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Demographic and Efficiency Analysis of Street Transportation Network in Districts of Tehran Metropolitan

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ABSTRACT

The primary goal of transportation accessibility is to improve travel efficiency by minimizing the distance between trip origins and destinations, thereby enhancing user experience. While conventional performance assessments focus on speed and distance, this study integrates demographic and spatial analytics to evaluate Tehran's mobility infrastructure. Using district-level population and census data from Tehran Municipality and the Statistics Center, four analytical steps were undertaken: mapping population density via ArcGIS 10.8, measuring real and straight-line distances with Google Earth Pro, and calculating accessibility using the route factor. The 2021 forecast reveals that approximately 67% of Tehran's population resides in suburban districts, with District 4 alone accounting for 10.57%. Despite this concentration, peripheral districts remain sparsely populated compared to central ones. Accessibility assessment classified internal district connections into five categories: excellent (38%), moderate (32%), and poor (30%). Tehran's average route factor of 1.52 indicates a moderate level of accessibility. These findings underscore a significant imbalance in population distribution and transport network efficiency. To address this, targeted investments in underperforming areas should be prioritized. This study demonstrates the value of combining demographic insights with spatial network analysis, delivering actionable intelligence for urban planners to optimize resource allocation and strengthen connectivity in Tehran's evolving metropolitan landscape.

1. INTRODUCTION

Understanding population statistics and their characteristics provides governments with the necessary foundation to formulate both micro and macro-level policies for social and economic development. These statistics not only help address current conditions but also support the development of long-term solutions to ongoing challenges. A review of national census data highlights the significant impact of population growth, particularly in Tehran, where this trend has led to the expansion of the metropolitan area and has introduced a range of urban planning and

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environmental challenges. The spatial distribution of this growth whether concentrated or sprawling largely depends on decisions made by urban planners and policymakers [1].

In contemporary urban life, residents frequently travel across city districts for purposes such as work, shopping, and recreation. This inter-district mobility underscores the dynamic interaction between the urban transportation system and land use patterns [2, 3]. Transportation infrastructure influences land use by improving accessibility, which in turn shapes urban development patterns. Conversely, land use patterns influence transportation demand by generating and attracting travel. Thus, changes in either system impact the other, leading to a cycle of mutual influence until a degree of equilibrium is achieved [4, 5].

Among the critical challenges facing Tehran today is air pollution an issue that demands immediate attention from urban management authorities. International experiences and studies confirm that reducing CO_2 emissions is achievable through the integration of land use and transportation planning. Such planning enhances accessibility and contributes to public health, environmental quality, and the overall well-being of urban populations [6].

Until the early twentieth century, cities such as Tehran featured compact, mixed-use neighborhoods, where essential services were typically accessible by foot. However, following World War II, rapid motorization and the implementation of modern land use regulations facilitated a shift toward sprawling urban development. This pattern, commonly referred to as horizontal or dispersed urban expansion, continues to define many urban areas in Iran today [7]. Societies experiencing sustained population growth often expand radially around central metropolitan areas [8].

Many urban planners and economists argue that transportation technologies fundamentally shape the urban form. Scholars like Edward Glaeser and Matthew Kahn contend that the automobile is a key driver of fragmented, low-density urban expansion. As the cost of commuting decreases, land consumption per capita increases, thereby extending the boundaries of cities [9]. Globally, the urban population increased from 34% of the total population in 1960 to 55% in 2018, and projections indicate that it will reach 68% by 2050, with the majority of this growth expected in Asia and Africa [10].

Tehran, one of the largest cities in Southwest Asia and ranked as the 21st largest city in the world, currently faces severe urban transportation challenges including traffic congestion, excessive fuel consumption, and multiple forms of pollution. The city comprises 22 districts and 123 zones. Achieving sustainable urban governance in a metropolis of this scale requires a comprehensive and integrated management strategy. In this study, population trends in Tehran over the past six decades were examined, revealing consistent growth. To better understand the spatial dynamics within the city, population density indices for all 22 districts were calculated and compared. Furthermore, intra-city connectivity was evaluated through an analysis of the road transportation network, using accessibility indices to assess the efficiency of the transportation infrastructure.

