URBAN RAIL TRANSIT USAGE IN DEVELOPING COUNTRIES: THE CASE OF ISTANBUL

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ABSTRACT
This study examines urban rail transit usage in Istanbul to shed light on broader challenges faced by developing countries. Using models based on node and place characteristics of stations, it evaluates their impact on passenger volumes across the rail network. Despite major investments and rapid urbanization since the 1960s, only a fraction of station areas saw concurrent increases in passenger and population figures between 2017 and 2022. While node and place variables showed some significance, the regression models could not fully explain usage variability, suggesting that institutional, socio-economic, and spatial dynamics play a disruptive role. The findings indicate that stations have been treated more as isolated nodes than integrated components of the urban fabric. The study calls for a planning approach that combines rail transit with broader urban development, tailored to the complex realities of developing cities for maximizing the transformative potential of rail investments and promote sustainable urban growth.

Keywords: Urban Rail Transit, Developing Country, Istanbul, Node and Place Characteristics

Introduction

Investments in urban rail systems have increased significantly on a global scale, encompassing both developing and developed nations (Newman & Kenworthy, 2015). This trend underscores the growing recognition of urban rail as a crucial solution to contemporary urban challenges. However, is urban rail exclusively concerned with enhancing public transportation efficiency? Certainly not. Scholars assert that rail stations have the potential to serve as dynamic urban hubs, fostering economic development by attracting businesses and residents to the surrounding areas (Yang, Zhong, & Gao, 2022). While this proposition appears promising, its applicability in developing countries remains an open question.

Developing cities are constantly evolving, driven by both urbanization and natural population growth. As a result, these cities undergo significant expansion, extending both horizontally through suburban sprawl and vertically through high-density development (Mahtta et al., 2022). However, urbanization in these regions is often chaotic, characterized by fragmented investments and weak urban planning (McGill, 1998; Abdi & Daudén, 2021). The rapid pace of urban growth often outstrips the capacity of local governments to implement effective infrastructure and regulatory frameworks. This lack of coordination leads to inefficient land use, inadequate transportation networks, and increasing socio-economic disparities. As a result, many urban rail projects face challenges in integrating seamlessly with the surrounding urban fabric, limiting their overall effectiveness. So, what happens when urban rail is introduced? The results vary—some areas attract more people, while others remain unchanged or even see decline. Why? The dynamic nature of developing cities plays a huge role. In this study, we dive into Istanbul—a city that perfectly captures these trends.

As the most populous city in Europe, Istanbul has embraced the global “railization” movement (Gökçe, 2024). This shift has been driven by increasing urban congestion, environmental concerns, and the need for sustainable mobility solutions. Consequently, the city has prioritized expanding its rail network to enhance connectivity and reduce reliance on automobile transport. These efforts align with broader global trends that seek to integrate public transportation more effectively into urban planning. Since 2000, the city has invested heavily in suburban, metro, and light rail lines. By 2017, almost 57% of the population had a rail station within a kilometer (Gökçe, 2024, p. 8). However, the presence of a nearby station has not consistently resulted in increased ridership or population growth. This discrepancy raises an important question: what underlying factors contribute to this unexpected outcome?

Building upon these observations, a comprehensive analysis was conducted on 137 station areas within a one-kilometer radius to evaluate changes in population and passenger usage between 2017 and 2022. The results indicated that only 27 stations (19.71%) experienced simultaneous increases in both population and passenger numbers. In contrast, 57 areas (41.61%) saw an increase in ridership despite a decline in population, while 53 stations (38.69%) experienced a reduction in passenger numbers. Notably, 20 stations with growing populations reported a decrease in transit users. These findings suggest that factors such as rail type, capacity, and land use significantly influence transit trends. However, they also highlight broader structural challenges in the development and integration of urban transit networks within rapidly evolving cities.

From these findings, valuable insights can be drawn regarding urban rail transit in rapidly evolving cities. This study provides an in-depth examination of urban rail transit in Istanbul, utilizing models based on node and place characteristics (Bertolini, 1996). Furthermore, it identifies inefficiencies within the system and proposes strategies to better integrate "transportation transformation" with "urban transformation." The study is structured as follows: Section 2 reviews transport trends in developing countries, Section 3 examines Istanbul's rail expansion, and Section 4 presents three analytical models—the Node model, the Restricted Node-Place model, and the Node-Place model—employing data from 2013, 2015, 2017, and 2019.

Nevertheless, a key challenge remains—while the models confirmed the significance of node and place characteristics, they did not fully account for the misalignment between ridership and population trends across the 137 stations. No statistically significant patterns were observed, suggesting that Istanbul's rapid urban transformation and shifting demographic patterns may have disrupted the anticipated relationship between transit usage and population density. This finding underscores an important consideration: rather than functioning as integral components of the urban fabric, Istanbul's rail stations have primarily been treated as isolated network nodes.

