

Evaluation of Bus Rapid Transit System: Riyadh city, Saudi Arabia

Ahmed Mohammed Alshehri

Arts Collage | King Abdulaziz University | KSA

Received:

10/01/2023

Revised:

12/01/2023

Accepted:

09/03/2023

Published:

30/06/2023

* Corresponding author:

file.msc@outlook.com

Citation: Alshehri, A.

M. (2023). Evaluation of

Bus Rapid Transit System:

Riyadh city, Saudi Arabia.

Journal of engineering

sciences and information

technology, 7(2), 48–81.

[https://doi.org/10.26389/](https://doi.org/10.26389/AJSRP.H100123)

[AJSRP.H100123](https://doi.org/10.26389/AJSRP.H100123)

2023 © AISRP • Arab

Institute of Sciences &

Research Publishing

(AISRP), Palestine, all

rights reserved.

• Open Access



This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC) license

Abstract: Al Riyadh city, the capital of the Kingdom of Saudi Arabia, is experiencing significant economic and population growth, it is also a major metropolitan area in Saudi Arabia and in the Gulf regions. This has led to a high level of car ownership and use of vehicles, and this has led to the construction of a series of slow-moving roads and roads around the city. Traffic congestion is a major problem, where road behavior has an economic and psychological impact on people. The Riyadh Bus stations and Bus Rapid Transit (BRT) System Project is an integral part of the current Riyadh metropolitan area including the new Riyadh Metro. The main objective of this paper's is to study the "Bus Rapid Transit" network in the city of Al Riyadh and to assess the functioning of this network using geographic information systems and the theory of graphs. A centralized geodatabase has been built for BRT lines and stations. A geometric network was conducted for BRT routes to facilitate moving from any location to another within Riyadh city. The assessment and evaluation of BRT routes focused on routes and station distribution regarding Riyadh city and how BRT solved population needs in Riyadh city. Using the powerful GIS network analysis functions, a navigation system was developed to assist passengers in planning their trips from one station to another giving detailed information about route directions and different BRT lines used.

The study reinforces the value of good design techniques for accessible public transportation systems. The utilization of accessible vehicles, such as low-floor buses, is needed but lacking for such an accessible system, planners and operators should be aware.

Keywords: Transportation network, Traffic conjunction, BRT, GIS Network Analysis.

تقييم نظام شبكات نقل الحافلات في مدينة الرياض، المملكة العربية السعودية

أحمد محمد الشهري

كلية الآداب | جامعة الملك عبد العزيز | المملكة العربية السعودية

المستخلص: تشهد مدينة الرياض، عاصمة المملكة العربية السعودية، نموًا اقتصاديًا وسكانيًا كبيرًا، وهي أيضًا منطقة حضرية رئيسية في المملكة العربية السعودية ومناطق الخليج العربي. وقد أدى ذلك إلى ارتفاع مستوى ملكية السيارات واستخدام المركبات البرية، هذا أدى إلى إنشاء سلسلة من الطرق بطيئة الحركة والطرق المختلفة حول مدينة الرياض، يعد الازدحام المروري مشكلة كبيرة، حيث يكون لسلوك الطريق تأثير اقتصادي ونفسي على الناس. يعد مشروع محطات حافلات الرياض ونظام حافلات النقل السريع (BRT) جزءًا لا يتجزأ من منطقة العاصمة الحالية بالرياض بما في ذلك مترو الرياض الجديد. الهدف الرئيسي من هذه الدراسة البحثية هو دراسة شبكة "Bus Rapid Transit" في مدينة الرياض وتقييم أداء هذه الشبكة باستخدام تقنيات نظم المعلومات الجغرافية ونظرية الرسوم البيانية.

تم إنشاء قاعدة بيانات جغرافية مركزية لخطوط ومحطات BRT ثم إنشاء شبكة هندسية لخطوط BRT لتسهيل الانتقال من أي مكان إلى آخر داخل مدينة الرياض. كما ركزت الدراسة على تقييم طرق حافلات النقل السريع على الطرق وتوزيع المحطات فيما يتعلق بمدينة الرياض وكيف تمكنت BRT من حل الاحتياجات السكانية في المدينة. باستخدام وظائف تحليل شبكة نظم المعلومات الجغرافية القوية، تم تطوير نظام ملاحية لمساعدة الركاب في التخطيط لرحلاتهم من محطة إلى أخرى لإعطاء معلومات مفصلة حول اتجاهات المسار وخطوط BRT المختلفة المستخدمة، تعزز الدراسة الحالية قيمة تقنيات التصميم الجيد لأنظمة النقل العام التي يسهل الوصول إليها. كما يبرز أهمية الحاجة إلى استخدام المركبات التي يمكن الوصول إليها، مثل الحافلات ذات الأرضية المنخفضة، والتي تفتقر إلى مثل هذا النظم، كما يجب على المخططين والمشغلين أن يكونوا على دراية بهذه الأنظمة.

الكلمات المفتاحية: شبكة النقل، اقتران حركة المرور، حافلات النقل السريع، تحليل شبكة نظم المعلومات الجغرافية.

Introduction

The capital and largest city of Saudi Arabia is Riyadh. The city is 600 meters above the level of the sea. It is situated in the middle of a desert because there are no lakes, rivers, or seas there, yet due to how vibrant and active it has become, it is no longer a desert. On the Najd plateau in central Saudi Arabia, it is located between the eastern portion of the Dahna desert and the western portion of the Tuwaiq mountain range (Figure 1). The government's primary administrative structures are located there. Historically, the city served as a crossroads for trade and pilgrimage between the Red Sea and the Arabian Gulf. The Najd region's history was centered on Riyadh, which has a long history that stretches back to 1704.



Figure 1 Riyadh City Location (Source; Modified after ArcGIS Data World).

Riyadh covers a total area of 1,798 kilometers sq. (694 sq. miles). Riyadh is nowadays a main international city with about eight million population (Figure 2), and fabulous services, as well as the economic, political, and cultural bastion in the Kingdom of Saudi Arabia. The Organization of Petroleum Exporting Countries (OPEC), the Arab Human Rights Organization, and worldwide energy firms including Aramco, Petromin, and Fuchs all have headquarters in Riyadh.

Although the Kingdom of Saudi Arabia's intellectual and cultural past mainly reflects the Arab and Islamic heritage, it intensively adopts and welcomes modern Western theories and realities in order to benefit from new and modern ideas and innovations willingly (ADA, 2015). The Islamic heritage of Saudi Arabia, which encourages tolerance, moderation, and respect for other people's cultures, is a major influence on Saudi culture. This culture also strengthens optimism and the ability to handle crises using information technology, logic, and good judgment. Before being acknowledged as being consistent with the perspective and goal of the kingdom, these possibilities must infiltrate various facets of the Saudi administration.

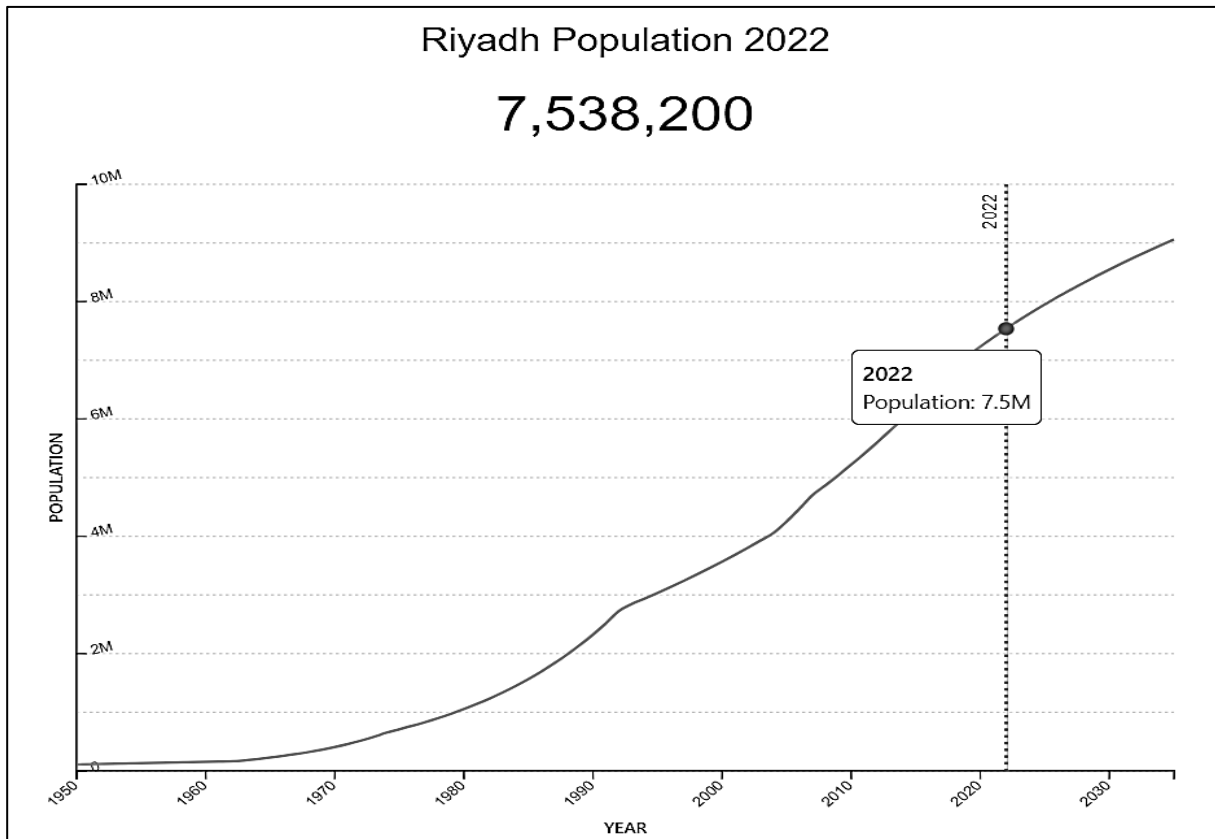


Figure 2 Riyadh Population (Source; General Authority for Statistics, kingdom of Saudi Arabia, 2010).

From medieval times to the present, history indicates that a well-developed transportation network has been and continues to be an important aspect of a region's growth.

Society today demands an effective and uncluttered road network after suffering serious issues or difficulties such as traffic jam, delays, contamination, rising car operating expenditures, and traffic accidents.

A study of a digitized BRT network in Riyadh city might be one of the best ways to alleviate the problems, taking into consideration the above mentioned requirements and traffic movement restrictions. This sort of inquiry is appropriate for ArcGIS, a Geographic Information System (GIS) program for analyzing, producing and accumulating maps for gathering data.

The research problem is traffic conjunction in Riyadh city

Congestion is "basically a relative phenomenon tied to the difference between what users expect from a transportation system and how the system actually works." Congestion is characterized by three interrelated characteristics in transportation engineering: speed, flow, and density. Flow is the term used to describe the vehicle speed at which cars pass a specific location over a specific amount of time (e.g. vehicles per hour). Density is defined as the number of cars using a unit of road space at any given time (e.g. vehicles per mile).

The capital of the Kingdom is Riyadh. It has changed from being a remote town to a contemporary metropolis in less than 50 years. Riyadh is a modern metropolis that is rapidly expanding and growing in size. In the past seven years, the population has grown by more than 16%. The majority of the increase is caused by and may be attributed to residents of Riyadh who have moved there from nearby villages and suburbs (United Nations Population Division, 2008). The increased burden on the transportation system is one consequence of this urban population growth. Transportation within and outside of the city has become time-wasting, hazardous, and risky as a result of the massive traffic, congestion, and road safety issues that have emerged as a result of population growth and increased economic activity. These issues have also had an impact on people's health. Future prosperity and the standard of living are thus in danger.



