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ANALYZING THE IMPACT OF DEMOGRAPHIC FACTORS AND URBAN DENSITY ON MODE CHOICE IN THE GREATER BRISBANE AREA

Summary. Understanding the influence of demographic factors and urban density on transportation mode choice is crucial for promoting sustainable mobility in urban areas. This study examines these influences in the Greater Brisbane Area using data from the Queensland Household Travel Survey (QHTS) collected between 2018 and 2023. We apply binomial logistic regression models to analyze how age, gender, employment status, presence of children, and urban density at origin and destination locations affect the likelihood of choosing transportation modes, including car, walking, bicycling, public transport, and Mobility as a Service (MaaS). The results indicate that higher urban density is significantly associated with reduced car usage and increased use of sustainable modes such as walking, public transport, and bicycling. Older individuals are more likely to use cars and less likely to choose active modes, while males have a higher propensity to bicycle compared to females. Employment status also influences mode choice, with employed individuals more likely to drive or use public transport and less likely to walk. Although the number of MaaS users in the dataset is limited, preliminary findings suggest potential higher adoption in high-density areas and among older individuals. These insights provide empirical evidence from Brisbane and have practical implications for urban planners and policymakers. Enhancing infrastructure for sustainable transportation in densely populated areas and considering demographic factors can promote sustainable mobility patterns. Future research should include additional variables such as transportation supply factors and use longitudinal data to explore causal relationships. Investigating the barriers to MaaS adoption in Brisbane would also be valuable for shaping future urban mobility strategies.

1. INTRODUCTION

Urban areas worldwide are continually striving to develop transportation systems that are both efficient and sustainable. The relationship between urban density and transportation mode choice is well-established in transportation research, with numerous studies demonstrating that higher urban density is associated with increased use of sustainable transportation modes such as public transport, walking, and cycling [1, 2]. However, there is a lack of recent, localized research examining this relationship within the context of the Greater Brisbane Area, particularly studies that also consider the influence of demographic factors.

Previous studies have often focused on broader contexts or different geographic regions. For example, Cervero and Kockelman (1997) explored the impact of urban form on travel behavior in U.S. cities [3], while Ewing and Cervero (2010) conducted a meta-analysis on built environment and travel

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patterns [4]. In Australia, studies like those by Burke and Brown (2007) have examined the relationship between urban form and travel in specific cities but may not reflect current trends or include comprehensive demographic analyses [5]. Additionally, while demographic factors such as age, gender, employment status, and household composition are known to influence mode choice [6, 7], there is insufficient research on how these factors interact with urban density in shaping transportation behaviors in Brisbane.

This study aims to address these gaps by analyzing how demographic characteristics and urban density levels at origin and destination locations influence transportation mode choice in the Greater Brisbane Area. Utilizing data from the QHTS collected between 2018 and 2023, we apply binomial logistic regression models to assess the relationships between these variables and the use of different transportation modes, including car, walking, bicycling, public transport, and MaaS.

By focusing on the specific context of Brisbane and incorporating both demographic factors and urban density into the analysis, this research provides updated empirical evidence that complements and extends existing literature. While the general trends relating urban density to mode choice are known, localized studies are essential for capturing regional variations and informing area-specific policies. The findings of this study can inform urban planners and policymakers in Brisbane by providing insights into current transportation behaviors and identifying factors that may encourage the adoption of sustainable transportation options.

Furthermore, the inclusion of MaaS as an emerging transportation option adds a contemporary dimension to the study. Although MaaS is still developing in Brisbane, examining its current adoption patterns can offer valuable information for future transportation planning and the potential integration of MaaS into the broader transport network.

In summary, this study contributes to the existing body of knowledge by providing a localized analysis of the influences of demographic factors and urban density on transportation mode choice in the Greater Brisbane Area. The insights gained can assist in tailoring transportation policies and infrastructure development to the specific needs and characteristics of Brisbane's urban environment, ultimately supporting efforts toward sustainable urban mobility.

2. LITERATURE REVIEW

Understanding the factors influencing transportation mode choice is crucial for developing effective transportation policies and promoting sustainable mobility. The literature on transportation mode choice has expanded significantly, incorporating various methodological approaches and examining a wide range of influencing factors, including demographic characteristics, urban density, and emerging mobility services like MaaS.

Discrete choice models, particularly binomial and multinomial logistic regression models, have been foundational in transportation research for analyzing individuals' mode choice behavior. McFadden's (1974) development of random utility theory provided the theoretical underpinning for these models, allowing researchers to model the probability of an individual choosing a particular transportation mode based on the utility derived from that choice [8]. These models have been instrumental in identifying the determinants of mode choice and predicting changes in response to policy interventions.

Early applications focused on basic factors such as travel time and cost [9]. Over time, researchers have incorporated more complex variables, including socio-demographic characteristics, land use patterns, and attitudinal factors [10, 11]. For example, Ben-Akiva and Lerman (1985) included variables like income and car ownership in their mode choice models [10]. While these models are powerful, they have limitations, such as the inability to fully capture complex interactions between variables and unobserved heterogeneity among individuals [12, 13].

