CAN RAIL INFRASTRUCTURE DETERMINE PERCEIVED QUALITY OF SERVICE OF SUBURBAN TRAINS? INSIGHTS FROM CERCANÍAS MADRID

Carlos Romero
TRANSyT – Centro de Investigación del Transporte, Universidad Politécnica de Madrid
Clara Zamorano
Departamento de Ingeniería del Transporte, Territorio y Urbanismo, Universidad Politécnica de Madrid
Andrés Monzón
TRANSyT – Centro de Investigación del Transporte, Universidad Politécnica de Madrid

RESUMEN

Public transport modes in urban peripheries have a twofold function: buses provide the territorial capillarity, while the suburban rail acts as the backbone of mobility. Despite its relevance there, suburban rail usually runs on pre-existing tracks for heavy rail services. Moreover, in the current context of rail liberalization in Europe, the infrastructure manager and the rail operator are separate organizations with impacts on suburban rail. Therefore, it is important to discern the responsibilities of both agents in providing a better service, to promote a more sustainable mobility. This work aims to explore how the perceived quality of service (QoS) of suburban rail services can be influenced by the rail network infrastructure. The suburban rail network of Madrid (Cercanías) has been selected as case study because of the combination of pre-existing and new tracks as well as having a total of 9 regular lines, enough to perform this analysis. Data is gathered from the 2019 annual Cercanías traveler satisfaction survey. First, different aspects of the lines are thoroughly examined, such as the travel time between stops, shared sections or the location of the different sections within the metropolitan area. These factors are transformed into indicators to ease comparison. Based on the main indicators and the average QoS, lines are classified into 4 groups. The joint analysis of the infrastructure indicators and the attributes from the traveler satisfaction survey suggests that lines with similar QoS also have features common regarding to infrastructure and operation such as line length or travel time between stations.

1. INTRODUCTION

In the last decades, cities have greatly increased their population that overgrow the cities' limits and settling in nearer population centers, thus configuring metropolitan areas. As an instance, 55% of citizens of main European metropolitan areas dwells in metropolitan rings, which remarks the incoming importance of these areas (EMTA, 2020). Compared with urban centers, these metropolitan peripheries have often lower population densities and less land use mix. That clearly conditions the current metropolitan mobility, since citizens must travel longer for both their daily home-to-work commuter trip and their non-obliged trips (shopping, leisure, etc.). For that reason, mobility policies should go towards a sustainable mobility not only in main cities but also in the whole metropolitan areas, as the European Commission’s new Sustainable and Smart Mobility Strategy states (European Commission, 2020).

Currently, mobility in metropolitan rings highly relies on cars (Wolny, 2019). The lower population density and lack of land use mix difficult public transport agencies and operators to provide a high frequency public transport, consequently reducing its competitiveness. Nevertheless, metropolitan areas get configured through corridors given the existing transport infrastructures that previously connected the city with some others: roads upgraded to highways and railway tracks. This is because inhabitants aim to reduce their transport cost living close to these infrastructures (Müller et al., 2010). Public transport can profit from these infrastructures to serve the population in these peripheries. Two main services emerge there: metropolitan buses and suburban railways, using each type of infrastructure. Metropolitan bus services provide the territorial capillarity and accessibility, reaching most of dwellers, and may benefit of high-capacity roads to provide faster connections. However, with great capillarity and low density comes lower frequency, and traffic jams – out of control of bus operators – clearly also affect bus regularity. Suburban rail often provides more frequent, reliable, and higher-capacity services, connecting metropolitan passengers with the main urban transport hubs, thus becoming the backbone of metropolitan mobility.
Furthermore, the previous stages in the liberalization of the railway sector in the European Union has caused, for suburban rail services, the coexistence two agents: the infrastructure manager (IM) and one railway undertaking (RU). Unlike metro networks, where a single company manages both infrastructure and rolling stock, for suburban railways the transport service is offered by the RU, whose rolling stock runs on tracks and stops at stations under the control of the IM. Some key variables for RU such as the track layout, the distance between stations or the maximum speed of each stretch are determined beforehand. In addition, under a railroad disruption to be fixed by the IM, trains cannot take an alternative route. Therefore, this situation can compromise the overall quality of the rail service provided by the RU despite not being its direct responsibility.

