Modeling the Influence of Socioeconomic and Land-Use Factors on Mode Choice: A Comparison of Riyadh, Saudi Arabia, and Melbourne, Australia

M. Alqhatani, S. Bajwa, S. Setunge

Abstract**—**Metropolitan areas have suffered from traffic problems, which have steadily increased in many monocentric cities. Urban expansion, population growth, and road network development have resulted in a structural shift toward urban sprawl, increasing commuters' dependence on private modes of transport. This paper aims to model the influence of socioeconomic and land-use factors on mode choice using a multinomial and nested logit model. Land-use patterns—such as residential, commercial, retail, educational and employment related—affect the choice of mode and destination in the short and medium term. Socioeconomic factors—such as age, gender, income, household size, and house type—also affect choice, while residential location is affected in the long term. Riyadh in Saudi Arabia and Melbourne in Australia were chosen as case studies. Riyadh is a car-dependent city with limited public transport, whereas Melbourne has good public transport but an increase in car dependence. Aggregate level land-use data and disaggregate level individual, household, and journey-to-work data are used to determine the effects of land use and socioeconomic factors on mode choice. The model results determined that urban sprawl is the main factor that affects mode choice, income, and house type.

Keywords**—**Socioeconomic, land use, mode choice, multinomial logit and nested logit.

I. Introduction

URBAN structure is a framework of housing, employment and developments (e.g., hospitals, education centers, and leisure facilities) that, combined with socioeconomic factors, influence and shape travel patterns. As such, varying urban structures in cities such as Riyadh and Melbourne can be anticipated (e.g. low density, high density, urban sprawl, and public transport), resulting in differing travel patterns.

Newman and Kenworthy [1] suggested that density correlates with traffic problems and gas emissions, although others argue that land-use factors are less important than socioeconomic conditions, with factors such as income significantly affecting travel patterns [2]. The increased suburbanization of the labor force, combined with the relationship between housing and jobs located in suburban areas, has decreased the distance of trips [3].

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Therefore, it is important to acknowledge and assess the relationship between land use and socioeconomic factors to improve traffic problems. The socioeconomic makeup of the traveler, along with the distribution of land use, will significantly affect the mode choice for both short- and long-distance trips [4]. This is reflected in Melbourne, where the process of employment decentralization in the middle and outer suburbs is dispersed, leading to issues for Melbourne's planning goals. For example, Mees [5] argues that the ability to create coherent land use and public transport systems leads to dispersed journeys. In Riyadh, increased car use and the subsequent decrease in the quality of life has had little effect, reflecting the distribution of land use, which necessitates people using private cars [6].

Melbourne and Riyadh are exposed to an increased use of private modes of travel for daily traveling, even though Melbourne has significant public transport facilities. Many developing countries have such facilities, but maintain a high level of private mode use, and Melbourne reflects a standard situation around the developed world. Moreover, Melbourne's motorization pathways are comparable to those found in the United Kingdom (UK) and the United States (US).

Riyadh needs to develop its public transport to decrease private mode use, long distances, and gas emissions. This study uses the comparative method to analyze Melbourne as a city within a developed country and Riyadh as a city within a developing country, because both cities have a comparable urban form and population. However, there are significant differences in their transport systems, as Melbourne has well-developed public transport options, whereas Riyadh has limited public transport that mostly comprises buses. Despite the differences, private mode use has increased in both cities; thus, this study aims to improve knowledge of the relationship between private mode use and socioeconomic and urban form in effecting mode choice.

As the aggregate level becomes increasingly clear, academic attention has turned to issues such as socioeconomic and urban form characteristics of cities. The focus of this study is to determine how mode choice differs between different zones and between different social groups.

This paper is organized into five sections. The first section reviews the current literature on the influence of the urban form and socioeconomic factors on travel mode. The second section outlines the methodology and scope of the data used to undertake the research. The third section assesses the development of the urban form and socioeconomic factors in Riyadh and Melbourne. The fourth section explores how the journey-to-work (JTW) travel mode is affected by private transport in Riyadh and Melbourne in relation to social groups and urban structure. The fifth section provides the outcomes of the analysis and identifies the factors that can be affected by travel behavior.

II. Literature Review

The most significant factor to shape mode choice is the level of urban decentralization [7], as the urban form can reduce urban dispersion, which causes pollution in residential sectors [8]. Researchers have started assessing sustainable development in terms of urban growth and conversion of cities' growth and function using design tools (e.g. compact urban form [polycentric form] and mixed land use) to reduce the likelihood of private mode use [8], [9]. To address private mode use, scholars have recently identified the use of density as a proxy to support moves away from private mode use. Urban form is thus measured in four ways: density and mixed use, location (job/housing balance), accessibility, and neighborhood design.

Higher densities and mixed land use can assist residents to increase their number of activities in a single trip made on foot [10]. Meanwhile, Reilly and Landis [11] suggested that higher density could lead to a greater chance of walking or using public transport. Zhang [12] observed that population and employment densities are positively associated with the use of both transit and non-motorized modes because population and employment densities function as parameters that can improve quality and total travel time [13].

Mixed land use positively affects access to activities and lowers trip distances such that density alone cannot fix the issue of private mode use. Therefore, distance, density, and accessibility operate as proxies to promote sustainable transport by decreasing the length of private mode trips. A study in Toronto, Canada, identified that the distance to the central business district (CBD) was significant in terms of the differences in daily private mode trip lengths, and that this was more important than densities [14]. Thus, accessibility is the closest option for accessing public transport stops, stations, and public transport supply [15].

Many developed countries are affected by urban sprawl structures, which create lower density, imbalance between the workplace and labor force, as well as longer distances between public transport services and activities. Urban structure affects travel patterns, as observed in the decentralized form of city sites in the US, Australia, and Canada. These cities support traveling and private mode use. In contrast, cities with high density and centralized land use (compact cities), as observed in Europe, Japan, and China, support sustainable transport (e.g. walk and bicycle) and public transport [16]. In Melbourne, a correlation was found between the labor force and workforce, and the municipality unit [17], as the commute between suburbs overlapped due to private mode use.

Moreover, in a study in the UK, Buchanan [7] identified that residential relocation can shape travel patterns by increasing the trip length. This finding is significant because Riyadh and Melbourne are both growing quickly. Between 1976 and 1996, Melbourne's population increased to 3.2 million people. Riyadh grew to 4.88 million by 2008. The growth of Riyadh is explained by commercial buildings, road networks, and government funding availability. Such factors have assisted in the promotion of residential relocation. In particular, funding availability to support the growth of the low residential and population density has allowed people to build new housing units in the outer city, ultimately creating urban scatter [18]. The development of commercial buildings on arterial streets and freeways has led to an increase in travel by cars and the length of the trips taken [18]. O'Connor and Healy [19] stated that Melbourne's urban structure would require a variety of jobs to minimize the overlap of trade traffic flow between suburbs and private modes of transport traffic.

