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Means of Transport and Population Distribution in Metropolitan Areas: An Evolutionary Analysis of the Valencia Metropolitan Area

Carmen Zornoza-Gallego

Inter-University Institute for Local Development, Department of Geography, University of Valencia, 46010 Valencia, Spain; carmen.zornoza@uv.es

Abstract: The purpose of this research is to find out how transport modes shape the configuration of a metropolitan area in terms of population. Evolutionary analysis is undertaken to ascertain the impact of mobility on population distribution over a number of stages. The case study analysis puts the spotlight on the Valencia Metropolitan Area (Spain) over a long period of time, from 1900 to 2021. The research focuses on quantification, first in terms of how different means of transport affect population distribution, and subsequently, on the time gap between the emergence of a means of transport and its potential in distributing the population. Results show that the prevalence of the means of transport in structuring a metropolitan area has varied over time. At first, trains and trams played a major role in shaping the urban area while, in more recent eras, cars have remodelled the urban space. It was found that municipalities which did not have a railway service had very low, or even negative, increases in population until 1981. By contrast, since then, they have outstripped the increases in municipalities with rail connections. The time gap between the emergence of a means of transport and its potential to distribute the population is quantified in terms of decades. Automobiles took less time than trains and trams to have an impact on population distribution. These results can be understood as an indicator of the length of time needed to change previous dynamics and can be used to guide new policies in the field.

Keywords: means of transport; population; residential mobility; metropolitan area

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1. Introduction

The historical use of the "city" concept conjures up a distinct place with clear boundaries that unmistakably set it apart from the countryside. However, the spaces currently viewed as city and countryside are no longer fully separate, since there are many mixed areas where their urban and rural functions intermingle and create new territorial realities. These mixed areas lead to the blurring of urban area boundaries. The concepts of a "diffuse city" [1] and a "city without boundaries" [2] describe the process which cuts across the old rural-urban divide. This shift involves large-scale land usage and a small increase in urban population [3]. According to the authors of [4], a new model of a dispersed city is created by residential and economic decentralisation resulting from factors, including improvements in communications systems, which engender less friction of distance.

Extensive urban development and population dispersion mean that cities need to be addressed as something more than just their physical structure. To gain a good grasp of the urban system, it is important to factor in the social relationships taking place inside them. This is precisely the idea behind the concept of the city in the social sciences, which is studied through the human relationships that occur within it. The author of [5] pointed out that historically, the boundaries between territories had been defined on the basis of these relationships and that, in turn, these boundaries were determined by transport capacity. From this standpoint, urban areas are envisaged over and above their morphology by building in the connection between their residents via daily mobility.

The potential of means of transport to shape new settlements and redistribute populations draws on the concept of time introduced by the work in [6]. This research, commissioned by the US Department of Transportation, conducted a robust analysis of travel habits. Three different levels were employed: the national level, followed by 21 urban areas with populations of between 70,000 and 16 million people, and a detailed study of Washington, D.C. It was observed that people commuted for a constant amount of time, quantified at one hour. Other researchers [7–9] estimated that in the past, humans spent the same amount of time on their daily journeys. A recent study by [10] found that the average times of standard journeys in different countries are currently relatively similar: 55 m in Hungary and France, 1 h 24 min in England, 1 h 23 min in Belgium, and 1 h 15 min in Denmark. According to the research in [11], surveys in US metropolitan areas showed that for the 90% of the population that commute by private vehicle, an hour is still the average travelling time. If this amount of time is considered stable, an increase in speeds will translate into an increase in distances and/or the number of journeys [12–14].

The relationship between urban structure and mobility was defined by the research in [15] as the "imperfect pairing". The urban structure in terms of the location of uses engenders different travel needs and encourages one modal choice or another [16–21]. Existing transport infrastructures (rail, cycling, roads, etc.) also shape people's daily modal choices [22–25]. However, this relationship can also be studied the other way around, whereby daily mobility alters the urban fabric [26–30]. The author of. [5] pointed out that the great urban expansion of the last century was made possible by the availability and the increased speed of the means of transport. People's daily horizons were broadened, and they were able to cover greater distances while sticking to the same travelling time.

Analysing the relationship between mobility and urban structure is essential to properly understand and examine today's cities. The author of [31] looked at the relationship between development and transport from a historical perspective to explore urban transformations and investigate the emergence of certain types of urban morphologies rooted in mobility and the effect of travel variables. The findings of the study, which are primarily about Sweden, point out how to redesign cities in order to fashion more sustainable ones. Understanding how they evolve and relate to each other is crucial if the negative externalities of this relationship are to be mitigated and the positive externalities maximised [32]. Policies to abate greenhouse gas emissions are essential in a climate emergency. Analyses that address the drivers of these emissions, such as mobility, can inform the development of mitigation policies.

The relationship between modes of transport and urban morphologies is explained using the terminology of the authors of [33], who identified three types: walking cities, transit cities, and automobile cities. While travelling on foot shaped cities, dense, mixed-use areas characterise this urban fabric. Most of these cities are 3–4 km in diameter and have developed around a central point. In the research in [7], the relationship between human beings and travel was analysed from an anthropological perspective, highlighting that pre-railway cities were no larger than 5 km in diameter, which is the distance that can be covered on foot in an hour. Transit cities extended the range of the walking city following train and tram routes, and specifically their stations. The increase in speed extended the walking city to distances of between 20 and 30 km. The shape that Geddes suggested in 1915 [5] was an "octopus" with a central part, which can be crossed on foot, and tentacles running out along the railway tracks. The automobile city stemmed from the uptake of the car as the main mode of transport, and this led to an extensive transformation of the urban form by extending distances to approximately 50 km in any direction. This form is characterised by low density and zoning, which separate uses. The sprawling suburbs created are highly dependent on automobiles [34,35]. These city types were not mutually exclusive and generally rubbed shoulders with each other over the course of each city's history.