The concept of Quality of Service (QoS) in PT is oriented to fulfil the requirements of passengers. With this aim, the EN 13816 Standard (CEN, 2002) proposes 8 categories that comprise the criteria from the user's point of view: availability, accessibility, information, time, customer care, comfort, security and environmental impact. The most widely method used to evaluate QoS in PT is the Traveler Satisfaction Survey (TSS), whose questionnaire is often based on the aforementioned categories. It must be stressed, however, that QoS and satisfaction are not the same concept – user satisfaction may be interpreted as the comparison between the expectations and the perception of the provided service (Mouwen, 2015). These TSS not only make it possible to measure the most highly valued attributes, but also to estimate their relative importance on the overall satisfaction.

Most studies about quality of PT services are focused on bus services or subway systems, which have different characteristics compared to suburban rail services. Nevertheless, several studies estimate the most important service attributes for suburban railway passengers: main factors are related to service supply (e.g. regularity and punctuality), vehicle cleanliness service supply, information and station accessing (de Oña et al., 2015, Weinstein, 2000). When working with TSS in PT services, two consideration must be bear in mind. First, the existence of a psychological “rail factor”, which makes rail services more attractive than buses. In terms of TSS, it results in a better valuation of train services than bus services (Scherer & Dziekan, 2012). Second, there are socio-economic and spatial differences on the perception of the quality of public transport services. As an instance, Grisé and El-Geneidy (2017) found an inverse relationship between socially deprived neighborhoods and passengers’ satisfaction with bus services. Besides, Eboli et al. (2018) found that areas with lower density of rail network leads to lower perceived QoS of Milan’s regional and suburban rail.

To the best of our knowledge, only Eboli et al. (2018) find a relationship between suburban rail network characteristics and perceived QoS. Furthermore, the studies analyzing the QoS on suburban rail does not focuses on the effects of both infrastructure manager and railway undertaking. This work aims to explore how the perceived quality of service of suburban rail services can be influenced by the rail infrastructure characteristics, taking into account the different responsibilities of both infrastructure manager and railway undertaking..

2. CASE STUDY: CERCANÍAS MADRID

We have chosen as a case study the Madrid Region’s suburban rail service, Cercanías Madrid. Madrid Region, located in the center of Spain, had about 6.7 million inhabitants in 2019, of those 3.3 million live in Madrid, the capital of Spain, and about other 3 million live in its metropolitan ring. GDP per capita in Madrid Region was 35,041 euro in 2018, 36 % over the national average (INE, 2020). However, Madrid Region presents a southwest-northeast line of social inequality, with lower incomes and higher unemployment in the southeastern half of the region (Leal & Sorando, 2015).

The public transport network in Madrid is composed by 440 metropolitan bus lines, 205 urban bus lines, 13 Metro lines and 4 light rail lines, 5 multimodal interchange stations – managed by the regional Public Transport Authority (PTA) – and 10 Cercanías lines. Cercanías is the suburban rail division of Renfe Operadora, the Spanish national railway undertaking. Cercanías Madrid was first put in service in 1985 using the long-distance, pre-existing railroad tracks. Currently, their trains run on ADIF tracks, the Spanish national IM. In addition to the pre-existing tracks, some sections specifically designed for suburban rail have also been built. It is noteworthy that Cercanías Madrid manages most stations (access, furniture, etc.) although they are owned by ADIF.

