THE LIGHT RAIL TRANSIT EXPERIENCE IN MADRID: EFFECTS ON POPULATION SETTLEMENT AND LAND USE

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ABSTRACT

Development of new transport systems often leads to demographic and socioeconomic changes in the implementation area. However, the extent and type of these impacts varies depending on the existing settlement patterns, socio-economic conditions and project objectives. To help better understand these impacts this paper examines the effects of building two new light rail lines in Madrid. The two lines were planned to serve different functions and their service areas have different land use characteristics. LRT Line 1 was designed to help promote urban development in a lightly settled area while Line 2 was designed to encourage public transport in an already developed area. As expected, the analysis shows that the impacts of these two lines have been very different. Along Line 1 a large amount of new development has taken place and there have been large increases in population, while along Line 2 land use and population are largely unchanged. This result demonstrates the critical importance of integrated transport and land use planning in the development of cities.

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1. INTRODUCTION

One of the main goals for transport investment is to increase development and economic value by increasing a settlement area's accessibility. Importantly, transport does not exist in a vacuum; it works hand-in-glove with an area's urban planning. Thus a new transport service alone will not lead to development, the area must be suitable for development and this development must be supported by other infrastructure and policies contained within the land use plan.

A key consideration for planners and policy-makers is determining the impact of new transport projects on development and economic value. The research shows that the impact is generally positive, but highly variable. Two of the most important factors are (1) whether the transport project was part of a coordinated transportation-land-use plan; and, (2) whether the project was designed to open new areas to development or improve service to an area already served with transport. The development of three new light rail transit (LRT) lines in Madrid provides an excellent opportunity to assess the impact of these factors on area development.

The objective of this paper is to describe how construction of Madrid's LRT lines and coordinated transportation-land-use planning helped influence population and land use development. The rest of this section provides an introduction to Madrid population and transport. Section 2 presents results of a literature review. Section 3 presents the methodology used in completing the analysis. Section 4 summarizes results and Section 5 presents conclusions.

Population

Madrid is the largest city in Spain and the third largest in the European Union. The city's metropolitan population was 5.6 million in 2010 (3.3 million in the city of Madrid and 2.3 million in the surrounding cities. See Figure 1). Madrid's population increased significantly between 2000 and 2010. The city center population increased by 9.7%, population in the city's outer areas increased by 15.4% and population in the surrounding cities increased by 27.3%. [1]

There are several reasons why population growth has been larger in the outer areas and surrounding cities. The main reason is that Madrid's center was already very densely developed and given its historic nature it was difficult to develop new buildings and projects. Moreover, the population density in the city center was already much higher than in the outer areas of the city and in the surrounding cities (Figure 1). Furthermore, areas outside the city center had larger amounts of underdeveloped land and lower land prices. Finally Madrid began to significantly improve mobility in the outer areas since the beginning of the 21th century by extending its public transport network to them [2].

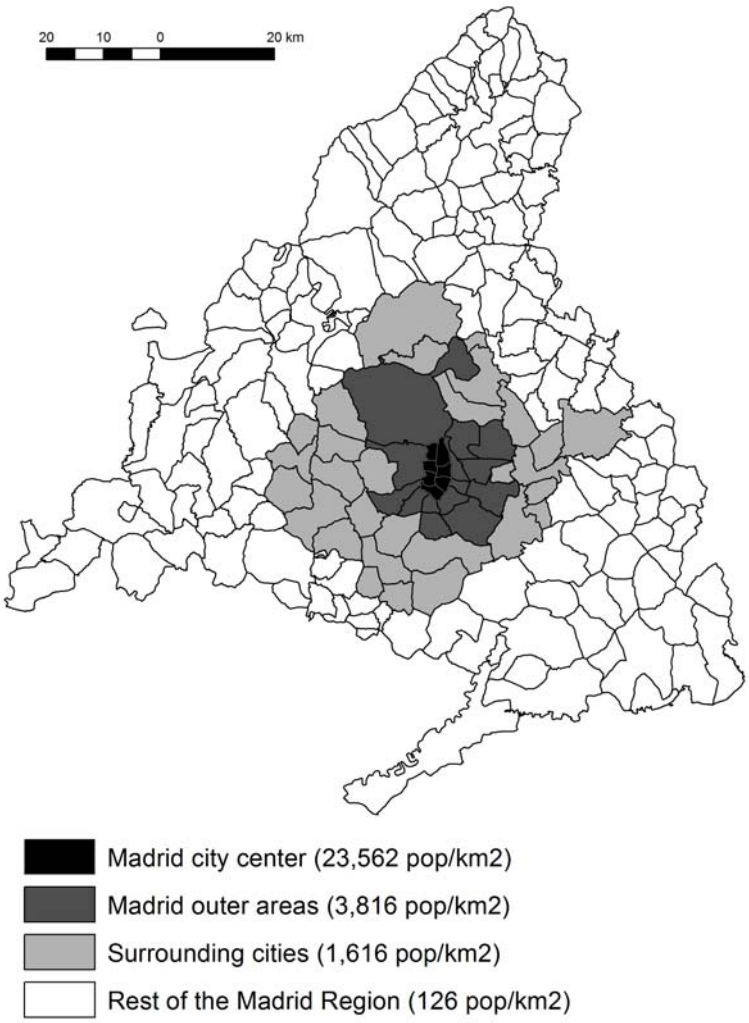


Figure 1 Region of Madrid.

Mobility

The number of daily trips in Madrid's metropolitan area increased by more than four million between 1996 and 2004, with commuting to work being the main reason for travel, followed by traveling to school/university. [3]

Public transport is the most widely used transport mode in the city of Madrid. In 2004, the mode split was 43% public transport, 28% private vehicles and 29% pedestrian. Interestingly while the amount of motorized travel has grown by approximately 4.2% per year since 1996, the modal split has remained nearly the same. [4] This reflects the high overall quality of Madrid's public transport and its extensive network.

Considering the whole Metropolitan Madrid Area, the mode split varies by zone with higher shares for public transport in the central areas and lower shares as distance to the center increases. The mode share in Madrid's center city is 70% public transport and 30% private transport. In the outer areas of the city it falls to 54% public transport and 46%

private, while in the surrounding cities mode split is 34% public transport and 66% private. Moreover, the largest increase in motorized travel (with an annual growth rate of 7.1%) took place in the surrounding cities. [4]

These data show that motorized travel has increased substantially more in the surrounding cities than in Madrid, and that transport demand tends towards private vehicles as one moves away from the Madrid's city center. This is because compact spaces, such as central Madrid, permit implementation of denser public transport networks and lead to shorter typical trip distances, thereby promoting public transport use and travel by foot. By contrast, in outer areas settlement patterns are more dispersed and fragmented, the public transport system is less dense and distances are greater, leading to increased use of private transport.

