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What would it take for the people of Riyadh city to shift from their cars to the proposed metro?☆

AHM Mehbub Anwar *, Abu Toasin Oakil, Abdelrahman Muhsen, Anvita Arora

King Abdullah Petroleum Studies and Research Center (KAPSARC), Department of Transport and Infrastructure, Airport Road, Al-Narjis District, Riyadh 11672, Saudi Arabia

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ABSTRACT

Modal shift from car to metro has positive impacts on the society including congestion reduction, energy efficiency, and reduction in carbon emission and air pollution. However, people often choose car over public transport for many reasons, for example, comfort, freedom, and reliability among many others. Barriers to shift to public transport can play even stronger role in cities like Riyadh, where the urban infrastructure as well as fuel price and the culture favor car travel. To what extent certain factors may influence modal shift from car to public transport in Riyadh is a critical question. In this study, we investigate the underlying factors that drive people of Riyadh to use the metro instead of car. Using stated preference survey data and mixed logit models, we analyzed modal shift from both car and taxi to metro. The results show that travel times, travel costs, walk times and transfer requirements significantly and negatively affect people's mode choices. Whereas young Saudis are more likely to shift to metro, the findings suggest that a very favorable walking situation is required for metro to be successful.

1. Introduction

Public transport will bring the next big travel behavior change in GCC cities. GCC countries are transforming from oil economy to energy economy and diversifying their economic activities other than oil. Climate challenges and net-zero emission targets are the impetuses for these changes. To make these changes happened, the cities need to transform as well. GCC cities are experiencing rapid economic growth and urbanization for the last few decades due to boom in oil economy. Often, this led the urban development of GCC cities towards automobilization and urban sprawl. Such urban development comes with many challenges - high per capita energy consumption, traffic congestion and pollution, unaffordable housing, and wellbeing issues. None of these helps achieving climate goals and net-zero emission. Therefore, most of the GCC cities such as Riyadh, Dubai, Doha, Kuwait City and Muscat are investing on public transport as a (re)new transport strategy. In this paper, we focus on Riyadh, the capital of the Kingdom of Saudi Arabia, and its proposal for public transport. We will specifically investigate the proposed metro system and people's willingness to use it.

Metro as a rapid mass transit system transports a large number of people from an origin to a destination at once and at high speed. It can bring benefits to the society in different ways. In general, metro as public transport is cheaper than private transports. This may create equitable opportunities for the participation in the society – either in economic activities or in leisure and social activities. Public transports are also safer and can reduce deaths in road transport which accounts for 1.25

☆ This study is a part of an ongoing project entitled "KAPSARC Spatial Urban Energy System." This project comprises two components, an urban energy model and a spatial economic model, and has three objectives. The first objective is to improve energy efficiency through transit-oriented development (TOD) in the transportation and electricity sectors. The second is to gain additional efficiency by realizing the potential opportunities of innovative and smart technologies offered by TOD. The third is to investigate the energy and economic impacts (including real estate development) of Riyadh's transportation, land use and urban planning interventions. This study falls within the first component and addresses the first objective. The energy-efficiency gains offered by TOD are directly related to land-use changes and modal shifts to public transport. In this context, understanding people's willingness to potentially shift their modes of transportation is important for implementing public transport infrastructure projects. Thus, it is imperative to understand the factors that may impact modal shifts to the new metro in Riyadh, a highly urbanized and motorized city.

* Corresponding author.
E-mail addresses: mehbub.anwar@kapsarc.org (A.M. Anwar), abutoasin@gmail.com (A. Toasin Oakil), abdelrahman.muhsen@kapsarc.org (A. Muhsen), anvita.arora@kapsarc.org (A. Arora).

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million deaths globally due to road traffic crashes (Aqib et al., 2019). Since public transport can carry a large number of passengers compared to private vehicles, it reduces pressure on the roads and thus, congestion. Moreover, it can bring environmental sustainability through energy efficiency. According to Kenworthy (Kenworthy, 2018), public transport can be 55 times more energy-efficient than automobile travel is. Energy efficiency goes hand in hand with reduced carbon emission and air pollution. Therefore, the number of metro systems is growing globally. The International Association of Public Transport (International Association of Public Transport, 2018) notes that 178 cities in 56 countries had metros at the end of 2017, among which 75 new metros have opened since 2000 mainly in Asia. On an average, metro carries around 168 million passengers per day worldwide.

Riyadh has also developed metro system for its residents ready to be opened as soon as Covid-19 situation eases. Currently, the energy consumption from Kingdom's transport sector is around 22%, which is largely based on fossil fuel. The estimated daily consumption of gasoline and diesel will be around 1.86 million barrels by 2030 (Amarnath and Henaki, 2019). The carbon emission from the transport sector is also high, contributes 22% in the KSA (Crippa et al., 2020). In addition, car accident rate in the KSA is very high making the KSA one of the world's highest rates in death and casualties (Al-Mosaind, 2018). Riyadh's vision for 2030 is to become an economic hub of the region and to become independent of oil economy. Riyadh intends to diversify its economy, which means catering for diversified people will be essential. People from different background, income group and age as well as temporary residents like tourists to permanent citizens will be living, staying, or working in Riyadh. Everybody will not be owning a car or may not be able to drive a car. But the city must be able to serve the citizens whether use a car or not if it wants to rise as an economic hub of the region. A shift from automobile to metro can certainly reduce energy demand and carbon emissions and increase safety as well as favor equitable society and economic development as visioned for Riyadh.

From the onset of oil economy, Riyadh has been growing rapidly. To accommodate such growth, Riyadh allowed uncontrolled growth leading to urban sprawl. Riyadh's urban sprawl is even faster than its economic growth. According to Mubarak (Mubarak, 2004), such dysfunctional sprawl is an outcome of planning negligence. He argued that central government ordinances helped such sprawl by mandating big lots and overly wide streets. Not only the Riyadh's urban infrastructure favored the automobiles but also Riyadh lacked proper planning for public transport. Riyadh's urban infrastructure can be characterized by the absence of credible public transport system, a network of unfriendly pedestrian pathways and unsuitable infrastructure for non-motorized travel (Al-Mosaind, 2018). Riyadh's mega-metro project, the world's largest urban rail project outside of China, would be the first integrated public transport initiative in the KSA. Aldalbahi and Walker (Aldalbahi and Walker, 2016) discussed in their research that there has been minimal attention to the public transport from the urban and transport planning authorities, and Riyadh's Islamic culture and conventions regarding privacy might also have a profound effect on the development of the transport system. For example, less than 9% of the total Saudi Arabia Public Transport Company (SAPTCO) ridership is constituted by women because of their privacy issue as well as availability of private cars and drivers (Aldalbahi, 2018). Thus, the nature of public transport makes it intrinsically unattractive for female users in this society and private cars become popular and convenient for them (Aldalbahi, 2018). Women were not allowed to drive until 2018 in KSA, but they can drive legally. Due to different expectations of women such as privacy, convenience, and comfort in accessing public transit facilities, like footpaths, lift Riyadh metro is expected to make sure those facilities. Women, who have access to the car or have the driver license might be less likely to use public transit unless they are met by their expectations. gasoline.