Cercanías Madrid has 9 regular lines and 1 touristic line. The infrastructure network lengths 370 km and has 90 stations. Cercanías Madrid also follows a clear radial structure, with a central area in the inner center of Madrid. That includes a main trunk section with two tunnels connecting the most important rail stations in Madrid (Atocha and Chamartín) and a partially tunneled section from Atocha to Principe Pío (Green Railway Corridor) based on the 19th century railroad track. A more in-detail scheme of the network can be found in Figure 1, including the southwest-northeast line of social inequality and the central area.

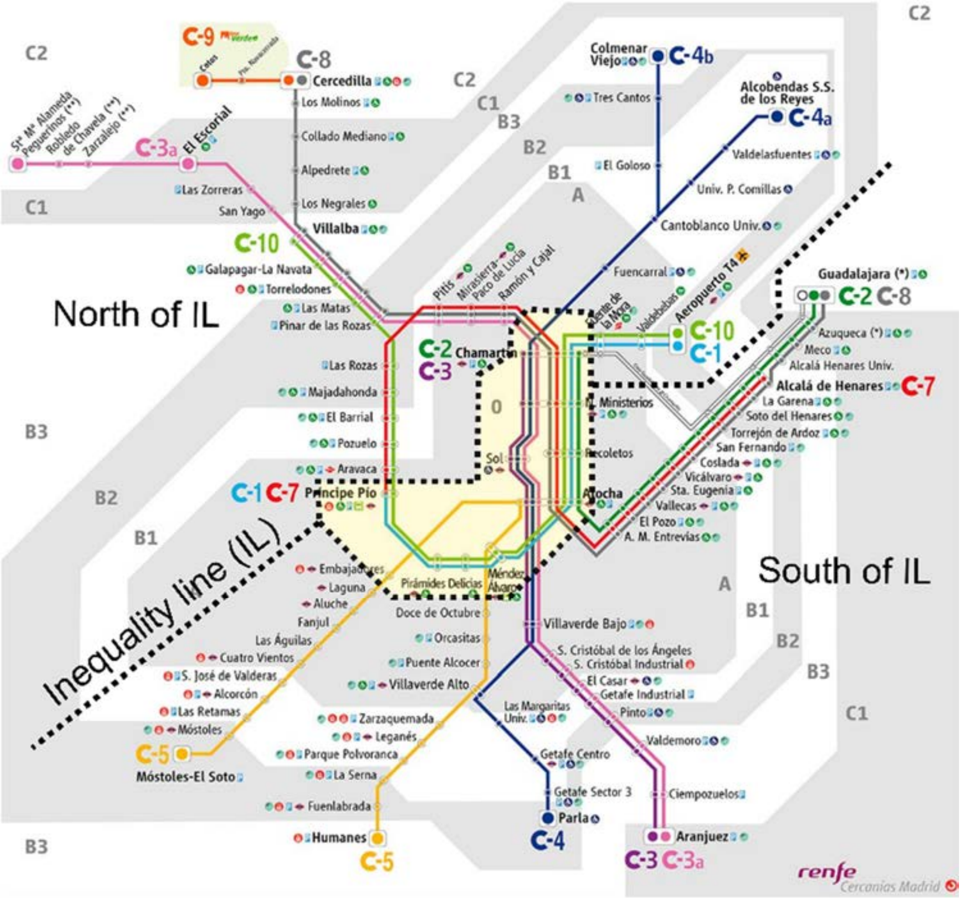

Fig. 1 – Cercanías Madrid network, with the inequality line and the central area (shaded in yellow).

3. METHOD AND DATA SOURCES

The analysis framework is divided in two steps. First, a description of the lines based on several key variables of railway infrastructure and operation. Then, a grouping of the different lines based on the passengers’ satisfaction that leads to a comprehensive analysis considering the previous infrastructure and operation variables. This section presents the data acquisition and next it explains the method of each step.

