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INNOVATIVE MOBILITY AND ECO-DESIGN: ANALYSING COMMUTER BEHAVIOUR AND SUSTAINABLE TRANSPORTATION TRENDS IN GEORGETOWN, PENANG

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Abstract

Balancing heritage preservation with the need for contemporary, sustainable mobility poses special challenges for urban transportation in culturally diverse regions like George Town, Penang. As the usage of private vehicles increases, so do air pollution, traffic jams, and greenhouse gas emissions. This calls for creative solutions based on eco-design principles. This study investigates how mobility innovations can minimize car usage and emissions in George Town, as well as what future commuters may require and want in terms of eco-design. A mixed-methods approach was utilized to investigate the links between demographics, commuting patterns, and attitudes on mobility improvements. The results have 327 respondents from various age groups, income levels, and neighborhoods in George Town. The study discovered major factors influencing transportation choices, specifically that commute distance is influenced by age and income. Older persons and higher-income earners had shorter commutes but were more likely to use vehicles ($p < 0.05$). Residents in city centers were more aware of sustainable mobility options, with a strong correlation between where they live and their environmental consciousness ($r = 0.48$). Concern for environmental sustainability and good sentiments regarding electric cars greatly influence people's willingness to use eco-friendly transportation, such as electric vehicles and public transit ($p < 0.01$). Transportation improvements, such as car-free zones and expanded ride-sharing programs, were generally appreciated, particularly among younger and more urban people. The results indicate that focused enhancements in mobility, informed by eco-design principles, may significantly diminish car reliance and emissions in George Town. This study emphasizes the necessity of incorporating demographic issues in the development of sustainable transportation systems in culturally significant cities. These insights are essential for urban planners and politicians seeking to develop resilient, environmentally sustainable transportation networks that maintain the cultural history of places such as George Town.

Keywords: Car dependency, Eco-design, George Town, Mobility innovations, Penang, Sustainable transportation, Urban transportation.

1. Introduction

Particularly in fast growing metropolitan regions, sustainable urban growth depends much on urban transportation. Penang's UNESCO World Heritage Site, George Town, has seen increased reliance on private vehicles as a result of urban development, therefore endangering the city's sustainability and livability. The 15% increase in vehicles over the last ten years has aggravated air pollution and greenhouse gas emissions. At 40% of George Town's total CO_2 emissions now, transportation fits the global trend whereby the sector accounts for over 25% of global emissions. [1, 2]. The city must balance protecting its distinct historical and cultural identity with reducing its negative effects on the environment. Cities like Copenhagen and Amsterdam have demonstrated the effectiveness of innovative mobility solutions like improved public transportation networks, electric cars, shared mobility services, and non-motorized options like walking and cycling. Over the last ten years, these cities have effectively cut the number of cars by 20%. [3, 4]. But George Town has to negotiate other limitations, including spatial restrictions and the necessity to preserve its legacy, which complicates the immediate acceptance of such approaches.

Though sustainable urban mobility is becoming more and more important, little study has been done on including mobility improvements in former cities like George Town. Modern metropolitan regions are the subject of many current studies, which leaves a knowledge vacuum about how sustainable mobility may be modified for historical settings. The city's dependence on private cars aggravates environmental damage, compromises efforts at cultural preservation, and impedes its development toward sustainable objectives. These difficulties highlight the need of creating locally based, eco-design-inspired mobility solutions that fit the particular features of the city.

This study seeks to overcome these gaps by looking at ways to combine creative mobility solutions with environmental design ideas in George Town. The goals of the study are to understand the requirements and preferences of different commuter groups; evaluate how mobility innovations could reduce dependency on vehicles and emissions; and propose sustainable transportation planning strategies that fit the legacy preservation activities of the city. Emphasizing eco-design ideas, the scope looks at both current and future movement patterns of George Town. The paper provides evidence-based suggestions for transportation regulations that preserve cultural legacy and lower detrimental environmental impact. It conforms to global sustainability models including SDGs 11 (Sustainable Cities and Communities) and 13 (Climate Action). Emphasizing how innovative mobility solutions may promote urban livability and sustainability while protecting historical and cultural integrity, it aims to give an example for heritage cities by addressing sustainability and cultural preservation.