To effectively address these challenges, cities, particularly in developing regions, must integrate public transit—especially rail—as a core element of urban planning. This integration should emphasize accessibility, efficiency, and sustainability to ensure long-term viability. Moreover, seamless coordination between transportation policies and urban development strategies is crucial to maximizing the socio-economic benefits of rail transit investments. Engaging the public and ensuring equitable access to rail services can further enhance the effectiveness and acceptance of these initiatives. Given that these concerns extend beyond Istanbul, they are equally relevant to cities worldwide. A well-structured planning framework that prioritizes transit in urban development is essential for optimizing rail investments. The fifth section provides key recommendations for addressing these issues and enhancing the role of rail transit in rapidly evolving urban environments.

The Background: Transportation In Developing Countries

Urban transportation in developing countries presents a complex and multifaceted challenge. The transportation systems in these regions often reflect a hybrid of modern and traditional elements, resulting in inefficiencies unique to the developing world context. Rapid urbanization, economic constraints, and evolving social dynamics necessitate a nuanced understanding of urban mobility. Despite the global trend of "railization," transportation networks in developing nations continue to grapple with mobility issues like those identified by Gakenheimer (1999).

One of the most pressing challenges is the rapid pace of motorization, which often outstrips the capacity of existing transportation infrastructure. This imbalance leads to severe congestion, with cities such as Istanbul experiencing higher congestion levels despite lower vehicle ownership rates compared to many developed cities. Moreover, excessive travel demand further exacerbates congestion, as transportation networks fail to keep pace with the growing number of private vehicles on the road.

Public transit remains a crucial component of urban mobility in developing countries, carrying a significant share of urban trips. However, the effectiveness of public transportation is frequently hampered by political and institutional challenges, including inadequate funding, fragmented governance, and policy inconsistencies (Cervero, 2013). The dominance of bus systems, which often suffer from congestion-related delays, underscores the need for strategic investments in dedicated transit lanes and signal prioritization.

Disparities in transportation access further complicate urban mobility, leading to inequitable distribution of resources and services. In many developing cities, marginalized communities face longer commute times and limited transit options, exacerbating socio-economic divides (Gakenheimer, 1999). Addressing these issues requires targeted policy interventions and infrastructure investments that prioritize inclusive and equitable transportation solutions. The decentralization of urban functions, often driven by motorization, tends to relocate employment opportunities to suburban areas, making access difficult for lower-income, non-motorized populations.

Additionally, the urban structures of many developing cities are not conducive to high levels of motorization. Narrow roads, often inherited from historical urban layouts, limit the space available for expanding vehicular infrastructure. The high density of both residential and commercial establishments further restricts the feasibility of large-scale road expansions. As a result, transportation planners must seek alternative mobility solutions that align with the existing urban fabric and prioritize sustainable transport options. Limited street space, high population densities, and mixed land-use patterns contribute to infrastructure inadequacies, further straining transportation networks (Bertolini, 2008). These constraints make it challenging to develop large-scale road expansion, leading to congestion and inefficiencies. Furthermore, mixed land-use patterns result in complex travel behaviors, as people need to navigate between residential, commercial, and industrial areas within short distances. The combination of these factors necessitates the adoption of innovative urban mobility solutions, such as improved public transit networks and non-motorized transport infrastructure, to enhance overall accessibility.

A significant factor fueling motorization is the strong desire for private vehicle ownership. Economic growth and aspirations for a modern lifestyle drive an increasing demand for automobiles, which, in turn, exacerbates congestion and environmental concerns. The introduction of new road systems often has a more pronounced impact on urban development in developing countries compared to their developed counterparts. The construction of highways, for example, tends to accelerate urban sprawl and alter existing urban structures, sometimes to the detriment of sustainable mobility (Cervero et al., 2009).

Furthermore, the diversity of vehicle types on the streets of developing cities presents unique challenges in traffic management. A mix of human-powered vehicles, motorcycles, minibuses, and high-speed cars complicates the efficiency and safety of urban transport. While informal transit options such as tuk-tuks in Thailand and minibuses in Turkey offer flexible mobility solutions, they also contribute to congestion and regulatory challenges.

Despite the increasing adoption of urban rail systems as a potential solution to congestion, rail transit alone cannot resolve the mobility crisis in rapidly growing urban environments. The success of such systems hinges on comprehensive planning, robust policy frameworks, and sustained political commitment (Cervero, 2013). Cities that fail to integrate rail investments with broader urban planning efforts risk underutilization and continued congestion.

