Case Studies on Transport Policy

Identifying and Understanding Determinants of Regional Differences in Light-Rail Patronage and Performance

--Manuscript Draft--

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Abstract:	For the past three decades light-rail transit has been a key strategy for advancing sustainable mobilities in cities around the globe. International comparative studies, however, are few and infrequent, and the factors behind previously noted regional performance differences are still unclear. This investigation registers and compares performance outcomes, and clarifies which factors are likely behind regional differences in patronage and performance for systems that operate in two European (Spain) and three North American (United States) cities. Data related to service quality, network topology, metropolitan and local land-use structure, ridership, and socio-economic factors were collected and harmonised; and systems were ranked using a standardised multi-dimensional performance score. System-level statistics were complemented with station-level multivariate regressions for a more comprehensive and nuanced analysis. Based on results, the authors posit that traditions in city planning and building, as manifest in the distinct metropolitan structure and local built-environment play a very important role in explaining notable differences in light-rail performance on cases documented in this study. Population levels, multimodal transit integration, and higher service levels are also found to be highly influential factors. The specific role of other socio-economic and cultural factors not registered in this study remains to be documented. The Spanish systems markedly outperform the North American ones on multiple performance measures and by orders of magnitude. Policy implications are discussed in response to these findings.

HIGHLIGHTS
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- Local population density is a dominant factor in LRT performance contrasts
- Bus-LRT connectivity and LRT service level follow as top-tier performance factors
- Regional city planning and urban design traditions influence performance outcomes
- Multifactor heuristics can effectively and fairly rank LRT systems on 14 measures
- Spanish LRT cases markedly outperform North American cases in this study

Introduction

Mass transit is considered a key strategy in advancing sustainability goals, together with fiscal and land-use policies geared to support transit patronage, reduce automobile-dependence, and reduce greenhouse gas emissions (Pachauri et al., 2014; Vuchic, 2007; Newman & Kenworthy, 1999; Cervero, 1998; Mackett & Sutcliffe, 2003; Currie & De Gruyter, 2018). Substantial capital investments and longer-term operational and maintenance costs are associated with mass transit systems. Periodical monitoring of their performance is thus called for in verifying that objectives and goals are being met in an effective and efficient manner.

Since the late 20th century several cities have implemented a form of rapid-transit known as light-rail (hereafter LRT, which excludes trams (*streetcars*) (Vuchic, 2007)). This, mostly in pursuit of goals that include congestion reduction, high-capacity commuting, greenhouse gas reduction, economic development, land-use redevelopment, and intensification, among others, with mixed results (Mackett & Sutcliffe, 2003). As of 2020, a total of 28 LRT systems now operate in the United States. As of 2018, 204 European cities had a tram or light-rail system running with 420 new km of LRT lines opened between 2015 and 2018 (Rail Unit of the UITP Secretariat, 2000). As of 2000, Spain had LRT systems in 11 metropolitan areas with more than 200 km of tracks opened since 1994 (Novales, Bertrand, & Fontaine, 2019). One attractive feature of LRTs is that on average they are 3 to 4 times less expensive to build as compared to heavy rail. Yet, according to a study of rapid-transit systems in the United States, LRTs average a substantial $53million per mile and their per-rider cost tends to be higher than that of heavy rail (Guerra & Cervero, 2011).

Despite decades of implementation, only a few international LRT comparative performance studies have been produced in the past ten years, at least in the English-language literature (see

Mackett & Sutcliffe, 2003; Currie, Ahern, & Delbosc, 2011; Currie & Delbosc, 2013; Currie & De Gruyter, 2016; Gruyter et al., 2020; Aston et al., 2021). In addition, a decline in transit patronage in the United States, mostly in bus transit but also including several LRT systems, reflects stagnant and declining pre-COVID-19 trends. Between 2014 and 2018, LRT systems in the United States experienced an average ridership growth of 3.86%. However, if we exclude the LRT systems that undertook network expansions during this period (n=6), LRT ridership declined on average 10.80% in the remaining subset of systems that reported statistics to the National Transit Database (NTD; n=16; FDOT, 2019). This United States based trend is concerning and merits study.

Meanwhile, ridership in European Western Mediterranean LRT systems is growing steadily, with an increase of 4.5% between 2015 and 2018 (Rail Unit of the UITP Secretariat, 2000). In Spain, LRT ridership within metropolitan areas that had reported full time-series data, has had a cumulative increase of 6.24% between 2014 and 2017 (Monzon et al., 2016, 2017, 2019; Casacajo, Monzon, Romero, & de Galarreta, 2018). Nevertheless, after the 2008 economic crisis, controversy has arisen in Spain over the worthiness of LRT investments in terms of levels of ridership and cost effectiveness, a situation that also gives relevance to this comparative study.

Of special interest in this study is the finding in one of the most recent comparative LRT studies (Currie et al., 2011) that routes operating in Europe yield notably higher ridership as compared to other systems operating in North America and Australia, controlling for several key factors. However, potential explanations of what the ‘European’ factor could mean were not considered in detail, and residential density, which often serves as a proxy for population levels, did not factor into the final models. This is an unexpected finding as residential density (or population levels) is a recurrent, significant factor in many transit ridership studies, including studies focused on LRT (Kuby et al., 2004; Guerra & Cervero, 2011; Foletta, Vanderkwaak, & Grandy, 2013; Ramos & Brown, 2016; among others). This was one of the motivations for the authors of this paper to look and compare cases from cities in Europe (Spain) and North America (United States) in more detail.

This paper aims to contribute to the international LRT planning and performance literature and shed light on key factors that may influence LRT's performance. The following research questions guided the investigation: How do most similar LRT systems from Spain and the United States compare in terms of transportation performance using standardised measures? Which factors could explain differences in performance, if any? Can key factors be identified that could be influential for policy analysis and considerations? The results of the study are presented here as well as recommendations for future studies.

This paper is organised as follows. In the first section, "Materials and Methods" we present the case studies and detailed descriptive data of the LRT systems and their contexts. The scientific literature on this subject is compiled and the main performance factors are defined. In addition, the research method developed is described based on three aspects: analysis of socioeconomic, transit and built-environment factors; analysis of LRT systems service indicators; and calculation of station-level regression. The "Results and Discussion" section presents and discusses the parameters and values collected and calculated to analyse the urban and socioeconomic context, the values obtained for the service indicators of each LRT and the results of the regression calculation. The "Conclusions and Policy Implications" section highlights the main factors on which to act from the territorial planning and the management of LRT systems to improve their efficiency and performance, based on the results of the analyses done.

Materials and Methods

Case studies selection & description

This investigation follows a comparative case-study research design in pursuit of better understanding of differences in regional performance of LRT. This approach seeks to examine both features and context when using a database of two or more instances of a specific phenomenon (Yin 2009). Spain and the United States were selected as regional sources of cases based on their divergent LRT patronage trajectories and data availability. Limited access to relevant data restricted the number of cases from Spain to two. Based on these, three cases exhibiting most similar characteristics were identified in the United States. The authors considered size and scope of the systems (< 34 stations; 1-2 lines), vehicle capacity, and providing service to the city centre as key selection parameters. Using this criterion in the selected systems for the United States were Charlotte's *The Lynx*; Cleveland's *Blue, Green, and Waterfront Lines*; and Norfolk's *The Tide*. The two Spanish systems are Granada's *Metropolitano de Granada* and Tenerife's *Metropolitano de Tenerife*.

These systems are described in **Tables 1 to 3** and **Figures 1 and 2**. Relevant differences between the Spanish and American cities are shown in the **Table 1**: figures for car availability, household income and car share are higher for the American cases; population density around stations is outstandingly higher for the Spanish cases; employment density around stations is similar for both countries and depends on the case study. **Table 1** also shows relevant statistics of the urban agglomerations where the five systems operate and details of the 600m network-based service area around the stations in each city. **Table 2** shows the operational characteristics: headways are consistently lower for the Spanish cases for every period type, while there are no clear differences in relation to hours of service. **Table 3** presents several aspects related to the infrastructure and the vehicles of each case study. It shows the similarities and differences among systems in relation to cost, number of vehicles, length, average distance between stations, percentage of different types of right of way, as well as vehicle capacity and characteristics. Data for **Tables 1-3** was collected from a variety of sources using secondary data with base year 2018. These include data directly provided by the transit agencies and operators, and sourced from government public records, such as the National Transit Database-Urban iNTD, FDOT; the Spanish National Statistics Institute; Canary Islands' Statistics Institute; Andalusia's Statistics and Cartography Institute; and Andalusian Employment Service.

Figure 1 shows the urban insertion of each system, at the same scale. The size of the circle representing each station is related to its boardings per year, the density of population plus employment in the service area of each station is presented with darker colours for the densest zones, bus and rail routes are presented in white, and special generators as a dark circle. This figure shows how the Spanish cases have, in general, larger proportions of high and medium density of population plus employment than the American ones, which have more zones with low values of this variable. Finally, **Figure 2** shows 2018 monthly ridership for each case, as well as the standardized monthly ridership by line km. The Spanish cases have, in general, higher values of these variables, and a drop in the summer figures is noticeable, due to the holiday season and the fact that most trips are related to work and study purposes in these systems (Novales, Muñoz, and Muñoz, 2019).

Table 1: Urban agglomeration, City, and Light-rail service area characteristics

			Urban Agglomeration-level Statistics *(Spain: AUF [‘Area Urbana Funcional’] U.S. MSA [Metro Statistical Area])*				
			Spain		United States		
		- *units* -	**Granada**	**Tenerife**	**Charlotte**	**Norfolk**	**Cleveland**
Urban Agglomeration	*Avg. Number of Cars per Household*	*Cars/hh*	1.29	1.34	1.82	1.80	1.59
	Commute Mode Share and Avg. Time:	-					
	Car (’11 ES, ‘10 USA)	*%*	47.91	56.03	91.02	90.50	89.92
	Public Transit (’11 ES, ‘10 USA)	*%*	11.48	8.87	1.86	1.78	3.50
	Walk (’11 ES, ‘10 USA)	*%*	13.03	8.58	n.a.	n.a.	n.a.
	Avg. commute time (’11 ES, ‘10 USA)	*minutes*	22.38	22.12	26.30	24.30	25.40
	Car	*minutes*	n.a.	n.a	26.01	24.57	24.82
	Public transit	*minutes*	n.a.	n.a.	48.30	39.20	47.40
	Median HH Income $(yr2018)	*MEV-adjusted*	$ 32,680	$ 35,510	$ 60,822	$ 64,534	$ 54,273
		PPP- adjusted	$24,384	$26,496	n.a.	n.a.	n.a.
			City-level Statistics				
			Spain		United States		
		- *units* -	**Granada** [a]	**Tenerife** [b]	**Charlotte City** [c]	**Norfolk City** [d]	**Cleveland Urban Area** [e] **(2017)**
City Area	Population (2018 ES, July 2018est. USA)	*Pop*	296,969	360,405	872,498	244,076	1,765,779
	Employment (2018 ES, 2017 ACS.USA)	*Emp*	106,861[f]	152,335 [f]	431,389	128,340	849,507
	Population + Employment (2018)	*(Pop+Emp)*	403,830	512,740	1,303,887	372,416	2,615,286
	Size of the cities or urban areas where the light rail goes through	*km^2*	175.91	252.62	794.04	137.99	2,004.11
	Population Density (2018)	*Pop/km^2*	1,688.19	1,426.67	1,098.81	1768.79	881.08
	Employment Density (2018)	*Emp/km^2*	607.48	603.02	543.28	930.07	423.88
	Population + Employment Density (2018)	*(Pop+Emp)/km^2*	2,295.66	2,029.69	1,642.09	2698.86	1,304.96
	Number of cars per household (2015 ES, 2017 ACS-USA)	*Cars/Household*	1.21[g]	1.36 [h]	1.66	1.54	1.60
	Number of cars (2015 ES, 2017 ACS-USA)	*Cars/1000 inhabitants*	460.72	523.26	602.88	549.35	669.56
			600m Network-Distance Service Area Statistics				
			Spain		United States		
		- *units* -	**Granada**	**Tenerife**	**Charlotte**	**Norfolk**	**Cleveland**
Light Rail Service Area (600m) [j]	Population (2018)	*Pop*	137,402 [i]	117,374 [i]	23,552	12,483	34,066
	Employment (2017 (US), 2018)	*Emp*	32,413 [i]	65,026 [i]	98,871	38,232	45,467
	Population + Employment (2018, 2017 (US))	*(Pop+Emp)*	169,815 [i]	182,400 [i]	122,423	50,714	79,533
	Actual size of adjusted 600 m areas around stations [k]	*km^2*	12.27	10.65	17.05	7.19	19.22
	Population Density (2018)	*Pop/km^2*	11,198.21	11,021.03	1,382.35	1,736.00	1,772.41
		Pop/ac	45.32	44.60	5.59	7.03	7.17
	Employment Density (2017 (US (2018))	*Emp/km^2*	2,641.64	6,105.73	5,798.92	5,317.00	2,365.60
	Population + Employment Density (2018 (SP), 2017 (US))	*(Pop+Emp)/km^2*	13,839.85	17,126.76	7,180.26	7,053.46	4,138.01
		(Pop+Emp)/ac	56.00	69.31	29.96	28.54	16.75

