Estimation of Trip Generation Rates for Residential Areas in Jordan

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ABSTRACT

The objective of this study was to develop trip generation for residential areas, where Irbid city was selected as a case study. Household survey was carried out to collect data on trips and their purposes on typical workdays and holidays. Socio-economic characteristics of households were also obtained through field interviews. A total sample of about 2500 households was interviewed. 100 households were interviewed for validation purposes.

Both regression analysis and cross-classification approach were used to model trip generation rates. Analysis carried out in the study indicated that the number of generated trips is influenced by family size, car ownership and income level. On workdays, the analysis indicated that the number of home-based work trips constitutes about one-third of the total home-based trips. Also, it was found that the number of trips on holidays represent nearly one-third of the number of trips generated on workdays. Although performance of both approaches was very well, cross-classification approach proved to yield more accurate values. Compared with developed countries, trip generation rates for residential areas in Jordan were found to be substantially low.

KEYWORDS: Trip generation, Residential areas, Regression analysis, Cross-classification approach.

INTRODUCTION

Transportation planning plays a vital role in the development of the transportation network. One of the key components in transportation planning is travel demand forecasting. Trip generation is the most important step in the four-step based model (Juan and Luis, 2011). There are two types of trip generation models: production models and attraction models. A production model predicts the number of home-based trips to and from the place where trip makers live (Bowman and Ben-Akiva, 2001). Trip generation provides the foundation for the travel demand forecasting process. Therefore, the accuracy of estimation is essential, since it can propagate the errors into the entire estimation process. In order to improve the precision of forecasting, sound trip generation models are required to consider local conditions rather than importing models developed for other countries (Golob, 2000).

Trip generation models or rates are considered as a corner stone for sound transportation network planning studies. *The Trip Generation Manual* published by the Institute of Transportation Engineers (ITE) provides general guidelines and values of trip generation for different land use developments (ITE, 2012). However, the manual has focused on vehicular trips, land uses in suburban settings and non-transit-oriented environments. Several studies reported that person trips estimated based on vehicular trips using the ITE manual resulted in an overestimation of such trips (Miller et al.,

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2006). For example, Al-Sahili (2010) and Mustafa (2016) indicated that trip generation rates for residential land use in Palestine are lower than the ITE rates. Thus, values provided in the manual should be calibrated for usage elsewhere outside the USA.

For Jordan conditions, trip generation models or rates for residential areas are not yet developed. The development of these models is vital for planners, developers and engineers. Thus, the objective of this study was to develop person-trip generation models and rates for residential areas in Jordan, where Irbid city was selected as a case study. Also, the impacts of socio-economic variables on trip generation levels were investigated. Models or rates were developed based on trip purpose.

DATA COLLECTION

To achieve the objective of this study, Irbid city was selected as a case study. According to the Population and Housing Census of 2015 (Department of Statistics, 2015), the city has a population of 313,830. The city consists of seven regions as shown in Figure 1.