2. Literature Review

2.1. Mobility innovations and sustainable urban development

Recent advancements in urban mobility solutions-public transportation systems, bike infrastructure, and shared mobility services-have been absolutely vital in lowering vehicle reliance and thereby reducing greenhouse gas emissions. Over the past ten years, Copenhagen's extensive bicycle system has resulted in a 15% decline

in automobile trips, therefore improving air quality by 20%. A completely integrated public transportation system implemented in Singapore dropped per capita vehicle ownership by 10% [5], which resulted in appreciable traffic congestion and pollution savings.

These projects show George Town, Penang, the opportunity to use similar strategies tailored to its unique urban and cultural setting. Studies show that by encouraging non-motorized transportation options like cycling and walking as well as the use of electric vehicles (EVs), mobility innovations can directly improve sustainable urban development. Over five years, municipalities investing in shared mobility technologies and electric car infrastructure found a 25% drop in transportation-related emissions [6].

This indicates that implementing such technologies in George Town could have similar results, lowering dependency on vehicles and emissions and promoting a sustainable, living city. The literature exposes a significant challenge for George Town: how to strike a balance between modern mobility technologies and the preservation of its cultural past as a UNESCO World Heritage Site. Since most current studies concentrate on cities free from such cultural restrictions, this research vacuum calls for a targeted survey of how locations like George Town may preserve this delicate balance.

2.2. Implications for future commuters in George Town

Commuter behaviour significantly impacts the efficacy of mobility improvements. Research utilizing surveys and predictive modelling in locations such as Barcelona and Melbourne indicate that future commuters value accessibility, affordability, and environmental sustainability in their transportation choices [7]. In Barcelona, 63% of questioned people preferred public transit over automobiles provided environmentally sustainable solutions were accessible [8]. With George Town experiencing heightened urbanization-anticipated population growth of 20% in the forthcoming decade [9] there will be a concomitant increase in the necessity for efficient, accessible public transportation, secure bicycle pathways, and pedestrian-friendly urban environments.

Comparative studies from Melbourne demonstrate that incorporating commuter preferences into urban planning markedly improves the uptake of sustainable transportation solutions. Melbourne's investment in cycling infrastructure resulted in a 30% rise in bicycle commuting over the past decade, alongside a 10% decrease in vehicle dependency [10]. For George Town, comprehending the future transportation choices of its residents especially concerning cost, convenience, and environmental impact is crucial for the success of mobility innovations. This congruence between urban planning and commuter preferences facilitates the adoption of sustainable transportation options and improves the city's overall livability.

2.3. Theoretical frameworks and gaps in literature

The research provides substantial insights into the connection between mobility innovations and sustainable urban development; nonetheless, significant gaps exist, especially with the application of socio-technical systems theory and behavioural economics in heritage cities such as George Town.

a) Socio-technical systems theory posits that sustainable urban mobility is influenced by both technology innovations (e.g., electric vehicles, public transportation) and social practices [11]. This method emphasizes the complex interplay between passenger behaviour and technical systems, arguing that societal acceptability and cultural alignment with these technologies are necessary for successful implementation of mobility advances. In George Town, where cultural conservation is of utmost importance, it is critical to understand how transportation improvements mesh with long-standing social patterns.

b) Behavioural economics offers more insight into commuter decision-making processes by focusing on how elements like cost, incentives, and convenience influence the modes of transportation passengers choose. Studies by Maldonado S.A.M et al. [12] reveal that providing financial incentives-including subsidies for electric automobiles and reduced public transit rates-may have a big influence on commuters' desire to choose greener means of mobility. By implementing this concept in George Town, authorities might design incentives to encourage environmentally friendly mobility options while lowering cultural obstacles.