Notes:	a. Towns of Granada, Albolote, Armilla and Macarena b. Towns of Santa Cruz de Tenerife and San Cristóbal de La Laguna c. 'City' geography as defined in US Census - 'Geography & ACS' (https://www.census.gov/programs-surveys/acs/geography-acs.html; boundary contains full-extent of light-rail lines) d. 'City' geography as defined in US Census - 'Geography & ACS' (https://www.census.gov/programs-surveys/acs/geography-acs.html; boundary contains full-extent of light-rail lines) e. 'Urban Area' geography as defined in US Census - 'Geography & ACS' (https://www.census.gov/programs-surveys/acs/geography-acs.html; boundary contains full-extent of light-rail lines) f. Values considering an even distribution of population and employment among municipalities of Granada and Santa Cruz de Tenerife province g. Considering the household size of the complete Andalusian region, number of cars, inhabitants and household size data from 2015 h. Considering the household size of the complete Canary region, number of cars and inhabitants data from 2015, household size data from 2011 i. Considering a proportional distribution among the houses and premises of the buildings around stations, based on population data in census sections and employment data in municipalities or counties. j. 500m is the standard station service-area distance parameter for LRT systems in Spain and Europe, whilst 800m is mostly used in the United States for fixed rail systems. 400m is also considered in some studies. For this study the authors agreed on 600m as an intermediate parameter for all cases. k. Pedestrian network-based distance as generated by the 'Network Analyst' tool in ArcGIS v.10.1

Table 2: Operational characteristics

		Spain		United States			
	units	**Granada** [a]	**Tenerife** [b]	**Charlotte** [c]	**Norfolk** [d]	**Cleveland** [e]	
Headways:							
Weekday Peak	*minutes*	8	5	10	10	20 (green) 20 (blue) 10 (green-blue)	20 (waterfront)
Weekday Off-Peak	*minutes*	10-15	7.5-15	15	15-30	30 (green) 30 (blue) 15 (green-blue)	30 (waterfront)
Weekend Average	*minutes*	11-15 30 (early morning)	10-15-20 30 (late night)	20-30 (day/evening) 30 (late night)	15-30	30 (green) 30 (blue) 15 (green-blue)	30 (waterfront)
Hours of Service:							
Monday - Thursday	*hours*	06:30 - 23:00 (16.5 h)	06:00 - 24:00 (18 h)	04:54 - 01:31 (20.5 h)	06:00 - 23:00 (17 h)	03:39 - 01:10 (21.5 h)	06:31 - 19:05 (11.5 h)
Friday	*hours*	06:30 - 02:00 (19.5 h)	06:00 - 24:00 (18 h)	04:54 - 01:31 (20.5 h)	06:00 - 24:00 (18 h)	03:39 - 01:10 (21.5 h)	06:31 - 19:05 (11.5 h)
Saturday	*hours*	07:30 - 02:00 (18.5 h)	00:00 - 24:00 (24 h)	05:30 - 02:00 (20.5 h)	06:00 - 24:00 (18 h)	03:39 - 01:10 (21.5 h)	09:18 - 19:05 (9.75 h)
Sunday	*hours*	07:30 - 23:00 (15.5 h)	00:00 - 24:00 (24 h)	05:15 - 00:45 (19.5 h)	10:55 - 21:00 (10 h)	03:39 - 01:10 (21.5 h)	09:18 - 19:05 (9.75 h)
	Notes:	a. Sources: https://metropolitanogranada.es/horarios and http://www.granadadirect.com/transporte/metro-granada-horarios/ b. Source: https://metrotenerife.com/recorridos-y-horarios-3/ c. Sources: https://web.archive.org/web/20180922194815/https://charlottenc.gov/cats/rail/lynx-blue-line/Pages/default.aspx; https://web.archive.org/web/20180530054225/http://charlottenc.gov/cats/bus/Documents/Charlotte-Riders-Guide.pdf; July 2018 schedule, accessed 7/8/2019. d. Sources: https://web.archive.org/web/20180901093430/https://gohrt.com/services/the-tide/; September 2018 schedule, accessed 7/8/2019 e. Sources: https://web.archive.org/web/20180713213023/http://www.riderta.com/sites/default/files/schedule-pdfs/BlueGreenWaterfrontLine.pdf; June 3, 2018 schedule, accessed 7/8/2019					

Table 3: General LRT system characteristics

		Spain		United States		
Characteristics	*units*	**Granada**	**Tenerife**	**Charlotte**	**Norfolk**	**Cleveland**
Year Open / Year Expanded and/or Improved	*years*	2017	2007	2007 / 2010 / March 16, 2018	2011	1913 (streetcar; Green Line); 1920 (streetcar; Blue Line); 1936 (streetcar; current lines); 1981 (light-rail vehicles); 1996 (Waterfront line)
Actual Capital Costs[a] (non-adjusted)	*€, $*	558.8 (M€-2016)	303.07 (M€-2007) + 59.16 (M€-2009)	462.75 (M$-2007) + 63.18 (M$-2010) + 1,160.08 (M$-2018)	315.76 (M$-2011)	n.a.; n.a.; n.a.; n.a.; 70.90 (M$-1996) (Waterfront Line only)
Predicted Capital Costs[a] (non-adjusted)	*€, $*	n.a.	n.a.	331.10 (M$YOE) + 63.18 (M$ CE; 2010) +1,160.08 (M$-2018)	210.80 (M$)	n.a.
Number of Lines	*n/a*	1	2	1	1	2
Number of Vehicles	*n/a*	13+2	17+2	14+6 / 42	6+3	34
Number of Stations	*n/a*	26	25	15 / 26	11	33 [d]
Avg. Distance Between Stations [b]	*meters*	636	629	1197	1181	724
Alignment Length	*km*	15.90	15.10	14.97 / 29.93	11.81	24.62 / 3.50 (Waterfront Line)
	miles	9.87	9.38	9.30 / 18.60	7.34	15.30 / 2.20 (Waterfront Line)
Cost per km[a]	*€/km*	35,144,654	24,639,837 L1 42,257,143 L2	50,748,009 [c]	19,196,651	15,962,628 (Waterfront Line)
	$/km	38,553,685	31,292,593 L1 54,215,915 L2	59,915,005 [c]	26,736,283	20,257,142 (Waterfront Line)
Cost per mile[a]	*€/mi*	56,616,008	39,653,973 L1 68,006,253 L2	81,660,641 [c]	30,887,256	25,395,090 (Waterfront Line)
	$/mi	62,107,761	50,360,546 L1 87,252,023 L2	96,411,619 [b]	43,018,462	32,227,272 (Waterfront Line)
Right of Way	*Exclusive (Class A)*	17.0%	7.2%	20.3%	5.6%	31.7%
	Semi-exclusive (Class B)	83.0%	89.8%	79.7%	60.1%	68.3%
	Mixed-Traffic (Class C)	0.0%	3.0%	0.0%	34.3%	0.0%
Vehicle	*Make/Model*	CAF Urbos 3	Alstom Citadis 302	Siemens S70	Siemens S70	Kulhman streetcar (1913-) / PCC streetcar (1947-1981) / Breda LRV
	Seating Capacity	48+6	56	68	68	84
	Standing Capacity (4 pass./m^2 ESP; 6 pass./m^2 USA)	167	144	168	168	186
	Total passenger capacity	221	200	236	236	270

	Maximum speed	70km/hr (43.5mph)	70km/hr (43.5mph)	115km/hr (71.5mph)	115km/hr (71.5mph)	90km/hr (55.9mph)
	Maximum operational speed	70km/h (43.5mph)	50km/h (31.1mph)	106km/hr (66.0mph)	106km/hr (66.0mph)	n.a.
	Power (kW)	480	6x120	130 kW x 4 (174 hp x 4)	131 kW x 4 (174 hp x 4)	478Kw x 2
	Power feed	750 V dc	750 V dc	750 V dc	750 V dc	600 V dc
	Power source	overhead wire, ultracaps + batteries	overhead wire	overhead wire	overhead wire	overhead wire
Notes:	a. Euro-US Dollar conversion factors obtained from OECD: https://data.oecd.org/conversion/exchange-rates.htm b. Alignment length divided by (n-1) stations. c. Calculated in constant value, base year 2018. d. The official count for Cleveland LRT stations is 34 (http://www.riderta.com/overview; retrieved 01/03/2018). However, for purposes of this study the ‘West Green’ and ‘Green Road’ stations are consolidated and analysed as a single station. Each accommodates boardings and alightings exclusively; and are positioned at opposite ends of the same park & ride facility, thus essentially functioning as a boarding-alighting node. Hence, the revised total number of stations is 33.					

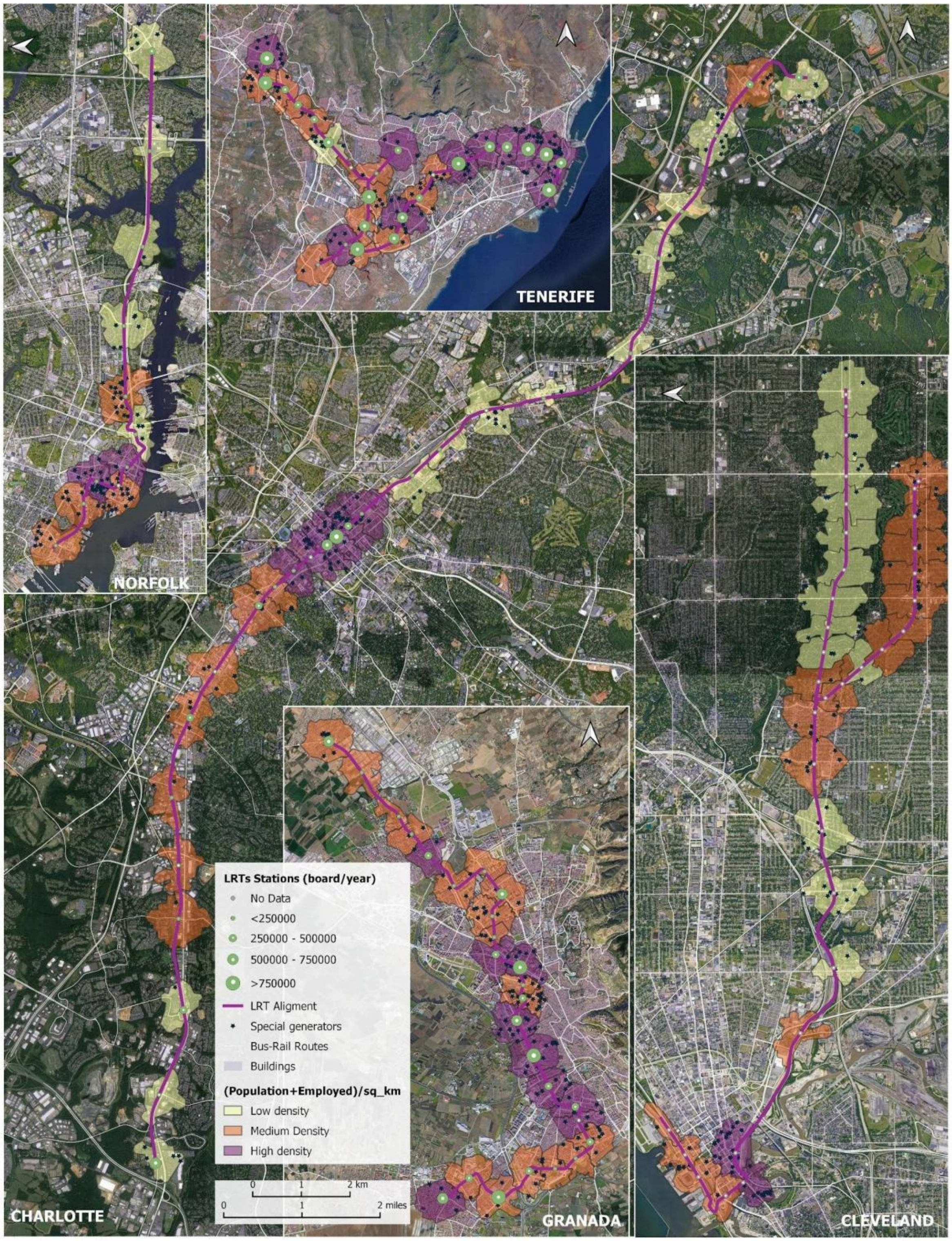


Figure 1 LRT Alignments, Stations, Annual Boardings, Special Generators, and Rail-Bus Networks