3.1 Data sources

This study needs to compile two different type of information for each line: infrastructure and operation key variables and data about quality of service. First, data on infrastructure and operation has been gathered from several sources. Travel times have been manually collected from Renfe Operadora website. Last, length of lines is obtained from Madrid Region PTA open data portal and the average commercial speed at peak hour and the number of train circulations in peak and off-peak hour are taken from Madrid Region PTA annual report (CRTM, 2021).

On the other hand, data about quality of service derive from the 2019 annual TSS carried out by Renfe Operadora. The survey was conducted in November and December 2019 to about 2,600 passengers, what means that about 200 – 250 surveys per line. The survey questionnaire includes general questions about trip habits (trip frequency, access and dispersion modes…) and passenger characteristics. It also asks to rate a list of service attributes on a scale of 0 to 10. For this work, there were only available the average values for each line.

3.2 Indicators

To properly describe the lines, a set of indicators are selected. Following Alonso et al. (2015), the indicators should ideally meet seven requirements: target relevance, validity, transparency, sensitivity, standardized for comparison, unambiguity, and data reliability and availability. In this case, we prioritize the last criterion over the others. Based on Nicholson et al. (2015) railway evaluation KPIs and public availability of data, 6 indicators are chosen: line *length*, number of *stations* per line, percentage of *shared sections* with other line/s, average *travel time between stations* (i.e. between two consecutive stations), operational *speed* at peak hour, and number of daily *services* per line. The indicators *stations* and average *travel time between stations* have been divided in 3 parts, based in the Madrid Region's southwest-northeast line of social inequality: north (N), central (C) and south (S). That is expected to help in the comparative analysis. Table 1 contains the values of the indicators for each of these lines, which are analyzed in detail in Section 4.

3.3 Grouping

In this step, lines are grouped according to passengers' satisfaction and some key infrastructure characteristics for better understanding the similarities and differences in QoS among lines. Furthermore, it will allow discussing which variables drive the perception towards the different services' attributes. It would be preferable to aggregate the infrastructure attributes into composite indicators. Nevertheless, to the extent of our knowledge, there are not composite indicators of railway infrastructure at line level which may serve as a reference. The solution taken here is to obtain the relative importance of the previous variables on the QoS by using the Pearson's correlation coefficients (Weinstein, 2000). Although it does not provide a direct relationship between these variables, it serves to rank the relative importance of service variables.

Then, groups are compared taking into account their infrastructure and operation characteristics as well as the different variables included in the Cercanías TSS: train supply, regularity and punctuality, travel time, information to passengers, easiness of access to station, station comfort, train comfort, station and train cleanliness, staff attention, customer relationship, security and fares. In the Cercanías Madrid case, the responsibility for train supply, regularity and punctuality, travel time and easiness of access can be shared between ADIF (the IM) and Renfe Operadora (the RU), while the rest of attributes lie predominantly with Renfe Operadora.

4. DESCRIPTIVE ANALYSIS OF LINES

Prior to the analysis of the lines of Cercanías lines, it is pertinent to point out some operational peculiarities of certain lines which may affect to the proper comprehension of the results. First, lines C3 and C3a are commercially two different lines although they run as a single line up to Chamartin, with some services ending at Chamartin (C3) and a few others running northwest. In this paper we have opted to consider it as a single line. Second, lines C4a and C4b operate as a single line with two branches in the north side, with different infrastructure characteristics.

The main variables of the lines are shown in Table 1 (infrastructure) and Table 2 (operation). The average length of lines is 70.5 km. However, it varies considerably from more than 120 km for lines C3a and C8 to just over 20 km for line C1. This clearly affects to the commercial speed: on average it is 50.1 km/h at peak hour, overpassing 55 km/h in the two longest lines and being lower in shorter lines (C1, C5). Despite that, C1 and C5 are the lines with lower average travel time between stations, along with the lines C4a and C4b. On the other side, C3a presents the longest travel time between stations (4.7 minutes), almost a minute above the average (3.8 minutes). It is also noteworthy to glance at the travel times between stations in the central area, since most lines share some sections. More in detail, travel time between Atocha and Chamartin is longer via Recoletos (4.3 min/section) than via Sol (3.7 min/section).

