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Modeling Factors Affecting the Choice to Use the Proposed Riyadh Metro System

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Key Points

The Riyadh metro system is being implemented as a sustainable transport option that will offer reliable, affordable and comfortable urban mobility. It is important to understand the factors influencing the likelihood that people will use the new metro system. Thus, this study's key objective is to investigate the underlying factors that drive people to use the metro instead of their current transport modes. We consider shifts from car and taxi use (hereafter, private vehicle use). We employ stated preference survey data to develop mixed binary logit models. We employ these models to analyze the factors that will influence the choice to use Riyadh's proposed metro system. The results show that private vehicle users may change their current mode choices when the metro system is completed, and taxi users are more likely to shift to the metro. Travel times, travel costs, walk times and transfer requirements significantly affect people's mode choices. Travel cost has a greater influence on car users, whereas travel time has a stronger impact on taxi users. Socioeconomic characteristics, such as age, nationality, education level and car ownership also significantly impact the choice to use the metro.

1. Introduction

The Kingdom of Saudi Arabia has expended considerable efforts to create an energy-efficient urban transport system (Oakil et al. 2022). Such a system can help the Kingdom achieve two important goals. First, the economic sustainability of the energy sector is a top priority for Saudi Arabia as it is one of the world's largest exporters of oil. According to the Saudi Arabian Monetary Agency, approximately 33.42% of the Kingdom's gross domestic product in 2019 was generated by the oil sector (Mahmood, Alkhateeb, and Furqan 2020). Second, achieving the country's net-zero by 2050 target is also a key priority. For instance, the National Renewable Energy Program (NREP) is a strategic initiative of Vision 2030. The program aims to increase the Kingdom's share of renewable energy production, achieve a balance in the mix of local energy sources and fulfill its obligations toward reducing carbon dioxide emissions. Both goals require the country to use all possible strategies to mitigate climate change and achieve energy efficiency. Transportation is a major energy-demanding sector and a major contributor to carbon emissions (Khalili et al. 2019), and is thus gaining importance in the Kingdom's energy policies.

Urban transport in Saudi Arabia is predominantly automobile oriented. A shift from automobiles to public transport can reduce energy demand and carbon emissions and thus improve the country's energy efficiency. However, the urgent need to reduce carbon emissions to mitigate adverse climate impacts requires a drastic shift toward more sustainable modes of transport. According to Kenworthy (2020), public transport can be 55 times more energy efficient than automobile travel. Thus, the Kingdom has proposed a metro system for Riyadh that is currently under development. However, the energy efficiency gains from this system will depend on people's willingness to switch from more traditional car use to metro use. Thus, this study investigates the factors that influence people's willingness to ride the proposed metro.

The number of metro systems is increasing globally, societies are becoming more urbanized, and metro systems are critical for mobility. The International Association of Public Transport (2018) notes that at the end of 2017, 178 cities in 56 countries had metros. Moreover, 75 new metros have been constructed since 2000, mainly in Asian countries. Metros transport an average of 168 million passengers per day worldwide (International Association of Public Transport 2018). The growing body of research on metros covers topics ranging from feasibility to operations enhancement and passenger satisfaction. Understanding the necessity of metro systems is helping to accelerate the construction of metro infrastructure.

Nonetheless, the modal shift from private cars to metros or bus rapid transit (BRT) is a relatively new research topic. Some recent examples include studies on the proportions of passenger car and motorcycle users shifting to BRT and rail (Kwan, Sutan, and Hashim 2018; Satiennam et al. 2016). Other recent studies analyze the health benefits of BRT (Bartels et al. 2016) and commuters' willingness to shift to the metro (Fraszczyk, Weerawat, and Kirawanich 2019). Anwar and Yang (2017) consider the effects of transport policy on the modal shift from cars to public buses. Krishna, Thomas, and Salini (2020) measure the reduction in fuel consumption and emissions resulting from this modal shift. Mostafi (2022) explores the importance of information and communication technology (ICT)-based mobility services in Cairo. The study examines parameters associated with the frequency of ridesourcing use as well as with the modal shift from different mobility modes, such as from public transport to ridesourcing. Finally, Shaheen and Cohen (2020) investigate mobility on demand and mobility as a service.

This study explores people's intentions to shift from their current modes of transport to the metro. Specifically, it considers the proposed new metro system in Riyadh, which includes six lines covering a 176-kilometer network as well as 85 underground, elevated or at-grade section stations (Royal Commission for Riyadh City 2022). The Riyadh metro is intended to achieve the city's sustainable transport goals. Thus, the factors that influence intention to ride the metro should be explored so that the government can formulate effective transport strategies.

This study attempts to provide recommendations for metro stakeholders. The recommendations it provides can help gauge respondents' willingness to shift to the metro and identify the preferred conditions that should be accommodated in planning policies. We also deliver empirical guidelines for understanding customers' perspectives and the mechanisms of shifting from other modes of transport to the metro. These guidelines can eventually be used to meet customer expectations after the new metro system is operational. We aim to understand the underlying factors influencing private transport users' intentions to shift from their current modes of travel to the metro once it becomes available. Using this information, we can better predict the direction of the resulting energy efficiency gains in the urban transport sector.

