Analyzing the Acoustic Urban Environment
A Geofencing-centered Approach in the Curitiba Metropolitan Region, Brazil

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Abstract: The industrial development and Brazilian economic context led to important structural changes, among others, the increase of population migration (rural to urban spaces), number of private vehicles (due to tax reduction and state subsidies for new cars and fuel), among others. Such changes impact not only the urban mobility at big cities but also the urban life quality, which is directly affected by pollutant emissions and noise. In order to limit emission impacts on sensitive population (children, elderly people, for example), city managers can enforce bounds on emissions and noise pollution generated by the city traffic in specific regions defined by geographical boundaries. This paper aims to contribute to the challenge of managing urban noise by exploring and analyzing the data with a geofencing approach. In particular, we present a exploratory data analysis toward a case study in Curitiba (1,800,000 inhabitants, a southern Brazilian city) aiming at analyzing possible sources of noise based on a particular data set of noise measurements, geographical information data, traffic, transportation and city licensing data.

1 INTRODUCTION

Since the late nineteenth century, noise has been the subject of complaints, regulation, and legislation. By the early 1900s, till today, cities have fought noise from factories, steam trains, automobiles, loud neighborhood, among others (Bijsterveld, 2008). Noise pollution in large urban areas can be directly linked to the traffic flow on roads and the types of vehicles, as well as several other sources (Rodrigues, 2010). The data analysis related to traffic flow as well as independent variables might impact urban management, the adoption of modals based on electric vehicles, the location of schools and hospitals, among others.

Controlling noise pollution can be achieved by two strategies: (i) coercion: to enforce the installation of noise control devices, in situations where compliance with the law is not observed; and (ii) prevention: to establish policies that disallow the concentration of activities in already polluted areas.

Through the concept of exploratory data analysis and geofencing, we can (i) explore patterns or clues from the available data (without any pre-conceived ideas), and (ii) restrict the analysis from a geographical perspective (such as the metropolitan region of a city). The objective is to restrict location-relevant information to a geographic "fence" or boundary around the information's demarcation area (Greenwald et al., 2011). The understanding of the related topics, however, is a non trivial task since it requires skills and knowledge of various domains (computational, urban planning, architecture, networks, cities domain, engineering, etc.), along with technologies to support the analysis process.

In particular, a group of cities, the *C40 cities* [1], had set ambitious targets to improve urban life quality and protect their environment. Curitiba has developed and implemented mass transport corridors, densification of land-use along these corridors, and mobility solutions using Bus Rapid Transit (BRT) systems, and became a model of sustainable city based on urban concepts that have shaped the city landscape. In spite of its urban planning model, in Curitiba, the geofencing concept has not been explored to minimize noise and particulate emissions coming from its Public Transportation System (buses). The impacts of a virtual perimeter is not fully understood, in particular, due the complexity of noise measurements and anal-

[1]http://www.c40.org Last visited on 30/05/2015.

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ysis (Zannin et al., 2003). A variety of factors, such as emission sources, available data, architecture characteristics,and climate conditions could directly affect the analysis and possible simulation of noise impact.

This paper presents the concepts, applications, and challenges towards a exploratory data analysis of noise through the concept of geofencing. The objective here is not to understand specific details (such as mathematical models), or integrate environment-related parameters (such as temperature or wind), but to understand sources and obstacles which create impact from a general overview. The main goal is to discover what the data can tell us about the observed noise with the help of visualization and display techniques of GIS perspective. The rest of this document is organized as follows: Section 2 contains an overview of a motivating example, Section 3 presents the related work. The methodology is presented within Section 4. Conclusions and future work are presented in Section 5.

2 A MOTIVATING EXAMPLE

Noise pollution is a serious environmental problem faced by several cities in Brazil (Zannin et al., 2003; Oliveira et al., 1999; Arndt et al., 2010; Rodrigues, 2010).

Curitiba has 1.8 million people inside a total area of 430,9 km^2, according to the Brazilian Institute of Geography and Statistics (IBGE) [2]. This area encompasses 75 neighborhood districts. Although noise in Curitiba has been studied under distinct perspectives (Zannin et al., 2002; Calixto et al., 2003; Zannin et al., 2003), we believe that new clues about possible noise sources can be derived from the analysis of new domains.