Both the railway city and the automobile city involve lower population density, as they enable people to settle at a certain distance from the centre of the area and commute

to it on a daily basis; yet, there are major differences between the structure of these cities and their mobility patterns. The accessibility of the transit city increases the closer the population is to the stations. Residents need to be situated around these stations to benefit from this accessibility. This means that urban growth must be scaled up around them as much as possible. Thus, if railways are the main means of transport in a metropolitan area, this has two crucial implications in terms of environmental sustainability: (1) reduced land use, as the morphology of residential areas is likely to be high density, and (2) reduced greenhouse gas emissions, as people can use a sustainable means of transport for their intercity journeys. The automobile city, by contrast, comes into being through the road network where each road node is a potential access point [36]. The likelihood of scattered occupation of the territory is much greater and it can spread out in all directions. Moreover, the higher speeds of this means of transport make it possible to engender extremely large urban areas. The most significant environmental sustainability implications related to the car city are: (1) huge land resource use, given that discontinuous, low-density growth is the main feature of these new urban patterns, and (2) a large amount of greenhouse gases released into the atmosphere, as the people living in these urban morphologies are entirely reliant on their cars for travel [18,37,38].

As shown, the most common way to address the growth of cities and mobility is to use their physical structure, which is very powerful in revealing changes. This paper analyses the topic from a social science perspective, focusing on the urban population to study the city; specifically, the analysis centres on the spatial distribution of urban populations and its relationship with the means of transport. There is a huge amount of literature available to explain the reasons behind intra-urban or short-distance residential mobility and immobility [39–46]. The vast majority of these studies are related to individual reasons, such as life cycle, quality of life, bigger dwellings, and job location [47–50]. These studies are very important to understand the personal drivers behind residential mobility. However, in this research, we only investigate residential mobility based on one structural fact, i.e., the mobility afforded by means of transport. This is defined as potential mobility [51].

This paper uses a case study to raise new questions about the evolution of the relationship between means of transport and the population distribution of a city. Evolutionary analysis is used, since current urban spaces are the outcome of the interaction of historical traits, coupled with new emerging conditions. The case study takes place in the Valencia Metropolitan Area (Spain) covering a long period of time so as to accurately describe the area's development processes from the early 20th century through 2021.

The main objective is to provide a historical narrative about how this relationship has developed. This overarching goal is achieved through two specific objectives:

1. To quantify the influence of the major modes of transport on the location of the population over time (1900–2021);
2. To quantify the time gap between the introduction of various means of transport and their influence on population distribution.

The research focuses on quantifying several parts of the aforementioned relationship. In a first stage, it addresses the importance of the means of transport in distributing the population. In a second stage, the time gap between the emergence of a means of transport and its potential in distributing the population is analysed. The expected results may be useful to recognise how the area was created but, most importantly, they aim to bring new insights into how means of transport and population distribution in a metropolitan area evolve.

There are two hypotheses to be validated:

1. The availability of means of transport in a metropolitan area is such a strong factor that it can explain the distribution of its population;
2. There is a time gap between the introduction of a means of transport in a metropolitan area and its influence on the distribution of its population.

Area of Study

The Valencia Metropolitan Area (VMA) is on the Spanish Mediterranean coast. It ranks third in terms of population in Spain and is home to 1,986,297 people (2021 Census). Since there are no official delimitations of metropolitan areas in Spain, one has to be chosen under the criteria considered appropriate by researchers. In this case, we have used the area proposed by the research in [52], based on data from the 2011 Census. This demarcation is founded on functional criteria employed to recognise the socioeconomic relationships between units in the study area. The location of the metropolitan area and the municipalities that make it up are shown in Figure 1.

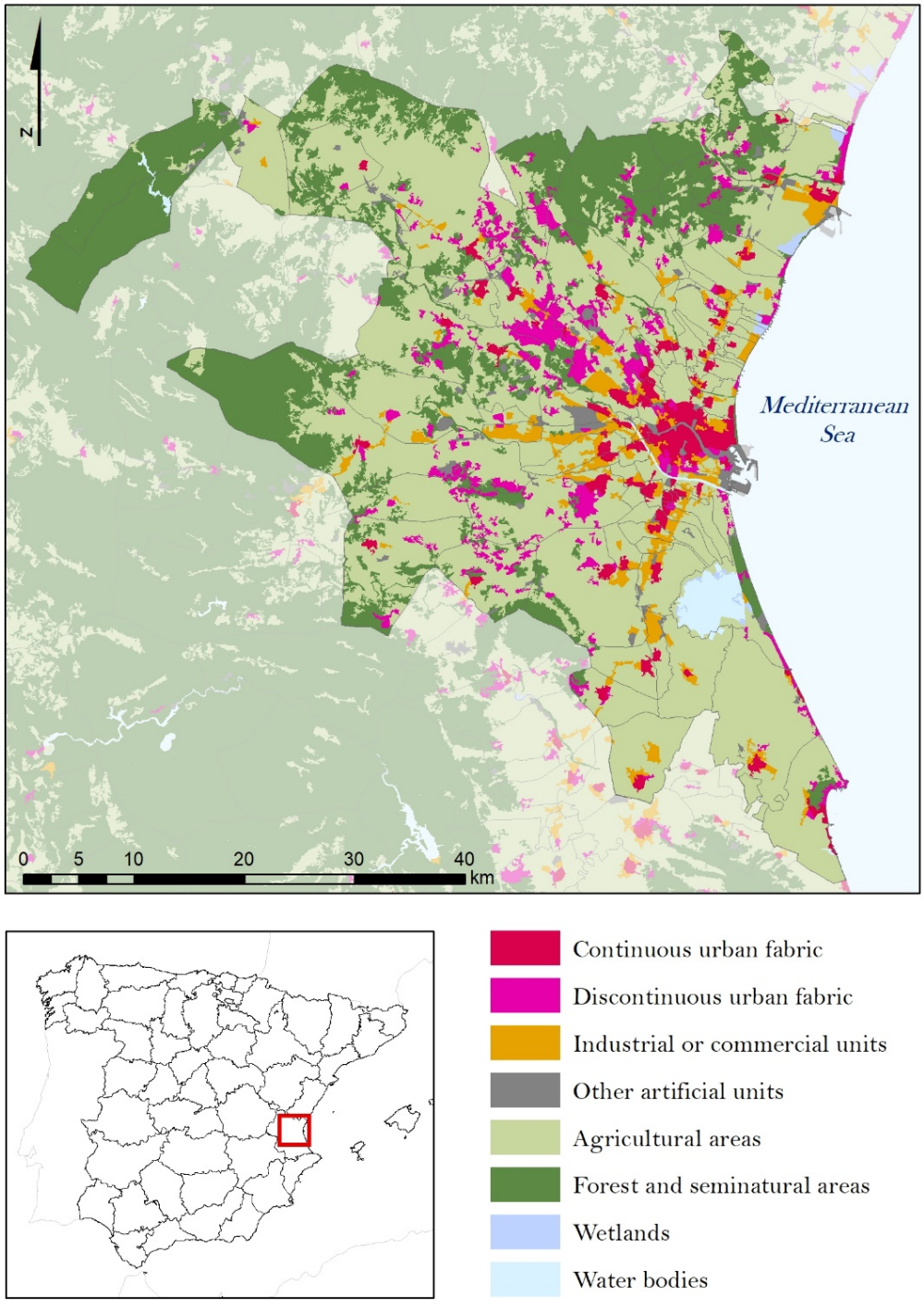


Figure 1. Land uses and location map.

