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Calibration of Gravity Model with Impedance Factors for Medium Town in India

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Abstract

Transportation planning is the process of defining future policies, goals, investments and design to prepare for future needs. Many urban cities and towns of India are facing transportation problems due to increased rate of urbanization, urban sprawl and tremendous increase in travel demand. Travel demand management is crucial part of transportation planning which depends on the socio-economic parameters of that area. The study has been carried out for Morbi (a medium town II) of Saurashtra region of Gujarat having population of 1.94 lakh. Morbi is ceramic hub of India which contributes more than 70% of the total ceramic production of India. It has also some other industrial development like manufacturing of wall clock, CFL bulbs and electric bikes which generates employment opportunities. There is remarkable rate of migration due to its industrial development. The public transportation system (city bus service) has been started in 2014 which is not sufficient to cope with the growing travel demand of Morbi. To overcome the transportation issues like increased travel demand, congestion, air pollution - a sustainable development is very much required for Morbi city. The first step taken by researcher is the digitization of map of Morbi city by using TransCAD software. The study area has been divided in to 14 zones. The Home Interview Survey has been carried out for socio economic data and trip information with sample size of 1 in 35 HH. The distances from CBD for all wards have been plotted on digitized map. Trip generation model with regression analysis in Excel sheet is developed for the study area. Mode choice for trips by two-wheeler (43%), Rickshaw (24%), Car (8%), Bus (2%), Bicycle (5%), and Walk (18%), are observed. Trip distribution is the second stage of travel demand modeling. This paper focuses on calibration of gravity model for medium sized city. Calibration parameters for four different impedance factors –Travel distance, Euclidean distance, Travel time and Travel cost have been derived. Trip length frequency distribution of observed trips and modeled trips is presented.
Keyword- Gravity Model, Impedance Factors, Mode Choice, Model Calibration, Trip Distribution, Trip Generation, Transcad Software

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I. INTRODUCTION

Transportation planning plays an important role in state, region and country's development and future development. It includes all possible strategies, an evaluation process and a collaborative participation of Government, relevant transportation agencies and a meaningful public participation.

The main purpose of transportation planning is the correct estimation of its usage and the transport supply should meet with the estimated travel demand. The basic parameters that determine the trip generation rate and trip attraction rate are economical-social factors and land use. Trip distribution is a part of transportation demand modeling which relates the distribution of trips between the given number of origins and destinations in a matrix form. Travel demand between two point increases with increase in attraction and decreases as the resistance to travel increases.

Hence, for the estimation of travel demand, it is necessary to understand the travel behavior through trip distribution. Factors affecting trip distribution are 1. Travel time 2. Travel cost 3. Availability of opportunity 4. Relative attractiveness of traffic zones like employment and other opportunity

A trip distribution model generates a new origin-destination trip matrix which shows new trips in the future made by population, employment and other demographic changes so as to reflect changes in people's choice of destination. They are used to forecast the origin and destination pattern of travel into the future and produce a trip matrix, which can be assigned in an assignment model and mode choice model.

II. CONCEPT OF GRAVITY MODEL AND LITERATURE REVIEW

Trip distribution models have been developed to assist in forecasting future trip pattern when important changes in the network take place. They start from assumption about trip making behavior which is influenced by external factors such as total trip ends and the distance travelled. The best known of these models is the gravity model, originally generated from the analogy with

Newton's Gravity law. The trip interchange is directly proportional to the relative attraction between zones, it is inversely proportional to the measure of spatial separation. The simple equation representing the above relationship is of the following form:

$$T_{ij}=KP_iA_jd_{ij}^n \qquad (1)$$

Where
T_{ij}= trips between zones i and j
P_i = trip produced in zone i
A_j= trips attracted in zone j
d_{ij}^n = distance between zone i and j
K = A constant
The classical version of doubly constrained gravity model is

$$T_{ij} = A_iO_iB_jD_jf(c_{ij}^n) \qquad (2)$$

where $f(c_{ij}^n)$ is a generalized function of travel cost while A_i and B_j are balancing factors.