Demographic characteristics significantly influence transportation mode choice. Age, gender, employment status, and household composition affect individuals' preferences and constraints. Scheiner and Holz-Rau (2013) found that age and life cycle stages impact mobility patterns, with younger individuals and those without children more likely to use public transport or active modes [14].

In Australia, Delbosc and Currie (2014) highlighted a decline in driver's license acquisition among young adults, indicating shifting preferences toward alternative modes [15].

Gender differences are also notable. Women may have different travel patterns due to safety concerns, caregiving responsibilities, and employment patterns [16]. Studies have shown that men are more likely to cycle, whereas women may prefer public transport or walking [17]. Employment status influences mode choice through income levels and commuting needs. Employed individuals may rely more on private vehicles due to time constraints, while unemployed individuals might prefer cost-effective modes like walking or public transport [18].

The relationship between urban density and transportation mode choice is well-established. Higher urban densities are associated with reduced car ownership and usage, and increased use of public transport and active modes [1]. Cervero and Kockelman (1997) introduced the "3Ds" – density, diversity, and design – as key land-use characteristics influencing travel behavior [3]. Ewing and Cervero (2010) expanded this to the "5Ds," adding destination accessibility and distance to transit [19].

In the Australian context, studies have confirmed similar patterns. Burke and Brown (2007) found that residents in higher-density Brisbane neighborhoods were more likely to walk or use public transport [5]. This suggests that urban form significantly impacts mode choice, and densification strategies could promote sustainable transportation behaviors [20].

MaaS represents a shift toward integrated, user-centric mobility solutions, combining various transport services into a single platform accessible on demand [21]. While MaaS is still emerging in Australia, interest and pilot programs are growing. Hensher (2017) discussed the potential of MaaS in the Australian context, emphasizing its ability to reduce private car use and enhance public transport efficiency [22]. Ho et al. (2018) investigated consumer preferences for MaaS plans in Sydney, finding that flexibility and cost savings are significant factors influencing adoption [23].

Urban density plays a role in the viability of MaaS. Dense urban areas may facilitate MaaS adoption due to higher demand, shorter distances, and better infrastructure [24]. However, challenges remain in integrating services and ensuring accessibility for all user groups. In Brisbane, research on MaaS adoption is limited, indicating a need for localized studies to understand its potential impact on mode choice.

While considerable research exists on the influence of demographic factors and urban density on mode choice, there is a lack of recent, localized studies focusing on the Greater Brisbane Area. Moreover, the integration of MaaS into mode choice models is still limited, especially in the Australian context. This study addresses these gaps by providing an updated analysis that incorporates demographic variables, urban density, and the emerging role of MaaS in Brisbane.

By utilizing recent data from the QHTS and applying binomial logistic regression models, this research offers new insights into the factors shaping transportation mode choice in Brisbane. The findings can inform policymakers and urban planners in developing targeted strategies to promote sustainable transportation options and effectively integrate MaaS into the urban mobility landscape.

3. METHODOLOGY

This study utilizes data from the QHTS and population density data from the Australian Bureau of Statistics to examine the influence of demographic factors and urban density on transportation mode choice in the Greater Brisbane Area. The methodology involves data preparation, descriptive analysis, and the application of binomial logistic regression models to analyze the relationships between the variables of interest.

The QHTS is a comprehensive survey that continuously collected data on individual travel behaviors in Queensland, Australia. Conducted by the Queensland Government's Department of Transport and Main Roads, the QHTS focuses on the everyday mobility of individuals by assessing the daily travel diaries of private households. The survey gathers detailed information on various aspects of travel behavior, including trip timings, modes of transport, trip purposes, frequencies, and distances, as well as demographic details of travelers such as age, gender, employment status, and household characteristics. Data collection methods include paper-based questionnaires, web-based questionnaires, and telephone interviews, ensuring a broad and representative sample.

For this study, the QHTS dataset was filtered to include only trips within the Greater Brisbane Area, resulting in a final dataset comprising 101,109 trip records. This focus allows for a detailed examination of transportation behaviors in a specific urban context. The dataset provides a valuable foundation for analyzing how demographic factors and urban density influence mode choice.

Population density data were obtained from the Australian Bureau of Statistics' Statistical Area Level 1 (SA1) data for the year corresponding to the trip. SA1 units are the smallest geographical regions for which the Australian Bureau of Statistics collects demographic data, providing detailed and accurate population statistics. The population density figures represent the number of people per square kilometer for each SA1 unit, based on the comprehensive census conducted in the relevant year. This data provides a reliable basis for analyzing the impact of urban density on transportation mode choice. The population density data were merged with the QHTS dataset based on SA1 codes, allowing for the assignment of density values to each trip's origin and destination.