Figure 1 represents land uses taken from the CORINE Land Cover 2018 Project. This information is useful to present the area, given that it provides a better understanding of the territory under study. The central part of the city is mainly made up of a continuous urban fabric. The discontinuous urban fabric is not located contiguously to the centre, as is usual. The central city of Valencia is surrounded by the *huerta* irrigated farmland area, which has enormous agricultural, historical, and cultural value. *Huertas* are among the most distinctive traditional agricultural systems in Europe [53,54] and are located around city perimeters [55].

In terms of population changes, one of the most important periods of the last century was 1950–1975. As reported by the research in [56], during this period there were 10 million internal displacements in Spain. This process, known as the "rural exodus", involved a redistribution of people from the countryside to towns and cities and led to significant changes in Spanish society's appearance and structure. Subsequently, the Spanish economic boom took place between 1995 and 2007. There was a huge influx of foreign immigrants, whereas movements in previous periods were domestic. The research in [57] found that the province of Valencia was one of the largest receivers of people flows in Spain.

2. Materials and Methods

Analysis over a long period of time (1900–2021) is highly instructive for illustrating the processes by which a metropolitan area is shaped, yet it also poses major methodological challenges. The main issue is that the data used have to be comparable with each other. In the case of mobility, currently, there is a large amount of data and records which can be drawn upon to identify daily mobility patterns (surveys, traffic flows, passenger transport statistics, censuses, new technologies, social media, etc.). However, these are not available for earlier periods.

Therefore, the absence of specific comparable records meant that two issues had to be assumed in order to put forward a methodology: (1) that this is a single-centre metropolitan area where most daily journeys involve movement towards the centre of the city, and (2) that mobility in a metropolitan area can be readily described on the basis of the availability of transport and its distance from the centre. The first of these assumptions in medium-sized metropolitan areas like Valencia is a generally accepted approach [58,59]. It is also the common initial model in the development of metropolitan areas and thus, a robust way to compare different eras. This approach has been used in multiple studies [60–63]. The second assumption is grounded in the fact that the presence of a mode of transport entails its use and that, in a monocentric metropolis, the central urban area is the primary place of origin or destination where exchanges and the main urban functions take place. According to the objectives of the research and the aforementioned assumptions, an analysis was proposed based on three main data sources: population, distance to the city centre, and the availability of means of transport. The basic unit of analysis was the municipality, as data were available for this unit.

The proposed methodology followed these steps:

1. Historical data reconstruction (1900–2021). Data refers to municipalities.
    a. Population;
    b. Distance to the city centre;
    c. Availability of means of transport.
2. Preliminary test to reveal the internal population dynamics of municipalities.
3. Analysis to quantify the influence of the main means of transport on the location of the population. Data from municipalities were divided into two groups, depending on the availability of the means of transport:
    a. General population distribution;
    b. Population distribution by distance to the centre.

The historical data reconstruction (population, distances, and means of transport) referred to each municipality in the area, as this was the unit for which current and previous

population data were available. This information came from the population censuses that were taken every ten years. Thus, the study periods corresponded to the publication of censuses in 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1981, 1991, 2001, 2011, and 2021. Data for 2021 were taken from the continuous registers, as the census is not yet available. The population figures from the censuses were not taken directly from them, but instead from the data in [64], in which they were recalculated based on the registered population and on the structure of the municipalities in the 2011 census.

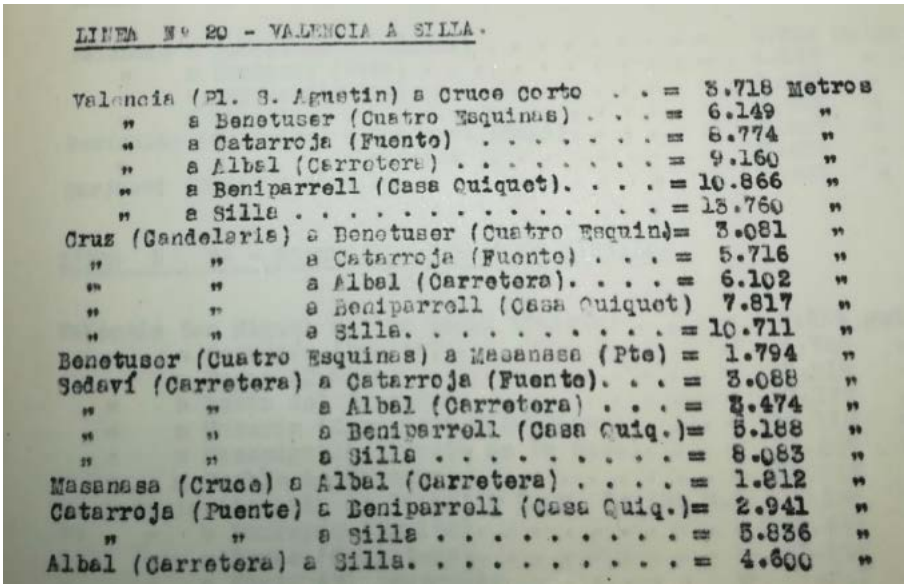
Distances from each municipality to the city centre were calculated as geometric distances, using GIS tools. The points referring to each municipality came from the basic Spanish gazetteer at the National Centre for Geographical Information (NCGI) (http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do?Serie=REDTR (accessed on 1 March 2022)).

