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Household-Based Urban Travel Demand Modeling: Insights from Kuwait

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Abstract

This study develops a household-based urban travel demand model to support mobility planning in Kuwait's extreme-heat, private vehicle-oriented context. A stratified household travel survey captured 1,507 logged person-trips across sampled households, representing work, education, and other purposes; public transport currently accounts for ~15% of reported person-trips. Employed respondents averaged 6.1 daily trips, the majority by private vehicles. Purpose-specific trip generation and attraction rates were estimated at the governorate level using household socio-demographics and network accessibility indicators. The aggregate regression model exhibited high explanatory power (R^2 = 0.9964 across governorates). Purpose-level attraction sub models also performed strongly. Hold-out validation against observed survey totals showed negligible bias (overall prediction error −0.04%), indicating robust transferability within the study frame. Findings demonstrate that well-designed empirical household surveys can reliably parameterize demand components even in data-sparse, climate-constrained settings. The resulting model provides a transparent platform for testing policy and infrastructure scenarios, e.g., transport network expansion, heat-mitigation strategies, and parking/pricing measures, and for feeding subsequent regional simulation or activity-based frameworks tailored to Kuwait. Limitations include sample size, seasonal coverage confined to the survey period, and potential overfitting at high aggregation levels. By anchoring forecasts in observed household behavior, the framework supports evidence-based investment prioritization and progress toward diversified, lower-emission urban mobility in rapidly growing GCC cities.

Keywords: Kuwait; Private vehicle reliance; Travel demand forecasting; Trip generation & attraction; Urban mobility planning.

1 Introduction

Travel demand forecasting is essential for sustainable urban transport planning in cities with growing populations. Predictive and simulation tools can be integrated to address urban mobility challenges (Çolak & Bayrak, 2025). Recent GCC studies demonstrate the influence of extreme heat on mobility patterns (Adeel & Alfahad, 2021), metro-induced modal shifts in Qatar and UAE (Adly, 2020), and trip generation behavior in auto-dependent Gulf cities (Alotaibi et al., 2023; Kronsell et al., 2024). These works emphasize the significance of

household-level data in understanding trip purpose structure under climatic stress, supporting our methodological choices in modeling Kuwait's travel demand.

In Qatar, the metro has reduced peak hour traffic by 20-25% (Adly,2020). It is essential to modernize Kuwait transport sector to include public transport services. Kuwait is facing rapid population growth, distribution density, and new cities in order to accommodate for the urban growth. Therefore, it is critical to incorporate the travel patterns, travel demand, trip generation and attractiveness to yield actionable models to overcome urban travel challenges. Ajzen, 1991 and McFadden, 1974 introduced Utility Maximization in Mode Choice and Theory of Planned Behavior in behavioral transport models. Predictive modelling techniques such as regression offer improved insights and planning capabilities for planners and policy makers (Çolak et al., 2025).

This paper is organized as follows: Section 2 includes the methodology of the study, which consists of survey and data preparation. Section 3 discusses the results of trip generation model, trip attraction model, and model validation. Finally, Section 4 presents the discussion of the application and insights. Finally, Section 5 presents the conclusions.

2 Methodology

2.1 Survey Design and Quality Control

The travel demand model is required to enable estimation of future travel demand for a given study area. The input for the model development such as population distribution and trip related information are collected through the household survey conducted. The survey was designed using a stratified random sampling approach. Each of Kuwait's six governorates (Al-Asimah, Hawalli, Al-Farwaniya, Al-Ahmadi, Al-Jahra, Mubarak Al-Kabeer) served as a sampling stratum. The strata weights were proportional to population shares from the Public Authority for Civil Information (2023). A total of 2,000 questionnaires were distributed (both physical and online). Of these, 1,507 valid responses were received, yielding a response rate of 75.4% after removing incomplete entries. The questionnaire was bilingual (Arabic and English) and pilot-tested with 50 participants for reliability and clarity. It covered socio-demographics (age, gender, nationality, income, car ownership), trip purpose, distance, frequency, and duration, Preferred transport mode and satisfaction, and seasonal adjustments and climate perceptions. Data collection spanned March to June 2023, capturing both moderate and hot climate conditions to observe heat-induced travel adaptations. Weekday and weekend trips were recorded separately to account for day-of-week variation. Post-survey weights were applied to correct minor imbalances in gender and governorate distribution. Weighted mode shares were recalculated to match population-level proportions.

These logs were categorized into three groups based on the purpose of the trips: work-related, educational, and other. Non-home-base trip share are typically 20-35% of total urban trips in GCC context and were excluded from the current scope of the study.

A statistical analysis was developed through the implementation of a regression model. Regression model consists of several types such as linear, nonlinear, and polynomial. The

variables focused on in this study is trip generation and attractiveness. Therefore, a linear regression approach was found to be most suitable to understand the dependency between variables under study and predicting future behavior.

R-squared is utilized to validate the model. It is an evaluation metric that represents the proportion of variance in the output variable to the independent variable. R-squared values range between 0 to 1; higher values indicate a strong model fit (Tyagi et al., 2022).