Figure 3 Riyadh during rush hour (King Fahad Road) (Source; ecaintlblog.wordpress.com)

King Fahad Road in the morning traffic hour is seen in (Figure 3). Of the three main north-south routes in Riyadh, King Fahad Road is the most crucial. It has ten lanes, five in each direction, giving it a theoretical capacity of more than 20,000 automobiles per hour, according to the Highways Capacity Manual (HCM). Even with such a high capacity, the rise in morning commuters overwhelms the system,

and the majority of arterial routes in the Riyadh City Core exhibit the same pattern. Undoubtedly, the Saudi Arabian government and the city of Riyadh are looking for alternatives when faced with such circumstances and scenarios.

Methodology

To reduce traffic congestion extensively, this project tried to build a network map of Riyadh city and to know the fastest path between two sites utilizing adequate investigation and digitization of the city's present network system.

Computer hardware, software, geographic information, and humans for gathering, storing, updating, editing, investigating, and showing all means of geographically related data are the main components of GIS.

Network Analyst is an ArcGIS analysis application that shows the closest facility in a network of digitized connections and helps in route optimization during emergency responses. The shortest road between needed origin and destination can be identified using Network Analysis.

Analysis is dependent on network attributes such as crossing distance, transit duration and cost, barriers, vehicle restrictions, and so on. All the main lines in Riyadh City that connect to one another has been digitized in a GIS environment and then used for realizing the goal.

Users can use ArcGIS Network Analyst at various periods of the day, involving turn limitations, speed limits, height restrictions, and traffic conditions.

ArcGIS is one of the most user-friendly, effective, and time-saving application in the domains of traffic engineering and transportation planning.

A Riyadh base map was imported to ArcGIS software from various sources and geo-referenced to gain the coordinates related to the BRT network analysis of Riyadh City. Geo-referencing is the process of aligning images in a coordinate system.

Study area

This field has been expanded to an easily workable scale as revealed in (Figure 4). Layers are the mechanisms used to display geographic data bases in ArcGIS.

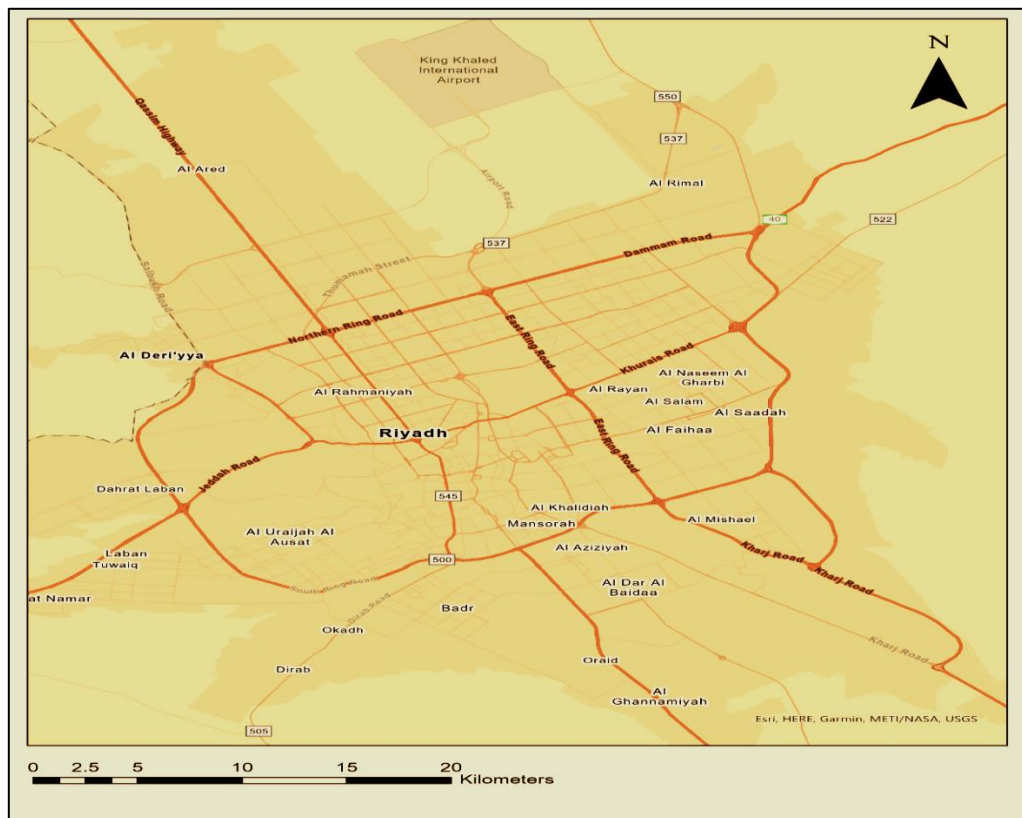


Figure 4 Study area, Riyadh City Location.

Riyadh city transportation network

One of Riyadh's key metropolitan landmarks is its road network. It has been built according to the highest standards and criteria and covers a large area. These roads are essential and urgent in advancing urban planning in the city and speeding up people's movement between locations. Significant funds have been allocated and set aside over the past 50 years to build a contemporary, hierarchical road network throughout the city's urban space. In the 1960s, a number of modest coach owners in Riyadh began using their vehicles to carry large sections of the local people. The services were erratic and disjointed, and these coaches were nicknamed locally as "coasters." Since these essential services were the only means of transportation, SAPTCO was established in 1979 to offer its services both within and between the cities of the Kingdom. With the exception of international transportation, all of these services were given to the firm as a monopoly. The Ministry of Transportation had oversight over how the business was handled (MOT).

Before SAPTCO was established, there were international bus services that are still in operation but are also governed by the Ministry of Transportation.

Hopefully, the minibus services would be provided after SAPTCO was established, however this hasn't materialized so far. Minibuses number has been risen to be seven times more than that of SAPTCO's buses.

Despite the fact that many cities, like Riyadh, are somewhat crowded and heavily reliant on private automobiles, it is evident that finding solutions to the issues of urban sprawl and the effectiveness of transportation networks is important and pressing. (Farhani, 2013).

"If parking is available, the private car offers a door-to-door service, which is one of its major benefits. Despite the fact that public transportation will never match this, the integration of services makes it possible to come closer than would otherwise be the case "(Simpson, 1994).

To achieve the integration of public transportation, government intervention or regulation may be required in particular situations when one form of public transportation may predominate and negatively impact other forms (Harrison and Gretton, 1985).

The Ministry of Transportation still spends the majority of its time building and maintaining motorways, although this pattern has fundamentally changed. A paradigm shift was signaled in 2003 when the cabinet asked the Ministry of Transport to do extensive public transportation studies in all Saudi cities, regardless of their sizes. These transit studies demonstrate a remarkable movement in transportation strategies away from merely cars and other motorized vehicles. (Al-Dubikhi, 2007). In light of the findings of these studies, public transit is currently being researched and examined as a means of reducing traffic and satisfying the city's future travel requirements (ADA, 2004). This includes the Riyadh Metro, the most expensive metro project ever, in which the government has invested significantly both financially and in terms of its reputation.

History and causes of transportation problem in Riyadh city

Since the 1950s, Riyadh has heavy traffic and so crowded with cars, and the prosperous economy of the 1970s made such problem tenser and harder. Over the previous two decades, the Saudi capital has witnessed a sudden increase in auto dependency. Between 1968 and 1996, the total number of used vehicles climbed from 26,880 to 670,300. (Al-Mosaind, 2001). Over the same period, the average household's ownership of a car increased by about 2.5 times (Al-Dubikhi, 2007). Riyadh's planning authority has been seriously considering offering a substitute to the private car and reducing reliance on vehicles since the early part of this decade, despite the lack of oil supplies and funding for more highways (ADA, 2004).

However, as the number of cars on the road increases, heavy traffic worsens, and the city's planning authority sees public transit as an effective way of reducing traffic congestion and satisfying the city's future travel demands. But this is not a straightforward matter. Riyadh's Islamic culture and privacy laws have a significant impact on the growth of its transportation infrastructure, which will be covered in more detail in this chapter. Before delving into these topics, the following phase of the investigation will cover Riyadh's transportation history from back to the 1940s, when vehicles were not yet in use.

Car ownership rates for 1000 persons in 1997 had been 224 (ADA, 2015), which is less when compared to similar international cities. The average number of owning cars per 1000 persons in major US cities is 604, compared to 491, 524, and 392 in Australia, Canada, and Europe (Alfoazn, 2011). The

trajectory of automobile use in Riyadh, on the other hand, is a distinguishing trait. In 1971, KSA had only 22,805 automobiles, as illustrated in (Figure 5). In 1996, the Ministry of Interior (MOI, 2015) reported a total of 2,052,934 automobiles. Although not everyone has access to a private car, many low-income individuals can purchase one, which helps make up for the dearth of a sufficient public transit infrastructure. (Alfoazn, 2011).

Due to the prevalent "predict and provide" mentality, these increased our expectations for simple movement to be fulfilled (Al-Dubikhi, 2007). Based on the ADA forecasts for 1968-2021, Riyadh's people and car ownership are forecast to rise over the next two to three decades.

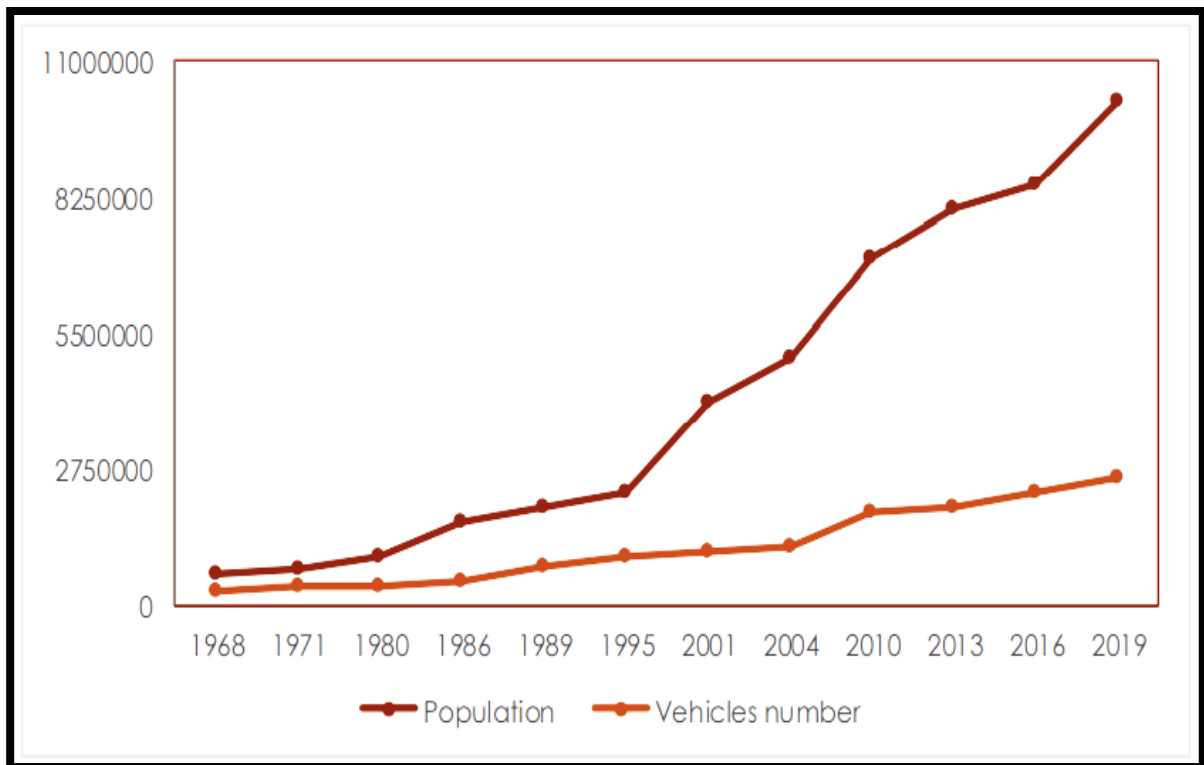


Figure 5 people and car possession in Riyadh 1968-2021 (source; ADA, 2015)

If no alternative realistic means of transportation or situations in the future act to restrict and regulate the growth in private car demand, it is estimated that private automobile usage would climb at an annual rate of 8%, meaning Riyadh will have a 100% increase in private car driving by 2029. (MOT, 2011). The term "Peak Automobile" (Gupta, 2014) describes a situation in which the assumptions of continuing automobile use and network growth have reached their limits. "Peak Car" poses a serious threat to Riyadh's long-held ideas and has never been fully studied.