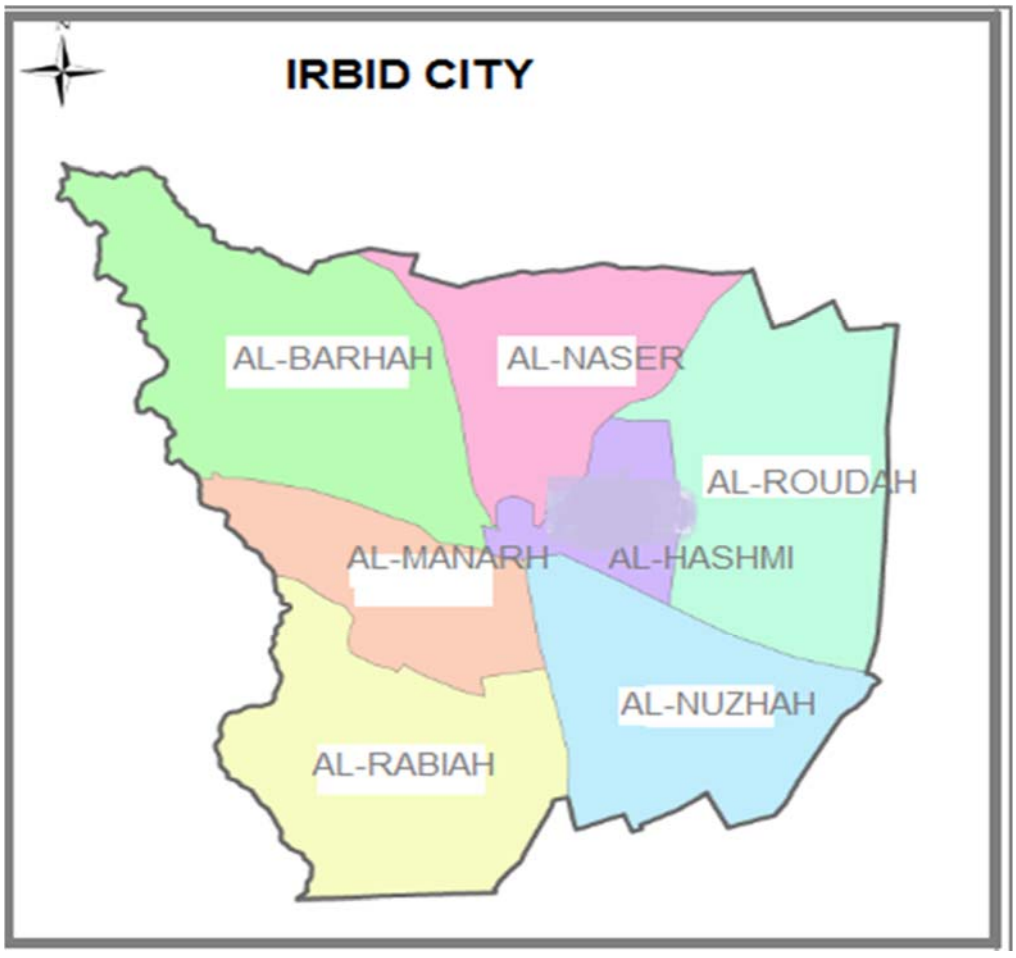

Figure (1): Residential regions in Irbid city

Household interview survey was carried out to collect data on trip and socio-economic characteristics (Sanaa, 2016). A questionnaire form was prepared for this purpose. The form included questions on income level, number of persons in the family, number of daily trips, mode of transportation, purposes of trips and car ownership. Households were randomly selected and interviewed at their homes. Direct personal interviews with respondents were made and the obtained data recorded in the prepared questionnaire sheet. The collected data included number of home-based or non-home-based trips on a typical workday and holiday, purpose of trip and mode of travel. Workday trips were classified as home-based work trips (HBW), home-based other trips (HBO) and non-home-based trips (NHB). HBO trips included school, recreation, medical treatment and visit or shopping trips. Holiday trips were classified as HBO and NHB. Eventually, data on income level and number of owned vehicles were also obtained.

For the city, the minimum sample size was computed as follows (Bartlett et al., 2001; Cochran, 1977):

$$n = (t^2 * s^2)/d^2 \quad (1)$$

where:
n = required sample size.
t = value for selected level of risk of error.
s= estimate of standard deviation in the population.
d = acceptable margin of error of mean.

Based on the results of a pilot study, the mean and standard deviation of the number of trips were 7.7 and 1.75, respectively. For level of risk of 1% (t=2.58) and 3% margin of error (Krejcie and Morgan, 1970), the required sample size for Irbid city was 385 (Sanaa, 2016). Since the computed sample size did not exceed 5% of the number of Irbid's households (60,000*0.05), Cochran's (1977) correction formula was not used. However, to obtain accurate results and fill all possible cells in the cross-classification analysis, a sample size of 2500 households was adopted. However, it was found that about 5% of households apologized and refused the interview. Therefore, only 2371 households were successfully interviewed. Also, an additional random sample of 100 households was obtained from all regions of the city for validation purposes. Table 1 provides a summary of the collected data.