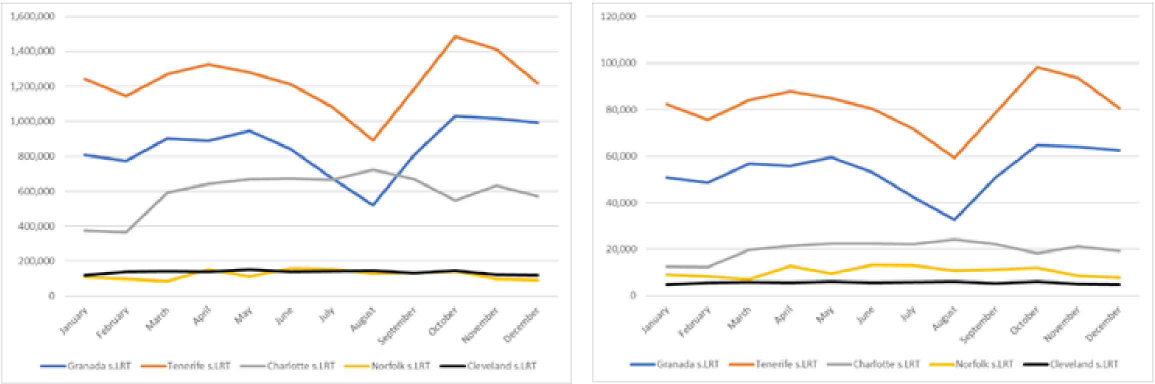


Figure 2 Monthly Ridership (left) and Monthly Ridership by Line Km (right) – CY 2018

Literature review and system ranking factors

In this part of the study, we identify in the specialised literature key factors associated with ridership and performance of transit systems, with emphasis on LRT.

Literature review on transit ridership determinants

Ridership is a key component of transit systems' performance indicators. Taylor and Fink (2003) organise transit ridership factors in two main categories: *external* factors outside direct control of transit planners and managers, such as land-use, built-environment factors, socio-demographics, among others; and *internal* factors, which are susceptible to influence by transit planners and managers, for instance service levels, fare, multimodal network connectivity and coordination, network alignment, right-of-way characteristics, among others. Most transit scholarship has emphasised the importance of socioeconomic factors (e.g., median household income; zero-car households; average access to vehicles) and built environment factors (e.g., land-use and urban design) as key external influences on ridership while acknowledging the critical roles played by internal factors such as fare and service level decisions (Brown & Thompson, 2012).

In general, research indicates that higher population and employment densities, more mixing of land use types, more walkable environments, lower levels of vehicle ownership, and lower unemployment rates are associated with higher numbers of transit trips (Sivakumaran, Lee, Cassidy, & Madanat, 2012; Iseki, Liu, & Knaap, 2018; Vergel-Tovar & Rodriguez, 2018). Researchers have also noted the significant influence of lower fares (Ramos-Santiago, Brown, & Nixon, 2015), more frequent service (Ramos-Santiago & Brown, 2016; Brown & Thompson, 2008), and better service coordination (Mees, 2009; Ramos-Santiago & Brown, 2016; Brown & Thompson, 2008) in promoting more transit usage. These results have been found at a variety of geographic scales using a variety of methodological approaches.

LRT-specific ridership and performance factors

Gordon and Willson (1984) was one of the first international LRT ridership determinants studies. It identified city density, gross national product, station spacing, per capita city automobile registrations, and the system's location in the United States or Eastern Block as significant factors in explaining passenger kilometres based on a total of 152 systems. The United States location dummy is still associated with lower ridership relative to Europe and Canada (Currie et al., 2011; Harris, 2020). Papa and Bertolini (2015) state that the average density in the city does not matter, “whereas the distribution of density relative to the railway network does”. Mackett and Sutcliffe (2003) identified several policies related to successful urban rail projects where most cases documented were LRT systems implemented in the last 20 years of the 20th century (n=8). Key factors related to physical and socio-economic characteristics of urban areas; route location; cost; operations; transport planning; and urban planning were identified as significant in explaining agencies achievement of five generally agreed key objectives: high patronage, build and operate the system cost-effectively, increase overall public transit patronage, reduce traffic congestion, decrease negative environmental externalities, and improve and guide land-use and growth patterns.

Station- and line-level direct-demand ridership models (DDM) have also been used to evaluate ridership factors for a variety of transit modes, including LRTs. Brinkerhoff P. Quade and Douglas Inc. (1996) and Kuby, Barranda and Upchurch (2004; n=268) find positive relationships between boardings and employment density within 800 meters of a station, the presence of park and ride facilities at a station, the number of connecting bus lines at a station, and the station's status as either a terminal or transfer station. The presence of special activity generators in proximity to transit stations has also been noted by Ramos-Santiago and Brown (2016), Foletta, Vanderkwaak, and Grandy (2013), and Zhao et al. (2014) as being strong and positively associated with more boardings. Furthermore, accounting for inter-station spacing has also resurfaced as having significant and strong influence in recent studies (Ramos-Santiago & Brown, 2016; Brinkerhoff P. Quade and Douglas Inc. 1996; Foletta et al., 2013).

On the other hand, a few key factors have consistently been associated with lower ridership. Higher average household automobile availability emerges as a significant deterrent of transit ridership (Ramos-Santiago & Brown, 2016; Chen & Zegras, 2016). This result should not be surprising as transit travel has been described as an inferior good in the urban mobility market in the United States (McLeod, Flannelly, Flannelly, & Behnke, 1991). Higher fare also results, as expected, in lower ridership levels (Ramos-Santiago et al., 2015; Ramos-Santiago & Brown, 2016).

A relatively recent route-level LRT ridership study (n=57) found the following explanatory variables highly significant in explaining boardings per route kilometre: vehicle trips per year, Europe, speed, employment density, share of track segregation, and integrated ticketing (Currie et al., 2011).

Harris (2020) also noted that in the United States urban transportation and land-use policies have been historically biased towards the automobile and suggests that some transit planning decisions are related to lower performance of LRT systems. For instance, alignment overextensions and route choices that are more “politically expedient than economically efficient”. This would include avoiding “dense walkable areas for ease of construction” (and lower costs) and running lines parallel to or within freeways rights-of-way that would result in less attractive and less developed pedestrian service areas.

Methods

In this study, descriptive and inferential statistics are documented and compared to analyse systems’ characteristics and contexts; calculate performance indicators; rank LRT systems; and identify key determinants. This framework mimics, adapts and improves on a previous study on the transportation performance of modern trams (streetcars) in the United States (Ramos-Santiago et al., 2015), here adapted to LRTs set of ridership and performance factors as found in the most recent literature (Mackett & Sutcliffe, 2003; Currie et al., 2011; Currie & Delbosc, 2013; Currie & De Gruyter, 2016; Ramos-Santiago & Brown, 2016; De Gruyter et al., 2020; Aston et al., 2021; among others).

Step 1: Identification and Measurement of Relevant Factors

Fourteen (14) factors were selected for assessment, based on the previous literature review, and these fall within three recurrent vectors of information in the study of transit ridership determinants and performance: socioeconomics (of users and/or service areas); land-use and built-environment characteristics; and transit service quality. These factors, their expected influence, justification, and sources are listed in **Table 4**.

Table 4: Performance Factors

Factor	Influence	Justification	Related Studies
Alignment Length	+	Network topology; network effect (geometrical growth of O-D pairs)	Ramos-Santiago et al., 2015
Alignment Type	+	Microeconomic utilitarian theory; more exclusive and semi-exclusive ROW allows for higher in-vehicle speed hence lower disutility for riders.	Currie et al., 2011; Crampton, 2002 (indirectly, travel time)
Population Covered	+	Transportation modelling theory; greater trip-generation potential	Sivakumaran, Lee, Cassidy, & Madanat, 2012; Iseki, Liu, & Knaap, 2018; Vergel-Tovar & Rodriguez, 2018; Papa and Bertolini, 2015; Crampton, 2002
Employment Covered	+	Transportation modelling theory; greater trip-attraction and trip-generation potential	Currie et al., 2011; Brinkerhoff P. Quade and Douglas Inc., 1996; Kuby, Barranda and Upchurch, 2004; Sivakumaran, Lee, Cassidy, & Madanat, 2012; Iseki, Liu, & Knaap, 2018; Vergel-Tovar & Rodriguez, 2018
Transit Connections	+	Transportation modelling theory + network effect; greater number of O-D pairs and larger service area usually results is higher ridership at main-trunk and network-level	Brinkerhoff P. Quade and Douglas Inc., 1996; Kuby, Barranda and Upchurch, 2004;
Avg. Num. Special Generators	+	Transportation modelling theory; above-average trip attractors, such as special cultural/sports venues; health care and research centres; regional commercial centres; etc.	Ramos-Santiago and Brown, 2016; Foletta, Vanderkwaak, and Grandy, 2013; Zhao et al., 2014;
Fare Level	-	Microeconomic utilitarian theory; higher fares would represent higher generalized travel costs, hence greater disutility to riders.	Brown & Thompson, 2012; Ramos-Santiago, Brown, & Nixon, 2015; Ramos-Santiago & Brown, 2016; Crampton, 2002

Transfer Policy (cost); 1/x	+	Microeconomic utilitarian theory; higher fares would represent higher generalized travel costs, hence greater disutility to riders.	Ramos-Santiago et al., 2015;
Headways (weekday-peak); 1/x	-	Microeconomic utilitarian theory; higher headways would represent higher wait times and greater generalized cost of travel, thus greater disutility to the rider. Research has shown that riders are two times more sensitive to wait-time (out-of-vehicle time) that to actual in-vehicle time.	Wardman, Hine, & Stradling, 2001; Brown & Thompson, 2012; Ramos-Santiago & Brown, 2016; Brown & Thompson, 2008; Crampton, 2002
Service Hours	+	Transportation modelling/accessibility theory; a wider service window can accommodate a greater potential number of trips and trip purposes during the day/night and increases overall accessibility.	Ramos-Santiago et al., 2015; Crampton, 2002
Seasonality	-	Transportation performance/economic theory; seasonality in aggregate trip behaviour, if not matched with adjustment in service provision could result in inefficiencies as result of mismatch between demand and supply .	Ramos-Santiago et al., 2015;
Freeway and/or Hwy km/Capita	-	Transportation economics; a community with a higher share of freeway and/or highway supply per capita would represent a more competitive travel market scenario for transit, especially in regions with higher income levels that correlate with higher automobile ownership and usage, and in communities with a bias towards automobility.	Chiou et al., 2015; Jun et al., 2015; Harris, 2020;
Freeway Access/Egress Ramps	-	Transportation economics and modelling theory; station service areas that accommodate freeway access/egress ramps sacrifice trip-producing areas (e.g., restriction on development) and introduce a strong incentive for automobile mobility by facilitating rapid access to main-trunk arterials. This effect would be accentuated in regions with higher automobile ownership and policy bias towards automobility.	Authors; Harris, 2020;

Avg. Num. Vehicle/Household	-	Transportation economics and modelling theory; a higher number of automobiles per household has been consistently shown to decrease the propensity for transit usage, and transit travel has been characterized as an inferior good in the metropolitan transportation market in various studies. Thus, regions with higher rates of automobile availability would register lower transit patronage, all else equal.	McLeod, Flannelly, Flannelly, & Behnke, 1991; Ramos-Santiago & Brown, 2016; Chen & Zegras, 2016; Sivakumaran, Lee, Cassidy, & Madanat, 2012; Iseki, Liu, & Knaap, 2018; Vergel-Tovar & Rodriguez, 2018; Manville, M., Taylor, B.D., Blumenberg, E. *et al.* (2022); Lee, Y., & Lee, B. (2022).