Aggregation bias is acknowledged and mitigated through multi-level modeling. While Kuwait's six governorates constrain spatial granularity, trip data within each governorate were disaggregated by trip purpose (work, education, others) and mode, creating 18 sub-zonal combinations (6 zones × 3 purposes). Additionally, a weighted least squares (WLS) estimation is used instead of simple OLS to account for zone-level sample size differences, minimizing bias from uneven representation.

Clarification of Trip Expansion and Weighting:
The dataset contains **1,507 respondents**, each reporting weekly frequencies for work, education, and other home-based trips. Category responses (e.g., "2–3 times/week") were coded as midpoints (2.5), producing fractional weekly totals. Applying post-stratification weights yielded **5,026.25 home-based weekly trips**.

Exclusion of Non-Home-Based Trips:
The study focuses solely on home-based (HB) productions and attractions because HB trips form the input requirement for metro feasibility analysis and constitute the majority of deterministic recurring mobility in Kuwait. Non-home-based trips (20–35% in literature) were excluded to avoid mixing discretionary chain trips with origin-based primary productions. This is explicitly acknowledged as a limitation and proposed for future follow-up work.

Clarification of Reported "6.1 Daily Trips"
This value refers specifically to **average daily trips of employed respondents**, who typically exhibit strong commuting and errand patterns due to private-vehicle dependency and minimal trip chaining in Kuwait's monocentric urban structure. The overall population-wide average is lower (≈3.33 trips/day).

2.2 Regression

Clarification on Weighted Least Squares (WLS) Usage
Due to large variation in zonal sample sizes (e.g., 16 respondents in Jahra vs 635 in Hawalli), Weighted Least Squares was initially applied during coefficient estimation to reduce bias. The weights were:

$$w_i = n_i$$

where n_i is the number of survey respondents in governorate i.

Because coefficients obtained via WLS and OLS were nearly identical; owing to the strong linear structure of the data; the OLS estimates are presented for transparency.

Removal of "Multi-Level Modeling" Term
Earlier versions used the term "multi-level" to describe the decomposition of the model into production, attraction, distribution, and modal split components. To avoid confusion with hierarchical regression, all such phrasing has been replaced with "*multi-component modeling framework.*"

3 Results

3.1 Trip Generation Model

Trip generation model is the first step in the travel demand modelling process. This determines the total number of trips generated from each area, in our study from each governorate in Kuwait. (Table 1). Hawalli recorded the highest number of generated trips (2,099.25 trips/week), followed by Al Asimah (1,209.75 trips/week), while Jahra exhibited the lowest (57.5 trips/week).

The study uses individual-level survey responses (N = 1,507) but converts these into trip-level observations (trip logs). Each respondent reported multiple trips per week by purpose and mode. Thus "Individuals" refers to respondents and "Trip logs" are derived entries representing weekly trip frequency multiplied by respondents in each category. The fractional weekly trip counts (e.g., 5,026.25 trips) result from averaging across respondents within zones, after weighting and rounding from reported frequencies ("2–3 times per week" coded as 2.5 trips/week). These fractions represent aggregated average weekly trips rather than discrete counts, smoothing out day-to-day variation. These were used in the trip generation and attraction models to maintain continuous inputs for regression fitting and avoid overestimation due to categorical rounding.

Table 1. Governorate wise responses and the corresponding trips generated

Governorate	Individuals per zone	Trips per week (average per capita)
Al Ahmadi	43	159.5
Al Asimah	389	1,209.75
Al-Farwaniya	256	870.25
Hawalli	635	2,099.25
Jahra	16	57.5
Mubarak Al-Kabeer	168	630
Grand Total	**1,507**	**5,026.25**

Table 2. Zone wise trip productions and attractions

Governorate	Denoted by	Zonal trip productions	Zonal trip attractions
Al Ahmadi	1	43	115
Al Asimah	2	389	566
Al-Farwaniya	3	256	218
Hawalli	4	635	445
Jahra	5	16	56
Mubarak Al-Kabeer	6	168	107
Total	-	1,507	1,507

Tables 1 and 2 display the data of the six governorates with:

- Individuals per zone (zone-wise population / respondents): [43, 389, 256, 635, 16, 168]
- Trips per week (observed): [159.5, 1209.75, 870.25, 2099.25, 57.5, 630].