Saudi Arabia comparison with other countries such as China is so interesting, where car ownership is less than 50 vehicles per 1000 people, but in the United States, car ownership was around 700 vehicles per 1000 people in the 1980s (Gupta, 2014). Meanwhile, in Riyadh, the Figure is 400 vehicles per 1000 people. (Figure 5) depicts the evolution of car possession in a variety of countries over the last six decades.

Effect of Traffic trend on Riyadh city

Long-term planning is required for infrastructure maintenance and modernization, land use, and environmental and climate change legislation, therefore forecasting future traffic trends is crucial. For a very long period, especially in Riyadh, it was predicted that the number of cars will continue to increase. Peak automobile seems to be the point in a city's development where the continuous use of cars and the expansion of the road system are no longer sustainable. In many ways, Riyadh is unique from every other metropolis in the globe. The strong Islamic culture, privacy traditions, and familial character can be used to explain a large portion of the current reliance on automobiles. These factors continue to have an impact on how the transportation system is developed.

Travelers are worried about their privacy. Instead of traveling with friends or family, people prefer to drive alone, and there are several customs specific to how women travel (with many choosing to travel with male relatives). This makes the pleasure of a private air-conditioned car evident, especially given the regularly harsh weather conditions (summer temperatures commonly approach 55°C).

The fundamental causes of this phenomenon are investigated as part of this study, with special emphasis on policy transfer and local culture.

1.5 public transportation solution

As evidenced by the image of congested highways and the concept of peak vehicles, Riyadh is plainly at a fork in the road. A symposium on public transportation was conducted in Riyadh in October 2000 to acknowledge this. To examine the issue, local/national government authorities gathered with transportation and planning experts. This conference emphasized the importance of enacting policies that will aid in future planning.

The Arriyadh Development Authority made a public transportation pilot study in response to the conference's findings to provide direction on how new public transportation projects could be used to better meet future expectations and hopes in travel demand.

The development of public transportation networks has typically followed the expansion of the city as a whole, resulting in services and systems that have evolved alongside the metropolis. "Ours is not the case in Riyadh, and hence this effort represents an once-in-a-lifetime chance to set up a modern public transportation system to a developed urban area that is, by any metric, devoid of recognized public transportation," according to the ADA (ADA, 2015).

Setting up a substantial infrastructure for public transit and then immediately demanding that people switch modes of transportation is challenging. It might be difficult to persuade vehicle owners to switch to public transit. In most other cities, the main issue is that drivers convert to public transit when the "offer" is comparable with private car use in terms of speed and comfort and is typically viewed as appealing and practical along the entire journey.

Most traditional modes of transportation are based on this. The harsh environment and Islamic culture in Riyadh add to the complexity, and both aspects are very strong in favoring the status quo. As a

result, the task is to affect Saudis' views regarding using public transportation daily. This is unlikely to be fulfilled shortly.

As people become more accustomed to the new services and that they would always perform as well as a private car, patterns and travel behaviors must gradually change. (23). In Riyadh and the Middle East in general, public transit must provide the privacy and other culturally influenced traditions that tourists demand and expect (Al Dubaiki, 2007). Owning a private car ought to comply with a number of rules.

According to the findings of a recent travel study conducted by King Saud University (University of Riyadh), a tram system like the one recently developed in Edinburgh, which is entirely accessible to all passengers, has few seats, and great interior/external views, would be regarded inadequate and unsuitable in Saudi Arabia; further concerns exist (Mubarak, 2004). One of the studies that was conducted revealed that respondents frequently avoid using public transportation because it is uncomfortable (in terms of accessibility, effectiveness, and reliability).

They have the ability to operate private vehicles. Additionally, they declared that if Riyadh's transit was widely acknowledged, they would utilize it to avoid clogged roads and being caught in traffic, particularly during peak hours. People who have utilized public transportation think that the focus of the transportation industry should be on underground subways, reliable transportation, and premium services (Mubarak, 2004). Even so, there is some complexity in this situation because what visitors claim to want is not always indicative of how they would behave if their demands are fulfilled.

As a result, Riyadh finds itself at a crossroads, and it has already taken some major decisions concerning its future course.

As of 2015, the city is investing heavily in a new metro system with the aim of reducing traffic congestion and contributing to the improvement of future transportation quality. Any city in the world is currently investing USD 22.5 billion in public transit, to put this into perspective (ADA, 2015).

The creation of a metro system, a bus rapid transit system, and other transportation facilities in the city of Riyadh is part of the Riyadh Public Transport Project (RPTP), which also includes the construction of the Riyadh Metro (ADA, 2015). Most certainly, Riyadh's best public transportation system is the metro network.

Bus rapid transit system (BRT) overview

BRT is a bus-based system that emulates the high capability, high productivity, and cost-effective attributes of urban rail systems. Brazil's Curitiba was the first city to implement BRT, and at the time, Jaime Lerner, the mayor, referred to the city's BRT system as a "surface metro" — a high-quality bus service that resembles a subway but is far less expensive. (Cervero, 2011, 2008).

In terms of pricing and service quality, BRT falls between the regular and the bus urban rail systems. It combines the best aspects of both worlds: the efficiency and dependability of rail with the cheaper cost and operating flexibility of a traditional bus (Deng and Nelson, 2011).

According to the Institute of Transportation & Development Policy (ITDP) in New York, which has been regarded as one of the strongest components of the technology, BRT is described as "a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and superiority in marketing and customer service." (Wright and Hook, 2007).

BRT provides some type of priority but does not provide fully separated busways, and rather than stations, bus terminal are frequently used. Therefore, the availability of exceptional or dedicated rights-of-way of operating buses, as well as larger station platforms and boarding areas, distinguishes high-end from low-end services. Bus stops are particularly important because they make it possible to pay for the fare before entering the bus, enabling quicker, more controlled multi-door boarding and landing, similar to urban rail systems. This reduces the amount of time spent waiting for passengers to board or deboard, enabling more dependable scheduling and services.



Figure 6: Bus rapid transit system (BRT)

High-end BRT includes AVL (automatic vehicle location) for real-time management and dispatching, which primarily takes into account treatment for signals for buses at signalized crossings, as well as real-time dynamic passenger data systems ("next bus" at stations; "next station" on buses).

The right to drive across or into a road before another vehicle (right-of-way) is an essential feature of BRT for adequately representing a mode that is competitive regarding time in relation to urban rail systems and private autos. In recent years, a new grading system for BRT service quality has emerged, employing the Olympic medals of Gold, Silver, and Bronze. In order to "keep the 'R' in Bus Rapid Transit" and achieve a Gold Standard in The BRT Standard 2013, a collection of pro-BRT organizations led by the Institute for Transportation and Development Policy (ITDP) have identified five crucial qualities.

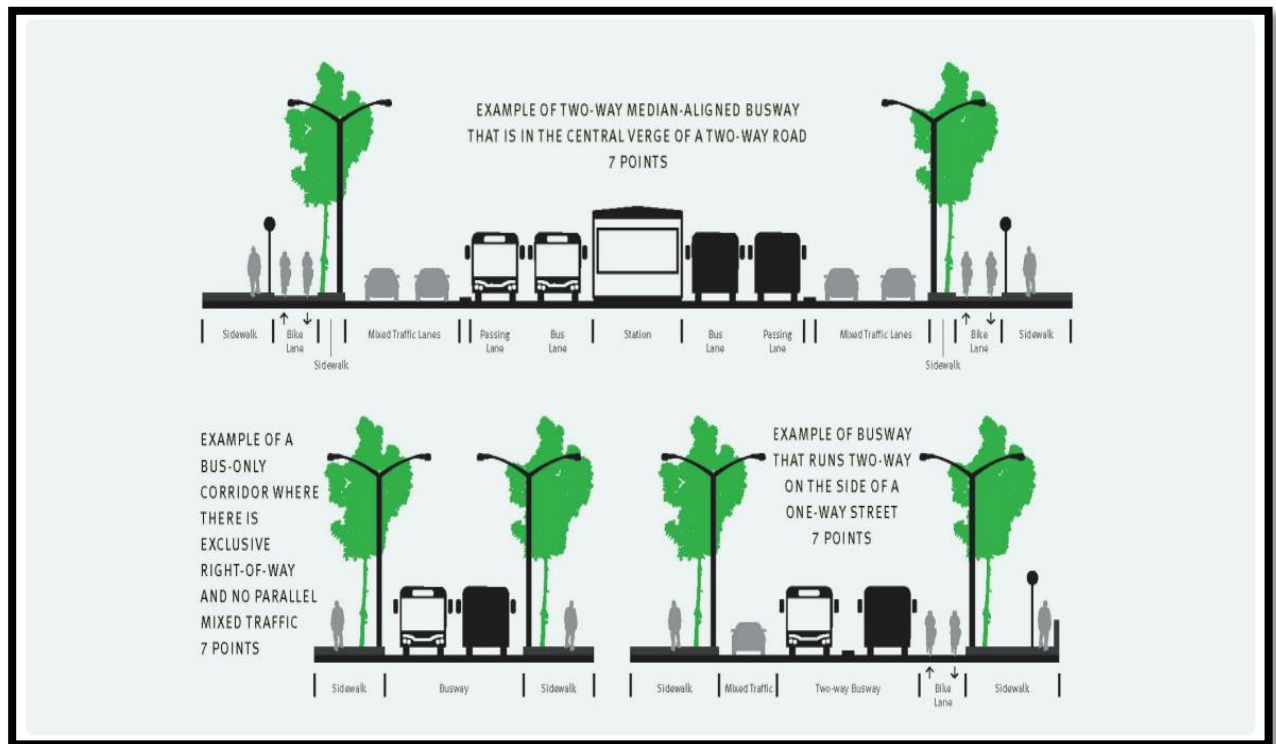


Figure 7: Desirable bus way alignments.

BRT global trends

BRT systems have been grown in over 150 cities throughout the world, transporting over 28 million passengers each day. There are 280 corridors in addition to routes of 4,300 kilometers, 6,700 stations, and 30,000 automobiles in BRT systems around the world. (BRTDATA.ORG).

BRT systems are presently being developed at a quick speed, garnering a particular appeal in the developing countries, following the well-publicized BRT successes in Bogotá, Mexico City, Ahmedabad, Curitiba, Istanbul, and Guangzhou. These new cities show that increased performance BRT systems with considerable transportation and environmental benefits may be introduced for a low price.