2. Literature Review

Travelers' mode choices are very complex. The current transport system, which favors automobile travel, must evolve to achieve sustainable urban mobility. The new system should prioritize energy efficiency, environmental sustainability and an overall better quality of urban life (Businge et al. 2019). De Witte et al. (2013) explain that transport mode choices are composed of multifaceted, interrelated factors and can be conscious or unconscious. Three major approaches are relevant to these choices. The rationalist approach assumes that trip decisions are based on utility maximization, which is attained by minimizing travel time and costs (Shen, Sakata, and Hashimoto 2009). The sociogeographical approach treats the demand for travel as a derived demand (Bhat and Singh 2000). Finally, the sociopsychological approach aims to understand individuals' attitudes and characteristics to determine their mode decisions (Anwar 2016; Johansson, Heldt, and Johansson 2006). The rationalist approach is the mainstream approach to decision-making in the literature, as it focuses on the utility maximization theory (Hollevoet, De Witte, and Macharis 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 directly observed. 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. Transport policies generally 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.

Thus, travelers make mode choices by carefully evaluating conditions and attributes such as travel costs, travel time, among other factors (Chakrabarti 2017). Determining and generalizing travelers' perceptions of the costs associated with a particular mode and their responses to change is a multifaceted process. As such, acquiring appropriate data and identifying a comprehensive list of attributes is always challenging (Cervero 2002). Moreover, choices are often governed by non-flexible personal attributes that may not be sensitive to cost. For instance, people are less likely to change their mode of choice for routine travel (Schneider 2013). Mehriar et al. (2020) notes that inhabitants who live in sprawling areas (Nowshahr and Hamedan in Iran) probably prefer private cars, and they use public transit less frequently than those who live in compact areas. Mehriar et al. (2020) also observe that inhabitants of sprawling areas are more dependent on cars for non-commuting trips. Hence, urban policies could address the negative aspects of sprawled neighborhoods by designing mixed land use that integrates workplaces with residential areas, contains safe routes for walking and biking, and has enhanced public transit.

One strand of research has focused on the barriers and bridges to certain modes of transport. Derek Halden Consultancy (2003) examine car users' barriers to switching to the metro, BRT, walking or bicycling, and identify bridges that enable this switch. Blainey, Hickford, and Preston (2012) show 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.

Blainey, Hickford, and Preston (2012) identify 37 distinct barriers divided into three broad groups, as Figure 1 shows. These groups represent hard barriers (e.g., travel time, reliability and cost), soft barriers (e.g., comfort, information and security) and complementary barriers (e.g., weather and lifestyle). However, the concepts of 'hard' and 'soft' factors or measures are not yet clearly defined. A consensus has formed that the former are more related to indicators and interventions on the supply side of the transport system. In contrast, the latter are more related to the demand side, which includes psychological and behavioral strategies (Queiroz, Celeste, and Moura 2020). Blainey, Hickford, and Preston (2012) also identify four types of bridges. These are enhancing alternative modes, making car travel less attractive, ensuring efficient management and administration, and providing information on available modes.

Other studies have found that individuals' socioeconomic characteristics strongly affect their mode choices (Limtanakool, Dijst, and Schwanen 2006; Munshi 2016). For instance, income, car ownership, gender, age, household composition and lifestyle are robust and relevant predictors of mode

Figure 1. Thirty-seven distinct barriers to modal shifts to rail.

Hard barriers

1. Travel time
2. Reliability
3. Service frequency and timetabling
4. Interchange
5. Network limitations
6. Cost
7. Station access and egress
8. Ticketing complexity and inter-availability
9. Structural car dependence
10. Land-use patterns
11. Government policy
12. Safety
13. Inherent unsuitability of trips for rail

Soft barriers

1. Inaccurate perceptions
2. Conscious car dependence
3. Convenience and freedom
4. Lack of control
5. Journey planning and requirements
6. Information provision
7. Station facilities
8. Cleanliness and maintenance
9. Personal security
10. Staff presence
11. Comfort
12. Crowding
13. Other passengers
14. Public transport image

Complementary barriers

1. Trip chaining
2. Habits
3. Individuality
4. Age, health and disability
5. Ethnicity, faith and culture
6. Goods and baggage
7. Locational preferences
8. Influence of employers
9. Suboptimal market prices
10. Weather

Source: Blainey, Hickford, and Preston (2012).

choice (Buehler 2011; Cheng et al. 2016). Stead and Marshal (2001) suggest that socioeconomic factors are vital to understanding mode choices. These factors are more powerful predictors of mode choice than land use characteristics (Alqhatani, Bajwa, and Setunge 2013).

Limtanakool, Dijst, and Schwanen (2006) focus on medium- and long-distance trips, defined as trips longer than 50 kilometers each way. They show that low-income travelers in the United States (U.S.) depend more on private cars, inter-city buses and trains relative to other income classes. Those in higher-income classes are more likely to use faster transport modes, particularly airplanes. The effects of age on travelers' modal choices are not sufficiently clear. Senior commuters are more likely to use private cars than middle-aged and young travelers. Georggi and Pendyala (2001) find that the elderly are more bus dependent. Kuhnimhof et al. (2012) observe a decrease in the share of car use among German travelers aged 18 to 29 years.

Some studies claim that individuals' socioeconomic characteristics and the built environment can both help explain people's travel behavior. Income and car ownership are determinants of transport and mode choices (Chen and McKnight 2007). Ter Schure, Napolitan, and Hutchinson (2012) suggest that the presence of car sharing and unbundled parking in residential developments significantly impacts vehicle ownership. They find that car-share members have significantly lower vehicle ownership levels.

The likelihood of a modal shift from private cars to public transit also depends on the competitiveness of the market. In the U.S., travel by private cars has historically been cheap, and shared modes of transport have struggled to attract passengers. Consequently, in the U.S., public transit is largely used by low-income people with limited means to use or own cars (Pucher and Renne 2003). In other countries, such as the United Kingdom and Germany, automobile transport costs are higher because of land use and pricing policies. Thus, public transit is more popular there (Buehler 2011; Giuliano and Dargay 2006).