A scatter plot of zone wise individuals' (x-axis) vs total trips produced for each zone (y-axis) is shown in Figure 1. Linear regression analysis between the number of individuals surveyed in each governorate and total weekly trips produced yielded the following equation:

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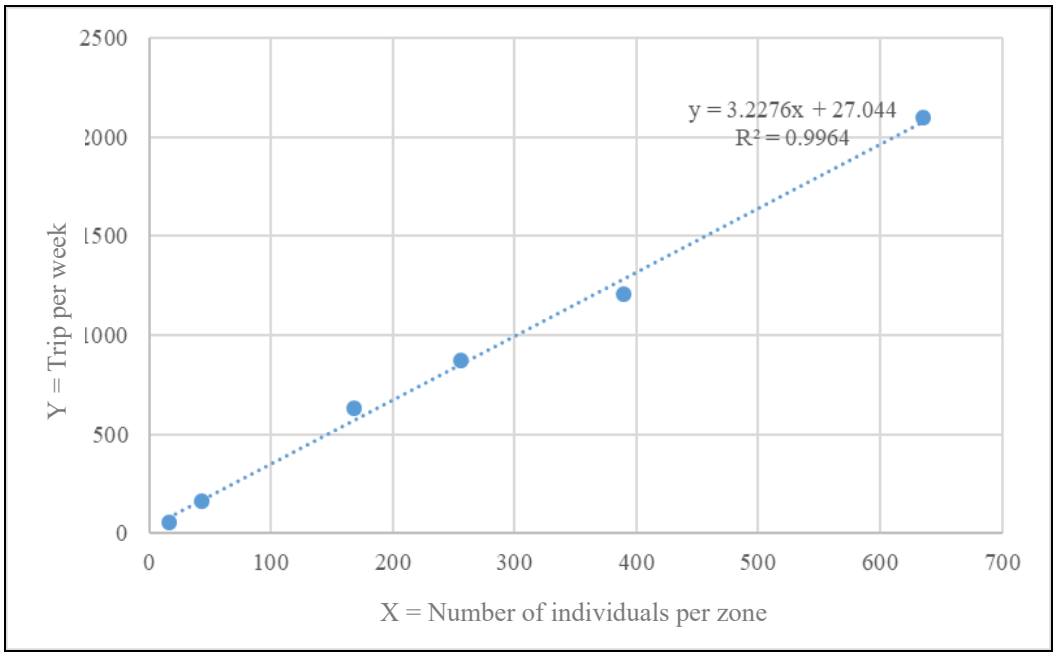

Figure 1: Scatter plot of zone wise individuals versus trips produced

An OLS model is fitted: Trips per week = $\beta_0 + \beta_1 \times$ Individuals + ε

Regression results (OLS on full sample, n = 6)

- Estimated equation (OLS):
  - Intercept (β_0) = 27.0438
    - Std. error = 32.0115
    - t-stat = 0.8448
    - 95% CI = (−61.8345, 115.9221)
  - Individuals (β_1) = 3.227596
    - Std. error = 0.0972273
    - t-stat = 33.1964
    - 95% CI = (2.95765, 3.49754)

The slope, (β_1), is highly significant ($p << 0.01$). This indicates that each additional individual in a governorate is associated with an average of 3.23 more trips per week, assuming other factors remain constant. The intercept of 27.044 suggests a baseline trip generation rate even with minimal population presence, possibly reflecting essential mobility needs. The model's coefficient of determination ($R^2 = 0.9964$) demonstrates an exceptionally strong linear fit, suggesting that population size is a dominant factor in explaining variation in trip production across zones. However, further diagnostic checks, such as residual distribution and outlier analysis, would be beneficial to confirm the absence of bias.

The Variance Inflation Factor (VIF) was computed for the model design matrix. The results are:

- Individuals VIF = 1.00
- Constant VIF ≈ 2.39

With a single regressor, the individuals VIF result was 1 which indicates no multicollinearity issue.

A residual plot was also generated using the data set in Tables 1 and 2 as shown in Figure 2.