The usefulness of urban design in an empirical sense will be determined by questions of safety regarding traveling on foot, the pedestrian environment, street design, and city shape [15]. The methods used to deliver sustainable transport options, such as walking and bicycle, at the neighborhood level, can also lead to a reduction of the use and ownership of private mode options [15].

The literature on land use in disaggregate mode-choice modeling ignores the place of socioeconomic factors, because the data are often captured after controlling for this dynamic [15]. Stead and Marshal [20] suggested that the inclusion of socioeconomic factors is vital, because they are more influential than land-use characteristics in mode choice. This was disputed by Chan and McKnight [21], who suggested that their effect is comparable. Various researchers have shown that income and car ownership variables can function as determinants of transport and mode choice [21]. Kunert and Lipps [22] highlighted the place of socioeconomic variables in industrial areas where the majority of households have car ownership. As such, in these situations, demographic factors such as age, gender, household size, as well as composition of a household and life cycle, may be important determinants of mode choice, especially in developed countries [23].

III. Methodology

This research applies a model of discrete choice-modeling techniques to identify individual choices of the various mode alternatives [24]. In discrete choice models, the probability of choosing one of the alternative options can be compared to the variance between its estimated utility and the estimated utility of other alternatives. As such, utility is understood to be a linear function that includes parameters that reflect aspects of the modes of transport. This includes travel time, cost, and frequency, as well as decision-maker factors (e.g. income, auto ownership, age, and land use), whereby the parameters of decision-making factors are based on population and employment density, and mixed land use. Utilizing maximum likelihood methods allows for the creation of estimated utility function coefficients [25].

The multinomial logit (MNL) model is a simple form that suggests that random error terms are both identically and independently distributed (IID), which is important when examining IID random errors. It also allows for the supposition of equal preference among alternatives, such as the use of MNL and the introduction of service improvements to an existing mode. Consequently, this leads to a reduction in the probability of other existing modes that correspond to probabilities before changing. The IID can be used in both flexible and complex model forms as a way of minimizing this issue. The nested logit (NL) mode is also applied in this research, as it assists in relaxing the independence assumption, therefore creating various degrees of similarity between subclasses (nests) of alternatives.

A. General Model Structure

The utility function form is:

$$Uij \equiv Vij + \varepsilon ij \tag{1}$$

where Uij is the utility of individual j for alternative i, Vij is the deterministic part of the utility of the alternative i for individual j and ij is the random component of the utility of the alternative i for individual j.

$$Vij = f(BXij) \tag{2}$$

where B is a vector to be estimated from data and Xij is the attributes of an alternative j and the socioeconomic characteristics of the decision maker i.

Equation (2) assumes that the exogenous variables in the car ownership model correlate with household characteristics. One benefit of the MNL model is that it allows for the effect of exogenous variables such as income to be negative for the utility of zero car ownership and positive for the ownership of one and two cars.

The distribution function of an IID error term (εij) with a gumbel distribution was assumed to identify the MNL model and determine the probability of a household choosing car ownership level J [26], as shown in (3):

$$Pij = \frac{e^{BJXi}}{\sum_{J=0}^{J} e^{BJXi}} \tag{3}$$

B. Choice Definition

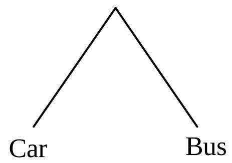
The alternative modes of transport are discussed here, with particular reference to the nature of each city. For example, Riyadh lacks both tram and train modes, yet Melbourne has four alternatives, which are car, train, tram, and bus. A concise summary of the choices and availabilities across both cities are presented in Table I.

TABLE I
CHOICE OF ALTERNATIVES IN THE DATA

Mode	Riyadh	Melbourne
Car	12,097	4274
Train	-	969
Tram	-	220
Bus	865	116
Total	12,960	9579

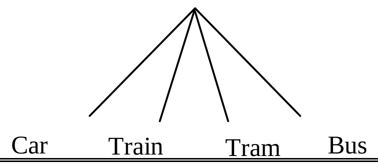
C. Model Structure

To identify the optimum fitting and explanatory model, a range of theories that explore relationship structures will be examined. First, the MNL logit model will be analyzed, based on an assumption that there is no relationship between any of the alternatives. This is presented in Fig. 1. Moreover, Melbourne's representation of the NL model is shown, but not for Riyadh, because it has no public transport (PT) equivalent to train and tram.



	Car	Bus
Car	x	
Bus		x

(a)

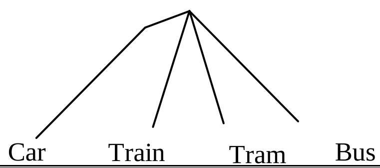


	Car	Train	Tram	Bus
Car	x			
Train		x		
Tram			x	
Bus				x

(b)

Fig. 1 Multinomial logit relationship form and relevant covariance matrix: (a) Riyadh and (b) Melbourne

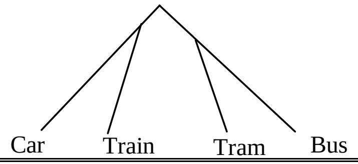
The nesting structure organized into two nests is shown in Fig. 2, where two alternatives are bundled together to form a separate nest, for example, train and car, and the other two alternatives form a single nest, in this instance, bus and tram. The corresponding covariance matrix for this form is represented (see Fig. 3).



	Car	Train	Tram	Bus
Car	x			
Train		x	x	x
Tram		x	x	x
Bus		x	x	x

Fig. 2 Nest logit (a) (two nests) relationship form and relevant covariance matrix

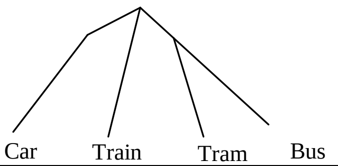
Fig. 3 highlights the NL model structure, showing that a grouping of two nests creates the nested logit. In this instance, car mode is a separate nest, whereas the alternatives of train, tram and bus are bundled together to create another single nest. The covariance matrix aligns with this structure, thus highlighting that alternatives train, tram and bus are correlated together, while is not.