These factors were measured for each system and ranked according to their relative values and direction of influence on ridership and/or performance (**Table 5**). After ranking each factor (range: 1-5) a simple sum of raw scores is calculated for each system and totals compared. In addition, a more nuanced sum of factors' *z-scores* is also calculated for each system, and totals compared (**Table 5**, bottom). Z-score, also known as 'standard score', registers the location of a raw score in terms of its distance from the mean, measured in standard deviation units (**Equation 1**). This second approach more fairly represents the relative position among the cases as compared to the sum of raw scores.

Equation 1

$$z\_score\ sum = \sum_{n=1}^{n} \frac{x-\mu}{\sigma}$$

Where x equals the factor value or the performance indicator value; μ equals the sample mean; and σ the standard deviation.

Step 2: Performance Indicators and Z-Score Calculations

In the second step performance indicators related to the studied transit systems are collected. Best practice guidelines for transit performance evaluation identify several measures and indicators to be considered. These are generally categorised under three rubrics: general performance indicators, effectiveness measures, and efficiency measures (Ryus, 2003; FDOT, 2014). Based on data availability and data harmonisation constraints, the performance indicators selected for comparison of LRT systems in Spain and the United States are grouped in three general categories: *service consumption*, *cost-effectiveness*, and *service quality*. Specifically, the measures documented and calculated are annual ridership, service productivity, three measures of cost effectiveness, average speed, and frequency (**Table 6**). The sum of the relative rank of each system for each indicator is provided at the bottom of the table in two scales: 1) basic ordinal ranking sum; and 2) *z-score* sum. In both cases a higher rank sum score represents better overall performance.

Ranking results from Step-1 and Step-2 are then compared for overall visual and theoretical/empirical pattern matching as evidence of validity of the heuristic.

Step 3 Station-Level Regression Analysis: Identifying and Confirming Key Factors

The third and final step is a more disaggregate station-level analysis and relies on a mixed-effects generalised linear regression of key predictors onto average daily boardings. Due to the typical non-negative and highly skewed distribution of count measures the model is implemented with a negative-binomial form (ME-NBREG; **Equation 2, Appendix 1**). Information for the model is drawn from 4 of the 5 cases for which station-level ridership data was available (n=88). These are Charlotte (US), Norfolk (US), Tenerife (Spain), and Granada (Spain). The data for the model is grouped in cities, and it is posited that city-level contextual factors would also generate variance in the model. This is handled in the multilevel model by the categorical variable ‘City’ at Level-2.

This last step helps identify the most influential station-level factors that would contribute to ridership and performance differences. The analytical strategy focused on statistical significance, directionality, and relative size effect of explanatory variables (e.g., *IRR* incidence rate ratios from the ME-NBREG model; and standardised *beta* coefficients from the OLS model). Correspondence of highly significant and influential station-level factors with any regional clustering patterns identified in the preceding stages of analysis was then ascertained (where systems that operate in Spain (n=2) represent the cluster for Europe (region #1) and systems that operate in the United States (n=3) represent the cluster for North America (region #2)). *Beta* coefficients from the OLS regression were also used as weight in calculating and comparing ridership factors among systems (**Figures 7-8**, **Table 6**).

Equation 2 (mixed-effects random intercept model)

$$ln\, \mu_{ij} \ = (n_{ij} + \ e_{ij}) = \ \gamma_0 + \ \sum_{h=1}^{r} \gamma_h x_{hij} + \ R_{ij} + U_{0j}$$

Where:

$_i$ = indicates level-one unit (e.g., light-rail station)

$_j$ = indicates level-two unit (e.g., grouping: *City*)

μ_{ij} = expected number of average daily boardings at station *i* in City *j*

$(n_{ij} + \ e_{ij})$ = allows for random variation of the expected number of boardings (nbreg)

γ_0 = average intercept

γ_h = coefficient vector

x_{hij} = explanatory variable

R_{ij} = level-one residuals

U_{0j} = level-two residuals (group effects)

Results and Discussion

Context: Urban Agglomeration and City-Level Built Environment and Socioeconomic Characteristics

Cities are open, complex systems characterised by multi-scalar and multi-temporal interactions. These occur along socioeconomic, built- and natural-environment, political-economy, cultural, policy, and technological vectors that may evolve at different timescales (Bettencourt, 2015). Transportation, land-use systems, and community-wide travel patterns influence each other in complex ways, and studies that focus on smaller spatial and functional urban units need to recognize and consider higher-order influences (Næss, 2012). It is with this understanding that the metropolitan contexts in which the five LRT cases operate are discussed and characterised.

As noted in **Table 1** (top) the three LRT systems in the United States, namely Charlotte, Cleveland, and Norfolk operate within metropolitan contexts that register higher median household income levels, greater availability of automobiles per household, and reflect modal shares (one-way commute) typical of what Newman and Kenworthy (1999) characterise as automobile-dependent communities.

These three urban agglomerations also reflect a much larger footprint and generally less dense along population and/or employment vectors as compared to the two Spanish metropolitan regions of Granada and Santa Cruz de Tenerife. This results in greater average distances between origins and potential destinations and a more convenient landscape for automobility than walking and transit (e.g., first-mile last-mile problem). This set of metropolitan characteristics increases the propensity of travel by car.

In contrast, the metropolitan and city areas of Granada and Santa Cruz de Tenerife are characterised by more compact metropolitan and city footprints, as well as higher rates of mix of uses with similar employment densities and superior population densities, when compared to the three cases in the United States. They also reflect lower automobile availability, lower median household incomes, and more balanced commute modal shares in which walking to work and transit commute register notably larger percentages as compared to the cases in the United States (**Table 1**). These spatial, travel, and socioeconomic characteristics are in part related to a landscape where origins and destinations are, on average, closer in proximity and where the urban footprint seems to be more pedestrian- and transit-friendly.

Although these results are not surprising, but rather expected in North American and European contexts, it is important to recognize the distinct nature of the metropolitan and city contexts in which the five LRT cases were implemented, as these are posited to influence ridership and performance outcomes. For example, higher income levels have been correlated with higher automobile availability; and this in turn has been associated with more frequent and longer trips by car and lower transit patronage (Newman & Kenworthy, 1999; Taylor & Fink, 2003; Ewing & Cervero, 2010; Shay & Khattak, 2012). And higher metropolitan and city-wide densities have been correlated with higher walking and transit habits (Shay & Khattak, 2012; Zhang et al., 2012). These larger-scale contextual influences would be captured in part by the latent construct ‘City’ in the mixed-effects model implemented in Step 3.

Factor and Performance Results and Comparison

The matrix of ridership and performance factors (**Table 5**) allow us to identify, compare, and assess which internal and/or external factors might help explain the differences in patronage and performance. **Table 6** registers system performance indicators and corresponding z-scores. The two systems from Spain registered the highest overall performance score, with the system from Tenerife reporting the highest levels for ridership, service productivity, three cost effectiveness indicators, farebox recovery, and service level. This is six out of a total of nine performance factors. Granada, Charlotte, Cleveland, and Norfolk follow in decreasing ranking order. Granada's LRT system (which opened to service 10 years later than Tenerife) registers the second-best overall performance score, annual ridership, farebox recovery, and cost-per-trip figures; Charlotte's light-rail registers the third overall performance score and best ranking and performance indicators for the United States case systems.

In general, the two Spanish LRT systems report the highest ridership and service productivity figures by almost a factor of two and three, respectively, as compared with the United States LRT systems. Tenerife and Granada LRTs also register notably better cost-effectiveness indicators, particularly cost-per-trip, and farebox recovery rates.

Table 5: Factor matrix and factor ranking total

		Spain		United States		
Factors	*unit*	**Granada**	**Tenerife**	**Charlotte**	**Norfolk**	**Cleveland**
Alignment Length	*km*	15.9	15.1	29.93	11.81	24.62
rank	***[1-5]*** *(z-score)*	***3*** *(-0.366)*	***2*** *(-0.485)*	***5*** *(1.718)*	***1*** *(-0.974)*	***4*** *(0.929)*
Alignment Type[a]	*Class (A+B) + C*	200.00	197.00	200.00	165.70	200.00
rank	***[1-5]*** *(z-score)*	***3*** *(0.591)*	***2*** *(0.369)*	***3*** *(0.591)*	***1*** *(-1.955)*	***3*** *(0.591)*
Population Covered[b]	*Count; dist=600m*	137,402	116,485	23,552	12,483	34,066
rank	***[1-5]*** *(z-score)*	***5*** *(1.814)*	***4*** *(1.409)*	***2*** *(-0.391)*	***1*** *(-0.606)*	***3*** *(-0.188)*
Employment Covered[b]	*Count; dist=600m*	32,413	64,688	98,871	38,232	45,467
rank	***[1-5]*** *(z-score)*	***1*** *(-0.791)*	***4*** *(0.550)*	***5*** *(1.970)*	***2*** *(-0.549)*	***3*** *(-0.248)*
Transit Connections	*Sum of bus + passenger rail line connections at stations*	268	298	195	36	29
rank	***[1-5]*** *(z-score)*	***4*** *(1.244)*	***5*** *(1.481)*	***3*** *(0.669)*	***2*** *(-0.585)*	***1*** *(-0.640)*
Avg. Special Generators per Station	*Count/stations*	*4.8* 125/26	*5.4* 135/25	*4.1* 107/26	*9.2* 101/11	*3.75* 124/33
rank	***[1-5]*** *(z-score)*	***3*** *(-0.185)*	***4*** *(0.121)*	***2*** *(-0.542)*	***5*** *(2.060)*	***1*** *(-0.720)*
Fare Level[c]	*per ride, per day- €*	€1.35 ride €4.50 day pass	€1.35 ride No day pass	€1.86 ride €5.59 day pass	€1.69 ride €3.81 day pass	€2.12 ride €4.66 day pass
	per ride, per day- $	$1.59 ride $5.31 day pass	$1.59 ride No day pass	$2.20 ride $6.60 day pass	$2.00 ride $4.50 day pass	$2.50 ride $5.50 day pass
rank	***[1-5]*** *(z-score)*	***5*** *(0.999)*	***4*** *(0.999)*	***2*** *(-0.713)*	***3*** *(-0.142)*	***1*** *(-1.585)*
Transfer Policy	*free transfer*	Free transfer (60 minutes)	Free transfer (45-120 minutes)	Free transfer (local bus; 90 minutes)/ $0.80 (express) $2.20 (express plus) $1.30 (community shuttle)	Free unlimited transfer requires purchase of 1-day GoPASS ($4.50)	5-trip fare card ($12.50) allows for free transfer (2-1/2 hour)/ time-based fares (all-day, 7-day, monthly) allow for unlimited transfers/ cash: full-fare on each trip/mode
rank	***[1-5]*** *(z-score)*	***4*** *(0.986)*	***5*** *(1.693)*	***3*** *(0.279)*	***2*** *(-0.428)*	***1*** *(-1.135)*
Headway (weekday-peak)	*minutes*	8	5	10	10	17.42
rank	***[1-5]*** *(z-score)*	***4*** *(0.318)*	***5*** *(1.050)*	***3*** *(-0.170)*	***3*** *(-0.170)*	***2*** *(-1.980)*
Service Hours	*hours*	16.5	18	20.5	17	19.8[d]
rank	***[1-5]*** *(z-score)*	***1*** *(-1.154)*	***3*** *(-0.189)*	***5*** *(1.418)*	***2*** *(-0.832)*	***4*** *(0.968)*
Seasonality	*yes/no*	yes	yes	no	no	no
rank	***[0,1]*** *(n.a.)*	***0***	***0***	***1***	***1***	***1***
Freeway + Highway km per capita within the LRT service area.[e]	*km/1000hab*	0.37 50.4 km 137,402 hab	0.26 30 km 116,485 hab	2.48 58.3 km 25,552 hab	2.27 28.3 km 12,483 hab	1.10 37.6 km 34,066 hab
rank	***[1-5]*** *(z-score)*	***4*** *(0.572)*	***5*** *(0.690)*	***1*** *(-1.698)*	***2*** *(-1.472)*	***3*** *(-0.213)*
Freeway Access/Egress Ramps within LRT Service Area (600m).	*count/stations*	1.77/station 46/26	3.36/station 84/25	0.92/station 24/26	5.54/station 61/11	0.63/station 22/35
rank	***[1-5]*** *(z-score)*	***3*** *(0.019)*	***2*** *(-0.857)*	***4*** *(0.487)*	***1*** *(-2.057)*	***5*** *(0.646)*
Automobile availability per household (600m)[f]	*avg. number of vehicles/hh*	*1.21*	1.36	1.99 (weighted) 2.27 (mean)	2.02 (weighted) 2.12 (mean)	1.76 (weighted) 1.93 (mean)
rank	***[1-5]*** *(z-score)*	***5*** *(1.289)*	***4*** *(0.833)*	***2*** *(-1.083)*	***1*** *(-1.174)*	***3*** *(-0.384)*
TOTAL[g]:		**45**	**49**	**41**	**27**	**35**
Z-score Sum[h]		5.336	7.664	2.535	-8.887	-3.959
Notes:	a. Class A and B: w=2, Class C: w=1; score=(%Ax2) + (%Bx2) + (%Cx1) b. 500m is the standard station service-area parameter for LRT systems in Spain and Europe, whilst 800m is mostly used in the United States for fixed rail systems. 400m is also considered in some studies. For this study the authors agreed on 600m as an intermediate parameter for all cases.					