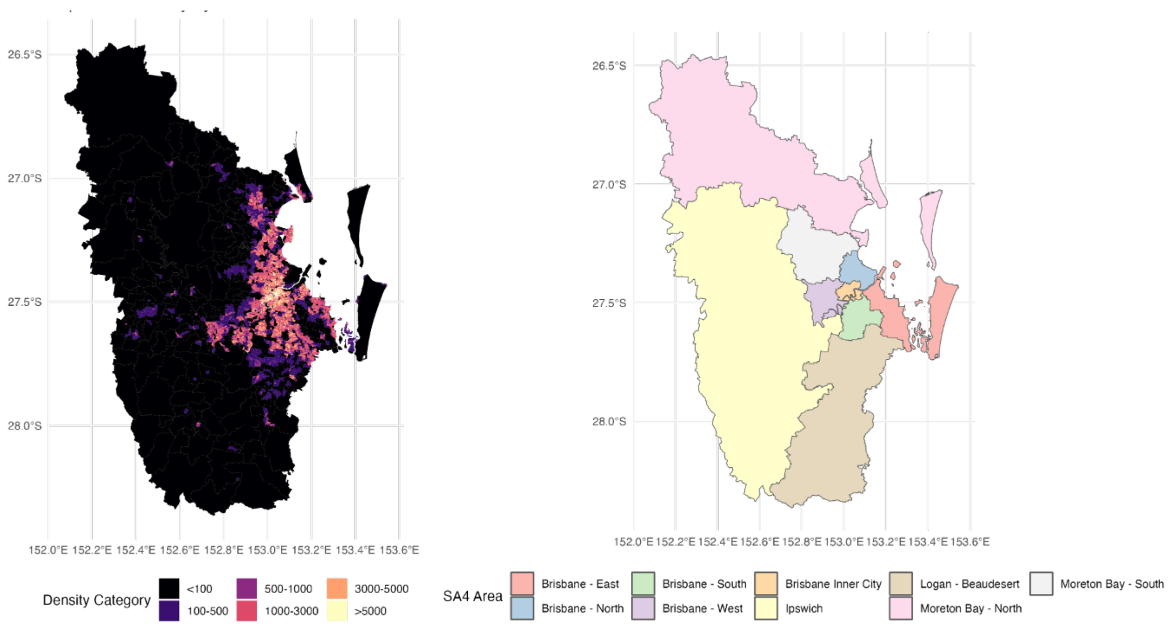

Fig. 1. Population Density by SA1 (left) and Brisbane city by SA4 (right)

An initial descriptive analysis was conducted to examine the distribution of key variables. This included calculating frequencies and percentages of different transportation modes (car, walking, bicycling, MaaS, public transport) to understand their prevalence in the dataset. A detailed mode analysis assessed the relative usage and contribution of each transportation mode to overall travel behavior. Additionally, trip distances were analyzed by examining the distribution and range of distances traveled using different modes of transportation. This analysis provided insights into how trip length influences mode choice and the extent of travel behaviors present in the dataset.

To investigate the influence of demographic variables and urban density on transportation mode choice, a series of binomial logistic regression models were developed. Separate models were constructed for each transportation mode (car, walking, bicycling, public transport, and MaaS) to estimate the probability of an individual choosing that mode based on demographic factors and urban density.

The dependent variables in the models are binary indicators of whether a particular mode was used for a trip. For each transportation mode *m*, the probability $P_i(m)$ that individual *i* chooses mode *m* is modeled using the logistic regression equation:

$$logit(P_i(m)) = \beta_0^{(m)}\beta_1^{(m)} \cdot Age_i + \beta_2^{(m)}Gender_i + \beta_3^{(m)}Employment_i + \beta_4^{(m)} \cdot Children_i + \beta_5^{(m)} \cdot Density\ Quartile_i$$

In this equation, logit($P_i(m)$) is the natural logarithm of the odds of choosing mode m, $\beta_0^{(m)}$ is the intercept, and $\beta_k^{(m)}$ are the coefficients for the independent variables:

- Age (Age_i): Continuous variable representing the respondent's age in years.
- Gender ($Gender_i$): Binary variable (1 for male, 0 for female).
- Employment Status ($Employment_i$): Binary variable (1 if employed, 0 if not employed).
- Presence of Children ($Children_i$): Binary variable (1 if there are children in the household, 0 otherwise).
- Urban Density Quartiles (Density $Quartile_i$): Categorical variable representing population density quartiles at both origin and destination SA1 areas (Quartile 1: lowest density to Quartile 4: highest density).

The logistic regression models were executed using a binomial distribution with a logit link function. The coefficients derived from the models were interpreted to understand the odds of choosing a particular mode of transport in relation to the independent variables. Positive coefficients indicate a higher likelihood of choosing a mode of transportation as the value of the independent variable increases, suggesting a strong relationship between that variable and transportation mode choice.

Urban density was a key focus in the analysis. The population density data were segmented into quartiles, dividing it into four distinct categories. This categorization allowed for a detailed examination of the impact of varying levels of population density on transportation choice behavior. Logistic regression models incorporated these density quartiles to assess how the density of the area from which a trip originates or to which it is destined influences the choice of transport mode.

While the study primarily focused on the key demographic variables and urban density, potential methodological considerations were acknowledged. Due to data constraints, it was not feasible to control for self-selection effects fully; therefore, findings related to urban density and mode choice are interpreted with caution regarding causality.

All statistical analyses were conducted using R software. The stargazer package was utilized to format regression outputs into a reader-friendly format, including labeling variables and annotating statistical significance levels. The results of the regression analyses provided insights into how different demographic factors and urban density levels relate to the preference for specific transport modes in the Greater Brisbane Area.