	Car	Train	Tram	Bus
Car	x	x		
Train	x	x		
Tram			x	x
Bus			x	x

Fig. 3 Nest logit (b) (two nests) relationship form and relevant covariance matrix

Fig. 4 reflects a nested structure where the alternatives are assigned to the three nests, with the car positioned in a separate nest, train positioned in a separate nest, and the combined tram and bus modes grouped in another nest. The covariance matrix corresponding for this structure is shown in Fig. 4.



	Car	Train	Tram	Bus
Car	x			
Train		x		
Tram			x	x
Bus			x	x

Fig. 4 Nest logit (three nests) relationship form and relevant covariance matrix

1. Non-Physical Characteristics (Socioeconomic Characteristics)

βage18–34: Coefficient representing the effect of age 18–34, where age 18–34 is a binary variable, 1 if commuter's age is between 18 and 34, otherwise 0.

βage35–54: Coefficient representing the effect of age 35–54, where age 35–54 is a binary variable, 1 if commuter's age is between 35 and 54, otherwise 0.

β55plus: Coefficient representing the effect of age 55 plus, where age 55 plus is a binary variable, 1 if commuter's age is more than 55, otherwise 0.

βmale: Coefficient representing the effect of male, where male is a binary variable, 1 if commuter is male, otherwise 0.

βfemale: Coefficient representing the effect of female, where female is a binary variable, 1 if commuter is female, otherwise 0.

βdriver license: Coefficient representing the effect of driver's license, where driver's license is a binary variable, 1 if commuter has a driver's license, otherwise 0.

βsingle: Coefficient representing the effect of single, where single is a binary variable, 1 if commuter is single, otherwise 0.

βcouple with no children: Coefficient representing the effect of couple with no children, where couple with no children is a binary variable, 1 if commuter is part of a couple with no children, otherwise 0.

βcouple with children one parent: Coefficient representing the effect of couple with children one parent, where couple with children one parent is a binary variable, 1 if commuter is part of a couple with children, otherwise 0.

βsaudi: Coefficient representing the effect of Saudi, where Saudi is a binary variable, 1 if commuter is a Saudi Arabian, otherwise 0.

βnon-saudi: Coefficient representing the effect of non-Saudi, where non-Saudi is a binary variable, 1 if commuter is a not a Saudi Arabian, otherwise 0.

βseparate: Coefficient representing the effect of separate, where separate is a binary variable, 1 if commuter is a separated, otherwise 0.

βhouse: Coefficient representing the effect if commuter lives at house, where house is a binary variable, 1 if commuter lives in a house, otherwise 0.

βhouse/town: Coefficient representing the effect if commuter lives at house/town, where house/town is a binary variable, 1 if commuter lives at a house/town, otherwise 0.

βapartment: Coefficient representing the effect if commuter lives at apartment, where apartment is a binary variable, 1 if commuter lives in an apartment, otherwise 0.

βno-full-time work: Coefficient representing the effect if the commuter's work is full-time, where a commuter's full-time work is a binary variable, 1 if commuter's work is full-time, otherwise 0.

βno-part-time work: Coefficient representing the effect if the commuter's work is part-time, where a commuter's part-time work is a binary variable, 1 if commuter's work is part-time, otherwise 0.

βno-casual work: Coefficient representing the effect if the commuter's work is casual time, where a commuter's casual work is a binary variable, 1 if commuter's work is casual, otherwise 0.

βlow income: Coefficient representing the effect of low income, where a low income is a binary variable, 1 if commuter's weekly income is low, otherwise 0.

βmedium income: Coefficient representing the effect of medium income, where a medium income is a binary variable, 1 if commuter's weekly income is medium, otherwise 0.

βhigh income: Coefficient representing the effect of high income, where a high income is a binary variable, 1 if commuter's weekly income is high, otherwise 0.

2. Physical Characteristics (Land-Use Characteristics)

βmixed density index (MDI): Coefficient representing the effect of MDI on mode choice, where the MDI is continuous, defined in (4).

βptcoverage: Coefficient representing the effect of density of public transport stops and stations on mode choice, where

PT coverage is continuous.

βCBD area: Coefficient representing the effect if commuter's workplace is in CBD, 1 if the workplace is in the CBD area, otherwise 0.

βinner area: Coefficient representing the effect if commuter's workplace is in inner area, 1 if the workplace is in the inner area, otherwise 0.

βouter area: Coefficient representing the effect if commuter's workplace is in the outer area, 1 if the workplace is in the outer area, otherwise 0.

βdistance: Coefficient representing the effect of commuter's trip distance on mode choice, where the distance is continuous.

βdistance more than 6 km: Coefficient representing the effect of commuter's trip distance greater than 6 kilometers on mode choice, 1, if worker works at a distance greater than 6 kilometers from the location of home, otherwise 0.

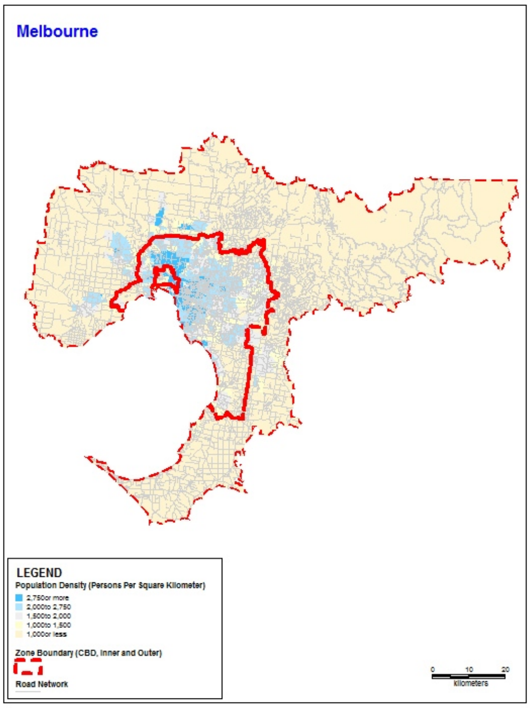
Two methods were used to explore the relationship between urban form and car ownership. The first was developed by Potoglou and Kanaroglou [27] and the second by Prevedouros and Schofer [28], which concerns the density of employment and population divided by the area in square kilometers. The first method developed by Potoglou and Kanarodlou [27] and Chu [29] is as follows:

