Trip Distribution Gravity Model of Al-Diwaniyah City: A Case Study

Rana A. Yousif, Sady A. Tayh and Abbas F. Jasim

Abstract The main objective of this study is the construction of trip distribution models for allotting trips from each traffic analysis zone to each other in the study area. For this purpose, the city of Al-Diwaniyah in Iraq has been separated into five subdivisions with 70 traffic analysis zones covering a total area of 52 km^2. Surveys were conducted throughout prearrangements with high schools, administrations, and some colleges. Five hundred questionnaires were distributed in the city with a response rate of 78.4%. Standard TransCAD Gravity Model software version 4.5 was used in the trip distribution modeling process. The gamma function was adopted for developing the friction factors for Al-Diwaniyah. The gamma coefficients were obtained for five trips purposes in Al-Diwaniyah. The friction factors were determined for up to 60 min using one-minute intervals. With increased travel time, friction factors decrease when the gamma coefficients (b and c) have negative values. The average trip length for the gravity model is range between 12.5 and 18.5 min for the five trip's purpose that was considered in the study. The trip Length frequency distribution (TLFD) of a home base work trip is 20–25 min. Home base educational trips have two ranges: 11–15 min for short trips (schools within the same zone) and 16–20 min for long trips. The home base shopping trips have an average TLFD of 6–10 min because the shopping destinations are within the TAZs.

Keywords Travel time · Trip distribution · TransCAD · Traffic analysis zone (TAZ) · Friction factor · Gravity model

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1 Introduction

Al-Diwaniyah city as many other Iraqi cities has no comprehensive published studies in transportation planning, or traffic management plans taking into account the annual growth in population, employment and car ownership, which made the performance of daily activities, represent a burden increases day after day. These reasons become necessary to prepare the transfer of detailed studies of the areas to identify the causes of these trips and then determine the origin and destination of these trips and identifies where the trips will go.

Travel demand can be defined as the number of vehicles or pedestrians during a period of time that can be expected to travel in a particular section of a transportation system over a diversity of social, economic, land-use, and environmental circumstances. Travel demand, in its forecasting process, can predict the type, number, and source of trips on a transportation system [3].

Numerous analytical approaches may be utilized to conduct transportation studies, design, or plans. Travel demand modeling is one of these approaches. The most popular method for travel demand modeling is the so-called four-step approach that takes into consideration distribution, generation, route allocation, and mode choice [6]. The first step of this modeling process is trip generation, which is a process that estimates the total number of trips produced from and attracted to each traffic analysis zone (TAZ) for each trip purpose [6].

Trip generation studies concentrate on residences, and trip production is considered a function of the socio-economic characteristics of households. The vocabulary of land use utilized for TAZs includes "producing" or "generating" trips. Additionally, terminuses of trips in TAZs are called "trip attractors." The study of attractors is concentrated on non-residential land uses [1].

Trip distribution represents the second phase of the traditional travel demand modeling process. The choice to travel for a specific purpose is known as trip production. Trip distribution is the method by which the trips produced in any sector are assigned to other different sectors in the study area. The distribution could be within the study area or reciprocal with neighboring areas [3].

The task of a trip distribution model is to "distribute" or "link up" the district trip terminals, that is, the productions and attractions for every sector as predicted by the trip generation model in order to estimate the flow of trips T_{ij} from each sector$_i$ to each attraction sector$_j$ [4].

One of the important issues that affect trip distribution is the cost of travel between two zones. This cost can be counted in terms of time, distance, or money units. An amount joining all the foremost elements related to the disutility of a trip is frequently utilized, which usually represents the overall cost of travel [6].

There are several essential methods utilized in trip distribution modeling. The trip distribution models are classified into two main categories: growth factor models and synthetic models. Growth factor models, which we will be discussing, are based on the hypothesis of the current pattern of travel that may be anticipated for the target year in the future by using specific growth factors. Growth factor models are classified into a uniform factor model, average factor model, fratar model, Detroit model, and doubly constrained growth factor model [7].

The most largely used and reported methods for trip distribution modeling is the gravity model, which deems that the number of trips between each two sectors is straight proportional to the number of trips generated from and attractions in each two sectors and contrariwise proportional to the expected travel time for the trip between the same two sectors [3].