	c. Euro-US Dollar market exchange value (MEV) conversion factors obtained from OECD: https://data.oecd.org/conversion/exchange-rates.htm d. 21.5 Blue/Green, 11.5 Waterfront. e. OSM equivalent: Motorway + Trunk + Primary f. For the three systems in the United States: weighted sum of averages based on census tract area proportions under station service areas (d=600m). g. A higher factor-ranking total is interpreted as having a more positive influence on ridership and performance outcomes. h. Z-score sum in this table does not include the 'Seasonality' factor as it is non-ordinal binary; see Equation 1.

Table 6: Key performance indicators and performance rank score - cy 2018

			Spain		United States		
		unit	**Granada**	**Tenerife**	**Charlotte**	**Norfolk**	**Cleveland**
Service Consumption	Annual Ridership	*person-trips*	10,205,446	14,757,687	7,123,618 [a]	1,461,451	1,624,634
	rank	***[1-5]*** *(z-score)*	***4*** *(0.681)*	***5*** *(1.659)*	***3*** *(0.019)*	***1*** *(-1.198)*	***2*** *(-1.160)*
	Service Productivity [b]	*pkm/vkm*	n.a.	39.70	[16.47-17.82] [c]	12.86	14.04
	New LRT patrons who previously relied on automobile for the same trip [b, d]	*%*	29.3%	22.2%	62.0% [e]	n.a.	n.a.
Cost Effectiveness	Operational Cost by Trip [f]	*€/per trip*	€1.30 ($1.53) [g, h]	€0.92 ($1.08) [g]	€3.13 ($3.69)	€6.35 ($7.49)	€6.27 ($7.40)
	rank	***[1-5]*** *(z-score)*	***4*** *(1.074)*	***5*** *(1.252)*	***3*** *(0.217)*	***1*** *(-1.290)*	***2*** *(-1.253)*
	Operational Cost by vkm [f]	*€/vkm*	€11.32 ($13.37)	€9.22 ($10.88)	€15.73 ($18.57)	€14.42 ($17.02)	€9.40 ($11.10)
	rank	***[1-5]*** *(z-score)*	***3*** *(0.290)*	***5*** *(1.163)*	***1*** *(-1.543)*	***2*** *(-0.999)*	***4*** *(1.088)*
	Farebox Recovery	*%*	63.64%	100.00% [i]	18.60%	14.75%	22.71%
	rank	***[1-5]*** *(z-score)*	***4*** *(0.800)*	***5*** *(1.768)*	***2*** *(-0.859)*	***1*** *(-0.983)*	***3*** *(-0.726)*
Service Quality	Average Speed	*rkm/rh*	20.6	21.3	25.08	21.03	21.76
	rank	***[1-5]*** *(z-score)*	***1*** *(-0.923)*	***3*** *(-0.446)*	***5*** *(2.130)*	***2*** *(-0.630)*	***4*** *(-0.132)*
	Headway (peak/non-peak)	*minutes*	8 / 10-15	5 / 7.5-15	10 / 15	10 / 15-30	10-20 (17.43) [j] 15-30 (27.19) [j]
	rank	***[1-5]*** *(z-score)*	***4*** *(0.515)*	***5*** *(1.724)*	***3*** *(-0.765)*	***2*** *(-1.476)*	***1*** *(0.001)*
	Customer Satisfaction [b]	*survey review rate*	8.3 / 10.0	8.13 / 10.0	9.6 / 10.0	n.a.	8.5 / 10.0
	Rank Sum [k]	*total*	**20**	**28**	**17**	**9**	**16**
	Z-score [l] *Sum*		*2.44*	*7.12*	*-0.80*	*-6.58*	*-2.18*
Notes:	a. 12-month CY 2018 aggregate. Source: NTD-FTA Monthly module UPT (unlinked passenger trips), database 2002-2019 Raw Monthly Report. b. Not ranked; indicator not available for one or more systems. c. Range estimates are based on average PM/trip from year 2017 and 2018, respectively; source: iNTD-URBAN. Source for VKM: NTD-FTA April 2002-2019 Monthly Raw Database CY 2018. d. Based on post-implementation survey estimates. e. 2008 LYNX Rider Survey, Final Report March 2009. Conducted by 'MarketWise' (MW#100802-1) f. Euro-US Dollar conversion factors obtained from OECD: https://data.oecd.org/conversion/exchange-rates.htm g. Not considering amortization costs. h. Estimation based on request for bid budgets. It does not consider the cost decreases on tender processes. i. Considering operation and maintenance costs, but not infrastructure construction debt payment. j. Value in parenthesis represents the headway weighted sum based on the proportion of stations per line (Waterfront, Blue, and Green lines). k. A higher rank sum score is interpreted as having a better overall performance. l. Describes the position of a raw score in terms of its distance from the mean; see Equation 1.						

Key LRT Ridership and Performance Determinants: Discussion

As explained before, **Table 5** registers measures and relative ranking of key internal and external factors that have been found to influence transit and LRT patronage and performance. After the analysis performed, we highlight five system-wide factors that stand out as likely culprits that would explain the notable differences in ridership, cost-effectiveness, and overall transportation performance.

1. Population and employment levels and densities

Population levels within light rail corridors are drastically different in Spain and the United States. The difference is close to a factor of six with Spanish LRT service areas accommodating larger volumes of people. Differences in trip generation potential would then partly explain differences in patronage and performance; and these are the result of the distinct demographic and built-environment conditions as determined by historical, cultural, as well as regulatory factors in both regions (**Figure 3**; Walters, 2007). It is important to note that the metropolitan population of two cities in the United States is notably larger than in the Spanish cities. Yet, population *densities* within LRT service areas are notably in favour of Tenerife and Granada (**Tables 1, 5** and **Figures 1, 3-4**).

Figure 3 presents aerial images of service areas from the five cases. Distinct urban-morphological and architectural-typological patterns are evident in the two regions. In the LRT cases from the United States (n=3) most stations exhibit lower-density single-family residential and/or industrial contexts, and their higher-density service areas are dominated by high-rise commercial buildings intermixed with older traditional building typologies as well as surface parking and parking garages. More workers than residents tend to populate these central areas in

United States cities (**Table 1, Figure 4**). Charlotte, however, registers a higher number of service areas with medium densities that manifest in 4-5 storied mid-rise residential buildings with some commercial areas at ground level. This could partly explain Charlotte's LRT higher performance results compared to Cleveland and Norfolk.

Figure 3 Population + Employment High-, Medium-, and Low-Density LRT Station Area Aerial Images (source: Google Maps, 2020 [online] [Access 10 October 2020])

It is important to note that employment levels at the larger city-level in Spanish and United States cities also report notable differences in magnitude, in favour of the United States. That is, the levels of employment in two of the three United States cities where LRT systems operate are higher than in the two Spanish cities; and both higher employment levels and the larger size of metropolitan regions have been associated with higher transit patronage and performance. However, the employment density within Spanish and United States LRT stations' service areas are similar and do not exhibit the drastic differences noted for population. This reduces the potential of higher city-level employment levels in the United States to compensate for less intense population levels at stations' service areas (**Table 1, 5** and **Figure 1, 4-6**).

Figure 1 shows how the 600m service areas with higher population and employment density levels are concentrated in small segments of the Cleveland and Norfolk networks, while the Granada and Tenerife lines have a notably larger spread. These characteristics may be the essential factors to boost patronage in Spanish systems in comparison to those in the United States. A more disaggregated station-level multivariate study allows for a more nuanced assessment of the relative influence these factors as compared to other determinants. This approach was implemented and discussed in a subsequent section in this paper.