Many developing cities also face institutional inefficiencies and social inequities that further complicate transportation management. Limited political will, insufficient administrative capacity, and corruption hinder the development of cohesive land-use and transportation strategies. In several cases, the influx of second-hand vehicles from high-income countries exacerbates congestion and contributes to higher greenhouse gas emissions. The fragmentation of urban services and a reactive rather than proactive approach to transportation planning often result in disjointed and ineffective mobility solutions.

The expansion of transportation infrastructure frequently leads to urban sprawl, marked by a "flattening of the density gradient" (Cervero, 2013, p. 14). This phenomenon is particularly evident in megacities like Istanbul, where transit investments can inadvertently contribute to socio-spatial segregation. Lower-income populations are often displaced to peripheral areas, while central urban districts undergo modernization catering to wealthier residents. However, successful cases from Bogotá and Curitiba demonstrate that well-integrated transportation and urban development strategies can lead to more sustainable and equitable mobility solutions. Investments in Bus Rapid Transit (BRT) systems and cycling networks have helped these cities accommodate growing mobility needs while promoting compact urban development.

Sustainable urban mobility in developing cities necessitates a strategic integration of land-use planning and transportation policies that emphasize accessibility and operational efficiency. The implementation of smart growth principles can significantly contribute to lowering emissions, improving air quality, and fostering overall urban livability. A comprehensive and resilient mobility framework must incorporate a diversified array of transportation modes, targeted infrastructure investments, and systematic institutional reforms. Among these, rail investments hold paramount importance as they mitigate congestion, enhance urban connectivity, and provide an environmentally sustainable alternative to road-based transport. When seamlessly integrated with land-use planning, rail systems have the potential to reduce reliance on private automobiles and facilitate transit-oriented development. Consequently, a clear strategic vision and sustained commitment from policymakers are essential for developing nations to not only alleviate congestion but also stimulate economic growth and promote social inclusivity.

The Backdrop: İstanbul's Changing Face Of Public Transit

Istanbul, with an estimated population approaching 16 million, is the largest metropolitan region in Europe—when considered alongside the adjacent Gebze region to the east, the total population nears 17 million. Since the 1960s, the city has undergone rapid urbanization, with its population expanding from approximately one million to its current scale. This unprecedented demographic surge, primarily driven by migration, necessitated extensive northward (inland) expansion, resulting in the proliferation of informal settlements, commonly referred to as squatter housing. By the 1980s, these initially low-rise, one- to two-story structures underwent significant transformations into multi-story apartment complexes to accommodate the escalating population density. Consequently, the urbanization of Istanbul has been characterized by a dual process of internal densification and peripheral sprawl, reshaping the city's spatial and infrastructural landscape (Figure 1).

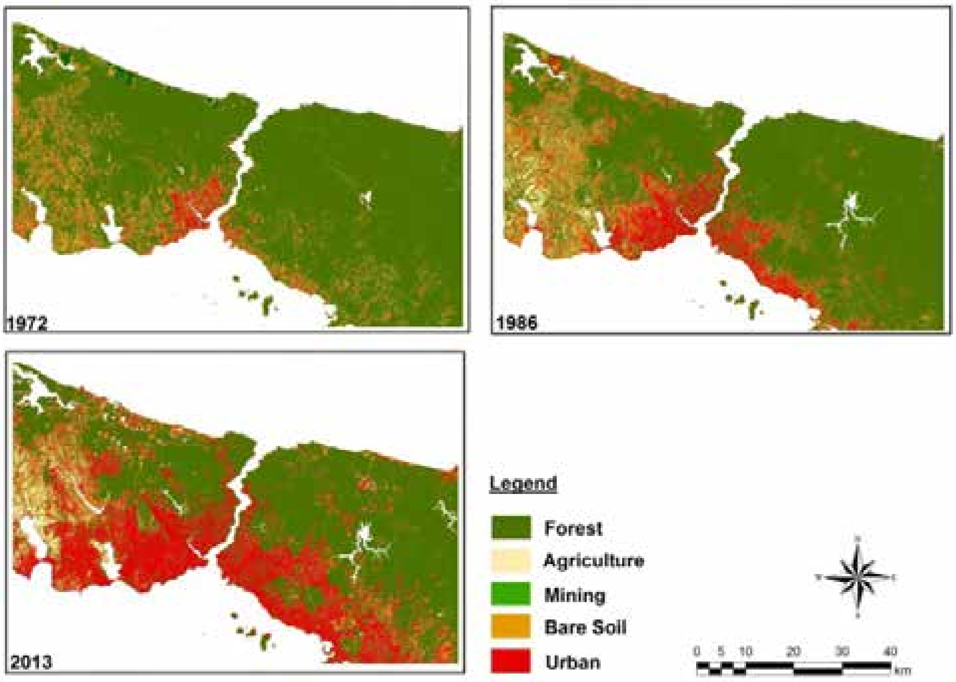


Figure 1 Urban expansion of İstanbul from 1972 to 2013 (Source: Akın et al., 2015, p. 506)