4. RESULTS

4.1. Trips analysis

In the following chapter, the results of the QHTS analysis are presented. The first table (see Fig. 2) displays the frequency of various transportation options. According to the data, car usage has the highest frequency with 85,954 cases, followed by walking with 9,571 cases, public transport with 3,789 cases, bicycling with 1,285 cases, and MaaS with 510 cases.

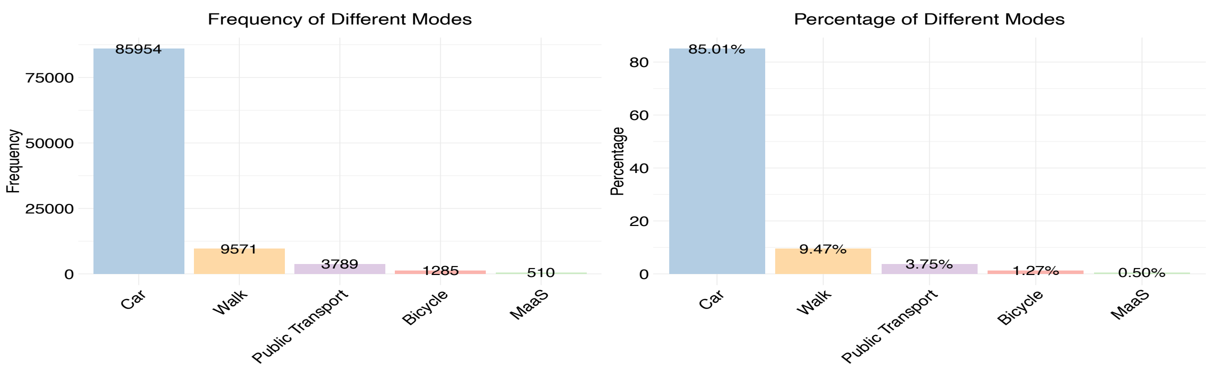

Fig. 2. Frequency and Percentage

The next step was to analyze the different transport purposes, as shown in Fig. 3.

Car: The most common travel purposes are "Pickup/Dropoff Someone" (19.3%) and "Shopping" (19.2%), followed closely by "Direct Work Commute" (18.4%). Other notable purposes include "Education" (10.3%) and "Personal Business" (7.75%). Smaller percentages are observed for "Recreation" (7.57%), "Social" (3.79%), "Work Related" (4.61%), and "Pickup/Deliver Something" (1.48%), with "Childcare or Kindergarten" being the least common (0.095%).

Walk: "Recreation" is the leading purpose for walking (38.6%). Other significant purposes include "Education" (16.7%) and "Direct Work Commute" (4.89%). Additional purposes like "Personal Business" (3.24%) and "Accompany Someone" (7.31%) account for smaller shares of walking trips.

MaaS: "Shopping" is the top reason for using MaaS (24.9%), followed by "Direct Work Commute" (16.5%) and "Work Related" (15.3%). Other purposes, such as "Recreation" (13.3%) and "Personal Business" (12.7%), are moderately common.

Bicycle: The leading purposes for cycling are "Education" (28%) and "Recreation" (26.5%). Other purposes include "Direct Work Commute" (21.9%) and "Shopping" (7.32%).

Public Transport: "Direct Work Commute" is the predominant purpose (43.1%), with "Education" also significant (27.4%). "Shopping" (10.1%) and "Recreation" (3.93%) are less common purposes for using public transport.

These results demonstrate that the chosen mode of transportation influences the intended travel purpose. For example, walking is more often used for recreational activities, while cars are frequently used for purposes such as picking up or dropping off someone and personal business. MaaS is mainly used for commuting, bicycles are often used for both education and work, and public transport is predominantly used for work and school.