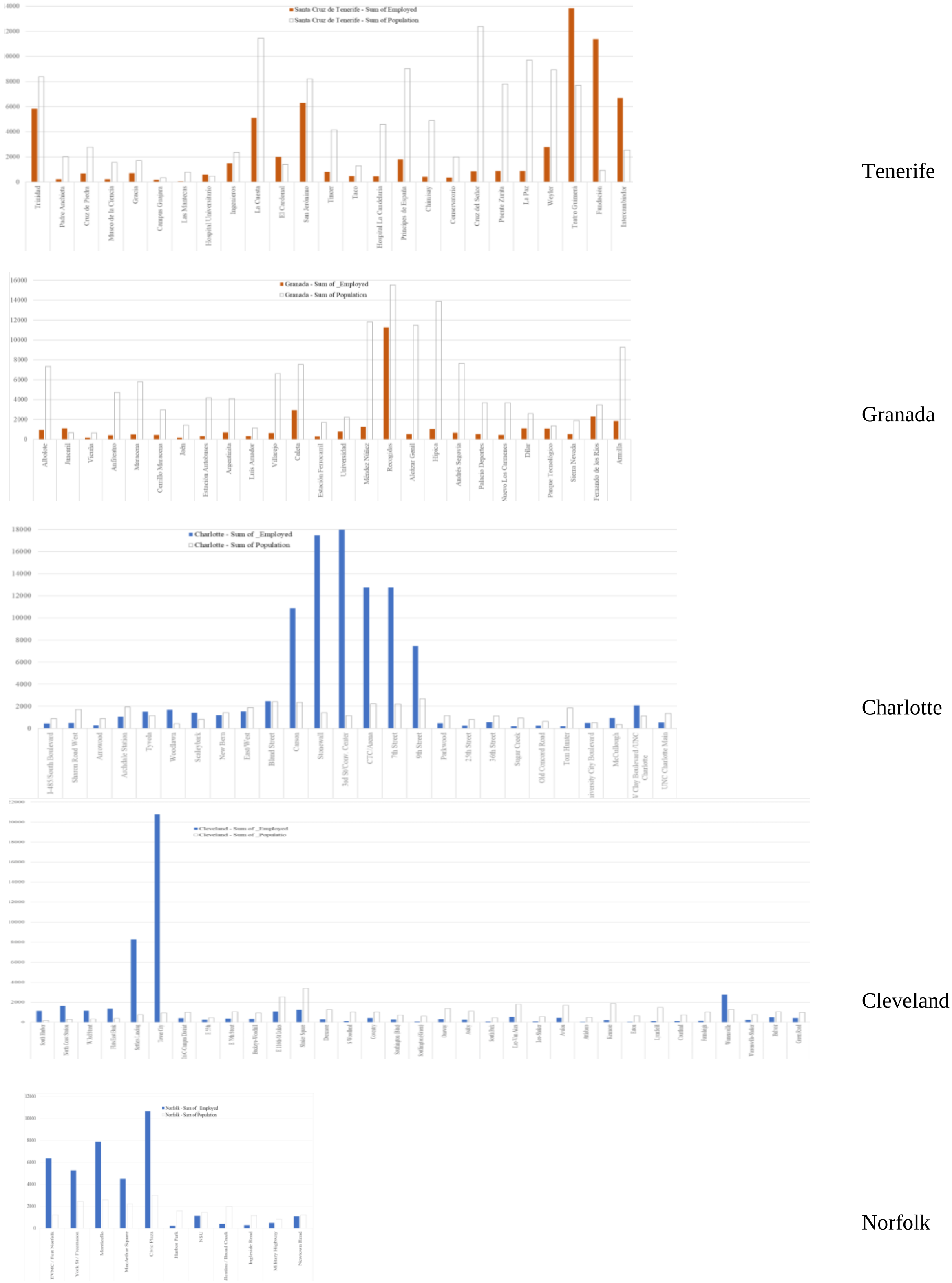
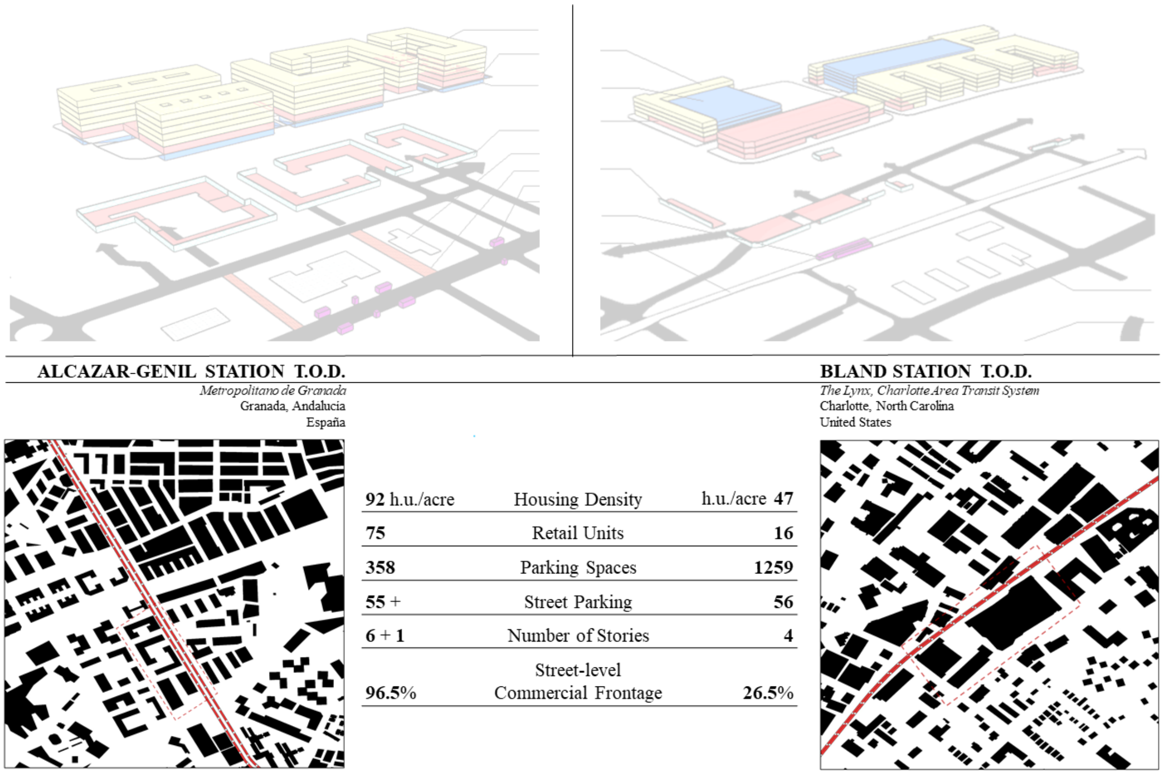


Figure 4 Employment Centres and Sub-Centres Along LRT Alignments by City and Station (Population levels are shown with non-coloured bars)

An analysis of urban-morphological and architectural-typological characteristics of two representative Transit Oriented Developments (TOD), one in Granada (Spain) and the other in Charlotte (United States), although not fully generalizable, reveals important differences in development characteristics that could impact transit ridership and performance. For example, housing density and percent of commercial frontage at street-level are notably lower in Charlotte's example; block size, often used as a proxy for street network connectivity and pedestrian-friendliness also tends to be larger in Charlotte's example; and the number of assigned off-street parking spaces is more than 3-times that provided in the Granada TOD (**Figure 5**). A cursory inspection of other developments around LRT stations in both cities suggests this is a recurrent architectural-typological pattern of TODs, although a more systematic and comprehensive assessment is warranted. As noted in previous studies these relative differences in urban design and architectural-typological characteristics would likely discourage more transit ridership (see Chatman, D.G., 2013; Ewing & Cervero, 2010; Ewing et al., 2015; Litman, 2017a, b).



92 h.u./acre	Housing Density	h.u./acre **47**
75	Retail Units	**16**
358	Parking Spaces	**1259**
55 +	Street Parking	**56**
6 + 1	Number of Stories	**4**
96.5%	Street-level Commercial Frontage	**26.5%**

Figure 5 Characteristics of two TOD examples in Granada (left) and Charlotte (right)

Also worth noting is that the LRT station service areas in the two Spanish LRT systems accommodate a similar number of workers and a notably greater number of residents as compared to the United States systems (**Table 1, Figure 4-6**). These densities have greater trip-producing potential and would allow their LRT systems to cater to a more diverse set of trip purposes (beyond commute) and sustain a greater number of activities and special trip generators (such as schools).

Furthermore, it is important to note that population densities registered for LRT stations in the three United States cases fall substantially below a cost-effectiveness minimum threshold, as defined by Guerra & Cervero (2016) for LRT systems in the United States. Guerra & Cervero's study, based on 33 LRT systems and 254 stations, concluded that the average light-rail system in an average light-rail city needs at least 30 people per gross acre to achieve high cost-effectiveness ranking.

In 2018 the mean population density within LRT stations in Charlotte, Norfolk, and Cleveland were 5.7, 7.2, and 7.3 persons per gross acre, respectively (see **Figure 6**). We estimated the minimum population density required for high cost-effectiveness for each of these three systems based on their per mile capital costs and using data points from the Guerra & Cervero (2016) paper to generate a basic linear model. The linearly extrapolated results indicate that the minimum population densities required for these three systems are 68.26 persons per acre in Charlotte, 30.45 persons per acre in Norfolk, and 22.85 persons per acre in Cleveland (data available for Waterfront Line only). Current population densities in these three cities are still far from desirable cost-effectiveness levels.

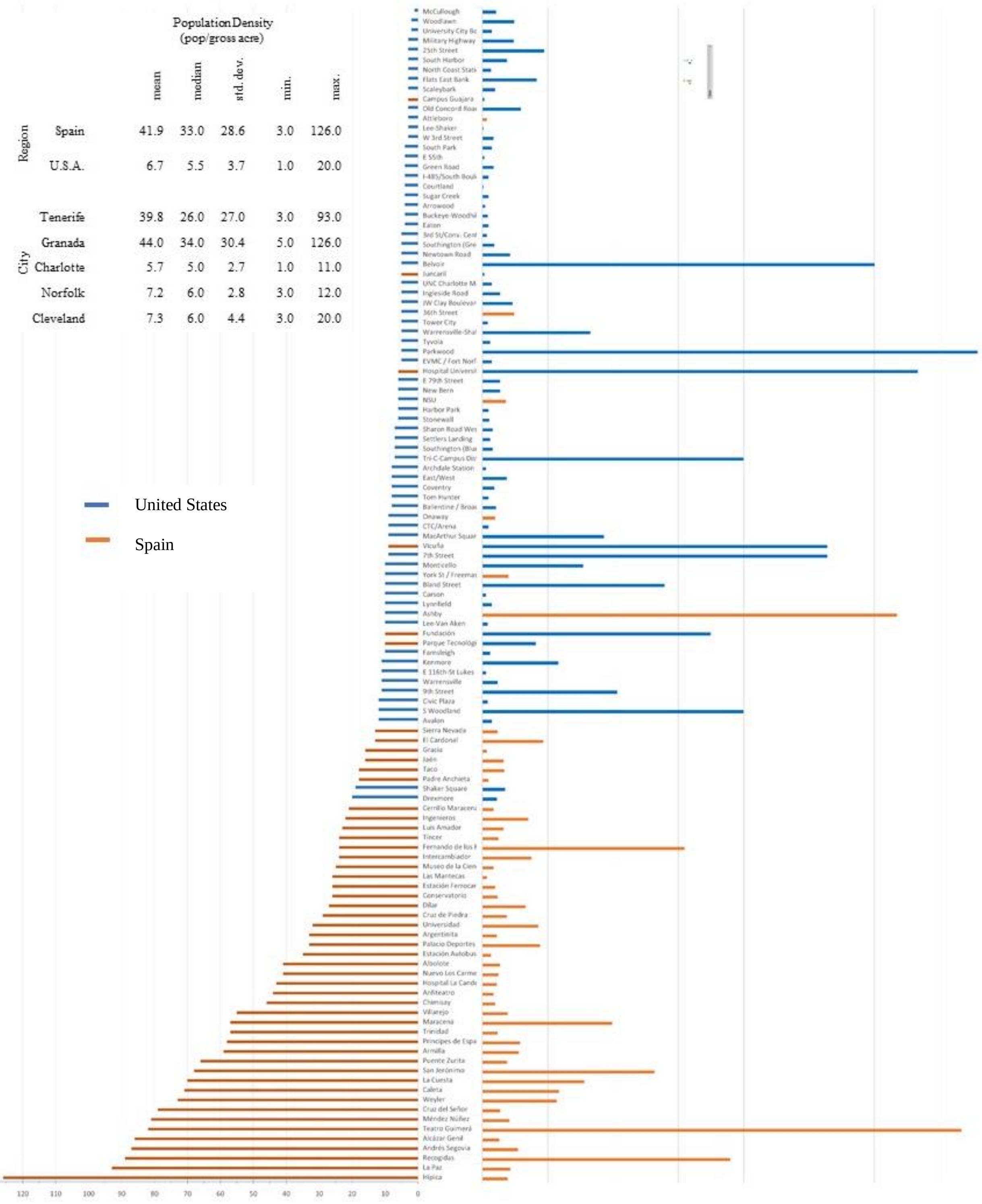
2. LRT route alignment and metropolitan structure

LRT route alignment and linkage to metropolitan nodes is another salient distinction between LRT cases in Spain and the United States (**Figure 1, Figure 4**). The three cases in the United States exhibit centre-focused (CBD) alignments, where non-CBD terminals are typically characterised by lower density areas often accommodating large automobile parking lots for a dominant commuter market. In Granada and Tenerife, the alignments not only link main historical city centres but also other urban sub-centres and/or industrial polygons at or near terminal stations. For example, the *Albolote, Juncaril*, and *Armilla* stations in Granada; and the *Trinidad* station in San Cristobal de La Laguna and *Teatro Guimerá* and *Fundación* stations in Santa Cruz de Tenerife.

These two Spanish LRT examples cater to urban sub-centres on opposite ends of the line, which accommodate important trip attractors and special generators (**Figure 1, Figure 5**). The coupling of LRT alignment and metropolitan sub-centres in Granada and Tenerife increases metropolitan connectivity and accessibility to key activity nodes and gives the two LRT systems in Spain an advantage when compared to the three LRT cases in the United States. It encourages more balanced bi-directional trip flows during their operational windows that would improve vehicle occupancy rates and passenger-vehicle kilometres. In addition, the count and intensity of special generators report an advantage in Granada and Tenerife.

3. Multimodal transit network connectivity

The total number of bus and passenger rail line connections at LRT stations in Tenerife and Granada are notably higher than those for Charlotte and Norfolk (**Table 5**). Transit research has consistently evinced the positive role of bus-rail integration (Ramos-Santiago, 2021) and inter-city and metropolitan lines integration at regional hubs for promoting greater accessibility, ridership, and system-wide efficiency.