Table 1. Sample size and household characteristics for each region

Region/Zone	Sample size	Average household size	Average income (JD)/HH	Average car ownership/HH
Al-Roudah	359	5.38	1318	1.39
Al-Hashmi	184	5.1	886.6	1
Al-Naser	187	5.03	873.8	0.79
Al-Rabiah	348	5.4	1017.8	1.35
Al-Nuzhah	374	5.32	1113.5	1.4
Al-Manarah	507	5.28	779.7	0.9
Al-Barhah	412	5.07	655.7	0.5
Total	2371	5.23	949.3	1.05

HH: Household.

ANALYSIS OF RESULTS

Descriptive Characteristics

Based on the analysis of the collected data, the average family size is 5.23 persons. Figure 2 illustrates family size distribution for the included data. On workdays, HBW, HBO and NHB were 32%, 52% and 16% of the total generated trips per household, respectively. Vehicle ownership distribution indicated that 32%, 44% and 24% of households (HH) had zero, one and two or more vehicles, respectively. Although seven classes of monthly income were suggested; namely, income ≤300 JD, 300 <income ≤500, 500 < income ≤750, 750 < income ≤1000, 1000 < income ≤1500, 1500 < income ≤2000 and income >2000 JD, the analysis revealed that the first four classes can be pooled together. In the same sense, the classes 1000< income ≤1500 and 1500 < income ≤2000 JD were pooled to form one class. Thus, three levels of income; namely, income ≤ 1000 JD, 1000 JD < income ≤ 2000 JD and income >2000 JD, were adopted for further analysis. These classes were designated as low, medium and high income levels.

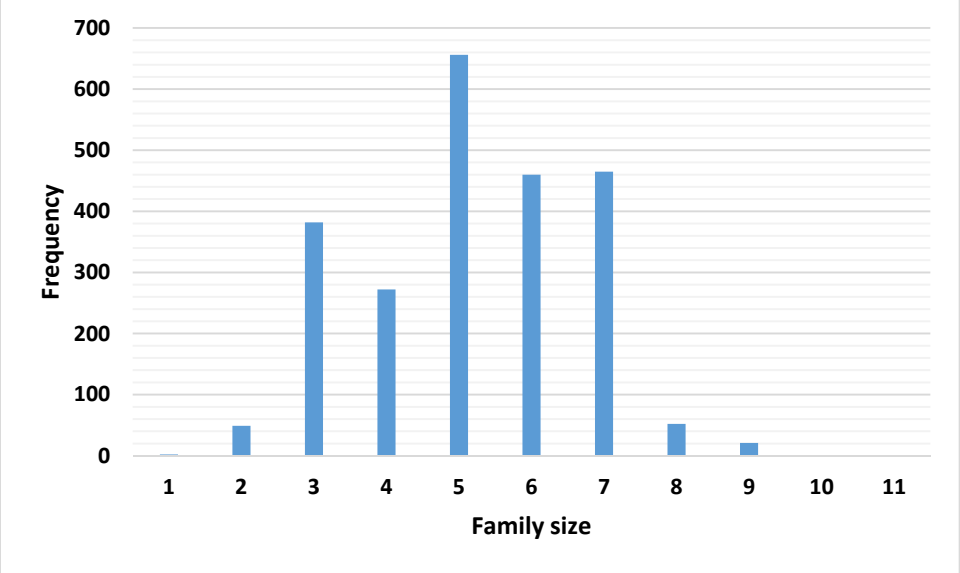

Figure (2): Family size distribution in Irbid city

Development of Trip Generation Rates

Trip rates were computed for each combination of family size, car ownership and income level. Tables 2 and 3 present the obtained rates for a workday and a holiday, respectively. Table 2 shows that none of the low income households had two or more vehicles. Irrespective of family size, income or car ownership, the majority of trips on workdays were HBO. Probably, the inclusion of education trips within HBO was the crucial factor. As anticipated, NHB trips represented the lowest fraction of all trips. Total trips on a holiday constitute nearly one-third of the total trips on a workday.