Empirical research indicates that increasing the cost of car use relative to the cost of transit is associated with greater transit demand (Asensio 2002; Gillen 1977; Washbrook, Haider, and Jaccard 2006). For example, parking prices and road use charges can be increased to raise car-use costs. Furthermore, it is well known that dense, mixed-use, pedestrian-friendly, transit-accessible and vibrant areas influence people to use transit more (Basheer, Boelens, and van der Bijl 2020; Ding and Zhang 2017; Wong et al. 2017; Yang et al. 2016). The higher cost of automobile travel may support this behavior. Crane and Crepeau (1998) observe a similar association between automobile travel costs and transit use.

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 farther from them (Chatman 2013).

Studies on mode choices or shifts in behavior involving public transit services generally utilize either 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 they disaggregated behavioral factors, such as individual mode choice behavior. For example, Boile, Spasovic, and Bladikas (1995) present an equilibrium demand–supply model consisting of a mode choice and a traffic assignment sub-model. They describe a commuter corridor with automobile, urban rail and intermodal autorail modes. They show that improving rail service and accessibility may be the best way to divert automobile trips to transit. These shifts can also be encouraged by increasing parking fees. Other researchers have applied complex mathematical models to quantify the effects of land use, travel costs and reliability on travel choices (Bhat and Sardesai 2006; Chang 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. (2020) develop mixed logit models to 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, while transfer distance, not owning a car, being a student and belonging to an enterprise are positively associated with bike-sharing usage. Weather and travel distance also have significant negative impacts on mode shifts. Wang et al. (2013) examine mode shifts by automobile, taxi, bus, electric and pedal bicycle users after the implementation of a metro service. 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. Finally, taxi and electric bicycle travelers who take longer trips prefer to use the newly introduced metro.

Ashalatha, Manju, and Zacharia (2013) employ multinomial logit models to explore commuters' mode choices in Trivandrum, India. The results show that increases in time and cost per unit of distance cause commuters to use cars. Thus, they recommend identifying such factors and altering them to formulate effective policies to improve public transit. Finally, Ding et al. (2017) investigate the effects of multiple transit priority strategies on car users' modal shifts using a logit model. They show that an increase in parking fees has the greatest impact on modal shifts, followed by managed bus lanes. A transit fare discount is less attractive to car users who are shifting to mass transit.

The literature described above indicates that insights from potential transit passengers remain unclear and thus have not yet been adequately captured. Few studies investigate people's pre-launch willingness to switch from their current travel mode to a new metro. Moreover, incorporating individual-level heterogeneity into a choice model is entirely novel in the context of Riyadh. In a recent study, Youssef, Alshuwaikhat, and Reza (2021) examine commuters' perceptions of the metro services in Riyadh. They also analyze the factors that affect commuters' willingness to shift to the metro. However, they do not consider individual-level heterogeneity; rather, they focus only on discrete experiments. Consequently, our study attempts to explore the factors that influence the likelihood of a modal shift by accounting for individual-level heterogeneity. We use stated preference (SP) survey data collected in Riyadh and perform a case study of Riyadh to provide evidence of users' perceptions regarding Riyadh's new metro system. Furthermore, the importance of the identified factors or attributes in relation to modal shifts may facilitate future shifts to the metro.

3. Research Methods and Data

Riyadh, the capital of and largest city in Saudi Arabia is used as a case study for this analysis. The cost of operating a car in the Kingdom is very low relative to other countries. The Kingdom has very low taxes, car registration fees and fuel costs. Thus, many lower income households[1] can afford to use private cars. Since the late 1950s, Riyadh has been a car-dominated city (Aldalbahi and Walker 2016). Private vehicle ownership in the city increased by 185.9% between 1996 and 2008. 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, Al-Badi, and Mayhew 2012). According to the Royal Commission for Riyadh City Population Study (2016), Riyadh has more than 2 million registered vehicles. Private cars are the major mode of transport in the city (77.2%), followed by private buses/vans (16.1%), taxis/limousines (3.7%), public buses (2.2%) and heavy trucks (0.8%) (Almannaa et al. 2021). Riyadh's mega metro project, the world's largest urban rail project outside of China, is currently underway and is expected to be operational soon.

3.1 Model Specification

The objective of this study is to understand whether people will shift from their current modes of transportation to the proposed metro. Given the binary nature of the choice and the associated heterogeneity in the choice processes, we apply a mixed binary logit model. Binary logistic models are widely used in transportation research. For example, they are used to analyze commuting modal shifts (Oakil et al. 2011) and car ownership changes (Oakil et al. 2014; Oakil, Manting, and Nijland 2016). They are also used to understand pedestrian behavior (Marisamynathan and Vedagiri 2018) and shifts to bicycle use (Oakil et al. 2016). However, standard binary logistic regression assumes that the parameters of the explanatory variables are fixed. Thus, this method cannot capture heterogeneous effects on modal shifts.

To account for unobserved individual heterogeneity, this study uses a mixed binary logit (MBL) modeling approach to capture the randomness associated with the parameters. This approach is necessary to understand the factors affecting modal shifts to the metro. Most models employed in the literature focus on deterministic approaches. In contrast, this study's MBL model employs a probabilistic approach based on the random utility model (RUM). The probabilistic approach offered by RUM is better than the deterministic approach because it can explain the differences, heterogeneity and uncertainty in the selection process. By contrast, the deterministic approach captures only the average decision-makers' behavior (Hensher, Rose, and Greene 2005; Train 2009).