Another factor driving the increase in motorized private transport is increased development of new residential, recreation, shopping centers and industry on the outskirts of Madrid. This decentralization encourages increased use of private transport since travel covers increasingly longer distances. Interestingly even for radial trips (i.e. trips from the surrounding cities to the city of Madrid – both outer and central Madrid) the share of public transport use is 50%, well below the 64% share it carries in the city of Madrid proper. [2] These conditions in Madrid are consistent with many growing cities and show the importance of making new development more compact and continuous to improve the efficiency of public transport.

Madrid Light Rail Transit Development

An important goal for Madrid is to increase transport system sustainability. One part of this was development of the Expansion Plan Metro de Madrid 2003-2007. This plan set forth improvements designed to improve regional public transport including construction of three light rail transit (LRT) lines designed to help address the large increase in population and car use outside central Madrid (both intra-zonal and radial trips) outlined in the previous section.

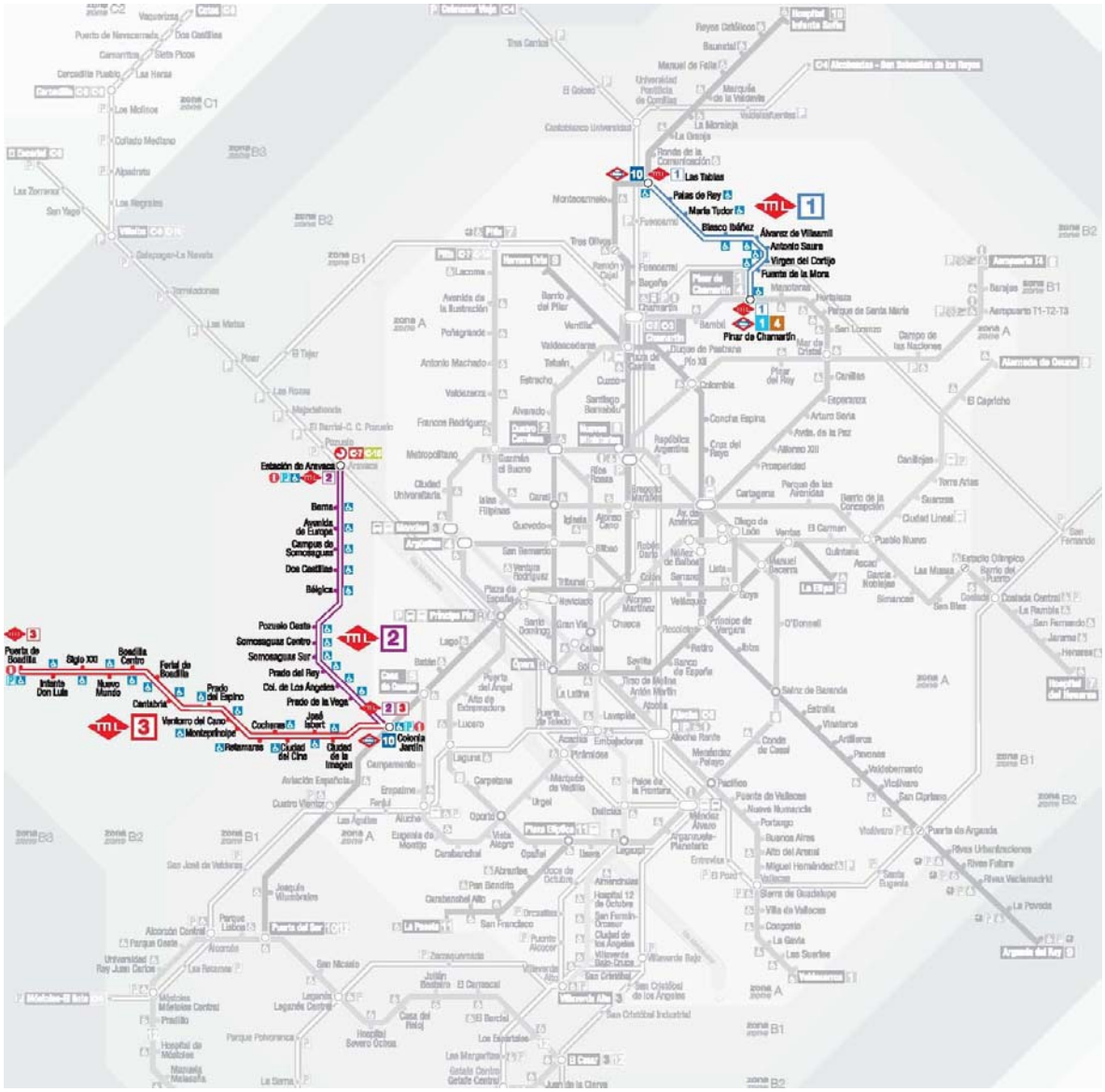
Madrid had an extensive tramway system until the end of the 1960s, when it began replacing trams mainly with buses. The last tram line closed in 1972. Only 13 years later the city decided to build new tram lines although the definite plan would not come until 2003. [2]

LRT was chosen because it provides high quality service but with lower capacity and cost than heavy rail. LRT was appropriate for these areas given their lower population density and level of urban development than central Madrid. Furthermore, the LRT lines were designed to serve as compliments to the existing metro and regional rail lines. The three lines (ML-1, ML-2 and ML3) started service in 2007 and are illustrated in Figure 2. Figure 2 shows (without scale) the metro (in grey) and LRT (in color) lines in the Madrid Region.

Madrid's LRT lines operate between 6:00 – 1:00 on weekdays. Frequency varies between 5 minutes during peak periods and 20 minutes off peak. Service is reduced slightly on weekends and holidays. In 2009 annual ridership on ML1 was 4.9 million passengers, on ML2 was 3.7 million and on ML3 was 3.7 million. [5]

Madrid's new LRT lines were built as part of a public private partnership. In the case of ML1, the construction and 30-year operating concession was awarded to Metros Ligeros de Madrid, a consortium of public (Subway operator) and private companies (consisting mainly of banks, construction and transport companies). For ML2 and ML3, the

construction and 30-year operating concession was awarded to Metro Ligero Oeste, a consortium that includes only private companies. [2] The government subsidizes these consortiums on a per passenger basis. Thus, for each traveler, the Regional Government of Madrid pays private consortiums a subsidy of 3.7 € / traveler (in ML2 and ML3), while the regular price of each ticket is 1.5. [6]



Source: [5]

FIGURE 2 Light Rail and Subway lines in the Madrid Region.