This densification, however, has left Istanbul grappling with inadequate infrastructure on multiple fronts. The swift population growth and the shift from squatters to apartments have placed immense pressure on the city's infrastructure, which has struggled to keep pace with the demands of such rapid urban development. Essential services and facilities, including transportation, sanitation, and public utilities, have often been overwhelmed, leading to significant challenges in terms of quality of life for residents. The city's infrastructure, originally designed for a much smaller population, has not been adequately upgraded to meet the needs of its current size, resulting in persistent issues with congestion, housing, and basic urban services.

To address these challenges more comprehensively, the municipal system for metropolitan areas was transformed into a two-tier system in the early 1980s. This new structure features an upper tier known as the metropolitan municipality and a lower tier consisting of district municipalities. The aim was to enhance effectiveness and efficiency by leveraging economies of scale through metropolitan-wide investments in transportation, water supply, wastewater management, and other essential services. This restructuring intended to streamline administration and improve service delivery across the rapidly growing urban landscape.

Recently, the concept of the metropolitan municipality has evolved into what is now termed the "greater municipality," with jurisdictional areas extending to provincial borders while maintaining the two-tier system. Provinces with populations exceeding 750,000 are designated as greater municipalities. This latest iteration of the municipal system has integrated rural areas into urban governance, placing them under the same administrative umbrella as their urban counterparts. This change aims to ensure more cohesive and unified management of resources and services, addressing both urban and rural needs within the same administrative framework (Tekeli & Okyay, 2014).

Before the 1990s, Istanbul's public transportation infrastructure was relatively underdeveloped. Apart from a century-old two-stop rubber-tired funicular, locally known as the "Tunnel," which connected the seashore to a higher point in the city center on a very short line, the city had two old suburban rail lines. These lines terminated at Sirkeci on the European side and Haydarpaşa on the Asian side, both located at the southern tips of the Bosporus. These suburban rail lines formed the backbone of public transit, running through legally established housing strips parallel to the Sea of Marmara, an inland sea that connects the Black Sea to the Mediterranean Sea. To the north of both suburban lines, towards the inner areas of Istanbul, a state highway (namely E5, which was later recoded as D100, connecting Turkey's interior regions to Europe) served as the main urban artery (Tekeli, 2009). In these northern areas, illegal housing settlements were linked to this backbone by small entrepreneur-operated minibuses and public buses operated by the Istanbul Electric Tram and Tunnel Company (İETT). The minibus transit system has evolved flexibly with urban expansion and, in many cases, has supported urban expansion in the form of squatter housing (Tekeli & Okyay, 1981).

The establishment of a metropolitan municipality brought significant changes to Istanbul's transportation landscape. In the 1990s, financially empowered metropolitan administrations began investing in rail transit lines. This period marked the beginning of an incipient "railization," although efforts to expand the rail network were initially hampered by economic downturns in the Turkish economy. Despite these challenges, the trend towards rail transit steadily increased after 2000, with new metro and tramway lines extending from the city center to densely populated inner areas. The central government further spurred these developments by taking charge of the rail construction phase, boosting the expansion of rail infrastructure. A significant milestone was the recent completion of a high-tech, driverless metro line connecting the newly built Istanbul Airport, one of the three largest airports in Europe, to the city center. Today, two of the main airports, bus terminals, and intercity rail terminals, as well as main activity centers, are interconnected via the urban rail network, highlighting the substantial progress made since the 1990s.