Nonetheless, it would be unwise to assume similar relationship exists between metro use and different factors such as socioeconomic, service attributes, and land-use as found in many other studies. It is understood that Riyadh needs to create a favorable condition for public transport, both from infrastructure perspective and from cultural and geographical perspectives. To achieve sustainable urban mobility, the current transport system, which favors automobile travel, must evolve. The new system should prioritize energy efficiency, environmental sustainability, and an overall better quality of urban life (Businge et al., 2019). The urgent need to cut carbon emissions to mitigate adverse climate impacts calls for a drastic shift toward more sustainable modes of transport and Riyadh is planning to do so with its largest public transport initiative in the Kingdom. However, the gains from the metro system will depend on people's willingness to switch from the more traditional car use to metro use. This study investigates different aspects of the Riyadh metro system including both service attributes and socioeconomic characteristics of the residents to understand the factors that influence people's willingness to ride the metro. Only relevant study was conducted by Youssef, Alshuwaikhat, and Reza (Youssef et al., 2021) showing commuters' perceptions of the metro services in Riyadh. We extend this line of research by using official data from Riyadh planning authority as well as adding taxi to metro component in the model. A well-designed data collection allowed to test different forms of modelling approaches such as random parameter and random effect models to incorporate individual-level heterogeneity into the choice model.

2. Literature review

Travelers' mode choices are complex. Transport mode choices are composed of multifaceted, interrelated factors and can be conscious or unconscious (De Witte et al., 2013). A shift from automobile to metro is not easily achieved. Blainey, Hickford, and Preston (Blainey et al., 2012) identified 37 distinct barriers divided into three broad groups (shown in Table 1) that may adversely affect use of public transport in general. These groups represent hard (e.g., travel time, reliability, and cost), soft (e.g., comfort, information, and security) and complementary (e.g., weather and lifestyle) barriers. The hard barriers are more related to indicators and interventions on the supply side of the transport system such as travel cost, time, or frequency, whereas the soft barriers are more related to the demand side including psychological and behavioral aspects (Queiroz et al., 2020).

From Riyadh's perspective, these barriers may play substantial role in how people will act to the proposed metro system. For example, the

Table 1
Barrier to public transport use.

Hard barriers	Soft barriers	Complementary barriers
1) Travel time	1) Inaccurate perceptions	1) Trip chaining
2) Reliability	2) Conscious car dependence	2) Habits
3) Service frequency and timetabling	3) Convenience and freedom	3) Individuality
4) Interchange	4) Lack of control	4) Age, health and disability
5) Network limitations	5) Journey planning and requirements	5) Ethnicity, faith and culture
6) Cost	6) Information provision	6) Goods and baggage
7) Station access and egress	7) Station facilities	7) Locational preferences
8) Ticketing complexity and inter-availability	8) Cleanliness and maintenance	8) Influence of employers
9) Structural car dependence	9) Personal security	9) Suboptimal market prices
10) Land-use patterns	10) Staff presence	10) Weather
11) Government policy	11) Comfort	
12) Safety	12) Crowding	
13) Inherent unsuitability of trips for rail	13) Other passengers	
	14) Image of public transport	

Source: (Blainey et al., 2012).

cost of operating a car in the KSA is very low relative to other countries worldwide. The KSA has very low taxes and registration fees for cars and very low fuel costs. Thus, many lower-income households can afford to use private cars. Since the late 1950s, Riyadh has been a car-dominated city (Aldalbahi and Walker, 2016). Between 1996 and 2008, private vehicle ownership in the city increased by 185.9%. About 85% of Riyadh's eight million daily trips are taken by car, whereas just 2% of its trips are taken by bus (Al-Fouzan, 2012, Alqahtani et al., 2012).

Whereas hard barriers such as cost, land-use, and accessibility can be overcome by designing the metro system carefully, the soft barriers and complementary barriers are culturally and geographically embedded in the society. Blainey, Hickford, and Preston (Blainey et al., 2012) argued that even when rail travel is the most cost-effective transport mode for a particular journey, many travelers still choose other modes. Thus, non-financial barriers to choosing rail transport exist. Riyadh people have been using cars for decades. More than 90% of the trips are made by cars or taxis in Riyadh. Such behavior may create a habit, which may discourage metro use by creating an inertia (La Paix et al., 2021). Car dependency or habit may also lead to different perception about the public transport. Such perception can be unfavorable to public transport use and still be inaccurate.

The likelihood of a modal shift from private cars to public transit will depend on the competitive advantage between the modes based on service attributes like travel cost and time. Pucher and Renne (Pucher and Renne, 2003) argued that the shared modes of transport have struggled to attract passengers in the United States because private car has been historically cheap. Consequently, public transit is largely used by low-income people with limited means to use or own cars. In countries like the United Kingdom and Germany, where automobile transport costs are higher because of land-use and pricing policies, public transit is more popular (Buehler, 2011, Giuliano and Dargay, 2006). Similar association between the cost of automobile travel and transit use is also found in several empirical research (Asensio, 2002, Gillen, 1977, Washbrook et al., 2006, Crane and Crepeau, 1998). This research mainly indicated that increasing the cost of car use relative to the cost of transit is associated with greater transit demand. For example, parking prices and road use charges can be increased to raise car use costs that may encourage travelers to use public transits. The relatively higher cost of automobile travel may support this behavior.

Studies also suggest that factors other than service attributes influence public transport use or mode choice in general. For instance, individuals' socioeconomic characteristics strongly impact their mode choices (Munshi, 2016, Stead and Marshall, 2001). Georggi and Pendyala (Georggi and Pendyala, 2000) find that the elderlies are more bus-dependent and Kuhnimhof et al. (Kuhnimhof et al., 2012) observe a decrease in the share of car use for German travelers age 18–29. Focusing on long-distance trips, Limtanakool, Dijst, and Schwanen (Limtanakool et al., 2006) show that low-income travelers in the United States depend more on private cars, inter-city buses and trains relative to other income classes, whereas higher income classes are more likely to use faster transport modes like airplanes.

Beside socioeconomic characteristics like age, gender, income, and household composition, other household situations such as household car ownership is relevant predictors of mode choice (Buehler, 2011, Cheng et al., 2016). Similarly, Chen and McKnight (Chen and McKnight, 2007) found income as well as car ownership as important determinants of travel choices. Ter Schure, Napolitan, and Hutchinson (Ter Schure et al., 2012) suggested that the presence of both car sharing and unbundled parking in residential developments significantly impact vehicle ownership. They find that car share members have significantly lower vehicle ownership levels.