The reconstruction of the means of transport was the most complex process. The first step required ascertaining which means of transport had an impact on the metropolitan area. The Metropolitan Mobility Plan of the Valencia Area (PMoMe, 2018) shows the share of the means of transport in intercity journeys. This plan estimated that private vehicles were used in 68.3% of intercity journeys, while public transport, whether by train, metro, tram, or bus, accounted for 30% of these journeys. The remaining 1.7% of journeys were made using other means of transport, such as taxis and car-sharing. Intercity bus journeys accounted for only 6.6% of public transport movements, while the rail network (train, metro, and tram) together made up 93.3% of the public transport total. The preceding data suggested that it was appropriate to study private vehicles and the rail network, while leaving aside the intercity bus network. In addition to the low metropolitan impact of buses, an analysis over such a long period of time was also extremely difficult. Changing routes and stops over time have made it a very flexible mode of transport in which data collection and analysis to establish patterns is a major challenge. Private vehicles and the rail network, which includes the train, tram, and metro, were therefore taken as the main means of transport. We used a similar approach to the authors of [65], who reconstructed the railway network over time to identify the stages of its development and relate them to urban morphology and population redistribution.

The reconstruction of the railway network started from the current situation and worked backwards. A deconstruction process was carried out to find out about changes in the network. The data referring to the geometry of the current railway network (layout and stations) were retrieved from the NCGI. Historical cartographic documents, railway guides, and information from a number of documentary collections were used to reconstruct the earlier network. Most of the historical information on the railway lines was provided by the Madrid Railway Museum (Figure 2). Data collection for intercity tram lines posed a different problem, since they were discontinued during a period of time [66–68]. Information which was not available in the Madrid Railway Museum collection was obtained using documents from the Valencian Regional Government Railways' Historical Archive (Figure 3).



Figure 2. Railway guides. Source: Madrid Railway Museum.



LINEA Nº 20 - VALENCIA A SILLA.

Valencia (Pl. S. Agustin)	a Cruce Corto	=	5.718 Metros
"	a Benetuser (Cuatro Esquinas)	=	6.149 "
"	a Catarroja (Fuento)	=	6.774 "
"	a Albal (Carretera)	=	9.160 "
"	a Beniparrell (Casa Quiquet)	=	10.866 "
"	a Silla	=	13.760 "
Cruz (Candelaria)	a Benetuser (Cuatro Esquin)	=	3.081 "
"	a Catarroja (Fuento)	=	5.716 "
"	a Albal (Carretera)	=	6.102 "
"	a Beniparrell (Casa Quiquet)		7.817 "
"	a Silla	=	10.711 "
Benetuser (Cuatro Esquinas)	a Masanasa (Pte)	=	1.794 "
Sedaví (Carretera)	a Catarroja (Fuento)	=	3.088 "
"	a Albal (Carretera)	=	4.474 "
"	a Beniparrell (Casa Quiq.)	=	5.188 "
"	a Silla	=	8.083 "
Masanasa (Cruce)	a Albal (Carretera)	=	1.812 "
Catarroja (Fuente)	a Beniparrell (Casa Quiq.)	=	2.941 "
"	a Silla	=	5.836 "
Albal (Carretera)	a Silla	=	4.600 "

Figure 3. Example of the documentation found for the location of tram stops. Source: Valencian Regional Government Railways' Historical Archive.

Automobile use is enabled by the road network, which has grown enormously over the last century. This network has covered all urban centres since the beginning of the period under study; therefore, it is fully accessible for the whole area. The main data needed for the analysis of private vehicles was the moment in which they started to be available to the population. To obtain this information, historical data of private vehicle registrations from the Directorate-General for Traffic (DGT) were used.

Once we had obtained the data, the next step was to address a key issue as a methodological premise, i.e., the analysis had to ascertain whether populations grow because of their internal dynamics before suggesting that they do so because of the use of means of transport. This was especially relevant in the case of the railway network, since its layout prioritised connecting the main towns and cities. The Pearson correlation coefficient test was proposed to see whether the variables of "initial population size" and "population growth" correlated positively. If this were the case, this would mean that the largest municipalities grew the most, rendering invalid the hypothesis that the influence of means of transport can be observed in an analysis of population distribution. If there was no correlation between these variables, or if the correlation was negative, this would mean that another factor might be driving the growth and the validation of the hypotheses could continue. This preliminary test was performed for each of the periods included in the study.

The next step, the previous test permitting, was to start with the analysis. The means of transport were classified into two groups to understand how they have influenced the population of municipalities. These groups were (1) municipalities on rail and road networks, and (2) municipalities only on road networks. While the railway network provides service to some of the area's municipalities, the road network caters to all of them. Since motorisation took place simultaneously across the area, and all residential locations boasted the requisite road network, private vehicles were considered to have the same influence on both groups. A comparison between the two groups would therefore show the impact of both the road and rail networks.

Using these two groups, the first analysis sought to understand the general dynamics of the area by comparing the two groups of municipalities. The percentage of population shares, the population increases compared to 1900, and the population increases with respect to the first year of each period were all calculated. The results show how the population of the two groups of municipalities changed in the different periods. The second analysis added "distance to the centre" in order to include the concept of time in the

analysis. According to the observations made by the authors of [6–10], people commuted a constant amount of time, which was quantified at one hour. The increased speed gained by the means of transport allows people to commute longer distances in the same amount of time. In metropolitan areas, this implies that the closest municipalities to the centre with access to a means of transport grow more than those that are farther away. To evaluate this, a Pearson correlation coefficient test was used to ascertain whether the correlation between the population increase of each municipality and the distance from the centre was linear. Finally, charts were drawn up to analyse other population growth distribution percentages.

3. Results

To recognise when a mode of transport starts to have an influence in an area, it is necessary to know when it first appeared and when it became popular. Figure 4 summarises the main data related to each of the means of transport in the city of Valencia.

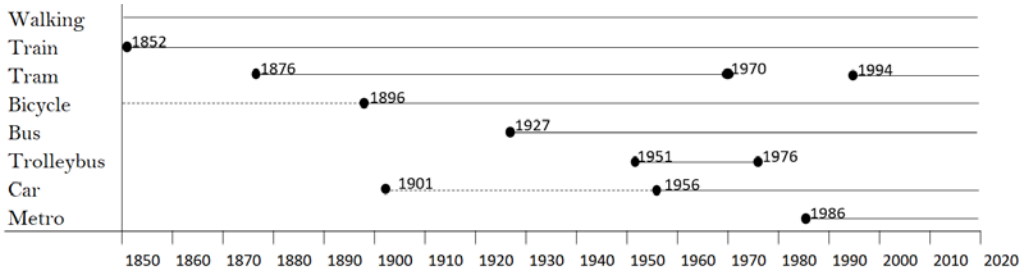


Figure 4. Implementation of means of transport in the city of Valencia (The years in the figure referring to trains, trams, buses, trolleybuses, and the metro correspond to the year in which the first lines were brought into service in the VMA. In the case of bicycles and cars, the points refer to the fact that the means of transport existed, but their use was restricted to a small part of the population. The specific year that is marked as the implementation refers to the year in which these vehicles were considered to be a common means of transport in Valencian society). Data from: [66–68] and the Directorate-General for Traffic (DGT).