It is also interesting to point out the spatial distribution of lines (Figure 1): C2, C3 and C5 only connects the southern areas of the region with the center of Madrid, while C1 and C10 are exclusive-northern lines. The remaining half of lines links north and south, among them the two longest lines (C3a and C8) are found.

Line	**Length (km)**	**Stations**				**Shared sections (%)**
		Total	**S (%)**	**C (%)**	**N (%)**	
C1	24.5	11	0	73	27	100
C2	64.2	19	79	21	0	100
C3 + C3a	128.9	24	38	17	46	85
C4a	48.2	15	40	27	33	73
C4b	59.2	15	40	27	33	73
C5	45.0	23	87	13	0	0
C7	79.4	24	46	21	33	100
C8	122.4	32	47	13	41	82
C10	62.3	21	0	38	62	100
Avg.	70.5	20.4	46	25	29	79

Table 1 – Main infrastructure variables of Cercanías lines

Line	**Travel time between stations (min)**	**Speed (km/h)**	**Services (% peak h.)**	**Average QoS**
C1	3.6	38.2	75 (37%)	7.21
C2	4.1	53.9	211 (45%)	7.01
C3 + C3a	4.7	58.9	160 (46%)	6.57
C4a	3.7	51.7	285 (49%)	7.08
C4b	3.3	46.4	302 (54%)	7.03
C5	2.5	46.4	302 (54%)	7.40
C7	4.0	50.2	101 (57%)	7.36
C8	4.4	55.4	46 (50%)	6.64
C10	4.3	39.2	165 (51%)	7.26
Avg.	3.9	49.5	149 (49%)	7.13

Table 2 – Main operation variables of Cercanías lines

5. COMPARATIVE ANALYSIS OF LINES BASED ON THE PERCEIVED QUALITY OF SERVICE

The descriptive analysis of the lines provides a general overview of the lines, with clear differences on length, operational speed at peak hour or travel time between stations. This may give a broad idea of the service offered, but it does not relate to the QoS perceived by travelers. To that extent, the relative importance of each service attribute is obtained using Pearson’s correlation coefficient. Then, the most important variables are line length (-0.79) and travel time between stations (-0.68). The negative sign implies that the longest the line and the travel time, the worst QoS. These three variables (QoS, line length and travel time between stations) are displayed in a scatter plot (Figure 2) where four groups of lines can be extracted. This analysis based in groups was carried out to ease the description of the results, without aiming to provide a statistically consistent classification of lines.