Trip Generation Models

Based on regression analysis, the following regression models were developed to estimate trips on workdays;

$$HBW = 1.60 + 0.11\ (X_1) + 0.69\ (X_2) + 1.97\ (X_3) + 0.67\ (X_4) + 0.22\ (X_5) \quad (2)$$

$$HBO = 1.12 + 1.00\ (X_1) + 1.32\ (X_2) + 7.24\ (X_3) + 2.24\ (X_4) + 1.63\ (X_5) \quad (3)$$

$$THB = 0.44 + 1.73 (X_1) + 1.59 (X_2) + 4.69 (X_3) + 1.50 (X_4) + 1.05 (X_5) \quad (4)$$

where:

THB = Total home-based trips (HBW plus HBO).

X_1 = Family size, persons.

X_2 = Income level, 1 if medium income and 0 otherwise.

X_3 = Income level, 1 if high income and 0 otherwise.

X_4 = Car ownership, 1 if one car and 0 otherwise.

X_5 = Car ownership, 1 if two cars or more and 0 otherwise.

Table 2. Cross-classification averages of HBW, HBO and NHB trips in Irbid city on a workday

Income level	Family size/HH (sample size)	Car ownership								
		Zero			One			Two+		
		HBW	HBO	NHB	HBW	HBO	NHB	HBW	HBO	NHB
Low income	≤3/(120)	1.62	5.18	.65	1.8	5.3	0.93	NA	NA	NA
	4/(201)	1.7	6.2	1.0	2.2	6.4	1.0	NA	NA	NA
	5/(191)	1.94	8.0	1.1	2.6	8.9	1.3	NA	NA	NA
	6/(195)	2.3	9.6	1.6	3.8	9.4	1.4	NA	NA	NA
	7/(162)	3.2	12.4	1.8	4.2	13.2	1.44	NA	NA	NA
	≥8/(119)	4.0	12.5	2.1	4.6	13.4	1.5	NA	NA	NA
Medium income	≤3/(124)	1.98	6.52	1.4	2.0	7.1	1.35	2.8	4.2	1.0
	4/(147)	2.4	9.0	2.3	2.7	9.2	1.6	1.6	11.7	1.0
	5/(163)	3.0	11.0	2.5	3.2	11.0	1.7	3.2	12.0	0.95
	6/(148)	4.0	11.2	2.7	4.2	11.28	2.0	4.8	12.2	0.90
	7/(155)	4.2	12.4	2.9	4.6	12.4	2.0	5.6	12.6	0.80
	≥8/(80)	4.6	12.5	3.1	5.6	13.2	2.3	6.2	14.4	0.70
High income	≤3/(24)	3.0	8.4	1.9	4.0	9.8	1.9	4.6	9.8	0.76
	4/(83)	4.0	8.78	2.3	4.2	10.2	2.4	5.4	10.2	0.70
	5/(79)	4.6	11.2	2.5	5.4	11.8	2.5	6.2	12.6	0.65
	6/(89)	3.6	12.2	2.7	5.8	14.8	2.8	6.6	15.0	0.63
	7/(77)	6.2	13.4	3.1	6.2	16.0	2.9	7.0	12.5	0.50
	≥8/(55)	7.4	14.3	3.5	6.8	18.2	2.9	8.2	20.0	0.40

NA: Not available.

Table 3. Cross-classification rates of HBO and NHB in Irbid city on a holiday

Income level	Family size/HH (sample size)	Car ownership					
		Zero		One		Two+	
		HBO	NHB	HBO	NHB	HBO	NHB
Low income	≤3/(120)	1.9	0.01	2.1	0.01	NA	NA
	4/(201)	2.0	0.03	2.5	0.03	NA	NA
	5/(191)	2.2	0.05	2.8	0.06	NA	NA
	6/(195)	2.3	0.05	2.9	0.05	NA	NA
	7/(162)	2.5	0.05	3.3	0.07	NA	NA
	≥8/(119)	3.5	0.06	3.8	0.07	NA	NA
Medium income	≥3/(124)	3.9	0.03	5.1	0.05	5.5	0
	4/(147)	5.0	0.05	6.1	0.07	6.5	0.03
	5/(163)	5.4	0.05	6.5	0.09	6.8	0.04
	6/(148)	5.55	0.06	6.9	0.11	7.3	0.03
	7/(155)	5.8	0.06	7.1	0.12	7.99	0.04
	≥8/(80)	6.1	0.07	7.3	0.13	8.1	0.06
High income	≤3/(24)	4.0	0	5.2	0.02	8.7	0.76
	4/(83)	5.2	0.04	5.5	0	5.9	0.7
	5/(79)	6.1	0	6.8	0.05	7.3	0.65
	6/(89)	6.6	0.07	7.1	0	7.56	0.63
	7/(77)	7.1	0	7.5	0	8.2	0.5
	≥8/(55)	7.5	0	7.9	0	9.3	0.1

