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Multimodal Transportation Planning for Intercity Travel Between Alexandria and Borg Al Arab Cities

Adel Elmenshawy[1], Ahmed Idris[2], Ahmed Nasr[1], Amira Mohamed[1*]

[1] Department of Architectural Engineering and Environmental Design, Arab Academy for Science, Technology and Maritime Transport, Alexandria 21913, Egypt
[2] Department of Civil Engineering and Environmental Design, Arab Academy for Science, Technology and Maritime Transport, Alexandria 21913, Egypt

Corresponding Author Email: amiramohamed9553@gmail.com

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ABSTRACT

Traffic congestion in Egyptian cities is a major issue due to unplanned and private vehicles, impacting land use, housing, and development. A study aims to improve accessibility and mobility by implementing a multimodal transportation system, reducing private vehicle usage, and attracting sustainable transit investments. The research questions include mode of transport, destination distance, passenger walking distance, integration principles, and multimodal effects on land use and attraction. The study employs a qualitative approach, utilizing data collection, literature reviews, and analytical examples. It employs a geographic information system (GIS) analysis program to examine existing and proposed cases, demonstrating the effectiveness of multimodal transportation in connecting intercity, promoting smart urban growth, and attracting investments. It transforms land use from mono-use to diverse, contributing alternative downtown and activating job opportunities. This approach revitalizes neglected lands, reduces traffic congestion, and creates green spaces. It also encourages the TOD concept. Furthermore, it improves the environment and health and reduces urban congestion, contributing to urban development. Overall, multimodal transportation is a significant contributor to urban growth. Moreover, future policies should consider various transportation modes, public-private partnerships, infrastructure investment, technology integration, accessibility, and sustainable modes, with community engagement and policy support prioritizing multimodal transportation and raising awareness.

1. INTRODUCTION

The concentration of activities in downtown cores and the marginalization of suburban areas have been spurred by industrialization and urbanization, leading to unplanned population growth and the spread of slums, ultimately causing a surge in traffic congestion. As a result, megacities have expanded, prompting increased demand for enhanced mobility, accessibility, and comfort within urban transportation systems. This has necessitated a shift and development from traditional transportation planning methodologies to integrating them with multimodal transportation planning strategies [1].

The "predict and provide" approach, on which traditional transportation planning is based, forecasts future trip-making behavior based on current transportation and land use plans and market trends, offering limited solutions to accommodate vehicular traffic demand rather than attempting to shape it. Consequently, developing multimodal transportation and integrating it with the traditional four-step model, as a contemporary approach to transport planning, has brought about a qualitative shift in land use dynamics. This shift aimed at diversifying activities and devising innovative solutions to combat traffic congestion. The implementation of multimodal transportation planning focuses on broadening the range of transportation choices available to individuals, coordinating land use decisions, and fostering a vibrant mix of activities, as shown in Figure 1 [1].

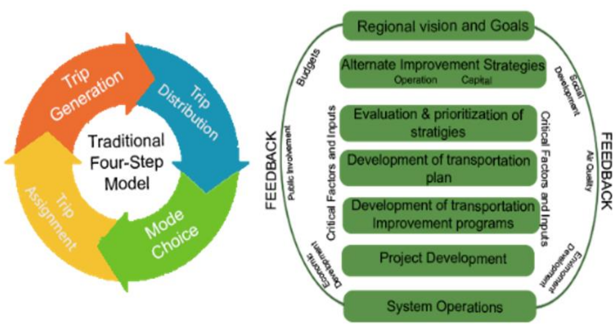


Figure 1. Traditional and multimodal transportation model steps
Source: The study [1] (Edited by author)

The key strategies emphasized by multimodal transportation planning include investing in multimodal transportation infrastructure, establishing efficient connections, and creating dense, interconnected streets conducive to transit-oriented development (TOD) principles, such as walking and cycling. Additionally, the concept emphasized the development of activity centers and revitalized neglected urban areas to render them more functional and vibrant [2]. Additionally, mobility is emphasized by multimodal transportation planning, which involves the utilization of various transportation modes by people to move between destinations, and accessibility, which measures the ease of reaching desired activities and services across defined geographic areas (e.g., traveling to many destinations from one origin). Moreover, transportation and land use are integrated to offer diverse mobility options, considering land use, system connectivity, and the interconnectedness of modes for the safe and efficient movement of people and long-term community viability, leveraging the full value of infrastructure investments. In addition, multimodal transportation planning is context sensitive, holistic, collaborative, and integrated between modes, focusing on broader land-use issues, leveraging intergovernmental partnerships, and examining pedestrian, transit, bicycling, and automobile travel [1, 3].

Furthermore, public transportation systems are provided with distinct functional positioning through multimodal transportation planning, which contributes to social development and equity by offering quality services to travelers through the cooperation of multiple modes and transit technologies [3].

A practical solution to reduce traffic congestion, reduce the number of vehicle kilometers traveled, and reduce the difficulties faced by low-income individuals living in low-density regions due to the limited availability of private mobility options or economic constraints is provided by multimodal transportation planning. Furthermore, the integration of different modes with public transit systems can significantly reduce travel time, emissions, and costs compared to those of standalone single-mode systems [3].

Figure 2. The traffic congestion in Alexandria

The intercity between Alexandria and Bodrum El Arab faces significant transportation issues due to the lack of public transportation stations, the availability of different transportation means, and the spread of unplanned and private transportation. This has led to traffic congestion, increased population density in the city Centre, neglect of suburbs, and increased slums. Statistics and field observations show delays in arrival, affecting many areas and causing traffic paralysis (as shown in Figure 2). It was also tracked and observed at different times of the day through Google traffic. For example, the main arteries within the city have an average flow speed of 60 km/h, but at work peak time, they move slower than normal (67%) and in normal time.

2. RESEARCH PROBLEM

The primary challenge addressed in this study is the inadequate transportation connectivity between Alexandria and Borg El Arab, which currently depends on informal transportation modes. This issue has given rise to various impediments, such as the promotion of increased internal migration from mono-use cities and suburbs to a more multiuse city (Alexandria) with better transportation facilities. This shift has led to increased population density and the proliferation of slums around transportation hubs in Alexandria. According to the General Mobilization and Statistics Authority, internal migration in Alexandria exceeds 15% annually (as shown in Figure 3). Therefore, unplanned slums occupy 45% of the urban area. This has negatively impacted infrastructure and transportation systems. Consequently, there is a scarcity of residents and investments in areas with restricted transportation options, including intercity areas and the Borg El-Arab. In addition, the increase in population density, coupled with the state's disregard of improving public transportation and addressing its inefficiencies, has led to an increase in the use of informal means of transportation and increased dependence on private cars. This has contributed to the development of severe traffic congestion.

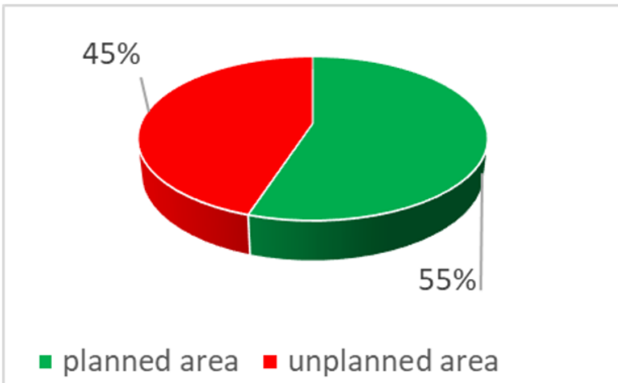


Figure 3. The percentage for informal settelments

3. METHODOLOGY

This research examines the effects of multimodal transportation on enhancing intercity connectivity (Alexandria-Borg El-Arab), land use, and accessibility. The study employs several methodological approaches, including the following:

1. The entropy equation is a tool used in spatial analysis to measure the value of land use systems and spatial phenomena in GIS. It provides a quantitative measure of spatial distribution, which is crucial for objective analysis. The

equation is versatile, applicable to various types of spatial data, and allows for comparative analysis to identify areas of high and low entropy. It is particularly useful when assessing the overall distribution pattern rather than specific clusters or central tendencies. Its application in different contexts makes it a valuable tool for understanding spatial phenomena. It will be used in a case study to assess the current land use, identify its deficiencies, and incorporate, with development, these findings into the proposal. The proposed stations are identified based on land-use diversity, land-use density is quantified, and land-use data are generated through the application of the entropy equation, which assesses the homogeneity of an area and calculates activity density and diversity indicators.

$$\text{Entropy} = -\frac{\Sigma_j (P_j \times \ln p_j)}{Lnj} \quad (1)$$

where,

P_j = the proportion of land development of the j_{th} type;

J_i = the number of different land use types.

2. Linear regression analysis was used to predict the future population distribution based on the entropy value of the proposed land use. Through population data: existing population data for each geographic region, providing a trend that helps predict future values.

3. A geographic information system (GIS)-based model of the existing and proposed land use and transit railway network for the Alexandria-Borg El-Arab corridor was constructed using the standard version of the ESRI ArcGIS 10.8, which based modeling is a framework for capturing, storing, analyzing, and managing spatial and geographic data. It offers advantages such as detailed spatial analysis, integration of multiple data sources, and powerful visualization tools. GIS-based models provide more accurate and contextually relevant results than traditional statistical methods and enhance remote sensing by providing tools for in-depth analysis and interpretation. The key advantage of GIS-based modeling is its ability to handle large volumes of data, provide detailed visualizations, and integrate multiple data sources, making it more reliable in various contexts, so it's more accurate and suitable for case study than (GEODA, ILWIS, OPENJUMP, …).

The data collection and analysis techniques used in this study are designed to provide a comprehensive understanding of the impact of multimodal transportation on improving connectivity, land use, and accessibility in a specified region.

4. LITERATURE REVIEW

4.1 Multimodal transportation system

According to critical analysis of past studies, that around 55% of the world's population lives in urban areas, but these areas only represent a small percentage of the total surface area. The impact of daily commuting patterns and mobility services on environmental factors, such as natural resource usage, pollution, and quality of life, is crucial for sustainable development goals. Numerous studies aim to optimize transportation systems planning and usage in urban scenarios, with multimodal transportation systems being a significant solution. However, the study of multimodal transportation systems has been underrepresented in travel surveying efforts, affecting researchers and professionals in travel modeling, urban planning, public health, and urban design [3]. In addition, multimodal transportation equity and justice have been a central focus in transport studies, with various conceptualizations and approaches for assessing the equity performance of transport systems [4]. So, Multimodal transportation involves using multiple modes of transportation, such as walking, cycling, automobiles, and public transit, to enhance accessibility and mobility from the origin to the final destination. This form of transportation is crucial for international travel and plays a significant role in the development and expansion of cities. It is important to note that incorporating various modes of transportation can improve accessibility and mobility, making it a crucial factor in urban planning and development. By utilizing multimodal transportation, we can create a more sustainable and efficient transportation system that benefits both individuals and communities. In addition, two main types of multimodal transportation are classified: road transportation (motorized-nonmotorized) and rail transportation (regional rail-urban rail) (as shown in Figure 4).

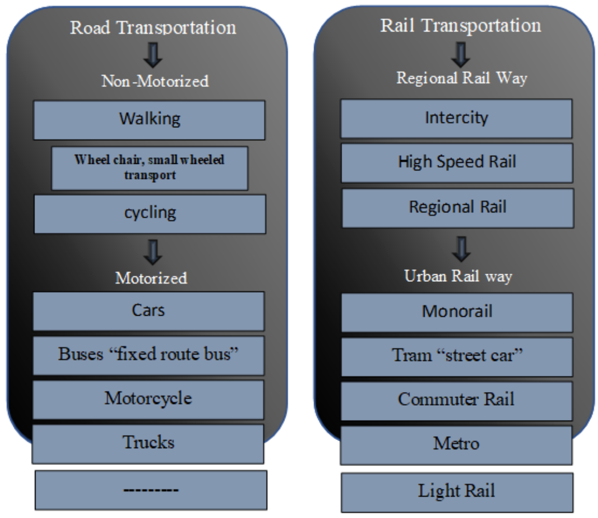


Figure 4. The multimodal transportation types

4.2 Transit oriented development (TOD)

The significance of multimodal transportation and its role in promoting transit-oriented development (TOD), a key element of smart growth that emphasizes mixed-use buildings, diverse housing options, transportation, development within existing neighbourhoods, and active community engagement, are topics of discussion in the literature review. The tenets of this approach are grounded in ten principles, including mixed land use, compact design, diverse housing options, walkable neighbourhoods, fostering unique communities, preserving open spaces, directing development toward established communities, providing various transportation options, making development decisions predictable, fair, and cost-effective, and encouraging collaboration between communities and stakeholders [5]. This study focuses on the relationship between station location and the level of service (LOS) of urban streets and how these factors influence efficient and equitable transportation systems. This section begins with an examination of the literature on the factors that influence the use of multimodal transportation and then delves into the determinants of mode choice, with an emphasis on spatial and contextual elements.

4.3 Accessibility measures

Mobility is the essential component of transportation planning, but accessibility has gained attention as a supplement to traditional metrics. Accessibility encompasses mobility, proximity, and opportunity, ensuring easy access to activities across multiple locations. The accessibility-based approach provides a comprehensive view of transportation performance. Enhancing accessibility can involve reducing travel time, speeding up travel, and making transportation more affordable. This strategy also encourages alternative land uses and demand management techniques to reduce traffic and environmental impact [6].