2. LITERATURE REVIEW

A city's transport system both generates transport demand and in turn provides a means (infrastructure and transport services) for meeting this demand. [7] In many cases the transport system has expanded as an afterthought to meet the needs of existing settlement

and development patterns (or development that was in the process of happening) rather than in response to land use master plans. [8]

However, it is worth bearing in mind that the location of population and employment is not independent of the transport system. Accessibility changes affect the development potential of an area, attracting population and economic activity. All this must be considered during the planning process. [9]

There are numerous ways to measure accessibility to public transport, each of which responds to a particular spatial conceptualization and analysis objective. [10][11][12][13] A simple indicator of public transport accessibility is the cumulative opportunities measure, which simply sums the population or economic activity within a given distance or time from the public transport station.

According to Pagliara and Papa, the population impacts of building a rail based public transport system vary depending on the specific location of the stations and the network itself. [14] Their work compares property prices and population growth in districts served by new rail lines and control districts. They place their findings in the context of a literature review that cites the different impact of public transport systems on development. For example, in the San Francisco Bay Area, districts with Bay Area Rapid Transit District (BART) have been shown to have less population growth than non-BART districts with the exception of districts in the city of San Francisco where districts with BART grew faster than districts without BART. Studies of New York's and Washington's rail systems show that most of the population growth occurs in the catchment areas of peripheral stations, located at the end of the lines.

Du and Mulley [15] found that new urban rail lines can play a key role in the ability to attract population and businesses to certain areas of a city by increasing their accessibility. However, accessibility is only one factor influencing growth, others include: the regional real estate market, availability of building land, the emergence of new forms of urbanization, changes in vehicle fleets, urban decline in city centers, and how well the new line connects to the city center.

In addition to population growth construction of new public transport lines also impacts the value of properties located near the new system. In almost all reported cases the new public transport increases values, but there is substantial variation in the amount of increase depending on specific local conditions. [14]

For example, Cervero and Duncan [16] found that the establishment of an urban rail line can increase the value of homes up to 25%, according to their study in Santa Clara County (California). Hess [17] found that the value of a house located near a station in Buffalo NY can be 5% over the city average. Du and Mulley [15] found that properties served by London's new Victoria Line have increased in value by 5% over areas not served by the line. In Strasbourg, Lille and The Netherlands (several cities), introduction of new LRT lines have been shown to increase property values by 10%, 10% and 32% respectively. In Madrid studies have shown that proximity to stations on the new Metrosur Subway line causes a positive impact on the sale of property and that property values decrease with increasing distance to rail transit stations. [18]

In summary, much research has been done to assess the impact of new rail transport lines on land use. The main conclusion is that the impact is positive both in terms of population growth (development) and property values, but the effects can vary greatly depending on the specific conditions. [14] Therefore, it is critical for planners to carefully

evaluate other factors influencing population growth and development rather than simply assuming that building a new rail line will increase development.

3. RESEARCH METHODOLOGY

This research consisted of comparing population growth in new Madrid LRT line station areas to contrast areas around other urban rail lines and areas without rail service (as an experimental control). This section describes the methodology used to make this comparison and the data used in the evaluation.

Selection of LRT Lines to Study

As outlined above, Madrid built three LRT lines in the last decade: ML1, ML2 and ML3. Lines ML1 and ML2 were chosen for analysis in this research because they had different design objectives (ML1 to encourage new development along part of its route and ML2 to improve transport in an existing well-developed area) and because they serve areas with different land use characteristics. The choice of these two lines enabled the researchers to consider how population growth could be impacted under two quite different situations. The ML3 line has characteristics similar to ML2 and therefore was not evaluated.

Defining the Contrast Areas

To evaluate the effects caused by the introduction of the new LRT stations it was necessary to identify contrast areas that could be compared to the areas around the LRT stations. The contrast areas should be located as closely as possible to the LRT corridors and should have similar land use, degree of urban development and population characteristics to the areas through which the line passes. In this research two types of contrast areas were considered:

- An area without existing urban rail service; this must have similar characteristics to those around the new LRT stations; this is the classical contrast area. [14]
- An area with existing urban rail service that has been operated for a long time before the study period and therefore is quite stable from a demographic and urban development perspective; this is a new type of control area developed in this research.

Determining Station Catchment Area (Radius of Influence)

Station catchment area is a key factor to consider when evaluating the impact of a new urban transport line. Station catchment area can be defined as the geographic area that is affected by the public transport station, or more simply as the area within which passengers will walk to the station. In general, the higher the quality of transport service provided by the new transport line (in terms of capacity, frequency, accessible destinations, intermodal connections, etc.), the larger the catchment area since passengers will accept longer access times when transport service quality is higher. Consistent with these assumptions, the catchment area for new stations served by high quality transport located in areas with a lack of competing public transport services will be greater than for stations located in already developed areas with existing high quality transport service (e.g. city centers).

As specified in the Transit Capacity and Quality of Service Manual, service coverage could be defined as the perceived usefulness of transport service from the passenger's point of view. [19] In other words, the real service coverage is the population actually affected by

the transport service, meaning people located close to the service stops and for whom the service constitutes a viable transport option.

Station catchment area is generally defined in terms of a radius extending out from the station. As outlined above, this radius varies depending on the particular conditions, some specific examples are:

- The Transit Capacity and Quality of Service Manual proposes a methodology for estimating the radius of influence based on a theoretical radius of 800-meters that is corrected by four factors: streets connectivity, streets grade, the proportion of older adults in the population and the accessibility to the transit stop. [19]
- Studies conducted in Calgary (Canada) concluded that the average access distance for LRT stations is between the 325 and 650-meters. [20]
- Research conducted by the RICS Policy Unit Report indicates that station area impact area can reach 1000-meters depending on the type of public transport and specific station area characteristics. [21]
- Research conducted in Naples to evaluate the impacts of urban rail lines considered a radius of influence of 500-meters around the stations. [14]
- Research conducted in Minneapolis indicates that in certain areas the station impact area can be extended to 1400-meters. [22]
- Research in Madrid to evaluate the impacts of Subway used radii of 300, 600 and 900-meters. These spatial limits correspond to 5, 10 and 15 minutes of access time. [3][23]

In this research the LRT station influence area radius was defined as 600-meters reflecting a 10-minute maximum walking time. This is consistent with the literature and provides an acceptable overlap between the stations' catchment areas given that stations are approximately 700-meters apart.