Furthermore, studies suggest that the built environment can help to explain people's travel behavior. Denser, mixed-use, pedestrian-friendly, transit-accessible, and vibrant areas influence people to use transit more (Basheer et al., 2020, Ding et al., 2017, Wong et al., 2017, Yang et al., 2016). Increasing the transit supply may also change mode choices and influence local land-use policies with coordinated land-use and transit planning. A previous study surveyed households in northern New Jersey living within two miles of rail stations. The results show that automobile ownership is substantially lower among households near these stations than among households that are farther from these stations (Chatman, 2013).

In addition, overall climate of Riyadh is arid. It is hot and dry. Average temperature during summertime is over 38c and humidity is only around 6%. This certainly does not favor outdoor activities, especially walking and cycling. Weather has certain influence on walking and cycling behavior (Dunn et al., 2012, de Montigny et al., 2012, An et al., 2019, Nahal and Mitra, 2018). Walking behavior in Riyadh would certainly be different than any European or North American cities. In general, weather situations such as rain, cold or heat negatively affect walking and cycling. Since walking is often unavoidable to access a metro station, people's willingness to use metro would be affected by the walking distance to metro station in Riyadh.

Travelers make mode choices by carefully evaluating conditions and attributes, such as travel costs, travel time and their individual characteristics (Chakrabarti, 2017). Determining and generalizing travelers' perceptions of the costs associated with a particular mode and their responses to changes is a multifaceted process. Often, choices are governed by non-flexible personal attributes that may not be sensitive to costs. For instance, people are less likely to change their mode choices for routine travel (Schneider, 2013). In addition, the impact and the importance of different factors may vary depending on the context. For instance, the effects of travelers' ages on their modal choices are not sufficiently clear for medium and long distance trips in the United States (Limtanakool et al., 2006). Although, socioeconomic factors are found to be vital to understanding mode choices and sometimes are more powerful predictors of mode choice than land-use characteristics are (Alqhatani et al., 2013). Insights from potential passengers can be diversified in diversified context and are not often fixed or conclusive. Therefore, an empirical perspective on Riyadh metro is important and can depict a different picture.

3. Methodology

The objective of this study is to understand people's willingness to shift from their current travel modes to the proposed metro. To fulfill the objective, the methodology requires two things – i) a data that would depict the preference for metro compared to their current mode and ii) a model that would explain the importance of different influential factors on the metro preference. The approaches for the data collection and the model development are as follows -

3.1. Stated preference survey

A stated preference survey was designed to collect the data regarding metro preference. Stated preference (SP) was the only option to get insight about people's intention to use metro since the Riyadh metro is not operational yet. An SP survey helps to understand people's preferences by asking the respondents about their possible choices in hypothetical situations under a specific set of conditions. The purpose of the survey was to capture different attributes that may influence metro use. The survey included many service attributes, such as travel time, travel cost, walk time and wait time. It also considered travelers' socioeconomic characteristics, such as their age, employment status, education level and family size. Results have been interpreted acknowledging the limitations of stated preference approach, especially in the context of an unknown and non-existence alternative, and uncertainty of tackling variation in tastes across the individuals. These limitations have been taken into consideration when addressing potential alternatives such as the Riyadh metro.

However, acquiring the appropriate data and identifying a comprehensive list of attributes is always challenging (Cervero, 2002). Given the novelty of the metro system in the KSA, the SP survey was conducted to capture the service attributes and socioeconomic characteristics. Developing scenarios for the built environment attributes would require more detail analysis and separate survey when metro is operational.

The SP survey data used for this study is owned by the Royal Commission for Riyadh City (RCRC) (formerly known as Arriyadh Development Authority). The RCRC hired Diadro Consulting to carry out this survey to evaluate the likelihood that private vehicle users will switch to the metro. The survey considered various attributes commonly found in literatures. The survey was carried out in two ways – i. using cards for visualization of hypothetical scenarios and ii. using questionnaire to know the background of the respondents. Cards were used to create hypothetical situations with various combinations of different attributes to see what the respondents prefer most. These attributes incorporated only mode-specific attributes, such as in-vehicle time, one-way travel costs, walking time and waiting time, and whether a transfer is required for the trip. An example of card is shown in Fig. 1 and a complete picture of the cards used can be found in the Appendix A. Finally, a questionnaire survey to incorporate important variables other than service attributes.

3.2. Model specification

Three major approaches to mode choice are relevant (De Witte et al., 2013). First, the rationalist approach assumes that trip decisions are based on utility maximization, which is attained by minimizing travel time and costs (Shen et al., 2009). Second, the socio-geographical approach treats the demand for travel as a derived demand (Bhat and Singh, 2000). Finally, the socio-psychological approach aims to understand individuals' attitudes and their own characteristics to determine mode decisions (Johansson et al., 2006, Anwar, 2016; Anwar & Yang, 2017). The rationalist approach can be seen as the mainstream approach to decision-making in the literature, as it focuses on utility maximization theory (Hollevoet et al., 2011).

The rationalist approach assumes that travelers choose a transit mode rationally by evaluating the characteristics of various competing alternatives to maximize their personal utilities (de Donnea, 1972). However, these utilities cannot be observed directly. Thus, utility-based models can estimate the probability of choosing a given alternative in two ways. One is to observe people's choices and behavior, and the other is to capture people's stated choices in hypothetical scenarios. In general, transport policies rely on the idea that travelers have a diverse set of mode options. The number of options can be increased or decreased to, for example, improve efficiency or reduce congestion and pollution.

Studies of mode choices or shifts in behavior involving public transit service generally utilize travel demand models or discrete choice models (Wang et al., 2013). Travel demand models mostly focus on transport analysis. They particularly consider transit-related factors, such as transit access, service frequency and travel time, and disaggregated behavioral factors, such as individual mode choice behavior. For example, Boile, Spasovic, and Bladikas (Boile et al., 1995) presented an equilibrium demand–supply model consisting of a mode choice and a traffic assignment sub-model showing that improving the rail service and its accessibility may be the best way to divert automobile trips to transit. Other researchers apply complex mathematical models to quantify the effect of land use, travel costs and reliability on travel choices (Bhat and Sardesai, 2006, Pinjari et al., 2007).

Discrete choice models that focus on travelers' behavioral responses to various mode options have become popular. For instance, Ye et al. (Ye et al., 2020) used mixed logit models. They examine the impacts of individual attributes, built environments and travel characteristics on the willingness to shift to bike-sharing-related transport modes. Age and income are negatively associated with bike-sharing usage, and transfer distance, not owing a car, being a student and belonging to an enterprise are positively associated with bike-sharing usage. Weather and travel distance have significant negative impacts on mode shifts. Wang et al. (Wang et al., 2013) examined mode shifts by automobile, taxi, bus, electric bicycle and bicycle users after a metro service is implemented. They develop a logistic regression model based on stated preference data. The results indicate that automobile travelers located in suburban regions are more willing to shift to the metro for work trips. Female taxi and automobile users are more likely to use the metro than male users are. Finally, taxi and electric bicycle travelers taking longer trips prefer to use the newly introduced metro.