The gravity model uses network travel-highway impedance and friction elements to distribute journeys between the sectors. The sector-to-sector travel obstacle matrix denotes the path of least impedance between each two sectors. The friction issue may be the degree of resistance or refusal of people to generate a trip depending on spatial split-up between sectors. K-factors are often utilized in the travel demand model to regulate the desirability of trips between two sectors because of a physical obstacle or separate zonal socio-economic property. K-factors were not utilized in the wide travel demand model [5].

The gravity model can be adjusted and applied to utilize traditional software for transportation planning. The methodology to adjust the gravity model is a repeated process, during which the travel time or resistance factors are established for each trip intention and a mathematical function. Numerous software packages are accessible to help in developing a four-step travel demand model. The predicting packages utilized globally include TransCAD, CUBE, EMME/2/3, and VISUM. All these listed software contain the means required to sustain four-step modeling methods with the support of scripting languages [8].

TransCAD (Caliper Corporation, Newton, MA, USA) is linked with ArcGIS into a single combined platform. This platform contains complicated GIS attributes like buffering, polygon overlay, and geocoding. TransCAD utilizes GIS Developer's Kit (GISDK) interface to obtain the travel demand modeling process and to generate add-in applications [2]. TransCAD offers alternative procedures for each step of the transportation predating method, and it provides features and tools to evaluate and analyze project outcomes [10].

2 Study Area

The study area comprises the city of Al-Diwaniyah, the capital of Al-Qadisiyah Province in Iraq. It is located on longitude 31° 59′ 4.88″ and latitude 44° 55′ 11.08″. The total area of Al-Diwaniyah is 319 km^2. The estimated population in 2015 was 42, 2512 according to the Directorate of Statistics of Al-Diwaniyah. The study area was divided into five sectors and 70 traffic analysis zones based on the division of the Municipal Council of Al-Diwaniyah as shown in Fig. 1 [9]. For the purpose of household data collection, two survey methods were used: questionnaires and full home interviews. Three hundred and fifty question aires were distributed through high school administrations and some colleges, while 150 forms were used for the home interview purpose. The data collection began on the 15th of February 2018 and was completed on 30th of April 2018. The questionnaire forms are distributed during the working days (Sunday–Thursday) while full interview is conducted in the weekend and begins at 10:00 AM and is completed at 6:00 PM. The questionnaire response rate was 78.4%.

3 Model Development

Trip distribution models can be used to estimate the exchange of trips between regions based on the characteristics of the land-use pattern and transportation systems within the study area. In the transportation planning process, the gravity model is the most commonly used model for trip distribution modeling. The gravity model estimates attraction by generating models of flight components according to the theory of gravity in Newton. The standard gravity model assumes that the number of trips between two zones is directly proportional to trips generated from and attracted to each pair of zones and inversely proportional to the required travel time for trips between each pair of zones [5].

The gravity model formulation states that the number of trips between each zone is equal to (see Eq. 1):

$$T_{ij} = P_i * \frac{A_j F_{ij} K_{ij}}{\sum_{j=0}^{n} A_j F_{ij} K_{ij}} \tag{1}$$

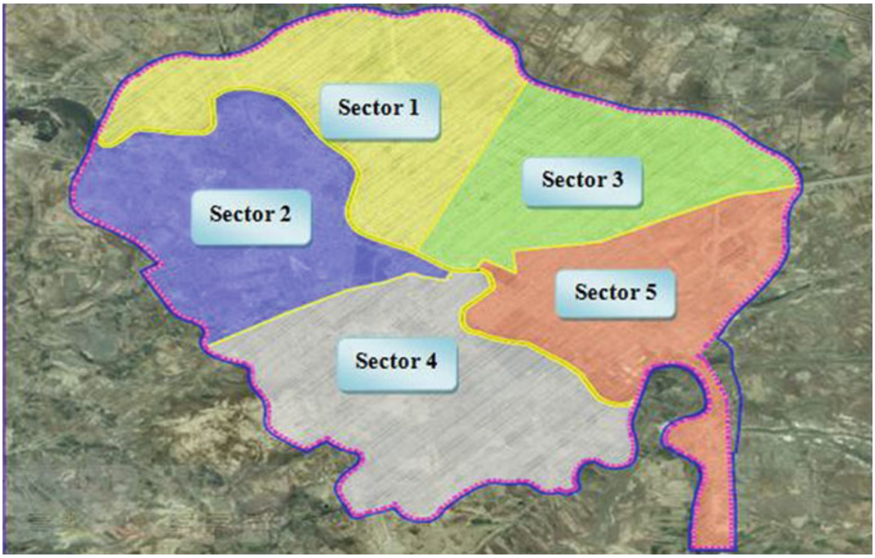

Fig. 1 Available sectors of the municipal council of Al-Diwaniyah [9]

where T_{ij} is the number of distributed trips from zone i to j, P_i is the number of generated trips in zone i, A_j is the number of attracted trips to zone j, $F_{ij}$is the friction factor according to spatial separation between zones i and j, and K_{ij} is the adjustment factor between zones i and j.