$$MDIi = \frac{(ED_1 \times PD_1)}{(ED_1 + PD_1)} \quad (4)$$

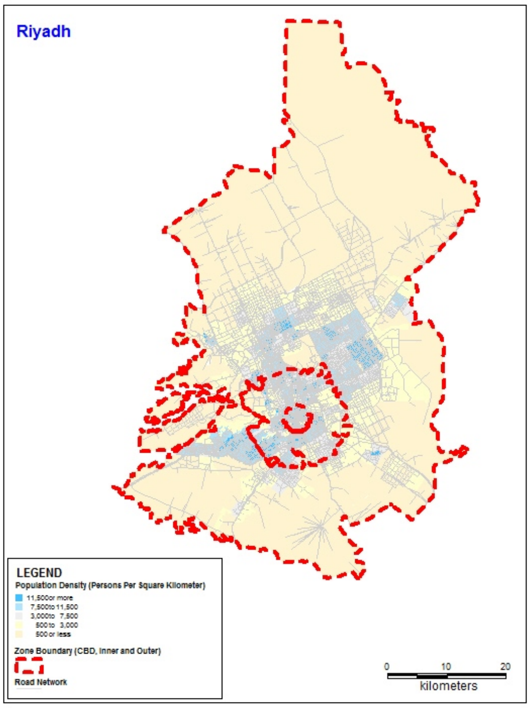
where EDi is employment density and PDi is population density.

The MDI variable explains self-containment, which provides the short distance and decreases the likelihood of household car ownership because work and home are close together. The distance variable was divided into two parts: first, the distance between the origin and destination centroid point using MapInfo software; second, the distance variable was used to measure the proximity of the home location to the work location. In Riyadh, we calculated the distance based on the origin and destination in traffic area zones (TAZs). However, the distance was not measured in suburbs in Melbourne in this way because Melbourne does not have TAZs. The mean, minimum and maximum for all categories were calculated for Riyadh and Melbourne to select compatible areas (TAZ areas for Riyadh and suburbs for Melbourne).

Riyadh and Melbourne were divided into large zones, which were categorized as the CBD, inner and outer areas (see Figs. 5 (a) and (b)). Households living in the CBD are less likely to own a car, whereas households living in the outer areas are more likely to own more than one car.



(a)



(b)

Fig. 5 (a) Melbourne's car ownership density and road network with large zones (CBD, inner and outer) (b) Riyadh's car ownership density and road network with large zones (CBD, inner and outer)

IV. Assessing the Effects of Land Use and Socioeconomic Factors on Travel Patterns: Evidence from Riyadh, Saudi Arabia, and Melbourne, Australia

The key findings below highlight the major implications of the research on land use and socioeconomic factors in Riyadh and Melbourne. These findings attempt to deepen the understanding of travel behavior and the accuracy of the relationship between land use and socioeconomic characteristics.

A. Socioeconomic Characteristics

Compared to land-use factors, socioeconomic determinants of travel pattern change were more critical, because they affected 21–58 of the differences in trip length at the individual and regional scales. Socioeconomic characteristics include age, income, household size, and car ownership.

1. Age

Table II shows that age is an important variable that affects travel mode. The highest percentage for all demographic categories was observed in the outer suburbs of Riyadh and the inner suburbs of Melbourne. For Riyadh, the highest rate of workers as a percentage of residents lived in the outer suburbs, compared to Melbourne, where the highest rate of workers lived in the inner suburbs. Most people of working age live outside of the CBD, and the cultures of Melbourne and Riyadh are similar in this way, because many Saudi nationals and Australians seek special features in their homes, such as garages and backyards. Such options are more easily obtained in the outer and inner suburban areas compared to the CBD. Additionally, this age group in the outer suburbs of Riyadh and the inner suburbs of Melbourne reflects workers with strong employment experiences.

TABLE II
Distribution of Ages Based On a Large Zone

Age	Riyadh			
	1–17	18–34	35–54	55+
CBD	4.3	4.0	3.2	0.4
Inner	13.7	11.7	9.5	1.9
Outer	19.7	17.0	12.1	2.6
Total	37.7	32.6	24.8	4.9
Number of population	4,881,578			
	Melbourne			
	1–17	18–34	35–54	55+
CBD	0.4	1.4	0.6	0.4
Inner	15.0	14.2	18.4	16.0
Outer	10.1	6.8	10.0	6.8
Total	25.4	22.4	29.0	23.2
Number of population	3,592,590			

2. Income

Household income is shown in Table III. The Riyadh income data were converted to Australian dollars based on the 2008 world currency exchange rate. Twenty percent of Riyadh households had an income of $200–$799 per week, compared to 78.86 percent in Melbourne. However, the cost of living is important, as a much smaller and cheaper lifestyle is available in Riyadh compared to Melbourne.

TABLE III
Percentage of Incomes Based On Household

Income	Riyadh	Melbourne
$1–$200	25.28	16.55
$200–$799	54.58	78.43
$800>	20.14	78.86
Number of households	1,127,244	1,283,301

3. Household Size

Household size is a critical factor in determining household mobility and car ownership. As such, Table IV reflects household size, with 58.59 percent of Riyadh households composed of four members compared to only 25.94 percent of Melbourne households. The largest categories of household sizes in Melbourne were in the inner suburbs, with two-person households (21.24 percent) and four-person households (15.19 percent). In contrast, the highest percentage of households with four members was 30.26 percent in outer suburban areas in Riyadh. This number suggests the number of workers in the same zones in Table IV.

The largest average household sizes comprised four (Riyadh) and two (Melbourne) members. This is understood in terms of culture and religious influences in Saudi, which supports the creation of families. In Melbourne, 31.64 percent of households have two members, arguably due to the influence of the high cost of living. The size of the household affects the number of children and workers who travel, which subsequently heightens the effects on travel and traffic jams.

TABLE IV
The Distribution of Household Sizes Based On a Large Zone

Zone	Riyadh (number of members)			
	1	2	3	4
CBD	1.16	1.79	2.26	6.74
Inner	4.32	4.69	5.86	21.59
Outer	9.93	5.56	5.84	30.26
Total	15.41	12.04	13.96	58.59
Number of households	1,127,243			
	Melbourne (number of members)			
	1	2	3	4
CBD	1.26	1.36	0.40	0.28
Inner	16.93	21.24	10.50	15.19
Outer	5.31	9.04	5.46	10.47
Total	23.51	31.64	16.36	25.94
Number of households	1,283,301			

4. Car Ownership

Table V reflects that, in Melbourne, the largest car ownership group was households with two private vehicles, which comprised 36.24 percent of the population, compared to the largest group in Riyadh, which are households with one private mode (52.62 percent). In Riyadh, outer suburban households with one private mode comprised 22.26 percent, compared to 24.18 percent for inner Melbourne suburbs. This suggests that the highest rate of private mode use is for households in outer suburban areas for Riyadh (39.98 percent) and inner suburban areas for Melbourne (58.44 percent). Thus, there is a positive relationship between car ownership, income, and worker concentration, reflecting the idea proposed by

Currie and Senbergs [30], who observed that low incomes correlate with high levels of car ownership in the middle and outer suburbs. The rate of car ownership was different in Riyadh (one car) compared to households in Melbourne (three cars), possibly because Saudi women do not drive. Households with multiple cars reflect the effect of household members who have different jobs in different locations. Thus, JTW occurs separately between household members.