A study found that Metrorail systems can be ten times more expensive than BRT systems of equivalent length (Suzuki et al., 2013). Using Light Rail Transit (LRT) can cost up to four times as much as taking the bus. In addition to the economic advantages, BRT has gained popularity because it can be built and expanded fast during peak hours and traffic jams in extremely crowded megacities around the world, including Jakarta, Sao Paulo, Delhi, and Lagos.

Politicians and taxpayers who desire for quick results will welcome the power to open segments prior the whole system being executed. Politicians are also interested in BRT's capabilities for economic development. According to 61 percent of mayors polled by the Economist Intelligence Unit (2011), "improving public transportation/roads" has been the most important thing they carried out to qualify their city with standards and facilities that that make it more competitive and attract businesspeople and international firms (Economist, 2011). Almost twice as many people reported that investing in education and schooling was essential for having economic competition.

The rationale for BRT costs grew with time. Many cities, including Curitiba and Ottawa, have busways because they are less expensive than Light Rail Transit (LRT) (Cervero, 1998). In addition, many cities have lately introduced BRT such as Seoul, Mexico City, and Bangkok as a reliable addition to existing urban rail networks.

Several emerging areas previously relied on an assortment of mostly uncoordinated private buses and unplanned paratransit services instead of a functioning public transportation infrastructure. As a result, they shift to implementing BRT as a fundamental transition. Examples of cosmopolitan cities are Lagos, Jakarta, and Ahmedabad. In many regions of Europe, particularly in medium-sized cities, BRT, also known as BHSL (Buses of High Level of Service), is being implemented as a less expensive alternative to tramways. It focuses on enhancing service dependability, punctuality, and comfort over the existing roadways. (Finn et al., 2011).

Ranks nations or regions based (Figure 8) on the number of cities that have BRT systems as of mid-2013. Over the past 15 years, the majority of these systems have been in operation. Brazil is well known for its development of BRT systems, with Curitiba's groundbreaking system presently serving thirty other cities. When it began operation in 1976, Curitiba's "Surface Metro" attempted to imitate several features of So Paulo's Metrorail system, including dedicated right-of-way, attractive stations, collection of off-board fare, and frequent, efficient service. The carrying capacity of buses with bi-articulated axles and carefully designed and planned boarding tubes increased significantly. Curitiba distinguishes itself by directing urban expansion along condensed, mixed-use lines that polarize transit riders (Cervero, 1998).

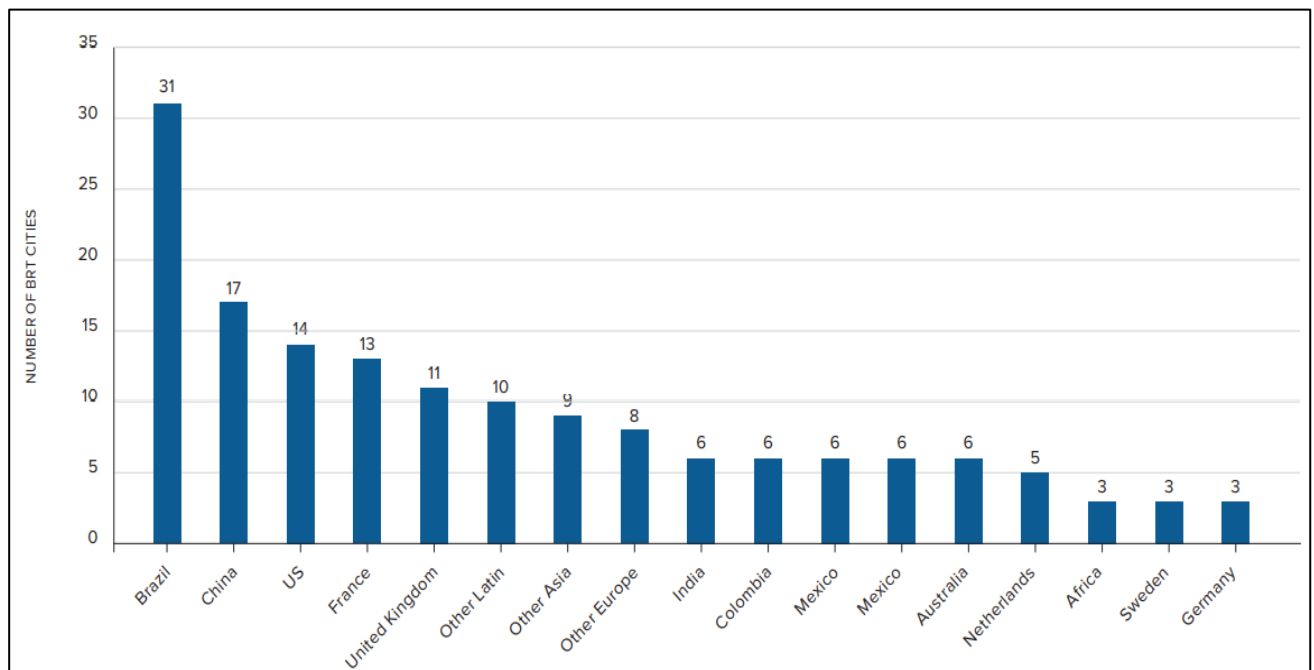


Figure 8: Number of BRT in different cities

According to (Figure 8), the US, France, and the UK are the three developed countries with the second-highest number of cities using BRT systems, following Brazil and China.

BRT stations

BRT systems added more than just signs that direct people to bus stops. High-end BRT systems offer fully equipped stations with reliable riders' information that is both dynamic (such as "next bus" at the station) and static (such as schedules, maps, and brochures), as well as fare machines, comfortable seats, and, in some cases, temperature control in the waiting areas. The public transportation system in Ottawa, for instance, has totally indoor stations that are heated in the winter and air-conditioned in the summer (which is necessary given that Ottawa is the second-coldest capital city in the world).

Huge awnings and shelters are present at station platforms in more than 30 BRT systems across the world, shielding passengers from the sun's heat and rain (CHINABRT.ORG). The majority of high-end BRT stations also incorporate plexiglass automatic doors to regulate passenger flow, reduce crush dangers, and shield passengers from entering forbidden station areas or falling into bus lanes. CCTV surveillance was erected absolutely BRT stations in China (for example, in Gaungzhou, Lanzhou, and Lianyungang).



Figure 9: BRT station sample, (Source; ADA, 2015).

Like other busways, most BRT stops are located in the middle of the road. At center stations, switching between buses is considerably simpler, however this usually comes at the sacrifice of customer access. Skywalks and flyovers can be challenging to navigate, especially for the elderly and disabled and in hot temperatures, and crossing severely congested parallel roadways at pedestrian crossings can be unsafe and dangerous. The network of metal skywalks in Bogota's key bus stations may be so noisy and congested during rush hour that they resemble a steel drum (Suzuki et al., 2013). According to the BRT Standard 2013, a mile or 1.5 kilometers should separate each station: Beyond this, individuals take too long to walk, and less than this, bus speeds are slowed down (ITDP et al, 2013). In populated areas, the majority of BRT stops are 500–600 meters apart. Because of their less average population densities, the Australian and US systems have a far long spacing of 1.5km (Hensher and Golob, 2008). The most distance between stations is 1750 meters in Amsterdam, followed by 1.5 kilometers in Los Angeles,

Bangkok, and Zoahuang, China (CHINABRT.ORG). Nantes has the nearest spacing among BRT systems with specific running paths, averaging 470 meters.

Last but not least, parking spots are only offered at a select few BRT stations (Figure 9), usually those that are close to terminuses, such the Orange Line in the city of Los Angeles. In Beijing and Amsterdam, bicycle parking is more prevalent at BRT stations. Near BRT stations in Guangzhou, Hangzhou, Nantes, and Mexico City, bike-sharing is also available. Wheelchair-accessible stations may now be offered in stations in the developing countries, in addition to BRT systems in Europe, North America, and Australia.

BRT vehicles

The high brand Trolleybuses, biofuel vehicles with more and wider doors than normal buses, together with a great image or brand, give modern BRT fleets a distinct advantage. Increased passenger traffic and the need to accommodate quick, large-size loading have led to a rise in the use of articulated and double-articulated buses with numerous doors (Levinson et al., 2003; Hildalgo and Gutiérrez, 2013). According to ITDP et al. (2013), conventional buses should have two doors, whereas articulated buses should have three. More than 150 passengers can be transported in congested areas using double- and triple-section articulated trucks. The 24m bi-articulated buses in Curitiba have a maximum carrying capacity of 270 people. The four-door Mercedes CapaCity buses in Istanbul have a capacity of 200 passengers. During peak times, there are much more people standing than sitting. Aisles that are wide permit for more movement.

BRT buses are now made by a variety of companies. Mexico City and Bogotá for example, run BRT buses from a variety of manufacturers, including Volvo, Mercedes, and Scania. The unique double-articulated buses and left-side boarding Ligeirinho or Speedy are produced in Curitiba, Brazil, by Volvo, which also has a bus manufacturing facility in South America. Tata has largely monopolized the BRT industry in India, whereas Chinese firms or co-partnerships typically manufacture China's BRT buses (e.g., MAN and Huanghai make buses for Dalian). Bus companies in China, such as Xiamen-based Kinglong, branch abroad, design and make buses for Guangzhou, Lianyungang, Zaozhuang, and Lima, Peru, in addition to Xiamen's high-end BRT system.

The majority of BRT buses today run on clean fuels that satisfy global Euro III and Euro IV emission standards. Due to Australia's natural resource basis, all BRT buses run on CNG in its cities. Because natural gas burns cleaner than liquid fossil fuels, it emits no diesel particles and significantly less Sulphur and nitrogen oxides than other liquid fuels. Due to a combination of fast vehicles on busways (such those in Brisbane, Adelaide, and Sydney) and clean fuels, Australian BRT services are among the greenest in the world. In addition to places in China, CNG buses can be found outside of Australia in Jakarta, Lima, Nantes, Los Angeles, and other locations. Beijing and Guangzhou both have LNG-powered fleets.

Biofuels are used to fuel up some of Curitiba's buses. Diesel-hybrid buses are running on Hefei, Istanbul, Zheng and Seattle roads. The 26-meter-long, 230-passenger ATC Phileas buses in Istanbul

operate on clean gasoline for high-speed travel and on electric batteries for low-speed travel. Electric vehicles provide a variety of benefits. Through regenerative brakes, they can transfer energy back into batteries or the electrical grid. They are also environmentally friendly. They do not release many pollutants. Seattle utilizes diesel-electric hybrid buses in tunnels that work side by side to hybrid vehicles outside the subway. Moreover, the most important characteristic is the least maintenance that they need in comparison to other modes of transportation.

BRT buses are also characterized by their branding. BRT's distinct identity is communicated through logos, color schemes, and other visual elements that differ them from usual buses. Old casino signs, for example, can be found on BRT buses and stations in Las Vegas, reflecting the city's distinguished identity. A perfect identity is in addition to trademark of Europe's BHLS systems, allowing high-quality bus services to be distinct and better than any normal bus services. The low-floor or kneeling form of BRT Lite buses permits same-level boarding and alighting at basic curbside locations. Ramps are used by higher-end buses that stop at high platforms or full-facility stations, such as those in Quito and Bogotá. Beijing and Hangzhou enjoy nice transportation system in which buses have low-floors with station platforms that are a little bit raised.

The distinction between BRT and rail is becoming less and less clear throughout Europe, particularly in France. In order to project a contemporary, rail-like image, French cities including Lyon, Nancy, Caen, and Rouen have chosen the Civis and TVR bus systems, which have rounded bodywork and covered wheels. In towns like Caen and Nancy, TVR—vehicles with rubber tires—run on and off a designated runway. However, Civis is an articulated hybrid diesel-electric vehicle with four doors, optical steering, and a wide aisle that resembles a train. Van Hool buses, which resemble trams, can be seen traveling through Metz. The Twisto system in Caen, which is propelled by a central rail and has rubber tires, is the most challenging to classify.