Ashalatha, Manju, and Zacharia (Ashalatha et al., 2013) employed multinomial logit models to explore commuters' mode choices in

	The Metro		The Car	
				
	Fare	5 SAR	Parking fee	10 SAR
Waiting time	7 minutes		-	
In vehicle time	8 minutes less than your last trip		Same as your last trip	
Walking time	5 minutes more than your last trip		Same as your last trip	

Fig. 1. An example of SP card showing a hypothetical situation.

Trivandrum, India. The results show that increases in time and cost per distance cause commuters to use cars. Thus, they recommend identifying such factors and altering them to formulate effective policies to improve the city's public transit. Ding et al. (Ding and Zhang, 2017) investigated the effects of multiple transit priority strategies on car users' modal shifts using a logit model, such as an increase in parking fees, managed bus lanes or a transit fare discount.

Following these studies, we also specified and developed our model based on discrete choice modeling. This study is using a mixed binary logit modeling approach to capture the randomness associated with the parameters. A mixed logit model uses a probabilistic approach based on the random utility model (RUM). The probabilistic approach offered by a RUM is better than the deterministic approach because it can explain differences, heterogeneity, and uncertainty in the choice process. In contrast, the deterministic approach only captures average decision-makers' behavior (Train, 2009, Hensher et al., 2005). According to Train (Train, 2009), a mixed logit model allows for random taste variations, unrestricted substitution patterns and unobserved factor correlations. The model can ease the strong assumptions of independent and identically distributed (i.i.d.) error terms (Campbell, 2007).

The reason to use binary model is the binary nature of the choices. The SP survey was designed to ask about the preference of metro based on the respondents' current mode of travel – i.e., car users were asked metro preference with respect to cars only. Binary models are widely and commonly used in transportation research not only to understand modal shifts (Oakil et al., 2016, Oakil et al., 2011) but also to understand other aspects such as pedestrians' behavior (Marisamynathan and Vedagiri, 2018). Based on the binary nature, if Y = 1 denotes a modal shift to the metro and Y = 0 denotes the use of the current mode of transport (no modal shift), the utility functions for these two options can be written as:

$$U_{MS} = V_{MS}(\beta_i, X_i) + \varepsilon \tag{1}$$

$$U_{NS} = V_{NS}(\beta_j, X_j) + \varepsilon. \tag{2}$$

Here, U_{MS} and U_{NS} are the utility functions for shifting to the metro and staying with the current mode of transport, respectively. Each utility is the sum of a systematic quantity of the alternatives depending on the explanatory variables (X) and a Gumbel-distributed random residual (ε). We set V_{NS} equal to zero, as it is the reference option. Then, the probability of a modal shift to the metro is:

$$\mathrm{PMS}(Y = 1) = \int \frac{\exp(U_{MS})}{1 + \exp(U_{MS})} f(\beta_i, \alpha_j) d\beta_i \tag{3}$$

Where, $f(\beta_i,\alpha_j)$ is the probability density function of the parameter β_i, and α is a vector of the parameters of the density function. Therefore, the unconditional probability is the integral of the conditional probability ($P_{MS} \mid \beta_i$) for the mixed logit model. If β_i is a vector of length K, then we need a K-dimensional integral making it difficult to estimate using quadrature methods. The practical solution is to simulate based on a number of parameters draw from the distribution of β and to estimate the expected value of conditional probabilities for each draw. The average of those conditional probabilities becomes the unconditional probability.

In addition, the model needs to account for repeated observation per individual. The SP survey presented every respondent with nine hypothetical scenarios. Thus, every individual has nine observations. In this case, we need to consider the panel data structure. This requires joint probability estimation for multiple observations and the log-likelihood. Given T number of observations per individual (*i*), the joint probability and the log-likelihood in this case are, respectively, -

$$P_i = \prod_t \prod_{MS} \frac{\exp(U_{MS})}{1 + \exp(U_{MS})} \text{ and}$$

$$\sum_i lnP_i \tag{4}$$

4. Analyses and results

Creating an energy-efficient urban transport system is one of the top energy policies of the Kingdom of Saudi Arabia (KSA). The KSA is one of the largest exporters of gasoline. According to the Saudi Arabian Monetary Agency, about 33.42% of the KSA's gross domestic product in 2019 was generated by the gasoline sector (Mahmood et al., 2020). The economic sustainability of the energy sector is therefore a top priority for the KSA. In addition, the KSA is committed to the Paris Agreement. Both goals require the KSA to use all possible strategies to mitigate climate change and achieve energy efficiency. The transport sector has high energy demand and is a major contributor to carbon emissions. Thus, it is gaining importance in the KSA's energy policies. The KSA is proposing metro system for major cities like Riyadh, Jeddah, and Dammam. Riyadh metro system is about to finish. Riyadh metro system includes six lines covering a 176-kilometer network and 85 underground, elevated or at-grade section stations (see Appendix B). The Riyadh metro is intended to achieve sustainable transport goals. In this regard, this section presents the results regarding the factors that would influence the metro ridership so that policy makers can formulate effective transport strategies.

4.1. Sample and data description

We are considering modal shifts from two different modes of travel (i.e., cars and taxis) to the metro. In Riyadh, more than 90% of the trips are made by private vehicles (car or taxi). The possibility of shifting to metro by these group represents most significant contribution towards sustainable mobility. In this regard, this study used data from stated preference survey in which total 275 car or taxi users were asked about their willingness to shift to metro. After considering non-response and missing values, the sample size remained 196 individuals who responded their responses against nine hypothetical situations (Appendix A), which is constituted by different travel times, fares, wait times, walk times, and transfer requirements (car users only) regarding car versus metro or taxi versus metro. The sample description can be seen in Table 2. Respondents were also asked about their personal characteristics, including employment status, age, gender, educational level, car ownership and nationality. For these exercises, the respondents were expected to compare the metro with their last trip (i.e., same purpose and frequency) and to think deeply about each option, consider the conditions of each situation and specify their preferred option in each case.

Table 2 summarizes basic statistics for our sample data by travel mode. We consider age, nationality, educational level, employment status, marital status, family type, car ownership and trip purpose. Most respondents use cars for work trips, whereas taxis are used most frequently for personal business trips. Almost 50% of car users have high levels of education (i.e., a bachelor's degree, master's degree, or Ph.D.). The greatest proportion of taxi users have an intermediate level of education. In terms of employment status, most of the respondents are employed, followed by students. Among car users, about 57% are Saudi citizens, whereas no taxi users are non-Saudi. Over 40% of trips are work trips by car, whereas most taxi trips are personal business trips, followed by shopping and recreation trips. Most of the respondents are from nuclear families.

Table 2 also provides the mean and standard deviation of travel cost, travel time, wait time and walk time for a one-way trip. Taxis have the highest cost, whereas car trips have the longest travel time. The survey asks respondents to compare the metro's travel time, cost, walk time and wait time to their current modes. For modeling purposes, however, we use data reflecting the values for each mode rather than in comparison to

Table 2
Independent variables in the utility function and sample description.