TABLE V
DISTRIBUTION OF CAR OWNERSHIP BASED ON A LARGE ZONE

Zone	Riyadh			
	None	1-car	2-car	3+-car
CBD	2.69	7.51	1.11	0.65
Inner	4.27	22.85	5.47	3.87
Outer	11.53	22.26	7.82	9.84
Total	18.48	52.62	14.40	14.36
Number of households	1,127,243			
	Melbourne			
	None	1-car	2-car	3+-car
CBD	1.15	1.49	0.59	0.11
Inner	7.06	24.18	23.13	8.57
Outer	1.67	9.24	12.53	5.91
Total	9.88	34.91	36.24	14.59
Number of households	1,283,301			

B. Land-Use Characteristics

As a form of travel behavior, JTW is affected by urban form. Therefore, urban form is critical for improving and decreasing private mode choice for JTW. However, there are key differences between Riyadh and Melbourne, which can be understood in terms of differences in work, population density, and travel.

1. Population Density

Table VI shows population density that is measured by inhabitants per square kilometer. There was an inverse relationship between population density and travel. Lower population densities correlate with higher trip length, whereas higher densities relate to lower trip length by private mode. Comparatively, only 0.02 percent of Saudis are located in areas of less than 1000 people per square kilometer, compared to 4.8 percent of Melbourne residents. In Melbourne, there is a higher rate of people who reside in areas of less than 3000 inhabitants per square kilometer (58.5 percent) compared to Riyadh (49 percent). Finally, in Riyadh, there are a number of people who live in areas of more than 5000 people per square kilometer (17.9 percent), compared to Melbourne (9.9 percent). Therefore, the significance of population distribution is legitimate, as the distributions are quite similar.

TABLE VI
POPULATION DENSITY OF RIYADH AND MELBOURNE

Person/sq. km	Riyadh	Melbourne
0–1000	0.02	4.8
1000–3000	49	58.5
3000–5000	33	26.7
5000>	17.92	9.9

2. Population Growth

Population growth was used as a proxy of urban expansion by measuring change in population growth during 1996–2006 in Melbourne and 1996–2008 in Riyadh (see Table VII). During the study period, the population rate change was 57.51 percent in Riyadh, compared to 31.69 percent in Melbourne. However, the higher rate of change was in terms of CBD living, with 187.40 percent in Riyadh and 91.35 percent in Melbourne, which reflects the concentration of labor in Riyadh's CBD. The cheaper cost of living in the CBD, combined with the lack of PT in Riyadh, contributed to the significant growth during the study period. The second highest rate of change was 84.84 percent in the outer suburban areas for Riyadh, compared to 27.87 percent in Melbourne. These measurements show the role of new decentralization of employment, shifting from the CBD and inner suburbs to outer suburbs.

TABLE VII
POPULATION GROWTH FOR RIYADH AND MELBOURNE

Zone	Riyadh*		
	Pop. 1996	Pop. 2008	Change
CBD	202,276	581,333	1.87
Inner	1,563,865	1,835,409	0.17
Outer	1,336,103	2,469,689	0.84
Total	3,102,245	4,886,431	0.57
	Melbourne**		
	Pop. 1996	Pop. 2008	Change
CBD	39,716	75,995	0.91
Inner	2,240,960	2,380,802	0.06
Outer	960,615	1,228,298	0.27
Total	3,241,291	3,685,095	0.13

* Population between 1996 and 2008. Source: ADA (32).

** Population between 1996 and 2006. Source: Australian Bureau of Statistics [31].

3. Job/Housing Balance

Table VIII shows that many types of employment have shifted from the CBD to the outer suburbs, including organizations, manufacturing and retail, so it is important to assess the balance between employment and housing in Riyadh and Melbourne.

The percentage of workers in the CBD, inner, and outer suburbs was assessed. Riyadh's CBD area has 9.69 percent of all workers compared to 17.6 percent in Melbourne. In Riyadh, the inner and outer suburban areas were 35.8 percent and 54.17 percent respectively. In Melbourne, they were 61.31 percent and 21.09 percent respectively. In Riyadh, the percentage of workers who work in the same area where they live was 4.98 percent in the CBD compared to only 1.85 percent in Melbourne. Moreover, the percentage of workers in the inner and outer suburbs was 24.71 percent in Melbourne and 13.36 percent in Riyadh, and 13.18 percent and 21.09 percent in Melbourne. In Riyadh, the distribution of workers working outside of their home suburb was 49.95 percent in the CBD, 25.75 percent in the inner suburban areas, and 28.32 percent in the outer areas. This was compared to Melbourne, which was 89.49 percent in the CBD, 22.76 percent in the inner and 26.94 percent in the outer suburban areas.

TABLE VIII
DISTRIBUTION OF EMPLOYED RESIDENTS AND TRAVEL MODE AND PUBLIC TRANSPORT IN MELBOURNE

Zone		Workers	Car	PT	Bicycle & Walked
CBC	CBD	1.8	0.3	0.5	47.5
	Inner	12.7	5.4	4.9	17.8
	Outer	3.0	1.8	0.8	1.9
	Total	17.6	7.5	6.2	33.9
Inner	CBD	1.3	0.7	0.2	6.6
	Inner	46.9	31.3	2.1	6.0
	Outer	13.2	11.4	0.4	1.1
	Total	61.3	43.3	2.6	5.7
Outer	CBD	0.1	0.1	0.0	0.8
	Inner	5.5	4.7	0.1	0.5
	Outer	15.4	11.4	0.2	4.4
	Total	21.1	16.2	0.3	2.3
		Other Mode	Bus & Tram Stop	Train Station	
CBD	CBD	1.5	33	40	
	Inner	3.5			
	Outer	3.1			
	Total	2.3			
Inner	CBD	1.5	17	20	
	Inner	8.3			
	Outer	2.4			
	Total	6.4			
Outer	CBD	1.3	9	10	
	Inner	6.6			
	Outer	0.3			
	Total	3.2			

In Riyadh, the largest concentration of workers outside of their home suburbs was 32 percent in the CBD, compared to 29.74 percent in the Melbourne CBD. The size of the two CBD areas is comparable, yet the lowest concentration was in Riyadh (25.84 percent) in the inner suburban areas compared to Melbourne (22.16 percent). Finally, the largest concentration of workers for the outer suburban areas was 28.32 percent in Riyadh and 26.94 percent in Melbourne.

