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A COMPARATIVE STUDY OF METHODS FOR THE DISTRIBUTION OF POPULATIONS IN RESIDENTIAL BUILDINGS FOR NOISE MAPPING PURPOSES

Álvarez Ruiz, Yesika Patricia[1] **Jiménez Pérez, Tamara**[2*] **Puyana Romero, Virginia**[1]
Sequera Soto, Martín[2] **Gey Flores, Ricardo**[3] **Cueto Ancela, José Luis**[1]

[1] Acoustic Engineering Laboratory. C.A.S.E.M. Building. Puerto Real. Spain
[2] Urci Consultores, S.L. Calle María de Guzmán, 54. Madrid. Spain
[3] Profcontrol Ingenieros S.L. Camino del granizo. Chiclana. Spain

ABSTRACT

This paper seeks to offer a thoughtful comparative analysis of different population distribution methods commonly used in the preparation of strategic noise maps, to assess their confidence levels. The examination encompasses three different approaches, including the one suggested by the Spanish Ministry of Transport, Mobility, and Urban Agenda. In the interest of studying which methods appear to be closest to reality, the paper proposes leveraging the "real" data provided by the city councils to serve as a reference ("benchmark") in the analysis. The statistical techniques employed in this study aim to identify statistical differences between the estimates derived from the various methods. Additionally, the study seeks to identify which methods provide estimates that are closest to the "benchmark." The findings from this study will hopefully allow for the formulation of recommendations that could contribute to more efficient territorial planning and better management of environmental noise in urban studies.

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[*]***Corresponding author***: tamarajimenez@urciconsultores.com

1. INTRODUCTION

From the perspective of the effective development of strategic noise maps, the geographic services providing spatial data in Spain have made a qualitative leap since the first round of strategic noise maps to the present. However, there are still data that must be estimated from proxy data and whose level of approximation to reality is questionable. Accurate population allocation on strategic noise maps is crucial for urban planning, as it enables an accurate assessment of environmental impacts and the development of effective mitigation strategies.

Regardless of the method used to assign noise exposure levels to the population residing in multi-occupied residential buildings, where the location of each dwelling within the building is unknown (tool 21.2 of GPG [1]), the population data for that building must be estimated accurately. In most cases, the municipality has the population by census tract, district, neighborhood, etc. (resolved by the tool 19.1: Number of residents of the mapping area or sub-area of GPG). The systematic use of GIS to obtain the residential area of each building within the district, and thus distribute the population by building seems quite reasonable. There are currently several estimation methods available, and the motivation for this study is to analyze the extent to which they deviate from reality. Therefore, this work aims to analyze the application of different population distribution methods in strategic noise mapping as this has an impact on the accuracy of estimates of the noise-exposed population.

2. METHODOLOGY

To this end, three different methods were implemented, since the fourth method corresponds to the actual figures provided by the Puerto Real City Council.

1. Method IMAGINE. The proposal was extracted from the IMAGINE project [2]. This method distributes the population based on the accommodation capacity of buildings. It starts with the number of dwellings per building and multiplies it by an average occupancy rate. The total population is then distributed proportionally across the study area according to accommodation capacity.
2. Method MTMUA. The proposal was extracted from the Ministry of Transport, Mobility, and Urban Agenda for the fourth round of strategic noise maps [3]. In this approach, the total number of dwellings per census tract is calculated, and then the population is assigned proportionally to each building according to its number of dwellings.
3. Method CADASTRE. Population Allocation Methods in Cadastral Parcels [4]. Residential Built-Up Area Method. This method assigns the population proportionally to the built-up area designated for residential use.
4. Benchmark. The Real-Data Method uses detailed census and administrative information to accurately assign the population to buildings and dwellings within a study area (the benchmark).

2.1 Case study and data collection before GIS estimation

Puerto Real (Figure 1) is a municipality in the province of Cádiz with approximately 42,000 inhabitants and an area of 197 km². Located on the Bay of Cádiz, it has important transportation infrastructure, such as the A-4 motorway and the AP-4 highway, which have a significant impact on environmental noise levels.

Figure 1. Aerial view of the municipality of Puerto Real showing the location of the two census tracts.

Census data from the Puerto Real municipality, cadastral records with information on buildings, and geospatial databases detailing urban characteristics and land use were collected. The collected information was integrated into a Geographic Information System (GIS) for subsequent analysis and application. Two census sections were chosen for the case study due to their different urban typologies.

- Census tracts 4-5 (Figure 2) present a high urban density, with mostly residential buildings of up to four stories, combined with small shops and public spaces.

Figure 2. Image of the typical type of configuration of residential building blocks (multi-story buildings) within census tracts 4-5.

- Census tract 3-10A, on the other hand, is characterized by a lower building density (Figure 3), with a predominance of single-family homes and some residential blocks of up to four stories. Its proximity to key road infrastructure exposes it to high noise levels, making it an area of interest for strategic noise mapping.

Figure 3. Image of the typical type of configuration of residential building blocks (semi-detached houses) within census tracts 3-10A.

For this study, 70 residential buildings containing 2,465 inhabitants were selected.