$$B_j = 1/\sum_i A_iO_if(c_{ij})$$
$$A_i = 1/\sum_j B_jD_jf(c_{ij})$$

Various studies have been carried out for calibration of gravity model. Salini P S et al. (2016) has shown the use of fuzzy rule based modeling or trip distribution. The model FL-UTDM shows improved results over the traditional gravity model. Mounir Mahmoud Moghazy Abdel-Aal (2014) has proposed a framework to calibrate a doubly-constrained gravity model for the trip distribution of the city of Alexandria based on a Household Travel Survey. Thomas G. Jina et.al. (2012) has developed an enhanced gravity model for distributing commodity flows to zones with composite friction factors and to commodity flow distribution in the state of Utah. This enhanced gravity model which consists of composite friction factors including physical distance, statistical distance (Euclidean distance), and economic factor consisting of the difference in population and the difference in employment among the zones which can affect commodity distribution. V.Thamiz Arasan et.al. (1996) has shown the estimation of travel deterrence for trips made for different purposes and by different modes through calibration of two types of gravity model formulations, using the data set pertaining to a medium-size city Tiruchirapalli with a complex travel environment in India. Hakan Guler (2014) has developed a travel demand modeling framework to calculate the transportation demand of the Marmaray corridor. In addition, a model including empirical modeling methods was developed for the highways to estimate the origin and destination matrices. The developed model was used to estimate freight and passenger transportation between Istanbul and other Turkish provinces.

III. STUDY AREA

The research work has been carried out for Morbi city in Gujarat state. Morbi is situated on the bank of river Machchhu and 60 km away from Rajkot city. Morbi is a historical city of Saurashtra region. It is a hub of ceramic industries. There are more than 700 units of ceramic production. There are some other industrial development like clock manufacturing and electronic bike production. There is high rate of migration to Morbi because of its industrial development. The major outgrowths of Morbi city are Trajpar, Sanala, Ravapar and Mahendranagar. The total area of Morbi city is 29 Km^2 approximately. There are 14 wards in Morbi city. The population of Morbi city is 1,94,947 (as per 2011 census).

Fig. 1: location of study area

The CBD of Morbi city is ward no. 6 which is also known as "Nagar Darwaja". It is highly congested and highly populous area. The population of ward no. 6 is 10650 and no. of households are 5099. The no. of households is higher compared to all other wards of Morbi city. New commercial and shopping centres are developed on Ravapar road and Sanala road adjacent to ward no. 6. Educational and institutional buildings are in ward no. 6.There are Darbar Gadh and Mani Mandir near to it, which are old and historic sites of Morbi city. Number of shops and other commercial activities are concentrated over here. Residential and commercial type of land use is observed in ward no 6.

IV. Data Collection And Data Analysis

By using TransCAD software the map of Morbi city is digitized and it has been divided in to 14 zones which are the wards of Morbi city as per 2011 census. The primary data have been collected by home interview survey while secondary data have been collected from census of India and Morbi Municipality. The Home Interview Survey (HIS) has been carried out for sample size of 1400 HH out of 52,497HH. From HIS forms the household information like size of HH, no. of workers, no. of students, age, vehicular ownership and income have been collected. The trip information like purpose of trip, origin and destination, travel time, travel distance, travel cost and distance from CBD have also been collected from HIS data.
The above figure shows the population density (inhabitants /sq.km) of the study area for all 14 zones.

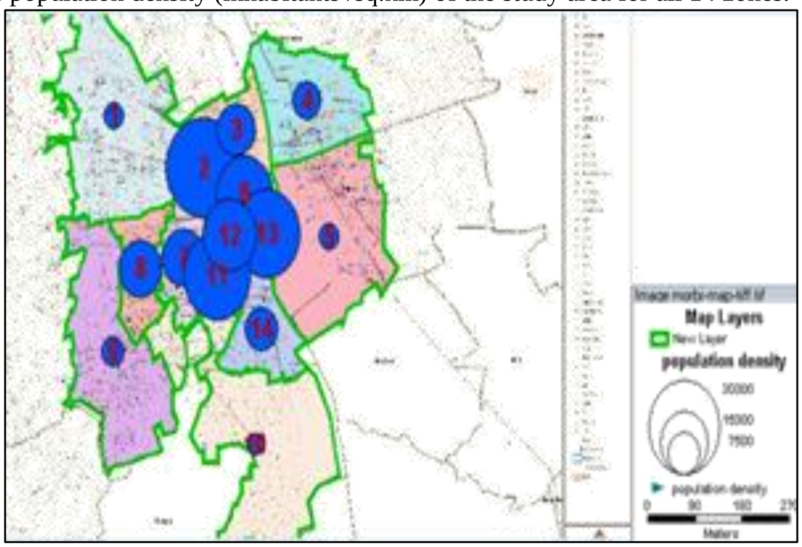

Fig. 2: ward wise population density of Morbi

Demographic details like population, area, no. of households, and population density of Morbi is shown in table 1 below.