In this study, Y = 1 denotes a modal shift to the metro. Y = 0 denotes the use of the current mode of transport, that is, no modal shift. The utility functions for these two options can be written as

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

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

Here, UMS and UNS 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 alternatives, depending on the explanatory variables (X) and a

Gumbel-distributed random residual (ε). We set VNS equal to zero as this is the reference option. Then, the probability of a modal shift to the metro is

$$P_{MS}(Y=1) = \int \frac{\exp(U_{MS})}{1+\exp(U_{MS})} f(\beta_I,|\alpha_j) d\beta_i. \quad (3)$$

where $f(\beta_i,|\alpha_j)$ is the probability density function of parameter β_i, and α is a vector of the parameters of the density function.

We include many service attributes in the utility function, such as travel time, travel cost, walk time, and wait time. We also consider travelers' sociodemographic characteristics, such as age, employment status, education level, and family size. Table 1 provides descriptions of the variables used in this study. We consider two independent MBL models to describe the shifts from two different modes of travel (i.e., cars and taxis) to the metro.

3.2 Data and Variables

This study aims to understand the trip characteristics of private transport users in Riyadh and their intentions to shift to the proposed metro. However, it is impossible to gather revealed preference data before a new service is offered. Thus, a self-potential (SP) survey, which can help predict people's decisions, is necessary for this study. The respondents to the SP survey are asked about their possible choices in hypothetical situations under a specific set of conditions.

We use SP survey data provided by the Arriyadh Development Authority (ADA) (now the Royal Commission for Riyadh City). The SP survey considers various combinations of different hypothetical situations. We incorporate mode-specific attributes, such as in-vehicle time, one-way travel costs, walking time and waiting time to determine people's willingness to switch to the metro. The knowledge acquired through this SP survey can help metro operators and authorities understand user behaviors and perspectives so that the new service can meet user expectations.

ADA hired Diadro Consulting to conduct this survey in 2013 to evaluate the likelihood of private vehicle users switching to the metro. In Riyadh, private vehicles (cars or taxis) are used for more than 90% of trips. If this group were to shift to the metro, it would represent the most significant contribution to sustainable mobility in Riyadh. In this regard, this study uses data from the 2013 SP survey in which 275 car or taxi users are asked about their willingness to shift to the metro. After considering non-responses and missing values, the sample size comprises 196 individuals who responded to the nine hypothetical situations (Appendix A). The situations compare car verses metro use or taxi verses metro use using different travel times, fares, wait times, walk times and transfer requirements (car users only). The sample description is shown in Table 1. 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., the same purpose and frequency). They were also expected to think deeply about each option, consider the conditions of each situation and specify their preferred option in each case.

Table 1. Independent variables in the utility function and sample description.

Descriptive statistics of choice attributes	**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	
Sociodemographics	**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

Source: Authors.

3. Research Methods and Data

Table 1 summarizes the basic statistics for our sample data based on the travel mode. We consider age, nationality, educational level, employment status, marital status, family type, car ownership and trip purpose. The majority of respondents use cars for work trips, whereas taxis are used most frequently for personal business trips. Almost 50% of car users are well educated (i.e., hold a bachelor's degree, master's degree or Ph.D.). The highest proportion of taxi users have an intermediate level of education. Most respondents were employed, followed by students. Approximately 57% of car users are Saudi citizens, whereas non-Saudis are found less taxi users. Over 40% of trips are work trips by car, whereas the majority of taxi trips are personal business trips, followed by shopping and recreation trips. The majority of the respondents were from nuclear families.

Table 1 also provides the mean and standard deviation of travel cost, travel time, wait time and walk time for a one-way trip. Taxis are the most expensive, whereas car trips have the longest travel times. The survey asked 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 with the current mode.

Finally, a limitation of the data is the small sample size. However, the data are the only available official data from the Riyadh planning authority. As they are official survey data, they are assumed to be reliable. We apply a sufficient modeling approach to achieve robust results using a small sample size.

4. Results of MBL Models

We evaluate the effects of travel time, travel cost, walk time, wait time and transfer requirements on the decision to shift to the metro. Table 2 presents the estimated SP results for the choice between car and metro travel, where car travel is a reference alternative. We estimate three models: Model 1 is a linear binary logistic model that includes only choice attributes, and Model 2 is an MBL model. Finally, Model 3 is an MBL model adjusted for individual characteristics. We evaluate the significance ranging from 10% to 0.1%. Model 3 fits the data better, as its R-squared value is greater than those of the other models. Moreover, the likelihood ratio test also identifies Model 3 as more robust than models 1 and 2.

Given that Model 3 has the best fit, we discuss the results of this model further. The signs of the coefficients are negative, as expected. All of the coefficients are statistically significant at the 99% confidence level. Thus, if the time to walk to the metro is increased, for example, respondents are less likely to shift to the metro. The other choice attributes can be similarly interpreted. Transfer requirements have the strongest effect on the choice to shift to the metro, followed by wait and walk times.

Among the individual characteristics, level of education has a very significant effect on modal choice. Highly educated car users are more likely to use the metro than less educated users. Moreover, older car users are less likely to switch to the metro than younger users. This result is consistent with previous findings that public transport may be inadequate and non-responsive to the needs of older adults (Dickerson et al. 2007). Among travel purposes, school trips have no statistically significant effects, while social trips have less significant effects on modal choice than other trips. Most other travel purposes have negative coefficients. Thus, work trips, the reference group, are more likely to shift to the metro than shopping, medical, personal, social, or recreational trips. In general, work trips are very regular in terms of both time and location and can easily be planned with minimal uncertainty. In contrast, other trips are often uncertain and have different destinations. Moreover, non-work trips may involve additional arrangements, such as traveling with family or a friend, or carrying groceries and other household items. These arrangements often encourage the use of private vehicles.