TABLE IX
DISTRIBUTION OF EMPLOYED RESIDENTS AND TRAVEL MODE AND PUBLIC TRANSPORT IN RIYADH

Zone		Workers	Car	Bus
CBD	CBD	5.0	1.82	0.03
	Inner	3.0	1.08	0.18
	Outer	2.0	0.07	0.07
	Total	10.0	2.97	0.29
Inner	CBD	3.0	12.54	0.18
	Inner	24.7	46.30	0.57
	Outer	8.2	5.37	0.17
	Total	35.9	64.21	0.91
Outer	CBD	2.0	2.96	0.07
	Inner	13.4	13.01	0.16
	Outer	38.8	14.67	0.74
	Total	54.2	30.65	0.97

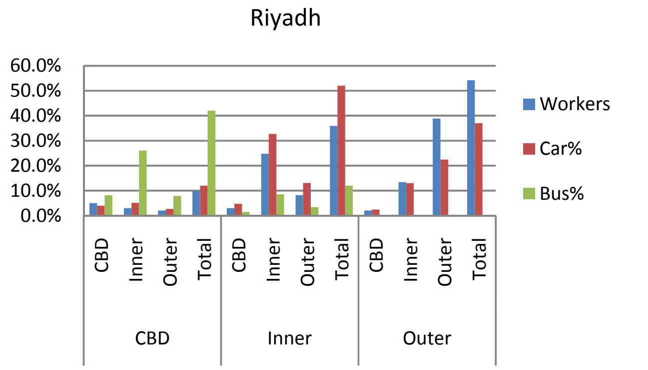


Fig. 6 Distribution of employed and travel mode in Riyadh

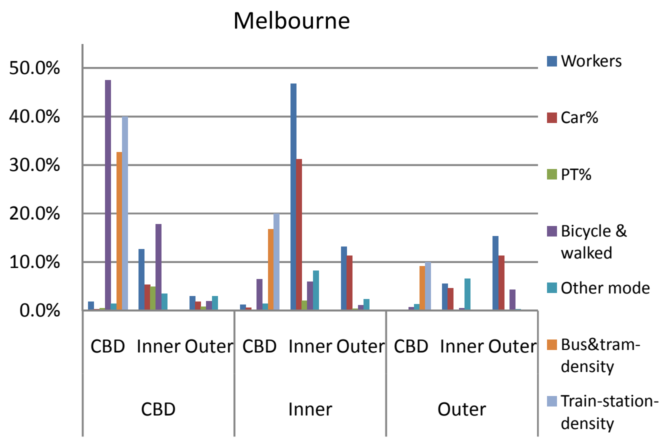


Fig. 7 Distribution of employed and travel mode in Melbourne

In Riyadh, private mode use was 91 percent, compared to 67 percent in Melbourne. In Melbourne, the percentage of workers who use private mode was 7.5 percent, compared to 6.2 percent who use PT, 33.0 percent bicycle and walking, and 2.31 percent by other modes in the CBD area. However, in Riyadh, the percentage of employees who use private mode was 2.97 percent, compared to 0.29 percent who used the bus. In the Melbourne CBD, the percentage of workers who use private mode from inner suburbs to other urban suburbs was 12.10 percent, compared to 0.60 percent by PT, 7.7 percent by bicycle and walking, and 3.9 percent by other modes. In Riyadh, the percentage of workers who use private mode was 17.91 percent compared to 0.35 percent by bus. However, in Melbourne, the percentage of workers who use private mode from outer suburbs to other urban suburbs was 4.0 percent, and 0.1 percent use PT, 1.30 percent ride or walk, and 7.90 percent use other modes compared to 15.97 percent by private mode and 0.33 percent by bus in Riyadh. In particular, Tables VIII and IX show that the percentage of workers who use private mode increases with external trips in the CBD, inner or outer suburban areas (see Figs. 6 and 7). The percentage of workers who use different modes decreases with longer trips from the CBD, and this provides an indication that the urban structure of both Melbourne and Riyadh is dispersed, affecting the distribution of employment, and finally leading to increased use of private vehicles. In Melbourne, both bus stops and train stations are more frequently distributed in the CBD area compared to the inner and outer areas due to the nature of the sprawling urban structure. This both undermines the use of PT and increases private mode and trip length. Moreover, such distribution of PT services is inefficient, and this suggests that there is a need for sub-centers to control urban sprawl by improving the public transport system to reduce private mode use.

V. Model Estimation Result

The closed from Gumbel Extreme Value distribution (GEV) parameters were estimated using the maximum log-likelihood function. Riyadh used Municipality of Riyadh 2008 data [32], and Melbourne used the VISTA07 2007 data [33] throughout this research. The BIOGEME software was applied to create a MNL Model

A. MNL Model

One of the benefits of using the MNL model is that it allows for service improvements to already functioning modes by decreasing the likelihood of other existing modes in terms of changes. Yet, the limitations of this approach are that there is an assumed equivalence between the different alternatives. The data applied in this model was based on the personal and land-use criteria of each user, per household, with the ultimate results from the MNL model with t-statistic presented in brocket, in Table X. The parameters will be identified at levels greater than 95 percent.

The full range of alternative specific constants (ASCs) were for both car and bus options (Riyadh) comparative to car, train, tram, and bus (Melbourne). Within Riyadh, the car alternative is fixed, yet the ASCs bus is negative. This suggests that the bus mode use is less expected. In Melbourne, all ASCs were negative, but the car was fixed, which suggests that there is less expectancy for use of PT modes.

In Riyadh, both Saudi and non-Saudi characteristics are identified because the majority of non-Saudi people do not utilize the car mode alternative. The positive Saudi variable with a car alternative shows that Saudi nationals can be expected to use the car mode more than a bus, due to the limitations with the bus mode. Additionally, the strong variable that has influenced the maximum likelihood to use bus mode was being male. This suggests that males will more generally use cars than females, as females travel in cars with drivers. However, such variables had no significance in Melbourne.