In the city, Twisto cars are run by overhead electrical wires, but in the suburbs, they can also work on diesel. Some European BRT systems are further distinguished by steering. Since 2001, Civis buses in Rouen have used optical guiding. In 2008, Castellón, Spain, accepts and put optimal guiding into effect. In Eindhoven, Phileas vehicles employ electromagnetic steering. These systems are much more well-designed than the first mechanical guiding systems used by the O'Bahn systems in Adelaide and Essen (which consisted of guide-wheels nestling beside horizontal tracks/stabilizers). Better mechanical curb-guided bus models have been put into operation in Ipswich, Bradford, Leeds, Sussex, Edinburgh, Luton, and Cambridge-St. Ives.

Data Sources

The government provided the majority of the geographic datasets used in this study. The databases included information about districts, BRT lines, stations, and the centerlines of roads and highways. State, county, and municipal boundaries, among other additional data, were used to generate the fundamental maps for this study.

In order to get this data, which was received electronically, explicit consent was required. All of the data was considered public domain and could be used for free. Except for UTM Zone 37N WGS84, this is the spatial reference for all data.

Available data

- A. BRT stations.
- B. BRT network (Figure 10).
- C. Riyadh city districts (Figure 11).
- D. Riyadh city roads network.

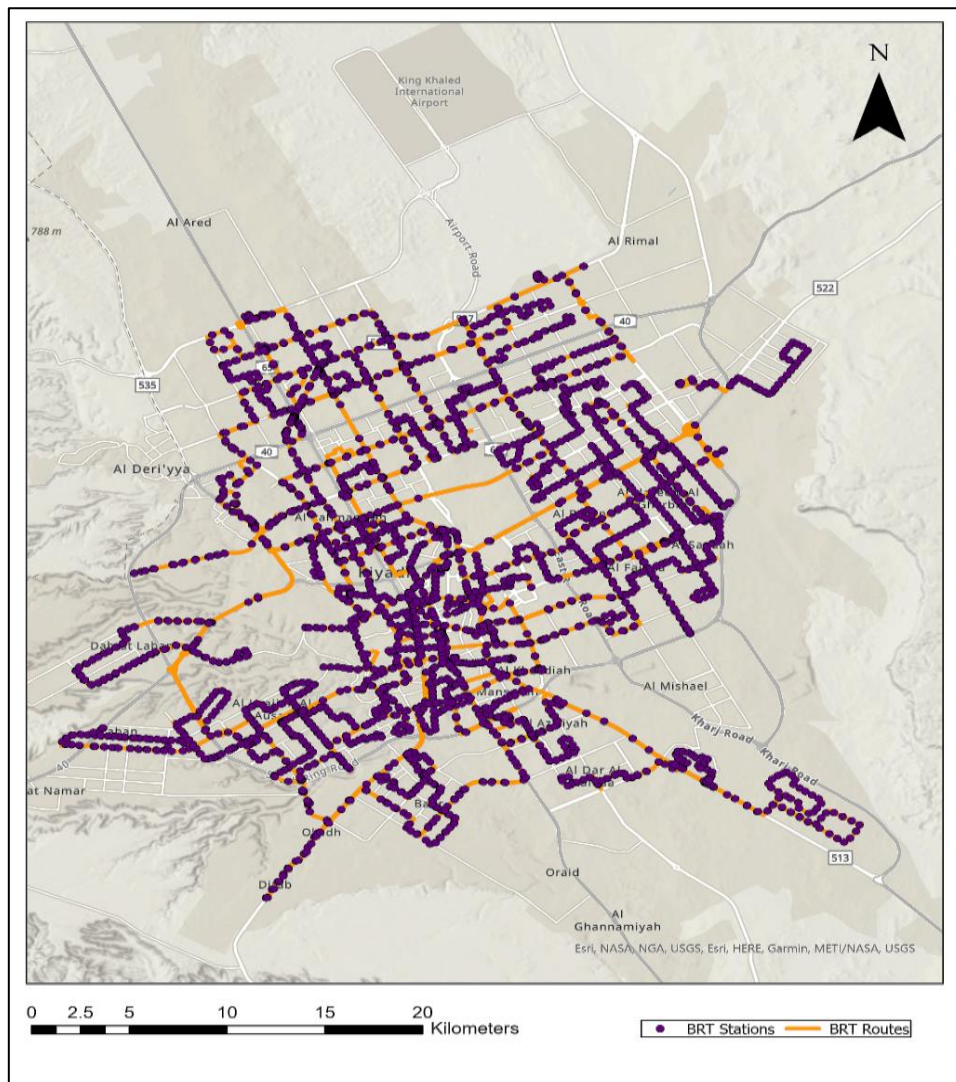


Figure 10 the BRT network routes and stations

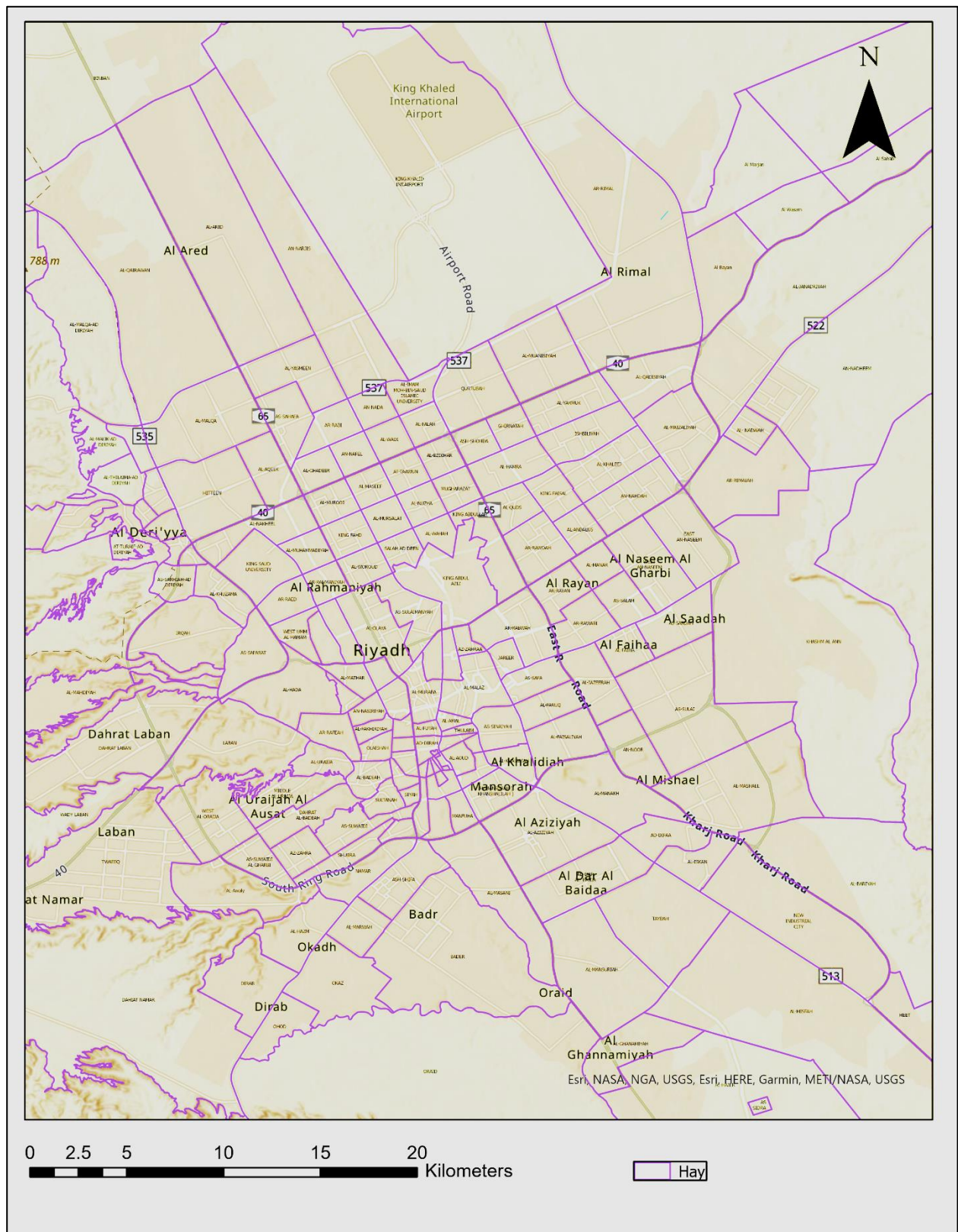


Figure 11 Riyadh districts

Data preparation

The Google earth tool was used to verify and digitize the BRT centerline data. Using Google Earth's on-screen digitization, begin digitizing the network center line from freely available satellite imagery. The

network attribute database then stores the names of routes and other attribute data. Utilizing the Arc Toolbox application, convert digitized lines KMZ data file to Database format using the conversion toolbox. Then On the BRT layer, apply data topology rules and data quality control. With a stated quality measurement, this approach maintains data integrity and shape.

BRT Network Centerlines

The Arriyadh Development Authority (ADA) provided the BRT network (Figure 12) centerline data in KMZ format; this layer has 112 routes, as can be seen in the graphic below.

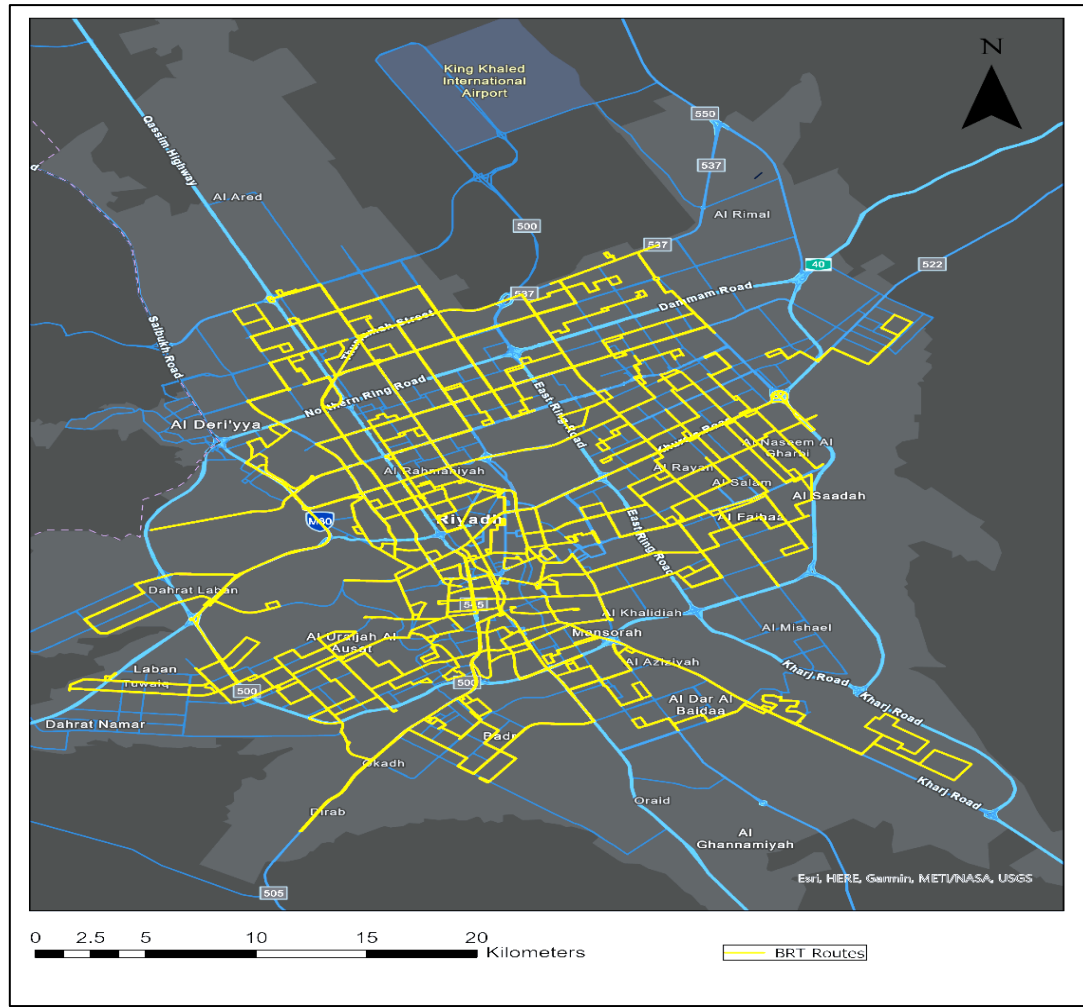


Figure 12 the BRT network

BRT layer categorization

For the analysis, the BRT layer was being categorized into four levels

1. First Level: Lines with specified (bus-only) lines.

This level contains the following bus routes, each with 103 stations:

- A. Al-Kharj Road, which is a 42 km extension of Salahuddin Al-Ayoubi Road to the north, followed by King Abdulaziz Road until it intersects with Prince Saud Bin Muhammad Bin Miqrin Road.