A formerly traditional residential area of Curitiba, with about 12,000 inhabitants, the Batel district is currently full of restaurants and options for nightlife. In the 18th century, the current Batel Avenue was one of the ways used by drivers. In the early 20th century, the region already had two breweries, two yerba mate processing plants, soap factories, and a small trade. One of the main mass transportation axis (express bus lanes) crosses the region, establishing an urban canyon of skyscrapers with the express bus lanes inside the deep valley. Curitiba was already stated as a city which has problem with noise pollution (Arndt et al., 2010), and according to (LNZ Soluções em Vibrações e Acústica, 2011), Batel is one of the most noisy region compared to all other regions in Curitiba.

[2]http://www.ibge.gov.br Last visited on 14/05/2015.

In order to investigate the reason for this, several data sources (e.g., health facilities, education facilities, streets, city hall noise measures, particular noise measures, bus lines), within different time range (from 1890 till 2014), were integrated and analyzed.

The noise measure report compared the data against the Municipal Law Number 10.625, published in 19/12/2002, which establishes noise limits[3]. The limits are fixed as follows: (i) daytime: from 07h:01 to 19h; (ii) evening: from 19h01 to 22h; (iii) nocturnal: from 22h01 to 07h.

Considering the information listed above, several questions might arise, such as why some locations produce more noise during the day compared to night and vice versa, or why specific locations produce more noise compared to others. The questions can be explored under different domains, such as GIS (through spatial locations), architecture (impact of noise on different building types) and mathmatics (through statistical models (Calixto et al., 2003)). Different domains might present different background concepts (theory, software, practice), along with domain limitations, which, if integrated, might provide better answers.

Briefly, the efforts of integrating different domains may vary in several directions: (i) from the GIS perspective, the challenge is how to explore data with efficiency (and to enable any future integration with other systems); (ii) from the integration perspective, the challenge is not to have a bottleneck; (iii) from the hardware perspective (for receiving noise data, for example), the challenge is how to detect limitations and standardize calibrations; (v) from the pedagogical perspective, the challenge is how to explore all this structure and have a interdisciplinary learning environment; (vi) from the software perspective, the challenge is how to adapt an interface which explores different points of view of analyzing the information.

3 RELATED WORK

3.1 Exploratory Data Analysis

Exploratory Data Analysis (EDA) is a philosophical approach to data analysis (NIST/SEMATECH, 2012). The posed question is: what data can tell us about certain relationships, properties or structures. There are no imposed techniques to apply to the data set but graphical visualization plays an important role in this approach (Hartwig and Dearing, 1979). The

[3]http://multimidia.curitiba.pr.gov.br/2010/00086318.pdf Last visited on 11/25/2015.

non-inferential approach in data analysis encourages the openness perspective required to integrate new domains. The availability of processing power and data storage provide new tools for handling massive amout of data processing allowing flexible search of evidences in the available data through designed experiments (Martinez et al., 2010).

3.2 Geofencing

Geofencing is a virtual perimeter for a real-world geographic area (Ravada et al., 2013). A geofence could be a radius around a store or point location, or a predefined set of boundaries, like zip code boundaries. Geofencing is still on-going research (Ryoo et al., 2012; Sheth et al., 2009), but basically it explores the containment of data "within" or "inside" an area. A lot of relevant techniques in GIS (such as geometry location, spatial indexing, and spatial query processing) can be explored from a database perspective.

From the GIS perspective, geofencing is explored through the definition of points (latitude/longitude), along with lines, polygons, and geometries defined across the data. But indeed, the same information can be visualized within different categories (Rodriguez Garzon and Deva, 2014) (as shown in Table 1).

Table 1: The different geofencing categories (Rodriguez Garzon and Deva, 2014).

Category	Adressing Scheme	Instances	Example
Spatial Geofence	Geometric	Circles, Polygons, Polylines	"Region of Berlin"
Hierarchy-based Geofences	Symbolic	Country, City, Street, Building...	"Germany/Berlin/ Ernst-Reuter-Platz"
Network-based Geofences	Symbolic	Cell-Ids, WLAN-(B) SSID,...	"BSSID of WLAN " in a McDonalds restaurant"
Semantic Geofences	Geometric and Symbolic	Combination of the above	"Close to a McDonalds restaurant"

Theoretically, geofencing can be formalized as a combination of states and transition-based geofence models, created by system notifications (such as incoming calls, emails, breaking news or software update notifications) (Rodriguez Garzon and Deva, 2014). In particular, we adopted the geofencing approach in order to take advantage of physical limits within districts and cities.