Calculating Station Catchment Area and Population

A Geographic Information System (ARCGIS software) was used to obtain the sphere of influence and the population served by the new LRT stations. The first step was to geo-reference the LRT stations using orthophotos. Next station catchment areas were calculated using the 600-meter radius. The overlaps between catchment areas for different stations were eliminated to obtain polygons around the stations. These catchment areas constituted the first GIS data layer.

The second GIS layer consisted of population data. Detailed population data based on census tracts available from the Region of Madrid were used in the research. [24]

The two layers were combined to obtain a third layer with the census tracts that belonged (totally or partially) within the station catchment area. The method proposed by Gutiérrez [25] and Chakraborty and Armstrong [26] was used to estimate the population within the catchment area. In this method when a census tract is located entirely within a station's catchment area its total population is considered to be served by the station, whereas for census tracts that are partially within the catchment area, only the population proportional to the part of the census tract within the catchment area is considered served by the station. This method is shown as Equation 1.

$$P = \sum_{i=1}^{n} p_i + \sum_{j=1}^{m} \left(p_j * \frac{a'_j}{a_j} \right) \quad (1)$$

Where:

P = population served by the station

i ... n = census tracts fully included in the catchment area of the station

pi = population in census tract i

j ... m = census tracts partially included in the catchment area of the station

pj = population in census tract j

a'j = area of census tract j within the catchment area of the station

aj = area of census tract j

4. ANALYSIS OF RESULTS

LRT Line 1

LRT Line 1 is located entirely within the city of Madrid, running through the city's outer areas in the northern periphery (Figure 2). The line starts at the Pinar de Chamartin station (where it connects with Metro lines 1 and 4) and ends at the Las Tablas Station (where it connects with Metro line 10). It also has connection with the suburban rail network in Fuente de la Mora. The line is 5.4 km long.

Line 1 has nine stations (Figure 3), five of which (Pinar de Chamartín, Fuente de la Mora, Virgen del Cortijo, Blasco Ibáñez and María Tudor) are underground. It crosses the established neighborhoods of Pinar de Chamartín, Virgen del Cortijo and new neighborhoods Sanchinarro and Las Tablas. These two new neighborhoods have been recently developed under two Urban Action Programs planned as part of the 1997 Madrid General Urban Plan. An Urban Action Program (PAU) is similar to a specific area plan.

A PAU must analyze the impacts of development, define the services and facilities needed to address these impacts, and present a plan for implementing these new services and facilities. Thus, PAUs must specify infrastructure (transport, water supply, sanitation, etc.) necessary for connecting the new district with the rest of the city. In this case the LRT line was included as the main public transport system serving the new neighborhoods and to establish connections with the rest of the metro network.

Regarding the selection of the contrast areas (Figure 3), Plaza de Castilla has similar population and land use characteristics (mainly residential, transport infrastructures and offices) to the stations located in the existing urban areas crossed by the LRT line (mainly Pinar de Chamartín). Moreover, the contrast area without urban rail is located mostly (entirely) in a PAU, and therefore has similar characteristics to the rest of stations of Line 1.

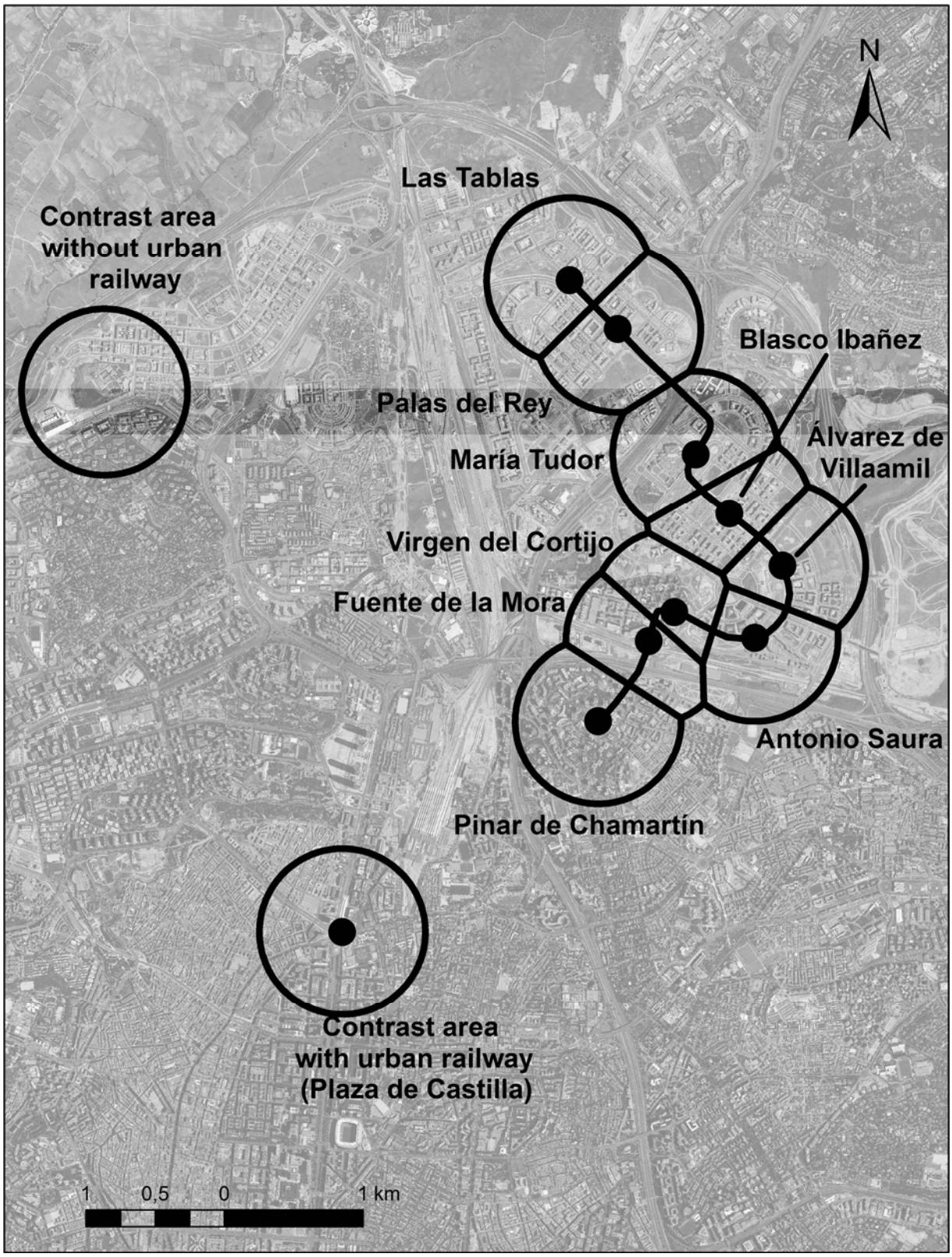
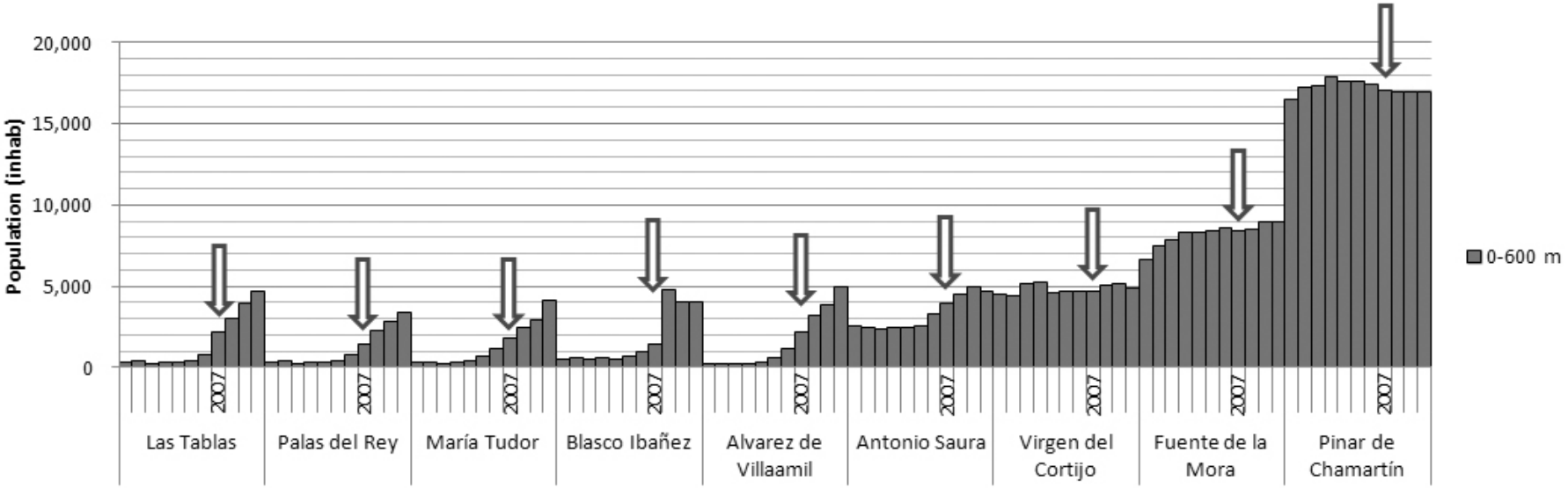