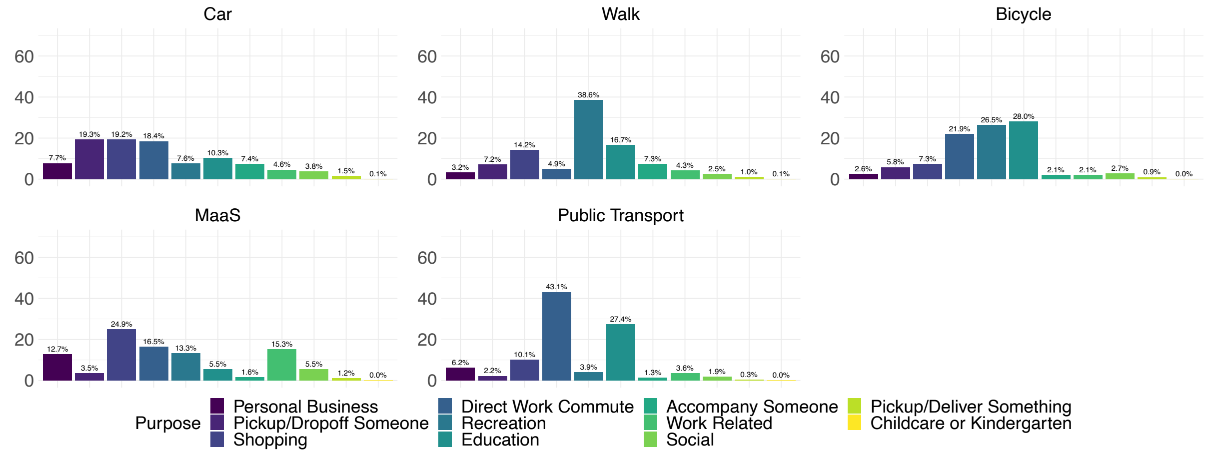

Fig. 3. Distribution of transport purposes

Fig. 4 shows statistical measures of journey lengths for various transportation modes, including car, walking, bicycle, MaaS, and public transportation. The data reveal significant differences in trip distances depending on the mode of transportation. Walking journeys are the shortest, with a median distance of 670 meters and a mean of 864 meters, showing the least data dispersion (SD = 811). In contrast, public transportation and car trips are the longest, with median distances of 11,030 meters and 5,260 meters, respectively, and mean distances of 12,860 and 7,790 meters. MaaS and bicycle journeys have median distances of 5,505 meters and 2,530 meters, and mean distances of 7,040 and 3,960 meters, respectively. Notably, all modes, except for walking, display high variability in trip distances, as evidenced by the larger standard deviations (SD for car = 7,016; bicycle = 4,345; MaaS = 6,195; public transport = 7,871), indicating significant dispersion in individual trip lengths.

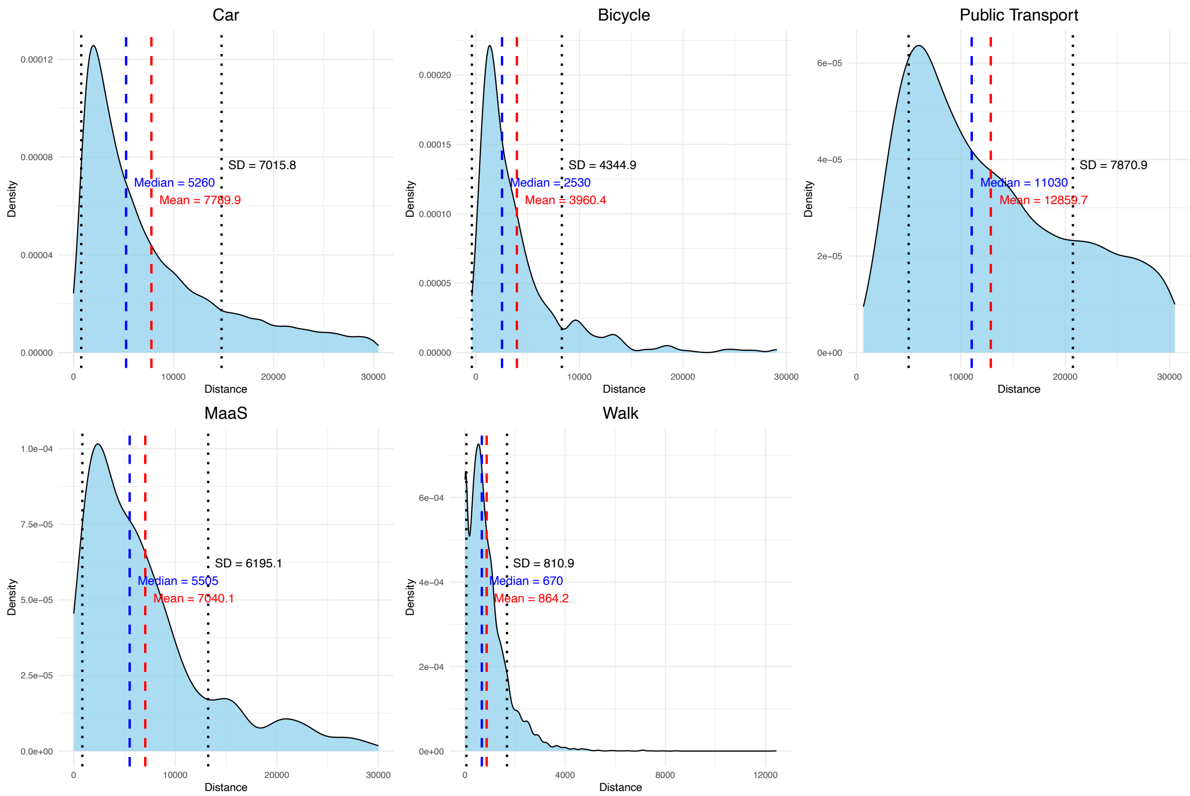

Fig. 4. Distance density of transport modes

4.2. Bi-variate binomial regression analysis

This section examines the relationship between various demographic and socio-economic factors and the choice of transportation mode. The analysis is based on bivariate binomial regression, and the results are detailed in Table 1.

Age and Transportation Mode: Age is a significant factor in transportation mode selection. Each additional year slightly increases the log-odds of using a car (0.005***) while decreasing the likelihood of using bicycles (-0.009***) and public transport (-0.009***). For instance, older individuals have higher odds of choosing cars and MaaS, with the coefficient for MaaS usage also showing a significant positive trend (0.011***).

Gender Differences: Gender differences also play a role. Females are more likely to choose cars (0.080***) and walking (0.045*) over bicycles compared to males, who show a higher likelihood of cycling (-1.099*** for females in bicycle use). The regression indicates that females are less likely to cycle and show a marginal trend toward increased car use.