3.3 The Acoustic Model

Sound is produced by sources (the noise emitting elements, having a geometry and properties which vary for each case), modified by obstacles (barriers to the propagation of sound, absorbing it or reflecting it in varying percentages, depending on their nature and their position in the vicinity of sources), and perceived by receivers (the elements which are disturbed by the noise, that is, buildings, installations, and people, or a combination of them). Sound (along with other parameters such as weather condition, level of air pollution, noise pollution, traffic condition) are widely monitored by sensors. One of the caveat of sensor data is that the data captured by sensors do not include information on the cause of the data. Thus, sensor data alone is not sufficient for drawing meaningful conclusion. In recent years, the idea of using citizens as sensors are gaining momentum (Mostashari et al., 2011). From the academic perspective, researchers are also proposing frameworks to effectively combine geofencing with mobile technologies to infer state of the user (Chen et al., 2014).

From the urban noise modeler's point of view, the mentioned parameters are impacted by the following acoustic modeling aspects: (i) the propagation and (ii) the combination of effects from sources. These two aspects are useful to other environmental problems (Oliveira et al., 1999). Further details about mathematical formulations to understand the impact of noise decay can be checked at (Oliveira et al., 1999; Rodrigues, 2010; Arndt et al., 2010) (Calixto et al., 2003). But indeed, the analysis is performed on a delimited area, combining the propagation and combination to a buffer polygon (through GIS), traced around the original interest area at a defined distance.

The noise impact inside a region under consideration can be estimated according to (Oliveira et al., 1999): (i) the noise considered by each economic activity; (ii) the traffic noise; (iii) the sound attenuation; (iv) the combination of the previous steps in order to obtain the noise generated by all sources.

Traffic noise poses also as one of the main problems for city managers to solve. Suitable measures for noise reduction includes asphalt type, grass covered tramways, noise barriers, soundproof windows, night driving bans for trucks (Louen et al., 2014), as well as, speed reduction zones (Madireddy et al., 2011) and electro-mobility solutions (Verheijen and Jabben, 2010).

Road traffic-induced air pollution is also one of the main sources of air pollution affecting environmental living quality in urban areas (Duclaux et al., 2002). However, the phenomenon of road traffic air pollution shows considerable variation within a street canyon, or horizontal and vertical obstacles.

Linking up dispersion models with a GIS environment is a mean to resolve this shortcoming. Providing information about traffic pollution **or noise**, and finding out its distribution is therefore a crucial starting point for planning effective measures to improve air quality **or traffic noise**.

4 OVERVIEW OF THE METHODOLOGY

The methodology used for the exploratory data analysis comprised the following steps: (i) the acquisition/characterization of the data sources; (ii) the data integration and processing; (iii) the data analysis (along with hypothesis and limitations); and (iv) the definition of parameters/challenges which impact the proposed problem solution.

4.1 Data Sources

The dataset used is based on Instituto de Planejamento de Curitiba (IPPUC), the city mall of Curitiba[4], along with data from Open Street Map [5]. Figure 1-top shows the input sources, with data ranged from 1890 till 2014 (as shown in Figure 1-bottom). Details are listed below.

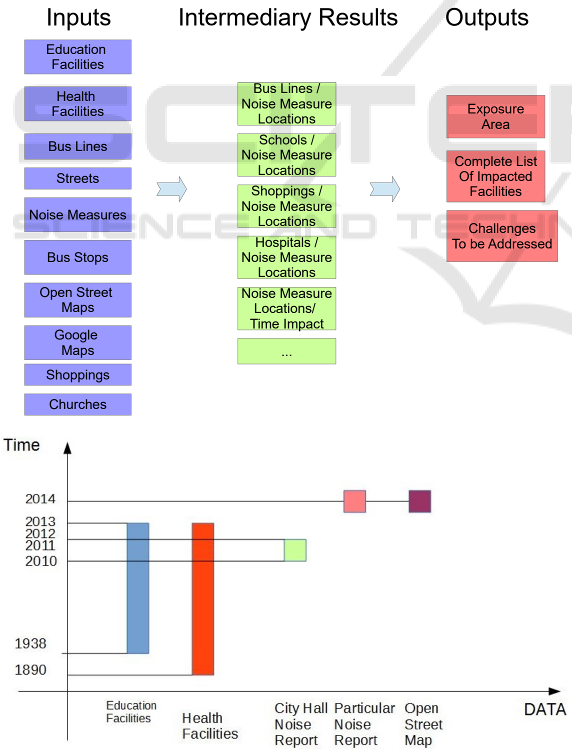

Figure 1: Schematic of the data model (top); and (B) Time Range of the input data (bottom).