The gravity model procedure produces a trip table for each trip purpose. While the common set of purposes is HBW, HBO, and NHB (Non Home base trips), for this study five trip purposes have been considered:

- HBW: Home base work trips
- HBO: Home base other trips. HBO is improved by further stratifying the purpose into:
- HBEd: Home base educational trips
- HBSR: Home base social/recreational trips
- HBSh: Home base shopping trips.

4 Travel Impedances

Highway obstruction is one of the key income parameters of the gravity model for trip distribution. Travel impedance can be defined as the least resistant road between each pair of zones. This impedance can be represented by distance, travel time, and/or tolls, which are summed for the links between each pair of zone. In this study, travel time between each pair of zones was considered as an impedance parameter.

The TransCAD software version 4.5 was used to produce a travel time's matrix, or travel skim, based on the minimum time path to move between each pair of zones. The free flow travel times were based on speed and distance only without delay or volume. Table 1 presents the free flow travel times between each pair of zones in the study area. The results in the table are symmetrical about the diameter which presents that, the minimum time path to move between each pair of zones is the same in the two direction this is due to the two way roads network.

Inter-zonal travel time is the travel time within the zone. Most inter-zonal trips take place on the local streets in the Al-Diwaniyah city roadway network that are usually not coded. Therefore, the inter-zonal travel time must be estimated. The inter-zonal travel times in the Al-Diwaniyah trip distribution model are calculated

Table 1 Average value of travel times between TAZs (min)

Zone	1	2	3	4	5
1	8.57	15.16	14.82	21.45	22.37
2	15.16	8.47	20.35	15.33	20.67
3	14.82	20.35	8.48	19.82	16.26
4	21.45	15.33	19.82	8.80	17.66
5	22.37	20.67	16.26	17.66	8.48

as one half the travel time from one zone to the three nearest adjacent zones (nearest neighbor technique) using a module of the TransCAD software [8].

The station's working hours represent impediments to the origin and destination of the trip, such as the amount of time it takes to walk to/from public transportation, parking, places to pay for parking, etc. [5].

Terminal times vary by zone type. The times of the terminals are directly proportional to the population and operational density of the area. In this study, the inter-zonal times were calculated before the terminal times were added. Table 2 shows the terminal time in minutes measured for each selected study area type in Al-Diwaniyah. The terminal time is directly proportional to population density of each study area type as shown in the table.

5 Friction Factors

The friction factor is the independent primary variable, the spatial separation effect meter, and the time between two regions in the gravity model. Friction is the inversely spatial separation between areas of factors associated with. For more travel time, reduce the friction factors.

Three different functional forms were used to calculate friction factors. The friction factors for the Al-Diwaniyah distribution model were developed using the gamma function described in Eq. (2) [5].

$$F_{ij} = a * t_{ij}^{b} * e^{c * t_{ij}} \tag{2}$$

where F_{ij} is the friction factors between regions i and j and coefficients a, b, and c; and t_{ij} is the time of the transition between regions i and j and the base of natural logarithms.

The gamma function is the most widely used and recommended in transportation planning practices. The friction is developed to model the distribution of Al-Diwaniyah trips using gamma function factors. The friction selected to study was based on criteria developed by Martin and McGuck [5] and was adjusted based on the observed travel data. The iterative process was used to calibrate the calculated friction factors to correspond to the average length of the trip and the frequency allocations observed. The initial gamma function coefficients were obtained from the National Cooperative Highway Research Program (NCHRP)

Table 2 Measured terminal time of each area type for Al-Diwaniyah

Area type	Terminal time (min)
Commercial/residential (high density)	5
Commercial/residential (moderate density)	4
Commercial/residential (low density)	3

Report 365[5]. In order to get gamma function coefficients, the NCHRP Report 365 provides three basic trip purposes: HBW, HBO, and NHB. The initial gamma function coefficients for HBO were used for HBSR and HBSh. The HBEd trip purpose employs the same friction factors as HBW in this study.