In both Riyadh and Melbourne, the age variables were divided into three groups: 18–34 years, 35–54 years and older than 55 years. The age variables 18–34 were negative with car mode in both cities, suggesting that this age group is less expected to use car modes compared to other age groups. The positive outcome of the 35–54 year variable with bus mode suggests that this group correlates with increased likelihood of using the bus mode. With respect to the car license variable, the variable is positive and significant. Within Riyadh, looking at the car mode, the driving license variables heighten the use of car mode more so than bus mode.

The household size variable was organized into different types of households: single, couples without children, couples with children, and single-parent households. Such variables were measured across both cities but were not statistically significant within Riyadh. The single variable in Melbourne with train mode was important as commuters used the train more than other modes, due to the concentration of single people living in the CBD and surrounding areas.

Household income variables were used, as they are important in terms of car ownership, and use. As such, the income variable was organized into low-, middle-range, and high-earner income, per week. Within Riyadh, the income variable was measured in Riyal currency and in Melbourne was measured in Australian dollars. The Riyal was then converted to Australian dollars using the parity exchange rate (PER 2012). Within both Riyadh and Melbourne, middle-range income had a positive and significant effect on bus mode, as the majority of employees come from the middle and lower income ranges. Prevedouros and Schofer [28] have suggested that high earner income households correlate with car ownership, and in Melbourne, low-income variables had a strong positive sign with bus mode. This suggests that the low-income commuters have low expectation for car ownership and use, and higher expectation for use of bus modes.

The use of MDI was conducted to assess the density of employment and residence within an area. MDI suggests that the likelihood of household ownership of cars and use decreases with mixed density. In both cities, the MDI variable had a small effect on mode choice, so it was ignored.

TABLE X
MULTINOMIAL LOGIT ESTIMATED PARAMETERS OF MODE CHOICE

Coefficients	Riyadh		Melbourne			
	Car	Bus	Car	Train	Tram	Bus
Alternative specific constant	-	-7.65(-10.2)	-	-4.53(-34.25)	-5.94(-14.80)	-5.79(-23.99)
Age 18–34	-2.44(-11.05)	-	-0.557(-8.22)	-	-	-
Age 35–54	-	2.47(11.89)	-	-	-	-
Age 55+	-	-	-	-0.247(-2.17)	-	-
Separate	-	-	0.384(5.04)	-	-	-
House	-	-	--		-	-
House/town	1.17(4.50)	-	0.36(4.4)	-	-	-
Apartment	-	-	-		-	-
No. of full-time work	-	-	-	-	-	-
No. of casual work	-	-	-		-	-
No. of part-time work	-	-	-		-0.559(-2.32)	0.655(2.96)
Car driver's license	3.15(31.56)	-	-	-	-	-
Household size	-	-	-	-	-	-
Single	-	-	-	0.616(4.57)	-	-
Couple with no children	-	-	-	-	-0.42(-2.46)	-
Couple with children one parent	-	-	-	-	-	0.771(2.35)
Households members (persons)	-	-	-	-	-	-
Saudi	2.47(14.23)	-	-	-	-	-
Non-Saudi (N Saudi)	-	-	-		-	-
Male	-	5.04(7.09)	-	-	-	-
Female	-	-	-	-	-	-
Low income	-	-	-	-		1.01(2.44)
Medium income	-	0.278(1.93)	-	-	-	-
High income	0.51(3.32)	-	-	-	-	
Land-use factors						
Mixed Density Index (MDI)	-	-	-	-	-	-
PT coverage	-	-	-0.02(-5.88)	-	0.036(6.06)	-
CBD zone	-	-	-	0.903(1.9)	2.08(3.53)	-
Inner zone	0.701(4.24)	-	-0.58(-2.41)	0.685(2.75)	2.03(4.39)	-
Outer zone	-	-0.558(-4.61)	-	-	-	-0.752(-1.98)
Distance	-	-	-	0.024(13.18)	-0.114(-8.48)	-
Distance more than 6 km	-	0.346(3.92)	-1.17(-11.22)	-	-	-
No. of observations	12965		9579			
No. of parameters	12		24			
Null-log likelihood	-8986.653		-13279.314			
Final-log likelihood	-1815.451		-4008.873			
Rho-squared	0.798		0.698			
Adjusted Rho-squared bar	0.797		0.696			

Both cities were divided into three large zones, which included the CBD, inner suburbs, and outer suburbs. The inner suburbs are those with land-use zoning around the CBD, whereas the outer suburbs are far from the CBD and in fact closer to the countryside. Such an index was used to explore the significance of residents' proximity to facilities and activities. Within Riyadh, such variables do not explain the effect on people's decisions about travel modes because of the significance of car dependence. Within Melbourne, the inner suburbs had a negative sign with car mode, reflecting that there are well-developed PT modes throughout this range of suburbs. Both the CBD and inner suburbs have a strong relationship with tram mode, and this suggests that people living in the CBD or close to it use tram mode more than other modes. Finally, the train mode has a negative relationship with the outer suburb areas, and there is less expectation to use the train in the outer suburbs because of the effect of urban structure and urban sprawl on mode choice.

B. NL Model

The limitations of the MNL model are based on the assumption of equal competition between all alternatives. To reduce the effect of this limitation, the IID was generalized to create a more comprehensive and fluid model. These were created using the NL model, which accommodates a variety of differences in the extent of similarities across different structures of nests and access model alternatives. To decrease the effect of such relationships, diverse NL structures (as shown in Figs. 2–4) were approximated using the same data. The significant variables across all three nested models were measured at significance levels of more than 95 percent.

Table XI shows the results of the three NL models, and suggests that all three nesting structures are significant. The value of PT coverage variable in two nests (b) is higher than the MNL model. Across all nests the value is lower. The low-income variable in the tram mode value is higher than the MNL model, and again has a lower value across all nest structures.