FIGURE 3 LRT Line 1 with station catchment areas and contrast areas.



Note: la flecha indica el año de inauguración

FIGURE 4 LRT Line 1: Evolution of station catchment area population 2000 – 2010.

Figure 4 shows the station catchment area population for the nine stations on Line 1 from 2000 until 2010. As shown the population decreases with increasing distance from consolidated urban areas (which comprises mainly of the Pinar de Chamartín, Fuente de la Mora and Virgen del Cortijo stations).

Figure 4 also shows that the new LRT line had a very large impact on population around the stations located in the new Sanchinarro and Las Tablas PAUs (the Las Tablas, Palas del Rey, María Tudor, Blasco Ibanez and Alvarez de Villamil stations).

Figure 4 shows clearly that population growth near the LRT stations serving the PAU areas was simultaneous or subsequent to the arrival of light rail. This shows the important role played by the introduction of light rail in the urban development of these areas. It should also be mentioned that due to the current economic crisis there are still many vacant plots of land in the area that could be developed in the future. The development pattern in these areas is mostly modern relatively high density mixed-use development. The architectural style is closed block developments.

TABLE 1 Population Variation Along LRT Line 1 Stations and Contrast Zones

Station	Land Use	Average Annual Population Growth (%)	10-Year Change Population (%)
Las Tablas (PAU)	Residential, offices, parks	39,0	1.275,1
Palas del Rey (PAU)	Residential, offices, parks	31,7	917,8
Maria Tudor (PAU)-Underground	Residential, shopping center, hospital	33,6	1.365,6
Blasco Ibanez (PAU)-Underground	Residential, urban services	33,0	642,0
Alvarez de Villaamil (PAU)	Residential, parks	41,8	2.303,4
Antonio Saura (existing urban area)	Residential, shopping center, transport infrastructures	6,7	82,7
Virgen del Cortijo (existing urban area)-Underground	Residential, urban services, parks, offices	1,1	8,6
Fuente de la Mora (existing urban area)-Underground	Residential, transport infrastructures, offices, parks	3,1	35,1
Pinar de Chamartin (existing urban area)-Underground	Residential	0,3	2,6
Five PAU area stations		35,8	1.300,8
Existing urban area stations		2,8	32,3
All nine stations		21,1	77,8
Contrast area with urban railway (Plaza de Castilla)		0,9	8,8
Contrast area without urban railway		3,3	37,6

Table 1 presents population data for the Line 1 stations and contrast areas. As shown, the average annual population growth during the study period around the five PAU stations has been between 31.7% and 41.8%. In the other four stations, i.e. those located in previously developed areas, the average annual population growth does not exceed 6.7%. Considering the contrast areas, the average annual population growth along the whole new line (21.1%) and overall around the PAU stations (35.8%) are both much larger than in the contrast areas, with (Plaza de Castilla) or without urban rail. Annual population growth in the new urban developments along Line 1 is even more significant when compared to the average annual population growth in the outer area of Madrid where it is located, of only 1.4%. [1]

Considering total population growth over the 10-year period, average growth around the five PAU stations is almost forty times greater than average around the four stations located in the existing urban areas. For the line as a whole population growth is also significant: 77.8% compared to 15.4% in the outer area of Madrid where the line is located). [1] The population increase around the new line is also larger than the 8.8%

increase for the contrast area served by urban rail and 37.6% for the contrast area not served by rail. These positive impacts are even larger if only the five PAU stations are considered: the 10-year population growth (1,300.8%) is 148 times larger than in the contrast area with urban railway and 34 times larger than in the contrast area without. This shows clearly that the LRT line helped to support increased development, overall taking into account that the contrast area without urban rail is also almost entirely within a PAU.

