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Deciphering Urban Traffic Patterns in Palma (Balearic Islands, Spain)

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Abstract. The effective monitoring of urban traffic can be successfully achieved through the use of fixed sensors based on inductive loop detectors. These devices provide valuable information about the intensity of vehicles traversing a specific street in a particular direction. This kind of data affords a comprehensive understanding of the city's mobility and traffic conditions. The primary aim of this study is to evaluate the spatiotemporal patterns of vehicular mobility in the city of Palma. Palma, the focus of this study, is a Mediterranean city located on the island of Mallorca (Spain). Palma has an approximate population of 400,000 residents. The city's economy is heavily reliant on tourism, with around five million tourists visiting annually. Spatiotemporal traffic dynamics were analyzed at six monitoring stations for the period 2003-2022 located in high, medium, and low-income residential areas. The results show a significant decrease in the total number of vehicles in all neighbourhoods. Daily, weekly, monthly, and yearly mobility patterns were examined, generally showing a substantial drop in the number of vehicles. Apparent causes behind this include the development of restrictive private vehicle mobility policies, the increase in bike lanes, the reduction in the number of lanes on main roads, and the delineation of no-traffic zones. These results allow for optimism for the future of vehicle traffic in Palma, in favour of a more sustainable city. Despite the decrease experienced in vehicle counts throughout the period analyzed for the selected sensors located in residential areas, the obtained results should be interpreted very cautiously, as this situation cannot be generalized to the rest of Palma's areas. There is evidence that traffic on certain city roads as Vía de Cintura has significantly increased.

Keywords. Urban traffic monitoring, traffic sensors, traffic spatiotemporal patterns, congestions, Palma policies

1. Introduction

Effective urban traffic monitoring can be attained through fixed sensors based on inductive loop detectors [1]. These devices offer essential insights into vehicular intensity on specific streets in particular directions, thereby facilitating comprehensive comprehension of city mobility and traffic conditions.

Traffic intensity fluctuations are instrumental in identifying population mobility patterns. These patterns could be annual, monthly, weekly, or daily, thus providing insights into the city's activities, including the commencement of work, the impact of mobility in different income-based residential areas, and peak activity times in various institutions.

Strategic sensor placement in areas such as residential, commercial, educational, health, industrial, and tourist sectors allows for detection of mobility patterns within each area. This critical information assists in traffic flow detection and congestion zone evaluation. Additionally, the study of urban traffic density represents a critical environmental and health issue in larger cities [2], [3].

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Several studies have evaluated mobility patterns through data analysis from vehicle measuring stations. For instance, Lin et al. [4] analyzed urban freeway traffic flow characteristics using a comprehensive highway dataset, revealing the significant influence of season, weekday, and hour on traffic characteristics. Abishek et al. [5] proposes a wireless sensor network solution to optimize traffic flow in Indian cities. By dynamically adjusting traffic signal timings, the system improves vehicle throughput by 7%, either allowing more cars to pass or reducing individual waiting times at junctions.

Traffic density estimation models are also prevalent. Zeroual et al. [6] introduced a statistical approach to reliable road traffic congestion detection, which estimates traffic density efficiently while reducing sensor implementation and maintenance costs.

There are various traffic monitoring sensor systems such as wireless sensor networks [7], [8], digital cameras linked to computer vision systems [9], social media analysis [10], and vehicles as dynamic sensor systems [11].

Geographical traffic pattern detection is a recurrent theme in scientific literature [12], [13].

This study aims to evaluate spatial-temporal patterns of vehicular mobility in Palma, aiming to assist urban planners in identifying congestion "hot spots". By leveraging the acquired data, city planners could improve traffic system efficiency in Palma, subsequently enhancing urban life quality.

2. Case study

Palma, the focus of this study, is a Mediterranean city located on the island of Mallorca. Serving as the capital of the Autonomous Community of the Balearic Islands, Palma boasts an approximate population of 400,000 residents (IBESTAT, 2022). The city's economy is heavily tied to tourism, with approximately two million tourists visiting annually. This influx of visitors, coupled with the resident population, influences the city's traffic dynamics significantly.

Palma's urban structure is concentric, characterized by an historical city center from which various main thoroughfares extend towards different towns across the island. This design contributes to a unique pattern of traffic flow, affecting the distribution and intensity of vehicular movement within the city.