All the above developed regression equations and their parameters were found to be significant at the 95% confidence level. For HBW, HBO and THB, the coefficients of multiple determination (R^2) had the values of 0.50, 0.64 and 0.67, respectively. For behavioral and observational data, these coefficients are considered to be satisfactory. For example, coefficients of determination in the Trip Generation Manual varied from 0.83 to 0.52 or even lower values (ITE, 2012b). However, Vermont Trip Generation Manual (2010) used regression equations only where $R^2 \geq 0.50$. Otherwise, trip generation rates should be used.

Figure 3 was drawn to judge the aptness of the HBO model, which shows the observed cumulative probability of residuals against their expected values when the distribution is normal. This figure indicates that the error terms are approximately normally distributed. Eventually, the linear regression approach is suitable to model the generated trips (Neter et al., 1985). Investigation of residuals revealed that no outliers were detected.

Although NHB trips were considered in the study, the developed regression equation was relatively weak (R^2 less than 0.5). The developed equation for NHB trips on working days was:

$$NHB = 1.03 + 0.05 (X_1) + 0.01 (X_2) + 0.60 (X_3) + 0.06 (X_4) \quad (5)$$

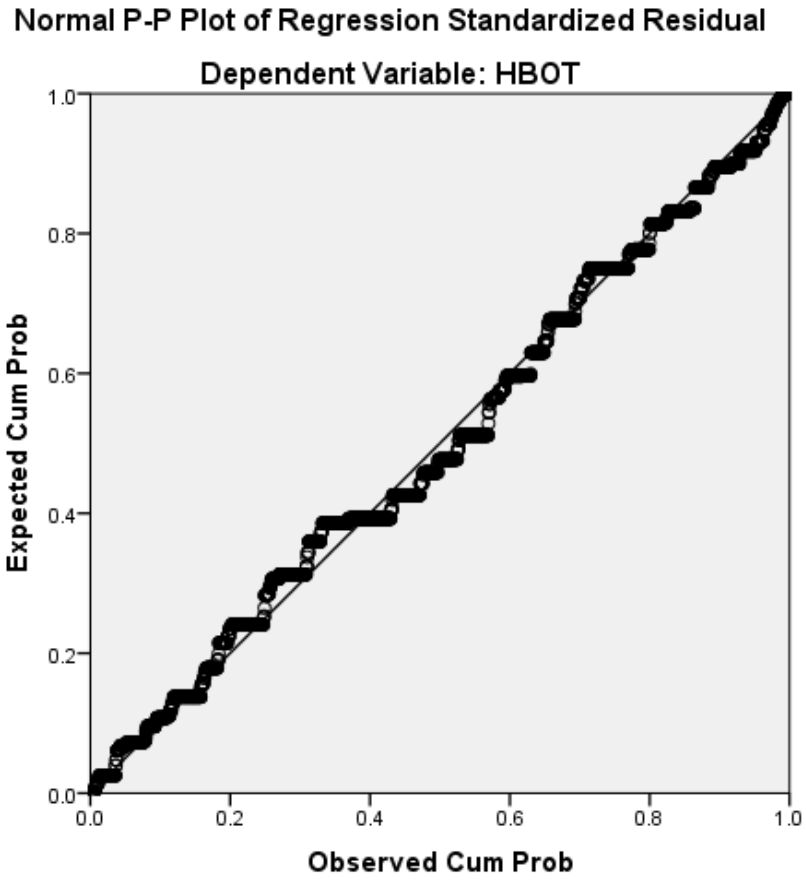

Figure (3): Expected cumulative probability *versus* observed cumulative probability for HBO trips model

Compared with HBW and HBO, NHB trips had lower parameter coefficients. Investigation of the collected data revealed that NHB trips formed nearly 16% of the total trips. Probably, residents have not managed their trips to perform more than one activity in one round trip or NHB trips are affected by other factors, which were not included in this study.