Education Facilities - The region has 15 education facilities (such as Colégio Nossa Senhora de Sion - Sede, Colégio Estadual Júlia Wanderley, Escola Osny Macedo Saldanha, Campus de Artes e Música da UFPR, Faculdade Fapar, Centro de Educação Infantil Engenheiros do Saber, among others). The data creation ranges from 1938 (Colégio Nossa Senhora de Sion - Sede) till the last update in 2013, having as source the IPPUC [6]. Education facilities present some categories, such as CEI (portuguese acronym for Municipal center of Early Childhood Education, divided between private and the ones who has a contract with the state government), UEI (portuguese acronym for Integrated Education Unit), State Schools, Private Schools, and Higher Education Institutions.

Health Facilities - The region has exactly eight health facilities (namely Hospital da Cruz Vermelha Brasileira, Hospital Geral de Curitiba, Clinica Central de Oftalmologia, Hospital de Olhos do Paraná, Hospital Santa Cruz and Hospital Vita Batel). The data creation ranges from 1890 till the last update in 2013, having as source the Instituto de Planejamento de Curitiba (IPPUC). Note that the older health facility - Hospital Geral de Curitiba, was initially created at 1890, and moved to the actual location in 1920.

Bus Lines - The region has 21 bus lines (such as InterHospitais, Circular Centro (Anti-Horário), Portão-Cabral, Interbairros I (horário), Interbairros I (anti-horário), Cic-Tiradentes (Manhã), Ctba-Campo Largo, among others). The 21 lines are divided within 8 bus categories ("Circular Centro" (1 type), "Convencional" (8 types), "Expresso" (1 type), "Interbairros" (2 types), "Interhospitais" (1 type), "Linha Direta" (2 types), "Metropolitano" (5 types) and "Troncal" with one type).

Street Data - The street data was explored both with the data obtain from IPPUC and Open Street Map.

Noise Measures - The first noise source explored data between 2010 and 2011 (LNZ Soluções em Vibrações e Acústica, 2011), having Batel as the district with higher noise measures within the city. Eight locations are explored for measuring noise: Sensor 10 (Rua Gonçalves Dias, 406), Sensor 11 (Rua Bispo Dom Jose, 2365), Sensor 12 (Rua Hermes Fontes, 506), Sensor 13 (Av. do Batel, 1750), Sensor 14 (Rua Francisco Rocha, 510), Sensor 15 (Av. do Batel, 1230), Sensor 16 (Rua Benjamin Lins, 555), and Sensor 17 (Rua Pasteur, 260).

The eight locations produced the noise measures listed in Table 2. The last two columns from the table list the noise law limit for that region, and how

[4]http://www.curitiba.pr.gov.br/DADOSABERTOS/ Visitado em 15/05/2015.

[5]http://www.openstreetmap.org Last visited on 14/05/2015.

[6]http://www.ippuc.org.br/ Last visited on 14/05/2015.

the noise measure percentage is above law. Note that (i) locations 13 and 14 produce more noise during the day and night and (ii) locations 11,13, and 14 produce more noise compared to the others. For the comparison, only the Equivalent Continuous Sound Level (Leq) was considered, under SAD69 database and UTM coordinates. The equipment used was Icel DL4200 type 2 and 01 dB Solo type 1. The report already stated that the majority of noise is related to the traffic within the region.

Table 2: Noise Measures within the Batel neighborhood.

Sensor	Period of the day	Date	Hour	Noise	Law Limit
13	Daytime	2010-12-22	09:27	76.7	55
14	Daytime	2010-12-22	09:00	74.4	55
11	Daytime	2010-12-21	09:20	74.3	55
12	Daytime	2010-12-21	09:00	63.2	55
16	Daytime	2010-12-22	10:51	70.8	65
15	Daytime	2010-12-21	09:43	67.3	65
10	Daytime	2010-12-21	09:43	67.3	65
17	Daytime	2010-12-22	10:35	62.8	65
13	Evening	2011-04-14	17:34	73.2	55
14	Evening	2011-04-14	17:05	70.2	55
11	Evening	2011-04-14	18:21	67.8	55
12	Evening	2011-04-14	17:26	62.5	55
10	Evening	2011-04-14	18:41	69.3	65
15	Evening	2011-04-14	18:41	69.3	65
16	Evening	2011-04-11	18:31	68.2	65
17	Evening	2011-04-11	18:51	65.5	65
11	Nocturnal	2010-12-20	23:25	74	45
14	Nocturnal	2010-12-21	23:39	71.4	45
13	Nocturnal	2010-12-21	23:20	70.9	45
12	Nocturnal	2010-12-20	23:00	57.2	45
16	Nocturnal	2010-12-22	23:05	68.9	55
10	Nocturnal	2010-12-20	23:47	67.6	55
15	Nocturnal	2010-12-20	23:47	67.6	55
17	Nocturnal	2010-12-22	23:02	59.1	55

Table 3: Number of noise complaints within the Batel neighborhood, within years 2010 and 2014.