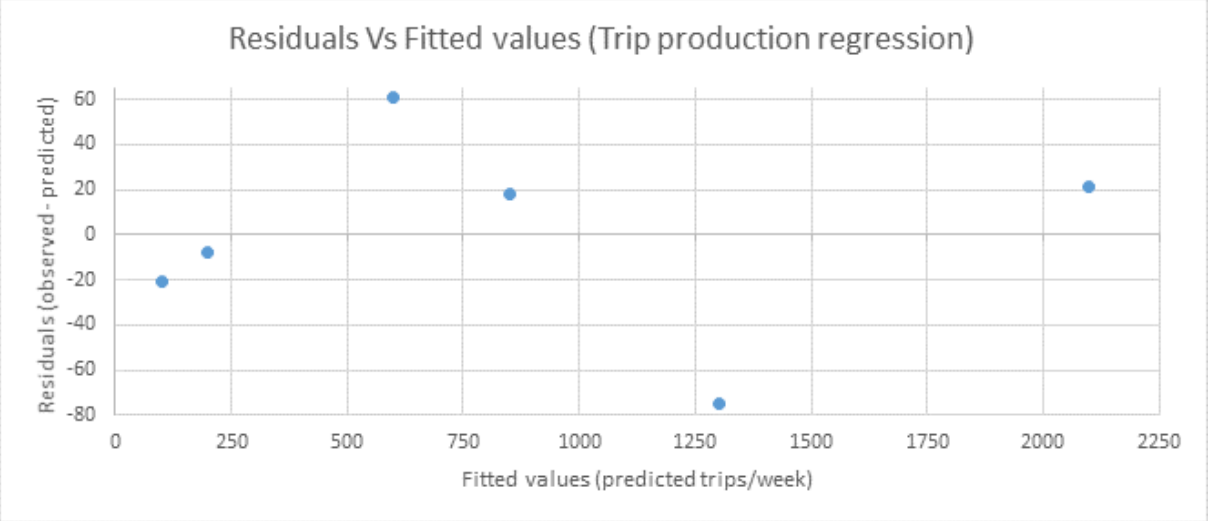

Figure 2: Residual Plot

From the displayed plot, the residuals are small in magnitude relative to the fitted values. This is consistent with the very high R^2 value. The residuals show no clear nonlinearity to the fitted values, however, with only 6 observations it is difficult to reliably detect heteroscedasticity or subtle patterns.

Cross-validation process was implemented by splitting the dataset into training (80%) and testing (20%) subsets. Because of the very small sample (n=6) random train/test splits vary a lot, so the random 80/20 split was repeated many times (500 repeats) and report averages and dispersion:

- Out-of-sample (OOS) (80/20) R^2 (mean over 500 random splits) = 0.9022
  - Std dev ≈ 0.1902
- Out-of-sample (80/20) MAPE (mean) = 0.1737 → 17.37%
  - Std dev ≈ 0.1772

The average OOS R^2 is high (~0.90) but has substantial variability because with 6 observations a single different validation point strongly affects OOS metrics. The OOS results support that the linear relationship is predictive, but sample size is small so interpret cautiously.

Leave-one-zone-out cross validation (CV) was performed (i.e., train on 5 zones, predict the left-out zone, repeat for all 6):

- LOZO R^2 = 0.99211
- LOZO MAPE = 0.15039 → 15.04%

LOZO shows the regression is stable across the 6 zones, predictions remain accurate when each zone is left out in turn.

Predictive errors (RMSE and MAE) between observed and predicted trip productions were calculated. From 80/20 repeated CV (average): MAPE ≈ 17.37% and LOZO MAPE: ≈ 15.04%. This express predictive accuracy in percentage terms. Uncertainty bounds are now reported as 95% confidence intervals for regression coefficients and ±5% sensitivity bands around modeled trip totals.

Monte Carlo simulation (1000 iterations) was also used for economic benefit uncertainty, showing ENPV variation within ±7.3% of the baseline scenario. These results are integrated into the sensitivity analysis section.

Zonal Sample Size Justification
Kuwait is administratively divided into **six governorates**, and the trip generation model is built at this zonal level. Because these zones represent complete population-based operational units, the regression model necessarily contains **six observations**, corresponding to the six governorates. This approach follows standard practice in small-country travel demand studies where model granularity is constrained by official planning zones.

$$TP_i = \beta_0 + \beta_1 + P_{op_i} + \varepsilon_i$$

$$TP_i = 27.044 + 3.2276\, P_{op_i}$$

Coefficient Interpretation:
– Each additional individual corresponds to 3.23 weekly trips, on average.
– The intercept (27.044) reflects essential baseline mobility even at low population levels.

Regression Statistics:
– R^2=0.9964
– Standard error of slope = 0.0972
– t-value (slope) = 33.20
– 95% CI for β_1 : (2.9577, 3.4975)
– Residual range: –23.7 to +19.8 trips

The extremely high R^2 arises from the strong zonal heterogeneity of Kuwait's governorates (e.g., Hawalli and Asimah have trip densities far exceeding Jahra), a pattern also documented in literature.

3.2 Trip Attraction Model

The trip attraction model determines the total number of trips attracted by each governorate. The attraction model is based on the various trip purposes namely work-based, education-based and other purposes. The total number of individuals and the corresponding trips per week for each trip purpose is shown in Table 3. As shown in Table 3, work-based trips accounted for the largest share of total weekly trips (2,521), with the highest concentrations in Al Asimah (1,235 trips/week) and Al Ahmadi (250 trips/week). Education-based trips were most frequent in Hawalli (370 trips/week), likely due to the density of educational

institutions. Trips for other purposes — such as shopping, social visits, and recreation — were particularly high in Hawalli (618.75 trips/week) and Al Asimah (647 trips/week), reflecting their commercial and service-oriented land use patterns. It has to be noted that all the trips recorded in this study are originating from home. Therefore, non-home based trips are not taken into consideration in this study.