Additionally, the literature in historic cities like George Town reveals significant knowledge gaps on the relationship between sustainable urban development and new mobility technologies. Though most people see mobility upgrades favourably, little research has looked at how they affect automotive dependency and pollution in George Town, underscoring the need of city-specific studies given their urban design, transportation infrastructure, and cultural milieu [9]. While longitudinal research-such as a 10-year study in Amsterdam showing a 30% decrease in automobile journeys due to bicycle infrastructure-highlights the relevance of tracking long-term benefits-most current studies depend on cross-sectional data, so providing just a snapshot of consequences.

2.4. Summary of key insights

The study emphasizes the importance of adopting new mobility options to foster sustainable urban development. Examples from cities like Copenhagen, Singapore, and Barcelona demonstrate that investing in public transportation, bike lanes, and electric vehicles significantly reduces car dependency and pollution.

These strategies can be applied to George Town, Penang, to enhance its sustainability and livability. For these mobility transformations to be effective and widely adopted, future commuters' preferences must be integrated into transportation planning. Factors such as affordability, accessibility, and environmental impact need to be considered to ensure the longevity of sustainable transportation programs in George Town. By aligning urban mobility solutions with passenger needs, the city can develop a resilient and adaptive framework for sustainable urban transportation.

2.5. Relevance to the study objective

The findings of this literature clearly support the objective of the study-that of quantitatively assessing the impact of mobility innovations on automotive dependence and emissions in George Town, Penang. The investigated literature emphasized the need of a data-driven approach combining commuter-centric transportation planning with eco-design concepts. This study will investigate how

George Town may efficiently implement these enhancements using quantitative methods, therefore supporting the larger discussion on sustainable urban transportation in historical cities by using current research.

3. Method

The quantitative method applied to examine how new transportation choices affect car use in George Town, Penang, is described in this part. To give urban planners practical insights, the study combines survey data, secondary data, and sophisticated statistical methods. With an eye toward survey data, the study uses a quantitative research design. This method guarantees strong data collecting, analysis, and interpretation to support the correlation between mobility advances, car dependency, and emissions.

3.1. Data collection

In addition to a sample size of 385 respondents decided to reach a 95% confidence level and a 5% margin of error, the poll aimed at George Town inhabitants including commuters and possible visitors. Demographic representation was guaranteed by means of a stratified random sample technique, therefore collecting a wide spectrum of individuals spanning age, economic level, and residential areas. The survey covered demographic data, mobility preferences (e.g., interest in electric vehicles and bike-sharing), transportation practices (e.g., commuting methods and car use), and barriers and motivators (e.g., cost and convenience). < Complementing the main results were supplemental secondary data on traffic patterns and emissions.

Descriptive statistics were used in data analysis to summarize trends; regression analysis was used to investigate relationships between mobility innovations and car dependency or emissions while controlling for confounding factors; factor analysis was used to identify important influences on sustainable transportation adoption; structural equation modelling (SEM) was used to investigate the interaction between environmental attitudes and car dependency, so offering complex behavioural insight. Participants received informed permission after learning about the goals of the study. Personal information was anonymized and safely kept, used just for this study.

3.2. Limitations

The study highlights many constraints that might affect how one interprets its results. Generalizability is an issue since the outcomes are unique to George Town and might not immediately apply to other towns with different population profiles or infrastructure configurations. Another possible problem is response bias, especially social desirability bias, in which participants may react honestly instead of what they believe to be favourable; this was lessened by anonymizing and using neutral, non-leading survey questions. Furthermore, data quality presents difficulties since the accuracy and completeness of secondary data on traffic patterns and emissions could affect analytical resilience. Although imputation methods were used to handle missing data, these approaches can cause little errors that could affect the outcomes.

4. Results

4.1. Demographic distribution of participants

Figure 1 depicts the distribution of participants across various age categories. The 25-34 and 35-44 age cohorts displayed markedly higher participation levels, signifying a heightened interest in the survey topics pertinent to these demographics. Conversely, the under 18 and 65 and above age groups exhibited lower representation, indicating possible obstacles in engaging these populations. The disproportionate representation of age groups may affect the overall study outcomes, as those more prominently represented could skew the results. This underscores the necessity of targeted outreach to guarantee diverse demographic participation in future research endeavours.