2.2 Statistical tests

To respond to the question that underlies this study, a proposal is hereby made for a comparison of the population data that has been generated by the four methods, on a building-by-building basis. This approach constitutes a relational (paired) analysis, as it involves the use of four quantitative estimates for the same units (buildings) which defines a data vector. Since we have the real data, the analysis consists of analyzing whether there are significant differences with respect to benchmarking using the three alternative estimation methods (named in this study IMAGINE, MTMUA, and CADASTRE). To this end, we will compute the Euclidean and Manhattan distances (also known as City Block) between the predictors with respect to the benchmark. Also, we estimate the Absolute Errors (AE) vector for each method with respect to the benchmark and the Mean Absolute Error (MAE). We will also measure the RMSE (Root Mean Square Errors) and corroborate the results using cluster analysis. Lower MAE & RMSE means a more accurate method, taking into account that RMSE penalizes large errors more than MAE. Take into account that Euclidean distance refers to a measurement metric between the two vectors in Euclidean space and, RMSE is the error function of the square root of the average square distance between the Benchmarking and predicted points of the two vectors. As MAE is the Manhattan distance divided by the sample size, only MAE is shown.

A nonparametric Friedman test is proposed for the absolute errors, wherein the medians are subjected to analysis. The null hypothesis is formulated as follows:

“Ho = there are no significant differences in the calculation and allocation of the population from building to building by the different methods with respect to the benchmark”.

After the global omnibus test, in the event that the null hypothesis is rejected, a Bonferroni post-hoc test will be utilized to evaluate the specific differences on a case-by-case basis (for between-subject factors, i.e., method by method).

3. RESULTS AND DISCUSSION

First, the distance between two vectors is calculated to assess their data-to-data similarity (Table 1). Then the RMSE and MAE (Table 2) is used to measure the difference between the predicted and observed data (of the same two vectors).

Table 1. Euclidean distances of the results of the methods with respect to the benchmark.

Distance	IMAGINE	MTMUA	CADASTRE
Euclidean	69.6	93.8	147.7

Table 2. MAE and RMSE.

Error	IMAGINE	MTMUA	CADASTRE
MAE	5.7	7.4	12.9
RMSE	8.3	11.2	17.7

Table 1 and Table 2, indicate that the IMAGINE method is closer to the actual estimate of inhabitants per building.

The diagram for the Absolute Errors (AE) of the three methods in comparison to the benchmark (Figure 4) shows some outliers. IMAGINE method exhibits 3, MTMUA 5, while CADASTRE scores 7. MTMUA shows a Skewed Box Plot.

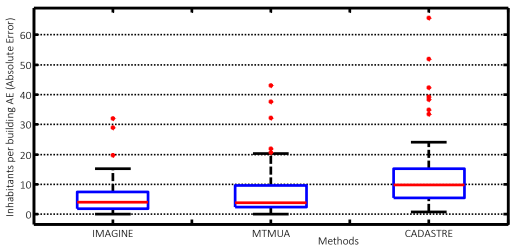

Figure 4. Boxplot of the distributions of population estimates building by building.

Meanwhile, the CADASTRE method points to the buildings with ID 1158548 and ID 600320. These last outliers are explained because the CADASTRE method makes estimates based on the built surface area per plot. If the area being analyzed is not occupied by buildings of a homogeneous type, this leads to large errors in population estimation sooner or later.

Figure 5. Picture of several single-family buildings that constitute a single cadastral reference with the largest area cataloged in the study.

There was an overall statistically significant difference between the mean ranks of the AE of the three methods with respect to the benchmark $\chi2(2) = 28.9$ $p < 0.001$. As the Friedman test is an omnibus test, a post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$ (as we have 3 tests to perform). There were no significant differences between IMAGINE and MTMUA ($Z = -2.03$, $p = 0.042$). However, there were statistically significant differences with the method CADASTRE in the other two cases with $Z = -4.6$ and -3.7 respectively, and $p < 0.001$ in both cases).

When applying a hierarchical Cluster Method in SPSS using the between-groups of average linkage, with Euclidean distance, the dendrogram corroborates this fact, since both IMAGINE and MTMUA methods perform close results that form part of the same cluster (Figure 6).

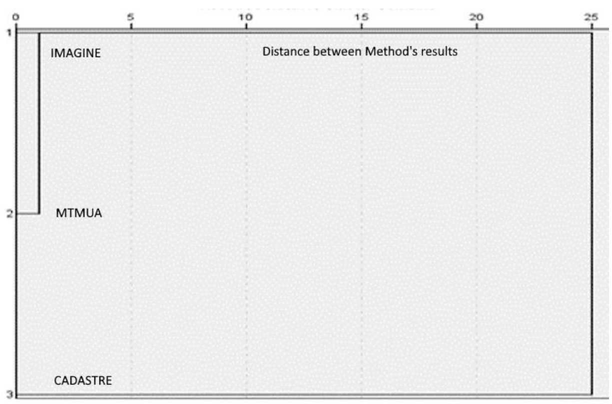

Figure 6. The dendrogram shows that Method 3 (CADASTRE) provides results very far from methods 1 and 2.

4. CONCLUSIONS

The results of this exploratory study indicate that the IMAGINE method is the most promising of the methods analyzed. Furthermore, the introduction of the complexity offered by the procedure proposed by Method 2 (Method MTMUA) appears to be unnecessary. Consequently, the number of dwellings per building does not guarantee a more accurate distribution of the population. A notable limitation of this study is its development in a case study context, indicating a need for further study that allows the generalization of the results. This study aims to advance toward a method that goes beyond those analyzed and that proposes the most interesting explanatory variables that complete the vision of estimating the number of people living in a building.

5. REFERENCES

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