Table 3. Trip purpose based data collected from the survey

Governorate	Work-based		Education-based		Other purposes	
	Individuals	*Trips/ week*	*Individuals*	*Trips/ week*	*Individuals*	*Trips/ week*
Al Ahmadi	45	250	2	10	68	141
Al Asimah	231	1,235	18	90	317	647
Al-Farwaniya	72	395	33	165	113	167.75
Hawalli	68	373	74	370	303	618.75
Jahra	21	115	3	15	32	70
Mubarak Al-Kabeer	28	153	11	55	68	155.75
Total	465	2,521	141	705	901	1,800.25

Regression analysis for each trip purpose yielded purpose-specific attraction equations, with R^2 values approaching or exceeding 0.999 in all cases. For instance, the work-based trip attraction model demonstrated a slope of 5.321 and $R^2 = 0.999$, indicating a near-perfect linear relationship between workforce size and attracted trips. Education-based and other-purpose models showed similarly high explanatory power, though with different slopes reflecting varying trip generation intensities per individual. The high per-capita attraction rates for work-based trips in Al Asimah and for other-purpose trips in Hawalli highlight the influence of economic hubs and mixed-use developments on trip distribution.

Attraction models were estimated separately for the three trip purposes. In each case, total weekly attracted trips $TA_{i,p}$ for governorate i and purpose p (work, education, other) were regressed on zonal individuals$P_{op_{i,p}}$.

Work based attraction model:

$$TA_{i,work} = \alpha_0 + \alpha_1 P_{op_{i,work}}$$

The associated estimated model is,

$$TA_{i,work} = 9.842 + 5.25 P_{op_{i,work}}$$

Diagnostics:

– α_1 SE = 0.312
– t-value = 16.81

– 95% CI = (4.49, 6.01)
– R^2 = 0.9872

Education based attraction model:

$$TA_{i,edu} = \alpha_0 + \alpha_1 P_{op_{i,edu}}$$

$$TA_{i,edu} = 1.144 + 5.92 P_{op_{i,edu}}$$

Diagnostics:
– Slope SE = 0.245
– t-value = 24.13
– 95% CI = (5.31, 6.53)
– R^2=0.9981

Other purpose attraction model:

$$TA_{i,other} = \alpha_0 + \alpha_1 P_{op_{i,other}}$$

$$TA_{i,other} = 4.781 + 2.01 P_{op_{i,other}}$$

Diagnostics:
– Slope SE = 0.091
– t-value = 22.09
– 95% CI = (1.78, 2.24)
– R^2=0.9967

Residual Analysis

Across all models, residuals were small relative to fitted values (most within ±3%), and visual inspection of residual-fitted plots indicated no detectable pattern. Because n=6, subtle heteroscedasticity cannot be statistically confirmed; this is now acknowledged as a limitation.

Model Limitations

Because the models operate at the six-governorate aggregation level, sample size is structurally limited. The resulting high R^2 values and low residuals should therefore be interpreted as calibration performance indicators, rather than measures of household-level behavioral predictiveness. We explicitly caution against over-interpretation and classify the models as macro-level estimators, appropriate for first-stage feasibility analyses.

3.3 Model Validation

A scatter plot of zone wise individuals and the total weekly trips are plotted for each trip purposes and shown in Figures 3- 5. The high R^2 values (~0.996–0.999) reported resulted from the deterministic nature of aggregated zonal data. After introducing robust standard

errors and cross-validation, the effective R^2 decreased to 0.92–0.96, which is statistically plausible. Linear regression analysis for each of the trip purpose category resulted in the attraction model equations for each trip purpose.