Accessibility is closely linked to land use patterns and transportation systems, and data on these factors is crucial for evaluating accessibility. Techniques like place rank, gravity-based, utility-based, constraint-based, composite, and cumulative opportunity approaches are commonly used in transportation planning [7].

The cumulative opportunity considered one of the simplest methods to measure accessibility is to count the number of opportunities that can be reached, such as jobs, coffee shops, and restaurants. This can be done by counting the number of opportunities that can be reached within a given duration or distance. This is known as the cumulative opportunity method. Both the expense and the appeal of getting to the work are ignored by this strategy. In contrast, the accessibility metric based on gravity takes opportunities' appeal into account, but it includes more variables. Using an impedance that decreases with trip time or distance, it weighs opportunities. Calculations are made more sophisticated by using its impedance function to estimate the impedance factor and compute destination weights. As a result of the clear connection between gravity-based measurements and cumulative opportunity. So, cumulative opportunity is still employed in this investigation [6].

5. MULTIMODAL SUCCESS IN VARIOUS CITIES

5.1 London

The transit for London (TFL) state planning commission acknowledged the necessity of establishing firm guidelines for directing the planning process before creating a multimodal transportation plan. Early decisions, made during the early phases of development, can significantly impact urban corridors and user behavior, influencing factors such as the mix of land uses and the quality of transportation links. Thus, it is crucial to recognize the following planning and design concepts for new urban mobility [8].

The design of the stations must provide an easy interchange system between modes of transport, which plays a crucial role in competing with taxi rental or delivery, and interchange from railways or buses to local shuttle buses, parcel receiving stations, or any other type. These mobility hubs should be designed to be conveniently visible from nearby streets and should include amenities such as wide sidewalks, covered parking, public parks, manned convenience stands for snacks, and travel information. To facilitate interchange, ample public space should be provided and protected for transport hubs.

Therefore, TFL, which applies multimodal technology through a multimodal transportation system in London, comprises various options, including walking, cycling, driving, riding, buses, Docklands Light Rail, trams, national rail, and taxis. According to Williams et al. [9], the national rail system consists of five renovated lines with peak speeds of 125 mph (200 km/h) and one high-speed line designed for speeds up to 186 mph (300 km/h). The various types of trains operated include Class 374, Eurostar e320, Class 395 Javelin, Class 800, and Class 390 Pendolino. The London Underground network has speeds ranging from 15 mph to 60 mph, while overground trains have a maximum speed of 75 mph but are limited to 45 mph due to network constraints. The tram network spans 28 km (17 mi) and has a capacity of 208 passengers. With fewer stations and automatic train operation, the Victoria Line has faster trains that can reach speeds of up to 50 mph (80 km/h) in one direction. The multimodal system also includes urban features such as safety, comfort, ancillary amenities, integration with the Internet of Things, affordability, availability, the TOD concept, and well-integrated modes of transportation systems through safe crossings, timetables, tickets, and fares (the Oyster card with zoning tariff system).

However, the city successfully improved the level of integration between public transport modes, nonmotorized modes and city infrastructure through the use of interchange stations and the provision of park and ride areas. Therefore, TFL prioritizes the use of multimodal transportation modes and walking rather than cars, which focuses on the TOD concept. However, no other similar metropolis in the world has experienced a change of this magnitude. In addition, multimodal transportation in London has had a positive effect on the urban fabric of the city by reaching a smooth and strongly interdependent multimodal network, which leads to urban growth, diversifying activities, and reducing internal migration. This has led to the development of urban corridors, changing their functions and activities, and balancing traffic while supporting walking and cycling with dedicated lanes and safer crossings.

5.2 Hong Kong (HK)

The transportation infrastructure in HK encompasses a range of modes, including ferry, walking, cycling, driving, light bus, metro, cable car, MRT rail, LRT, and taxi. The Mass Transit Railway (MTR) constitutes the primary rail system in Hong Kong, with 167 stations distributed across HK Island and the New Territories and 10 lines operating every 2-4 minutes. The MTR system spans 240.6 km of rail, comprising both light subsurface and aboveground tracks, and includes 98 heavy rail stations, 68 light rail stops, and one high-speed rail terminal. The MRT high-speed rail is the fastest cross-border land transit route in Hong Kong, achieving speeds of up to 350 km/h in the HK section and 200 km/h in the mainland section [10-12].

HK has developed an extensive transportation network that facilitates the efficient movement of people and goods and contributes to the city's social and economic development in an environmentally sustainable manner. The key components of this system include multimodal transportation planning, land use diversity, and the potential for increased commercial value [13, 14].

The MTR primarily serves the northern part of HK Island, while buses are widely available throughout the city, including in the southern region. The tramline operates solely in the northern part of HK Island, with six routes and 120 tram cars running every 2-4 minutes. Additionally, ferries offer a convenient and cost-effective mode of transportation between

HK Island and Kowloon and are the only means of transportation to the Outlying Islands. Taxis in HK are classified into three categories, with red, green, and blue taxis providing services to all metropolitan areas. Green taxis cater to new areas. Improving the station infrastructure is essential for providing a positive passenger experience. Transit organizations should ensure that stops are designed to meet quality requirements, such as having an elevated area for improved safety and providing relevant information to passengers, including fare information, schedules, and route maps. Transfer stations should be well designed to facilitate seamless transfers between different modes of transportation, such as the recent development in HK, which requires passengers to take only a few steps between vehicles on the same platform level. This approach not only improves journey time and passenger comfort but also ensures that transit times are minimized. As the attractiveness of public transportation systems is heavily influenced by the perception of comfort, it is crucial that stations are accessible under all weather conditions and provide suitable protection.

To improve the efficiency of public transportation, it is essential to integrate land use and transport planning and study the impact of railways on passenger movement. This will reduce the need for travel and expensive infrastructure. Better coordination between different transportation modes is also important, as is timely provision of transport infrastructure that aligns with actual demand. Furthermore, new technologies should be used to strike a balance between demand for transportation and how it is met. Passenger movements can be influenced by various modes, and it is crucial to consider their impact on the transportation system and the environment.

The optimal planning process to achieve safer and more convenient pedestrian facilities is widely regarded as the most ecologically friendly form of transportation. To enhance the use of this mode of transportation, three key areas can be addressed: access to public transport, direct pedestrian links, and the pedestrianization of local streets. Additionally, it is crucial to consider public opinion and determine whether this is the preferred transportation system for the people of Hong Kong. By increasing the focus on pedestrians in land-use and transportation planning and promoting the use of efficient mass transportation, particularly rail, the transportation system can be made more effective. The economic aspect of transportation planning involves assessing whether the transportation plan is cost-effective for the community. A developmental study is being conducted to determine whether the transportation plan contributes to land use and other forms of development. Furthermore, the study considers the requirements of current and future generations, in accordance with the statutory Outline Zoning Plans (OZP), including reviewing building heights and densities for the future.

However, the growing traffic volume may also present challenges for land value capture initiatives. Property prices near railway lines can increase by 5% to 17%, while incorporating transit-oriented design features, such as pedestrian-friendly buildings and station linkages, can potentially lead to a 30% premium [15].

5.3 Doha

Doha has implemented a multimodal transportation system that includes various modes of transportation, such as walking, cycling, driving, buses, metros, trams, and taxis. The Doha Metro and Lusail Tram are considered the main modes of transportation in Doha. The Doha Metro Network is a 350-kilometer-long project designed to connect all major Olympic venues. The network consists of 98 stations served by the four lines of the metro. Each station has an elevator, and every rail vehicle has room for strollers and wheelchairs [16]. Additionally, Free Metro Link buses travel practical routes between 2 and 5 km from stations [17]. The Lusail Tram is a 30.5 km network with 36 stations and four main tramlines. Lusail and Legtaifiya are the two interchange stations where the Lusail Tram and Doha Metro are connected. Trams are greener and handle traffic better than buses, and they use roads more efficiently, as one train may replace approximately 40 automobiles. Buses also play a significant role in Doha, covering the majority of the city and nearby communities. All bus lines are at least 700–800 meters away from each servicing point via foot. There are two Doha Metro bus networks, the Metrolink and the Metro Express. 19 Metrolink lines operate every day of the week, and there is no cost for the buses [18, 19].

It improved the utilization of undeveloped land in the metropolitan area and created a more compact city. The proposed metro network presents an opportunity to develop, plan, and revitalize important neighbourhoods and precincts within Doha. This will enhance the city's quality of life. The current ring road network and conventional radial route pattern have led to urban sprawl outside the city centre, with restrictive zoning laws allowing for the expansion of medium- and low-density housing and residential settlements. Additionally, outer-city shopping malls, schools, and sports facilities have been developed in areas that can only be accessed by private vehicles due to a lack of public transport alternatives. The urbanization of the central business district has resulted in the abandonment of traditional residential and commercial spaces in Favor of contemporary office and residential structures. Consequently, many Qatari households relocated to suburban areas in search of a more rural lifestyle. In Doha, various types of urban land use include industrial land, which is strategically significant to the nation's economic health and development, especially QP industrial cities, and land inside a designated zone subject to certain laws intended to attract foreign investment, known as the Qatar Economic Zone. The application of transit-oriented development (TOD) has demonstrated that such integration generates economic benefits in the vicinity of these nodes, resulting in an increase in land value [16, 20].

6. SUCCESS PREVIOUS STUDIES

These examples were shared in the application of multimodal transportation to implementation and respect theories and considerations.

6.1 Multimodal effects on transport connectivity

Transport integration and connectivity are strongly associated. It is known as the "density of connections" in a transport network, and accessibility tends to rise with more connectedness. As a result, the effectiveness of intermodal transfers within the urban mobility system determines the availability of various mobility subsystems as well as their functionality. Consequently, the physical presence of intermodal activities and the high standard of comfort at the interchanges are seen as two strongly associated and significant features of connection, as shown in Figure 5. Differentiating between the many modes of transportation that passengers can use to get to a transit station—such as a bus, shuttle, taxi, car, bicycle, or foot—is made possible by modal interchanges. As a result, the design of the station should have elements required to give users easy access to the station. Walking is typically the last form of transportation used before boarding a transit vehicle. As pedestrians interact with various modes at the station, the design approach should guarantee their smooth and safe movements, as shown in Figure 6.

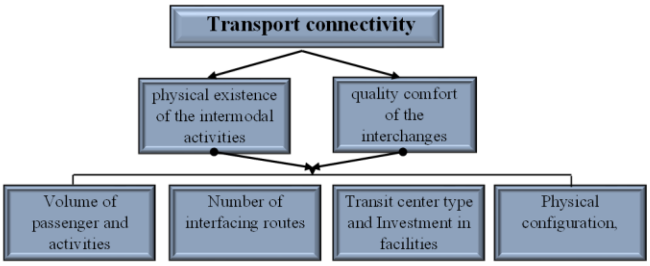


Figure 5. Transport connectivity system principles

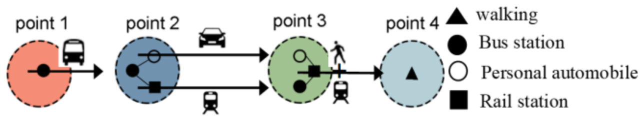


Figure 6. Transport connectivity chain and integration
Source: The study [21]

6.2 Effects of the multimodal scale on land use

Accessibility in land use is influenced by factors like walkability, density, mix, and connection. Smart development, which involves a more accessible land use pattern, reduces mobility for accessing activities and destinations, based on the imagined triangle linking home, work, and services (as shown in Figure 7) [22].

Enhancing accessibility and reduce transportation costs, it's essential to expand services and improve transportation options. Therefore, the amount of travel needed to get to a place increase with its dispersion. The amount of time needed to go between two places will be halved if they are half a mile apart on average. People can take public transportation and walk to locations if they are fairly near to each other. Thus, activities tend to be more densely packed and accessible, and transportation alternatives might be enhanced by lower travel distances as shown in Figure 8 [22].