Variables	Sample: Car to metro		Sample: Taxi to metro	
Total observations	1,332		432	
Choice attributes	**Car** mean (sd)	**Metro** mean (sd)	**Taxi** mean (sd)	**Metro** mean (sd)
Walk time to access the transit mode	4.05 (3.22)	6.43 (3.96)	2.94 (1.18)	11.27 (3.10)
Wait time for the transit mode	0 (0)	4.43 (2.20)	2.98 (1.22)	4.33 (2.06)
Travel time for the transit mode	33.50 (18.29)	28.39 (18.94)	24.63 (9.23)	16.63 (9.96)
Cost of the transit mode	12.65 (12.62)	4.83 (1.59)	30.00 (10.86)	5.00 (1.63)
Descriptive statistics of respondents				
Total number of respondents	148		48	
Socioeconomics	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Age: Younger than 30 years	75	50.7	23	47.9
Age: 30 to 45 years	59	39.9	19	39.6
Age: 45 years or older	14	9.5	6	12.5
Nationality: Non-Saudi	63	42.6	0	0.0
Nationality: Saudi	85	57.4	48	100.0
Education level: Low	27	18.2	14	29.2
Education level: Intermediate	50	33.8	19	39.6
Education level: High	71	48.0	15	31.3
Employment status: Employed	109	73.6	24	50.0
Employment status: Student	27	18.2	18	37.5
Employment status: Retired	2	1.4	3	6.3
Employment status: Looking for work	10	6.8	3	6.3
Marital status: No	74	50.0	19	39.6
Marital status: Yes	74	50.0	29	60.4
Family type: Single person	23	15.5	9	18.8
Family type: Nuclear family	112	75.7	38	79.2
Family type: Extended family	9	6.1	1	2.1
Family type: Other types	4	2.7	0	0.0
More than one household car: No	59	39.9	24	50.0
More than one household car: Yes	89	60.1	24	50.0
Travel purpose: Work	61	41.2	3	6.3
Travel purpose: Shopping	28	18.9	8	16.7
Travel purpose: Personal business	8	5.4	12	25.0
Travel purpose: Social and recreation	32	21.6	6	12.5
Travel purpose: Medical	2	1.4	6	12.5
Travel purpose: School	6	4.1	6	12.5
Travel purpose: Others	11	7.4	7	14.6

the current mode.

4.2. Results from mixed logit models

This study specifies and empirically estimates an explanatory model for the decision to shift to the metro. As mentioned earlier, we estimated mixed logit model for two situations – for the respondents who were asked to report their preferences of modal shift from car to metro and from taxi to metro. We used 'mlogit package' from R, which can account for heteroscedastic, nested and random parameter models (Croissant, 2012). Croissant (Croissant, 2012) showed how the estimation results from 'mlogit package' is comparable with well-known estimation results such as the heteroskedastic logit model developed by Bhat (Bhat, 1995). Using this R-package, we evaluated the impacts of travel time, travel cost, walk time, wait time, and transfer requirements on the modal shift decision.

As mentioned earlier, modal shifts from car and taxi were estimated separately. For each estimation, three models were tested –

i. a logit model including only choice attributes.
ii. a mixed logit model with random parameter estimates and panel data consideration in addition to the first model.
iii. a mixed logit model including individual specific characteristics in addition to the second model.

Three models were performed to understand how models would develop with consideration of different variables and different model specification, and whether such variable inclusion or model specification was necessary. For example, likelihood ratio test suggests whether addition of new variables or consideration of random parameters would improve the model estimation significantly or not. Based on which we can choose the best model and presenting all estimations in a table helps interpretation of the results.

The estimation results are shown in Table 3 and 4. Table 3 shows the estimated SP results for the choice between car and the metro, where car was a reference alternative. In the same way, Table 4 shows the results for the choice between taxi and the metro, where taxi was a reference alternative. In general, the third model performed better in terms of ρ-squared value. It was also significantly better as found from likelihood ratio test and χ-squared values. This implies consideration of random parameter, panel effect, and individual specific attributes improved the model and thus, the third model is more robust than the first and the second models. Because the third model was the best fit, we discuss the results of this model further. The statistical significance of the variables is evaluated at the range from the 10% level to the 0% level.

Table 3 shows that the influences of choice attributes are negative, as expected, and the coefficients are statistically significant at the 99% confidence level. Thus, if the time to walk to the metro is increased, for example, the respondents are less likely to shift to the metro. The other choice attributes can be interpreted similarly. Transfer requirements have the strongest effect on the choice to shift to the metro, followed by wait and walk times. To simplify the results, a monetary value for each attribute can be considered. For instance, we can consider a monetary value of about 2.75 (i.e. $-0.314/-0.115 = 2.73 \approx 2.75$) SAR per minute walking given the mean coefficient of -0.314 and -0.115 for walk time and travel cost respectively. For every minute of walking to metro station, metro cost should be 2.75 SAR less than the car cost. A shift may be very difficult given that car travelers have very low travel cost and mostly zero walk time to car. Most of the places in Riyadh can be reached by car with a cost less than 5 SAR implying a metro fare to be less than 2.25 SAR for only a minute of walk to station. Even very high-density development around the station will not be able to bring many people within one minute walk to the station.

However, a compelling situation may arise due to ever increasing congestion and thereby, increasing car travel time in and around Riyadh. From the coefficients of -0.122 for travel time, a monetary

Table 3
Estimated SP results for comparisons of car and metro travel (reference: car travel).