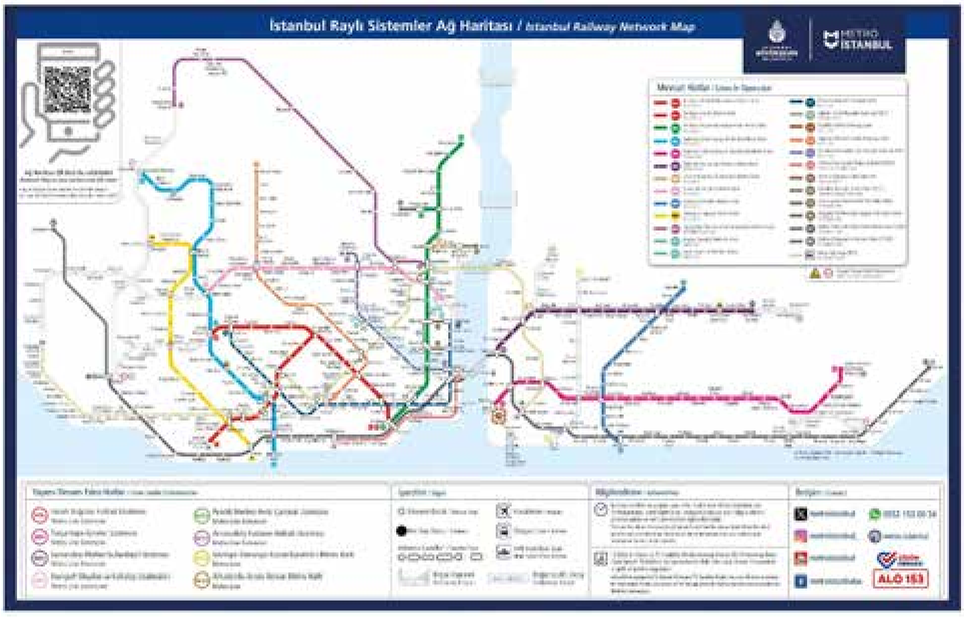
Recently, the Bosporus has been underpassed by two tunnels: one for the suburban rail line (Marmaray Tunnel inaugurated in 2013), which connected independent lines on the European and Asian sides, and the other for motor vehicles (Eurasia Tunnel inaugurated in 2016). The addition of a third bridge on the northern frontier of the Bosporus has further increased urban mobility, which seems to be driving further urban expansion in the northern regions. Today, a seamless trunk suburban line, Marmaray, runs from Gebze, the westernmost district of the neighboring Kocaeli province, to Halkalı, the terminal station of the suburban line on the European side, covering a stretch of 86.6 km with 43 stations (Figure 2).

Figure 2. Main road corridors and Marmaray suburban line (highlighted in solid red line) in İstanbul (Source: Canitez et al. , 2020)

Over nearly three decades, the sustained effort in "railization" has transformed Istanbul's transportation system from a predominantly rubber-tired network to a more sophisticated rail network based on a node-place topology. Historically, the metropolitan administration's organizational structure was not designed to support such a network; it was geared towards a rubber-tired system. This necessitated significant changes to adapt to the new rail-based system. However, these changes required not only extensive physical infrastructure investments but also a thorough organizational restructuring to manage and operate the new node-place topology effectively (Cervero, 2013).

The main issue is that the rail network in Istanbul is designed for nodes without adequately developed station areas (i.e., places). This is a serious problem that needs to be addressed through capacity building. Developing station areas into functional, vibrant places is essential for maximizing the benefits of rail transit. Enhancing the integration of these nodes into the urban fabric will require strategic urban planning, improved land use policies, and the creation of amenities and services that make these areas attractive and accessible to residents (Bertolini, 1996, 2008; Cervero, 2008, 2013). By focusing on building capacity in these areas, Istanbul can ensure that its rail network not only serves as a means of transportation but also contributes to the overall livability and functionality of the city.

Especially after 2010, rigorous investments in rail transit has turned disconnected rail lines into a highly connected rail network as depicted in Figure 3a. As of 2024 number of transfer stations has increased to more than 40 stations (including with BRT system, the Metrobüs). In the next ten years the network is likely to increase another 250 km reaching the network depicted in Figure 3b.



-a-

-b-

Figure 3. The 2024 rail network (a) and the expected rail network at 2030(b) in İstanbul (Source: Metro Istanbul Accessed: October 15, 2024)

To support this transformation, Istanbul had to build new capacities within its administrative framework. This included developing specialized skills and capabilities within the city's transport authorities and restructuring existing organizations to better manage the integrated rail network. The transition also necessitated the implementation of new technologies and management practices to ensure the efficient operation of the expanded rail system. As Istanbul continues to grow, the ongoing development of its rail infrastructure remains a critical priority. The city plans to further expand the network, particularly along the south-north axis, to meet the needs of its burgeoning population and to maintain its position as a major metropolitan hub in Europe.

Urban Rail Transit Usage And Population Interaction Around Station Areas In Istanbul
Between 2017 and 2022, Istanbul experienced a 5.85% increase in population, expanding from 15,029,231 to 15,907,951. In parallel, Turkey's total population grew by 5.53%, rising from 80,810,525 to 85,279,553. Simultaneously, Istanbul's urban rail transit system recorded a substantial 47.95% increase in weekly ridership, surging from 14,408,882 to 20,844,589. This expansion was primarily attributed to the introduction of new lines and stations. Notably, when using 2013 as a baseline instead of 2017, the increase in weekly trips reaches 116.26%, underscoring the rapid growth and utilization of rail transit over the past decade.