Impact of Employment Status: Employment status influences transportation choice significantly. Employed individuals are more likely to walk (-0.502***) and less likely to use a car (0.245***), while the likelihood of choosing MaaS is notably higher (0.323***). Unemployed individuals, on the other hand, show different tendencies in transportation choice.

Effect of Having Children: The presence of children in a household affects certain transportation choices. For example, the likelihood of using public transport decreases for those with children (-0.750**), suggesting a preference for private modes. However, there is no significant correlation between having children and the use of MaaS. Table 1 below provides a comprehensive view of these findings.

Table 1

Bi-variate binomial regression analysis of all modes

	Dependent variable:				
	Car	Walk	Bicycle	Public Transport	MaaS
	(1)	(2)	(3)	(4)	(5)
Age	0.005***	-0.001*	-0.009***	-0.009***	0.011***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Gender (Female)	0.080***	0.045*	-1.099***	-0.233**	0.005
	(0.018)	(0.022)	(0.062)	(0.089)	(0.033)
Employment (Employed)	0.245***	-0.502***	-0.036	0.060	0.323***
	(0.018)	(0.022)	(0.056)	(0.089)	(0.034)
Child (No Child)	-0.073	0.156	0.338	-0.750**	-0.047
	(0.074)	(0.094)	(0.270)	(0.255)	(0.133)
Observations	101,109	101,109	101,109	101,109	18,827

Note: *p<0.5 **p<0.01 ***p<0.001

Numbers in parentheses are standard errors.

4.3. Binomial regression analysis

Our analysis used binomial regression to examine the relationship between population density and the choice of transport modes, including car, walking, bicycle, public transport, and MaaS. Population density was divided into quartiles, and both destination-based (Table 2) and origin-based (Table 3) densities were analyzed.

In areas of increasing population density, the analysis revealed a notable decline in car usage. This trend, significant across all density quartiles, was especially pronounced in the highest-density areas. The negative coefficients in the regression model indicate that as population density rises, factors like traffic congestion, limited parking, and improved accessibility to alternative transport options contribute to a reduced preference for car usage. This aligns with urban planning theories that advocate for reduced car dependency in denser urban areas.

Conversely, walking emerged as a significantly favored mode in higher-density areas. Positive coefficients across all quartiles, particularly in denser regions, suggest that walking becomes more preferable as population density increases. This trend may result from the pedestrian-friendly design of densely populated areas, where amenities and services are often within walking distance, promoting a more active, pedestrian-oriented lifestyle.

The relationship between bicycle usage and population density was more complex. Positive associations were observed in some density quartiles but were not consistently significant. This suggests that bicycle usage may depend on factors beyond population density, such as the availability of cycling infrastructure, cultural attitudes towards cycling, and geographic features, which vary across urban and suburban areas.

Public transport usage showed a very strong positive correlation with higher density quartiles. This trend indicates that public transport is increasingly relied upon as a primary mode in densely populated areas, likely due to the robust public transport networks typically found there. This finding supports urban development strategies that prioritize extensive and efficient public transport systems in dense areas. For MaaS, the analysis indicated a growing inclination in higher density areas, although significance levels varied across different quartiles. This trend suggests a rising interest in flexible and on-demand transport solutions in urban settings, reflecting evolving urban mobility needs. The varied significance might point to the nascent stage of MaaS in many regions or the different degrees of its integration into the existing transport ecosystem.

These findings suggest that people in densely populated areas are more inclined towards environmentally friendly transportation methods such as walking, bicycling, and public transport, while car reliance decreases. Notably, the MaaS model shows an increased likelihood of adoption in the highest density quartile, suggesting a potential preference for MaaS solutions in highly populated areas.

Table 2
Binomial regression analysis of population density (based on SA1 destinations)

	Dependent variable:				
	Car	Walk	Bicycle	Public Transport	MaaS
	(1)	(2)	(3)	(4)	(5)
Density Quartile 1	-0.596***	0.655***	0.421***	0.463***	-0.098
	(0.028)	(0.035)	(0.084)	(0.057)	(0.140)
Density Quartile 2	-0.719***	0.729***	0.265**	0.738***	0.269*
	(0.028)	(0.035)	(0.086)	(0.054)	(0.129)
Density Quartile 3	-0.929***	0.873***	0.452***	1.025***	0.443***
	(0.027)	(0.034)	(0.083)	(0.052)	(0.124)
Constant	2.336***	-2.864***	-4.652***	-3.865***	-5.461***
	(0.022)	(0.028)	(0.065)	(0.044)	(0.097)
Observations	101,109	101,109	101,109	101,109	101,109
Log Likelihood	-42,062.470	-31,272.180	-6,867.858	-15,927.320	-3,194.663
Akaike Inf. Crit.	84,132.940	62,552.350	13,743.720	31,862.640	6,397.325
Note:					*p<0.5**p<0.01***p<0.001

Numbers in parentheses are standard errors.

5. DISCUSSION

5.1. Trips Analysis

The extensive analysis of the QHTS data reveals critical insights into the dynamics of urban mobility choices. The predominant use of cars, with 85,954 instances, underscores a strong reliance on personal vehicles within urban settings. This is followed by walking (9,571 cases), suggesting a significant portion of the population opts for this mode for short-distance travel, indicative of a potential shift towards more sustainable and health-conscious travel behaviors.