As indicated on Table 1, there is no significant difference in population evolution between the underground and surface stations located in the recently developed areas.

In summary, these data show that the provision of high quality light rail transit service appears to have had an important impact on population growth around the stations. While the population increase depended on many factors including existing population, economic situation, home prices and settlement patterns, the new LRT line made a difference. Furthermore, the success in attracting greater development to the PAU areas adjacent to the new LRT stations than the development in the PAU areas without LRT clearly shows the benefits of integrated transport and land use planning.

LRT Line 2

Madrid LRT Line 2 is situated in the western part of the metropolitan area. The line is located mostly within the surrounding city of Pozuelo de Alarcón, although the two end stations, Colonia Jardín and Aravaca, are located in the outer area of Madrid (see Figures 1 and 2). Line 2 is 8.7 km long and has 13 stations, 3 of which are underground (Colonia Jardín, Somosaguas Sur and Avenida de Europa).

The line runs through the high-income Somosaguas residential suburb, the Somosaguas University Campus and the city of Pozuelo de Alarcón. The Colonia Jardín station provides an interchange with Metro line 10 and LRT line 3, while the Aravaca station provides an interchange with regional rail lines C-7 and C-10. Figure 5 shows the Line 2 station areas and contrast zones.

Regarding the contrast zones, Batán was chosen because it is an urban area that includes both very densely populated areas (similar to Colonia Jardin) and low densely areas (due to a less intensive residential use and to the existence of parks), since it occurs at the beginning of the line. The contrast zone without rail was chosen for having similar characteristics (namely population and residential land use) to those at the end of the line, located in the center of Pozuelo de Alarcón.

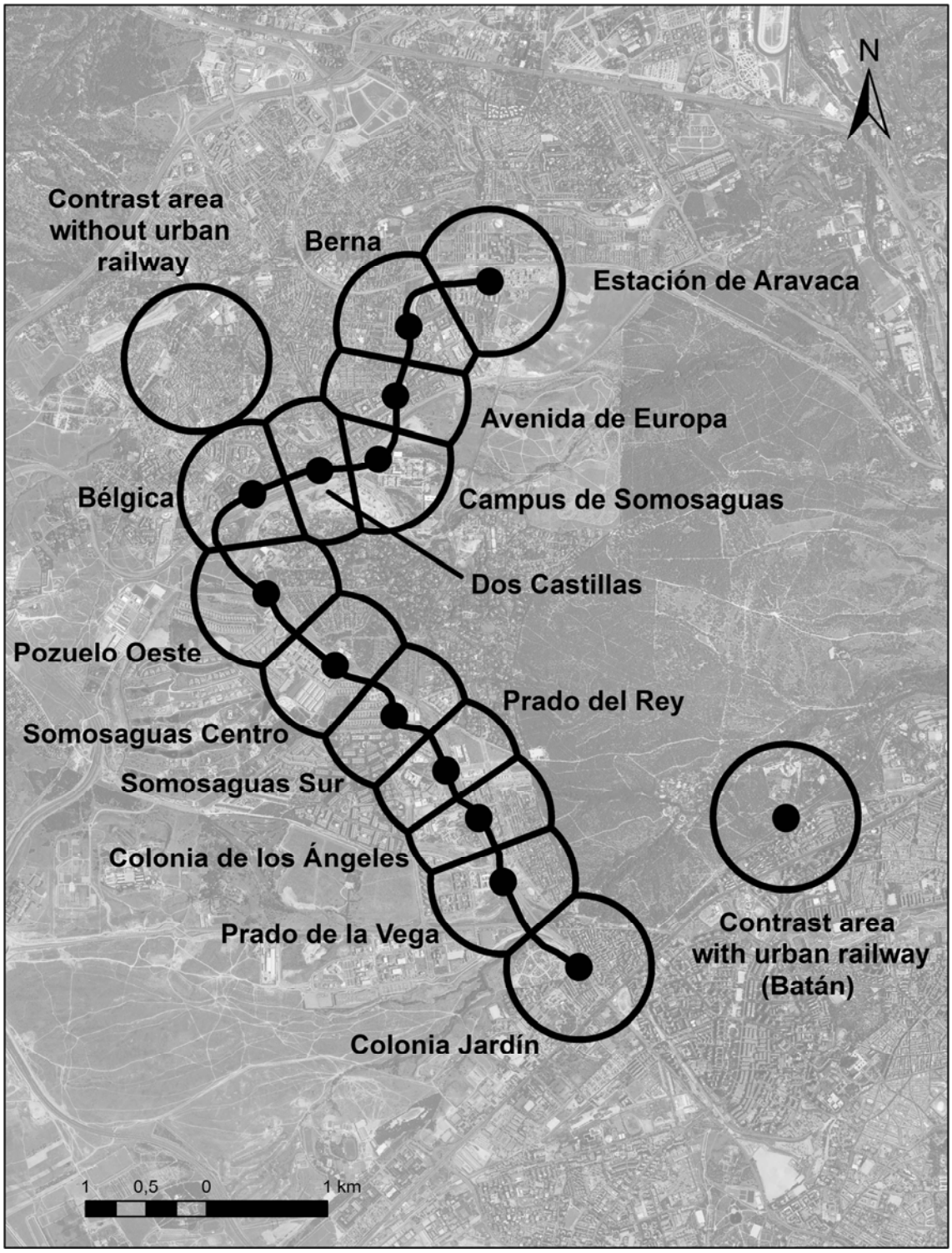
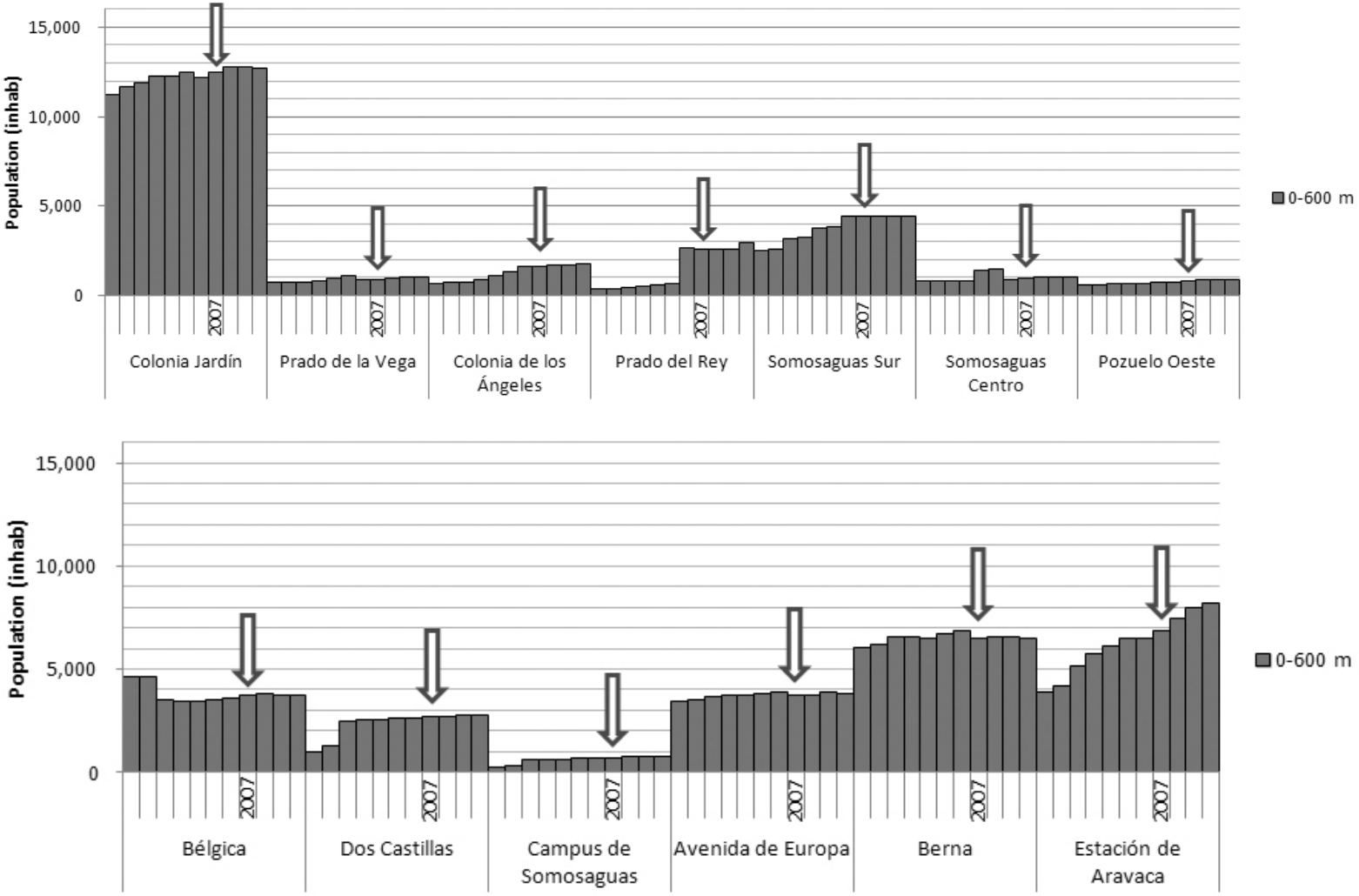