Until 1852, the "walking city" was the only kind of city in the area. In this type of pre-industrial city, there was a stable relationship between space and time, as there were no technological changes which altered the proportion between them [15]. Distances were no greater than the one that could be covered on foot in an hour. In Valencia, this city type is the current historic centre, which is 1.6 km in diameter. As a side note, in Barcelona, the pedestrian city measures 2 km in diameter and in Madrid, 2.5 km.

In 1852, the first train was brought into service in Valencia, marking the beginning of the emergence of what is called the "transit city". Fifteen train and tram lines were built in the VMA, fourteen of which began to operate before 1895, and the last coming into service in 1925. As shown in Figure 4, trams stopped running in 1970, until they were reintroduced in 1994. Meanwhile, the first bicycle shop was established in the city in 1896 [68]. The availability of cheaper models and the introduction of hire purchase meant that bicycles were no longer a luxury, and they began to be used by the working classes as well. Meanwhile, the bus started to run its scheduled routes in 1927.

The beginnings of the emergence of the "automobile city" date back to the time when large numbers of people began to acquire private vehicles. Figure 5 shows the evolution of new registrations of private vehicles in the province of Valencia, drawing on historical data from the Directorate-General for Traffic (DGT).

Although cars emerged gradually, there were times when their progression became more marked. In the province of Valencia, this was the case between 1953 and 1956, when the number of registrations rose yearly by between 1.5 and 3 times compared to the previous year. The greatest increase came in 1956, precisely the year after intercity tram lines were scrapped in 1955. It was also in 1956 that the first Land and Urban Planning Law was enacted, which laid down the principles for town planning and zoning. This law was

extremely significant for Spanish urban planning, as it introduced private capital gains in response to the needs of local authorities with insufficient resources to undertake urban development [69]. Hence, the beginning of the nascent spread of cars, the scrapping of tram lines, and the new land law warrant the choice of this date, 1956, as the beginning of the automobile city. With the key data for understanding the evolution of transport in the VMA in place, the influence of the means of transport on the location of the population in the area could be examined.

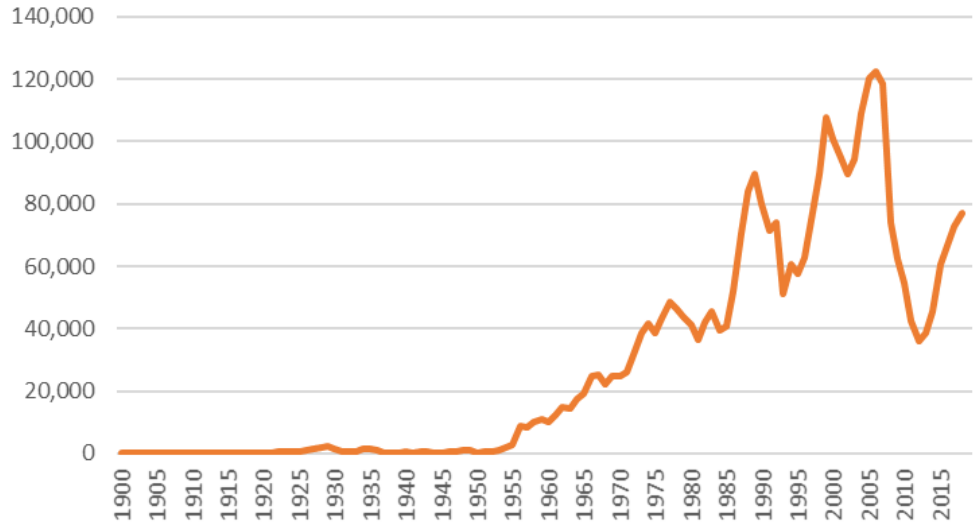


Figure 5. Vehicles registered per year since 1901, province of Valencia. Data source: DGT official statistical yearbooks.

The preliminary test was based on rejecting the hypothesis that the biggest municipalities grow more due to their own dynamics, which would mean that population growth could not be related to metropolitan transport, as intended. The Pearson correlation coefficient test analysis (Table 1) showed a widespread lack of significance between the variables "initial population size" and "population growth". The relationship was only significant at a 95% confidence interval in three non-consecutive periods, which means an overall absence of a linear correlation between the variables. In the case of the three periods in which these variables were significant, a weak positive relationship was apparent in 1950–1960 and 1970–1981 at R = 0.256 and R = 0.273, respectively, while in 2001–2011, the relationship was negative (−0.306). As we are comparing the "initial population size" and "population growth", this negative relationship in 2001–2011 means that the smallest populations were the ones which grew the most.

Table 1. Pearson test (initial population size-population growth variables).

Period	R Pearson	Significance	Significance (for a Confidence Level of 95%)
1900–1910	−0.18	0.875	NO
1910–1920	0.14	0.899	NO
1920–1930	−0.52	0.647	NO
1930–1940	0.36	0.749	NO
1940–1950	0.203	0.071	NO
1950–1960	0.256	0.023	YES
1960–1970	0.212	0.059	NO
1970–1981	0.273	0.014	YES
1981–1991	−0.145	0.199	NO
1991–2001	−0.212	0.059	NO
2001–2011	−0.306	0.006	YES
2011–2021	−0.096	0.395	NO

In view of these results, the hypothesis that the largest municipalities increase their population the most can be rejected. Therefore, the analysis of the influence of the main means of transport on the location of the population could be addressed.

The total population data were studied to shed light on the general dynamics of the two groups of municipalities, namely (1) municipalities on rail and road networks, and (2) municipalities only on road networks. In 1900, municipalities with a rail service accounted for 85.8% of the population, while 14.2% did not have this service. These differences steadily widened until 1981, when municipalities without a rail service were home to just 5.6% of the area's population. In 1991, the proportion remained stable, while from 2001 onwards, municipalities without a rail service began to increase their population share to reach 7.5% in 2021. The railway network layout covers the vast majority of the area's population at the municipal level. The 1981–1991 period points to a shift in the trend between the two groups of municipalities and thus, in the importance of means of transport.