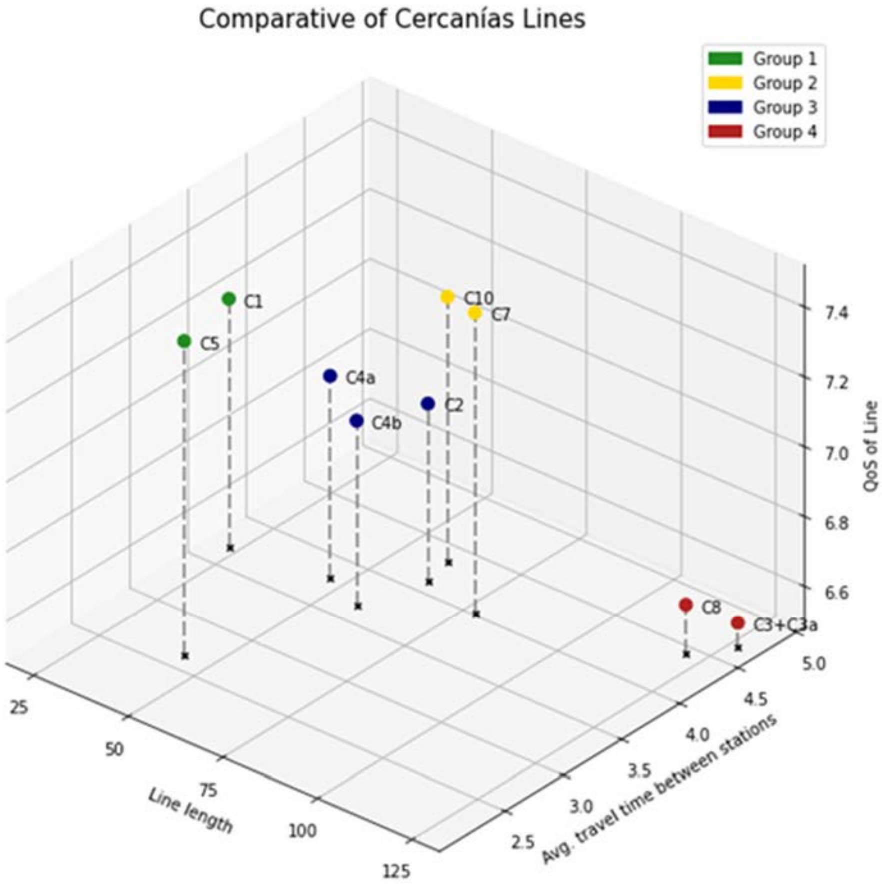

Fig. 2 – Grouping of lines according to the passengers' satisfaction and key infrastructure satisfaction as defined in Section 3.2

The four resulting groups are sorted based on their average QoS, resulting in Group 1 (C1, C5), Group 2 (C7, C1, C10), Group 3 (C4a, C4b, C2) and Group 4 (C3, C8). Hereby, Group 1 has the higher overall perceived quality (+0.27 above average), followed by Group 2 (+0.18). At this stage, we include into the analysis the passengers' perception towards the different service attributes mentioned in Section 3.3. To ease comparison, Table 3 shows the difference, for each attribute, between the groups' rating and the network average and also the highest difference between groups. Overall perceived quality is also included in Table 3 to facilitate the discussion. Below the four groups are analyzed in detail, followed by some considerations on infrastructure issues.

Attribute	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Max. difference among groups**
Supply	0.19	0.25	0.09	-1.06	1.31
Regularity	0.33	0.00	-0.09	-0.69	1.01
Travel time	0.41	0.12	-0.29	-0.56	0.97
Information	0.11	0.29	-0.06	-0.47	0.76
Access to station	0.11	0.17	-0.11	-0.38	0.55
Station Comfort	0.15	0.09	0.06	-0.53	0.68
Train Comfort	0.16	0.09	-0.08	-0.26	0.41
Cleanliness	0.11	0.08	0.00	-0.39	0.50
Staff attention	0.08	0.22	-0.19	-0.13	0.40
Customer relationship	0.19	0.31	-0.08	-0.60	0.91
Safety	0.11	0.36	-0.05	-0.29	0.65
Fares	0.11	0.09	-0.04	-0.32	0.43
Overall perceived quality	0.22	0.18	-0.09	-0.54	0.76

Table 3 – Attribute rating among clusters. Difference between value of group and Cercanías Madrid average.

5.1 Group 1: Short, well-perceived lines

The first group consists of C5 and C1. This is the group with less travel time between stations (3.0 min on average) and with more daily circulations (188 on average), although its operational speed is lower than the average. This situation clearly impacts to the satisfaction results. In addition to being the highest-rated group, the service's attributes where the group overperforms are regularity and travel time, which seems to be in consonance with the operational characteristics of the lines.

5.2 Group 2: Long, well-perceived lines

The second-best rated group comprises lines C7 and C10: two long lines (70.8 km on average) that connect the city of Madrid with one edge of the metropolitan area. They share a common section at the northwest of the inequality line, and they mostly serve to the northern half of the network, which could explain why this group is perceived as the most secure (+0.36) and with the best customer relationship (+0.31)). This group is also well rated at train supply (+0.25) – while they are below average in daily services (11% below average), this is the group that most concentrates its supply during peak hours (53% of services) and furthermore two or more lines stop at every station of this group, so passengers may perceive a greater supply than other groups.