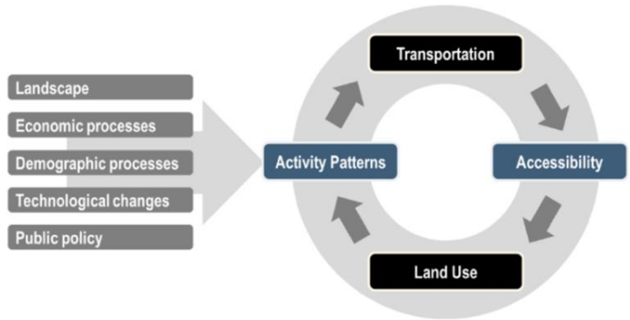


Figure 7. Transportation-land use interaction

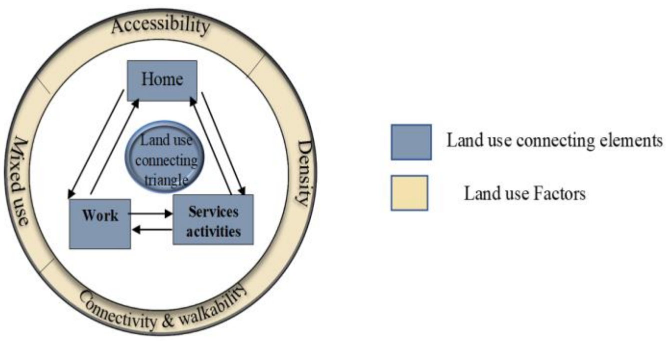


Figure 8. Land use and multimodal access

Table 1. Planning elements and strategies for the integration of multimodal transportation and land use

Consideration Planning Elements	Land Use Organization/ Location Efficiency	The strong central core comprises transit hubs, government buildings, town squares, with surrounding nonresidential development, land use divisions, and high-density residential construction.
	Land Use Mix and Balance	The urban center should have a balanced mix of land uses, significant land uses, land use ratios, and jobs to population ratios.
	Activity Centers	Walking, biking, and public transit can be made easier as alternatives to driving by the proximity to nearby residential areas, retail centers, services, and job centers.
Strategies	Density	Employment and population by geographic unit expressed as (as: per square mile).
	Diversity	The combination and degree of balance of land uses, usually consisting of both residential and commercial development.
	Design	Neighborhood layout and street characteristics, including connectivity, sidewalks, and design features like shade, scenery, and attractive homes and stores, enhance pedestrian and bicycle-friendliness in an area.
	Destination Accessibility	The ease or convenience of trip destinations from the point of origin is often measured at the zonal level, referring to the distance from major centers.
	Distance to Transit	Access to transit from home or work, such as a bus or rail stop within ¼ to ½ mile of trip origin, is made easier.

Source: The study [21]

6.3 Integrating multimodal data with land use

Multimodal transportation planning emphasizes the interconnectedness of transportation and land use, focusing on managing travel demand and coordinating land use strategies to address traffic congestion and population overpopulation. It is context sensitive, holistic through identifying and integrating transportation solutions for land use issues, ensuring the long-term viability of a corridor, collaborative, and multimodal, considering pedestrian, transit, bicycling, automobile, and rail modes, and identifying supporting strategies. To achieve high integration between multimodal transportation and land use, existing and proposed maps should be reviewed, transportation systems identified, and appropriate organizations, mixes, and densities of multimodal options should be considered according to the following standards and strategies [21], as shown in Table 1.

6.4 Road and transportation safety measures

The extent of safety through maintenance, design, and infrastructure can be measured through a survey of traffic fatalities and injuries. To ensure optimal safety, safety devices such as cameras and alarms should be included. Additionally, public transportation stops should be equipped with adjacent pedestrian-oriented lighting to ensure visibility, and stops should not have limited or obstructed visibility to adjacent buildings, as shown in Figure 9 [22, 23].

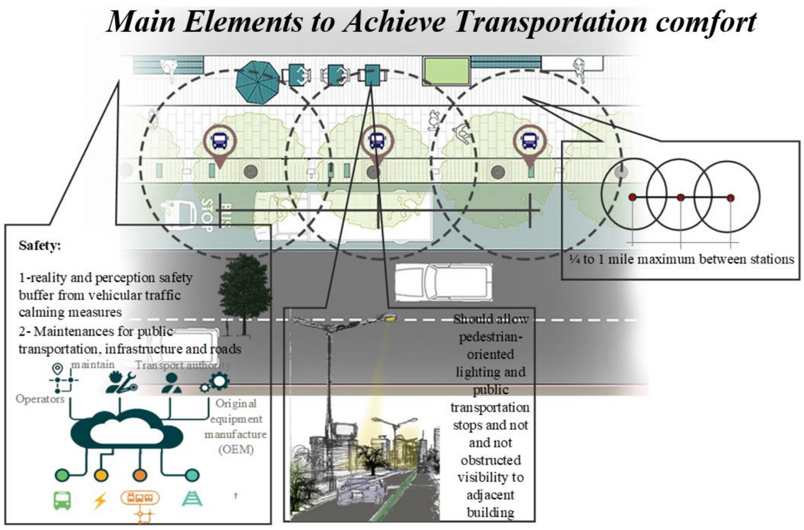


Figure 9. Safety elements

Table 2. Factors affecting the PLOS

Road Cross	Crosswalk convenience factors include the distance and location of midblock crosswalks, the quality of crossing facilities, including waiting space, crossing distance, and obstruction, and the total time spent by pedestrians waiting to cross the street.
Sidewalk and Path	Sidewalk Width Impact on Safety Perception • Greater sidewalk width enhances pedestrian safety. • Comfort increases, resulting in higher LOS (Jena, 2019).
Roadway Width	Increased Road Width Decreases LOS • Difficulty for pedestrians to cross. • Decreases LOS from one end to another.
Traffic Volume	Traffic Volume and PLOS • Increased traffic leads to decreased PLOS. • Heavy traffic increases pedestrian safety concerns.
On Street Parking	Positive Influence of Traffic Buffer on LOS • Acts as buffer between traffic and pedestrians, • Provides sense of security. • Increases perceived safety, resulting in higher LOS.
Encroachment by Vendors	Footpath Congestion Caused by Vendors • Causes traffic congestion, • Requires Road occupation for movement.
Pavement Condition	Pavement Condition Impact on Movement • Increases comfort, • Enhances Los.

Source: The study [24]

6.5 The level of service (LOS) for urban streets

Multimodal level-of-service indicators evaluate transportation modes and impacts, focusing on speed, convenience, comfort, and security.

a-Pedestrian LOS (PLOS): This parameter is influenced by factors such as sidewalk width and boulevard width, which affect safety and convenience. The characteristics of the factors are shown in Table 2 [24].

b-Public transportation LOS (PTLOS): The public transportation LOS depends on transit quality, availability, comfort, and convenience, as well as urban street facilities, which affect local residents' choice of public or drive.

Transit facilities: Public transit facilities, including transit stops, running methods, and buffer zones, contribute to achieving the following [25, 26]:

PTLOS contributed to the study.

There are three types: transit stops/zones, transit running ways, and buffer zones.

The main types are transit lanes, transitways, and transit streets.

Minimum vehicle lane width: 3.5.

Parking lane width: 1.8-2.5.

Cycle lane width: 2.1.

Park and ride facilities: These facilities promote public transport usage, alleviate traffic congestion, and should be strategically located at rail stations and major interchanges in urban areas; therefore, the choice of the P+R site should be [14]:

Enhanced interchangeability near public transport nodes.

Not located in congested areas.

It is more convenient for drivers who reside in less accessible places to utilize their vehicles to access the train system.

Station guidelines: Stations are urban nodes that serve as focal points of activity, attracting people with diverse transport modes and services. To ensure their design, elements, types, and configurations must be present [27, 28], as shown in Figure 10.

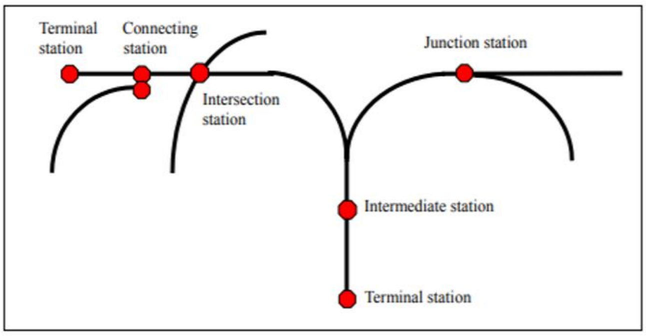


Figure 10. Stations configuration types [27]

Terminal stations: These are the endpoints of corridors, including those in the middle of networks where most trains terminate their journeys. They can accommodate larger facilities and facilitate physical integration of trunk lines. They consist of two types: pass-through stations, where transport modes can pass, and heading stations, where all transport modes come to a stop.

Intermediate stations: Most of these stations are intermediate stations on route networks. **Junction stations**: Break off from moderate stops on different lines. **Connecting stations**: Contiguous or intersecting stations on two lines are joined stations; two lines are joined in close proximity.

Cross stations: Two lines cross on various levels.

6.6 Station considerations

To function properly, vehicles must overtake buses at sub stops, with a minimum distance of one-half the bus length. This spacing should be 1.7 times the vehicle's length. The area should have enough space for infrastructure, circulation, waiting areas, and lateral infrastructure. Users should have a shy distance (0.3-0.5 m) to avoid walking near walls, fences, and curbs. The station height should be at least 3.5 m for partially enclosed stations and 4 m for fully enclosed stations for buses and rails. Station and road cross-sections may vary depending on urban corridor conditions, but general guidelines can be applied [27, 29, 30].

The narrowest stations are 4 meters long, 5 meters wide, and 6 meters wide for both sides of the platform. For mixed traffic lanes of 2.8 meters, walkways can be narrowed to 2 or 1.5 meters. Bike lanes: 1.5 to 1 meter in low-volume locations. Stopping lane: 3 meters if passing lanes exist. The lengths of the metro and LTR stations are 2.8 km and 0.65 km to 1.6 km, respectively. Considerations of various railway services for station distance calculations shown in Table 3.

Table 3. Speed design system according to service [31]

Features	City or Urban Railway Service	Suburban Railway Service	Main Line Railway Service
Maximum speed	120 kmph	120 kmph	160 kmph
Distance between stations	Up to 1 km	1 to 8 km	More than 10 km
Acceleration	1.5 to 4.0 kmphps	1.5 to 4.0 kmphps	0.6 to 0.8 kmphps
Retardation	3 to 4 kmphps	3 to 4 kmphps	1.5 kmphps

7. STUDY CONTEXT AND DATA

This study focuses on the development of intercity travel between Alexandria and Borg El Arab, two existing adjacent cities with varying land use patterns. Alexandria, Egypt's historical capital, is the second-largest city in Egypt in terms of population density and traffic congestion, with a population of 5,441,865 in 2022, while Borg El Arab included approximately 299,364 people according to the latest report of the Egyptian Central Agency for Public Mobilization and Statistics (CAPMAS).

Alexandria, Egypt's largest seaport, handles 80% of its imports and exports, while Borg El Arab is an industrial city. While, The Alexandria governorate is divided into eight districts and further subdivided into smaller administrative divisions (Marakz and Sheiakhat). This study aims to enhance regional transportation networks, provide different modes of transportation, reduce traffic congestion and overpopulation, and create suitable land areas for urban development without affecting agriculture or tourism. This study analyzes the impact of multimodal transportation on land use at linkage corridors and applies the findings of the multimodal transportation study to the public transportation of Alexandria and the Borg El Arab networks. The analysis is conducted using geographic information systems (GIS) and will provide recommendations and indications for improving the situation [32].

The Alexandria-Borg El Arab case study area faces severe traffic congestion and population growth due to unplanned transportation and the extensive use of private vehicles. The city's main arteries have an average traffic speed of 60 km/h, which is much lower during peak times. The government's development strategy for 2032 does not address the root problems of unqualified and unsustainable infrastructure, lack of complete transportation hubs, or disregard for TOD. Poor urban design and delays in projects further worsen traffic congestion and encourage the exploitation of unplanned modes of transportation. Despite development, public transportation operates independently and does not respect pedestrians or TOD concepts [33].

This research aims to link existing Egyptian cities and villages to each other at different planning scales to achieve high accessibility and mobility by applying a multimodal transportation system, which can reduce the use of private and unplanned transport and public transportation. Additionally, the sustainable urban design for nonmotorized transportation (NMT) choices is also established by this research. To ensure mobility comfort and encourage a change in travel behavior, the environment surrounding transit mode intersections is designed and built using SWOT analysis, which also helps to identify the strengths, weaknesses, opportunities, and threats for both current and proposed government transportation development (as shown in Figure 11).

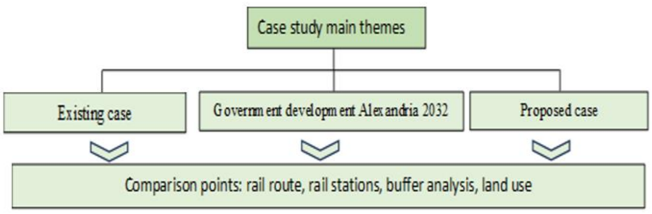


Figure 11. Classification case study

7.1 Existing transportation system

Alexandria, Africa's first rail network city, will be studied from Misr station to Borg El Arab. The case study focuses on Alexandria's challenges, such as overpopulation, slums, lack of public transportation, and inner migration, as a major development Centre, and studies the effects of multimodal transportation on it. So, the current transport situation consists of:

Planned transportation, as Alexandria has four major harbors, including the main west harbor, which handles 60% of exports and imports. The city is served by two main airports, Alexandria International Airport and Borg El Arab Airport, which serve nearly 250,000 passengers annually. Taxis are widely accessible, but Egyptian legislation mandates meters. The Alexandria Intercity commuter rail service runs in two directions, while the Traveler Line trains are powered by diesel. The Alexandria Governorate hosts two major intercity railway stations, serving both Alexandria Governorate commuter rail and Egyptian National Railways inter-city passenger service. The oldest tramway network in Africa, built in 1860, spans from Al Raml District to Victoria District. Bus services are mainly dependent on fixed routes within the city, but electric buses have expanded in recent years.