2. RESEARCH GOALS AND QUESTIONS

The metropolis of Tehran, as a result of rapid population growth and extensive urban development, is currently experiencing severe traffic congestion, accompanied by escalating social, economic, and environmental costs. These growing pressures underscore the importance of identifying the key factors contributing to urban traffic and analyzing travel distances between origins and destinations within the city's transportation network.

Accordingly, the primary aim of this study is to analyze population growth trends in Tehran, assess the spatial distribution of population across its districts, and evaluate the efficiency of inter-district accessibility within the city's street transportation network. This research is guided by the following key questions:

- What proportion of Tehran's population is concentrated in the central and suburban districts?
- How effective and accessible is the street transportation network in facilitating movement between different districts of the city?

3. RESEARCH BACKGROUND AND THEORETICAL FOUNDATIONS

The concept of accessibility is central to understanding the interaction between transportation systems and land use. As accessibility directly influences land use patterns, its measurement serves as a critical link between the spatial distribution of human activities and the transportation infrastructure that connects them. In its simplest form, accessibility can be defined as the ease of reaching desired locations or services through a given transportation network, and is typically quantified in terms of either distance or travel time [11].

The relationship between transportation and land use is multidimensional and can inform strategic planning through the integration of mobility features, socio-demographic characteristics, environmental considerations, and urban network accessibility [12]. The underlying principle is that travel behavior is inherently demand-driven: individuals travel not for the sake of mobility itself, but to access services, employment, and other daily necessities [13-15].

Among the various metrics for assessing accessibility, the Route Factor (RF) is one of the most established indicators. Introduced by Chapman (1980), the RF is calculated as the ratio of the actual travel distance between two points over the straight-line (Euclidean) distance between them. A higher RF indicates a less direct, and thus less efficient, travel path [16]. Later, Gutierrez and Monzón (1998) expanded upon this concept with network performance indicators, designed to minimize spatial bias and evaluate the infrastructure potential of transportation networks [17]. One such indicator, the Network Efficiency Index (NEI), compares access to existing infrastructure with an idealized network, offering insights into areas for performance improvement.

Sprawling urban development often leads to land use patterns that are less accessible and more dependent on private vehicle usage. Suburban areas, characterized by low population density, typically experience higher car usage, which contributes to increased traffic congestion, fuel consumption, road accidents, and air pollution [18]. For example, Vulević et al. (2017) examined accessibility in Serbia's central and peripheral regions using the network density index and found strong correlations between accessibility and demographic dynamics, identifying accessibility as a key driver of regional success [19].

Research in urban transportation also emphasizes the importance of integrating land use with transportation planning. Although much attention has been paid to urban systems and planning theories, the practical incorporation of land use–transportation interaction into policy remains underdeveloped [20]. In Iran, several studies have explored these dynamics. Shoorcheh et al. (2016) critiqued Tehran's comprehensive growth management plan, highlighting the resulting sprawl and automobile dependency [21]. Similarly, Gholami et al. (2019) analyzed land use's impact on traffic volumes in Kashan through interviews and spatial data [22]. Nikpour et al. (2018) used indicators such as density, connectivity, and land use mix to examine the relationship between urban form and accessibility in Babolsar, employing Hansen's model and finding a significant correlation [23].

Plasencia-Lozano (2021) utilized route factor and network density indices to assess the transport infrastructure in Spain's Extremadura Region, concluding that economic development is closely tied to the quality of transport connectivity [24]. In a similar effort, Christodoulou et al. (2019) introduced a route factor inspired index to identify infrastructural inefficiencies and guide regional investment priorities [25]. International best practices seen in cities like Stockholm, Portland, Copenhagen, Toronto, and Hong Kong underscore the effectiveness of integrating accessibility measures in transportation policy [26].

