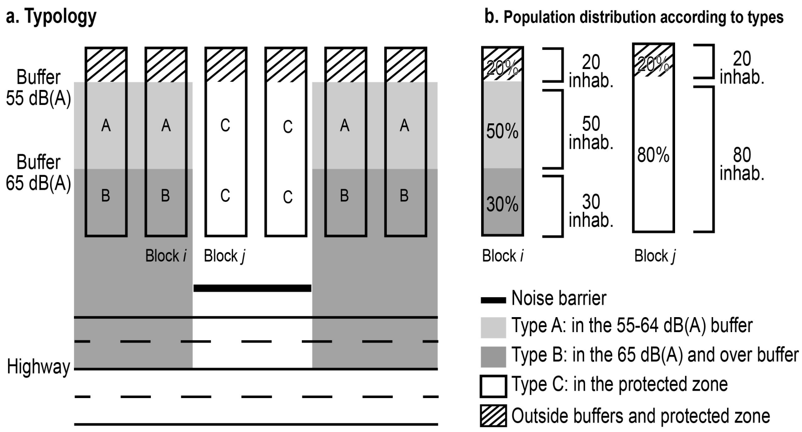


Fig. 5. Typology of block parts according to buffers around noise barriers.

Table 1. Constants of the isophone curves

Buffer zone	55 dB(A)		65 dB(A)	
Speed limit	*m*	*b*	*m*	*b*
70 km/h	0.624	-0.467	0.658	-1.265
90 km/h	0.609	-0.331	0.653	-1.168
100 km/h	0.606	-0.287	0.647	-1.109

Table 2. Calculation of EJ indices for the Montreal Metropolitan Community (MMC) study areas.

Groups	Montreal Metropolitan Community (MMC)	City of Montreal	Independent municipalities	Laval	North Shore	South Shore
Buffer comparison index	BCI	BCI	BCI	BCI	BCI	BCI
0-14 years old	0.976	1.057	0.907	1.018	0.935	0.879
65 and over	1.094	1.082	1.053	0.898	1.049	1.242
Low-income population	1.084	1.055	1.186	0.821	1.045	1.313
Visible minorities	1.245	1.310	1.013	1.093	1.294	1.325
Area comparison index	ACI	ACI	ACI	ACI	ACI	ACI
0-14 years old	0.977	1.062	0.894	1.022	0.934	0.879
65 and over	1.102	1.089	1.064	0.900	1.055	1.246
Low-income population	1.095	1.057	1.260	0.809	1.057	1.370
Visible minorities	1.234	1.246	1.018	1.086	1.371	1.346

Table 3. Multinomial logistic regression for Montreal Metropolitan Community study areas (dependent variable: buffer 55 - 64 dB(A)).

	Montreal Metropolitan Community					City of Montreal				
Category [a]	Coef.	OR	CI (95%)		Pr.	Coef.	OR	CI (95%)		Pr.
	0-14 years old									
B	-0.044	0.957	0.949	0.966	<.0001	-0.007	0.993	0.969	1.018	0.590
C	0.035	1.035	1.025	1.046	<.0001	0.075	1.078	1.050	1.106	<.0001
	65 and over									
B	-0.016	0.984	0.979	0.990	<.0001	-0.010	0.990	0.976	1.005	0.190
C	0.007	1.007	1.000	1.014	0.040	0.020	1.020	1.008	1.033	<.0001
	Low-income population									
B	-0.002	0.998	0.990	1.005	0.560	0.007	1.007	0.994	1.019	0.290
C	-0.057	0.944	0.935	0.953	<.0001	-0.057	0.944	0.930	0.959	<.0001
	Visible minorities									
B	-0.003	0.997	0.993	1.002	0.220	0.009	1.009	1.002	1.016	0.010
C	0.025	1.025	1.021	1.029	<.0001	-0.028	0.972	0.964	0.980	<.0001
AIC complet	13963					3689				
R2 (Cox & Snell)	0.109					0.132				
R2 (Nagelkerke)	0.131					0.156				
	Independent municipalities					City of Laval				
	0-14 years old									
B	-0.051	0.950	0.922	0.979	<.0001	-0.093	0.911	0.848	0.979	0.010
C	0.204	1.227	1.149	1.310	<.0001	0.023	1.024	0.989	1.060	0.190
	65 and over									
B	-0.014	0.986	0.968	1.004	0.120	0.024	1.025	0.997	1.053	0.090
C	-0.030	0.970	0.925	1.018	0.210	0.019	1.019	1.000	1.039	0.050
	Low-income population									
B	-0.010	0.990	0.963	1.017	0.450	-0.010	0.990	0.905	1.084	0.830
C	0.005	1.006	0.956	1.057	0.830	-0.016	0.984	0.949	1.022	0.410
	Visible minorities									
B	-0.008	0.992	0.978	1.006	0.250	-0.010	0.990	0.956	1.025	0.570
C	0.001	1.001	0.980	1.022	0.950	-0.010	0.990	0.975	1.006	0.220
AIC complet	1180					1119				
R2 (Cox & Snell)	0.014					0.078				
R2 (Nagelkerke)	0.099					0.095				

a. See the categories in Figure 3.

Table 3. Multinomial logistic regression for Montreal Metropolitan Community study areas (dependent variable: buffer 55 - 64 dB(A)) (continued)

	North Shore					South Shore				
Category [a]	Coef.	OR	CI (95%)		Pr.	Coef.	OR	CI (95%)		Pr.
	0-14 years old									
B	-0.023	0.977	0.962	0.993	<.0001	-0.054	0.947	0.935	0.959	<.0001
C	0.055	1.057	1.026	1.088	<.0001	0.059	1.061	1.040	1.081	<.0001
	65 and over									
B	-0.030	0.971	0.958	0.983	<.0001	-0.006	0.994	0.986	1.002	0.130
C	-0.010	0.990	0.966	1.014	0.400	-0.026	0.974	0.959	0.990	<.0001
	Low-income population									
B	-0.019	0.981	0.958	1.004	0.110	-0.026	0.975	0.959	0.991	<.0001
C	-0.082	0.921	0.875	0.971	<.0001	-0.089	0.915	0.890	0.940	<.0001
	Visible minorities									
B	-0.044	0.957	0.939	0.975	<.0001	-0.010	0.990	0.981	0.999	0.030
C	0.060	1.062	1.041	1.083	<.0001	0.051	1.053	1.044	1.061	<.0001
AIC complet	2802					4039				
R2 (Cox & Snell)	0.134					0.227				
R2 (Nagelkerke)	0.169					0.276				

a. See the categories in Figure 3.

Table 4. Synthesis of equity situation in the subregions of the Montreal Metropolitan Community (MMC).

	Situation 1: doubly advantageous situation [a]	Situation 2: corrective situation [b]	Situation 3: doubly disadvantaged situation [c]
City of Montreal		Children, Seniors	Low-income individuals, Visible minorities
Independent municipalities	Children		Low-income individuals
Laval	Seniors		Low-income individuals
North Shore	Children	Visible minorities	Low-income individuals
South Shore	Children	Visible minorities	Low-income individuals, Seniors

This synthesis is based on the results reported in Table 2 and 3.
Non-significant results are not shown in the table.
a. The group is underrepresented in proximity to major routes and more present in zones protected by the presence of noise barriers.
b. The group is overrepresented in proximity to major traffic routes, but also more present in zones protected by a noise barrier.
c. The group is not only overrepresented near major traffic routes, but is also underrepresented in zones protected by a noise barrier.