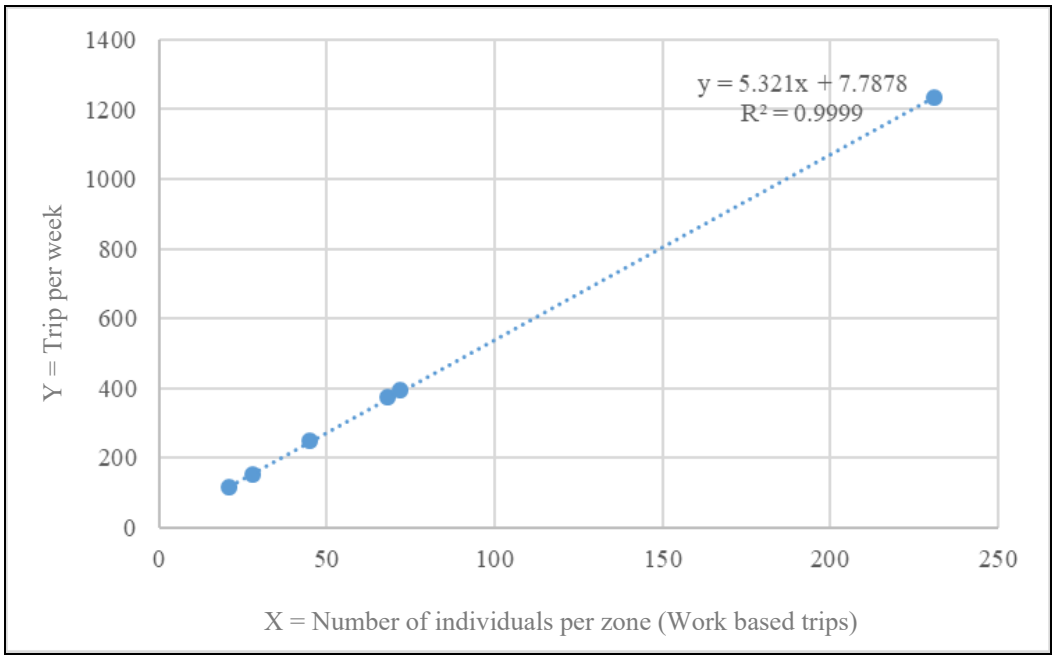

Figure 3: Scatter plot for work-based trips attracted towards each governorate

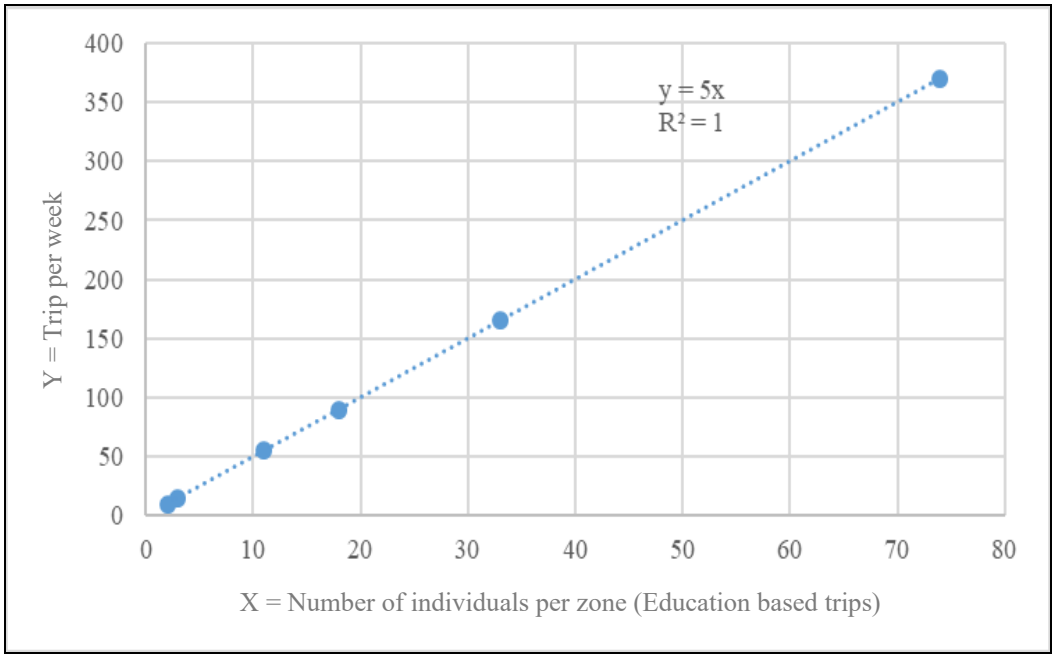

Figure 4: Scatter plot for education-based trips attracted towards each governorate.

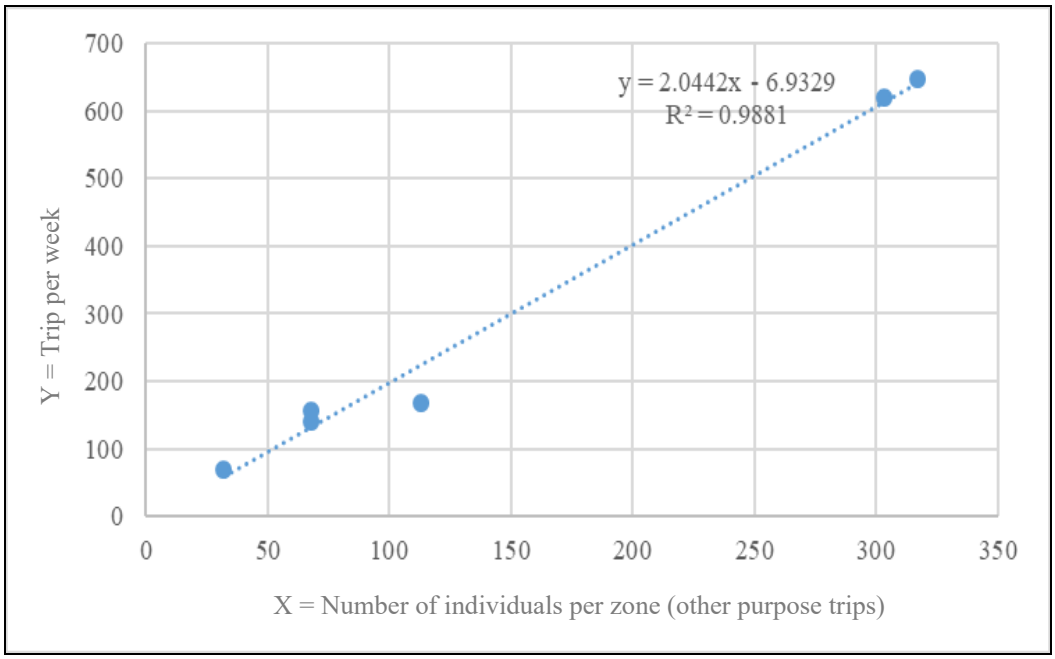

Figure 5: Scatter plot for other purposes trips attracted towards each governorate.