The primary advantage of evaluating transportation network performance through accessibility is that it captures the synergy between land use, mobility, and social needs. Unlike mobility-focused assessments, accessibility-based analysis offers a comprehensive perspective by integrating both spatial distribution and transport efficiency, revealing that improving mobility alone is insufficient for achieving effective accessibility.

4. METHODOLOGY

Urban development is a dynamic and ongoing process, particularly in societies experiencing continuous population growth. Such growth inevitably drives physical expansion and land use changes. Whether this expansion occurs in a compact or fragmented form depends on the planning and governance frameworks in place. One of the critical drivers of urban expansion is population growth, and understanding its characteristics enables policymakers to develop appropriate micro and macro-level strategies. In this context, guiding land use change to improve accessibility to services and infrastructure is essential, as inefficient land use can have severe consequences for environmental sustainability and urban livability.

4.1. Study Area

This study focuses on the metropolis of Tehran, the capital and most populous city of Iran. Based on the 2011 census, Tehran's population exceeded 8 million residents. The city covers an area of approximately 616 square kilometers and is administratively divided into 22 districts and 123 urban zones. Tehran is one of the most significant urban centers in the Middle East and faces complex challenges in urban transportation, land use, and environmental management, making it a compelling case for studying the relationship between population distribution, accessibility, and transportation network efficiency.

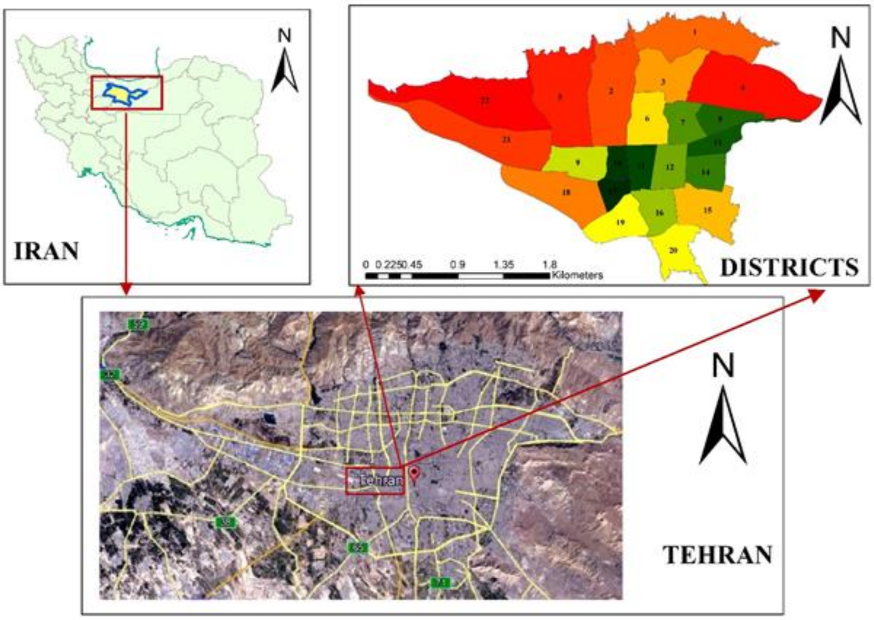

Fig. 1. Location of the study area

4.2. Data collection methods

Arc GIS 10.8 software was used to prepare the study map. Google Earth Pro software was used to estimate the real and ideal distance. Data from the Statistics Center and Tehran Municipality were used to study the population and determine the density of districts. Excel software was used to draw charts, prepare tables and sort data.

4.3. Population density index

Since population growth is important for managers to plan, Figure 2 shows the population changes in Tehran in the last 60 years.