	Model 1			Model 2			Model 3		
	Coef.	OR	p-value	Coef.	OR	p-value	Coef.	OR	p-value
Choice attributes									
Walk time to access the transit mode	−0.160	0.852	0.000***	−0.292	0.747	0.000***	−0.314	0.731	0.000***
Wait time for the transit mode	−0.167	0.846	0.000***	−0.411	0.663	0.000***	−0.381	0.683	0.000***
Travel time for the transit mode	−0.074	0.929	0.000***	−0.124	0.883	0.000***	−0.122	0.885	0.000***
Cost of the transit mode	−0.031	0.969	0.000***	−0.099	0.906	0.000***	−0.115	0.891	0.000***
Transfer required (Yes)	−1.419	0.242	0.000***	−1.911	0.148	0.000***	−1.864	0.155	0.000***
Metro-specific coefficients									
Alternative specific constant	−0.651	0.522	0.001***	−0.594	0.552	0.016**	−1.436	0.238	0.005***
Individual characteristics									
Age: Younger than 30 years (ref.)									
Age: 30 to 45 years							−0.580	0.560	0.022**
Age: 45 years or older							−0.897	0.408	0.054*
Nationality: Non-Saudi (ref.)									
Nationality: Saudi							1.241	3.459	0.000***
Education level: Low (ref.)									
Education level: Intermediate							1.370	3.935	0.000***
Education level: High							1.641	5.160	0.000***
Employment status: Employed (ref.)									
Employment status: Student							−0.656	0.519	0.037**
Employment status: Retired							−0.591	0.554	0.545
Employment status: Looking for work							−0.392	0.676	0.349
Family type: Single person (ref.)									
Family type: Nuclear family							−0.276	0.759	0.392
Family type: Extended family							−1.221	0.295	0.019**
Family type: Other types							0.932	2.540	0.140
More than one household car: No (ref.)									
More than one household car: Yes							−0.717	0.488	0.007***
Travel purpose: Work (ref.)									
Travel purpose: Shopping							−1.063	0.345	0.001***
Travel purpose: Personal business							−1.365	0.255	0.025**
Travel purpose: Social and recreation							−0.551	0.576	0.052*
Travel purpose: Medical							−2.224	0.108	0.019**
Travel purpose: School							0.237	1.267	0.655
Travel purpose: Others							0.016	1.016	0.970
Standard deviation of random parameter									
Walk time to access the transit mode				0.212	1.236	0.007***	0.278	1.320	0.000***
Wait time for the transit mode				0.367	1.443	0.000***	0.331	1.392	0.000***
Travel time for the transit mode				−0.002	0.998	0.992	0.006	1.006	0.982
Cost of the transit mode				0.080	1.083	0.000***	−0.003	0.997	0.986
Model results									
Log-likelihood:	−642.310			−580.340			−560.560		
McFadden ρˆ2:	0.108			0.194			0.222		
Likelihood ratio test:	χˆ2 = 155.96		***	χˆ2 = 279.9		***	χˆ2 = 319.46		***

Note: OR = Odds ratio; *** = significant at the 1% level;** = significant at the 5% level;* = significant at the 10% level.

value of about 1 SAR per minute travel can be considered. Given the average car travel time of 33 min from our survey data, a 5-minute reduction in travel time by metro would give a comparative advantage. In the other words, every minute of walking to the station the travel time by metro should be 2.75 min less than that by car. Therefore, the travel time on the road network of Riyadh would influence the pricing and accessibility policies for Riyadh metro.

In addition, the model shows an initial resistance to modal shift through the high and negative metro specific constant (-1.436). The constant represents the effect for the reference categories of individual specific characteristics. For our model, this implies that young, single, non-Saudi and less educated person with one available car in the household is less likely to make a metro trip for work purpose when all choice attributes remain same. The likelihood to choose the metro increase if the person is highly educated, whereas it decreases if the person is older. Often public transport is inadequate and non-responsive to the needs of elderly people (Dickerson et al., 2007), for instance, they may find it difficult to walk to the station. It is also found that highly educated people often show pro-environmental behavior (Meyer, 2015) and thus, they may prefer metro over car. The result also suggests that Saudis are more likely to choose metro than non-Saudis. One of the reasons may be related to income differences, but difficult to explain from this analysis as survey did not offer the income data. In general, young Saudis with higher education are more likely to use metro. This is positive indication, because almost 50% of the population in Riyadh region are younger than 30 years (General Authority for Statistics, 2016).

Among travel purposes, most of the travel purposes have negative

Table 4
Estimated SP results for comparisons of taxi and metro travel (reference: taxi travel).

	Model 1			Model 2			Model 3		
	Coef.	OR	p-value	Coef.	OR	p-value	Coef.	OR	p-value
Choice attributes									
Walk time to access the transit mode	−0.121	0.886	0.000***	−0.212	0.809	0.001***	−0.179	0.836	0.002***
Wait time for the transit mode	−0.112	0.894	0.010***	−0.157	0.855	0.050**	−0.096	0.908	0.211
Travel time of the transit mode	−0.069	0.933	0.011**	−0.130	0.878	0.004***	−0.108	0.898	0.014**
Cost of the transit mode	−0.040	0.961	0.000***	−0.118	0.889	0.000***	−0.117	0.890	0.000***
Transfer required (Yes)									
Metro-specific coefficients									
Alternative specific constant	−0.415	0.660	0.355	−1.837	0.159	0.008***	−0.140	0.869	0.931
Individual characteristics									
Age: Younger than 30 years (ref.)									
Age: 30 to 45 years							−1.242	0.289	0.087*
Age: 45 years or older							−2.337	0.097	0.028**
Nationality: Non-Saudi (ref.)									
Nationality: Saudi							.		
Education level: Low (ref.)									
Education level: Intermediate							0.533	1.704	0.362
Education level: High							1.242	3.463	0.043**
Employment status: Employed (ref.)									
Employment status: Student							−0.131	0.877	0.859
Employment status: Retired							1.092	2.980	0.331
Employment status: Looking for work							1.594	4.923	0.063*
Family type: Single person (ref.)									
Family type: Nuclear family							0.332	1.394	0.478
Family type: Extended family							−2.232	0.107	0.094*
Family type: Other types									
More than one household car: No (ref.)									
More than one household car: Yes							1.442	4.229	0.008***
Travel purpose: Work (ref.)									
Travel purpose: Shopping							−1.503	0.222	0.195
Travel purpose: Personal business							−2.600	0.074	0.046**
Travel purpose: Social and recreation							−2.027	0.132	0.099*
Travel purpose: Medical							−3.181	0.042	0.032**
Travel purpose: School							−4.933	0.007	0.003***
Travel purpose: Others							−4.029	0.018	0.006***
Standard deviation of random parameter									
Walk time to access the transit mode				0.200	1.221	0.000***	0.091	1.095	0.186
Wait time for the transit mode				0.521	1.684	0.001***	−0.360	0.698	0.008***
Travel time of the transit mode				0.000	1.000	1.000	0.048	1.049	0.619
Cost of the transit mode				0.053	1.054	0.004***	−0.045	0.956	0.039**
Model results									
Log-likelihood:	−277.080			−240.300			−230.910		
McFadden ρ^2:	0.075			0.198			0.229		
Likelihood ratio test:	χ^2 = 44.716		***	χ^2 = 118.28		***	χ^2 = 137.05		***

Note: OR = Odds ratio; *** = significant at the 1% level; ** = significant at the 5% level; * = significant at the 10% level.

and significant coefficients. These include shopping, medical, personal, and social and recreational trips. The respondents are less likely to use metro for these travel purposes compared to work purpose. Potter (Potter, 2003) also found that public transport occupancy is very high compared to car for commuting purposes. In general, work trips are very regular in terms of both time and location and, thus, can easily be planned with less uncertainty. In contrast, other trips are often uncertain and have different destinations. For example, people may not travel to the same shopping center or may not choose to shop at the same time of the day. Some trips may also be urgent such as medical trips, and thus, difficult to coordinate with the fixed timetables of metro. Moreover, non-work trips may involve additional arrangements, such as traveling with family or a patient or carrying groceries and other household items. Often, these arrangements encourage the use of private vehicles. With respective to car ownership, the results are also logical. It shows that respondents with more than one household cars are less likely to shift to metro. Having more than one car available at the household often discourages to shift from car (Oakil et al., 2011).