5.3 Group 3: Balanced lines

The third group includes the lines C2, C4a and C4b. While C4a and C4b lines share most of the route and only split at the north, line C2 does not have any section in common with the former lines. Their most distinctive feature is the number of daily services, 10% above average, while the other attributes are quite close to the network average. In addition, this group has most of their service attributes rated just a bit below the average: only station comfort (+0.06) and train supply (+0.09) overperform; the latter having a meaning given the high volume of daily services.

5.4 Group 4: Underperforming longest lines

The remaining lines C3 and C8 form the last group. This group has the lowest overall perceived quality (0.52 below average) and being the worst rated group in every attribute except for the “staff attention” (-0.12). In contrast to the Group 2, train supply (-1.06), regularity (-0.69) and travel time (-0.56) are three of the most underperforming attributes. As already mentioned, they are the longest lines. In addition, they are the lines with the highest number of stations and the longest travel time between stations, despite being the lines with highest operational speed.

5.5 Effects of rail infrastructure on QoS and stakeholders’ responsibilities

It is also possible to perceive some effect of the infrastructure on QoS, based on similarities and differences of attributes ratings among groups, with data extracted from Table 3. The attributes with the least variation among groups are train comfort (0.41), staff attention (0.40) and fares (0.43), which are independent of the infrastructure characteristics. Conversely, the most divergent attributes are train supply (1.31), regularity (1.01) and travel time (0.97), in which both the infrastructure manager and the railway undertaking are involved.

6. DISCUSSION AND CONCLUSIONS

This study aims to obtain an overview of the quality of service in suburban rail considering general infrastructure and operational parameters. To achieve that objective, we take a line-based approach and apply a two-steps procedure to the Cercanías Madrid case study. We first analyze the general characteristics of that lines and then we classify the lines in four groups according to the average passengers’ satisfaction and key characteristics of lines, leading to a comprehensive examination of the service considering both sides.

The most relevant line attributes seem to be the travel time between stations and the total line length. In fact, the best rated group (Group 1, 0.22 above average) has the lower travel time between stations (3.0 min), which may be coupled with a much higher ratings of regularity and travel time. On the other hand, the worst rated group (Group 4, 0.54 below average) only comprises the longest lines, having the higher average speed but also the higher average travel time between stations. We find that the most constant attributes from the TSS depend solely on the RU, while the most varying ones depend both on RU and IM, thus having the infrastructure some sort of effect on the perceived QoS. Last, as for the socioeconomic or territorial effects on the service, we can only suggest a slight positive relationship with perceived security in north-based lines, but that deserves to be analyzed more in depth.

Future work should be directed at quantifying the effect of the different parameters of infrastructure (e.g. length, travel time) on passengers' satisfaction and, more specifically, on some attributes such as the passengers' satisfaction with regularity or travel time. There is also room for exploring the responsibility of IM and RU by including variables related to railroad capacity and/or blocking. That gained knowledge will help both agents to enhance certain aspects of the service, leading to the identification of areas for individual and joint improvements. In the end, it will result in an increase in satisfaction and a potential increase in the ridership of the suburban railroad, promoting a more sustainable mobility in metropolitan areas

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Spanish Ministry of Transport and Renfe Operadora for their support in the preparation of this article by providing us with data related to the annual passenger satisfaction survey.