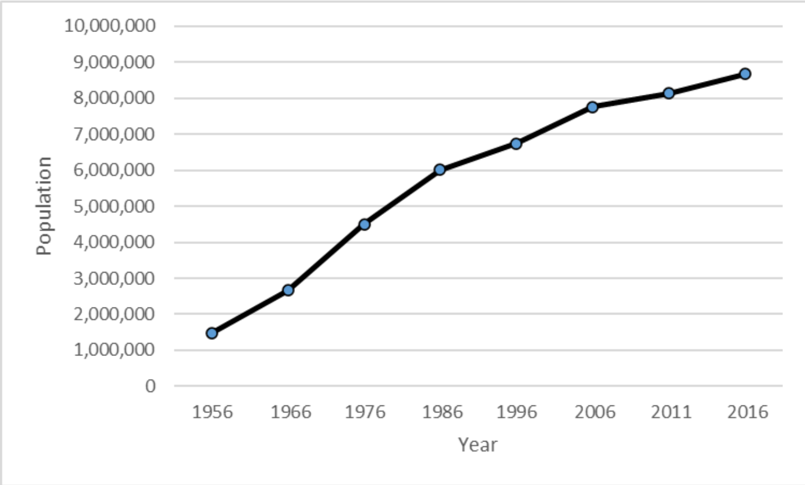

Fig. 2. Population chart of Tehran from 1956 to 2016 [27]

Having the population and housing census data of 2011 and 2016 of the Statistics Center of Iran, the population of 22 districts of Tehran for the year 2021, was predicted using Equation 1 [27].

$$P_n = p_o(1+r)^n \Rightarrow r = \sqrt[n]{\frac{P_n}{P_o}} - 1 \tag{1}$$

Pn: Population at the end of the period (final year)
P0: Population at the beginning of the period (base year)
r : Average annual population growth
n : The time interval between the beginning and the end of the period in years

Then the comparison of the population of the districts in the last ten years is given as shown in Figure 3. In Tehran, in 2021, district 4 with 979826 people (11%) and district 9 with 185771 people (2%) were the most populous and least populated districts of Tehran, respectively. In 2011, district 4 with 861280 people (10.6%) had the highest population and district 22 with 128958 people (1.6%) had the lowest population among the districts of this city.

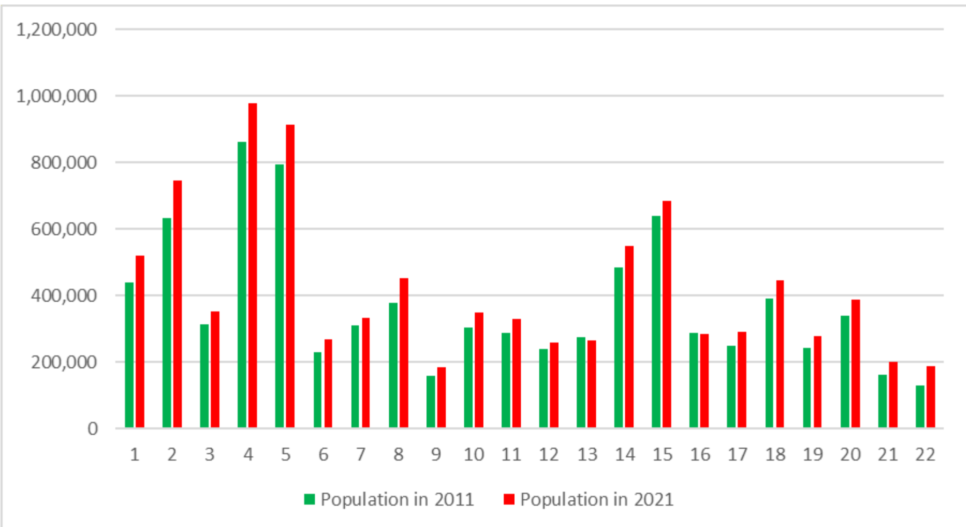

Fig. 3. Population of Tehran city districts in 2011 and 2021

In recent years, Tehran has experienced significant population inflow due to factors such as employment opportunities, income generation, and easy access to public services and social amenities. As a result, the spatial distribution of the population shaped by patterns of human migration and settlement has become a critical component of the city's demographic structure.

To analyze this phenomenon in greater detail, the population data for the year 2021 has been disaggregated at the district level, enabling a clearer assessment of how residents are distributed across the city. This district-level breakdown facilitates the identification of patterns in population concentration, and allows for a more precise evaluation of the role of population growth in urban development.