Year	Daytime	Evening	Nocturnal
2010	69	24	50
2011	84	18	59
2012	78	29	42
2013	58	28	31
2014	48	15	64

The drawback of having just one sample over time divided between two years sent us to the second noise dataset. The second source registers citizen complaints against noise within years 2010 till 2014 (obtained from the city hall of curitiba - Table 3). The average is 58 complaints by month, having February as the worst month (average of 75 complaints, generally the month of the Brazilian Carnival). In Curitiba, 50% of the citizen complaints are related to noise. The majority are related to bars and cars with high volume music. Within this source, Batel is the 5th district with more noise complaints (with 58% of complaints during the day) and is located next to the most noisy district (Downtown).

4.2 Data Integration and Processing

The complete IPPUC dataset along with the noise source 1 (extracted from (LNZ Soluções em Vibrações e Acústica, 2011)) and noise source 2 (within data from the city mall) were inserted in a PostGIS [7] database. Different sources were created as different tables in the database. Later, specific tablespaces and indexes were created in order to optimize the access. Since semantic errors were present (different sources presented different street names for the same location, for example (Barczyszyn, 2015)), geolocation and specified time range were used to correlate the data.

4.3 Data Analysis

The objective was apply a geofencing around the district of Batel, and using the available datasets, locate the less impacted area and the most impacted area within the district. The data analysis process used the QGIS visualization tool [8]. The integration of the 8 intermediary input GIS layers (illustrated in Figure 1-A) produced intermediary results, such as the relation of bus lines $\times$ noise measure locations, the impacted schools and hospitals in the region, the impact of shopping centers within the region, along with the how the time distribution of each facility impacted the final analysis. Note that we decided to combine different source of data, in order to explore different domains of information.

As final outputs, the exploratory analysis identified the exposure area and the complete list of impacted facilities. Figure 2 lists the main schools, health facilities, bus stations and the main streets. The exposure area was limited to Batel neighborhood (centralized in the figure). The complete list of impacted facilities can be visualized at the same figure.

If we consider a 300 meters radius from the point of measurements of noise, for example, four colleges, three private CEIs, three state schools, five hospitals, and two churches are impacted, as shown in Figure 2 (right). Within this approach, note that the upper part of the district (next to sensor 12) is still the less noisy region, comprised within a residential area.

If we increase the radius to 600 meters, all schools, hospitals and churches are impacted within the district, through the day, afternoon, and night. This approach suggests that all the district is affected by the noise.

The integration of the second noise source (Figure 3, left) stresses that complaint regions remain the same along the years, with an average of 121 registers per year. This source reinforces that the region around sensor 12 is less noisy, and the top right region is the region with the majority of citizen complaints (even

[7] http://www.postgis.net Last visited on 15/05/2014.

[8] http://www.qgis.org Last visited on 15/05/2015.

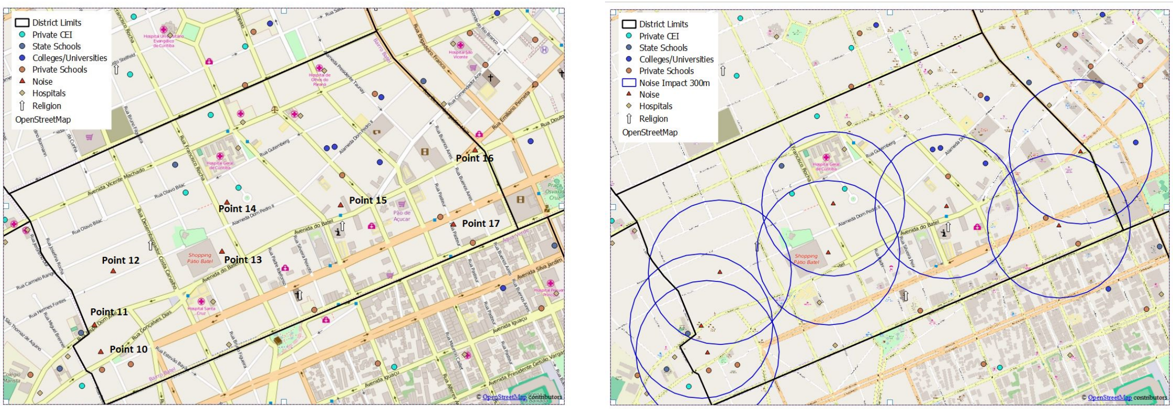

Figure 2: The eight noise measure locations (left) and the impacted schools in 300 meters radius (right).