Unplanned transportation, as Mini buses and tok-tok are unsafe and unplanned modes of transportation in the governorate. Microbuses share multiple routes, contributing to traffic congestion. Tok-toks are motorized three-wheeled vehicles with cabins, linked to accidents and traffic jams. A case study will explore the development and integration of road transportation services between Alexandria and Borg El Arab, aiming to establish new nodes and expand existing modes of transportation, as shown in Figure 12.

So, private vehicles dominate transportation, contributing to traffic congestion and environmental pollution. High car ownership increases greenhouse gas emissions and un planned urban sprawl. Public transit systems in cities reduce congestion but face challenges like underfunding, aging infrastructure, and service frequency and reliability. However, in suburban areas, is often less developed, leading to limited mobility options for residents. issues pose challenges which encouraging inner migration. furthermore, non-motorized transport, such as bike lanes and safe pedestrian pathways, lack dedicated infrastructure and can discourage usage. Addressing these challenges is crucial for reducing urban sprawl and promoting sustainable transportation.

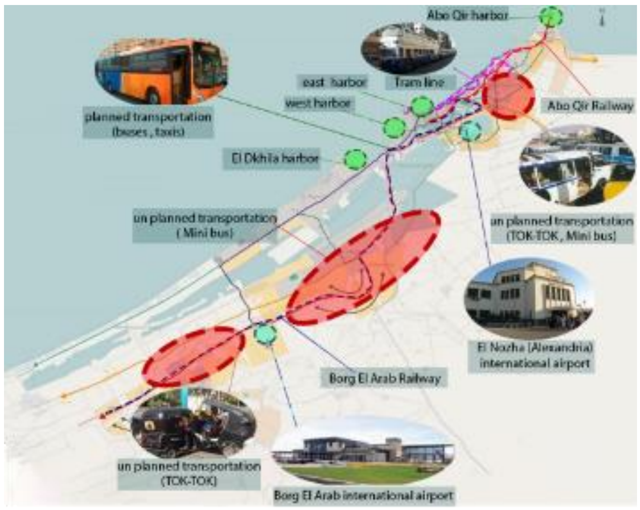


Figure 12. Existing transportation modes in Alexandria governorate

A-Physical context of case study (Existing phase):

The main data used from censuses and land uses of case study area were obtained from the Central Agency for Public Mobilization and Statistics. The map of the Alexandria station shows 13 main stations between two terminal stations, namely, the Misr and Borg Al Arab stations (as shown in Figure 13(c) and Table 4). The rail service between Sidi Gaber and Borg El Arab is currently experiencing a malfunction with its internal stations. The line operates on a direct route between the two stations at specific times rather than throughout the day. This lack of consistent service makes the city an unattractive location for investments and residents. Each train has a capacity of 600 passengers according to the Sidi Gaber station head and director Traffic in the Egyptian National Railway Authority, as shown in Table 5.

The distances between the existing stations from Alexandria to Borg El Arab are far apart and are not suitable for meeting the needs of passengers, as most stations deteriorate (as shown in Table 4).

Table 4. Existing rail station distances and conditions in Alexandria (Misr station – Borg Al Arab station)

Stations		Distance Between Stations (Km)
Misr station		-
Sidi Gaber station		4.5
Muharram Bik Station		9
Muharram Bik Station	Qabbary Station	4.5
	Almitaras station	6.4
Almitaras to El Max station		2
El Max station	Altaarikh Bridge Station	8.13
	Al-Amriyah railway station	17.46
Al-Amriyah to King Marabout Station		3.9
Borg El Arab Airport Station		9.4
Borg El Arab Airport Station	Bahij station	8.9
	New Borg El Arab station	19.1
Bahij to Borg El Arab station		11.8

Table 5. Existing rail station active and non-active and its frequency analysis in Alexandria between Misr station and Borg Al Arab station

Stations		Active (A)/Non-Active (NA) Station	Frequency	Type of Train and the Capacity of Trip
Misr station		**NA**	**The frequency** according 4 times in schedules of (Sedi Gaber to borg Elarab station) about 1 hour between each train. **Time at schedule:** **6:30, 7:30 Am** **3:30, 4:30 pm**	**Type: commuter Rail** **Capacity: up to 600 passengers**
Sidi Gaber station		A		
Muharram Bik Station		**NA**		
Muharram Bik Station	Qabbary Station	**NA**		
	Almitaras station	**NA**		
Almitaras to El Max station		**NA**		
El Max station	Altaarikh Bridge Station	**NA**		
	Al-Amriyah railway station	**NA**		
Al-Amriyah to King Marabout Station		**NA**		
Borg El Arab Airport Station		**NA**		
Borg El Arab Airport Station	Bahij station	**NA**		
	New Borg El Arab station	A		
Bahij to Borg El Arab station		A		

Table 6. Existing rail station frequency, active station and train type in Alexandria between Misr station – Borg El Arab station

Districts / Sections for Stations	400-Meter Buffer Area	Population at 400 m Cut Area	1km-Meter Buffer Area	Population at 1km Cut Area
Elraml[2nd]	**Not covered**	**Not covered**	**Not covered**	**Not covered**
Sedi Gaber	502655	10030	3121549	62288
El Attarin	287450	6,248	1349734	29336
Bab-sharq	**Not covered**	**Not covered**	380798	16522
Moharram Bik	717858	5378	4242064	31781
karmoze	**Not covered**	**Not covered**	258769	303
El-Laban	**Not covered**	**Not covered**	120919	4780
Mina El Basel	1188475	32716	6324145	174091
El Gomrok	**Not covered**	**Not covered**	514178	5627
El-Dakhila	791716	8530	4288114	46203
El Amria[1st]	464728	641	2866137	203
El Amria[2nd]	1043235	441	6742910	2853
Borg Elarab	1005310	119	6853568	810
New Borg Elarab	502654	158	3141593	9875

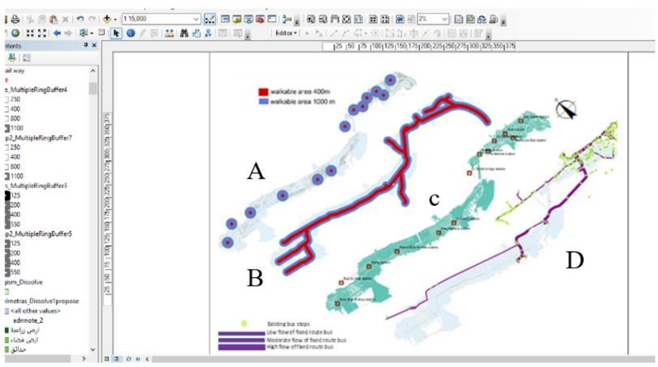


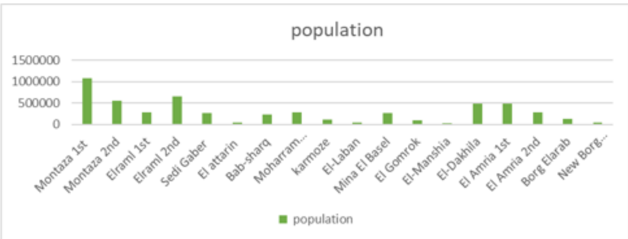
Figure 13. Existing rail station buffer area in Alexandria between Misr station – Borg Al Arab station
Source: Studies [32, 34]

The mobility buffer zone area serves the population around stations: Mobility hub buffer zones were established for the current stations to assess the coverage of districts and sections as well as the number of residents benefiting from each distance (400 meters buffer area [five minutes' walk] and one kilometer walk and catchment drive), as shown in Figure 13(a) and 13(b). A district scoop and a total number of residents who were not covered according to the buffer area were also included. Table 6 shows the results.

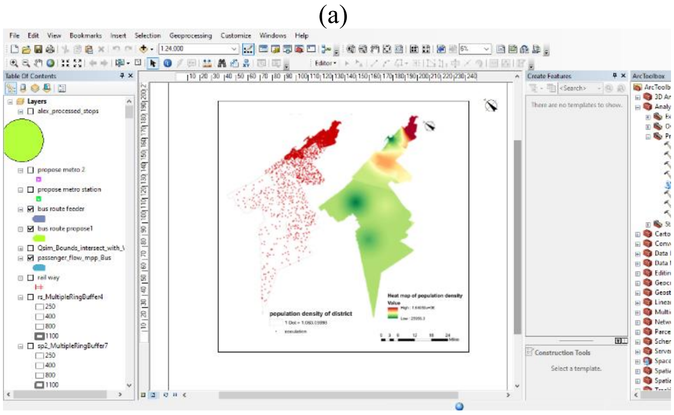
It is clear from the previous table, after applying buffer zones in the two different areas (400 m-1 km), that the existing stations are not at a sufficient level for covering and serving all areas and populations in the study area (El-Ramel, Bab-Sharq, El-Gomrok, El-Laban, etc.).

Existing bus stops: In the present bus route configuration, the bus stops are not uniformly spaced and are not aligned with the needs of passengers or the accessibility of their destination. Despite the high traffic in certain densely populated areas, there is a lack of bus stations, as shown in Figure 13(d) [34].

Population densities: Alexandria's high population density has resulted in an increase in slums, traffic congestion, unplanned urban sprawl, and a lack of reconstruction. According to the 2022 population census conducted by the Mobilization and Statistics Center, both the Borg El-Arab and the intercity appeared to be "ghost cities". A heatmap depicting the current population density across the Alexandria governorate, based on data from the Mobilization and Statistics Center, highlights the extent of population concentration in the city center and around transportation hubs. Conversely, the map also shows a lack of population density in the suburbs, as people continue to move away from these areas due to the lack of public transportation and services, as shown in Figure 14(a)-(b) [32].



(a)



(b)

Figure 14. (a). Existing population densities graph; (b). Existing population densities heat map

Existing land use: The land use map presented in Figure 15 indicates the current land use and the number of different land use types in each district and part of the case study area. Additionally, it experiences a lack of variety of land use and homogeneity. Furthermore, in defining the regions of unplanned urban growth, more than half of Alexandria's population lives in unplanned areas and lacks service buildings around them.

Furthermore, the buffer zone extending along the railway line encompasses an area of 400–2 km and has contributed to the categorization of a considerable portion of the land as single-use or "ghost city." Additionally, the scarcity of the concept of TOD has led to the absence of facilities for cycling and pedestrian paths, green areas, and a lack of emphasis on sustainability. These factors have resulted in an increase in the proportion of the city's population residing in the downtown area, exacerbating traffic congestion and the proliferation of slums. To provide a clearer understanding of the situation, the most recent census data for Alexandria in 2022 are presented in Table 7, which shows the individual land use types and areas for each district and section, as well as the number of individuals between the ages of 6 and 16 who have access to educational facilities in those respective areas, as shown Figure 15.

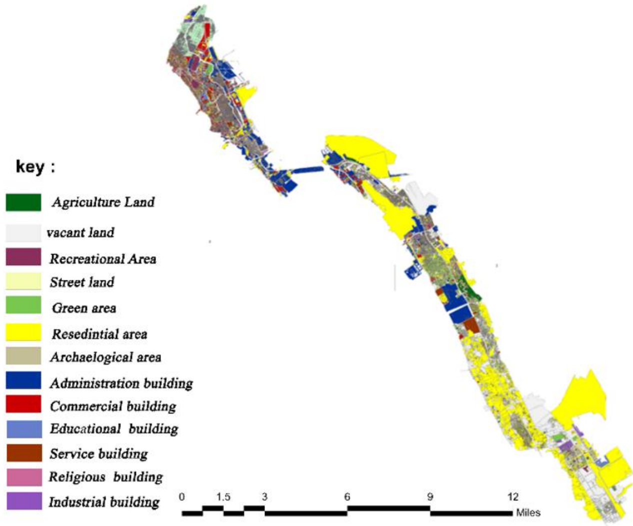


Figure 15. Case study existing land use

B-Government vision for Alexandria 2032:

The transportation system in Alexandria has experienced a 17% increase in population density and a decline in service quality due to inadequate road and building density. The system also lacks modernization and is inconsistent, especially during rush hours. In 2016, the Ministry of Transportation proposed a strategic transportation plan, including building a tram and creating the Abu Qir Metro to reroute traffic from the east to the city center until 2032, as shown in Figure 16. The plan includes a 22.1 km tram, a 14.5,5-kilometer fast bus line, and an 18.8-kilometer line on the Corniche. A high-speed train project is also being implemented, costing approximately 180 billion pounds in three stages: Cairo to Road El Farag, Alexandria and El-Alamein, and El-Ain El-Sokhna. as shown in Figure 17 [33].