Public transport and bicycling, while less frequent, highlight key aspects of urban mobility. The 3,789 cases of public transport usage reflect its role in urban commutes, whereas the 1,285 cases of bicycling indicate a growing interest in eco-friendly transportation, albeit with room for increased adoption.

Table 3
Binomial regression analysis of population density (based on SA1 origins)

	Dependent variable:				
	Car	Walk	Bicycle	Public Transport	MaaS
	(1)	(2)	(3)	(4)	(5)
Density Quartile 1	-0.596***	0.655***	0.421***	0.463***	-0.098
	(0.028)	(0.035)	(0.084)	(0.057)	(0.140)
Density Quartile 2	-0.719***	0.729***	0.265**	0.738***	0.269*
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Observations	101,109	101,109	101,109	101,109	101,109
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Note: *p<0.5 **p<0.01 ***p<0.001
Numbers in parentheses are standard errors.

The relatively nascent presence of MaaS, with 510 cases, suggests its emerging role in the urban transport landscape. As urban areas continue to evolve, MaaS could play a pivotal role in reshaping transportation choices, offering a flexible and potentially more sustainable alternative to traditional modes.

The transport purposes analysis further enriches our understanding. The use of cars predominantly for shopping, picking up or dropping off someone, and work commutes mirrors their integral role in daily urban life. The preference for walking for recreational activities suggests an opportunity for urban planners to promote pedestrian-friendly infrastructure. The role of bicycles in educational travel implies a growing awareness among younger populations about sustainable transportation.

5.2. Bi-variate Binomial Regression Analysis

The bi-variate binomial regression analysis sheds light on the influence of demographic factors on transportation mode choice. Age significantly impacts mode selection, with older individuals showing a preference for cars and MaaS. This indicates a potential market for MaaS providers to cater to older demographics and highlights the need for age-inclusive transportation planning.

Gender differences in transportation choices are significant. Women are more likely to drive cars and walk, while men are more likely to choose bicycles. There is a significant difference between genders in the use of bicycles and public transport, with men being more likely to bicycle and less likely to use public transport compared to women. The higher likelihood of males using bicycles suggests the need for gender-responsive transportation policies, particularly in enhancing safety and accessibility in cycling infrastructure.

The impact of employment status on transportation mode choice is profound. Employed individuals are more likely to drive cars and less likely to walk, while unemployed individuals show a higher tendency to use MaaS. This could reflect economic factors and varying time availabilities, emphasizing the need for affordable and flexible transportation options in urban planning.

The presence of children in the household significantly affects the use of public transportation, with households without children more likely to use public transport. There is no significant correlation between the use of MaaS and the presence of children in the household.

5.3. Binomial Regression Analysis

The binomial regression analysis on urban density provides transformative insights into urban transportation patterns. The decrease in car usage with increasing destination density signals a shift towards sustainable transport options in densely populated areas. This trend is crucial for urban planners focusing on reducing congestion and environmental impact in city centers.

The positive correlation between walking, bicycling, public transport, and higher urban densities confirms a preference for eco-friendly transportation modes in densely populated areas. This aligns with global sustainability goals and urban initiatives aiming to promote green mobility.

The analysis divides the target population density into quartiles, with data points evenly distributed. The likelihood of choosing a car as a means of transport decreases with increasing population density. Conversely, the probability of walking, cycling, or using public transportation increases.

For MaaS, the analysis indicates a growing inclination in higher-density areas, with significant positive associations in some density quartiles. This suggests a rising interest in flexible and on-demand transport solutions in urban settings, reflecting evolving urban mobility needs. The significant influence of population density on the likelihood of choosing MaaS highlights its potential as a viable transportation option in densely populated areas.

6. CONCLUSIONS

The comprehensive analysis of the QHTS has offered a multifaceted view of urban transportation dynamics, revealing how demographic factors, urban density, and personal preferences collectively shape transportation choices in urban areas. At the core of this study is the persistent reliance on cars, highlighting the ongoing centrality of personal vehicles in urban mobility. Yet, the notable use of walking, public transport, and bicycles points towards a gradual shift in urban travel behaviors, leaning more towards sustainable and health-conscious choices.

A significant aspect of this research is its demographic insights. Age and gender have emerged as key determinants in transportation mode preferences. The preference of older individuals for cars and MaaS signals a need for transportation systems that cater to the comfort and accessibility requirements of an aging population. Similarly, the gender-related trends, particularly the increased inclination of males towards bicycling, emphasize the need for gender-sensitive urban planning, focusing on safety and accessibility.

The influence of employment status on transportation mode choice also sheds light on the socio-economic dimensions of urban mobility. The higher propensity of unemployed individuals towards MaaS underscores the importance of economic factors in shaping transportation preferences, highlighting a demand for affordable and flexible mobility solutions.

Perhaps the most crucial finding of this study is the relationship between urban density and transportation choices. The data clearly show a trend of decreasing personal vehicle use in high-density urban areas, with a corresponding increase in more sustainable modes of transport like walking, bicycling, and public transport. This trend has significant implications for urban planning and environmental sustainability, indicating a need for a shift in focus towards infrastructure and policies that support sustainable transportation options.