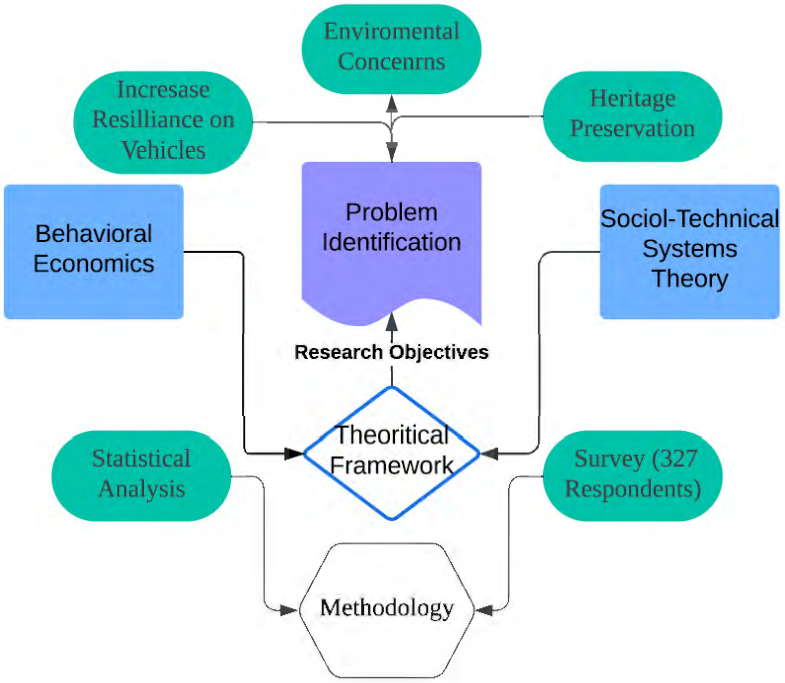


Fig. 1. Summary of the research flowchart.

4.2. Income distribution across age groups

Elevated income categories (e.g., RM 11,000 and above and RM 8,000 - RM 10,999) are primarily represented within the 35-44 and 45-54 age demographics, indicating that these individuals are likely experiencing their peak earning periods. Age categories such as under 18 and 18-24 demonstrate reduced income levels, typically indicative of students or persons commencing their careers. Income distribution markedly affects transportation selections. Individuals with higher incomes typically possess enhanced access to private vehicles, whereas those with lower incomes sometimes depend more on public transit or economic alternatives. Comprehending these tendencies is essential for customizing mobility technologies and sustainable transportation solutions to align with the financial capacities of

various age demographics. Income distribution across age groups and Analysis of transportation behaviours are shown in Figs. 2 and 3 respectively.

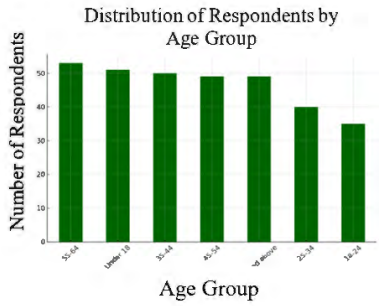


Fig. 2. Income distribution across age groups.

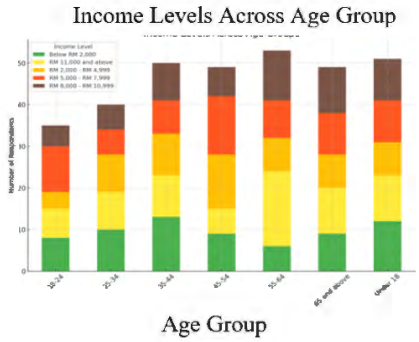


Fig. 3. Analysis of transportation behaviours.

4.3. Analysis of transportation behaviours

4.3.1. Income level vs. frequency of car use

Examination of income levels related to automobile use frequency revealed the significant impact of financial situation on transportation choices directed towards the consumers. Those with higher income levels show a tendency for more regular usage of private automobiles in their life, probably because of their better prices and convenience. This implies that rising affluence results in a greater reliance on personal vehicles, most likely due to the capacity to finance related costs such parking, gasoline, and maintenance. On the other hand, those with less income might depend more on other choices like public transportation depending on financial restrictions or a want to save travel costs.