Although the interpretation and discussion on the results are based on the mean effects of the variables, the estimated standard deviations of the random parameters for the walking time to access the metro and the wait time for the metro are significant. The effects of the walk and wait times on the decision to shift to the metro exhibit considerable heterogeneity among respondents. Therefore, the discussion mentioned earlier cannot be generalized to get the overall implication of the results. However, the random parameters are not statistically significant for travel time and cost. Thus, the effects of these variables are similar across respondents.

In terms of the choice between taxi and metro (Table 4), all choice attributes have negative coefficients, as expected. In contrast to the analysis for car users, wait times do not significantly affect taxi users' modal shift decisions. This may be due to wait time involvement with taxi travel since taxi requires time to arrive at the desired location after the call. Therefore, the respondents are indifference about wait time. However, Uber or Kareem might draw more customers than traditional taxis because the wait time is consistent across day, time, and space. In general metro has short wait time and real-time arrival information although they are critical for metro users. (Rayle et al. 2016), and these factors are likely equally critical for Uber or Kareem users as well. The impacts of other choice attributes are similar in magnitude, meaning that they affect taxi users' mode choices in similar ways. Whereas we have seen substantial higher impact from walk time compared to cost variable for car users, we do not see such large variations in the influence of choice attributes for taxi users.

In addition, the metro specific constant for taxi users is insignificant, meaning no initial resistance from taxi users at the reference. The reference individual is defined as young, single, low educated, employed traveling for work. In terms of individual characteristics, the results are similar to car users. It shows that younger people (under 30 years old) are more likely to use the metro than people in other age groups are. Possible explanations for this result may be that young people have less income, are single or are more flexible in terms of time. People with more education are more likely to take the metro instead of a taxi once the metro is in operation. Extended families who use taxis are less likely to use the metro relative to the single people. Often, extended families travel with multiple people who have different travel requirements. For instance, families with children or elderly members require special accessibility. Unfortunately, all taxi users in the sample are Saudis; thus, the difference between Saudis and non-Saudis cannot be estimated.

Compared to work trips, the coefficients for the travel purpose variables are negative. Thus, taxi trips for work are more likely to shift to the metro than trips for other purposes are. As mentioned earlier, sometimes urgency or necessity to travel with families, patients or just groceries may encourage the use of taxi since taxis are not bound by any fixed service schedule. Car ownership also influences the choices of taxi users in a similar way as it does to car users. However, the reason may be higher negative influence on taxi use than the positive influence on metro use.

Table 4 also shows that the random parameters for wait time and travel cost have significant effects. Hence, the impacts of these variables differ among taxi users. The random parameters for walk time and travel cost have no significant effects, and, thus, these variables have similar effects for all taxi users.

Lastly, Table 3 and 4 contains 3 models each. Model 1 reflects the results of the logit model, whereas models 2 and 3 describe the outcomes of mixed logit models.Model 3 includes sociodemographic characteristics whereas models 1 and 2 donot. Among 3 models, model 3 depicts better fit as McFadden ρ̂2 is seen higher, meaning that inclusion of sociodemographic characteristics in the model brings better results.

5. Discussion and conclusions

Transport energy efficiency can be achieved in different ways such as by avoiding travel, shifting to non-motorized or public transport, and improving vehicle efficiency as suggested by the A-S-I (Avoid-Shift-Improve) approach. Whereas we should pursue all possible solutions for energy efficiency and emission reduction, public transport offers additional benefits in terms of reducing congestion on road and thereby, saving time. Furthermore, it seeks to achieve GHG emission reductions, energy efficiency, and less congestion in socially equitable way, especially ensuring mobility for them who cannot afford or drive cars. Therefore, GCC cities including Riyadh are transforming to encourage use of public transport.

Public transport is not a new concept in GCC countries or in Saudi Arabia, but it has never been got such attention until recently. This work is a contemporary effort to provide some empirical evidence regarding respondents' willingness to shift to the proposed Riyadh metro. There is limited empirical research to shed insights regarding the system. Empirical findings to understand customers' perspectives and mechanisms to use the metro can eventually be used to meet customers' expectations. For instance, the insights from this analysis can be helpful to identify which preferred conditions should be accommodated in planning policies and to find recommendations to manage respondents' willingness to shift to the metro.

In addition, the success of the proposed metro system depends on the metro ridership. Potter (Potter, 2007) showed that public transport may offer 1.5 to 4 times greater energy efficiency relative to cars when the capacity is considered, but the energy efficiency is only zero to two times greater when the actual occupancy rate is considered. We may assume that shifts to public transport increase vehicle occupancy and, thus, improve fuel efficiency and the modal shift approach can reduce the demand for private car mobility. But this demand is driven by multiple factors.

This study reports the underlying factors influencing private vehicle users' intentions to shift from their current modes of travel to the metro once the metro is available. We see that young Saudis as well as highly educated people show higher preference to use metro. From demographic perspective, the prospect for metro is promising because the population of Riyadh is mostly (almost 50% younger than 30 years) young, and the Kingdom also expects an increased share of Saudi work force in Riyadh labor market in the future. Furthermore, the level of education among Saudis is getting higher. Most young Saudis are attending universities and pursuing higher education. About 47% of the population aged 18–22 years were attending university in 2017 (General Authority for Statistics, 2017). The predictions based on the estimated coefficients for some hypothetical scenarios for young, employed and highly educated Saudis for work trips are shown in Table 5. It suggests that young and employed Saudis with high education have 0.81 probability to use metro for work trips, when service attributes of car and metro are the same (Scenario 1).

However, the service attributes between car and metro will hardly be the same. Even in a very optimistic scenario, we need to consider at least a minute of walk to the metro station, whereas people can access their

Table 5
Choice probabilities of young, employed and highly educated Saudis for work trips.

Hypothetical scenarios	Car situation	Metro situation	Choice probability	
			Car	Metro
Scenario 1	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min Travel cost = 3	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min Travel cost = 3	0.19	0.81
Scenario 2	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min Travel cost = 3	Transfer = 0 **Walk = 1 min** Wait = 0 min Travel time = 30 min Travel cost = 3	0.25	0.75
Scenario 3	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min Travel cost = 3	Transfer = 0 Walk = 1 min Wait = 0 min **Travel time = 27 min** Travel cost = 3	0.19	0.81
Scenario 4	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min Travel cost = 3	Transfer = 0 **Walk = 5 min** Wait = 0 min Travel time = 27 min Travel cost = 3	0.45	0.55
Scenario 5	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min **Travel cost = 8**	Transfer = 0 Walk = 5 min Wait = 0 min Travel time = 27 min Travel cost = 3	0.35	0.65
Scenario 6	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min **Travel cost = 13**	Transfer = 0 Walk = 5 min Wait = 0 min Travel time = 27 min Travel cost = 3	0.26	0.74
Scenario 7	Transfer = 0 Walk = 0 min Wait = 0 min Travel time = 30 min Travel cost = 13	Transfer = 0 Walk = 5 min Wait = 0 min **Travel time = 24 min** Travel cost = 3	0.21	0.79

cars without spending any time on walking. Table 5 shows that such a minute of walking reduces the metro choice probability by 6% (Scenario 2). Scenario 3 in the table suggests that the negative influence of one-minute walk can be compensated by an improved travel time situation for metro that reduces travel time for metro by 10%. A more pragmatic walk situation where people have to walk about 5 min to reach a metro station would result in only 0.55 choice probability for metro (Scenario 4). This is difficult to be compensated by adjusting travel costs. For a situation that adds cost to the car travel even by 10 SAR (Scenario 6) may lead to metro choice probability of 0.74. We need to consider about 20% reduction in metro travel time in addition to travel cost adjustments.