Similarly, an equation was developed to estimate HBO trips on holidays:

$$HBO = 0.63 + 0.77(X_1) + 2.01(X_2) + 9.21\ (X_3) + 2.907(X_4) + 1.85\ (X_5). \quad (6)$$

The regression equation above and all its parameters were significant at the 95% probability level, with a coefficient of determination of 0.65. It should be noted that Equations 3 and 6 were developed for the same trip purpose HBO, but different coefficients were obtained, specifically for income and car ownership variables. As stated before, HBO trips included social visits, shopping and recreational trips. Most of these trips are normally made at weekends, as such coefficients associated with income level and car ownership in Equation 6 are larger than those in Equation 3. This is logical, since residents who had higher car ownership and wealthy status may perform more trips on holidays.

Again, the relationship between NHB trips and the collected socio-economic variables, on holidays, was very weak and as such NHB trips were excluded from further analysis. Compared with NHB trips on workdays, the number of NHB trips on holidays was very low (see Tables 2 and 3).

Validation Analysis

As stated in the data collection part of this study, a random sample of 100 observations was selected from all regions to check the performance of the developed regression and cross-classification approaches. These 100 observations were not used in regression analysis or in rate development. Table 4 illustrates the performance of regression and rate approaches to estimate HBW and THB trips on workdays. This table shows the average values of actual (observed) and estimated trips using regression and rate approaches. Although the outcomes of both approaches were comparable and consistent with the actual field data, the rate approach provides better estimates. Thus, both models are applicable to estimate residential trips, provided that the data are within the limits and context of Irbid city. These limits included residential areas in Middle East medium size cities in medium-income developing countries with average car ownership of nearly one car per household.

DISCUSSION

Previous studies and existing trip generation manuals provide essential guidance into the process of trip generation forecasting. This study described trip generation rates as a function of socio-economic parameters of households. According to the research findings, there is a linear relationship between trip generation and car ownership, household size and level of income of households. These findings are compatible with those of previous studies (Sowgat, 2012; Daniel and Ituen, 2013; Golob, 2000; Oyedepo and Makinde, 2009). For example, Sowgat (2012) investigated residential trip rates in Bangladesh using linear regression analysis, while Oyedepo and Makinde (2009) used multiple regression analysis to model residential trips in Nigeria. These studies revealed that residential trips are mostly related to socio-economic variables.

For Irbid city conditions, the average household size is 5.23 members with a range from two to nine persons. In general, a total of 7.7 trips were generated by a household on a workday. Again, this result is comparable with the value obtained by Dodeen (2014), who investigated trip generation rates for residential areas in Jericho city, Palestine. He reported that an average family size of 5.03 persons generated about 6.9 trips per workday.

Contrary to the findings of this study, most previous studies on trip generation did not investigate non-home-based trips; however, results of this study showed that the relation between NHB trips and socio-economic characteristics was very weak. Clearly, other variables or behavioral issues may capture such large variations. For example, Juan and Luis (2011) indicated that household structure variables, such as age, sex, marital status and proportion of women joining the labor force as well as accessibility may impact the number of generated trips. For Jordan conditions, it is recommended to estimate NHB using rates rather than the developed equation (Equation 5).

Table 5 shows a comparison between home-based trip generation rates in Irbid city as per the findings of this study, ITE (ITE, 1997) and Duhok city in the Northern part of Iraq (Al-Taei and Taher, 2006). Trip generation rates obtained in this study are similar to the values presented for Duhok city due to similarity of socio-economic parameters and size of population. In contrast, values listed in the ITE are substantially larger than values concluded for Irbid city. In fact, differences in cultural and behavioral patterns, employment level, dominant mode of transport, land-use planning, among other factors, may contribute to these differences. Thus, every country should develop its own manuals for accurate trip generation estimates and ultimately improve travel forecasting outcomes.