To further illustrate the spatial dynamics between central and peripheral areas, both a pie chart displaying the percentage of the population across districts and a demarcation map of Tehran were presented together in Figure 4. These visual tools help to distinguish between central urban cores and suburban areas.

The analysis reveals that 66.5% of Tehran's population resides in the peripheral districts, with Districts 4, 5, and 15 representing the highest population shares. In contrast, Districts 9, 21, and 22 account for the lowest percentages of the city's total population. This uneven distribution has substantial implications for urban traffic and transportation systems, as population concentration in peripheral areas often results in longer commutes and greater strain on the transport network. Consequently, understanding population distribution is essential for effective transportation planning and sustainable urban development.

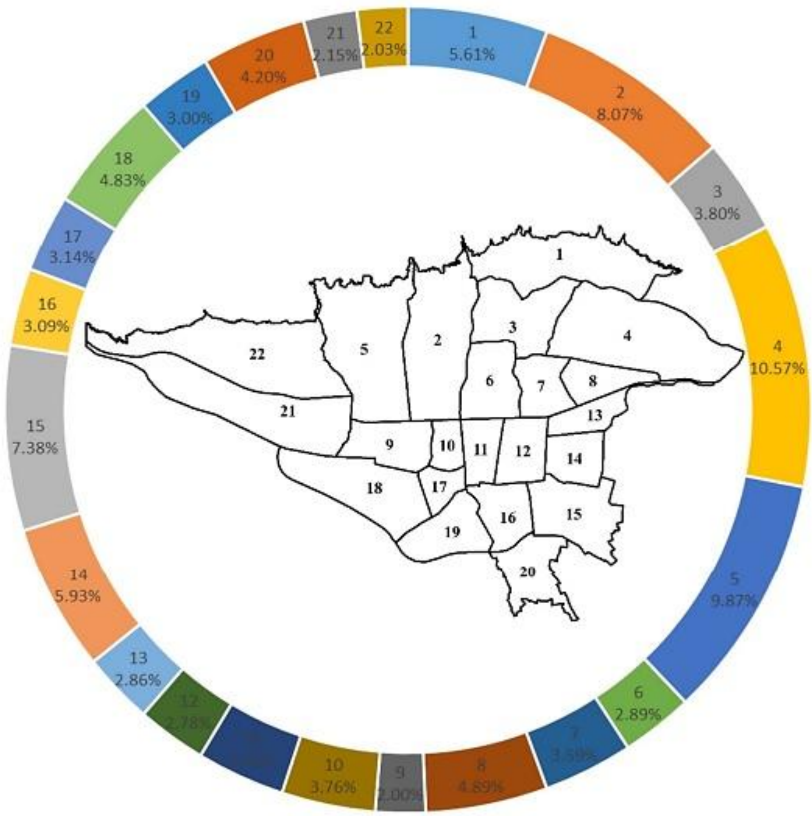

Fig. 4. Comparison of the percentage of population in 22 districts of Tehran in 2021

One of the factors influencing travel demand is density. This factor affects the travel pattern and the length of the trip, so that with increasing density, the length of trips becomes shorter and the use of personal vehicles decreases and the use of public vehicles increases. In terms of comparing population density in 2021 can be obtained. The highest density is related to districts 10, 14 and 17 and the lowest population density is related to districts 22, 21 and

9. After classifying the population density of 2021 into five classes, it can be seen that the suburban districts with high area are in the classes of medium, low and very low population density. People living in these districts have to travel long distances, especially in private cars, to meet their basic needs.