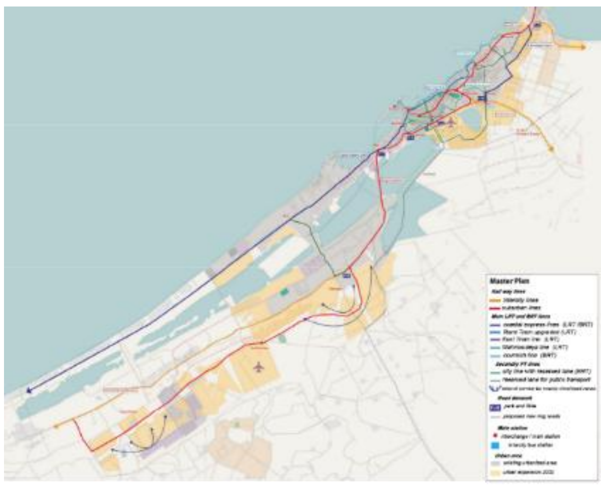


Figure 16. Transport development alex.2032
Source: The study [32]

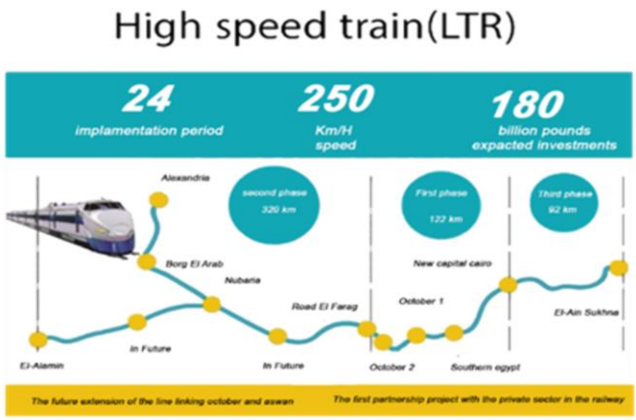


Figure 17. Population density
Sources: The study [33]

Land use sector: Alexandria faced significant challenges due to the proliferation of informal settlements and unchecked population growth. The government has proposed that by the year 2032, approximately 18,932 acres, or 16% of the total land area, will be designated for regional and investment purposes, 2,298 acres, or 2%, for public services, and 14,776 acres, or 12%, for residential buildings. At present, there are 19% of the existing regional service lands and 17% of the existing water bodies, with 34% of the area currently designated as urban blocks.

In addition to the development of certain investment and residential projects in different districts, there are plans for a project in the Al-Ajami district, which is located in the city of Sidi Krir, as well as in the Amriyah district. The project will involve the establishment of an urban community, commercial buildings, and exhibition and conference grounds. Furthermore, a logistics zone will be developed in Burj Al Arab and Burj Al Arab Airport City, which will rely on investment and industrial buildings. This will result in the creation of 11,650 new job opportunities and attract 16,000 residents to the area.

On the other hand, the state's implementation and development of land use disregarded green spaces while prioritizing industrial areas over recreational, service, and commercial spaces. This approach has resulted in a lack of separation between residential and industrial areas, which could compromise the health and well-being of the population, as well as the environment, as shown in Figure 18.

Proposal planning phase: A proposed plan to restructure the Alexandria-Borg El Arab Railroad, distribute stations, and integrate transportation modes, based on analysis and user survey, will go through several stages.

a-Classification: Alexandria was classified into districts, Markaz, and sections to assess population density, movement path, land use, and train mode compatibility with metro and LRT distances.

b-Applying Entropy: This study utilized the "entropy method" to identify proposed stations based on land-use variety, quantifying density and diversity, and designing land-use data. Entropy measures homogeneity within an area, allowing for the calculation of activity density and diversity indicators.

$$\text{Entropy} = -\frac{\Sigma_j (P_j \times \ln p_j)}{Lnj} \quad (1)$$

where, P_j represents the percentage of land development of the jth category, and J denotes the total number of land use categories. An improved balance of mixed land use is indicated by higher entropy levels, which vary from zero to one. Several entropies were calculated and included to the mode choice models to take into consideration the effects of mixed land use (residential/nonresidential) and mixed employment (retail/nonretail) at both trip origins and destinations as shown in Table 7. The replacement and design of rail stations, bus stops, sidewalks, and bike paths were determined by the entropy value and design indicator availability within 400 m of trip origins and destinations [6].

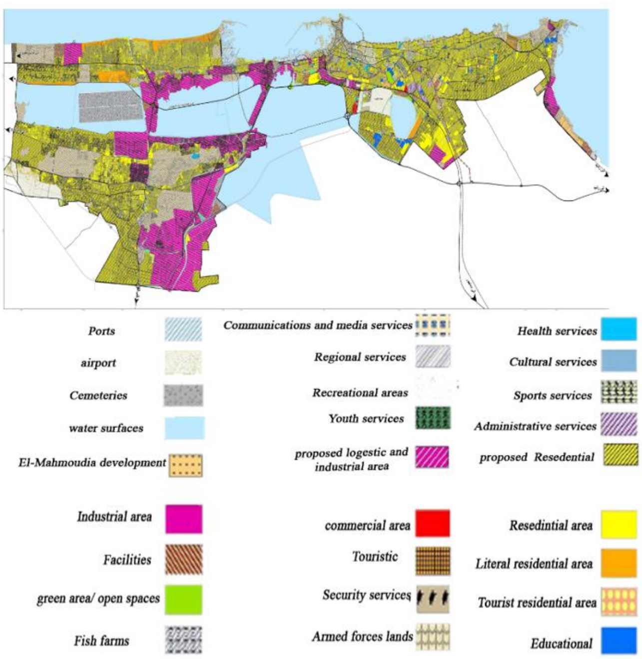


Figure 18. Government development land use for 2032
Source: The study [33]

Table 7. Land use percentages and variations in the existing phase

District	Educational	Vacant Land	Religious	Total Comm.	Total Resid.	Education Serves People Age	Total Area of District	Total Area of District at Buffer Zone	Education Serves People Age at Buffer Zone
Gomrok	7140		922	808,574	273245	29488	8832957	1089880	3638
El dkhila	31173	31200	7333	4816253	480746	182432	45935245	5338704	21203
Elattarin	6804	9483	34411	658373	427855	11300	1775940	1198163	7624
El laban	26747	155	52443	26945	79711	12983	1086511	186001	2223
El manshia	5656	3887	16211	289354	41666	7292	603981	356774	4307
Awl raml	101929	15540	66887	690734	534449	91524	4142651	1409539	31141
Awl amria	108139	6971961	68349	462724	28609780	191554	360716112	36220953	19235
El montaza	18356	82011	4957	471504	265606	553346	498582-84	842434	9350
Bab sharq	554972	46232	61651	2388203	887979	76452	5469726	3939037	55057
Borg el arab el gdeda	811553	17028861	27659	2927221	32064036	18131	145891439	52859330	6569
Borg el arab	21698	5939540	8534	779001	19431488	53027	1094919871	26180261	1268
Tany raml	118167	314320	287205	3261915	2612242	236743	33398953	6593849	46739
Tany amria	118152	8275946	216260	16571909	13387078	111761	688497124	38569345	6261
Sedi gaber	338105	272007	86755	7519839	1738312	83951	13197480	9955018	63325
karmoze	1266	81660	29487	1540403	335396	37061	3030836	1988212	24312
Moharam bek	428665	198850	144120	5492734	1542358	94272	27106104	7806727	27151
Mina elbasel	194396	333054	154487	3602556	1815814	89698	9605629	6100307	56965
% of land use	1.18%	14.47%	0.57%	13.76%	59.68%	1881015 (0.08%)	2494068843	200634534	386368 (0.19%)

Note: Unit: (m^2) All areas and total commercial and residential areas within the buffer zone 2 km from the railway way.

Table 8. Existing and propose rail types in Alexandria between Misr station and Borg Al Arab station.

Stations		Distance Between Stations (km)	Commuter Rail 8 km:200 km	LRT 0.65km:1.6km	METRO 0.45:2.8km
Misr station		-			
Sidi Gaber station		4.5	×	×	×
Muharram Bik Station		9	√	×	×
Muharram Bik Station	Qabbary Station	4.5	×	×	×
	Almitaras station	8.8	×	×	×
Almitaras to El Max station		2.4	×	×	√
El Max station	Altaarikh Bridge Station	8.13	√	×	×
	Al-Amriyah railway station	17.46	√	×	×
Al-Amriyah to King Marabout Station		3.9	×	×	×
Borg El Arab Airport Station		9.4	√	×	×
Borg El Arab Airport Station	Bahij station	8.9	√	×	×
	New Borg El Arab station	19.1	√	×	×
Bahij to Borg El Arab station		5.4	×	×	×
SPEED		45-128 km/hr		Up to 105km/hr	Up to 130km/hr
Actual speed		50-80		90-100	90-120
Cost		Medium		High	Medium
Server		High frequency for long distance service		Service on busy urban corridors, connecting major destinations such as downtowns, shopping districts and campuses	High frequency urban rail service High capacity for short-distance trips also Service on busy urban corridors

Table 9. The entropy of Misr station – Burj Al-Arab station

Area	Entropy	Population	Population Density(p/km^2)
El attarin	0.55	38293	19832
Bab sharq	0.62	235433	47087
Sedi Gaber	0.6	266259	20481
Raml 1st	0.34	287972	71993
Raml 2nd	0.42	654456	19832
Moharem bek	0.38	290745	10768
Karmoz	0.6	108093	36031
Amoud elsawary	0.47	3731	3731(at 0.2km^2)
Kafr ashry	0.57	4594	4594

El Laban	0.66	42615	42615
El Qabbary	0.53	7266	7266
El mafroza sharq	0.56	61461	15365
El mafroza garb	0.3		
Tabia Saleh	0.5		
El wardian sharq	0.52		24370
El wardian garb	0.57	73110	
El wardian qebly	0.45		
El metras	0.5	102868	102868
El max	0.35	14711	3678
El Dkhila	0.23	100356	2952
Awl amria	0.25	493440	1673
King mariout	0.35	66008	493
El hawaria	0.16	8534	533
Bahig	0.3	37239	955
Borg El Arab	0.12	22266	495
New borg El Arab	0.76	45503	260

Table 10. The calculation of the total terminal distance (travel round trip)

Distance		T_{r1} (S= 100km/h)	Distance		T_{r1} (S= 100km/h)	Rapid Station Distance		T_{r2} (S=120km/h)
D_1	**1.55**	0.93	D_{13}	**2.5**	1.5	D_{Rt1}	4 km	2
D_2	1.55	0.93	D_{14}	1.6	0.96	D_{Rt2}	19 km	9.5
D_3	1.83	1.098	D_{15}	2.3	1.38	D_{Rt3}	10 km	5
D_4	2.3	1.38	D_{16}	3.2	1.92	D_{Rt4}	18 km	9
D_5	2.5	1.5	D_{17}	2.75	1.65	D_{Rt5}	12 km	6
D_6	1.54	0.924	D_{18}	1.1	0.66	Stations that provide rapid access to the most frequently needed locations have been selected as fast transit stations. These include (Misr Station - Sidi Gaber Station - Abdel Qader Station, in the middle of Amriyah and King Marriot - Burj Al Arab Airport and Burj Al Arab)		
D_7	2.11	1.266	D_{19}	3.9	2.34			
D_8	1.2	0.72	D_{20}	4.7	2.82			
D_9	2	1.2	D_{21}	2.2	1.32			
D_{10}	1.7	1.02	D_{22}	2.9	1.74			
D_{11}	1.58	0.948	D_{23}	6	3.6			
D_{12}	2.4	1.44	D_{24}	3	1.8			

When applying the entropy method, most values ranged from 0.5 < 0, which indicates poor diversity of land use and a lack of homogeneity (as shown in Table 8).

c-Cycle time and number of metro cars needed: The train station route design includes multiple terminals, and calculations are required to determine the cycle duration and number of rail cars. The metro was chosen to meet user needs, infrastructure development, and frequent stop speeds equation (as shown in Table 9).

The terminal stop time for each station is assumed to be 30 seconds, and a headway interval of at least 5% of the round-trip duration must be included at both ends of the routes. The preceding stages will be implemented using a logarithm equation (as shown in Table 10).

The total terminal distance (travel round trip) is calculated as follows:

$$S = \frac{D}{Tr} \qquad (2)$$

where, (S) is the speed of the rail, (D) is the distance between stations and (Tr) is the time taken between each station, as shown in Figure 19.

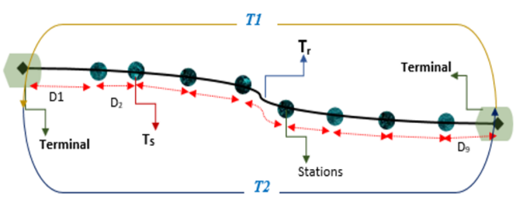


Figure 19. Total terminal distance (travel round trip)

Therefore, T1 and T2 are the travel round trips without any layovers/recovery, and T2 is assumed to be T1 at time and distance, which is calculated as follows:

$$T_1 = \Sigma\, Tr + \Sigma Ts \qquad (3)$$

$T_1 = 37 + (22*.5)/T_1 = T_2 = 48$

Rapid station: $T_1 = 31.5 + (3*.5)/T_1 = T_2 = 33$

$$\text{Cycle time} = T_1 + T_2 \qquad (4)$$

Cycle time = 48 +48 = 96

RTS cycle time = 33+33 = 66

Then, the cycle time, including the layover/recovery periods, was adjusted.

C = Travel Time + Layover/Recovery Time (5)

C = 96 + 96*(10%); C = 66 + 66*(10%)

C = 105.6 minutes ≅ 106 min./for **RTS C** = 72.6 minutes ≅ 73 min (rounded to the next whole number). Next, determine the number of trains that are needed:

Number of train = cycle time/headway (6)

Number of trains = 106/30 = 3.5 trains ≅ 4 trains

RTS Number of trains = 73/30 = 2.5 trains ≅ 3 trains (rounded to the next whole number)

Since the number of trains and the headway are set, the new cycle time must be solved, and the layover/recovery period must be determined.