FIGURE 5 Madrid LRT Line 2: Station catchment areas and contrast areas.



Note: The arrow indicates the year of LRT opening.

FIGURE 6 Madrid LRT Line 2: Evolution of station catchment area population 2000 – 2010.

Figure 6 shows the station catchment area population for the 13 stations on the LRT Line 2 for the years from 2000 until 2010. As shown the most populated areas are at the beginning and end of the line. These are located in Madrid's historic La Latina district (Colonia Jardín station) and in Pozuelo de Alarcón's urban center (Avenida de Europa, Avenida de Berna and Aravaca stations).

As it can be inferred from Figure 6, the opening of LRT Line 2 seems to have had little influence on population. This is because it runs through previously developed areas, either areas of intensive residential use (neighborhood of La Latina and center of Pozuelo de Alarcón) or non-intensive residential use such as suburban developments of scattered single family homes or townhouses (Somosaguas) or service areas (University of Somosaguas, shopping centers) and office areas (TV studios at Prado del Rey).

Figure 6 shows that, in the Line 2 corridor, development generally took place before LRT construction. The only exception is at the Prado del Rey station where there has been simultaneous development of new residential areas. The growth around the Aravaca Station was unrelated to the new light rail line, but rather as a result of transforming former industrial land to residential.

TABLE 2 Population Variation Along LRT Line 2 Stations and Contrast Zones

Station	Land Use	Average Annual Population Growth (%)	10-Year Change Population (%)
Colonia Jardín-Underground	Residential, parks	1,2	13,0
Prado de la Vega	Hospital	4,9	49,5
Colonia de los Ángeles	Residential, barracks	10,4	158,0
Prado del Rey	TV studies, residential, urban services	40,1	796,8
Somosaguas Sur-Underground	Residential, urban services	6,0	74,7
Somosaguas Centro	Offices, shopping center	4,8	26,3
Pozuelo Oeste	Urban services, transport infrastructures, parks	4,1	49,7
Bélgica	Residential, transport infrastructures	-1,8	-19,4
Dos Castillas	Residential, transport infrastructures	13,5	179,5
Campus de Somosaguas	University	14,4	212,5
Avenida de Europa-Underground	Residential, parks	1,2	12,3
Berna	Residential, parks	0,8	8,2
Estación de Aravaca	Residential, urban services	8,0	113,5
Colonia Jardin y Estación de Aravaca (Madrid)		4,6	15,4
Rest of stations (Pozuelo de Alarcón)		9,0	27,3
All stations		8,3	40,4
Contrast area with urban railway (Batán)		0,6	6,0
Contrast area without urban railway		2,7	30,3

Table 2 presents population data for the Line 2 stations and contrast areas. As shown, despite the fact that Line 2 was not planned to help increase population or economic activity in the area it served, it seems to have had some positive impacts. For example, the average annual population growth during the study period around the Prado del Rey station was 40.1%. Moreover the average annual population growth around the two Madrid stations (4.6%) and the Pozuelo de Alarcón stations (9.0%) is larger than for the outer areas of Madrid (1.4%) and in the surrounding cities (2.7%). [1] Moreover, all the average annual population growth data (those from the Madrid stations, Pozuelo de Alarcón stations and all the stations together) are larger than in the contrast areas.