The population density index of Tehran's districts is shown in Figure 5:

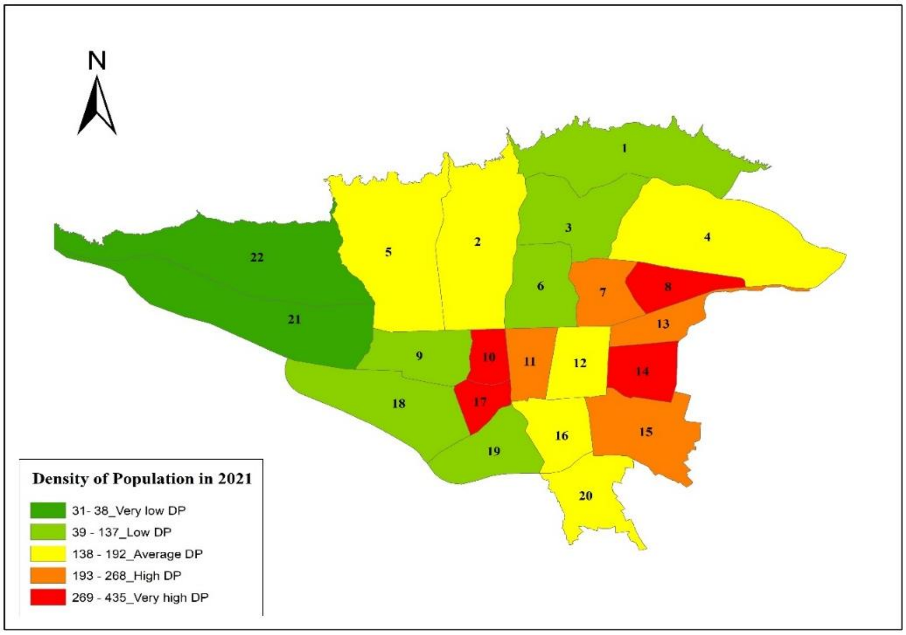

Fig. 5. Population density of Tehran's districts in 2021

4.4. Rout factor accessibility index

Different formulas and relationships can be used to calculates accessibility depending on the available information. In this research, the following relation is given to estimate access. This index reports the efficiency of the transportation network. If there are two or more routes between the origin and destination of the trip, the shortest route is selected. If it is a path, the same path is chosen. The path factor determines the relationship between both real and ideal distances [24, 28]:

$$r_{ij} = \frac{d_{ij}}{dg_{ij}} \tag{2}$$

r_{ij}: The route factor between points i and j
d_{ij}: Minimum distance (actual operating distance) using the transport network between i and j
dg_{ij}: Physical distance in a straight line (ideal distance) from i to j

Using Equation 2, the access between the districts is examined using the route factor, which indicates the quality of the infrastructure between the districts. The ideal operating distance data between districts is routed through Google Earth Pro software and the results after the calculations are given in Table 1:

Table 1. Route factor index of Tehran city districts

Districts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	_	1.37	1.30	1.67	1.32	1.34	1.44	1.54	1.43	1.32	1.37	1.29	1.35	1.62	1.33	1.30	1.39	1.40	1.32	1.40	۱.49	1.22
2		_	1.67	1.29	1.18	2.15	1.74	1.50	1.81	1.47	1.69	1.95	1.46	1.85	1.70	1.53	1.43	1.39	1.53	1.60	1.88	1.24
3			_	1.41	1.35	1.62	1.39	1.61	1.53	1.41	1.42	1.30	1.52	1.71	1.35	1.22	1.35	1.38	1.36	1.48	1.56	1.20
4				_	1.16	1.44	1.37	1.48	1.44	۱،۳۱	1.32	1.24	۱،۳۱	1.22	1.32	1.43	1.56	1.59	1.39	1.47	1.42	1.17
5					_	1.54	1.39	1.33	2.27	1.62	1.63	1.76	1.38	1.64	1.58	1.53	1.64	1.77	1.65	1.56	2.40	1.36
6						_	1.36	1.27	1.81	1.68	1.37	1.79	1.28	1.64	1.44	1.33	1.36	1.62	1.39	1.33	1.69	1.33
7							_	1.49	1.87	1.35	1.52	1.58	1.46	1.83	1.50	1.37	1.31	2.15	2.01	1.26	1.39	1.28
8								_	1.31	1.23	1.38	1.48	1.48	1.29	1.42	1.71	1.83	1.69	1.61	1.52	1.52	1.17
9									_	2.36	2.01	1.82	1.47	1.59	1.66	1.69	1.94	1.71	1.93	1.55	1.30	1.77
10										_	1.36	1.77	1.20	1.31	1.34	1.51	1.52	1.26	1.73	1.50	1.68	1.48
11											_	2.19	1.31	1.41	1.74	1.53	1.24	1.19	1.53	1.42	1.48	1.43
12												_	1.66	1.57	1.35	1.62	1.44	1.30	1.59	1.24	1.52	1.50
13													_	1.35	1.67	1.71	1.28	1.71	1.55	1.56	1.26	1.25
14														_	1.65	1.59	1.28	1.67	1.56	1.56	1.55	1.40
15															_	1.58	1.28	1.51	1.51	2.06	1.34	1.40
16																_	1.80	1.67	1.40	1.56	1.83	1.45
17																	_	1.40	1.74	1.63	1.64	1.47
18																		_	1.96	1.45	1.85	1.72
19																			_	1.50	1.84	1.53
20																				_	1.53	1.43
21																					_	2.00
22																						_