The implications of this study are far-reaching for urban transportation planning and policy-making. There is an evident need for comprehensive, integrated transportation strategies that account for the varied needs of diverse urban populations. Emphasis should be placed on enhancing infrastructure and services for sustainable transportation modes, particularly in densely populated areas. Additionally, the potential of MaaS as a flexible and inclusive mobility solution should be explored further, tailoring it to suit the needs of various demographic groups, including the elderly and the unemployed.

While this research has provided substantial insights, it also opens up several avenues for future investigation. Longitudinal studies could offer a deeper understanding of how transportation preferences evolve in response to technological advancements and changes in urban landscapes. Further exploration into the barriers to adopting sustainable transportation modes and the effectiveness of various policy interventions would also be beneficial.

In conclusion, this study makes a significant contribution to our understanding of urban transportation choices, underscoring the importance of considering demographic factors, urban density, and sustainability in urban mobility planning. The insights gained are not only academically valuable but also offer practical guidance for the development of efficient, equitable, and sustainable urban transportation systems. As urban environments continue to grow and change, the findings of this study will play a crucial role in shaping future transportation systems that align with the diverse needs of urban populations and global sustainability goals.

References

1. Newman, P. & Kenworthy, J. *Sustainability and cities: overcoming automobile dependence.* 1998.
2. Cervero, R. Built environments and mode choice: toward a normative framework. *Transportation Research Part D: Transport and Environment*. 2002. Vol. 7(4). P. 265-284.
3. Cervero, R. & Kockelman, K. Travel demand and the 3Ds: Density, diversity, and design. *Transportation research part D: Transport and environment*. 1997. Vol. 2(3). P. 199-219.
4. Ewing, R. & Cervero, R. Travel and the built environment. *Journal of the American Planning Association*. 2010.
5. Burke, M. & Brown, A. Distances people walk for transport. Road & transport research. *A Journal of Australian and New Zealand Research and Practice*. 2007. Vol. 16(3). P. 16-29.
6. Scheiner, J. & Holz-Rau, C. Travel mode choice: affected by objective or subjective determinants? *Transportation.* 2007. Vol. 34. P. 487-511.
7. Delbosc, A. & Currie, G. Causes of youth licensing decline: a synthesis of evidence. *Transport Reviews.* 2013. Vol. 33(3). P. 271-290.
8. McFadden, D. *Conditional logit analysis of qualitative choice behavior.* 1972. Available at: https://escholarship.org/uc/item/61s3q2xr
9. Domencich, T.A. & McFadden, D. *Urban travel demand-a behavioral analysis*. North-Holland Publishing Co. 1975.
10. Ben-Akiva, M.E. & Lerman, S.R. *Discrete choice analysis: theory and application to travel demand.* Vol. 9. MIT press. 1985.
11. Train, K.E. *Discrete choice methods with simulation*. Cambridge university press. 2009.
12. Hensher, D.A. & Greene, W.H. The mixed logit model: the state of practice. *Transportation.* 2003. Vol. 30. P. 133-176.
13. Bhat, C.R., Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model. *Transportation Research Part B: Methodological.* 2001. Vol. 35(7). P. 677-693.
14. Scheiner, J. & Holz-Rau, C. A comprehensive study of life course, cohort, and period effects on changes in travel mode use. *Transportation Research Part A: Policy and Practice.* 2013. Vol. 47. P. 167-181.
15. Delbosc, A. & Currie, G. Changing demographics and young adult driver license decline in Melbourne, Australia (1994-2009). *Transportation*. 2014. Vol. 41. P. 529-542.
16. Ng, W.-S. & Acker, A. Understanding urban travel behaviour by gender for efficient and equitable transport policies. *International Transport Forum Discussion Paper.* 2018.
17. Garrard, J. & Rose, G. & Lo, S.K. Promoting transportation cycling for women: the role of bicycle infrastructure. *Preventive medicine.* 2008. Vol. 46(1). P. 55-59.
18. Haas, A. & Osland, L. Commuting, migration, housing and labour markets: Complex interactions. *SAGE Publications*. 2014. Vol. 51(3). P. 463-476.
19. Ewing, R. & Cervero, R. Travel and the built environment: A meta-analysis. *Journal of the American planning association.* 2010. Vol. 76(3). P. 265-294.

20. Curtis, C. Planning for sustainable accessibility: The implementation challenge. *Transport policy*. 2008. Vol. 15(2). P. 104-112.
21. Hietanen, S. Mobility as a Service – The new transport model? *ITS & Transport Management Supplement. Eurotransport*. 2014. Vol. 12(2). P. 2-4.
22. Hensher, D.A. Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change? *Transportation Research Part A: Policy and Practice*. 2017. Vol. 98. P. 86-96.
23. Ho, C.Q. & et al. Potential uptake and willingness-to-pay for Mobility as a Service (MaaS): A stated choice study. *Transportation Research Part A: Policy and Practice*. 2018. Vol. 117. P. 302-318.
24. Smith, G. & Sochor, J. & Karlsson, I.M. Mobility as a Service: Development scenarios and implications for public transport. *Research in Transportation Economics.* 2018. Vol. 69. P. 592-599.

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