For the 137 stations that were operational in both 2017 and 2022, weekly passenger numbers increased by 9.20%, a rate surpassing the overall population growth during the same timeframe. Analyzing these stations in terms of passenger volume and station area populations—where 103 of the stations are on the European side—reveals no significant difference in passenger usage between the European and Asian sides of the city.

Among the 137 stations examined, 84 stations (61.31%) registered an increase in weekly passenger numbers. A paired t-test shows an average increase of 9,561 weekly passengers per station between 2017 and 2022 (p=0.063, d.f.=136), adding to an average weekly ridership of 103,894 passengers per station. As discussed in the introduction, the stations have been categorized into four groups based on changes in passenger volumes and surrounding population between 2017 and 2022 (Figure 5).

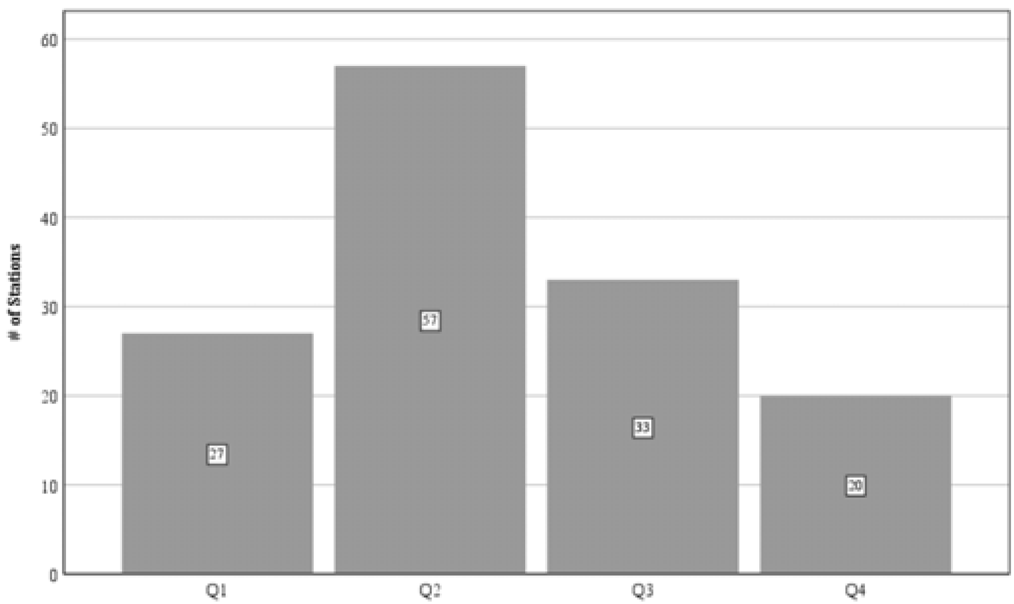


Figure 4. Changes in passenger values of rail stations and population of station areas (1 km radius) between 2017 and 2022

The first group (Q1) consists of stations where both population and passenger numbers increased. The second group (Q2) includes stations where passenger numbers rose while population figures declined. The third group (Q3) represents stations where both population and passenger values declined. Lastly, the fourth group (Q4) encompasses stations where the station-area population increased while passenger usage decreased. Figure 4 illustrates the distribution of stations across these four groups.

A general trend of population decline is observed in station areas categorized as Q2 and Q3, representing 65.69% of the total stations. The number of stations experiencing population loss (Q2 and Q3) surpasses those witnessing passenger growth (Q1 and Q2). Additionally, more stations recorded simultaneous declines in both population and ridership (Q3) than those where both increased (Q1). The mixed findings in Figure 4 suggest a strong intra-metropolitan shift of both population and commercial activities, facilitated by increased motorization. A detailed examination of land use patterns and their changes in different station groups offers explanations for these shifts.

Stations in Q1, where both passenger numbers and population increased, are predominantly residential areas near the city center. Conversely, Q2 stations, situated in central locations or urban transformation zones, have seen a decline in population due to redevelopment activities. Stations in Q3, which primarily serve mixed land-use areas dominated by retail businesses, appear to have suffered from both population relocation to outer areas and widespread business closures, particularly during the COVID-19 pandemic. Q4 stations, which primarily belong to metro lines running parallel to the D100 highway, seem to have lost passengers to private vehicle usage.