REFERENCES

ALONSO, A., MONZÓN, A., CASCAJO, R. (2015) Comparative analysis of passenger transport sustainability in European cities. Ecological Indicators, 48, pp. 578-592. https://dx.doi.org/10.1016/j.ecolind.2014.09.022

CONSORCIO REGIONAL DE TRANSPORTES DE MADRID – CRTM (2021). Informe anual 2019 [Annual Report 2019]. Retrieved from: https://www.crtm.es/media/880193/informe_anual.pdf

DE OÑA, J., DE OÑA, R., EBOLI, L., MAZZULLA, G. (2015). Heterogeneity in Perceptions of Service Quality among Groups of Railway Passengers. International Journal of Sustainable Transportation, 9(8), pp. 612-626. https://dx.doi.org/10.1080/15568318.2013.849318

EUROPEAN COMMISSION, 2020. Sustainable and Smart Mobility Strategy – putting European transport on track for the future. https://eur-lex.europa.eu/resource.html?uri=cellar:5e601657-3b06-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF

EUROPEAN COMMITTEE FOR STANDARDIZATION – CEN (2002). EN 13816 Standard. Transportation – Logistics and services – public passenger transport – service quality definition, targeting and measurement.

EUROPEAN METROPOLITAN TRANSPORT AUTHORITIES – EMTA (2020). EMTA Barometer 2020 – Based on 2018 data. Retrieved from: https://www.emta.com/IMG/pdf/2018_emta_barometer-200526.pdf?4014/a35af27b041fa58335d2edbbc4963d8addf34000

EBOLI, L., FORCINITI, C., MAZZULLA, G. (2018). Spatial variation of the perceived transit service quality at rail stations. Transportation Research Part A: Policy and Practice, 11, pp. 67-83. https://dx.doi.org/10.1016/j.tra.2018.01.032

GRISÉ, E., EL-GENEIDY, A. (2017). Evaluating the relationship between socially (dis)advantaged neighbourhoods and customer satisfaction of bus service in London, U.K. Journal of Transport Geography, 58, pp. 176-175. http://dx.doi.org/10.1016/j.jtrangeo.2016.11.016

LEAL, J., SORANDO, D. (2015). Economic crisis, social change and segregation processes in Madrid. In: TAMMARU, T., MARCIŃCZAK, S., VAN HAM, M., MUSTERD, S. (ed.) Socio-Economic Segregation in European Capital Cities. East meets West. New York: Routledge.

MOUWEN, A. (2015). Drivers of customer satisfaction with public transport services. Transportation Research Part A 78, pp. 1-20, https://dx.doi.org/10.1016/j.tra.2015.05.005

MÜLLER, K., STEINMEIER, C., & KÜCHLER, M. (2010). Urban growth along motorways in Switzerland. Landscape and Urban Planning, 98(1), 3–12. https://doi.org/10.1016/j.landurbplan.2010.07.004

NATIONAL STATISTICS INSTITUTE – INE (2020). Spain in Figures 2020. Retrieved from: https://www.ine.es/ss/Satellite?param1=PYSDetalleGratuitas&c=INEPublicacion_C&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&cid=1259924856416&L=1

NICHOLSON, G.M., KIRKWOOD, D., ROBERTS, C., & SCHMID, F. (2015). Benchmarking and evaluation of railway operations performance. Journal of Rail Transport Planning & Management, 5, 274 – 293. https://dx.doi.org/10.1016/j.jrtpm.2015.11.004

SCHERER, M., DZIEKAN, A. (2012). Bus or rail: An approach to explain the psychological rail factor. Journal of Public Transportation 15 (1) pp. 75-93. https://dx.doi.org/10.5038/2375-0901.15.1.5

WEINSTEIN, A. (2000). Customer satisfaction among transit riders: How customers rank the relative importance of various service attributes. Transportation Research Record: Journal of the Transportation Research Board 1735, pp. 123-132. https://dx.doi.org/10.3141/1735-15

WOLNY, A. (2019). Are suburban commuters confined to private transport? A case study of a medium-sized functional urban area (FUA) in Poland. Cities, 92 (March), pp. 82–96. https://dx.doi.org/10.1016/j.cities.2019.03.013