Population	*1,94,947*
Area	*29 Sq Km*
Population density	*6722.3 Inh./km^2*
Male	*52%*
Female	*48%*
No. of Household	*52497*

Table 1: Demographic Details of Morbi

Annual Income(Rs) Lakh	*Income Group*	*%*
< 1	*EWS (Economically Weaker section)*	*8*
1 to 2.5	*LIG (Low income Group)*	*41*
2.5 to 5	*MIG (Medium Income Group)*	*30*
>5	*HIG (High Income Group)*	*21*

Table 2: Population Distribution by Income Group

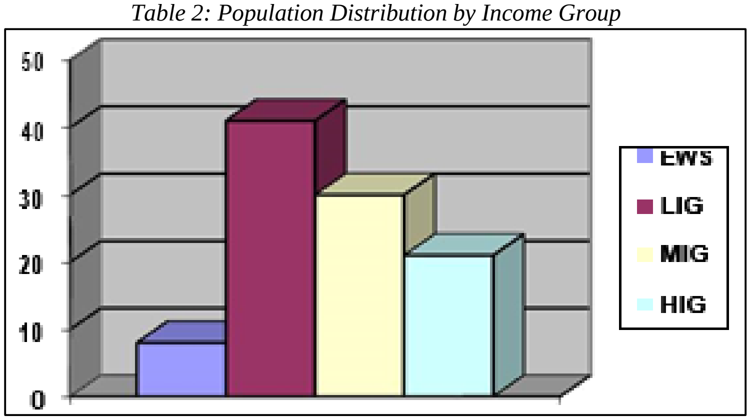

Fig. 3: income wise population distribution

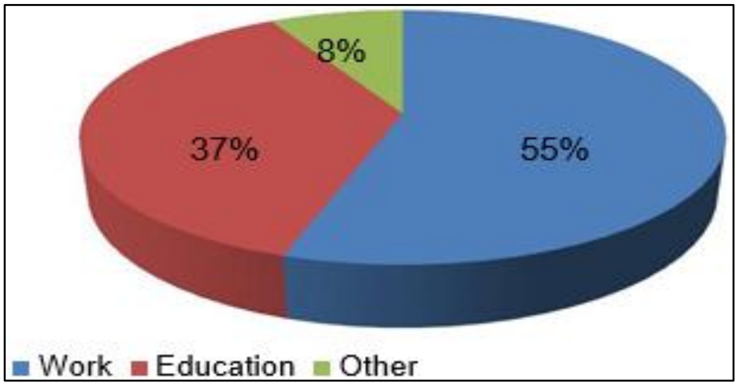

Fig. 4: trip purpose composition

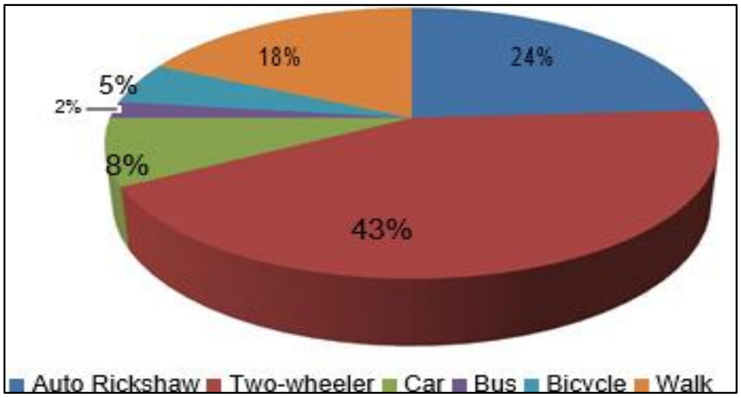

Fig. 5: share of mode of trip

Ward /zone no.	*Production*	*Attraction*
1	*122*	*23*
2	*63*	*25*
3	*84*	*13*
4	*101*	*61*
5	*55*	*148*
6	*137*	*115*
7	*100*	*353*
8	*95*	*153*
9	*65*	*54*
10	*92*	*41*
11	*129*	*39*
12	*73*	*187*
13	*66*	*40*
14	*100*	*30*
Total	*1282*	*1282*

Table 5: Zonal Trip Productions and Attractions (HBW)

Data collection is carried out purpose wise. For the analysis of trip distribution three purposes have been considered.