Surrounding the city's core, a bypass forms a compact boundary for urban activity. This bypass plays a significant role in the city's mobility, channeling and controlling traffic movement around the urban center and affecting how vehicles access the city's central and peripheral areas.

Significant traffic concentrations occur along the 'Avenidas', a major avenue that demarcates the city's historical center. All vehicular flows within the city converge at these avenues before radiating out to the various zones of the city in a radial pattern. This distinctive flow structure provides an intriguing area of study in analyzing traffic and mobility patterns within Palma.

This study will delve into understanding these complex dynamics of traffic in Palma. By leveraging data from fixed sensors based on inductive loop detectors scattered across the city, we aim to unearth patterns and identify congestion hot spots. This knowledge will provide invaluable insights to support city planners in making data-driven decisions to manage traffic congestion more effectively and promote smoother urban mobility.

Existen algunos trabajos que han evaluado el impacto de la actividad turística sobre la congestión del tráfico en la isla de Mallorca [14], [15].

3. Methods: Data and process

The data utilized in this study were provided in a digital format by the Department of Mobility of the Palma City Council. The dataset comprises information from a total of 299 monitoring stations dispersed across the urban area of the city. These stations continuously record the number of vehicles passing through, with readings taken every fifteen minutes from 2003 to 2022.

To simplify the analysis and achieve more precise results, a selection of these vehicle counting stations was made and only 23 where selected. These chosen stations are located in various zones: high-income residential areas, medium-income residential areas, low-income residential areas, industrial zones, and tourist areas. This stratification of data sources aids in better understanding the differential traffic dynamics present within these diverse urban zones. In this study only the six stations located at residential areas have been considered.

Data from each of these stations were analyzed separately on an hourly basis, and then aggregated at the annual, monthly, and daily levels. This methodology provides a layered view of the traffic patterns in each area, facilitating the detection of trends and patterns over time. The statistical analysis of this data is key to unveiling the intricacies of traffic dynamics in each zone.

For the data analysis, we employed R programming language, a powerful tool well suited for handling, analyzing, and visualizing large datasets. In conjunction with R, the ArcGIS Pro Geographic Information System (GIS) software was used. The combination of these technologies allowed for robust data processing, analysis, and visualization, enhancing our ability to detect and interpret spatial-temporal patterns of vehicular mobility in the city of Palma.

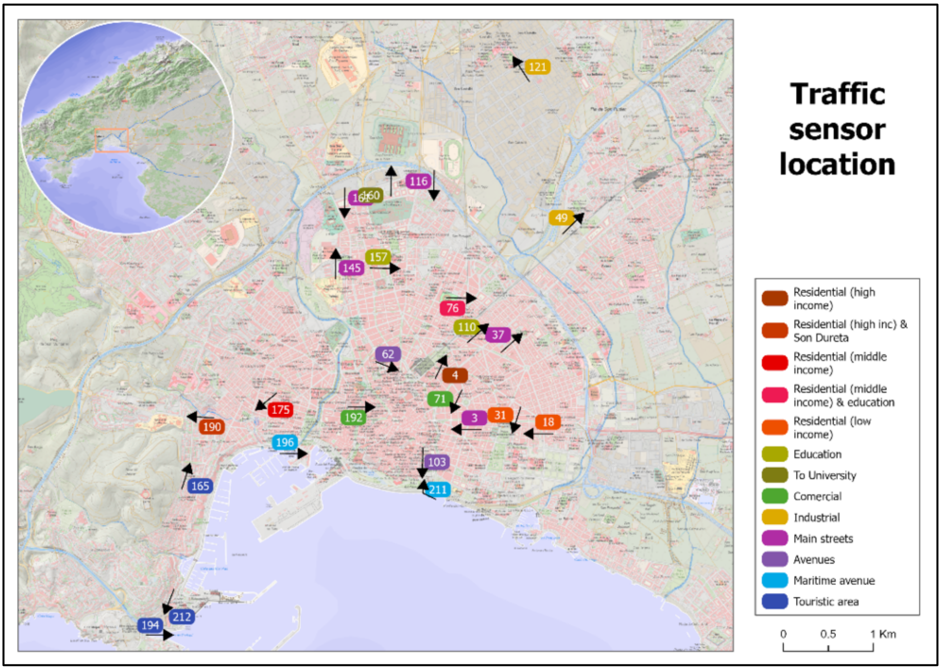

Figure 1. Location of traffic sensor selected by land use.