- B. The 23.5 km-long Hamzah Bin Abdulmuttalib Road, Dirab Road, and Prince Muhammad bin Abdulrahman Road.
- C. The whole length of this line is 12 km, which includes Imam Al-Street Shafe's up to its intersection with Prince Saad Bin Abdulrahman I Road and Khalid Bin Al-Waleed Road from its junction with Imam Saud Bin Abdulaziz Bin Muhammad Road to its junction with Khurais Road.

2. Second level: The circle lines.

This level is important for serving the city's major residential areas because it has two main lines with a combined length of 83 km and 67 stations. The two main lines are:

- A. Imam Saud Bin Abdulaziz Bin Muhammad Road, Prince Turki Bin Abdulaziz I Road, King Saud Road, Omar Bin Al-Khattab Road, Salahuddin Al-Ayoubi Road, and King Abdulaziz Road, totaling 37.4 km in length.
- B. Khalid Bin Al-Walid Road, Imam Saud Bin Abdulaziz Bin Muhammad Road, King Abdulaziz Road, Salahuddin Al-Ayoubi Road, Prince Saad Bin Abdulrahman I Road, and Imam Al-Shafe'i Road, totaling 45.8 km in length.

3. Third level: The ordinary lines.

Here are some of the key highways that connect the residential areas of Riyadh city, which are connected by 17 lines totaling 444 km in length:

- A. Al-Takhassusi Road
- B. Al-Orouba Road
- C. Abu Bakr Al-Siddiq Road
- D. Omar Bin Abdulaziz Road
- E. Othman Bin Affan Road
- F. Haroon Al-Rasheed Road
- G. Saeed Bin Zaid Road ...and others

4. Fourth level: The feeding Lines

This level will be within the 600 km of residential districts that make up the majority of Riyadh.

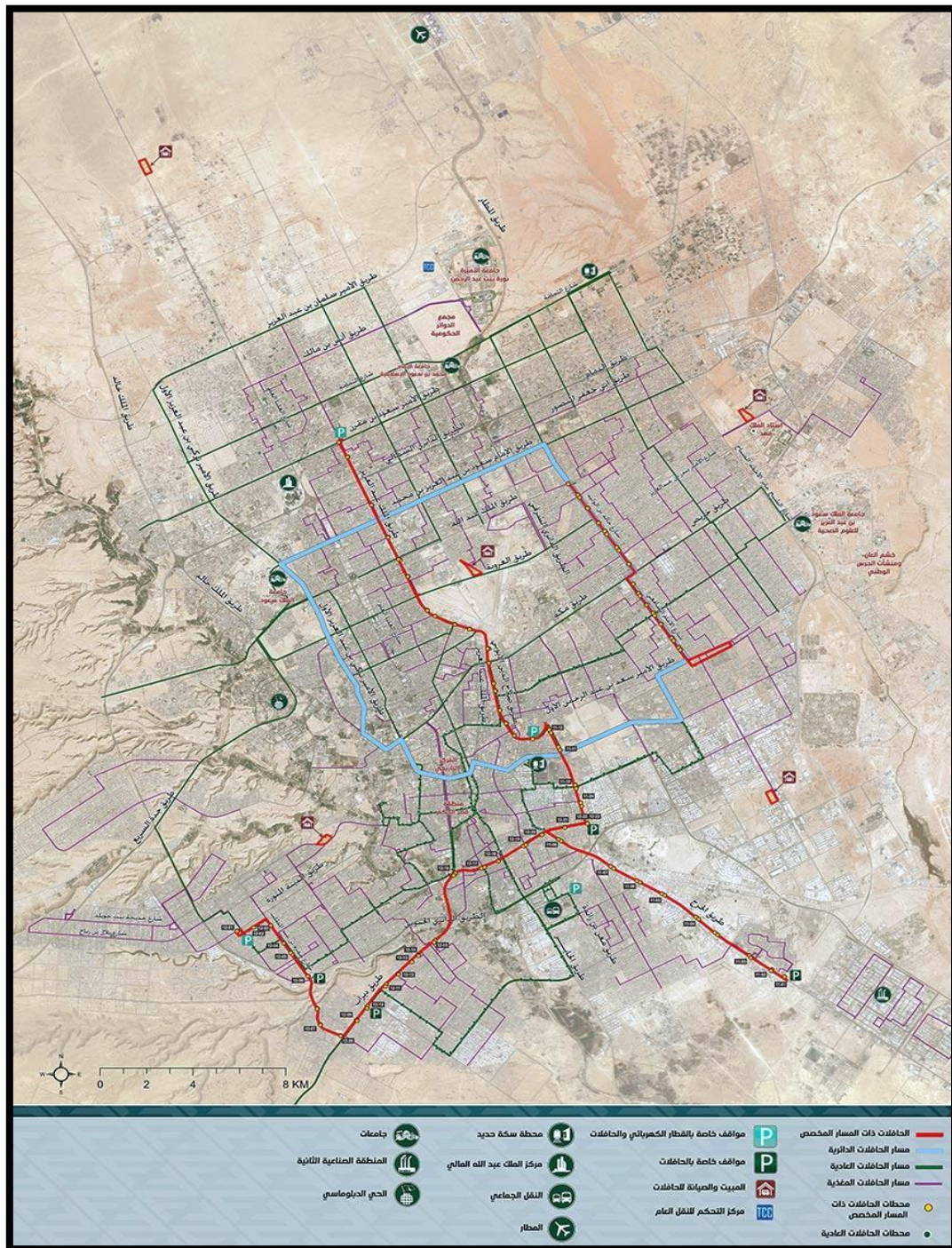


Figure 13 The bus network was developed and built to offer four tiers of transportation services.

Following the successful development of each layer, the basic map of each layer was designed for building the frame of the current road network.

Digitization is the act of making an electronic representation of a real-world event so that it may be saved, shown, and edited on a computer and informed through the internet.

Network Analysis

Graph theory and topology are mathematical sub-disciplines that offer the theoretical foundation for network analysis in GIS. The most common and popular network models describe networks with

which a considerable section of the public connects daily, such as transport and communications networks (Figure 13).

Choosing a course of travel (routing) is the most basic logistical function of network analysis. Recently, much advancement have been done in this area, capacity to provide multi-modal networks, and the use of simulation methods to present network solutions, despite the fact that network analysis in GIS has traditionally been dedicated to the most basic routing functions. There are so many problems and complexities related to many key network applications.

The quickest route and travel demands (trips created and attracted) from the facility to the related area should be identified to state and introduce urban facilities in a region with a complex road network.

A variety of map services and commercial navigational products can be used to find and determine the quickest route between two sites in a network. There are distinct and fabulously efficient algorithms for selecting the best path, with Edgar Dijkstra's algorithm being the most often referenced (in the year 1959).

In 1956, Dutch computer scientist Edsger Dijkstra made Dijkstra's Algorithm and then published in 1959. It relies on graph search: the edge and vertex give the shortest way between two vertexes. The algorithm displays the shortest path (or path with the least cost) between a particular source vertex (or node) in the graph and every other vertex. In summary, the primary function of this algorithm is to determine the shortest routes between nodes in a graph representing a network of roadways.

The algorithm is represented in brief as below:

$$\mathbf{G} = (\mathbf{V}, \mathbf{E})$$

Where V is a set of vertices and E is a set of edges.

Dijkstra's algorithm keeps two sets of vertices:

S = the group of vertices whose shortest paths from the source have already been identified.

V-S = the residual vertices.

The other information structures needed are:

D = array of perfect estimates of the shortest path to each vertex

Pi = a number of predecessors for each vertex

The main mode of operation is:

1. Initial is **d** and **pi**,
2. Set **S** to empty,
3. While there are still vertices in **V-S**,
 - a. Sort the vertices in **V-S** according to the current best estimate of their distance from the source,
 - b. Add **u**, the closest vertex in **V-S**, to **S**,
 - c. relax all the vertices still in **V-S** connected to **u**

Pseudo code for Dijkstra's Algorithm:

Distance [s] ← 0 (distance to source vertex is zero)

For all $v \in V - \{s\}$

Do distance $[v] \leftarrow \infty$ (set all other distances to infinity)

$S \leftarrow \emptyset$ (S , the set of visited vertices is initially empty)

$Q \leftarrow V$ (Q , the queue initially contains all vertices)

While $Q \neq \emptyset$ (while the queue is not empty)

Do $u \leftarrow \min \text{distance}(Q, \text{distance})$ (select the element of Q with the min. distance)

$S \leftarrow S \cup \{u\}$ (add u to list of visited vertices) for all $v \in \text{neighbors}[u]$

Do if distance $[v] > \text{distance}[u] + w(u, v)$ (if new shortest path found)

Then $d[v] \leftarrow d[u] + w(u, v)$ (set new value of shortest path)

Developing the Road Network Model

Esri ArcGIS Network Analyst was used to create a dynamic road network model and a Spatio-temporal database in order to integrate the data and perform the shortest path analysis. This network software offers so many advantages and is distinguished by effectiveness and simplicity.

This program outlines shortest paths closest facilities, so you can choose the best location, and find out the less busy routes for a fleet of vehicles.

ArcGIS is the best tool for this kind of research because it is available commercially and the Network Analyst extension is included in the student edition. One of the advantages of using a network analyst is the ability to estimate the network's time-dependent costs and obtain historical traffic Figures.

Understanding how a road network is represented and operated in Network Analyst requires knowledge of the term Network Dataset (ND). According to Esri, it is a collection of topologically connected network elements, such as edges, junctions, and turns, that are used to represent a road network. These elements are formed from network sources, like features and classes.

Each network component is connected to a set of network features (e.g., cost, descriptor, hierarchy, and limitation). A network dataset serves as the basis for all analyses performed in Network Analyst (Esri 2013b). This expression is used to describe a road network's properties.

The BRT network dataset required a variety of processes to develop. The initial step was to select a file geodatabase (FGDB) as a repository for all network-related elements and feature classes, as well as the collected tables. The network dataset was created as a feature dataset to preserve topology and spatial reference.