1) Home-based work (HBW)
2) Home-based education (HBE)
3) Home-based other (HBO)

The proportion of HBW trips is 55%. For HBW purpose the generated O-D matrix is as shown in table 6 below.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*P*
1	*0*	*5*	*3*	*11*	*18*	*7*	*28*	*21*	*12*	*6*	*3*	*7*	*0*	*1*	*122*
2	*4*	*0*	*0*	*6*	*13*	*4*	*22*	*5*	*1*	*1*	*2*	*3*	*1*	*1*	*63*
3	*0*	*1*	*0*	*2*	*9*	*10*	*29*	*22*	*0*	*3*	*0*	*7*	*0*	*1*	*84*
4	*1*	*4*	*3*	*0*	*29*	*7*	*21*	*9*	*1*	*2*	*5*	*12*	*2*	*5*	*101*
5	*0*	*0*	*0*	*8*	*0*	*11*	*6*	*4*	*0*	*1*	*1*	*19*	*5*	*0*	*55*
6	*0*	*10*	*4*	*10*	*9*	*0*	*41*	*11*	*3*	*1*	*4*	*27*	*14*	*3*	*137*
7	*6*	*0*	*0*	*4*	*8*	*19*	*0*	*22*	*4*	*6*	*7*	*17*	*2*	*5*	*100*
8	*0*	*0*	*2*	*6*	*9*	*4*	*29*	*0*	*9*	*5*	*8*	*23*	*0*	*0*	*95*
9	*2*	*0*	*0*	*3*	*13*	*3*	*19*	*12*	*0*	*6*	*2*	*5*	*0*	*0*	*65*

10	0	1	0	5	21	6	32	10	8	0	0	6	2	1	92
11	0	0	1	2	3	9	45	10	11	2	0	33	0	13	129
12	6	0	0	0	4	13	32	9	2	2	5	0	0	0	73
13	1	3	0	2	5	12	22	6	2	2	0	11	0	0	66
14	3	1	0	2	7	10	27	12	1	4	2	17	14	0	100
A	23	25	13	61	148	115	353	153	54	41	39	187	40	30	1282

Table 6: O-D Matrix for Home Based Work (HBW) Trip

The base year O-D matrix is expanded O-D matrix by using expansion factor and sample size. From the above matrix it is observed that ward no. 6 has the highest trips. Expanded matrix indicates 530 trips in ward no. 6. Total trips in Morbi city as expanded trips 4686.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	19	10	20	23	16	20	21	20	23	25	21	0	20
2	14	0	17	25	20	13	18	21	30	15	17	13	15	15
3	0	15	0	25	20	10	19	21	0	21	0	10	0	10
4	21	16	14	0	13	19	20	21	36	28	13	15	17	16
5	34	0	10	10	0	11	22	22	37	30	15	12	11	0
6	16	9	9	13	14	0	15	15	20	19	8	8	10	11
7	11	0	0	22	15	10	0	11	15	9	10	14	10	16
8	25	0	20	21	22	12	10	0	9	10	10	13	0	0
9	22	0	0	30	27	28	17	16	0	16	12	20	0	0
10	0	17	0	20	20	15	16	11	19	0	0	11	7	15
11	26	0	16	30	25	11	17	20	18	14	0	12	0	17
12	20	0	0	0	14	11	13	16	15	27	9	0	0	0
13	23	21	0	22	22	10	19	25	25	27	0	13	0	0
14	30	20	40	18	26	16	27	29	33	21	10	14	14	0

Table 7: Travel Time Matrix (minute)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.00	3.67	1.33	6.73	7.09	3.14	4.45	5.04	3.67	5.21	5.60	4.71	0.00	5.00
2	1.96	0.00	2.00	4.33	4.26	1.47	2.51	3.41	3.50	3.00	1.25	1.10	1.00	3.50
3	0.00	1.00	0.00	3.00	3.12	1.82	2.66	4.20	0.00	6.67	0.00	1.81	0.00	3.00
4	5.41	3.75	2.10	0.00	2.19	3.40	4.11	5.25	8.11	4.00	2.10	2.77	2.75	3.10
5	4.57	0.00	2.50	2.90	0.00	2.60	3.52	4.14	7.50	6.25	3.00	3.00	2.20	0.00
6	2.38	0.86	1.04	2.75	2.94	0.00	1.73	2.32	2.93	3.24	1.08	1.24	0.87	2.33
7	4.23	0.00	0.00	4.50	4.46	1.85	0.00	2.73	3.22	1.87	1.41	1.72	2.20	3.60
8	3.60	0.00	3.15	4.02	4.72	2.56	1.65	0.00	1.48	1.83	1.90	2.18	0.00	0.00
9	5.00	0.00	0.00	5.50	6.38	6.67	3.07	2.08	0.00	2.41	3.50	3.33	0.00	0.00
10	0.00	2.00	0.00	4.60	5.48	3.00	3.17	2.23	3.43	0.00	0.00	2.33	2.00	6.00
11	1.64	0.00	2.33	4.50	6.00	1.64	1.99	2.79	3.59	1.39	0.00	1.12	0.00	2.05
12	3.84	0.00	0.00	0.00	3.67	1.31	1.74	2.50	5.00	3.50	1.40	0.00	0.00	0.00
13	3.60	2.80	0.00	4.50	3.42	1.02	2.64	3.55	5.63	4.22	0.00	2.12	0.00	0.00
14	5.00	5.00	4.00	4.50	4.38	2.24	3.49	7.06	4.40	3.20	1.00	1.69	1.72	0.00