Figure 6 shows the total population increases with respect to the same year of origin and reveals how the progression of municipalities with rail services is much higher than those without them. It is also noticeable that in the 1981–1991 period, municipalities not on a railway line began to gain a greater population share.

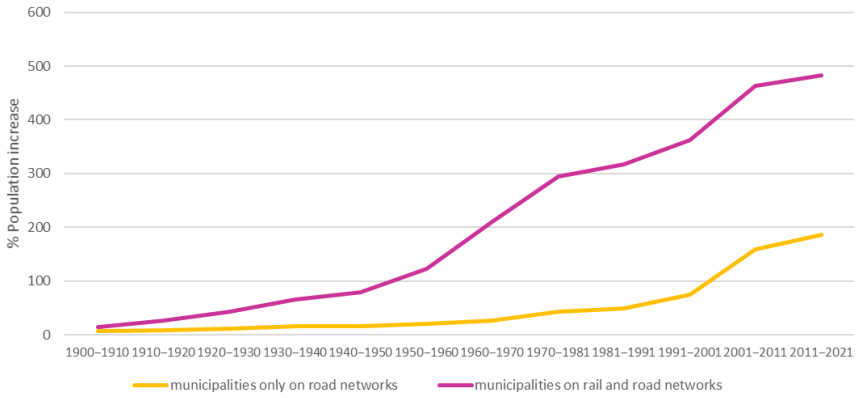


Figure 6. Percentage increases in population compared to 1900.

After looking at the distribution of the general population in the area and its long-term changes, the most immediate modifications between the census years are now examined. Figure 7 shows the variation percentages for the decades compared to the first year of each period (In other words, 1991 is taken as the reference year for calculating the population increase between 1991 and 2001).

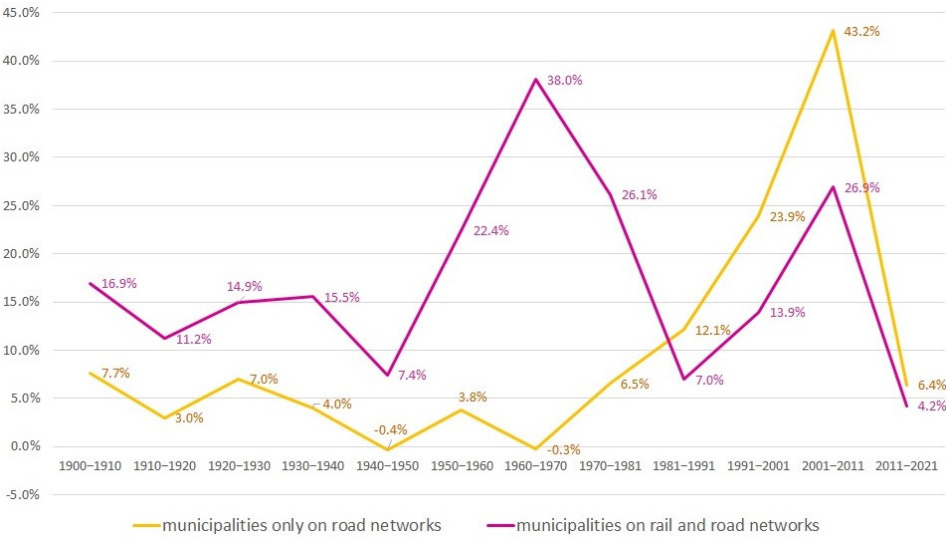


Figure 7. Percentage increases in population compared to the beginning of each period.

The first idea that comes from this data is that it is possible to observe different patterns in municipalities depending on the means of transport available. It is also interesting to see how trends of increase or decrease are aligned in both groups, with the exception of the three periods from 1960 to 1991. From 1900 to 1970, municipalities without rail transport showed moderate or negative growth, yet this was always lower than municipalities which had this service. They then began to grow sharply until 2011, with a 51.8% population increase in just 10 years. Municipalities on the network grew more than the ones that were not until 1950, albeit only moderately. The increase is very striking from 1950 onwards, reaching a peak in 1960–1970 at 38%, although the figure was still very high in 1981 at 26.1%. These findings are of great interest in relation to the population dynamics of the historical period. This was the process referred to in the introduction as the "rural exodus", when people from the countryside migrated to urban areas [56] from 1950 to 1975. There was a discernible rise in the VMA's population during this period, although the difference between the groups analysed shows that newcomers preferred to settle in municipalities on the railway network.

However, from 1981 to 1991, the pattern was reversed, with municipalities not on the rail network leading the way in terms of population growth. In other words, this period can be dated as the turning point in the significance of the means of transport in structuring the area. These results are extremely significant, as they run counter to the structuring effect of the railway that had been observed until then.

Figure 7 shows that in the periods from 1991–2001 and 2001–2011, both groups of municipalities followed an upward trend. In the case of municipalities with a rail service, the previous downward trend was reversed. These data reflect the influx of immigrants during the Spanish economic boom between 1995 and 2007.

Finally, the last figure in the graph for 2011–2021 is still significantly shaped by the 2008 financial meltdown, which had a huge impact across all sectors in Spain. The research in [70] stated that the Valencian Region was one of the worst hit due to its high dependence on the property market, and this reversed its capacity to attract immigration. The study in [71] found that the migratory balance became negative in 2012–2013 until 2015, when the loss of foreign-born residents slowed down. The economic recovery led to a resumption of immigration and a decrease in emigration. The population balance observed in the VMA for both groups of municipalities was positive, although it was much lower than in the previous period.

The Pearson correlation coefficient test was used to determine the linear correlation between the distance to the centre of the metropolitan area and population increases. The test result for municipalities not on the railway network was non-significant in all cases, i.e., it cannot be concluded that these variables are related at a 95% confidence interval. This means that the municipalities not on the rail network have not grown in greater proportion because they are closer to the centre of the metropolitan area.

Applying the same test to municipalities on the railway network yielded different results. The linear correlation was significant from 1910–1920 until 1971–1981 (Table 2), but was no longer significant from 1981–1991 until the present.

Table 2. Pearson test (population growth-distance to the centre variables).