The estimated standard deviations of the random parameters for the walk time to the metro and the wait time for the metro are significant. Thus, the effects of walk and wait times on the decision to shift to the metro exhibit considerable heterogeneity among respondents. The random parameters are not statistically significant for travel time and cost. Thus, the effects of these variables are similar across respondents.

Table 2. Estimated SP results for comparisons of car and metro travel (reference: car travel).

	Model 1			Model 2			Model 3		
	Estimate	**Pr(>lzl)**		**Estimate**	**Pr(>lzl)**		**Estimate**	**Pr(>lzl)**	
Choice attributes									
Walk time to access the transit mode	-0.160	0.000	***	-0.292	0.000	***	-0.314	0.000	***
Wait time for the transit mode	-0.167	0.000	***	-0.411	0.000	***	-0.381	0.000	***
Travel time for the transit mode	-0.074	0.000	***	-0.124	0.000	***	-0.122	0.000	***
Cost of the transit mode	-0.031	0.000	***	-0.099	0.000	***	-0.115	0.000	***
Transfer required (Yes)	-1.419	0.000	***	-1.911	0.000	***	-1.864	0.000	***
Metro-specific coefficients									
Alternative specific constant	-0.651	0.001	***	-0.594	0.016	**	-1.436	0.005	***
Individual characteristics									
Age: Younger than 30 years (ref.)									
Age: 30 to 45 years							-0.580	0.022	**
Age: 45 years or older							-0.897	0.054	*
Nationality: Non-Saudi (ref.)									
Nationality: Saudi							1.241	0.000	***
Education level: Low (ref.)									
Education level: Intermediate							1.370	0.000	***
Education level: High							1.641	0.000	***
Employment status: Employed (ref.)									
Employment status: Student							-0.656	0.037	**
Employment status: Retired							-0.591	0.545	
Employment status: Looking for work							-0.392	0.349	
Marital status: No (ref.)									
Marital status: Yes									
Family type: Single person (ref.)									
Family type: Nuclear family							-0.276	0.392	
Family type: Extended family							-1.221	0.019	**
Family type: Other types							0.932	0.140	

More than one household car: No (ref.)									
More than one household car: Yes							-0.717	0.007	***
Travel purpose: Work (ref.)									
Travel purpose: Shopping							-1.063	0.001	***
Travel purpose: Personal business							-1.365	0.025	**
Travel purpose: Social and recreation							-0.551	0.052	*
Travel purpose: Medical							-2.224	0.019	**
Travel purpose: School							0.237	0.655	
Travel purpose: Others							0.016	0.970	
Standard deviation of random parameter									
Walk time to access the transit mode				0.212	0.007	***	0.278	0.000	***
Wait time for the transit mode				0.367	0.000	***	0.331	0.000	***
Travel time for the transit mode				-0.002	0.992		0.006	0.982	
Cost of the transit mode				0.080	0.000	***	-0.003	0.986	
Model results									
Log-likelihood:	-642.310			-580.340			-560.560		
McFadden R^2:	0.108			0.194			0.222		
Likelihood ratio test:	chi sq=155.96		***	chi sq=279.9		***	chi sq=319.46		***

Source: Authors.
Note: *** = significant at the 1% level; ** = significant at the 5% level; * = significant at the 10% level.

4. Results of MBL Models

Given that Model 3 has the best fit, we discuss the results of this model further. The signs of the coefficients are negative, as expected. All of the coefficients are statistically significant at the 99% confidence level. Thus, if the time to walk to the metro is increased, for example, respondents are less likely to shift to the metro. The other choice attributes can be similarly interpreted. Transfer requirements have the strongest effect on the choice to shift to the metro, followed by wait and walk times.

Among the individual characteristics, level of education has a very significant effect on modal choice. Highly educated car users are more likely to use the metro than less educated users. Moreover, older car users are less likely to switch to the metro than younger users. This result is consistent with previous findings that public transport may be inadequate and non-responsive to the needs of older adults (Dickerson et al. 2007). Among travel purposes, school trips have no statistically significant effects, while social trips have less significant effects on modal choice than other trips. Most other travel purposes have negative coefficients. Thus, work trips, the reference group, are more likely to shift to the metro than shopping, medical, personal, social, or recreational trips. In general, work trips are very regular in terms of both time and location and can easily be planned with minimal uncertainty. In contrast, other trips are often uncertain and have different destinations. Moreover, non-work trips may involve additional arrangements, such as traveling with family or a friend, or carrying groceries and other household items. These arrangements often encourage the use of private vehicles.

The estimated standard deviations of the random parameters for the walk time to the metro and the wait time for the metro are significant. Thus, the effects of walk and wait times on the decision to shift to the metro exhibit considerable heterogeneity among respondents. The random parameters are not statistically significant for travel time and cost. Thus, the effects of these variables are similar across respondents.

Table 3 presents the estimated SP results for the choice between taxi and metro travel. Taxi travel is the reference alternative for these models. As before, we estimate the three models. Model 3 has the best fit as it has the greatest values for the R-squared and likelihood ratio tests. As expected, all the choice attributes have negative coefficients. Wait times alone do not significantly affect the modal shift decisions of taxi users. The impacts of the choice attributes are similar in magnitude, implying that they affect taxi users' mode choices in similar ways.