The results in Table 1 show five levels of accessibility between districts of Tehran. The lowest value of the route factor (4,5) is 1.16, which means that the distance traveled through the street transport network is 16% longer than the ideal route (straight line). Because the value obtained for the two districts is the lowest value in the table, it indicates the sub-urbanity of the two districts and high efficiency. In general, districts with low route factor values are due to the suburban of those districts, which indicate the best communication with other municipal districts and the most efficient street network.

The maximum value of the route factor between districts (4,21) is 2.40, which indicates an exaggerated difference between the road transport network and the ideal route. Despite the proximity of the two districts, the exaggerated index is approximately 2.5 times ideal route. This means that the operational route between the two districts has a greater deviation than the ideal. In general, neighboring districts have a high amount of route factor. Because the ideal distance between them is very small compared to the real distance. Districts with average route factor values include the districts between the suburb and the center. The average route factor of Tehran city is 1.52, which indicates the average level of accessibility.

Table 2. Route factor accessibility levels analysis in Tehran's districts

Districts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	_	1.37	1.30	1.67	1.32	1.34	1.44	1.54	1.43	1.32	1.37	1.29	1.35	1.64	1.33	1.30	1.39	1.40	1.32	1.40	1.49	1.22
2		_	1.67	1.29	1.18	2.15	1.74	1.50	1.81	1.47	1.69	1.95	1.46	1.85	1.70	1.53	1.43	1.39	1.53	1.60	1.88	1.24
3			_	1.41	1.35	1.62	1.39	1.61	1.53	1.41	1.42	1.30	1.52	1.71	1.35	1.22	1.35	1.38	1.36	1.48	1.56	1.20
4				_	1.16	1.44	1.37	1.48	1.44	1.31	1.32	1.24	1.31	1.22	1.32	1.43	1.56	1.59	1.39	1.47	1.42	1.17
5					_	1.54	1.39	1.33	2.27	1.62	1.63	1.76	1.38	1.64	1.58	1.53	1.64	1.77	1.65	1.56	2.40	1.36
6						_	1.36	1.27	1.81	1.68	1.37	1.79	1.28	1.64	1.44	1.33	1.36	1.62	1.39	1.33	1.69	1.33
7							_	1.49	1.87	1.35	1.52	1.58	1.46	1.83	1.50	1.37	1.31	2.15	2.01	1.26	1.39	1.28
8								_	1.31	1.23	1.38	1.48	1.48	1.29	1.42	1.71	1.83	1.69	1.61	1.52	1.52	1.17
9									_	2.36	2.01	1.82	1.47	1.59	1.66	1.69	1.94	1.71	1.93	1.55	1.30	1.77
10										_	1.36	1.77	1.20	1.31	1.34	1.51	1.52	1.26	1.73	1.50	1.68	1.48
11											_	2.19	1.31	1.41	1.74	1.53	1.24	1.19	1.53	1.42	1.48	1.43
12												_	1.66	1.57	1.35	1.62	1.44	1.30	1.59	1.24	1.52	1.50
13													_	1.35	1.67	1.71	1.28	1.71	1.55	1.56	1.26	1.25
14														_	1.65	1.59	1.28	1.67	1.56	1.56	1.55	1.40
15															_	1.58	1.28	1.51	1.51	2.06	1.34	1.40
16																_	1.80	1.67	1.40	1.56	1.83	1.45
17																	_	1.40	1.74	1.63	1.64	1.47
18																		_	1.96	1.45	1.85	1.72
19																			_	1.50	1.84	1.53
20																				_	1.53	1.43
21																					_	2.00
22																						_