Period	R Pearson	Significance	Significance (for a Confidence Level of 95%)
1900–1910	−0.106	0.437	NO
1910–1920	−0.352	0.008	YES
1920–1930	−0.399	0.002	YES
1930–1940	−0.421	0.001	YES
1940–1950	−0.346	0.009	YES
1950–1960	−0.502	0.000	YES
1960–1970	−0.475	0.000	YES
1970–1981	−0.371	0.005	YES
1981–1991	−0.094	0.490	NO
1991–2001	0.125	0.358	NO
2001–2011	0.180	0.185	NO
2011–2021	−0.102	0.452	NO

The significance results point to two key issues: (1) the large differences in the processes guiding population evolution between municipalities on and not on the railway network, and (2) the change in trend after 1981 in terms of the influence of the railway network on population distribution.

The comparison of the Rs, which indicate the correlation between population increase and distance from the centre, shows how this relationship has changed over time. It rose steadily from 1910–1920, reaching a peak in the years 1950–1960, and then declined until 1971–1981, which was the last stage in which there was a significant linear correlation. A negative R indicates that the population increase is greater the shorter the distance to the centre of the metropolitan area, indicating the expected relationship up to 1981.

The results of the relationship between population changes and distance are shown in Figure 8. The change in the shape of the regression curves is particularly salient. The first period of the formation of the metropolitan area was from 1900–1940, when population increases were greater the shorter the distance from the centre, although there was a substantial dispersion of values. The period of greatest adherence to the model was 1940–1981, where municipalities at distances of less than 10 km from the centre showed large population increases. Nevertheless, it is already evident in the last record for 1970–1981 that growth had shifted slightly to some municipalities in the second belt at a distance of 10–20 km. Finally, 1981–2021 can be considered as the third period, where the curve plotted by the values shows how municipalities at intermediate distances (10–30 km) gained momentum in their population growth, while those at shorter distances declined. As a note, when reading the figure, the same *Y*-axis is not used because the difference in growth makes it impossible to observe the distribution. Figure 7 is therefore used to compare growth, while Figure 8 shows the relationship of the increases with distance. This information accounts for the results in the Pearson correlation coefficient test, since the relationship with distance is not linear. After 1981, a polynomial function is a better fit, in which the largest population increases are found at average distances.



Figure 8. Relationship between population increase and distance to the centre in municipalities with a rail transport service.

Finally, the evolution of unserved municipalities with respect to distance since 1981 and their comparison with the other group is also of interest (Figure 9). The same determination as in the previous figure is used for the *Y*-axes, prioritising the observation of the distribution of values.

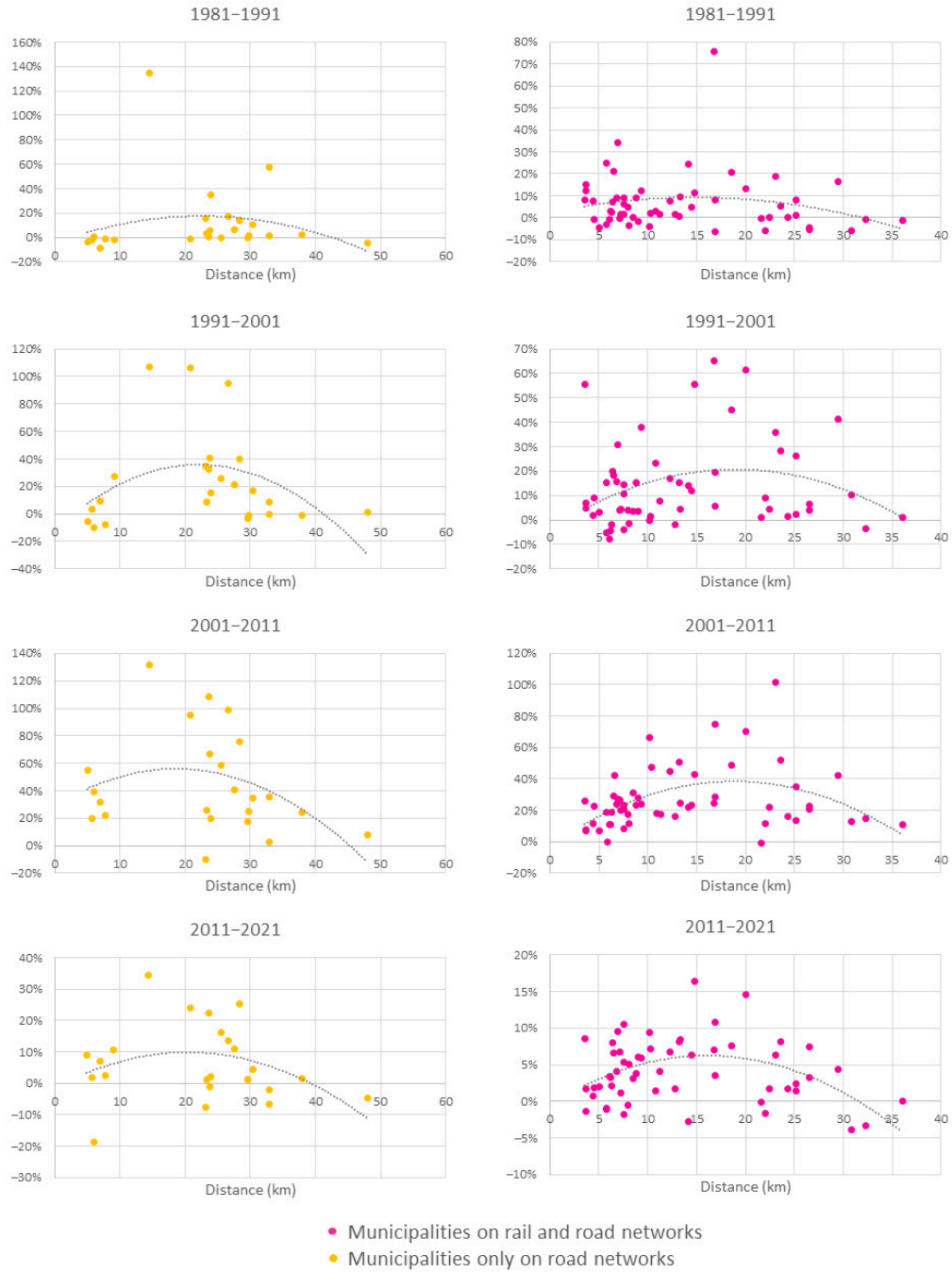


Figure 9. Relationship between population growth and distance to the centre in municipalities with and without a rail transport service, 1981–2021.