A more comprehensive analysis is conducted using a panel regression model, incorporating weekly passenger data from the second week of December in 2013, 2017, 2019, and 2022 as the dependent variable. The Random Effects Panel Regression model employed in this study is structured as follows:

(1) $$y_{it}=\beta_1+\boldsymbol{\beta}'\mathbf{x}+(e_{it}+u_i)$$

where,
y = natural logarithm of passenger values
x = the column vector of independent variables
β = the row vector of parameters
t = years of observation (2013, 2015, 2017, 2019, 2022)
i = rail transit station
e = station based temporal error term
u = station based error term
In this system a generic error term is defined as

(2) $$v_{it}=(u_i+e_{it})$$

Variance of the generic error term is as

(3) $$\sigma_v^2=\mathrm{var}(v_{it})=\mathrm{var}(u_i+e_{it})=\sigma_u^2+\sigma_e^2$$

In the model provided above, the covariance between the measurements of a station at two different times is assumed to be the same for all stations, while the covariance between two stations at the same time is set to zero. Using these assumptions, the correlation of the number of passengers served by a station between two time periods is calculated as follows:

(4) $$\rho=corr(v_{it},v_{is})=\frac{cov(v_{it},v_{is})}{\sqrt{var(v_{it})var(v_{is})}}=\frac{\sigma_u^2}{\sigma_u^2+\sigma_e^2}$$

In the model structure presented above, two groups of independent variables are used. The first group represents node characteristics, while the second group consists of place variables that characterize the station areas. However, not all independent variables are available for all years. Station area populations are available for 2017 and 2022, while the number of work locations is available only for 2022. Therefore, place variables are not usable for all years. Table 1 provides the dependent and independent variables along with summary statistics. Variables are categorized according to Bertolini's scheme (12, 13).

There are five node variables and two place variables. Note that the population variable restricts the panels to only two time points, 2017 and 2022. The number of work locations reduces the analysis to multiple linear regression as it is only observed in 2022.

Table 1. Descriptive Statistics of Regression Variables

Variable	# of Observations	Mean	Std. Deviation	Min.	Max.
N. of Passengers (ln) / dependent variable	762	11.01	0 .89	6.93	13.358
N1: Indicator for suburban rail, MARMARAY	762	0,13	0,34	0	1
N2: Indicator for light rail transit	762	0.35	0,48	0	1
N3: Indicator for European side rail	762	0,73	0,44	0	1
N4: Number of transfers to other lines at the station	762	0,16	0,41	0	2
N5: Number of stations to go on the line to reach the city center	762	9,95	6,44	1	29
P1: Resident population in 1 km radius of the station (ln)	324	10,64	1,15	3,14	12,30
P2: Number of work locations in 1 km radius of the station (ln)	180	7,87	1,38	3,91	10,91

Based on the dataset depicted in Table 1, three regression models were devised and named according to the variables included. For all the available years in the dataset, i.e., 2013, 2015, 2017, 2019, and 2022, since we only have node variables, the model is named **the Node Model** (Table 2). There are two regression models based on panel data, i.e., ***Model 1***, and ***Model 2***. While ***Model 1*** is named as the Node model, ***Model 2*** is named as **the Restricted Node-Place Model** as it includes only resident population around 1 km of stations (***P1***) without including data on work locations (***P2***)—data about work locations were only available for 2022. ***Model 2*** reveals insignificant coefficient value for the place variable (***P1***). However when we turn to a linear regression model conducted for a single year, 2022 (***Model 3***), both place variables (***P1***, ***P2***) attain significant positive coefficient values. Estimation of the regression coefficients are presented in Table 2.

In all models, we have negative coefficients for Marmaray (***N1***) and LRT (***N2***). Unlike metro rail stations, which are actively used throughout the week, both LRT and Marmaray stations serve fewer passengers on average. Weekly passenger levels at Marmaray and LRT stations are approximately 10% and 40% lower, respectively, than those at metro stations, respectively. Therefore, we have negative coefficients for Marmaray (***N1***) and LRT (***N2***) stations. The regression based on panel data does not reveal significant coefficients for the European side rail, ***N3***. However, the regression model conducted for a single year (2022) reveals a significant, but negative, value. Consistent negative results lead us to conclude that the Anatolian side population is more reliant on the rail system than the European side population. This is closely related to the development patterns on both sides of the Bosporus, as shown in Figure 1. The number of transfers (***N4***) available at a station increases weekly passenger levels to more than twice the average values. Although its effect decreases in models that include place variables, it still retains its importance as a node feature.