The calculation of the friction factors runs for up to 60 min, in one-minute periods. During the calibration process, it should be noted that the friction factors decrease faster as the length of the trip shortens.

Table 3 shows the final gamma function coefficients for the selected study area. Friction factors over time decrease when the gamma coefficients (b and c) have negative values.

The measured friction factors estimated in Fig. 2 are provided according to the purpose of the trip. This plot provides the sensitivity of the image of the traveler to travel time depending on the purpose of the trip. More sharp curves mean more sensitivity to travel time. As the travel time increases the friction factors sharply decreases for example for HBW trips at 5 min travel time, the friction factor is 10,000

Table 3 Calculated gamma function coefficients for Al-Diwaniyah model

Trip purpose	A	b	c
HBW	35,250	−1.331	−0.0651
HBEd	55,600	−1.521	−0.0523
HBSR	85,150	−1.066	−0.0911
HBSh	32,500	−1.230	−0.0266
HBO	65,200	−0.943	−0.0780

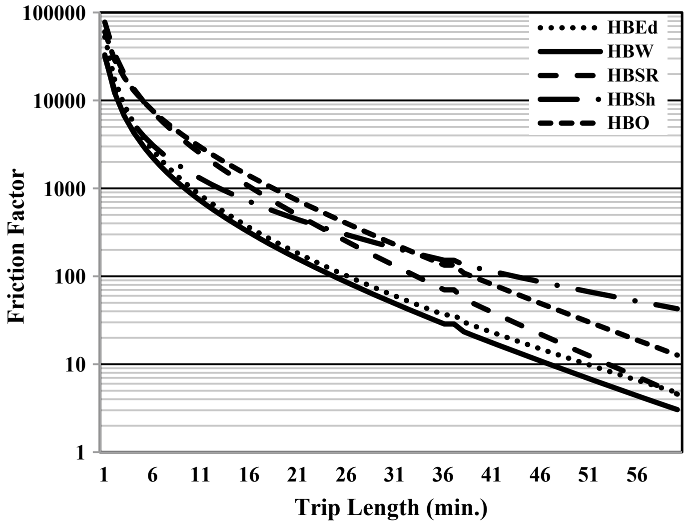

Fig. 2 Estimated friction factor for Al-Diwaniyah

but when the travel time increases to 60 min. the friction factors will be only 3. The sharpness in the figure is not clear due to the use of logarithmic scale for y-axis.

6 Average Trip Length

The most desirable source used to calibrate trip length data was derived from a questionnaire conducted during a household interview with people in the study area. The average trip lengths for business trips were generally from 15 to 20 min in small communities and up to 25–30 min in large communities, according to a report [5].

The average trip lengths by trip purpose for the models were compared against the household travel survey data are presented in Table 4.

Two reasonable checks should be performed on these results.

(1) The average length of the journey for home-work trips resulting from the gravity model should be compared to the average length of the home-work journey derived from the home interview surveys. The average trip length produced by the gravity model should be less than the average trip length derived from the surveys. The average modeled homebase work travel time of 22.26 min is less than the 25.66 min revealed in the household surveys.
(2) The average length of the other domestic journeys should be about 80% of the average length of the journey for domestic work trips. From the household surveys, this corresponds to 20.11 min for homebase other trips. The model results showed average trip lengths of 17.99 min for homebase other trips. They are well within areas on able range.

7 Trip Length Frequency Distribution

Along with the average length of the trip, another indicator of the distribution of trips is the frequency distribution of the length of the trip. Trip length frequency distribution (TLFD) describes the shape of the curve that is summed up by the average length of the trip.

Table 4 Average trip length by trip purpose

Trip purpose	Average trip length (min)		
	Free flow	Al-Diwaniyah city model	Household survey
Home based work	16.21	22.26	25.66
Home-based education	14.23	19.33	22.18
Home-based social recreational	13.22	17.12	19.64
Home-based shopping	10.66	13.45	15.36
Home-based other	13.99	17.99	20.11

TLFD of the trip for each journey purpose in the running model compared with data observed from the household surveys. The curves in Figs. 3, 4, 5, 6, 7 and 8 show the TLFD curves by trip purpose which present a reasonable results between models run and the household survey. From these figures, it can be concluded that:

The domain of trip length frequency distribution of home base work trips is averaged 20–25 min, while educational trips had two primary domains: 11–15 min for short trips (such as going to school within the same area) and 16–20 min for longer trips.