	Very good accessibility	$1 < r_{ij} \leq 1.20$
	Good accessibility	$1.20 < r_{ij} \leq 1.40$
	Average accessibility	$1.40 < r_{ij} \leq 1.60$
	Poor accessibility	$1.60 < r_{ij} \leq 1.80$
	Very poor accessibility	$r_{ij} > 1.80$

Table 3. Percentage of accessibility levels in the districts

Accessibility quality	Number	Percent of total
Very good accessibility	7	3%
Good accessibility	80	35%
Average accessibility	74	32%
Poor accessibility	45	19%
Very poor accessibility	25	11%
Total route factors	231	100%

According to Table 3, a total of 30% of districts have poor and very poor accessibility levels and 32% have average accessibility level and 38% of districts have good and very good accessibility levels. This means that most city trips do not have an efficient network.

5. DISCUSSION AND CONCLUSION

The examination of population trends over the past six decades reveals a continuous increase in Tehran's population, emphasizing the need for serious attention from urban managers and planners. As shown in Figure 2, this steady growth trajectory highlights the city's ongoing urban expansion and the resulting pressure on its infrastructure and services.

According to Figure 3, in 2011, District 4 recorded the highest population with 861,280 residents, while District 22 had the lowest population, with 128,958 residents. By 2021, District 4 retained its top rank, increasing to 979,824 people, whereas District 9 dropped to the lowest position with a population of 185,771. A comparative analysis over the last decade shows that population growth has been especially prominent in the northeastern and northwestern peripheral districts.

Based on the 2021 population percentages illustrated in Figure 4, District 4 accounts for 10.57% of the city's population the highest among all districts while District 9 represents only 2%, the lowest share. Overall, approximately 67% of Tehran's population is concentrated in the outer (peripheral) districts, reflecting the suburbanization trend.

In terms of population density in 2021 (Figure 5), the highest densities are observed in Districts 10, 14, and 17, while Districts 22, 21, and 9 have the lowest densities. Notably, the central districts tend to have higher population densities compared to the outskirts. The exception is District 9, which despite being centrally located exhibits low density due to the presence of Mehrabad Airport, military installations, and non-residential zones near Azadi Square, making large areas uninhabitable.

When classifying population density into five categories, it becomes evident that outlying districts with larger land areas typically fall into the medium to very low density classes. Residents in these districts often rely on private vehicles for commuting long distances to access essential services and amenities.

To assess the efficiency of Tehran's road transportation network, the Route Factor was employed. This indicator compares the actual travel distance through the street network to the ideal straight-line distance between origins and destinations. As shown in Table 1, the lowest route factor value (1.16) corresponds to the route between Districts 4 and 5, indicating that the actual travel path is only 16% longer than the ideal route suggesting relatively efficient connectivity.

The overall accessibility levels were categorized into five classes: *very poor*, *poor*, *moderate*, *good*, and *very good*. According to the results in Table 3:

- 38% of inter-district connections are at good or very good levels of accessibility, implying relatively short travel distances and efficient connectivity.
- 32% fall under the moderate category.
- 30% of connections are rated poor or very poor, indicating inefficient transport links that may hinder accessibility and mobility.

Based on these assessments, the overall accessibility index for Tehran is calculated as 1.52, which falls within the moderate range. These findings offer valuable insights for urban policymakers and transportation planners, emphasizing the need for targeted investment in transport infrastructure to improve connectivity—especially between districts with low accessibility levels. The integration of population data with transport efficiency metrics provides a comprehensive framework for addressing Tehran's mobility challenges.

Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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