Cycle Time = Number of trains * headway (7)

The cycle time = 4 * 30 = 120**,** so the actual travel time is 106 minutes, the total cycle time is 120 min, and the total layover/recovery period is 7 minutes for each end.

The **RTS cycle time is 3 * 30 = 90,** so the actual travel time is 73 minutes, the total cycle time is 90 minutes, and the total layover/recovery period is 8.5 minutes for each end.

The metro train, consisting of eight cars with 150 passengers per car, serves more than 4,300,000 citizens annually. Made by Hyundai Rotem, it costs $20 million and is known for its quality, sustainability, maintenance, and environmental preservation.

Fixed route bus, Rapid bus: The bus and RBT stops are determined using the same formula as the metro rail, with different stopping times and lengths for each station and crossing. Terminal stops will have a 15-second terminal stop time, and a layover/recovery period of 5% must be included at both ends of routes. A logarithm equation will be used to accomplish the previous stages (as shown in Table 11).

The fixed bus and BRT serve over 130,000 citizens annually, with the fixed bus carrying 900 passengers and the BRT carrying 1350 passengers. Both vehicles carry 90 passengers each, with the fixed bus being manufactured by BYD ebus k9 and Yutong e bus due to their quality, sustainability, maintenance, and environmental preservation. Both vehicles cost approximately 2.8 million dollars per vehicle.

The station and stop integration buffer: Placing the proposed stations along the road is considered a case study, and the dimensions are based on theories. However, the spacing of the stations has increased, contrary to theories, in the suburban areas of King Mariout-Borg El Arab due to the lack of population and services; however, integration will be achieved in that area by placing stops of buses and BRT to serve passengers, and from here, integration will be achieved, and there will be no disruption or slowdown in access. In the future, when investments and services increase and population density increases, it will be possible to supply stations in the second stage, as shown in Figure 20.

Table 11. The Calculating the cycle time and capacity for bus (Travel round trip)

Speed		**Distance**	ΣT_r	**No. of Stations**			
				Fixed Rout Bus	**Rapid Bus Transit**		
Main arteries Within the city	60 km/hr	12km	12min.	30	10	Capacity of fixed rout bus carried around (90pass/ vehicles)	**Capacity**
Main arteries on the desert road	100 km/hr	48 km	28 min.	80	33	Capacity of rapid bus carried around (130 pass/ vehicles)	
ΣT_s				27 min.	10 min		
$T1=T2 = \Sigma T_r + \Sigma T_s$				67	50		
Cycle time				134 min.	100 min.	Bus: 900pass	
Cycle time *(10%)				147	110	Bus at peak time :1350 pass.	
No. Of vehicles = cycle time/ headway				10 vehicles	7 vehicles		
No. Of vehicles at peak time				15 vehicles	11 vehicles	BRT :910 PASS BRT at peak time:1430 pass	
Cycle time = No. Of vehicles* headway				150	105		
Cycle time at peak time				150	110		

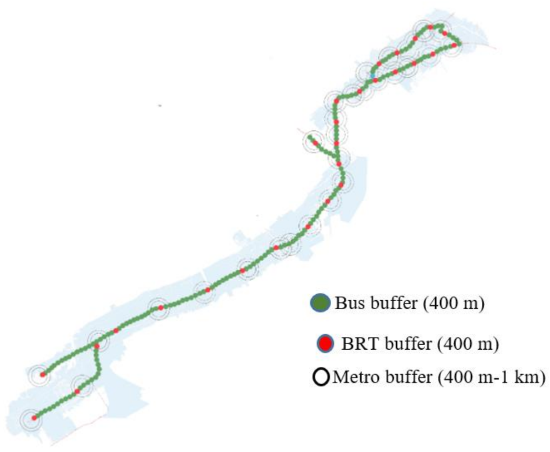


Figure 20. impact of MMT on proposed hubs

Tariff system: In public transportation systems, various ticket tariffs are employed to address the issue of unequal transportation costs. Typically, passengers are required to pay for their trips on buses or trains. The available ticket prices in public transportation are determined by the tariff system, which consists of two primary sectors: flat and differential. A flat system is an existing system, while a differential system is based on factors such as distance, quality, time, sections, and zones [35].

To ensure a fair ticket price for citizens and promote the use of public transportation in the study area, a combined tariff system will be established. This system will include several types of tariffs and will be divided into 8 categories based on the number and distance of the stations. The cost will be determined by the number of additional stations on the ticket and the type of tariff system used. For example, the quality tariff system will be combined with the exit of the same mode of transportation, such as a bus or train, on the same line and direction. However, the transport network is divided into two types of stations: rapid transit stations, which are available only at major intersections with high frequency and density, and normal lines, which stop at all stations. The pricing will depend on the type of tariff system and the stations, as shown in Figure 21.

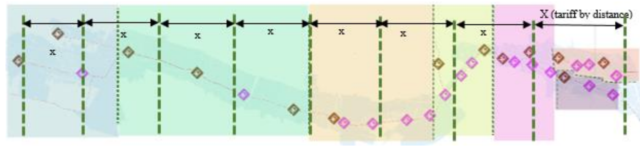


Figure 21. The tariff system by distance and stations

Land use impact: Land use and transportation are closely connected, and new transportation modes proposed to improve accessibility can impact urban land usage patterns by increasing land values and land use densities. This, in turn, affects urban land use patterns. The study included various categories of land use, such as vacant lands, residential buildings, recreational areas, green lands/gardens, religious buildings, educational buildings, archaeological buildings, agricultural lands, administrative buildings, industrial buildings, commercial and service buildings, and transportation networks. The study also involved analyzing transportation infrastructure, the city's exits and entrances, districts, and the distribution of proposed transportation stations, as well as existing ones. The distribution of land uses was based on theories and analytical studies, which helped determine the relationship between land use and transportation stations. As a result, land use was directly affected by this development, as shown in Figure 22. The expansion of land use and built-up areas, particularly in the suburbs, was achieved through increased investment in commercial and industrial buildings and the provision of services. This, in turn, attracted residents to remote areas with planned urban growth, which provided suitable residential buildings, recreational places, and green spaces. The implementation of diverse land uses was performed while respecting developed traffic spaces and building laws.

Table 12. Comparison of entropy between existing and proposed land use types affected by MMT

Area	Existing Entropy	Propose Entropy	Area	Existing Entropy	Propose Entropy
El attarin	0.55	0.85	Tabia Saleh	0.5	0.81
Bab sharq	0.62	0.91	El wardian sharq	0.52	0.85
Sedi Gaber	0.6	0.92	El wardian garb	0.57	0.83
Raml 1st	0.34	0.79	El wardian qebly	0.45	0.84
Raml 2nd	0.42	0.82	El metras	0.5	0.88
Moharem bek	0.38	0.87	El max	0.35	0.87
Karmoz	0.6	0.83	El Dkhila	0.23	0.87
Amoud elsawary	0.47	0.88	Awl amria	0.25	0.85
Kafr ashry	0.57	0.89	King mariout	0.35	0.86
El Laban	0.66	0.82	El hawaria	0.16	0.85
El Qabbary	0.53	0.87	Bahig	0.3	0.87
El mafroza sharq	0.56	0.85	Borg El Arab	0.12	0.84
El mafroza garb	0.3	0.82	New borg El Arab	0.76	0.86

Entropy was used to determine the degree of use efficiency and enhance land use regions through the development of land uses in the study area. Table 12 shows the degree of land use region development between the existing and proposed scales from 0 to 1. The land uses in districts and sections increase closer they are to 1, and vice versa. The aforementioned table illustrates the degree of parity and variety in proposed land uses, the resurgence of activity and vitality, and the demise of the type of mono-use ghost city compared with existing land use entropy, as shown in Table 11.

The land use changed, while the existing land uses included residential buildings (approximately 59.68%), commercial buildings (6.33%), commercial buildings (2.14%), service buildings (0.99%), industrial buildings (1.18%), educational buildings (14.47%), vacant lands (0.57%), religious buildings (2.49%), green areas (0.67%), recreational areas (0.84%), agricultural areas (0.01%), arable areas (10.63%), and administrative and institutional buildings. A lack of green and recreational areas within the scope of 2 km was observed. The area built for residential, commercial, and service uses was mostly located in the city center. After developing transportation modes and land use patterns, the distribution of buildings became as follows: residential buildings, approximately 30%; commercial and investment areas, 19.34%; service areas, 9.87%; industrial areas, 11.78%; educational areas, 3.98%; vacant lands, 0%; religious buildings, 2.59%; green areas, 5.61%; recreational areas, 2.12%; agricultural areas, 1.44%; archaeological areas, 0.01%; and administrative and institutional buildings, 13.66%. as shown in Figures 22-23.

The distribution of the green spaces followed the guidelines and standards for the urban coordination of open areas and green spaces that were approved by the Supreme Council for Planning and Urban Development in compliance with Law No. 119 of 2008 and its executive regulations. In desert cities, the average area per person ranged from 5-7 m2 and for other populations, between 1.66 and 0.8 m2. Furthermore, the vacant land used to include green spaces/gardens and recreational areas. In addition, the preservation of heritage buildings and archaeological areas, as shown in Figure 21.

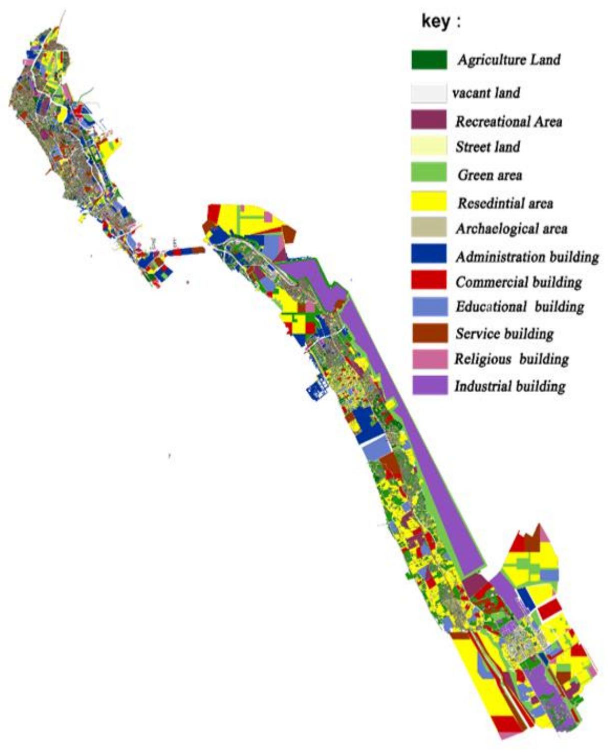


Figure 22. Impact of MMT on land use

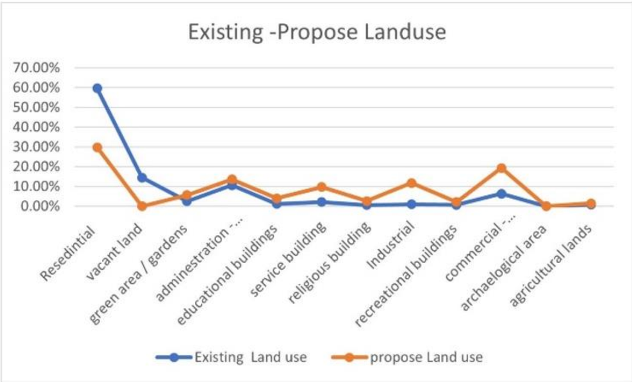


Figure 23. Graph showing developing between existing and propose land use

Land value: The proposed transportation plan, which calls for the construction of new metro stations in addition to fixed-route buses and rapid buses, will improve access to and supply of transportation, which will have a positive and significant impact on both urban development and land value. The prices of the region's developable and investable lands will increase. Lands close to railroad terminals are often taller than those in other areas, as shown in Figure 24.

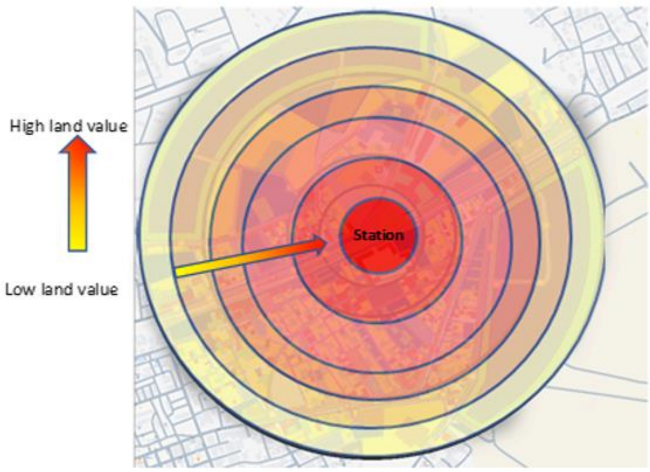


Figure 24. Impact of MMT on land value

Propose Population densities: Propose Population densities by influencing the location, scale, density, design, and mix of land uses as well as the pattern of growth of public transportation (M.M.T.). Therefore, planning makes it safer and easier for people to access employment, stores, recreational centers, and services by bicycle, public transportation, and foot. Decreasing the distances between destinations also helps minimize the need for travel. In sequence, the development of transportation modes and mixed land use will be reflected in a change in population density, as shown in Figure 25, through the application of a linear regression equation. as shown in Figure 26.

$$Y=a+bx \quad (8)$$

where, y = expected population (dependent variable), a= Y intercept, b= X (existing entropy) line slope, X= proposed land use entropy (independent variable).