TABLE XI
NESTED LOGIT ESTIMATED PARAMETERS OF MODE CHOICE

Coefficients	2 Nest NL mode				Melbourne 2 Nest NL model				3 Nest NL model			
	Car	Train	Tram	Bus	Car	Train	Tram	Bus	Car	Train	Tram	Bus
Alternative specific constant	-	-5.70 (-29.29)	-6.12 (-12.13)	-4.54 (-13.23)	-	-3.83 (-9.66)	-5.59 (-11.41)	-4.19 (-18.6)	-	-3.94 (-7.23)	-5.38 (-8.48)	-3.91 (-9.00)
Age 18–34	-0.549 (-8.64)	-	-	-	-0.565 (-5.3)	-0.244 (-2.03)	-	-	-0.35 (4.06)	-	0.244 (2.06)	-
Age 35–54	-	-	-	-	-	-	-	-	-	-	-	-
Age 55+	-	-0.224 (-2.01)	-	-	-	-	-	-	-	-0.166 (-2.07)	-	-
Separate	0.223 (3.40)	-	-	-	0251 (4.38)		-	-	0.164 (3.16)	-	-	-
House	-	-	-	-	-	-	-	-	-	-	-	-
House/town	-	-	-	-	0.231 (3.86)	-	-	-	-	-	-	-
Apartment	-	-	-	-	-	-	-	-	-	-	-	-
No. of full-time work	-	-	-	-	-	-	-	-	-	-	-	-
No. of casual work	-	-	-	-	-	-	-	-	-	-	-	-
No. of part-time work	-	-	-0.495 (-2.41)	0.578 (3.09)	-	-	-0.497 (-2.41)	0.628 (3.21)	-	-		0.444 (2.74)
Car driver's license	-	-	-	-	-	-	-	-	-	-	-	-
Household size	-	-	-	-	-	-	-	-	-	-	-	-
Single	-	0.671 (5.03)	-	-	-	0466 (4.44)	-	-	-	0.452 (4.11)	-	-
Couple with no children	-	-	-0.398 (-2.69)		-	-	-0.319 (-2.14)	-	-	-	-0.358 (-2.66)	-
Couple with children one parent	-	-	-	0.629 (2.29)	-	-	-	0.682 (2.4)	-	-	-	0.587 (2.37)
Households members (persons)	-	-	-	-	-	-	-	-	-	-	-	-
Saudi	-	-	-	-	-	-	-	-	-	-	-	-
Non-Saudi (NSaudi)	-	-	-	-	-	-	-	-		-	-	-
Male	-	-	-	-	-	-	-	-	-	-	-	-
Female	-	-	-	-	-	-	-	-	-	-	-	-
Low income	-	-	-	0.780 (2.27)	-	-	-	0.809 (2.35)	-	-	-	0.695 (2.22)
Medium income	-	-	-	-	-	-	-	-	-	-	-	-
High income	-	-	-	-	-	-	-	-	-	-	-	-
MDI	-	-	-	-	-	-	-	-	-	-	-	-
PT coverage	-0.016 (-4.46)	-	0.0287 (4.86)	-	-	-	0.0458 (10.11)	-	-0.016 (-3.27)	-	0.0282 (5.55)	-
CBD zone	-	2.74 (5.02)	3.12 (5.97)	-	-	1.77 (7.62)	2.54 (4.85)	-	-	1.7 (6.37)	-1.69 (-4.06)	-
Inner zone	-	2.51 (14.23)	3.46 (8.74)	-	-	1.89 (4.00)	3.03 (7.20)	-	-	1.7 (6.74)	2.92 (6.85)	-
Outer zone	-1.72 (-9.69)	-	-	-2.45 (-7.13)	-1.28 (-7.28)	-	-	-2.32(-6.02)	-1.16 (-5.91)	-	-	-1.69 (-4.09)
Distance	-	0.0269 (13.81)	-0.1 (-7.86)	-	-	0.0181 (8.38)	-0.103 (-8.4)	-	-	0.0178 (6.3)	-0.0854 (-6.56)	-
Distance more than 6km	-0.96 (-9.19)	-	-	-	-0.739 (-7.83)	-	-	-	-0.75 (-6.37)	-	-	
µu	1.28(10.00)				1.56(9.19)				1.48(7.45)			
No. of observations	9579				9579				9579			
No. of parameters	24				24				24			
Null-log likelihood	-13279.314				-13279.314				-13279.314			
Final-log likelihood	-3961.362				-3955.915				-3961.433			
Rho-squared	0.702				0.702				0.702			
Adjusted Rho-squared bar	0.700				0.700				0.700			

VI. Conclusion

The results of this research have been gathered from a complex comparative study of mode choice. The two case studies focused on Riyadh, Saudi Arabia, and Melbourne, Australia, due to the capacity for identifying similarities and differences in urban form, as well as travel behaviors across land use, transport, and socioeconomic criteria. The dataset utilized to create such analysis for Melbourne was based on the Census Bureau and Transport Survey Organization [33], whereas for Riyadh, the Municipality of Riyadh dataset was used for the analysis [32].

It was found that distance, and a distance greater than six kilometers from workplace to home, affects household decisions to use cars or PT. Within Melbourne, the CBD and inner suburb area variables were identified as having a positive effect on decisions made by commuters to use PT instead of their cars. Within both Riyadh and Melbourne, the decreasing distance between work and home locations also corresponds with decreased capacity of households to use PT in outer suburb areas.

High-income levels have a positive effect on decisions made by commuters to use the car mode. The middle-range income variable has a strong effect on commuter decisions to use bus mode. Within Melbourne, the low-income variable correlates positively with commuter decisions to use the bus, yet this variable was not significance with high and medium income variables.

In both Melbourne and Riyadh, comparable to other developed cities with strong car dependence and a decentralized structure, there are problems with low-density suburban areas creating the largest percentage of car trips. This has been identified by a range of authors, including Chu [29], Potoglou and Kanaroglou [27], and Li, Walker, Srinivasan, and Anderson [15]. These studies have found that as income and the number of licensed driver's variables grows, the preference for households to own cars also increases.

In Melbourne, the CBD variable is the strongest indicator of non-ownership of cars, due to the balance among land-use developments. Urban sprawl is the single most important issue that shapes commuters' decisions about car mode use comparative to PT modes. Non-car modes and mass transit use therefore need greater support and development to increase the utilization [15].

Unsurprisingly, the Melbourne NL models perform better than MNL, as observed in Fig. 4, which shows that the three assumed nesting structures have two nests (car, and PT modes of train, tram, and bus). This arrangement of nesting structures performs the best, yet alternative nesting structures were significant, pointing to the potential for a variety of options to belong to more than one nest.

The study has a range of outcomes that could be useful for recommendations and practical application in both Melbourne and Riyadh, as representative of cities within developed and developing countries. Both cities have moved from being organized as monocentric areas with high population and employment densities, to urban sprawl-oriented cities with low population densities and scattered employment. It is recommended that a polycentric structure (compact form) that draws from a strong PT system and high employment and population density would be beneficial. This could be achieved using greater levels of sustainable urban planning, such as self-containment. This potentially leads to decreased car dependence, while simultaneously heightened sustainable transport alternatives, such as walking and cycling. The effect of metropolitan urban form scale characteristics is stronger than neighborhood scale, self-environmental characteristics on traveling by car during a weekday [33].

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