In general, Riyadh planning principles led to urban sprawl and automobile dependency (Mubarak, 2004). Together with the extreme weather condition, there has been a little interest among the people to walk. This eventually led to less attention from policymakers on the pedestrian facilities as well. People's responses regarding walk time from this study are largely influenced by these factors. Studies focusing on walkability, weather, and the build environment characteristics are necessary next step to understand what would encourage people to walk more. Scholars in GCC often suggests to utilize the traditional alleyways that connects different places through spaces within or between buildings (Alawadi et al., 2021b, Alawadi et al., 2021a). These alleyways create high connectivity but also a cooler micro-environment to walk to a particular destination. In addition, people tend to realize walking as a safer and healthier option to travel a short distance or just to stroll to unwind themselves during the COVID-19 pandemic. Abdullah et al. (2021) observed that walking and bicycling increased during the pandemic because of safety and security, cleanliness, as well as infection concern and so on. This implies that people may already have a different and favorable preference regarding walk to station.

The extent to which a better build environment, improved connectivity through alleyways, or preference change due to the pandemic would affect walking preference is not within the scope of this study. Nonetheless, this study empirically shows how importance walk time is for the Riyadh metro. Even an extreme cost adjustment by using policies like car parking charges may fall short with respect to accessibility to the metro station. Policymakers should give special attention to the walking need of the people in Riyadh to make the metro successful. Walking or driving to transit is often a question of accessibility, distance, and convenience. To increase transit or metro ridership and reduce reliance on cars, constructing housing near transit stops or creating TOD are common in local level planning strategies. Housing development is not necessarily constructed within the walking distance to the transit stops, so there exists another strategy of creating parking lots near transit centers, called park-and-ride lots, or PnR, which can encourage the people to use metro, and eventually increase the metro/transit ridership. Several research generally found that the presence of PnR facilities could correlate with increased ridership (Duncan, 2010, Guerra and Cervero, 2011, Kuby et al., 2004). One of the recent proposals for Riyadh relating to metro is transit-oriented development (TOD). The idea of TOD is to create high density development around metro stations so that metro can easily be accessed by many people (Dittmar and Ohland, 2012). In general, TOD increases transit ridership (Parker et al., 2002, Cervero, 1994), but with varying impact (Cervero, 2004). Furthermore, the findings suggest to consider non-active last mile solution to access and egress the metro stations such as e-scooter or e-bike infrastructure. Especially because, e-scooter is becoming popular in Saudi Arabia (Almannaa et al., 2021).

Whereas walk time comes as a primary concern, travel time can also play an important role in attracting people to use the metro. With the increasing use of car, Riyadh roads are getting congested and travel time by car is increasing. Riyadh metro may provide an opportunity for those who want to save travel time. However, the locations of firms and residences will affect the travel time. Metro development would lead to change in land-use and activity pattern in and around Riyadh. Policymakers can focus on land-use planning in a way that encourages better accessibility by metro giving metro a direct connection to many activities, and thereby creating opportunities for shorter travel time.

However, pricing policy is not easy to implement not only because introducing charges on car such as parking fees or taxes on fuel can be disliked by the car users but also making metro cheaper is a challenge because of the current low operating cost of car. Also, a transit fare discount does not play as important role as parking fee does (Ding and Zhang, 2017). Therefore, other policies may need to be considered that could affect cost in different ways. For example, employers' contributions for transport can focus on public transport. Rather than contributing certain amount as transport reimbursement, employers can fully contribute towards metro commute. This may also encourage people to live nearby metro station and thereby, helping policymakers to implement land-use policies that encourage high density and better connectivity for the metro.

At this moment, only about 30% of the trips are covered by metro reachable area assuming metro reachable area is within 800 m from the station and 80% of the people living there consider metro as an alternative. As seen from this analysis, this implies very little ridership of metro in the context of Riyadh as a whole. Young Saudis living beside the station may have 80% chance of taking metro. People living further away from the station will have low probability to choose metro. This will be even less for those who are not young or less educated. However, people may still access the station by cycle, car, or other modes. In this analysis, we cannot assess the impact of these on the metro ridership. Given a substantial investment on bus services in Riyadh, bus access to the metro stations will play a significant role. In addition, we have focused only on metro ridership and the public bus ridership would add to public transport use in Riyadh. In this regard, future studies should focus on the contribution of public buses in Riyadh both in terms of public transport ridership and accessibility to the metro stations. Nonetheless, better service attributes of metro compared to car and the accessibility to the metro stations will be necessary to divert automobile trips to metro (Boile et al., 1995). Accordingly, the results show that the Riyadh metro can significantly lead travelers to change their mode choice from taxi and car users. This may be because the new Riyadh metro is committed to providing reliable, efficient, and affordable public transport for Saudi residents. Additionally, metro cars and stations will be under continuous advanced surveillance and will be equipped with the latest technological advancements to ensure user safety.

6. Further research

The majority of people in the Kingdom of Saudi Arabia (KSA) live a sedentary lifestyle as 92% of the population still depend on private cars, and rarely rely on public transport or any sustainable travel mode (UN-Habitat, 2020). Extreme weather condition such as too hot and less humid does not favor outdoor activities, especially walking and cycling. In addition, the Saudis' conservative culture encourages people to have more cars as each family has more than one car for different purposes. Therefore, walking and cycling did not get popular with the majority of people in Saudi. Therefore, there is no data available relating to walkability and cycling, and models did not include these components. Due to similar reasons, investing in transport infrastructure development has not been incorporated in the model as well. Currently, several greening projects are in progress across cities, and transit-oriented development (TOD) is being encouraged, for instance, Riyadh metro is going to open soon, and Riyadh Commission for Riyadh City (RCRC) is investing in TOD. Thus, walking and cycling can be seen in the transport mode choice set in coming years, and the further research option can include them in the models.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Code availability

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Authors' contribution

AHM Mehbub Anwar: Wrote the whole paper except a part of introduction section, conducted data analysis and assisted mixed binary model estimation**. Abu Toasin Oakil**: led the model estimation and wrote a part of introduction. **Abdelrahman Muhsen**: Collected the data, prepared the database for modelling, and reviewed the paper. **Anvita Arora**: Reviewed the paper, and made comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cstp.2023.101008.

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