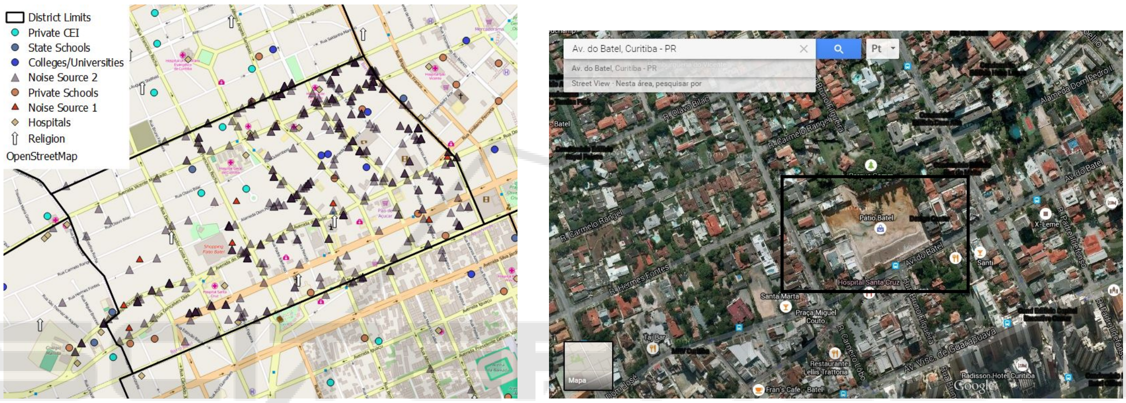

Figure 3: Additional noise source data from all years (left) and the same neighborhood location provided by Google Earth (right).

the concentration of black triangles are superimposed within the Figures). Note that this is a residential area with a lot of bars, and has a physical perimeter with the downtown district, which is the top one on the list of the noise complaints. In summary, Batel geofence from is impacted by a "noisy" district, the downtown district.

Along with the impacted region, authors also wanted to explore other factors, such as bus lines. The initial hypothesis considered was that the region was noisy due to a high number of bus lines. Nevertheless, the data indicates toward other direction: the locations with higher noise measures did not present an expressive number of line buses within their range. Measure point 10, for example, has 5 lines within the same area (V.Sandra, Tramontina, Jd.Social-Batel, R. XV-Barigui, Camp. Siqueira-Batel); measure point 11 has exactly the 5 lines as measure point 10, but some have duplication (due to the two-way street); measure point 13 has the same 5 lines of point 10; measure point 14 is impacted by only one bus line (Interbairros I anti-horário); measure point 15 is impacted by the union of bus lines from point 10 and 14; and point measure 16 is impacted also by the same bus lines presented in point 10. Briefly, if we remove the point measure 14, all the locations are impacted by almost the same bus lines. Note that the bus categories already listed in phase one stated that this region is not impacted by the biggest type of bus available in curitiba (the "expresso", a biarticulated bus with 28 meters).

Figure 3 (right) explores the same region under Google Satellite. Note that Figure 3 provides a new visual information: when the region was analyzed by Google, the new shopping Pátio Batel (within the black square) was still under construction. The building construction started back in 2008 and opened only in 09/09/2013 - exactly at the same time range in which the the noise data samples were collected. If Google had already updated the satellite information till the end of this paper publication, it would be rather difficult to navigate historically through time to understand the same point of view.

In summary, the integration of several sources, along with a summarized visual analysis stated that district is impacted by noise, but there are less noisy regions (around sensor 12) and worst noisy regions (top right area). Note that all surrounded facilities (hospital, schools, among others) are impacted day and night by noise created by constructions, traffic, and bars. Once the impacted areas were identified, and the period of the day which they are impacted, short term solutions could include measures toward citizen life quality, such as noise barriers and soundproof windows. In particular, from the computer science perspective, remains some challenges of integrating sources (such as Google Earth), applications and methodologies which contribute to the analysis.