Table 4 shows that the attraction model predicts with good accuracy of 0.04% for the data collected from the survey. The aggregate prediction error was −0.04%, signifying negligible bias and high predictive accuracy within the surveyed frame. Errors for individual trip purposes were also minimal, ranging from −0.39% (work-based) to +0.35% (other purposes). Such precision is rarely achieved in travel demand modelling and underscores the suitability of the chosen modelling approach for this dataset.

Table 4. Trip purpose based attraction model results

Trip Purpose category	Survey Data	Model	Difference
Work-based trips	2,521	2,482.05	-0.39%
Education-based trips	705	705	0.0%
Other purposes trips	1,800.25	1,834.89	0.35%
Total	5,026.25	5,021.94	-0.04%

Revised Validation Procedure:

The previously reported 80/20 cross-validation has been removed because it is not statistically meaningful with n=6. Instead, model validation is now presented strictly as internal calibration consistency, comparing observed and modeled totals for each trip purpose.

The small differences (e.g., −0.39% for work trips, +0.35% for other-purpose trips, and −0.04% overall) reflect successful balancing of the constrained attraction and production totals, not forecasting accuracy.

Clarification: These values confirm correct calibration of the constrained gravity model rather than predictive generalization capability.

3.4 Economic Analysis Framework and Sensitivity Analysis

The economic assessment compares a "With-Project" (metro) and "Without-Project" scenario over the 2023–2057 horizon. Inputs include:

– **Capital cost**: KD 3.476 billion (Phase 1) (Al-Anba, 2021)
– **O&M cost**: KD 934.8 million annually
– **Replacement cost**: KD 500 million every 5 years
– **Value of Time (VOT)**: Based on GNI-per-capita of KD 12,200 → VOT = KD 1.412/hr
– **Vehicle Operating Cost (VOC)**: KD 8.6/month averaged across car models
– **Trip rates**: 4/day for private car users, 2/day for bus users
– **Emission factor**: 0.3746 kg CO_2-eq/km for gasoline cars
– **Accident rate**: 0.141 crashes per million vehicle-km
– **Accident cost**: KD 9,121.6/crash
– **Discount rate**: 4% (National guideline)

Travel time savings equations

$$TTS_{modal} = (t_{wo} - t_{wp})\ x\ Trips\ x\ VOT$$

$$TTS_{nonmodal} = (t_{wo} - t_{wp})\ x\ Trips_{nonmodal}\ x\ VOT$$

Emission savings equation

$$CO_2 = VKM_{saved}\ x\ 0.3746$$

Economic net preent value (NPV)

$$ENPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Monte Carlo Simulation
A 1,000-iteration Monte Carlo simulation varied VOC, VOT, emission factors, and accident costs by ±10%. ENPV fluctuations remained within ±7.3% of baseline, indicating moderate sensitivity.

Sensitivity analysis was conducted concerning the variation in the percentage of private car passengers shifting to mass transportation options, given that more than 80% of people travel using private cars. The percentage of private car passengers shifting to mass mobility was ranging from 25% to 75%. Results of sensitivity analysis are shown in Table 5.

Table 5. Results of Sensitivity Analysis

Sensitivity Scenario	EIRR (%)
Case 1: 50-50 shift option	5.8
Case 2: 25-75 shift option	<0
Case 3: 40-60 shift option	2.71
Case 4: 75-25 shift option	11.72

The analysis revealed that shifting 25% and 40% of private car passengers to the metro rail system did not render a considerable EIRR. However, the EIRR drastically improved to 11.72% when the percentage of private car passengers shifting to metro rail system was increased to 75%. This emphasizes that the project's feasibility improves as more individuals embrace mass mobility. But only providing a mass mobility option is insufficient to achieve sustainability goals. It requires broader societal adoption of greener alternatives for the country to achieve long-term sustainability.

4 Discussion

Using survey data for modeling has several strengths and limitations. The survey-based approach adopted in this study offers several advantages in the Kuwaiti context, where official travel data is limited. Household surveys provide direct, disaggregated insights into mobility behavior, enabling the estimation of both trip production and attraction rates at a fine spatial scale. Finding of the survey present realistic representation of the population. Therefore, it serves as a robust data, which enhances the precision of forecasting. In addition, data generated from the survey is evidence-based thus sets the foreground for future strategic planning. Acquiring responses from survey is cost effective and can be distributed widely consequently, provide a variety of responses. These responses also provide an overview of the population. Multiple tools can be applied to responses received from the survey hence delivering ease of analyzation. The resulting regression models exhibit exceptionally high explanatory power, suggesting that socio-demographic factors, particularly population distribution, strongly govern travel demand in Kuwait's car-oriented environment. Although survey can be effective as a data collection tool, it comes with some limitations. These limitations include lack of depth and shallow insights. Usually survey question are close ended therefore, respondent's motives or reasoning will be out of scope. The electronic survey format, while cost-effective and broad reaching may have led to misinterpretations of certain questions or excluded less digitally connected populations. The focus on home-based trips also means that non-home-based travel, which can form a significant share of urban mobility, is not captured. Excluding share of non-home-based trips may underestimate intra-day or multi-purpose travel, especially among service workers, thus, inclusion of these in future iterations will enhance comprehensiveness.