		Population Density (pop/gross acre)				
		mean	median	std. dev.	min.	max.
Region	Spain	41.9	33.0	28.6	3.0	126.0
	U.S.A.	6.7	5.5	3.7	1.0	20.0
City	Tenerife	39.8	26.0	27.0	3.0	93.0
	Granada	44.0	34.0	30.4	5.0	126.0
	Charlotte	5.7	5.0	2.7	1.0	11.0
	Norfolk	7.2	6.0	2.8	3.0	12.0
	Cleveland	7.3	6.0	4.4	3.0	20.0

Figure 6 LRT Stations' Pedshed Population Density (left) and Employment Density (right) by Region (table), City (table), and Station (figure)

4. Lower fare levels and less restrictive transfer policies

Lower fares and transfer policies are also more convenient for users of LRT in Tenerife and Granada as compared to those in Charlotte, Norfolk, and Cleveland. Higher fares and more restrictive transfer policies have consistently been shown to increase the generalised travel cost of transit users and possibly play a role in the lower ridership and performance outcomes in the United States systems. It is important to note that in Spain it is the public jurisdiction that politically establishes fare levels, not the transit agency. In this research fare levels have been considered by their absolute value. Nevertheless, when comparing fare levels, it may be advisable to consider the relation between fare levels and the average income level of the served zone. The income level by served zone data was not available in this study, but this will be considered in future research.

5. Service levels

Service levels (e.g., number of trips per day, headway) on average also register more convenient figures for users in Tenerife and Granada, considering the extended weekend service hours, shorter weekday off-peak headways, and generally competitive and shorter weekday peak headways (**Table 2**); all of which seems bespoke and to better serve diverse local travel demand patterns.

Other Citywide relevant factors

Other factors to consider include level of motorization (automobile availability); with United States cases registering, as expected, higher ratios. Likewise, the supply of automobile-oriented infrastructure in the form of freeway and highway Km per inhabitant is higher in the United

States. This represents a more competitive metropolitan travel market for LRTs in the United States, which can explain in part their lower transit patronage and performance.

Finally, the ranking order based on general performance indicators (**Table 6, Figure 7**) mimics that of the ridership factors matrix (**Table 5, Figure 7-8**), which gives credence to evidence found in the literature and suggests the method elaborated in this paper is a useful heuristic for comparative assessments.

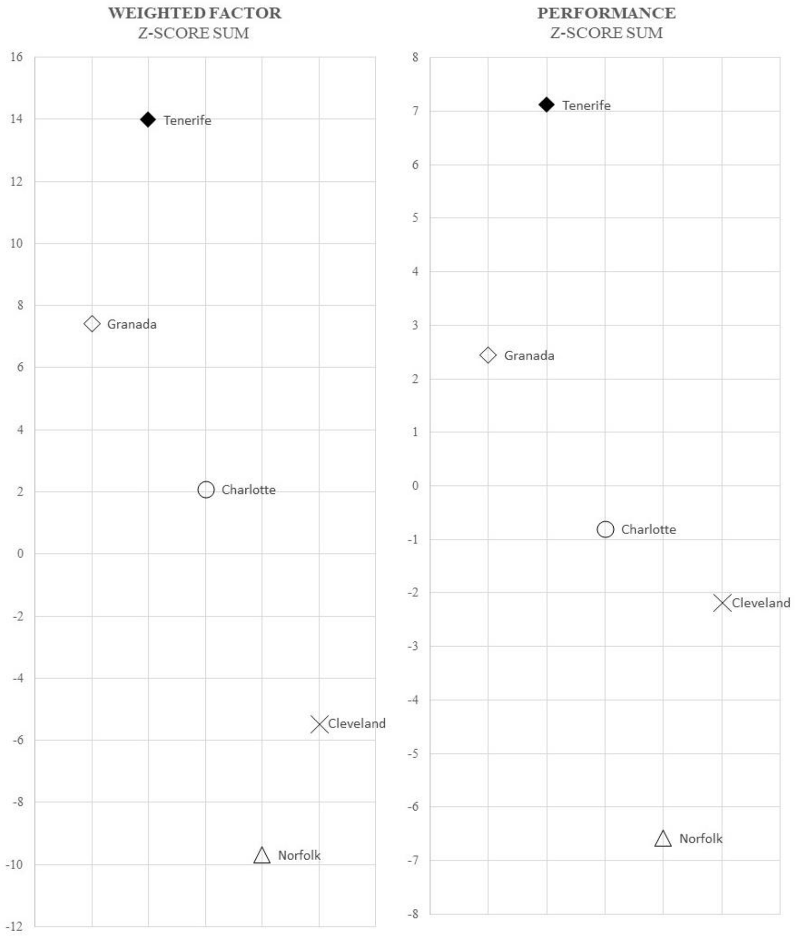


Figure 7 Weighted Factor Z-Score Sum (left) and Performance Indicators Z-Score Sum (right)

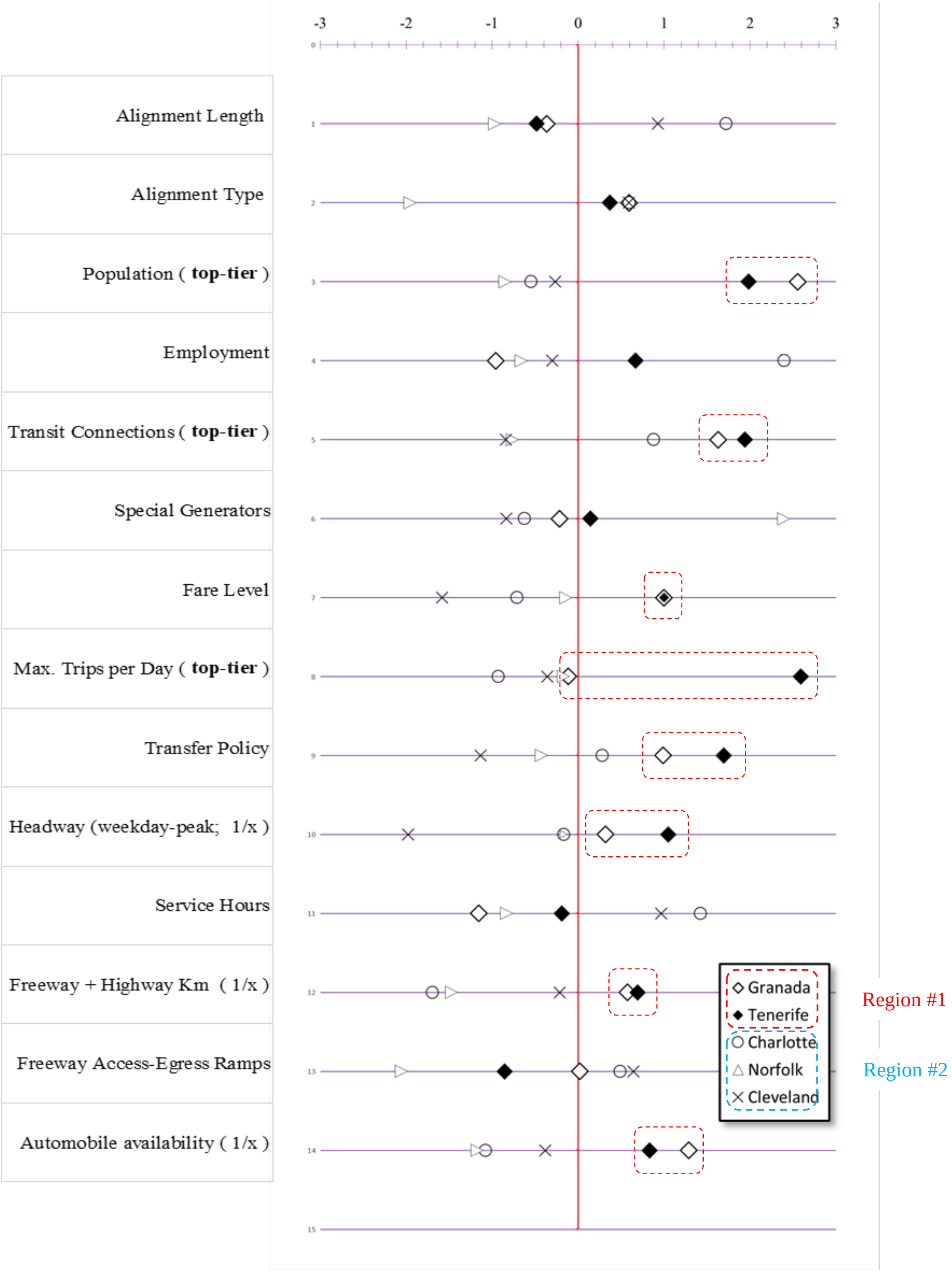


Figure 8 Weighted Z-Score Diagram of Factors for LRT Cases in Charlotte, Cleveland, Granada, Norfolk, and Tenerife.

Station-Level Regression Results and Insights: Confirming and Gaging the Relative Importance of Key Factors

Models fit statistics, residual plots, and predicted-vs-observed scatter plots were assessed and reflect a general good fit. Most of the variance is explained by the specified predictors, and multilevel treatment based on ‘City’ data grouping improves fit. Because of high multicollinearity some predictors were not included in the final models, and only the most statistically significant and/or those with theoretical relevance were kept in final models. Three extreme outliers (SD>2.5) were removed from the models. Comparative fit statistics AIC/BIC indicate that the ME-NBREG model fits the data better, and our analysis and discussions are based for the most part on its results. Yet, we still considered VIF statistics and standardized *Beta* coefficients from the OLS regression for assessment of predictors relative influence on the outcome (**Table 7, Appendix 1**). Incidence rate ratios (IRR) from the ME-NBREG model are interpreted as semi-elasticities.

For the most part, except for one variable, ME-NBREG results are consistent with precedent transit ridership and performance literature. Populations levels, employment levels, transit service levels, multimodal connectivity, number of parking spaces at station, number of special generators, and key station topological features (Terminal) all register highly significant ($p<0.001$) or significant ($p<0.05$) positive associations with average daily boardings. Only one variable, ‘Centrality’, registers a non-significant association and sign that is opposite of that reported in a precedent LRT ridership study based on United States cases (see Kuby et al., 2004).

Table 7: ME-NBREG Model and OLS Model Regression Results

	ME-NBREG			**OLS** [b]			
Avg. Daily Boardings	IRR [a]	*p*	*sig*	Coef.	*Beta* [c]	*p*	*sig*
Fixed-effects:							
Population (1000s)	1.090	*0.000*	***	98.728	$\boxed{0.409}$	*0.000*	***
Employment (1000s)	1.029	*0.056*	*	47.690	0.214	*0.006*	***
Multimodal Connectivity	1.020	*0.000*	***	21.081	$\boxed{0.309}$	*0.000*	***
LRT Vehicles/Day	1.005	*0.000*	***	3.202	$\boxed{0.374}$	*0.000*	***
Centrality (scaled)	1.645	*0.184*		31.129	0.006	*0.941*	
Terminal	2.700	*0.000*	***	732.355	0.268	*0.001*	***
Special Generators	1.050	*0.000*	***	31.199	0.160	*0.036*	**
Number of Parking Spaces	1.001	*0.027*	**	0.692	0.193	*0.016*	**
Random-effects:							
	var	*std err*	*95% C.I.*	*na*	*na*	*na*	*na*
City', var (cons)	0.204	0.163	[0.043-0.973]	*na*	*na*	*na*	*na*

Indicates top-tier Beta: $\boxed{\#.\#\#\#}$

Model Fit:			
N:	85	N:	85
(fixed-effects) Pseudo-R^2 :	0.654	R^2 :	0.661
(full effects: fixed + random):	0.719	Adj. R^2 :	0.626
AIC :	1253.127	AIC :	1320.028
BIC :	1279.996	BIC :	1342.011

Notes *a*: *Incidence Rate Ratio are interpreted as semi-elasticities*
b: *Dependent variable log-transformed in OLS model*
c: *Standardized coefficients used to compare relative strength of predictors*

‘Centrality’ is often defined as a normalized measure of the travel time from a station to all others in a network, and often registers a negative sign as related to boardings in US systems. This variable does not register high correlation with other predictors in the model. We posit that this negative association with ridership reflects on a typical metropolitan structure found in most United States cities that feature a strong city centre (e.g., CBD, Downtown) and a less developed suburban periphery. In those settings, most transit systems and first phases of LRT implementation accommodate this still important node and to a dominant commuter market, which results in alignments where LRT line terminals are often located in less developed peripheral city areas. Terminals, by virtue of their location in the network, tend to register the highest Centrality values (farther away relative to all other stations), and often report lower relative boarding levels after controlling for bus connectivity, dedicated parking supply, and other relevant controls. Hence, the negative association found in studies based on United States systems.