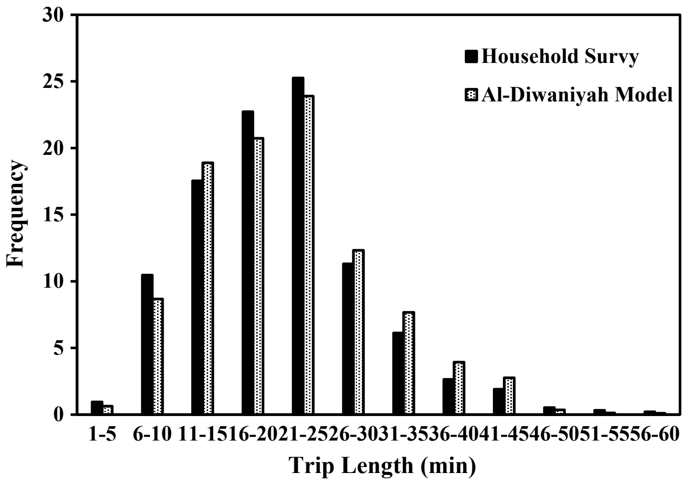

Fig. 3 Trip length frequency distribution for HBW

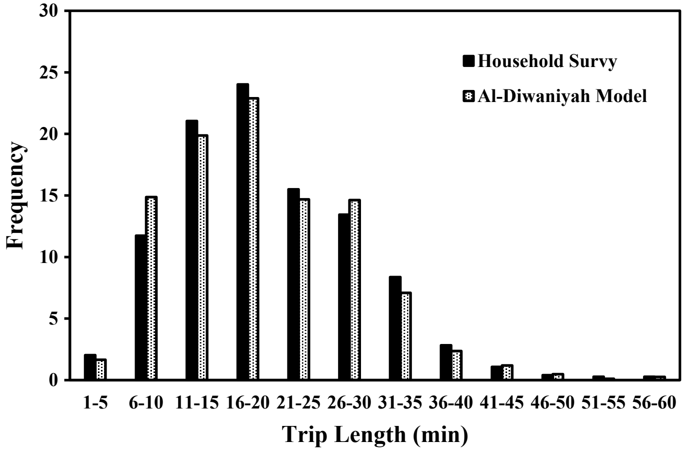

Fig. 4 Trip length frequency distribution for HBEd

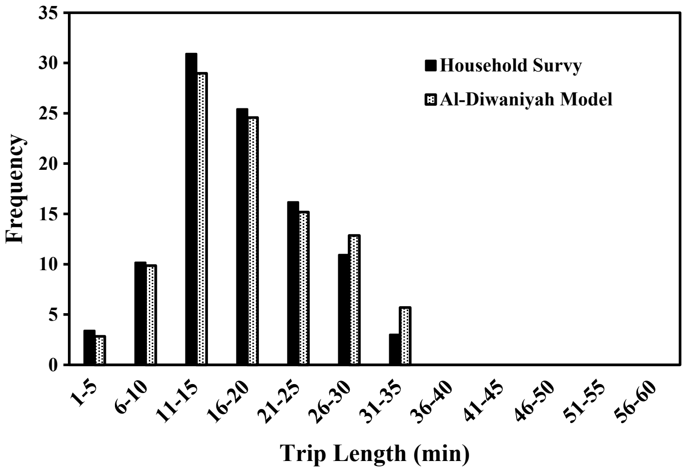

Fig. 5 Trip length frequency distribution for HBSR

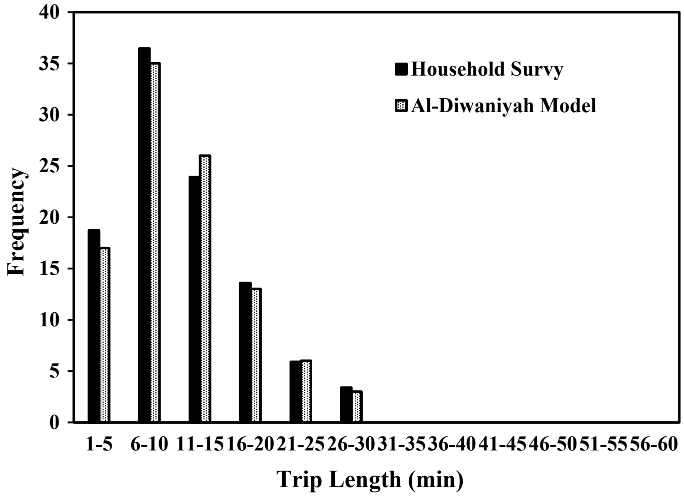

Fig. 6 Trip length frequency distribution for HBSh

The home base social/recreational trips have had two domains also, the first ranged between 11 and 15 min for social/recreational short trips which happen in the same zone and the second ranged between 16 and 20 min for long trips.