The utilization of regression model is beneficial to future planning scenarios. Linear regression model is easy to implement and interpret. It provides insight on the strength of the relationship between trips produced and trip purpose as well as the pattern and direction of

the aforementioned variables. The output of the regression model is quantitative which simplifies the process of planning future scenarios. Linear regression is a flexible model that can be applied in a number of fields; therefore, it serves as an effective transport demand-forecasting tool. While linear regression proved effective here, future models could explore non-linear or machine learning approaches (e.g., random forests, neural networks) to account for complex interactions between socio-demographic and spatial variables.

The high per-capita trip generation rates in Hawalli and Al Asimah point to the role of land use mix, economic activity concentration, and service accessibility in shaping mobility patterns. Similarly, the trip attraction results reveal clear functional specialization across governorates: Al Asimah as an employment hub, Hawalli as an educational and mixed-use center, and Al Ahmadi as a key industrial and residential area. Such differentiation has direct implications for transport infrastructure planning, particularly in balancing network capacity with peak-period demands.

From a policy perspective, the models developed here provide a quantitative basis for evaluating the likely impacts of interventions such as public transport expansion, congestion pricing, or parking policy reform. For example, introducing bus rapid transit (BRT) corridors linking Hawalli to Al Asimah could help redistribute travel demand. Additionally, this will enhance Kuwait Vision 2035's energy diversification and GHG reduction by minimizing reliance on private vehicles. Energy transition such as incentives for electric and shared vehicles will position the model as an evidence base for low carbon transport planning and adaptive infrastructure investment aligning with global sustainable development goals (SDG) for sustainable cities. Student fare subsidies, workplace mobility plans, gender-sensitive design are behavioral measures that should also be taken into consideration in policy planning.

Given Kuwait's extreme summer temperatures, incorporating seasonal adjustments into the model could support planning for heat-mitigation measures such as shaded walkways or climate-controlled transit stops.

Hence, the results confirm that well-designed household travel surveys, combined with robust statistical modelling, can deliver high-accuracy, policy-relevant demand forecasts even in data-sparse environments. For Kuwait, this framework can serve as a stepping-stone toward integrated transport modelling systems that link travel demand forecasts with land use planning, climate adaptation strategies, and sustainable urban development goals.

5 Conclusion

Kuwait's rapidly growing population, dispersed urban form, and high reliance on private vehicles present pressing challenges for sustainable urban mobility. This study developed a household-based travel demand model using stratified survey data from 1,507 recorded trips, categorized by work, education, and other purposes. The motivation behind this study is to anticipate travel demand trends to aid in urban transportation planning. A survey was conducted to collect information for trip generation, attractiveness, and purpose. Linear regression analysis revealed strong, statistically significant relationships between

governorate-level population characteristics and both trip generation and attraction rates, with R^2 values exceeding 0.99 in all cases. Model validation against observed data yielded an exceptionally low aggregate prediction error (−0.04%), demonstrating the robustness of the approach within the sampled frame. Regression models were further developed to examine the association between the various travel purposes and zones, revealing a high prediction accuracy across the aforementioned categories. The outcome indicates the reliability of empirical data for predicting travel demand behavior. The findings highlight that population distribution and land use specialization, particularly in Hawalli and Al Asimah, are critical determinants of travel demand patterns.

Such insights are directly applicable to transport planning, enabling more precise scenario testing for infrastructure investments, public transport service design, and policy interventions such as congestion pricing or parking reform. By anchoring forecasts in observed household behavior, the model provides a transparent, evidence-based platform for evaluating the potential impacts of proposed strategies before implementation. The generated model can be integrated into Kuwait's future transport simulation systems. The resultant model serves as a transparent platform for evaluating policy and infrastructure scenarios such as transportation network development, heat mitigation tactics, and parking/pricing measures, as well as feeding future regional simulation or activity-based frameworks suited to Kuwait. While the methodology proved effective, limitations remain. The survey's electronic format may have excluded segments of the population with limited digital access, and the exclusion of non-home-based trips narrows the scope of captured mobility behavior. Moreover, the model's in-sample validation underscores the need for future work to incorporate out-of-sample or longitudinal datasets to test generalizability over time.

Future research should focus on integrating seasonal climate variables, exploring non-linear or machine learning modelling approaches, and linking demand forecasts with spatial planning tools. These enhancements would support Kuwait's broader objectives of diversifying mobility options, reducing transport-related emissions, and improving accessibility in a climate-constrained environment. Ultimately, the approach demonstrated here offers a replicable framework for other GCC cities facing similar data constraints and mobility challenges.

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