Table 4. Performance of regression and rate approaches to estimate HBW and THB trips

Region/Zone (sample)	HBW			THB		
	Actual	Regression	Rate	Actual	Regression	Rate
Al-Roudah (15)	2.1	2.3	2.0	12.1	14.0	13.1
Al-Hashmi (10)	2.3	2.6	2.1	11.2	14.1	14.0
Al-Naser (16)	2.8	3.2	3.0	13.4	16.0	14.3
Al-Rabiah (18)	4.0	4.2	4.0	16.5	14.2	17.3
Al-Nuzhah (14)	4.0	4.6	4.2	17.2	20.0	17.0
Al-Manarah (15)	4.2	3.8	4.6	14.1	12.4	13.0
Al-Barhah (12)	3.2	4.0	3.0	15.2	17.0	14.6

Table 5. Comparison between total home-based production trips

Income level	Family size	Car ownership								
		Zero			One			Two+		
		Irbid	ITE	Dohuk	Irbid	ITE	Dohuk	Irbid	ITE	Dohuk
Low income	≤ 3	6.8	10.3	7.07	7.1	9.9	7.2	NA	NA	NA
	4	7.9	11.5	8.36	8.5	10.3	8.4	NA	NA	NA
	5	10.1	13.2	11.77	11.5	14.2	11.92	NA	NA	NA
	6	12.0	15.6	12.3	13.2	15.8	13.13	NA	NA	NA
	7	15.8	19.8	16.1	17.5	19.7	18.0	NA	NA	NA
	≥ 8	16.5	NA	16.49	17.8	NA	18.1	NA	NA	NA
Medium income	≤ 3	8.5	14.1	10.1	9.1	15	10.5	11.2	16.3	NA
	4	11.8	14.5	12.3	12.9	16.9	13.0	14.9	17.1	NA
	5	14.1	17.1	14.67	13.9	17	14.1	16.1	17.4	NA
	6	15.3	18.9	15.2	14.8	18.1	15.0	16.9	18.1	NA
	7	16.3	19.1	16.1	16.7	19.2	17.2	17.9	19.3	NA
	≥ 8	17.1	NA	18.2	18.8	NA	19.1	20.5	NA	35.6
High income	≤ 3	11.4	15	12	13.8	15.9	14.1	14.4	17.0	NA
	4	12.78	15.3	14	14.6	17.0	15.0	15.8	18.3	NA
	5	15.8	28.0	16.1	17.4	18.2	17.7	18.5	19.0	NA
	6	15.8	NA	18.0	19.1	20.0	20.0	21.6	NA	21.7
	7	19.4	NA	20.1	23.1	NA	23.5	22.6	NA	23.1
	≥ 8	21.7	NA	22.0	25.0	NA	35.2	28.1	NA	28.3

NA: Not available.

Finally, the results of validation indicated that both cross-classification and regression approaches provided comparable results. The obtained estimates using both approaches were very close to the actual field data. However, cross-classification approach provided more accurate results. Probably, the included variables in the regression models could not capture all trip variations. Thus, further studies are recommended in this area to highlight this issue, specifically MHB trips.

CONCLUTIONS

Based on the results presented in this study, the following points were concluded:

1. The number of generated residential trips in Irbid city is highly dependent on socio-economic variables, including household size, car ownership and household income level.
2. For residential areas, the total generated trips on holidays constitute nearly one-third of the total trips generated on workdays. Also, the number of home-based work trips represent about one-third of the total home-based trips on workdays.
3. Multiple linear regression models were found to be suitable to estimate trips generated from residential areas. Socio-economic variables, including household size, car ownership and income level were the main factors in predicting the number of trips.
4. Compared with developed countries, residential areas in developing countries generated lower trip rates.
5. Both regression analysis and cross-classification approaches provided comparable trip rates. However, cross-classification approach provided closer estimates when compared with actual field data.

Acknowledment

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