Younger people (under 30 years) are more likely to use the metro than people in other age groups. A possible explanation for this result may be that young people have lower incomes, are single or are more flexible in terms of time. People with higher education levels are more likely to use the metro instead of a taxi once the metro is in operation. Extended families who use taxis are less likely to use the metro than single people. Often, extended families travel with multiple people with different travel requirements. For example, families with children or elderly members require special accessibility. The coefficients of all travel purpose variables are negative. Thus, taxi trips to work are more likely to shift to the metro than trips for other purposes.

For the random parameters, we find that wait time and travel cost have significant effects. Hence, these variables may affect taxi users' mode choices differently. The random parameters for walk time and travel cost have no significant effects; and thus, these variables have similar effects for all users.

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

	Model 1			Model 2			Model 3		
	Estimate	Pr(>lzl)		Estimate	Pr(>lzl)		Estimate	Pr(>lzl)	
Choice attributes									
Walk time to access the transit mode	-0.121	0.00	***	-0.212	0.001	***	-0.179	0.002	***
Wait time for the transit mode	-0.112	0.010	***	-0.157	0.050	**	-0.096	0.211	
Travel time of the transit mode	-0.069	0.011	**	-0.130	0.004	***	-0.108	0.014	**
Cost of the transit mode	-0.040	0.000	***	-0.118	0.000	***	-0.117	0.000	***
Transfer required (yes)									
Metro-specific coefficients									
Alternative specific constant	-0.415	0.355		-1.837	0.008	***	-0.140	0.931	
Individual characteristics									
Age: Younger than 30 years (ref.)									
Age: 30 to 45 years							-1.242	0.087	*
Age: 45 years or older							-2.337	0.028	**
Nationality: Non-Saudi (ref.)									
Nationality: Saudi									
Education level: Low (ref.)									
Education level: Intermediate							0.533	0.362	
Education level: High							1.242	0.043	**
Employment status: Employed (ref.)									
Employment status: Student							-0.131	0.859	
Employment status: Retired							1.092	0.331	
Employment status: Looking for work							1.594	0.063	*
Marital status: No (ref.)									
Marital status: Yes									
Family type: Single person (ref.)									
Family type: Nuclear family							0.332	0.478	
Family type: Extended family							-2.232	0.094	*
Family type: Other types							0.932	0.140	

Family type: Other types									
More than one household car: No (ref.)									
More than one household car: Yes							1.442	0.008	***
Travel purpose: Work (ref.)									
Travel purpose: Shopping							-1.503	0.195	
Travel purpose: Personal business							-2.600	0.046	**
Travel purpose: Social and recreation							-2.027	0.099	*
Travel purpose: Medical							-3.181	0.032	**
Travel purpose: School							-4.933	0.003	***
Travel purpose: Others							-4.029	0.006	***
Standard deviation of random parameter									
Walk time to access the transit mode				0.200	0.000	***	0.091	0.186	
Wait time for the transit mode				0.521	0.001	***	-0.360	0.008	***
Travel time for the transit mode				0.000	1.000		0.048	0.619	
Cost of the transit mode				0.053	0.004	***	-0.045	0.039	**
Model results									
Log-likelihood:	-277.080			-240.300			-230.910		
McFadden R^2:	0.075			0.198			0.229		
Likelihood ratio test:	chi sq = 44.716		***	chi sq = 118.28		***	chi sq = 137.05		***

Source: Authors.
Note: *** = significant at the 1% level; ** = significant at the 5% level; * = significant at the 10% level.

5. Discussion and Conclusions

Vehicle technology is not the only solution for achieving sustainability in the transport energy sector. Instead, it is worth exploring the effects of potential policies to stimulate behavioral changes. One such avenue may be policies that shift a substantial amount of travel to public transit. Many policies are advocating for such a shift in response to the transport sector's environmental impacts and energy demand. Understanding modal shift scenarios requires information on travel behavior and other specific factors that are available for the Riyadh metro.

Reductions in energy use and carbon dioxide emissions through the modal shift to public transit depend on train and bus occupancy rates, which can vary significantly. Potter (2007) observes that buses and trains offer 1.5 to 4 times greater energy efficiency than cars in terms of seat kilometers. However, their energy efficiency is only zero to two times greater when their current occupancy is considered. These results also vary according to trip purpose. For example, in the case of commuting, car occupancy is lower and public transport occupancy is very high. Thus, the average car commute uses over five times as much energy as the average public transport commute (Potter 2003). However, the gap is narrower when all trip purposes are considered.

We may assume that shifts to public transport increase vehicle occupancy and thus improve fuel efficiency per passenger kilometer. Furthermore, we assume that the modal shift approach can reduce the demand for private car mobility. This demand reduction is driven by a combination of better urban planning, improved infrastructure and better public transit systems. In addition, effective policy measures can encourage the use of public transit modes, such as the metro and BRT. In practice, modal shift patterns are constrained by various factors, such as people's willingness to change their behavior and government policies. Constraints on the levels of investment and costs of using the respective modes also impact the modal shift patterns.