The homebase shopping trips can be characterized as short trips with an average TLFD of 6–10 min because the shopping destinations are within the TAZs. Finally

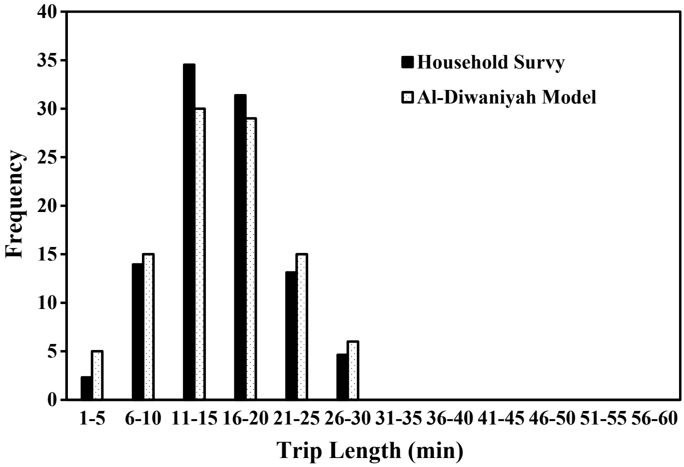

Fig. 7 Trip length frequency distribution for HBO

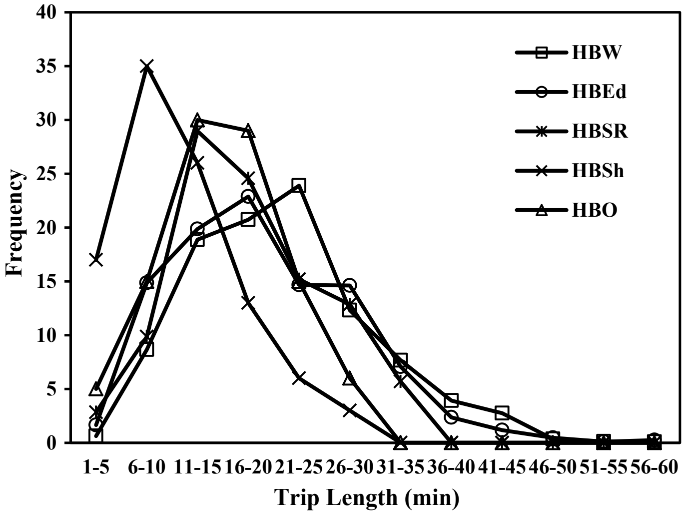

Fig. 8 Trip length frequency distribution for all trips

the trip length frequency distribution of home base other trips had a wide domain ranged between 11 and 20 min this is due to the variety in the destinations of these trips according to their objectives. Figure 8 shows the trip length frequency distribution of all trips in accordance with their objectives for the study area.

8 Conclusions

1. Friction is the main independent variable that affects a user's model of gravity in the distribution of flight operation for a worker in the city of Al-Diwaniyah.
2. The results show that the gamma function is the best function form to calculate the friction factors that reflect the traveler's sensitivity to travel time in Al-Diwaniyah.
3. With increased travel time, friction factors decrease when the gamma coefficients (b and c) have negative values.
4. The average trip length for the gravity model is range between 12.5 and 18.5 min for the five trip's purpose that was considered in the study.
5. The trip Length frequency distribution (TLFD) of a home base work trip is 20–25 min. Home base educational trips have two ranges: 11–15 min for short trips (schools within the same zone) and 16–20 min for long trips. The home base shopping trips have an average TLFD of 6–10 min because the shopping destinations are within the TAZs.
6. The home base social/recreational trips have had two domains, the first ranged between 11 and 15 min for social/recreational short trips which happen in the same zone and the second ranged between 16 and 20 min for long trips.
7. The trip length frequency distribution of home base other trips had a wide domain ranged between 11 and 20 min this is due to the variety in the destinations of these trips according to their objectives.
8. It is recommended to apply similar studies to all of Iraq's provinces in order to recognize the different variables that influence the generation and distribution of trips and then identify the solution for the problems that may face the transportation planner.

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