In a network dataset built on a geodatabase, all feature classes serving as sources are maintained in a feature dataset. (Figure 14) shows a representation of the file geodatabase data model. The study couldn't begin until the network dataset was created. Building the network dataset is the process of creating network elements, establishing connectivity, and assigning network values (Esri 2013c).

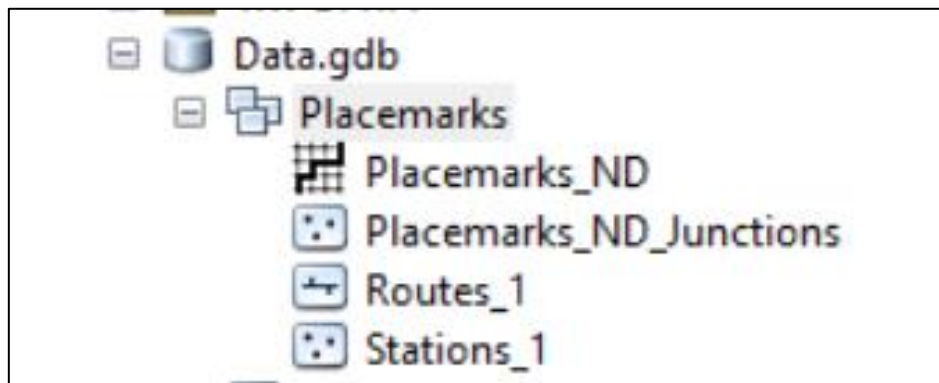


Figure 14 Database elements

Applying network analysis

Point-to-point analysis

A point-to-point analysis is the most common routing trouble involving a group of points for finding out the most optimal route according to specific standards. And this analysis can be done using different criteria as below:

- Find Nearest – Where is the nearest destination? So, it can discover and spot the nearest destination according to a starting point with multiple potential destinations.
- Shortest Distance – What's the quickest route? Where this analysis can calculate and measure all distances, when one travels out from one point to the other, then, it can find the way with the shortest distance.
- Quickest route – this route takes the least time? This network analysis considers speed limits, road classification, and other costs for identifying the least travel time.

Other kinds of point-to-point analysis include the environmentally -friendliest, scenic, and winding routes. Each kind of network analysis introduces directions from origin to destination.



Figure 15 solving a route

It can also have the ability to select the mode of travel like emergency cars, trucks, pedestrians, transit, or cycling.

And as in BRT, all buses' speed is the same, so we used the shortest distance between any two points in Riyadh city, as shown in the (Figure 17), two points are identified on the map (start point (1) and endpoint (2) and the model will solve the network and provide the possible route depending on BRT network as shown in yellow color.

The direction can be shown as a routing guide from starting point (1) to ending point (2), with information of each BRT line used as (name, distance, direction) as shown in (Figure 15).

[-] Route: Graphic Pick 1 - Graphic Pick 2		5.7 km	Map
1:	Start at Graphic Pick 1		Map
2:	Go northeast on Abu Dhabi Square - King Saud University (for Health & Science)	2.8 km	Map
3:	Continue on Hassan ibn Thabit Street 2	33 m	Map
4:	Turn right at Abu Dhabi Square - King Saud University (for Health & Science) / Hassan Bin Thabit Street - Al Khaleej to stay on Hassan ibn Thabit Street 2	33 m	Map
5:	Continue on Abu Dhabi Square - King Saud University (for Health & Science)	5 m	Map
6:	Continue on Hassan Bin Thabit Street - Al Khaleej	45 m	Map
7:	Continue on Hassan ibn Thabit Street 2	13 m	Map
8:	Continue on Hassan Bin Thabit Street - Al Khaleej	1.7 km	Map
9:	Continue on National Museum - King Saud University (for Health & Science)	1.0 km	Map
10:	Finish at Graphic Pick 2, on the left		Map
Driving distance: 5.7 km			

Figure 16 the route directions

Each route can be presented as a map with a detailed route as shown in (Figure 16)

[-] Route: Graphic Pick 1 - Graphic Pick 2		5.7 km	Map
1:	Start at Graphic Pick 1		Hide
2:	Go northeast on Abu Dhabi Square - King Saud University (for Health & Science)	2.8 km	Hide
3:	Continue on Hassan ibn Thabit Street 2	33 m	Map
4:	Turn right at Abu Dhabi Square - King Saud University (for Health & Science) / Hassan Bin Thabit Street - Al Khaleej to stay on Hassan ibn Thabit Street 2	33 m	Map
5:	Continue on Abu Dhabi Square - King Saud University (for Health & Science)	5 m	Map
6:	Continue on Hassan Bin Thabit Street - Al Khaleej	45 m	Map
7:	Continue on Hassan ibn Thabit Street 2	13 m	Map
8:	Continue on Hassan Bin Thabit Street - Al Khaleej	1.7 km	Map
9:	Continue on National Museum - King Saud University (for Health & Science)	1.0 km	Map
10:	Finish at Graphic Pick 2, on the left		Map
Driving distance: 5.7 km			

Figure 17 direction can be shown in a map

Finding Coverage analysis

This type of analysis can result in corresponding drive-time areas to the distance where that can be reached within the least amount of time.

Service Areas – These areas can be spotted within 5, 10, and 15 minutes from a station, this type of network analysis can as well cover a lot of businesses and narrow these gaps (Figure 17).

(Figure 18) depicts and shows service area analysis with multi-ring buffer zones to illustrate the suitable coverage of BRT stations.

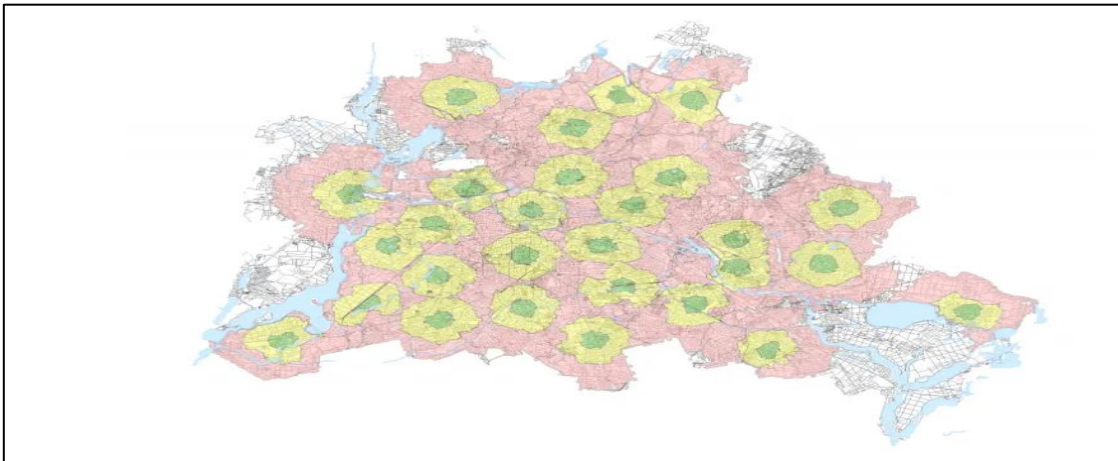


Figure 18 station service area analyses

Same as station gap analysis, also BRT network buffer can be done within 500 meters on both sides of the BRT network as shown in (Figure 18).

As shown the BRT network covers all of Riyadh city, and most citizens can access the network station within 5 minutes of walking about 500 meters.

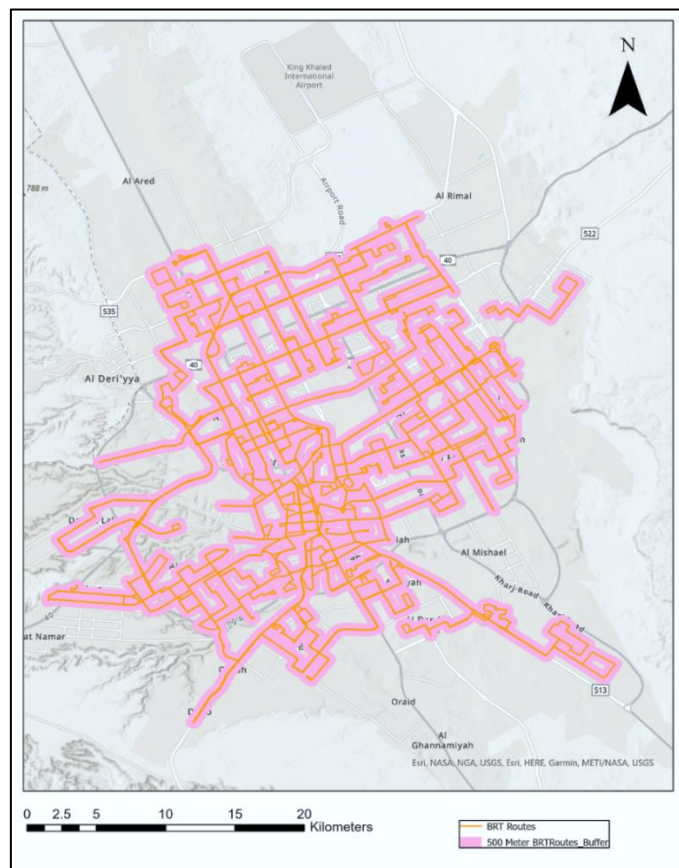


Figure 19 the BRT network

Examining Network

This analysis comprises a routing example centered on different popular selected locations shown in Table 1.

Table 1 routing scenarios

scenario	Routing distance	Start point	Name	End point	Name
S1	26 KM	P1	National Museum	P2	King Soud university

There are two scenarios for each case. The first scenario, designated S1, denotes a user's desire to go from Point 1 (National Museum), which is located east of Riyadh City, to Point 2 (King Soud University), which is located west of Riyadh.

The "Route" solver in Network Analyst was chosen and utilized to determine the fastest method using a time-based attribute known as the "free-flow travel time," the ideal route using a time-varying feature according to coverage of the BRT network, and the shortest path using the BRT network.

The similarities and variations between route directions, distances, and travel times from each feature are compared and examined for both routing (finding the best path) situations.

Routing Case1

(Figure 20) shows first scenarios from Point 1 (National Museum) located east of Riyadh city to Point 2 (King Saud university) located west of Riyadh with a total distance 26 km, and Figure 21 shows the directions used from point 1 to point 2 with a description of each route and its distances in KM. Then Figures from 20 to 24 shows route direction in detail.

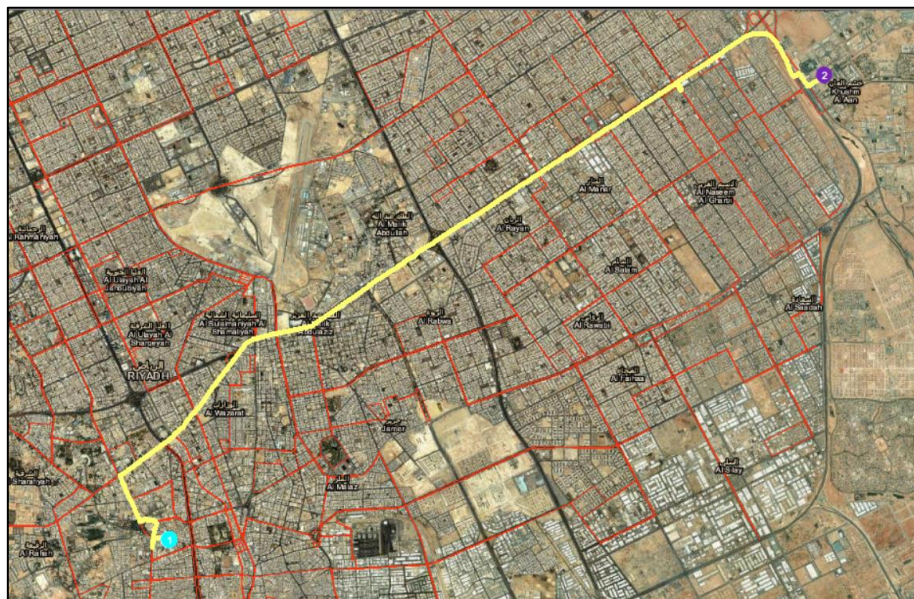


Figure 20 Route from National Museum to King Soud University (Source; Google Earth software).