Modal shift patterns are also strongly associated with the pattern of land use in a city. To reduce passenger kilometers by private cars, land use and public transit must be well integrated. Efficiently integrating the two can be complex, and it is not always clear how to optimize one mode over another. Changing land-use patterns can directly affect transport systems and vice versa, and thus can affect modal shifts. For instance, metro development can lead to much denser land use patterns around stations, which can drive travelers to shift from cars to the metro. Cuenot, Fulton, and Staub (2012) indicate that managing land use in an area can reduce the number of trips elsewhere by up to 30%. They show that imaginative parking policies can achieve at least a 10% shift away from private vehicles. They find that BRT systems can shift at least 5% of trips from cars to mass transit. Finally, they explain that the modal shift of car and taxi users to BRT in cities implementing this system is between 6% and 21%. The estimated models provide some direction for determining the impacts of such shifts in travel patterns.

According to the model estimation results, taxi users are not sensitive to wait times. This result is reasonable because the average wait times for taxis and the proposed metro are not very different. Thus, wait times may not significantly influence taxi users' modal shift decisions. In contrast, all the attributes included in our models affect car users' decisions. Older travelers prefer to keep using their current mode, whereas younger car and taxi users intend to switch to the metro. Travelers with higher education levels are likely to change their current modes to the metro. The reason for this result may be that well-educated people prefer environmentally friendly transport options such as the metro. Moreover, the switch from car to metro travel for work trips is likely associated with educational attainment. Shopping, personal business, and social and recreational trips are less likely to shift to the metro than work trips. This may be because serious traffic congestion can add more uncertainty to work trips. Metro services may be more reliable than driving.

Overall, people who are employed, single, traveling for work, and are more educated are more likely to choose the metro. By contrast, people who are less educated, unemployed, part of a nuclear or extended family or travel for non-work reasons are more likely to maintain their current transport mode. Furthermore, the models show that the new metro can significantly lead travelers to change their mode choice. The proportions of taxi and car users that shift to the proposed new metro service may reach 51% and 23%, respectively. 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.

These study findings are useful for metro planning in Asian cities such as Riyadh, where private vehicles generate the majority of trips. The results show that the metro has a high potential to attract users of private vehicles, such as cars and taxis. Adequately improving the metro's service level and introducing road pricing, including parking fees for high importance zones, such as shopping malls, are highly likely to enable a modal shift to the metro. The metro system should be planned to significantly decrease travel times and be affordable to limit the use of private vehicles. Finally, this study provides explicit knowledge on and facilitates an understanding of travelers' perceptions of the metro service, including factors that impact their chosen modes of transportation. This information can lead to sustainable transport development in Riyadh. Moreover, strong measures can be adopted on short- and long-term bases and progressively strengthened over time. In this case, a much greater modal shift can be achieved, thereby creating energy efficiency gains.

Finally, our results are based on a survey conducted in 2013, when women were not allowed to drive in Saudi Arabia. Since June 2018, women have been allowed to drive in the Kingdom. Consequently, about 81% of women in the country have expressed their intention to obtain a driving license, and among them, about 36% wanted a license immediately after the ban was lifted. Approximately 76% of women intended to drive after the ban was eased (Al-Qarawi et al. 2018). Riyadh Province has the highest proportion of women who intend to drive. Therefore, easing the ban has undoubtedly added to car travel, which might have caused increased travel times/congestion, as well as higher emissions. This additional scenario could not be reflected in this analysis because the survey the analysis is based on was conducted before 2018.

Furthermore, Saudi Arabia has adjusted gasoline prices on a quarterly basis since early 2019, and this adjustment would also bring some changes in the modal choice of private car travelers.

Endnotes

[1] Disposable incomes are no longer as high as they were during the oil boom years of the 1970s or the years immediately following the boom (Opoku and Abdul-Muhmin 2010).

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Appendix A

Diadro Consulting Espana, a consulting firm based in Spain, was commissioned to conduct a stated preference survey to evaluate metro preferences. The survey designed the following hypothetical situations for car and taxi users.

Car users

Attributes	S1 Metro	S1 Car	S2 Metro	S2 Car	S3 Metro	S3 Car	S4 Metro	S4 Car	S5 Metro	S5 Car	S6 Metro	S6 Car	S7 Metro	S7 Car	S8 Metro	S8 Car	S9 Metro	S9 Car
Fare / parking fee	3 riyals	Free	5 riyals	10 riyals	3 riyals	Free	7 riyals	Free	7 riyals	Free	7 riyals	Free	5 riyals	10 riyals	3 riyals	Free	5 riyals	10 riyals
Wait time	7 mins	None	7 mins	None	4 mins	None	2 mins	None	7 mins	None	4 mins	None	2 mins	None	2 mins	None	4 mins	None
Travel time	Last trip – 15 mins	Same as last	Last trip – 8 mins	Same as last	last trip – 8 mins	Same as last	Last trip – 8 mins	Same as last	Last trip – 5 mins	Same as last	Last trip – 15 mins	Same as last	Last trip – 15 mins	Same as last	Last trip – 5 mins	Same as last	Last trip – 5 mins	Same as last
Walk time	Same as last	Same as last	Last trip + 5 mins	Same as last	Last trip + 3 mins	Same as last	Same as last	Same as last	Last trip + 3 mins	Same as last	Last trip + 5 mins	Same as last	Last trip + 3 mins	Same as last	Last trip + 5 mins	Same as last	Same as last	Same as last