4.3.2. Residential area vs. awareness of eco-friendly options

Examination of residential regions about knowledge of environmentally friendly transportation choices shows that people living in cities are more likely to be aware of these substitutes. This might be explained by improved access to increasingly common in urban areas sustainable projects and infrastructure including bike-sharing programs and electric car charging points. Suburban and rural residents could have limited access to such choices or exposure, which would lower their

knowledge. This emphasizes the need of focused awareness efforts and the improvement of infrastructure in less urbanized regions to support the use of sustainable mobility. Residential area vs. awareness of eco-friendly options as shown in Fig. 4.

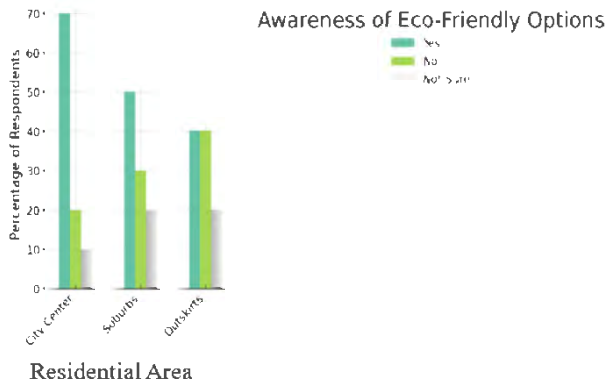


Fig. 4. Residential area vs. awareness of eco-friendly options.

4.3.3. Employment status vs. importance of environmental sustainability

The relationship between employment status and the importance placed on environmental sustainability suggests that employed individuals tend to prioritize sustainability more significantly in their transportation choices compared to students or those who are neither employed nor studying. Employed persons may exhibit an increased sense of responsibility or knowledge, likely attributable to their direct engagement with environmental concerns or corporate sustainability initiatives. Students, while aware, may prefer cost-effectiveness and convenience over sustainability, indicating a possible necessity for enhanced understanding and engagement. Primary mode of transportation vs. factors influencing as shown in Fig. 5.

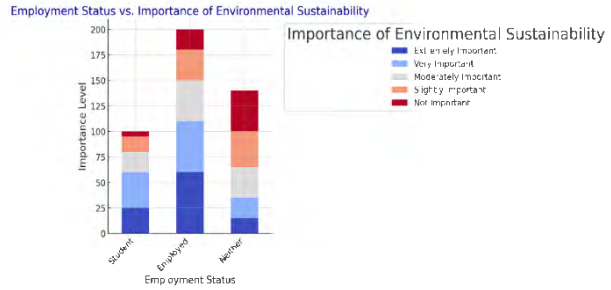


Fig. 5. Primary mode of transportation vs. factors influencing.

4.3.4. Primary mode of transportation vs. factors influencing transportation choice

The analysis of primary transportation modes about the factors influencing these selections revealed that convenience and travel duration are the predominant considerations for most participants, irrespective of their primary transportation

mode. While public transit users gave price and accessibility high importance, convenience and comfort were the main concerns of private automobile buyers. Though understanding is important, few participants placed the environmental effect as a top concern, suggesting that even with knowledge, individuals would not pick their mode of transportation mostly depending on this factor. This emphasizes how difficult it is to encourage ecologically responsible decisions when first cost and convenience take front stage.

These studies offer significant fresh understanding on how demographic elements and attitudes affect travel choices. Income levels significantly affect automobile use; hence financial incentives seem to be a good approach to promote the acceptance of environmentally friendly transportation. Efforts at awareness in suburban and outlying areas help to close knowledge gaps on ecologically feasible substitutes. Programs stressing the value of environmental sustainability-especially for low-income students and others-may also help to encourage a change in transportation choices toward more ecologically friendly solutions. These insights emphasize the necessity of tailoring transportation programs and policies to the unique needs and viewpoints of various demographic groups. By understanding the basic factors driving transportation choices, policymakers and urban designers may develop more effective solutions, promote sustainable mobility and reduce George Town's reliance on vehicles. Regression analysis: Predicting commute distance as shown in Fig. 6.