4. Results and discussion

Analysis of the time series of traffic intensity at the monitoring stations in the residential areas shows a generally declining traffic profile across the board (Figure 2). The temporal evolution since 2003 reveals a reduction in traffic year after year in all the sampled neighborhoods, showing statistically significant yet moderate or low negative correlation. Specifically, in low-income neighborhoods, the regression appears less negative than in the rest, where the two sensors exhibit similar trend behaviors. However, sensor 18 exhibits less stability than sensor 31, which shows greater regularity throughout the series, primarily because it is located in what we have identified as a purely residential neighbourhood.

The negative trend is the general norm in the vast majority of sensors available in the database. The data were grouped into four five-year periods (Table 1), and the results show that 73% of the stations (those with records in all four created periods) experienced a percentage decrease in the 2008–2012 period compared to 2003–2007. In the next period (2013–2017), the percentage of sensors showing a decrease rose to 83% compared to 2008–2012. Finally, in the latest period (2018–2022), the number of sensors showing a decrease between five-year periods increased slightly to 85%. Therefore, it can be stated that intra-city traffic, in general, experiences a decline in vehicle traffic according to the data provided by the sensors.

The dynamics of traffic reduction in the residential areas of Palma are confirmed by the interpretation of the values obtained in the Mann-Kendall test and Sen's Slope values (Table 2). It is observed that the highest negative values occur in neighbourhoods with high- and medium-income levels. Therefore, it is the neighbourhoods with lower income levels that maintain high levels of traffic density.

Moreover, it aligns with the observation that the most significant decrease in traffic occurs in census districts with higher incomes. Likewise, all available sensors have been compared and grouped according to the type of district based on the average annual per capita income. While the decrease in vehicle circulation on the streets of Palma (regardless of the average per capita income) is generally and relatively significant, the main difference lies in the order of magnitude of the decrease. High-income neighborhoods have seen a larger decline, especially in the last five years (from 2018 to present). In contrast, low and middle-income neighbourhoods have experienced similar declines in different periods, except for 2008–2012.

Table 1. Census districts traffic intensity (average monthly) according to income

Income Level	2003 - 2007	2008 - 2012	2013 - 2017	2018 - 2022	Diff
High	47,805	43,819 (-8%)	41,064 (-6%)	34,166 (-17%)	-28%
Medium	38,456	34,487 (-10%)	33,234 (-4%)	30,415 (-8%)	-21%
Low	28,559	27,368 (-4%)	25,752 (-6%)	23,737 (-8%)	-17%

Table 2. Mann Kendall and Sen's slope referred to complete time series (2003 – 2022)

Income Level	Sensor	Mann-Kendall test	Sen's Slope
High	4	tau = -0.64 pvalue =< 2.22e-16	-77.67 pvalue =< 2.22e-16
	190	tau = -0.415 pvalue =< 2.22e-16	-28.96 pvalue =< 2.22e-16
Medium	175	tau = -0.675 pvalue =< 2.22e-16	-77.7 pvalue =< 2.22e-16
	76	tau = -0.632 pvalue =< 2.22e-16	-45.29 pvalue =< 2.22e-16
Low	18	tau = -0.322 pvalue =1.2995e-13	-31.22 p-value = 1.3e-13
	31	tau = -0.313 pvalue =5.3858e-13	-13.46 p-value = 5.386e-13