The figure reveals a new issue, which is that in serviced municipalities, the highest growth is closer to the centre in the 10–20 km range, while in the other group, there are sharp increases up to 30 km. This indicates that the car, the only means of transport available in this group, is less affected by longer distances than is rail transport. This difference between the friction of distance in means of transport is related to the different speeds they can reach.

4. Discussion

The analysis quantified certain aspects related to the influence of means of transport and the distribution of the population in a metropolitan area. It has revealed that, although trains were brought into service in 1852, they had no influence on the distribution of the population until 1910–1920. When this influence comes into play, it indicates the existence of functional relations between the municipalities and the centre, which is the start of the emergence of the metropolitan area itself. Accordingly, the beginning of the transit city in Valencia was 1910. This type of city continued to develop vigorously until 1970–1981. The results show the enormous potential of the railway network to impact the population growth rate.

The year 1956 is considered as the year when private vehicles became popular in the area. A number of events coincided at this time: an upsurge in the number of cars, the discontinuation of intercity tram lines, and a change in urban planning legislation. Although this was taken as the starting point, it has been observed that the greatest influence on the population started in the period 1981–1991. This was the time when municipalities which were only on the road network took the lead in percentage increases in population; that is, they grew more than municipalities with a rail service. When interpreting these results, it should be borne in mind that municipalities with rail services do not only rely on this form of transport, as local people can also travel by private vehicle. Thus, the period of 1981–1991 was when the sum of both means of transport had less potential to attract new residents than the private vehicle alone. This does not make sense unless it is related to previous growth dynamics and the property market. As has been shown, municipalities not on a railway line presented weak population growth, or even losses, until 1970–1981. In other words, their lack of connections meant these municipalities had not undergone development related to the metropolis up to that date. Therefore, when the private car became an option for commuting to the city centre every day, these settlements began to expand. At that time, they also had large amounts of land available. Using these results, it is considered that the "automobile city" was established in Valencia in 1981.

Another important outcome from the analysis is related to the distances from the city centre where the main population growth has taken place. Until 1981, the municipalities closer than 10 km from the city centre were the ones that grew the most. Since 1981, the municipalities between 10 and 30 km have grown more than the former group. This might be accounted for by the metropolitan belt growth model [72]. This could fit for the municipalities on the railway network, as previous growth in the nearest municipalities might have led to overcrowding of urban spaces. However, it is also the case in municipalities not on the railway network, which did not experience significant growth in the past, making it difficult to account for any overcrowding. The main explanation suggested here is the type of space that surrounds the central city. As it was pointed out previously, the *huerta* is peri-urban farmland which has a high agricultural, historical, and cultural value. While its appearance has changed greatly during the last century, its high value has warded off comprehensive urban transformation. The high price of the land means that most urban development has been shifted towards rain-fed crop land, situated further inland. Furthermore, the emerging trend towards low-density residential development may have played a role in shifting development away from the centre. Low density residential areas are more land-intensive and therefore, more price-sensitive. The research in [73] points out that in regions where the productive value is high, cities develop more compactly than in regions with low agricultural values. This contention is consistent with the results derived here.

The strength of the results has already been pointed out, but it is important to highlight the importance of the proposed methodology. We consider it to be very useful because of the simplicity of the methods and the data. It makes the proposal easy to replicate in any other area in the world.

As for the limitations of this research, it is acknowledged that the location of the population in a metropolitan area cannot be explained solely by mobility. A recent study in the Pearl River Delta (China) found that natural, socioeconomic, and transport factors have

a substantial influence on the expansion of built-up land [74]. Future work will seek to address not only population, but also land-take parameters in order to study the robustness of the residential sprawl pattern in the area. Previous research by the author (2021) showed that artificial land increases associated with second homes were very common in the area, and that there was a significant imbalance between increases in artificial areas and population. Hence, in order to study urban space in relation to the mobility of its inhabitants, the idea is to build a model in which the number of residents in each period is associated with the artificial land areas. This viewpoint paves the way to a fresh opportunity to make progress on the research question under study. This would enable a distinction to be made within municipalities on the network between the population with good rail access and people whose main means of transport is the private vehicle. This future research could create a framework with a stronger spatial analysis component that would furnish a better territorial understanding of the relationship between means of transports and population settlements.

5. Conclusions

The research shows how different means of transport have changed their prevalence in structuring the metropolitan area. It also reveals how this dominance has changed the territory, in population terms, over time. The first hypothesis has been validated, i.e., the availability of means of transport is a useful factor to explain the population distribution in a metropolitan area. The second hypothesis, centring on the existence of a time gap between the introduction of a particular means of transport in a metropolitan area and its influence on the distribution of its population, has also been validated and, moreover, it has been quantified.

This data can have a major impact on the reading of the contemporary city and can help to shape the future metropolis. The data reveal that it takes decades for a means of transport to bring about a change in the population structure. In the case of the railway city, in the VMA, it took six decades for it to have an influence on the population structure. The car city took 25 years to have an impact. Obviously, the emergence of a mode of transport does not mean that it is fully accessible to the entire population; therefore, this assumption can never be fully accepted. The substantial amount of time quantified can be taken as an indicator of how difficult it is to change previous dynamics. These results may be the starting point to guide future research.

One of the most interesting future research questions is linked to the observations of other authors [75–77], who have pointed to the emergence of a new mobility era, called "peak car", in which car usage hits its zenith and then begins to decline. If these current observations, taken from several European capitals, were to spread into other territories, what are the implications in terms of population distribution? If they are related to sustainable policies, how long will it take to observe the changes? The evolution of metropolitan areas can historically be understood in terms of the mobility of their population, which has led to enormous growth in terms of land use and population. If the use of cars begins to decline, are we going to observe new densification processes?

As a proposal to guide new urban processes towards the best relationship possible between mobility and urban structures, there is a need to deal with transport policy and urban planning holistically. Some authors [9,78–80] have pointed to the ineffective management that separates treatment of these two issues involves. This research has been designed from the standpoint that the connection between mobility and urban structure is a two-way process. They both affect and shape each other, so the pathway to sustainability ineluctably involves establishing a good relationship between the two factors.

In conclusion, the research conducted furnishes a better understanding of the development of urban areas. The results point to the need to address both variables together in order to make steady progress towards sustainable scenarios. A territorial culture which holistically manages urban and transport planning under sustainability parameters is needed, since the habitability of cities hinges upon it [81].

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