In Granada and Tenerife, the metropolitan land-use structure and local built-environment around terminals is more diverse and distinct from those in Charlotte, Cleveland, and Norfolk. As discussed, terminals and adjacent stations in the two Spanish cases cater to sub-centres with higher population and/or employment levels as compared to the United States cases, and more often register higher boardings. These conditions in the two Spanish systems appear to dampen the highly significant negative association found in United States LRT systems and result in a non-significant and positive ‘Centrality’ coefficient in this study.

Highly influential station-level factors, defined in this study as top-tier (*Beta* ≥ 0.30) with highly significant coefficients are: *population levels*, *multimodal connectivity*, and *transit supply levels* (**Table 7**). These key factors register higher system-wide scores and exhibit regional clustering, with the two Spanish cases (region #1) reflecting higher values for most indicators (**Figure 8**).

Conclusions and Policy Implications

International comparative case studies provide useful frameworks for better understanding and learning. Careful collection and harmonization of data, and detailed observation and consideration of contexts have provided more clarity and insights on the issues pursued in this paper. Both Spain and the United States can better situate their LRT systems in terms of performance and on which internal and external attributes, and local- and metropolitan-scale factors are key in maintaining and improving ridership and performance outcomes.

The two Spanish LRT cases, Granada and Tenerife, register superior overall performance, outnumber the three LRT systems in the United States, Charlotte, Cleveland, and Norfolk, when most performance indicators are evaluated, and with orders of magnitude superior to 2.

Four main factors are in large part associated with this outcome. Two factors are outside the direct purview of transit planners (*external*) and two are influenced by transit planners and decision-makers (*internal*). The first two refer to overall metropolitan structure and local population levels. These metropolitan and local built-environment attributes are the result of long-term and relatively slow processes that respond to distinct land-use, city planning and building traditions in Spain and the United States. These manifest in dominant spatial activity patterns, urban design, and in building typologies and characteristics that can accommodate different levels of population, automobile parking, and/or jobs. These distinct urban-morphologies and architectural-typologies have been associated with cultural, regulatory, policy, and historical factors. As such, city building and land-use traditions in Spain and the United States have resulted in contexts that are more, or less, amenable for effective and efficient transit service operations. This suggests that LRT systems' ridership and performance may be subject to path-dependence, where built landscapes are in part the legacy of policies and decisions made decades, or more, before.

The third and fourth highly influential factors are under direct transit planners' and key decision-makers' purview and relate to service levels (e.g., headway, number of LRT trips per day) and multimodal transit connectivity (e.g., number of bus and rail line connections at LRT stations).

Higher bus-rail network integration has repeatedly been shown to strongly relate with better performance and higher ridership as recently shown by Ramos-Santiago (2021) and others. Recently, Aston et al. (2021) identified transit supply as an explanatory variable to transit ridership, and the transfer opportunities with bus is associated with a higher use of train systems in their study, focused on the cities of Amsterdam, Boston, and Melbourne.

On the other hand, the effect of station topological attributes like ‘Centrality’ is highly contextual as noted in the non-significance and directionality registered in the results of this study, which contrasts with results found in other recent LRT studies based solely on systems in the United States (see Kuby et al., 2004).

The present study clarifies and highlights the importance of metropolitan structure and local population levels, together with transit service levels and multimodal integration for LRT ridership and performance. The population factor (using housing as proxy) did not emerge as significant in a recent international LRT performance study (see Currie et al., 2011) and this could have been caused by a statistical artefact. An ‘European’ factor, however, did turn-up as highly significant and highly influential in that same study. Likewise, an ‘European’ factor (dummy variable) in this study reports a positive significant influence in regression outcomes (not shown in the final regression table as it is highly correlated with higher service levels that produce better model fits). Still, it is suggestive of a potential cultural factor that merits further study. It should be noted that more recent studies found that population density is positively associated with tram ridership: Aston et al., 2021 pointed out this finding both for tram and train systems, while De Gruyter et al. (2020) did so only for tram (finding a negative relationship for train and bus use in their case study of Melbourne).

At least for the cases evaluated in this study, the ‘European’ influence is in large part explained by built-environment characteristics that can accommodate higher local population-density levels; provide lower car storage capacity; allow more land-use mix; and reflect more diverse metropolitan structure. These distinct attributes can also be claimed as part of regional cultural patterns and practises in city planning and building. Likewise, it is reasonable to think that other cities in these regions with similar settlement patterns would reflect similar outcomes, all else equal. Nevertheless, this hypothesis should be confirmed in future works by applying the same methodology to an expanded number of cases at system-level (that, as stated before, is limited to 5 cases in this research) and larger sample size at station-level (n = 85 in this study).

Results from this multiple case-study also confirm previous studies’ findings of lower performance transit systems in the United States as compared to those in Europe and Australasia and reveal key land-use, urban design, and transit service quality factors that impact performance outcomes of the five LRT case-study systems evaluated.

While the authors of this paper acknowledge the role of larger-scale metropolitan socio-economic characteristics (e.g., median household income levels, automobile availability); land-use structure (overall metropolitan density, sprawl/compactness, and size); and community-wide mobility patterns (e.g., modal share, automobile-dependency, and long-term habits), the empirical results from this study also evince a strong influence of local land-use characteristics and local population density. It is there that the most salient differences in magnitude and influence, and practical opportunities for policy intervention can be found.

Larger-scale metropolitan transformations in urban systems are considered slow variables that may take decades or more to manifest, if at all. Smaller scale transformations such as TOD developments and urban-design/building-typologies parametrizations aimed at transformation of the local built-environment can be considered more moderate variables (McGrath 2013, Bettencourt, 2015). Given favourable development conditions (e.g., economic, regulatory, fiscal incentives) these would be more likely to take place in a shorter time as compared to larger-scale transformations.

The authors of this paper suggest a combined land-use/transportation policy aimed at improving the performance and ridership of lower ranking systems and maintaining the performance of higher-ranking systems. Consistent and long-term efforts to increase both population and employment levels around LRT stations, ideally in denser pedestrian-friendly mixed-use environments and at a higher intensity than those currently realised in Charlotte's TODs, which is the best performing of the three United States LRT cases and where many examples of TOD development and opportunities exist. Reducing levels of on-site TOD residential parking supply and increasing commercial frontage at street-level are typical attributes of Spanish cities and LRT corridors that could inform TOD development parameters in the United States. Encouragement of employment and special generators in new sub-centres at, or near terminals, all else equal, could favour more bi-directional flows and LRT patronage. Market, political, and/or regulatory obstacles to these recommendations are not however considered in this study but worthwhile issues to be explored.

The land-use and transportation policies recommended here entail a very close collaboration and coordination between transit planners, land-use planners, developers, and designers (e.g., architects, urbanists, landscape architects, civil engineers) working within a multidisciplinary framework. From a transportation perspective, planning and supporting multimodal transit integration, improved service levels, and a multimodal *network* approach to transit planning and service delivery represent a rational direction that could synergize with the recommended built-environment policies in pursuit of more sustainable urban mobility.

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Appendix 1

Descriptive Statistics of Station-Level Regression Variables

Variable	Obs.	Source	Year	Mean	Std. Dev.	Min	Max
dependent:							
Average Daily Boardings	85	Transit Agency: *Metropolitano Tenerife* *Metropolitano Granada* *CATS-The Lynx* *HRT-The Tide*	2018	1016.49	886.73	49.00	4045.00
independent:							
Population (1000s)	85	U.S. Census Bureau ACS; ES 2018	2018	3.37	3.68	0.26	15.54
Employment (1000s)	85	U.S. Census (LEHD); ES 2018	2018	2.58	3.99	0.04	17.99
Multimodal Connectivity	85	Transit Agency maps; Transit agencies' GTFS files; Google Earth bus-stop & route data information	2018	9.00	13.02	0.00	84.00
LRT Vehicles/Day	85	Transit Agency schedules	2018	189.06	103.54	57.00	540.00
Centrality (scaled)	85	Transit Agencies' GTFS files; U.S. Census (LEHD) and ES 2018; travel time cost-matrix implemented in ArcGIS PRO - Public Transit Network Tool	2018	0.70	0.17	0.42	1.00
Terminal	85	Transit Agency maps	2018	0.12	0.32	0.00	1.00
Special Generators	85	OpenSreetMap (OSM); Google Earth; Transit Agency website	2018	5.33	4.54	0.00	22.00
Number of Parking Spaces	85	Transit Agency website	2018	90.89	247.47	0.00	1513.00

Appendix 2

ME-NBREG Model Results, AIC and BIC Statistics, and OLS VIF Statistics

```
Mixed-effects nbinomial regression              Number of obs     =         85
Overdispersion:            mean
Group variable:           _City                 Number of groups  =          4
                                                Obs per group:
                                                              min =         11
                                                              avg =       21.3
                                                              max =         25
Integration method: mvaghermite                 Integration pts.  =          7
                                                Wald chi2(8)      =     149.06
Log likelihood = -615.56359                     Prob > chi2       =     0.0000
------------------------------------------------------------------------------
     avg_DAY |        IRR   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    POP_000s |   1.089668   .0182845     5.12   0.000     1.054414    1.126101
    EMP_000s |    1.02853    .015133     1.91   0.056     .9992937    1.058622
    BUSCON_3 |    1.02038   .0046759     4.40   0.000     1.011257    1.029586
   TRIPS_DAY |   1.005359   .0011274     4.77   0.000     1.003152    1.007571
    lcl_Cent |   1.644991    .615876     1.33   0.184     .7897291    3.426486
    Terminal |   2.699651   .5893415     4.55   0.000       1.7599    4.141211
  special_ge |   1.049717   .0137077     3.72   0.000     1.023191     1.07693
     NUM_pkg |   1.000594   .0002687     2.21   0.027     1.000068    1.001121
       _cons |   68.59915   29.22882     9.92   0.000     29.76032    158.1248
-------------+----------------------------------------------------------------
    /lnalpha |  -1.698963    .155613                     -2.003959   -1.393967
-------------+----------------------------------------------------------------
_City        |
   var(_cons)|   .2037504   .1625461                      .0426614    .9731107
------------------------------------------------------------------------------
Note: Estimates are transformed only in the first equation.
Note: _cons estimates baseline incidence rate (conditional on zero random effects).
LR test vs. nbinomial model: chibar2(01) = 17.88      Prob >= chibar2 = 0.0000

Akaike's information criterion and Bayesian information criterion

-----------------------------------------------------------------------------
       Model |        Obs  ll(null)  ll(model)      df         AIC        BIC
-------------+---------------------------------------------------------------
           . |         85         .  -615.5636      11    1253.127   1279.996
-----------------------------------------------------------------------------
               Note: N=Obs used in calculating BIC; see [R] BIC note.

. vif (note: based on OLS regression):

    Variable |       VIF       1/VIF
-------------+----------------------
    lcl_Cent |      1.55    0.647074
   TRIPS_DAY |      1.54    0.650454
    Terminal |      1.48    0.675099
     NUM_pkg |      1.37    0.731073
    EMP_000s |      1.30    0.769567
  special_ge |      1.26    0.793303
    BUSCON_3 |      1.24    0.804300
    POP_000s |      1.20    0.831479
-------------+----------------------
    Mean VIF |      1.37

Akaike's information criterion and Bayesian information criterion
-----------------------------------------------------------------------------
       Model |        Obs  ll(null)  ll(model)      df         AIC        BIC
-------------+---------------------------------------------------------------
           . |         85 -697.0482  -651.0138       9    1320.028   1342.011
-----------------------------------------------------------------------------
```

Revision #1 Author Contributions Section

AUTHOR CONTRIBUTIONS

Luis Enrique Ramos-Santiago: Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization, Supervision, Project Administration. **Margarita Novales Ordax:** Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original draft, Writing – Review & Editing, Visualization. **Francisco Alberto Varela-Garcia: Conceptualization**, Methodology, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original draft, Writing – Review & Editing, Visualization.