4.4 Important Parameters to Consider for Solving the Geofencing Problem

The challenges and difficulties of exploring noise impacts through a GIS perspective are as follows:

- **Integration with Different Sources:** (i) within the noise measures data sample, several challenges arise, such as the non-correlation of addresses and coordinates, the use of different equipments for the samples and a non-regular data sampling over time; (ii) the complete data characterization itself is a challenge, due to issues such as the non matching of locations and the comparison of latitude/longitude, UTM coordinates and addresses; (iii) the standardization of the data and schemes; (iv) and the integration with different data sources, such as Google Satellite, and images might help to understand the historical spatio-temporal gaps which alphanumeric data sources might not answer (such as the construction of a shopping that was accidentally captured by Figure 3), among others. Solutions might include manual intervention, frameworks, linked data (Moura and Davis Jr., 2013), and data sources quality ranking (with metrics such as PageRank (Brin and Page, 1998)).
- **Updated Data:** Different data sources might have different time ranges for updating the data. Their maintenance over time might be costly, and eventually manual intervention is necessary. Some solutions include the use of linked data (Moura and Davis Jr., 2013) and Volunteered Geographic Information (VGI) (Mcdougall, 2011).
- **Methodology Issues:** evaluate noise measure values with a consistent period of time (considering different periods of day, but maintaining the pattern of noise/period samples and equipments); specify a criteria for choosing the noise measure locations; find a standard schema to integrate the data; consider different strategies for evaluating the environmental noise in a city (Brown and Lam, 1987) including those based on crowdsourcing (Schweizer et al., 2011);
- **Hardware Issues:** different hardware calibrations, along with the information that hardware without maintenance might impact final results (Schweizer et al., 2011);
- **Spatio-temporal Data Issues:** data might not comprise the complete spatio-temporal windows (as shown in Figure 1), and the relationship semantics and spatial location might be an issue over time (such as perimeters which impact other regions). Solutions include the adoption of moving objects databases (Erwig et al., 1999), and RDF triples as implementation technique (Moura and Davis Jr., 2013).
- **Domain Knowledge:** depending on the analyzed problem (along with the data limitations), the exploratory data analysis is not enough to solve a question: additional domain knowledge is necessary (such as the construction year of the biggest buildings in the area).

5 CONCLUSION

Research in urban noise pollution is not recent, but the exploration through different domains is still an ongoing effort. The possibility of implementing models within GIS and integrating them with different sources provides planners with a powerful and flexible tool for analyzing the land use, and deciding on new business permits and living quality. This paper presents the concepts, applications, and challenges of exploring noise through the concept of geofencing. Later these definitions are explored in a practical case study, within the Curitiba metropolitan region, Brazil, with data analysis aimed at supporting noise and pollution control. Future work includes the study of the noise impact decay, the integration of additional data, and the use of personalization and recommendation techniques in order to explore the data.

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REFERENCES

Arndt, L. T., Philips, J. W., and Barbosa, W. A. (2010). Sistema de informações geográficas para mapeamento do ruído urbano. In *SIMGEO '10*, pages 001–0010.

Barczyszyn, G. L. (2015). Integração de dados geográficos para planejamento urbano da cidade de Curitiba (Integration of geographic data for the urban planning of the city of Curitiba). Universidade Tecnológica Federal do Paraná.

Bijsterveld, K. (2008). *Mechanical Sound: Technology, Culture, and Public Problems of Noise in the Twentieth Century*. The MIT Press.

Brin, S. and Page, L. (1998). The anatomy of a large-scale hypertextual web search engine. In *Proceedings of the Seventh International Conference on World Wide Web 7*, WWW7, pages 107–117, Amsterdam, The Netherlands. Elsevier Science Publishers B. V.

Brown, A. and Lam, K. (1987). Urban noise surveys. *Applied Acoustics*, 20(1):23–39.

Calixto, A., Diniz, F. B., and Zannin, P. (2003). The statistical modeling of road traffic noise in an urban setting. *Cities*, 20:1–74.

Chen, R., Chu, T., Liu, J., Chen, Y., Chen, L., Xu, W., Li, X., Hyyppa, J., and Tang, J. (2014). Development of a contextual thinking engine in mobile devices. In *UPINLBS '14*, pages 90–96.

Duclaux, O., Frejafon, E., Schmidt, H., Thomasson, A., Mondelain, D., Yu, J., Guillaumond, C., Puel, C., Savoie, F., Ritter, P., Boch, J., and Wolf, J. (2002). 3d-air quality model evaluation using the lidar technique. *Atmospheric Environment*, 36(32):5081 – 5095.