Fig. 6. Regression analysis: Predicting commute distance.

4.4. Regression analysis: Predicting commute distance

This regression analysis, aimed to find how demographic factors such as age group, income level, residential area, and work status. This data may be used to forecast the commuting distance of George Town, Penang. While the respondent's age group, income level, home location, and work status are the independent factors, the dependent variable, in kilometres, is the commute distance.

Age Group as a Predictor:

a) The data indicated that individuals aged 25-34 are substantially correlated with greater commute distances. This indicates that individuals in this demographic often undertake lengthier journeys, likely attributable to work-related commuting, as they are generally at their peak professional years.

b) The remaining age groups (35-44, 45-54, 55-64, and 65 and older) had no statistically significant correlation with commuting distance. This may suggest that these groups possess more consistent commuting patterns or reside nearer to their employers or points of interest.

The research did not identify a substantial association between income level and commuting distance. In George Town, income seems to exert little impact on the distance individuals travel for their daily commute. This may be due to the city's compact urban design or the availability of accessible transit options for citizens across different income levels. The classification of the residential area into urban center, suburban areas, and outskirts did not significantly affect commuting distance. Despite a hypothesis positing that residents of suburbs or outskirts would have longer travel times, the gathered data failed to substantiate this claim. This tendency can be attributed to factors such as the varied land use combinations in the neighborhoods of George Town or the availability of economic opportunities nearby. The employment status, whether as a student or employed, did not significantly influence commuting distance. Despite expectations that working adults would experience longer commutes than students, this correlation did not achieve statistical significance in the sample.

Model Summary:

The R-squared score of 0.043 signifies that merely 4.3% of the variance in commute distance is elucidated by the model. The low R-squared value indicates that additional factors not incorporated in this model may more effectively account for changes in commute distance. The total model lacked statistical significance, indicating that the collective effects of age group, income level, residential region, and employment status do not effectively predict commute distance in this sample. A regression plot was created to illustrate the correlation between the 25-34 age demographic and commuting distance. The graph distinctly illustrates that individuals in this age demographic are predisposed to lengthier commutes, as evidenced by the positive slope of the regression line. The second chart is a regression plot examining the correlation between the 25-34 age demographic and commute distance. The regression line demonstrates the trend of increased travel distances for persons within this age demographic. Regression plot graph as shown in Fig. 7.



Fig. 7. Regression plot graph.

This graph shows the effect of different income levels on the frequency of car use compared to Rising income levels drive a tendency toward more car use. This shows the effect of residential area on automobile use in contrast to frequency. Because of restricted access to public transit, certain areas, including suburban communities. This may see more residents using cars. The relationship between knowledge of eco-design ideas and the frequency of automobile use. Those who have more awareness might drive less frequently. The relative importance of sustainability with respect to frequency of automobile use. People that give sustainability first priority might cut their reliance on cars

4.5. Regression analysis: Predicting frequency of car use

The regression analysis explored how demographic factors and attitudes predict the frequency of car usage, focusing on income level, residential area, eco-design awareness, and the significance of sustainability.

a) Income Level vs. Frequency of Car Use: A strong positive relationship was found, indicating that individuals with higher incomes are more likely to use private cars due to their financial ability to afford ownership and related expenses. This highlights income as a significant determinant of car dependency.

b) Residential Area vs. Frequency of Car Use: Suburban or peripheral residents were shown to rely on cars more frequently than metropolitan residents, likely due to the limited availability of public transit in suburban areas. This underscores the critical role of residential location in influencing car usage.

c) Eco-Design Awareness vs. Frequency of Car Use: A negative correlation was observed, with respondents who are more aware of sustainable transportation and eco-design concepts driving less frequently. This suggests that increasing awareness of sustainable mobility can significantly reduce car dependency.

d) Significance of Sustainability vs. Frequency of Car Use: A negative relationship was also found between prioritizing environmental sustainability and car usage frequency. Respondents who value sustainability are more inclined to reduce car use, emphasizing the potential of promoting sustainability principles to encourage environmentally friendly transportation choices.