Taxi users

Attributes	S1 Metro	S1 Taxi	S2 Metro	S2 Taxi	S3 Metro	S3 Taxi	S4 Metro	S4 Taxi	S5 Metro	S5 Taxi	S6 Metro	S6 Taxi	S7 Metro	S7 Taxi	S8 Metro	S8 Taxi	S9 Metro	S9 Taxi
Fare	3 riyals	Same as last	5 riyals	Same as last	3 riyals	Same as last	7 riyals	Same as last	7 riyals	Same as last	7 riyals	Same as last	5 riyals	Same as last	3 riyals	Same as last	5 riyals	Same as last
Wait time	7 mins	Same as last	7 mins	Same as last	4 mins	Same as last	2 mins	Same as last	7 mins	Same as last	4 mins	Same as last	2 mins	Same as last	2 mins	Same as last	4 mins	Same as last
Travel time	Last trip – 13 mins	Same as last	Last trip – 7 mins	Same as last	Last trip – 7 mins	Same as last	Last trip – 7 mins	Same as last	Last trip – 4 mins	Same as last	Last trip – 13 mins	Same as last	Last trip – 13 mins	Same as last	Last trip – 4 mins	Same as last	Last trip – 4 mins	Same as last
Walk time	5 mins	Same as last	8 mins	Same as last	12 mins	Same as last	5 mins	Same as last	12 mins	Same as last	8 mins	Same as last	12 mins	Same as last	8 mins	Same as last	5 mins	Same as last

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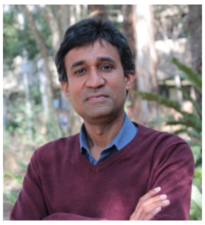
About the Authors



AHM Mehbub Anwar

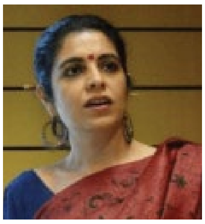
Mehbub is a Research Lead at KAPSARC. He currently leads the maritime project, in collaboration with the Kingdom's energy ecosystem. This project investigates future port activity and fuel forecasting. He also works on the KAPSARC Spatial Urban Energy System (KSUES) project. Prior to joining KAPSARC, he worked in Transport for New South Wales (TfNSW), a state government organisation, as a transport planner, and at the University of Wollongong (UOW) in Australia as a researcher. He led the update on the state of transport in the TfNSW regions as part of the strategic planning for its Future Transport 2056. He has also worked as a lecturer at Khulna University of Bangladesh and was later promoted to a professor in urban transport planning. He holds a Ph.D. with an examiners' commendation for an outstanding thesis from the UOW. His thesis focused on modeling travellers' preference heterogeneity.

Abu Toasin Oakil

Toasin has an extensive experience in urban planning and transport modeling. He was Research Lead in KAPSARC's Transport and Infrastructures program, where he focused on the urban transformation of Riyadh, and Saudi Arabia more generally. He worked on developing different decision tools to understand the impact of transit-oriented development (TOD) on the energy market, and evaluating and assessing urban policies that relate to sustainable transport and energy consumption. Toasin has worked as a scientific researcher at universities and in public organizations, and as a consultant in the private sector. He holds a Ph.D. in transportation planning from Utrecht University, an M.Sc. in urban planning from the London School of Economics, and a Master and Bachelor of Urban Planning from Bangladesh University of Engineering and Technology. While at university, he received several accolades for his work, including the 2014 Ph.D. Dissertation Award in Transportation Geography from the American Association of Geographers (AAG) and the Prime Minister's Gold Medal for his academic achievements.

Abdelrahman Muhsen

Abdel is a geospatial leader, certified in GIS (GISP), with over 18 years of experience in GIS and spatial data management. He has a proven track record of leading and delivering enterprise GIS projects for international corporations in North America and the Middle East. His work focuses on spatial economic modeling to better understand and forecast the interactions between economic activities, energy demand, land use, and transportation in urban areas. Before joining KAPSARC, Abdel worked for world-renowned, global companies, such as Accenture and ESRI, in North America and the Middle East. He served as a technical leader and a senior consultant, guiding clients in the energy sector on how to extract value out of geospatial data assets and GIS investments. Abdel holds an M.Sc. in geomatics engineering from the University of Calgary, Canada.



Anvita Arora

Anvita is the Director of the Transport and Infrastructure program at KAPSARC. She is an architect and transport planner whose current areas of research at KAPSARC include energy efficient and sustainable cities. Before joining the Center in February 2018, she was the managing director and CEO of Innovative Transport Solutions (iTrans), an incubatee company of IIT Delhi, where she led over 40 applied research and planning projects for 10 years for clients ranging from city level and country level authorities to funding agencies including the United Nations Environment Programme, the World Bank, the Asian Development Bank, and the United Kingdom's Department for International Development. Supporting cities to become sustainable, inclusive and climate resilient was the primary focus of her work. Anvita taught transport planning at the Urban Design Department of the School of Planning and Architecture in Delhi and was also associated with the Transportation Research and Injury Prevention Program (TRIPP) at IIT Delhi, a Volvo Research and Educational Foundations (VREF) Centre of Excellence, for nearly 12 years.

About the Project

This study is part of the ongoing project, KAPSARC Spatial Urban Energy System (KSUES). It comprises two components: an (i) urban energy model (UEM) and (ii) a spatial economic mode (SEM). The project has three objectives: (i) to achieve energy efficiency through transit-oriented development (TOD) in the transportation and electricity sectors, (ii) to gain additional efficiency by realizing the potential opportunity of innovative and smart technologies offered by TOD, and (iii) to investigate the energy and economic impact (including real estate development) of Riyadh transportation, land use and urban planning interventions. The energy efficiency gains through TOD are directly related to land use changes and a modal shift to public transport. Knowing residents' willingness to make a potential modal shift is an important step in implementing the public transport infrastructure project. Therefore, it has become imperative to obtain a better understanding of the factors that might impact travelers' intentions to embrace a modal shift in a highly urbanized and motorized city like Riyadh.

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