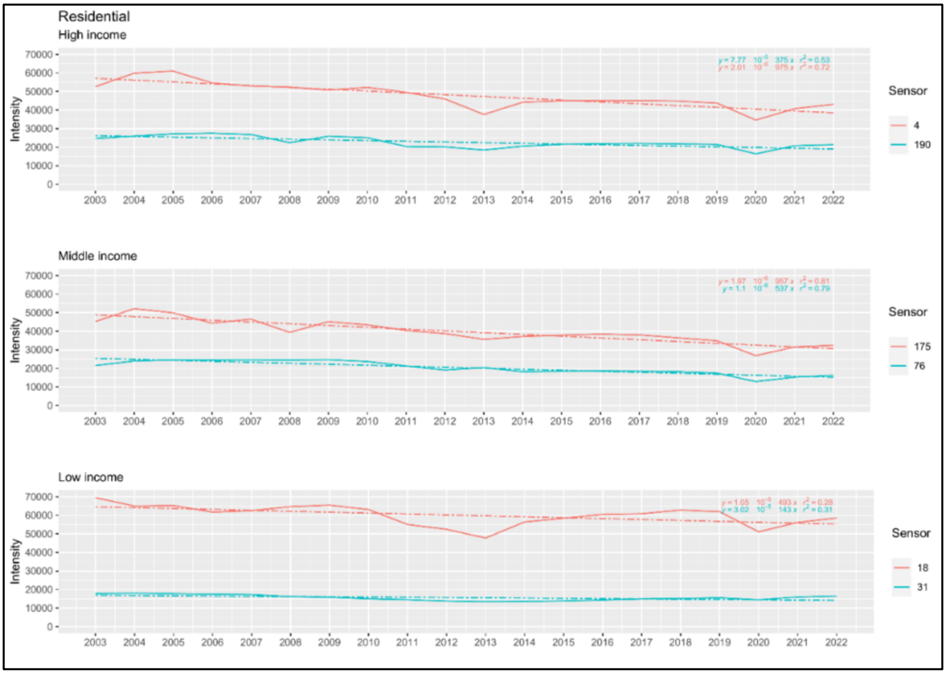

Figure 2. Evolution of traffic intensity by year in residential areas.

Figure 2 also shows the impact of the economic crisis of 2009-2013 and the COVID-19 pandemic over the period 2020-2021, leading to a significant reduction in vehicle traffic intensity. The effects are always greater in neighbourhoods with lower income levels.

The weekly and hourly traffic dynamics in residential areas (Figure 3) show that on weekdays, traffic activity starts at 5:00 AM and then picks up again until 18:00/19:00 PM in the evening. On public holidays these dynamics are maintained, but the intensities are much lower. Daily routines also differ among neighborhoods: lower-income areas start their working day earlier and exhibit a pattern on Saturdays more similar to a workday than that of high/middle-income areas. This suggests that residents of low-income neighborhoods may work more Saturdays, a conclusion that aligns with job types and patterns observed during the COVID-19 pandemic. Further research will be necessary to more fully understand these disparities and their implications. Patterns of forced mobility to work are evident in the temporal dynamics of traffic.