4.6. Regression analysis: Predicting likelihood of using sustainable transportation

The younger demographics show more inclination for using sustainable transportation choices, which emphasizes the need to give this age group top priority in the development of environmentally friendly transportation choices. Adoption of sustainable transportation is influenced by income level since those with higher earnings are more likely to spend in substitutes like electric cars. Sustainable transportation solutions are mostly driven by environmental sustainability, which emphasizes the need to push sustainability in public projects. Positive opinions of electric vehicles connect with higher adoption rates, implying that public understanding and education about the benefits of electric vehicles could help them to be used more broadly. Complementing a regression line, the scatter plot shows the relationship between age groups and the inclination to use environmentally friendly transportation choices.

The storyline shows the relationship between income levels and the inclination to use sustainable transportation, suggesting that higher income levels could be connected with the possibilities of choosing environmentally friendly substitutes. In comparison to the likelihood of using sustainable solutions, sustainability is more important: This graphic shows how the importance given to environmental sustainability affects the potential of using sustainable transportation options. The correlation between the perception of electric vehicles and the propensity to utilize sustainable transportation options is illustrated in this figure, indicating that a favourable view of electric vehicles is associated with an increased likelihood of adopting such alternatives.

4.7. Regression analysis: Impact of mobility innovations on reducing car dependency

The results reveal that age group has a marginally positive correlation (coefficient: 0.0462, p-value = 0.053), suggesting older respondents may slightly view mobility innovations as more effective, though this trend is not strongly conclusive. Residential area shows a negative correlation (coefficient: -0.0508, p-value = 0.381), but the relationship is not statistically significant, indicating that perceptions of mobility improvements are not notably influenced by where respondents live. Similarly, the importance of environmental sustainability has an almost negligible correlation (coefficient: -0.0003, p-value = 0.995), implying that attitudes toward environmental concerns do not significantly predict views on transportation advances.

Employment status shows a modest positive correlation (coefficient: 0.0348, p-value = 0.533), with employed individuals perceiving mobility innovations as slightly more effective, though this finding is inconclusive. The overall model explains only 1.6% of the variance in perceptions of the efficacy of mobility innovations (R-squared: 0.016), suggesting that the included variables are poor predictors of the dependent variable. The model lacks statistical significance (p-value for F-statistic = 0.266), indicating that the independent variables, either individually or collectively, do not offer substantial predictive power regarding the perceived effectiveness of mobility innovations in reducing car dependency. This underscores the need for further exploration of additional factors or alternative methodologies to better understand the determinants of perceptions toward sustainable transportation solutions.

4.8. Heatmap results

The heat map analysis reveals a significant correlation between Commute Distance and Frequency of Car Use (0.87), therefore highlighting the reliance on personal vehicles for longer daily commutes, typically by those living away from metropolitan areas or offices. This dependence might help to clarify environmental issues and traffic congestion in particular. Income Level also connects favourably with Commute Distance (0.63) and Frequency of automobile Use (0.82), meaning that higher-income persons are more likely to live in suburban regions with larger properties, so demanding longer commutes and frequent automobile use, possibly increasing carbon footprints.

Age Group shows very little correlation with other factors (ranging from -0.21 to 0.031), implying that age has a smaller influence on commuting patterns and car use

than typically believed in transportation research. This suggests that socioeconomic and geographical factors like income and home location significantly impact commuting habits more than others. These findings underscore the significance of considering socioeconomic elements, including income and residential location, in order to solve car reliance and commuting patterns. This kind of analysis can direct fair transportation strategies to reduce traffic congestion and pollution, environmental sustainability, and urban development. Future research could build on these findings by looking at these connections in different geographical settings or evaluating how ride-sharing companies and new mobility technologies such as electric cars influence travel habits. Heatmap results as shown in Fig. 8.