Locating the main transit hubs to increase accessibility: The proposed metro station locations were determined by analyzing regional factors, including demand, supply, passenger flow, traffic patterns, and road capabilities. The team also considered the locations of frequent destinations, traffic patterns, and crowded areas. In addition, accessibility and connectivity are key factors in evaluating transportation networks. This involves assessing the connection to transport centers, travel time, frequency of service, and access to different destinations. Studying road networks, land uses, and population density in a region can enhance transportation service comfort and attract passengers. Environmental impact assessment is also crucial for ensuring system safety and efficiency. Near the transportation system, commercial and multifamily residential land use has grown significantly, which impacts urbanization and land use. The relationship between these factors was investigated within a 3–10-minute walking distance from metro station hubs, which corresponds to a range of 250–400 m to 800 m, as shown in Figure 27.

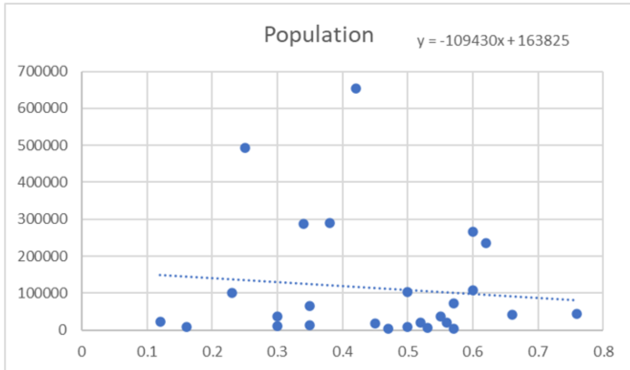


Figure 25. Expected population densities through linear regression

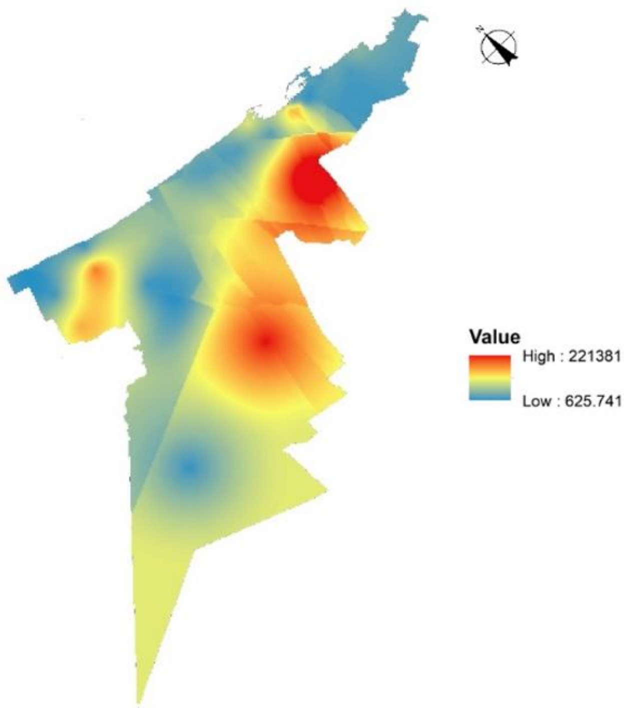


Figure 26. Impact of MMT on the expected population density distribution according to linear regression on heat map

Figure 27. Proposed hubs and rapid stations

Integrated transport with an intermodal station strategy: Metro, bus, and BRT terminals were used in the case study by choosing three transit mobility hubs that were replicated with distinct characteristics and enhanced through the establishment of interchange stations. The population and density of traffic in the area were considered while selecting the transit hubs (Ameriya, Moharram Bey, and Sidi Gaber). The transit mobility hubs were separated into four zones: walking for 3 minutes (250 meters), walking for 5 minutes (400 meters), and walking for ten minutes (800 meters). A total of 10-15 minutes were also assigned for driving (>800 meters). Utilizing the central portion of the transportation hub, which is situated at a distance of 250 meters, the central and main metro stations were outfitted with passenger service buildings, waiting areas, open spaces, and designated walking spaces. Additionally, amenities were placed in close proximity to the stations and the transit corridor, resulting in the creation of a unique and user-friendly central location.

Park and ride services are prioritized to encourage private vehicle drivers to use public transportation. These centers are designed to be located in close proximity to neighborhoods, local areas, and district centers. The business buildings next to the terminals attract investment and provide designated areas and lanes for walking to the stations. Stations and parking are designed to have strong links and integration, with areas designated for direct and safe transit.

The street network is designed to accommodate high traffic flows in activity nodes, commercial corridors, and major parks, reducing traffic speeds and lane widths. Lane allocation for BRT, fixed-route buses, Metro, trams, cycling, and walking is performed on arterial roads. Side roads are reserved for bicycles and pedestrians, and parking spaces are available. Urban street elements are considered and provided, including all-inclusive networks of sidewalks and other amenities that make transportation easier for users, particularly disabled people.

Improving pedestrians and cycling by providing grade-separated pedestrian and bicycle crossings in residential, mixed-use centers, commercial corridors, and community facilities. Traffic-calming techniques are used in mixed-use centers to prioritize pedestrians. Land use development includes the integration of various activities along corridors; the provision of open, recreational, and service spaces; walking and cycling spaces within residential spaces; and the development of building forms to improve the environment and urban sustainability. Implementing the public transportation development pattern (M.M.T.) can help people reach employment, stores, recreational facilities, and services more safely and easily, shorten travel times, and increase the use of land in the metropolitan region, as shown in Figure 28.

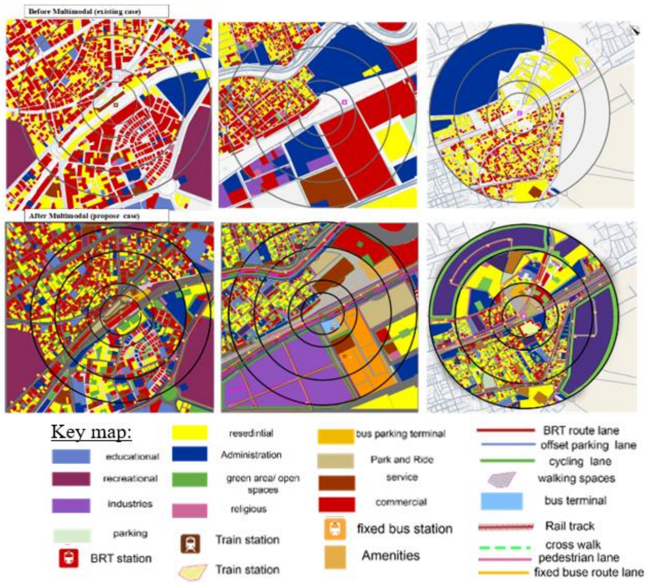


Figure 28. Impact of MMT on proposed hubs

8. MULTIMODAL IMPACT ON URBAN DEVELOBMENT

Environmental: Implementing multimodal transportation promotes a healthy street environment, reduces emissions, and improves city resilience to climate change. Building parks, green networks, recreational facilities, and planting trees contribute to climate preservation and sustainable development. Transitioning to electric public transportation supports clean energy sources and zero emissions. Health Street through transit-oriented development reduces air pollution, improves accessibility, and increases walking reliance.

Economic growth: The implementation of multimodal transportation in Alexandria and Borg El-Arab regions is expected to boost economic activity, attract investments, and create mixed-use areas. This environmentally friendly approach will attract investments in industries, commerce, tourism, and other sectors. Urban expansion, job hubs, and public transit are expected to yield maximum economic benefits. Economic centers will be established around public transportation hubs.

Socio-economic growth: The proposed solution promotes social integration, reduces travel times, costs, and frequencies, reduces migration, and promotes savings for commuters through affordable fares, thereby creating a more inclusive labor market.

Social: The TOD promotes a safe, convenient, and healthy transport environment, enhances quality of life, reduces travel anxiety, improves user interaction, promotes social equality, reduces migration, and offers significant savings for commuters through affordable fares and more jobs.

Urban growth: The population will focus on transportation hubs, with proposed and existing stations attracting residents to suburbs and outer cities. New services like buses, metro, and BRT will reduce private vehicle demand, speed up trips, and enhance connectivity from Alexandria to Borg El-Arab.

Multimodal transportation contributes to urban growth, activity diversification, and decreases internal migration. The governorate plans to expand urban areas, improve public transportation, and attract local and foreign investments to promote the region as an industrial and commercial destination as shown in Figure 29.

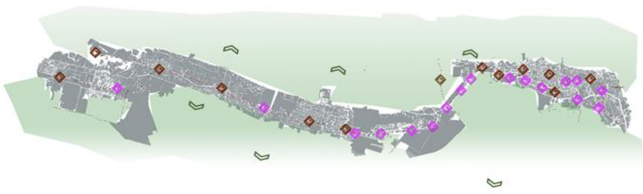


Figure 29. Impact of MMT on urban growth

Transportation: The proposed plan aims to improve connectivity, reduce traffic congestion, promote sustainability, and enhance public transportation through Metro, Bus, and BRT terminals. It also encourages alternative transportation options, reducing reliance on private vehicles. Public-private partnerships will enhance the development of environmentally friendly public transportation systems. This will increase efficiency and cost-effectiveness by optimizing existing infrastructure and resources. The plan also aims to improve accessibility for diverse populations, including those with disabilities and the elderly.

Land use: The proposal advocates for compact and mixed land use development, promoting public transit, walking, and cycling, and transit-oriented development. It emphasizes pedestrian infrastructure, green spaces, and non-motorized transportation. This approach increases land value by attracting businesses, investment, and employment, and contributing to appreciation in land values.

9. RESULTS AND DISCUSSION

The case study successfully achieved its objectives by implementing multimodal transport, including attracting passengers who rely on private and unplanned public transport. This was achieved by providing various modes of transport with high integration and frequencies, covering service areas and populations, and providing accurate information schedules. This has alleviated traffic congestion and made the area attractive to suburbs of cities. The diverse land uses have been affected, attracting investments and restoring life in neglected areas. Transit oriented development (TOD) was implemented, providing bicycle lanes and pedestrian-only areas, reducing dependence on transportation. A tariff system was applied based on distances to tickets for achieving societal equality. This has significantly influenced urban development, environmental preservation, economic growth, and social development.

10. CONCLUSIONS

This study utilized Alexandria to Borg El-Arab as a case study to investigate the effectiveness of a multimodal transportation system (MMTS) for smart urban growth. The researcher examined the existing transportation modes and land use, as well as the government's future vision and projects. Throughout the methodology and theories, the multimodal transportation system was applied, and the results demonstrated that it is a crucial component of planned and sustainable urban growth. The study considered the existing design considerations of the city and implemented multimodal transportation, land use development, and urban extension. The results indicated that applying multimodal transportation system theory to the proposed case study achieved the highest multimodal transportation system level of service (LOS). Furthermore, the study revealed that the multimodal transportation system provided a planned and integrated means of transportation for the case study, increasing accessibility between cities while reducing traffic congestion. This was attributed to smart growth city planning and the organization of the transportation network, which offers high-speed and high-frequency service. The researchers also proposed implementing a tariff system based on stations and distance to provide fairness between users, in addition to offering different payment methods, including daily, monthly, and annual cards.

Transportation advancements have played a crucial role in facilitating the growth of departments, districts, and sectors and in the redistribution of land use. By creating mobility hubs and utilizing multimodal transportation, the proper transit of high- and low-density areas can be facilitated, decreasing the usage of private vehicles. The focus on development directed toward TOD and the application of multimodal transportation has helped achieve planned urban growth expansion and draw people to the city's suburbs, increasing the average density of remote areas on the suburbs of the city with an increase in investments and commercial and industrial buildings and a variety of land use. In turn, this will bolster the growth of transportation and infrastructure development in the future. The proposed multimodal transportation system presents several strengths and opportunities for enhancing connectivity, sustainability, and quality of life in the region by integrating various transportation modes and leveraging smart urban growth strategies. The proposed case study aims to address the challenges of traffic congestion, environmental impact, and limited accessibility between Alexandria and Borg El Arab by improving social life, the economy, the environment, and equity.

The present case study indicates that efforts are being made to develop infrastructure, but these developments are not comprehensive and are considered temporary solutions to the problem at hand. Specifically, there is insufficient connectivity between Alexandria and Burj Al Arab through planned public transportation, as well as traffic congestion and a lack of integration of transportation. Furthermore, economic factors, a disregard for sustainability and safety for citizens, and the absence of suitable public transportation options pose significant threats to the area. In terms of state planning for the year 2032, the focus was placed on the eastern region of Alexandria. In addition, the Ain Sokhna monorail project, which connects El Alamein, Burg El Arab, and Alexandria, did not include stops at the departments and sheikhs between the cities to serve their citizens. Despite interest in sustainability, infrastructure development, and land use, the proposal for land use was limited to increasing industrial and residential buildings without separating them, which poses a threat to the health of citizens and the environment. However, there are efforts to enhance economic growth and develop infrastructure.