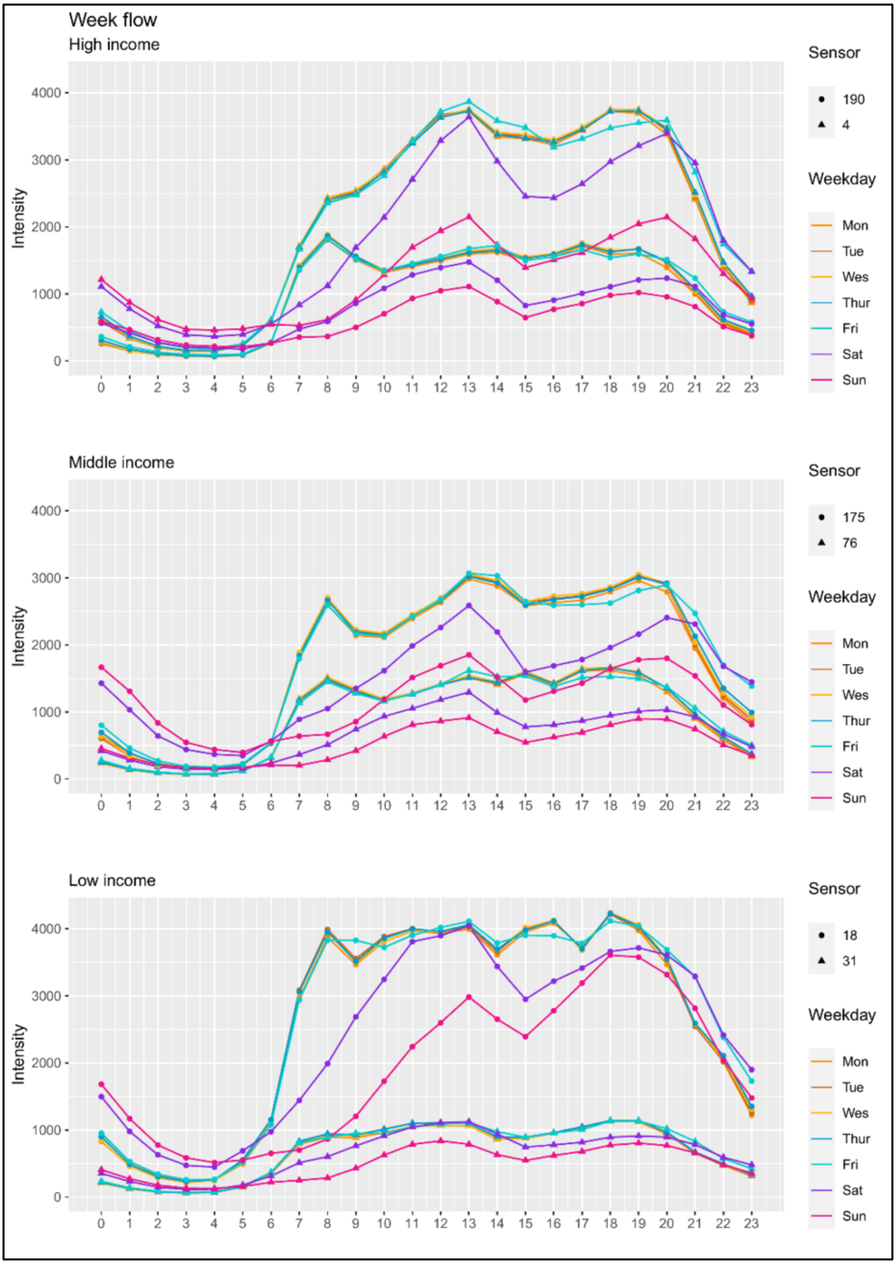

Figure 3. Evolution of traffic intensity by hour and week day.

Despite a possible hypothesis that traffic in Palma has been increasing year over year, an analysis of spatiotemporal transit data over the last 20 years reveals an unexpected finding: traffic within the city has actually been decreasing. This conclusion seems to contradict pre-existing data indicating a growing population, increased airport arrivals, and an escalating number of registered vehicles in Palma over the same period. However, the decrease in traffic can be attributed to municipal policies focused on reducing greenhouse gas concentrations, improving air quality, and reclaiming streets for pedestrian use. Such measures include the creation of pedestrian precincts, restriction zones, and enhancements to public transportation.

This trend, however, is not seen in the metropolitan area surrounding Palma, where vehicle pressure continues to rise due to an inefficient public transport network connecting the rest of the island to the city. Furthermore, while the general decline in vehicle traffic is a positive indicator for the environment and public health, the magnitude of this decrease varies by neighborhood income levels. Notably, middle-to-high income neighborhoods exhibit the greatest reduction in traffic, suggesting a potential imbalance in the availability of sustainable and pedestrian-friendly areas within the city.

5. Conclusion

The spatiotemporal analysis of traffic using inductive loop detectors in residential areas of the city of Palma (Balearic Islands, Spain) for the period 2003-2022 has allowed us to detect that, in general, there has been a decrease in vehicle traffic throughout the city. The analysis also confirms the effects that the 2009-2013 crisis and the COVID-19 pandemic had, both events leading to a significant reduction in vehicle traffic. The changes most sensitive to the economic effects of the crisis are primarily manifested in low-income neighborhoods. The trend towards reducing the number of vehicles could be due to the development of restrictive policies on the use of private vehicles and the promotion of active mobility modes in the city. In this regard, the deployment of bike lanes throughout the urban area stands out, as well as the reduction in the number of traffic lanes and the delimitation of restricted traffic zones. The results allow us to be optimistic about the future of traffic in the city.

Agreements

Comunitat Autonòma de les Illes Balears through the Direcció General de Política Universitària i Recerca, with funds from the Tourist Stay Tax Law (PRD2018/52–ITS 2017-006). Servei de Mobilitat - Ajuntament de Palma. Programa SOIB Recerca i Innovació 2022-2023. UIB-GOIB.

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