Directions (Route)		
[-]	Route: Graphic Pick 1 - Graphic Pick 2	26 km Map
1:	Start at Graphic Pick 1	Map
2:	Go west on National Museum - King Saud University (for Health & Science) toward Transportation Centre - Prince Mashal Ibn Abdulaziz & Western Rd / Khalid Ibn Alwalid Road - An Naseem	909 m Map
3:	Make sharp right on Khalid Ibn Alwalid Road - An Naseem	2.3 km Map
4:	Turn right on Abu Dhabi Square - King Saud University (for girls)	29 m Map
5:	Continue on Ministry of Interior 2	1.2 km Map
6:	Turn right on Ministry of Interior 2 and immediately turn left on Ministry of Interior 2	433 m Map
7:	Bear left on Abu Dhabi Square - King Saud University (for girls)	803 m Map
8:	Make sharp right on Transportation Centre - Northern Vegetable Markets and immediately make sharp left on Abu Dhabi Square - King Saud University (for girls)	2.5 km Map
9:	Continue on Abu Dhabi Square - King Saud University (for Health & Science)	12.2 km Map
10:	Continue on Hassan ibn Thabit Street 2	33 m Map
11:	Turn right at Abu Dhabi Square - King Saud University (for Health & Science) / Hassan Bin Thabit Street - Al Khaleej to stay on Hassan ibn Thabit Street 2	33 m Map
12:	Continue on Abu Dhabi Square - King Saud University (for Health & Science)	5.4 km Map
13:	Make sharp right on National Museum - King Saud University (for Health & Science)	44 m Map
14:	Finish at Graphic Pick 2, on the left	Map
Driving distance: 26 km		

Figure 21 Route directions

- Start at Graphic Pick 1
- Go west on National Museum - King Saud University (for Health & Science) toward Transportation Centre - Prince Mashal Ibn Abdulaziz & Western Rd / Khalid Ibn Alwalid Road - A Naseem



Figure 22 Direction 1 (Source; Google Earth software).

- Make sharp right on Khalid Ibn Alwalid Road - A Naseem
- Turn right on Abu Dhabi Square - King Saud University (for girls)
- Continue on Ministry of Interior 2



Figure 22 Direction 2 (Source; Google Earth software).

- Turn right on Ministry of Interior 2 and immediately turn left on Ministry of Interior 2



Figure 23 Direction 3 (Source; Google Earth software).

- Bear left on Abu Dhabi Square - King Saud University (for girls)
- Make sharp right on Transportation Centre - Northern Vegetable Markets and immediately make sharp left on Abu Dhabi Square - King Saud University (for girls)
- Continue Abu Dhabi Square - King Saud University (for Health & Science)



Figure 24 Direction 4 (Source; Google Earth software).

- Continue on Hassan ibn Thabit Street 2
- Turn right at Abu Dhabi Square - King Saud University (for Health & Science) / Hassan Bin Thabit Street - Al Khaleej to stay on Hassan ibn Thabit Street 2
- Continue on Abu Dhabi Square - King Saud University (for Health & Science)
- Make sharp right on National Museum - King Saud University (for Health & Science)



Figure 25 Direction 5 (Source; Google Earth software).

- Finish at Graphic Pick 2, on the left



Figure 26 Direction 6 (Source; Google Earth software).

Conclusion

The study reinforces the value of good design technique for accessible public transportation systems. The utilization of accessible vehicles, such as low-floor buses, is needed but lacking for such an accessible system, planners and operators should be aware of. This study used geographic information system technology. It also used the most trustworthy tools and methodologies to present the facts and information that were gathered, in order to examine and evaluate the BRT system. Bus rapid transit (BRT), which introduces a higher passenger capacity, less costly, convenient, and flexible option for high-performance transit systems, has gradually drawn the attention of policymakers.

A centralized Geodatabase has been built for BRT lines and stations. A geometric network was conducted for BRT routes to facilitate moving from any location to another within Riyadh city. The assessment and evaluation of BRT routes focused on routes and station distribution regarding Riyadh city and how BRT solved population needs in Riyadh city. Using the powerful GIS network analysis functions, a navigation system was developed to assist passengers in planning their trips from one station to another giving detailed information about route directions and different BRT lines used.

The complexity and preparation time involved in creating and maintaining the road network dataset were challenges. Directionality, connectivity, and the insertion of one-way limitations were part of the plan to limit traffic on one-way highways and stop route anomalies. A few problems that required attention were overshooting of roads, traveling the wrong way on a motorway, and entering or leaving a ramp in the wrong direction because of defective road junction and road segment design.

The network has been edited for hours in order to fix the problems with the road margins, intersections, and associated attribute fields. This approach might have been quicker and simpler with more experience. The typical process involved spotting and determining defects or irregularities, fixing it through digital programs or reattribution, reconstructing the network dataset, and regular checking.

Recommendations

1. BRT coverage and route analysis may benefit from using data on population densities for various urban districts and converting it to persons per kilometer.
2. This study could help transit planners decide where the ideal places are to place new bus stops or reassign current bus stops.
3. Develop a mobile application that can use routing services developed by this study that can help passengers in selecting the right BRT line when choosing starting point (source) and ending point (destination) on the Riyadh city map, the application appears the BRT lines needed with its information (station name, routes directions, BRT name, and timing).
4. Transit professionals will promote and enhance the level of analysis by developing, optimizing, and/or enlarging the use of GIS in the planning process.
5. Ascertain how the geometry of the surrounding pedestrian road network may affect the indices' values, a complete examination of the produced indices will be conducted. By looking at the locations of transit stations on a spatial basis rather than just looking at their spacing and circular access coverage.

REFERENCES

- **ADA.**: Investment climate report. Riyadh: ADA. Retrieved from A comprehensive strategic plan for the city of Riyadh, Riyadh_Metropolitan_Development_Strategy_Executive_Summary, (2015).
- **ADA.**: Public Transport Study For the City of Arriyadh: Pilot Project - Phase I (Executive Summary). Riyadh: Ar-Riyadh Development Authority. (2004).
- **Al-Dubikhi, S. A.**: Exploring the potential for successful public transport in Riyadh (PhD thesis).University of Melbourne, Melbourne, (2007).
- **Al-Fouzan, S.:** Reducing Car-Dependence in Ar-Riyadh City through the Integration of Land-use Planning and Transport. Unpublished PhD, Department of Architecture and Building Science, Strathclyde, Glasgow, UK, (1995).
- **Al-Mosaind, M.:** The Effect of Changes in Land Use Distribution on Travel Patterns in Riyadh, Saudi Arabia. Paper presented at the Conference of Planning for Cities in the 21st Century: Opportunities and Challenges (WPSC), Shanghai, (2001).
- **BRTDATA.ORG.**: Accessed July 24-25, (2013).
- **Cervero, R., & Kang, C.:** Bus rapid transit impacts on land uses and land values in Seoul, Korea. *Transport Policy*, 18(1), 102–116., (2011).
- **Cervero, R., & Murakami, J.:** R+P as transit-oriented development rail + property development: A model of sustainable transit finance and urbanism (pp. 21–30). Berkeley, US: MTR Corporation, (2008).
- **Cervero, R.:** The transit metropolis: a global inquiry. Washington, D.C.: Island Press, (1998).
- **CHINABRT.ORG.**: ITDP China, Institute for Transportation & Development Policy, Guangzhou, China. Accessed data July 24-25., (2013).
- **Deng, T., & Nelson, J. D.:** Recent developments in bus rapid transit: A review of the literature. *Transport Reviews*, 31(1), 69–96. (2011).
- **Economist Intelligence Unit.:** Lievanomics: Urban liveability and economic growth. London: The Economist.(2011).

- **Farahani, R.Z.:** Miandoabchi, E., Szeto, W.Y., Rashidi, H.: A review of urban transportation network design problems. *Eur. J. Oper. Res.* 229, 281–302. doi:10.1016/j.ejor.2013.01.001., (2013).
- **Finn, B., Heddebaut, O., Kerkhof, A., Rambaud, F., Lozano, O., Soulas, C.:** Buses with High Level of Service: Fundamental Characteristics and Recommendations for Decision-making and Research. Brussels: European Cooperation in Science and Technology, (2011).
- **Gupta G.D., Dey, G., Mg, S., Ramalingam, B., Shameer, K., Thottacherry, J.J., Kalappurakkal, J.M., Howes, M.T., Chandran, R., Das, A., Menon, S., Parton, R.G., Sowdhamini, R., Thattai, M., Mayor, S.:** Population distribution analyses reveal a hierarchy of molecular players underlying parallel endocytic pathways. *PLoS ONE* 9(6): e100554. (2014),
- **Harrison, A and Gretton, J:** Transport UK, 1985 Policy Journals, Newbury. (1985)
- **Hensher, D. and Golob, T.:** Bus rapid transit systems: a comparative assessment. *Transportation* Vol. 35, No. 4, pp. 501-518., (2008).
- **Hidago, D. and Gutiérrez, L:** BRT and BHLS around the world: explosive growth, large positive impacts and many issues outstanding. *Research in Transportation Economics*, Vol. 39, No. 1, pp. 8-13., (2013).
- **ITDP:** Institute for Transportation & Development Policy), ClimateWorks Foundation, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), International Council on Clean Transportation, and Rockefeller Foundation.. The BRT standard 2013. New York.(2013).
- **Levinson H., Zimmerman, S., Clinger, J., and Gast, J.:** Bus Rapid Transit: Synthesis of case studies. *Transportation Research Record* 1841, pp. 1-11., (2003),
- **Ministry of Interior:** Riyadh province. Riyadh: Author. Retrieved from <https://www.moi.gov.sa/wps/portal/Home/Home.>, (2015).
- **Ministry of Transport.:** National transportation strategy. Riyadh: Author. Retrieved from <https://www.mot.gov.sa/Ar/Documents/Final%20Report%20English%20New.pdf.>, (2011).
- **Mubarak, F. A.:** Urban growth boundary policy and residential suburbanization: Riyadh, Saudi Arabia. *Habitat International*, 28(4), 567–591. doi:10.1016/j.habitatint.2003.10.010., (2004).
- **Shaw, S L:** Moving toward spatiotemporal GIS for transportation applications. In: *Proceedings of the 20th ESRI User Conference*. Available from <http://proceedings.esri.com/library/userconf/proc00/professional/papers/PAP205/p205.htm> [Accessed 16 May 2012]., (2000).
- **Simpson, B, J.:** *Urban Public Transport Today*, Published by E & FN Sponl, 2-6 Boundary Row, London, SE1 8HN, UK. (1994)
- **Suzuki, H., Cervero, R. and Iuchi, K:** Transforming cities with transit: transit and land-use integration for sustainable urban development. Washington, DC: World Bank., (2013).
- **Wright, L. and Hook, W:** *Bus rapid transit planning guide*. New York: Institute of Transportation & Development. . (2007).