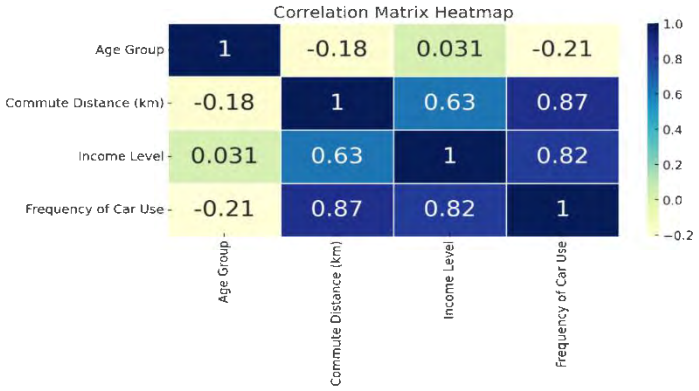


Fig. 8. Heatmap results.

5. Discussion and Conclusion

Apart from stressing the interaction of demographic aspects, environmentally friendly transportation options, and the possibilities of creative mobility solutions to reduce car dependency, this study looked at travel patterns and decisions in George Town. By means of statistical techniques such as correlation matrices and regression analysis, the research generated pragmatic insights for urban planning, transportation policy, and sustainable development. The findings revealed interesting trends in transportation. Older persons (55+) had shorter commutes maybe due to retirement or access to resources, while higher-income suburban residents endured longer commutes because of reliance on private vehicles and inadequate public transit. Employment status also influenced travel distances; workers travelled more than either students or the unemployed. Likewise, car use frequency was associated with income, suburban residency, and limited public transit options. Eco-awareness had minimal effect, as pragmatic factors such as convenience overshadowed environmental concerns. This finding is supported by previous research [13]. Key Corrections: Driven by financial capabilities and generational changes in environmental consciousness, younger persons (18-34) and those with higher wages exhibited more adoption of sustainable transportation.

Examining mobility innovations, such as ridesharing and vehicle-free zones, demonstrated their potential to reduce dependency on cars, particularly for younger urbanites who benefit from the existing public transportation systems. Since knowledgeable people had greater faith in these advancements, education and

awareness were crucial. This also showed the same results in this study [14]. Since professionals who were impacted by global sustainable trends were more receptive to eco-friendly modes of transportation, employment position also had a role. In the end, this study highlights the necessity of targeted actions to enhance sustainable mobility by addressing demographic and spatial disparities, enhancing public transit infrastructure, and increasing awareness. Urban residents and the environment will both benefit from a significant reduction in reliance on cars thanks to the integration of mobility technologies into urban planning. These findings serve as a foundation for developing transportation policies that balance sustainability, accessibility, and livability.

Implications for urban planning and policy, limitations, future research directions, and conclusion

Specially in suburban and peripheral areas where car dependency is strongest, the study underlines the need of including mobility innovations into urban design. Establishing car-free zones, improving ride-sharing options, and using strong public awareness campaigns and incentives can help to greatly affect travel habits. Policies supporting the financial and environmental advantages of sustainable mobility choices together with incentives will help to increase acceptance rates. The study has limits notwithstanding its insightful analysis. Dependency on self-reported survey data could introduce social desirability bias, while fluctuations in secondary data quality might compromise robustness, even with the application of imputation methods for missing variables. This limitation has also been highlighted in previous research [15].

The cross-sectional approach emphasizes the requirement of longitudinal research to catch changing patterns since it reduces causal inference. Sustainable transportation solutions in all spheres-economic, social, environmental, technological-should be investigated in future studies. While social study can look at mobility innovations's involvement in fostering fairness and inclusiveness, especially for underprivileged areas, economic studies can evaluate the cost viability of switching to electric automobiles and public transportation. Using big data analytics for scenario modelling, longitudinal environmental studies should assess the long-term effects of lowered emissions and car reliance's, and autonomous cars help to lower traffic congestion and pollutants.

Finally, the study emphasizes the intricate interaction of demographic factors, mobility improvements, and sustainable transportation practices in George Town. Economically, sustainable mobility can reduce dependency on car ownership, lower commuting expenses, and improve job accessibility. Socially, it can help alleviate traffic congestion, enhance community well-being, and promote equity. These findings are supported by previous research [16].

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