The objective of this study area is to enhance public transportation, including the metro, BRT, and fixed buses, as well as their integration, alongside the provision of safe bicycles and pedestrian lanes in accordance with TOD, which promotes well-integrated development. All of these efforts contribute to the development of land use. This development is exemplified by the presence of residential, recreational, industrial, green, educational, and religious spaces while also considering the separation of industrial and residential buildings through green belts, which is vital for the well-being of citizens and the preservation of the environment and sustainability. Furthermore, applying fair tariffs for passengers encourages the use of public transportation, leading to increased investment, job opportunities, and social justice in the study area. On the other hand, the three facets share threats, such as the state's economy and natural disasters, which affect the flexibility of transportation infrastructure, as shown in Table 13.

The utilization of multimodal transportation system theories in the proposed case study resulted in the highest MMT LOS. This was accomplished through the growth of departments, districts, and sectors, as well as the redistribution of land use. The integration of transportation facilitated easier and faster movement, revitalizing abandoned cities. The emphasis on development focused on TOD and multimodal transportation, which contributed to planned urban growth expansion, increasing the average density of remote areas with respect to urban features and amenities. In addition, mobility and accessibility should be improved with high integration between modes. This attracted investments, commercial and industrial buildings, and public–private partnerships. The use of smart technologies optimized transportation efficiency and safety, enhancing social life, the economy, the environment, and equity compared to the current situation and developments in the country, as evidenced in Table 14.

In conclusion, the implementation of multimodal transportation in the Alexandria-Borg El Arab corridor offers a promising solution to the region's growing transportation challenges. By integrating various modes of transportation, such as buses, trams, bicycles, and pedestrian pathways, this approach aims to enhance connectivity, accessibility, and sustainability in the region. Through improved infrastructure, efficient coordination, and strategic planning, multimodal transportation has the potential to alleviate traffic congestion, reduce carbon emissions, and enhance the overall quality of life for residents. Moving forward, continued investment, collaboration among stakeholders, and proper monitoring will be crucial in realizing the full benefits of this innovative transportation system.

Table 13. SWOT analysis for existing, government development and proposal

	Existing
Strength	Alexandria and Borg El Arab have developed infrastructure to accommodate various transportation modes, including buses, taxis, private vehicles, commuter rail, and unplanned modes. Street signs and traffic lights control vehicles and pedestrians, and ticket offices are present. Some regions have various land uses.
Weakness	Traffic congestion is a major issue, especially during peak hours, due to limited public transportation options and lack of integration between different modes. There are also issues with stop amenities, parking, open spaces, and safe crosswalks. Unplanned transportation demand leads to traffic congestion and accidents. The lack of trees, inconsistent building heights, and intersections contribute to pollution and health issues. Stations and stops have poor condition, and lighting is not always working at night. The lack of mixed use and transportation modes in outer cities leads to overpopulation and settlements. Limited coverage and outdated infrastructure also pose challenges.
Opportunities	Investments in infrastructure, alternative transportation, technological advancements, expansion, and green initiatives can improve the transportation system. Public–private partnerships and smart city integration can optimize services. Alexandria - Borg El Arab metro electric rail, bus, BRT, cycling, and pedestrian lanes will be established.
Threats	Economic factors, natural disasters, and political challenges can impact transportation infrastructure funding and maintenance in Alexandria. Regular updates and consulting with local authorities are crucial. Rising fuel prices can discourage private vehicles and taxis. Safety measures for crossing railroad tracks, high stairs on bridges, and regional population decline can also affect transportation. New development projects must respect existing urban forms.
	Government development 2032
Strength	The government's support for developing Alexandria's transportation systems can provide resources and funding for infrastructure projects. Improvements in the east of Alexandria and between Alain El-sokhna and El-Alamine, Matrouh, Borg El Arab, Alexandria offer opportunities for new modes and enhanced accessibility. This can boost economic growth, improve smart urban growth, and contribute to environmental awareness, infrastructure development, and job creation in eastern Alexandria.
Weakness	The government's budget constraints and infrastructure limitations may hinder large-scale transportation projects, while political instability can disrupt long-term planning. The Ain Sokhna project, targeting regional sectors, lacks integration between modes, open spaces, and service buildings. The overlap of industrial and residential spaces, lack of pedestrian crossings, station amenities, and TOD concepts contribute to pollution and health issues. Limited coverage and outdated infrastructure also pose challenges. Dependence on traditional transportation contributes to environmental issues and pollution.
Opportunities	The government can enhance transportation by partnering with private entities, focusing on sustainable modes like public transit and cycling infrastructure. Technological advancements and green transportation initiatives can improve efficiency and convenience. Smart city integration can optimize transportation systems. The Alexandria - Borg El Arab metro electric rail will be established, along with bus, BRT, cycling, and pedestrian lanes. Open spaces, recreational areas, parks, and replanned land uses can also be developed.
Threats	Economic downturns can impact government funding for transportation projects, while infrastructure vulnerability to natural disasters threatens stability. Social equity concerns arise from exacerbated inequalities, while resistance to change may arise from stakeholders. Transportation development may lead to the removal of residential buildings, posing threats to citizens. Investments in infrastructure, technology, and maintenance are crucial, but regulatory and policy hurdles may arise. Alexandria's susceptibility to natural disasters could also threaten multimodal transportation infrastructure's resilience.
	Proposal

Strength	Alexandria's integrated transportation system, including buses, metro, cycling, and BRT, improves connectivity to Borg El Arab. Smart traffic management technologies optimize traffic flow, reducing congestion. Accessibility and mobility are enhanced, fostering economic development and social interactions. The system includes a tariff system for low-income individuals and students, constant distance bus and metro stations, amenities, and crosswalks. Land uses are developed, with service, educational, and health buildings integrated into residential buildings. Green spaces and parking spaces are provided. This system contributes to smart urban growth, strengthens the local economy, preserves the environment, provides jobs, and enhances social life.
Weakness	Implementation challenges: Implementing a multimodal transportation system requires significant financial resources, coordination between stakeholders, which might pose challenges during the execution phase. Disruption during construction: The construction of new transportation infrastructure might cause temporary disruptions, affecting traffic flow and inconveniencing commuters and local businesses. Therefore, alternative means of transportation must be provided. Resistance to change: The public may resist adopting new transportation modes or changing their communication habits, which could impact the successful implementation of the proposal.
Opportunities	Collaboration with private entities can fund and develop a multimodal transportation system, contributing to environmental sustainability. It can be integrated into a smart city framework, enhancing urban planning and management. Efficient movement stimulates economic growth, and future demand can be anticipated. Utilizing technologies like IoT and AI can enhance efficiency and sustainability. The combination of smart urban growth and multimodal transportation can improve the quality of life.
Threats	The multimodal transportation project in Alexandria faces several challenges, including shifting political priorities, opposition from community segments, potential natural disasters, funding constraints, regulatory and policy hurdles, and the city's susceptibility to natural disasters. The project's success may be hindered by these factors, and securing sufficient funding for infrastructure, technology, and maintenance could be challenging. Additionally, adapting existing regulations and policies to accommodate smart transportation solutions and urban growth plans may require significant coordination among government agencies and stakeholders. The city's susceptibility to natural disasters also poses a threat to the project's stability and resilience.

Table 14. Factors of LOS achievement for existing, government development and proposal

Factors	Existing	Government Development 2032	Proposal
Various transit modes	√		
Fixed Bus	√	√	√
Commuter rail	√	×	×
LRT	×	√	×
BRT	×	√	√
Metro	×	×	√
Taxi	√	√	√
Tram	√	√	√
Cycling	×	√	√
Walking	×	√	√
Private vehicles	√	√	√
Unplanned transportation	√	√	√
TOD Concept			
Achieved TOD concept	×	×	√
Well interact with traffic	×	×	√
TOD nodes for integration PT	×	×	√
Compact, mixed urban development, particularly TOD, was create areas where common services easily accessible, often within a 5-minute walk or bicycle ride of homes and worksite locations.	×	×	√
Providing cross walk, Active mobility (cycling and pedestrian lanes)	×	**M**	√
Good walking and cycling conditions	×	**M**	√
Accessibility and connectivity	×		
Provision transport network connectivity	×	√	√
Improve Active hubs	×	×	√
Improve active transport	×	√	√
Ease flow of traffic circulation	×	√	√
Reduce traffic congestion	×	**M**	√
Improve access between employment and their labor place	×	×	√
Improve access for pedestrian and cycling	×	×	√
Disabled access, no blockages	×	×	√
Ease of integration and switching modes	√	**M**	√
Hubs/stations within a distance 5 min walk	×	×	√
Provide services around hubs and stations	×	√	√
Space to increase range and scale of services	×	√	√
Plans for a network of hubs	×	√	√
Public transport, e.g., rail, tram, bus	√	√	√
On-demand buses, taxis, private hire	√	√	√

Well various land use occurs	×	×	√
Transportation design and mobility			
PT. availability	√	√	√
Provide bus route, BRT route	×	√	√
Provide mixed traffic route	×	√	√
Provide cycling route, pedestrian route	×	×	√
Provide offset parking route	×	×	√
Parking provision and supply	×	√	√
Shift away from private vehicles	×	**M**	**M**
Success integration with different modes	×	**M**	√
Interchange stations	×	√	√
High quality public transit services, with good coverage, frequency, comfort, safety and affordability for both local and interregional (between city) services	×	**M**	√
Stations and stops			
Platforms			
Buses stops	split slide aligned station	split slide aligned station	Directional station platform, split slide aligned station
Rail stations	Standard	Standard	flow through platform, (Elongated, intermediate, junction intersection terminal stations)
Alignment	√	√	√
P+R	×	√	√
K+R	×	×	√
Safety			
Street lighting	**M**	√	√
No hidden areas around the hub	×	**M**	√
Clear signage with network labeled	×	√	√
Safe crosswalk	×	**M**	√
Safe pedestrian routes	×	**M**	√
Safe cycle routes	×	×	√
Street scape	×	√	√
Stop and station amenities	×	**M**	√
No building blockage	**M**	**M**	√
Paved roads	**M**	√	√
Real-time transport information	×	√	√
Easily accessible transport timetable	×	√	√
Simple ticket purchase options	√	√	√
Digital support (transport info, ticketing, wayfinding, walk distances, local services)	**M**	√	√
Local tourism information	×	×	√
Integration fares and tickets through tariff system	×	×	√
Enhance: Community, environment, social through interaction between people	×	**M**	√
Result	Worst Multimodal LOS	Moderate Multimodal LOS	High Multimodal LOS

Note: ×: Absence; √: High presence; **M**: Moderate presence

11. RECOMMENDATION

Planning carefully, collaboration, and taking a variety of factors into account are necessary for the implementation of an efficient urban multimodal transportation system. In order to improve urban multimodal transportation, the government should consider the following recommendation:

Integrated planning: Formulate all-encompassing urban planning plans that take into account walking, cycling, public transportation, and private automobiles. For well-rounded urban areas, land-use and transportation planning should be integrated.

Public-private partnerships: Encourage cooperation between the public and private sectors to make the most of resources, knowledge, and creativity. The construction and management of multimodal infrastructure and services can be improved through public-private partnerships.

Investment in infrastructure: Provide enough funding for the construction and upkeep of multimodal infrastructure, including bike and bus lanes, pedestrian-friendly walkways, and effective intermodal transfer hubs.

Technology integration: Utilize technology to create intelligent transportation systems. Implement real-time tracking, data analytics, and smart traffic management to optimize the efficiency of each mode and provide users with timely information.

Accessibility and inclusivity: Ensure that the multimodal transportation system is accessible to people of all abilities and socioeconomic backgrounds. Design infrastructure and services that consider the diverse needs of the community.

Promotion of sustainable modes: Encourage the use of sustainable transportation modes, such as walking, cycling, and electric public transit. Implement policies and incentives to promote eco-friendly options and reduce reliance on single-occupancy vehicles.

Community engagement: Involve the community in the planning and decision-making processes. Gather feedback, address concerns, and create a sense of ownership among residents to ensure the success and acceptance of multimodal transportation initiatives.

Policy support: Implement supportive policies that prioritize and incentivize the use of multimodal transportation. This could include zoning regulations that promote mixed-use developments, congestion pricing, and incentives for businesses adopting sustainable commuting practices.

Geographic and environmental factors should be considered, given that they may have an effect on planning process. Moreover, Policies should be developed by the government to support clean technology and lower CO2 and GHG emissions. So, government should have policed and certain laws for land to intend to attract foreign investment.

Education and awareness: Raise awareness about the benefits of multimodal transportation and educate the public on how to use the system effectively. Provide information on routes, schedules, and the environmental and health benefits of choosing sustainable modes, in addition, promote low-carbon transportation modes such as electric buses.

Adaptability and future-proofing: Design the multimodal transportation system with scalability and adaptability in mind. Anticipate future technological advancements and changes in urban demographics to ensure the system remains effective and responsive to evolving needs.

Incentives for sustainable commuting: Introduce incentives for sustainable commuting, such as employer-sponsored transit passes, bike-sharing programs, and carpooling initiatives. These incentives can encourage residents and employees to adopt sustainable public transportation options. Through the implementation of these recommendation, cities may establish a multimodal transportation system that is both well-integrated and efficient, meeting the different demands of urban people and fostering sustainability, accessibility, and economic vibrancy for both new and existing cities.

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