In terms of total population growth over the 10-year study period, Table 2 shows that population around stations in the Line 2 corridor has grown by an average of 40.4% compared to

30.0% in the contrast area without urban rail and 6.0% in the contrast area with urban rail (Batán). That 10-year population increase around the Line 2 stations is larger than the population variation in the areas where it is located: 15.4% in the outer areas of Madrid and 27.3% in the surrounding cities like Pozuelo de Alarcón. [1] However, because Line 2 passes mainly through sparsely populated areas, the absolute population growth over the 10-year period has been small.Since the Line 2 corridor was already fairly well developed it was not possible to identify any significant differences between surface and underground stations on Line 2.

In summary, the data show that although LRT Line 2 was not designed to increase population it seems to have had a slightly positive impact on population growth in the station areas.

Comparison Between LRT Lines 1 and 2

The research results show that the amount of development along LRT Line 1 is greater than along LRT Line 2. This result was expected because LRT Line 1 was planned as part of a coordinated transport and land use planning process with the objective of increasing development along the corridor. In contrast Line 2 was not built with the objective of supporting new development but rather to improve public transport service and connections to the regional pubic transport network in an already developed area. The research does not attribute all the growth along Line 1 to the LRT, but rather that the LRT and coordinated development were important factors supporting this growth (further research is planned to better understand the specific LRT impact).

Another way to assess the impact of LRT lines is to compare the average population density before (2000-2006) and after (2007-2010) inauguration of service. This research found that density increased from 5,719 to 8,480 inhabitants/km2 (Table 1) in the vicinity of stations on Line 1 (48.3%). In the case of Line 2, density increased from 3,888 to 4,681 inhabitants/km2 (20.4%). This shows population settlement around Line 1 has been more than twice that of Line 2. Again, this result is to be expected based on the different objectives for the two lines.

The higher density and higher density variation on Line 1 compared to Line 2 can also be explained by predominate land use and building types along each line: modern high density residential blocks on Line 1, and for Line 2 scattered single-family and townhouses combined with service industry and vacant parcels.

Since the LRT lines have only been operating for a short time, there is not yet enough data available to draw final conclusions, although a preliminary analysis of demand and its relation to population growth and changes in land use and in transport issues around the new light rail lines can be made.

Regarding the expected demand, Line 1 has met its ridership targets (2009), while demand on Line 2 falls well below projections (Table 3). These results indicate that the increase in population due to new residential developments along Line 1 has lead to the estimated (or expected) transport demand. On the other hand, the lower density, the smaller increase in population and, especially, competition of private vehicle and bus (with much shorter travel time and better intermodal connections in the case of the bus) have caused the low demand in Line 2. Therefore, while in the case of Line 1 the objective has been met (to meet transport demand caused by new urban developments), in the case of Line 2 the main objective (capture transport demand from car and bus) has not been met.

TABLE 3 Travel Demand and Cost of LRT Lines 1 and 2 [27, 28, 5]

LRT Line	Forecasted Annual Demand. Million passengers (2008)	Actual Annual Demand. Million passengers (2008)	Actual Annual Demand. Million passengers (2009)	Daily Demand. Passengers (2009)	Investment million EUR/km
1	4.6	3.3	4.9	13,425	47.0
2	8.0	2.8	3.7	10,137	29.9

Finally, considering that the maximum transport capacity of light rail may be 10,000 to 20,000 passengers per hour in each direction [19], both lines are clearly underutilized, especially taking into account their high cost (Table 3). This perhaps should have tipped the balance to an alternative transportation solution (high capacity bus with reserved platform, for example) during the planning stage. In any case, it should also be kept in mind that the best use of the light rail (especially in the case of Line 1) will come when the new urban development being constructed along the line are completed and occupied.

5. CONCLUSIONS

The research shows that Madrid's LRT lines 1 and 2 have both encouraged population growth around their station areas in comparison to similar contrast areas and in comparison to the Madrid areas where the lines are located. The results are consistent with previous research on the impact of rail transport on land development, particularly the finding that the impact of LRT construction is highly variable and depends on specific conditions in the project area.

Madrid's LRT Line 1 line was planned as part of an integrated approach to land use development and transportation. This average annual population growth around stations in the areas slated for new development (35.8%) was much higher than around stations in the already developed areas (2.8%). The average annual population growth is much higher in the zone of influence of Line 1 (overall in the areas where new urban development was planned) than in the contrast areas and than in the outer area of Madrid where the line is located. In terms of total population, station areas along the Line 1 corridor grew by 77.8% during the 10-year period, compared to approximately 37.6% for the contrast area without rail service, 8.8% for the contrast area with rail service and 15.4% for the Madrid area within which the line was located.

This positive impact is even larger if only the five PAU stations (areas slated for new development) are considered: the 10-year population growth around these stations is 34 times larger than in the contrast area without urban rail. This shows clearly that the LRT line helped to support increased development, overall taking into account that the contrast area without urban rail was also almost entirely within a PAU, as was the case for Line 1.

LRT Line 1's impact on population growth was due to the fact that it served a large area of generally undeveloped land well located in relationship to the center of Madrid and neighboring municipalities. The line was planned as part of a comprehensive land use planning process (PAU) and was built concurrently with the new residential development projects. In many ways it is a perfect example of coordinated transport and land use planning.

In contrast, Line 2 was built to encourage the use of sustainable transport (an objective that seems to have failed) in an already developed area consisting of mainly low intensity residential, offices, entertainment and service uses. It was not planned as part of an effort to increase population or development. So it is no surprise that there have been no major changes in the

population or land uses since LRT construction. However, population growth along the Line 2 corridor has been higher (40.4%) than in the contrast areas without or with urban rail (30.3% and 6.0% respectively) and also for the zones where the line is located (15.4% in the outer areas of Madrid and 27.3% in the surrounding cities). The absolute population increases along the Line 2 corridor are relatively small given the low base from which they started. So, although Line 2 was not planned as part of a comprehensive land use and transport planning process it seems to have generated some positive effect in terms of population.

These results are similar to the effects of the extension of the Madrid subway's system, which took place during the same time period [29]. Moreover, the results from Line 1 show that the effects on population are greater in peripheral stations. This is consistent with results described by Pagliara and Papa in cases of Washington and New York. [14]

In summary the Madrid research shows that new public transport rail lines can have an impact on population growth in station areas. The largest impact can be expected when lines are built as part of coordinated land use and transport planning processes where one of the goals is to increase development. However new lines may also encourage a small amount of population growth even without being part of comprehensive development plans.

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