Erwig, M., Guting, R., Schneider, M., and Vazirgiannis, M. (1999). Spatio-temporal data types: An approach to modeling and querying moving objects in databases. *GeoInformatica*, 3(3):269–296.

Greenwald, A., Hampel, G., Phadke, C., and Poosala, V. (2011). An economically viable solution to geofencing for mass-market applications. *Bell Lab. Tech. J.*, 16(2):21–38.

Hartwig, F. and Dearing, B. (1979). *Exploratory Data Analysis*. 07. SAGE Publications.

LNZ Soluções em Vibrações e Acústica (2011). Diagnóstico de Ruídos Urbanos - Relatório Final. Technical report, Prefeitura Municipal de Curitiba - Secretaria Municipal do Meio Ambiente .

Louen, C., Wehrens, A., and Vallée, D. (2014). Analysis of the effectiveness of different noise reducing measures based on individual perception in germany. *Transportation Research Procedia*, 4:472–481.

Madireddy, M., De Coensel, B., Can, A., Degraeuwe, B., Beusen, B., De Vlieger, I., and Botteldooren, D. (2011). Assessment of the impact of speed limit reduction and traffic signal coordination on vehicle emissions using an integrated approach. *Transportation research part D: transport and environment*, 16(7):504–508.

Martinez, W., Martinez, A., and Solka, J. (2010). *Exploratory Data Analysis with MATLAB, Second Edition*. Chapman & Hall/CRC Computer Science & Data Analysis. Taylor & Francis.

Mcdougall, K. (2011). The potential of citizen volunteered spatial information for building sdi. In *GSDI-11 Conference*.

Mostashari, A., Arnold, F., Maurer, M., and Wade, J. (2011). Citizens as sensors: The cognitive city paradigm. In *CEWIT '11*, pages 1–5.

Moura, T. H. V. M. and Davis Jr., C. A. (2013). Linked geospatial data: desafios e oportunidades de pesquisa. In *XIV Brazilian Symposium on GeoInformatics.*, pages 13–18. SBC.

NIST/SEMATECH (2012). *E-Handbook of Statistical Methods, available at http://www.itl.nist.gov/div898/handbook/*.

Oliveira, M. P. G., Medeiros, E. B., and Davis, Jr., C. A. (1999). Planning the Acoustic Urban Environment: A GIS-centered Approach. In *GIS '99*, pages 128–133, New York, NY, USA. ACM.

Ravada, S., Ali, M., Bao, J., and Sarwat, M. (2013). Acm sigspatial gis cup 2013: Geo-fencing. In *SIGSPATIAL'13*, pages 584–587, New York, NY, USA. ACM.

Rodrigues, F. (2010). *Metodologia para investigação de relação entre ruído de tráfego e condições operacionais do fluxo em centros* . PhD thesis, Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia - UFRJ.

Rodriguez Garzon, S. and Deva, B. (2014). Geofencing 2.0: Taking location-based notifications to the next level. In *UbiComp '14*, pages 921–932, New York, NY, USA. ACM.

Ryoo, J., Kim, H., and Das, S. (2012). Geo-fencing: Geographical-fencing based energy-aware proactive framework for mobile devices. In *Quality of Service (IWQoS), 2012 IEEE 20th International Workshop on*, pages 1–9.

Schweizer, I., Darmstadt, T., Probst, F., Bärtl, R., Darmstadt, T., Mühlhäuser, M., Darmstadt, T., Schulz, A., and Darmstadt, T. (2011). Noisemap - real-time participatory noise maps. In *PhoneSense'2011*.

Sheth, A., Seshan, S., and Wetherall, D. (2009). Geofencing: Confining wi-fi coverage to physical boundaries. In *Pervasive '09*, pages 274–290. Springer-Verlag.

Verheijen, E. and Jabben, J. (2010). Effect of electric cars on traffic noise and safety. *Bilthoven: RIVM*.

Zannin, P. H. T., Calixto, A., Diniz, F. B., and C., J. A. (2003). A survey of urban noise annoyance in a large brazilian city: the importance of a subjective analysis in conjunction with an objective *Environmental Impact Assessment Review*, 23:245–255.

Zannin, P. H. T., Diniz, F. B., and Barbosa, W. A. (2002). Environmental noise pollution in the city of Curitiba, Brazil . *Applied Acoustics*, 63(4):351 – 358.