The southern tips of the Bosporus on both the European and Asian sides resemble city centers in terms of the rail network. Nearly all rail trips use these two locations as reference points in daily journeys. A station's relative position on the network, denoted by ***N5***, is determined with respect to intermediate stations and the city center. The models reveal significant and consistent values for the ***N5*** variable, which remain unaffected by the inclusion of place variables. The relative position is relatively immune to additional explanatory variables in the models. City centers on both sides of the Bosporus are important hubs for all rail trips. There is always an increasing trend of passengers at stations toward the city center, regardless of the rail type. We do not expect changes in this pattern in the future, even with the ongoing relocation of the population.

Table 2. Regression Results

Variable	The Node Model (Model 1)		The Restricted Node-Place Model (Model 2)		The Model 3: The Node-Place Model (Model 3)	
	Linear Regression with Random Effects (Years of The Panel Dataset: 2013, 2015, 2017, 2019, 2022)		Linear Regression with Random Effects (Years of The Panel Dataset: 2017, 2022)		Linear Regression (Year of The Dataset: 2022)	
	Coefficient	z-statistic	Coefficient	z-statistic	Coefficient	t-statistic
Constant	11.26**	78,50	10,58**	21,34	8,64**	12,87
N1	-0,33*	-2,27	-0,05	-0,31	-0,07	-0,51
N2	-0,22	-1,59	-0,20	-1,49	-0,30*	-2,16
N3	-0,05	-0,40	-0,05	-0,41	-0,26*	-2,05
N4	0,99**	10,56	0,87**	6,78	0,71**	5,45
N5	-0,02*	-2,46	-0,02*	-2,28	-0,03**	-3,57
P1			0,70	1,56	0,16**	2,78
P2					0,18**	4,16
# of Stations	194		187		180	
# of Observations	762		324		180	
u	0,71		0,60		NA	
e	0,31		0,43		NA	
	0,84		0,66		NA	
R^2	0,21		0,22		0,35	

** = significance <0,01, * = significance <0,05

The results presented above suggest that the impact of node and place characteristics on rail station usage is mixed and insufficient to explain more complex relationships. This could be due to the unique characteristics and inherent dynamism of developing countries, a phenomenon elaborated in the second section. Additionally, each developing country has its specific backdrop, as detailed in the third section for Istanbul. Although the regression analyses provided intuitive results, further investigation is needed to explain the mixed outcomes observed for the 137 stations (see Figure 4).

We believe Figure 4 reflects the unique context and dynamism of developing countries, in contrast to the regression results. Since none of the regression analyses conducted on the 137 stations yielded significant coefficients for population change on changes in passenger values, there must be other intervening factors, such as institutional and administrative dynamics, as well as ongoing socio-economic and demographic processes. In an urban setting that is still evolving, as seen in developing countries, should rail transit planning adopt a different approach? This question highlights the need for a new planning paradigm that considers these unique challenges.

Conclusions

In the context of developing countries, urban transportation systems often face unique challenges and exhibit specific characteristics. Rapid urbanization in developing countries results in a mismatch between old and new infrastructures, which creates inefficiencies and ineffectiveness. Moreover, the specific backdrop of each developing country adds another layer of complexity. In Istanbul, significant investments in the rail network began in the 1990s, marking the start of an "incipient railization." Despite economic downturns, this trend continued, leading to a substantial expansion of the rail network in the post-2000 era.

The central government's support further accelerated "railization", with notable achievements such as undersea tunnels over the Bosporus, driverless metro line connecting Istanbul Airport to the city center. However, the mixed results from the 137 stations between 2017 and 2022 underscore the varied impact of these investments. While some stations saw increased passenger values and populations, others did not, reflecting the city's complex urban dynamics and the multifaceted nature of urban transportation challenges in developing contexts.

The regression models, although they provide insights into rail transit usage, do not fully capture the complexity of the observed patterns, necessitating further exploration of the interplay between urban dynamics, socio-economic factors, and transportation infrastructure in developing countries. Addressing these challenges requires a multifaceted approach. Developing countries need to prioritize integrated urban planning, ensuring coordination between transportation and land use policies. Strengthening regulatory frameworks and institutional capacities is essential to create an environment conducive to investment and sustainable development.

In this framework, each rail station should be viewed as an asset to foster policies that enhance both node and place characteristics. Accordingly, each station should be considered a reference point for developing an urban fabric conducive to sustainable transportation modes such as walking, bicycling, and transit altogether, rather than merely a node for transit access (Newman & Kenworthy, 2015; Cervero et al., 2009; Cervero & Murakami, 2009). In conclusion, while urban rail investments have the potential to transform land use and promote sustainable development, realizing these benefits in developing countries requires addressing them in a broader context. By adopting integrated planning approaches, strengthening institutional capacities, and fostering inclusive development, developing countries can unlock the full potential of urban rail investments and create vibrant, equitable, and sustainable urban environments.

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