Table 8: Travel Distance Matrix (km)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	14	5	247	29	15	17	20	24	25	30	19	0	20
2	11	0	6	17	22	4	9	19	10	10	8	1	1	10
3	0	0	0	0	5	3	4	8	0	8	0	2	0	10
4	20	15	9	0	10	13	16	18	32	17	8	11	6	5
5	15	0	15	16	0	11	16	18	21	15	12	13	8	0
6	11	1	4	8	10	0	9	12	17	10	3	4	0	7
7	18	0	0	14	14	5	0	9	11	7	3	4	7	11
8	13	0	9	14	14	8	5	0	4	7	6	6	0	0
9	30	0	0	22	27	20	11	11	0	7	21	12	0	0
10	0	4	0	30	38	14	16	15	22	0	0	9	8	48
11	15	0	4	30	24	4	8	11	16	7	0	3	0	9
12	17	0	0	0	12	3	5	9	10	10	6	0	0	0
13	14	6	0	10	9	1	7	12	14	13	0	7	0	0
14	15	1	0	10	8	3	7	6	18	10	0	4	1	0

Table 9: Travel Cost Matrix (Rs.)

The calibration of gravity model for HBW trip has been carried out using TransCAD software. The frequency distribution of the observed total trips by plotting histogram indicates that the travel behavior of observed trips follow the inverse power function which has been considered in the Gravity model. The following table shows the calibration parameters for different impedance factors.

Impedance factors	*Calibration parameter (inverse power function)*

Travel distance	*0.6464*
Travel time	*1.0458*
Travel cost	*0.3310*

Table 10: Calibration Parameters

A. Trip Length Frequency Distribution

Trip length frequency distribution (TLD) for home based work (HBW) is as shown in figure 6,7 and 8 by considering different impedance factors. The calibrated gravity model is tested by trip length frequency distribution. The average trip length in terms of travel distance is 1.72 km for HBW. The average trip length (travel distance) in km for observed and simulated trips is as shown in figure-6 below.

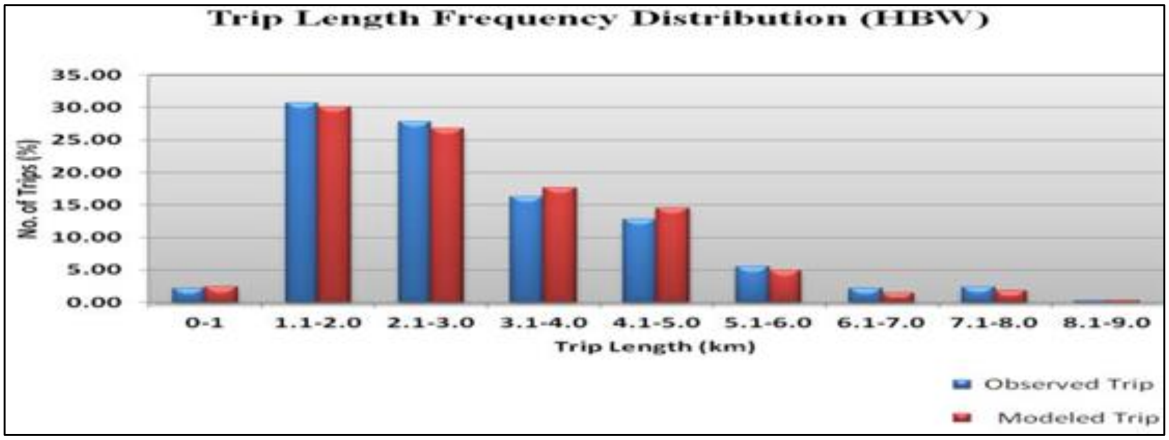

Fig. 6: TLD for HBW trip (Travel Distance)

The average trip length in terms of travel time is 15.6 minutes for HBW. The travel time in min. for observed and simulated trips is as shown in figure-7 below.

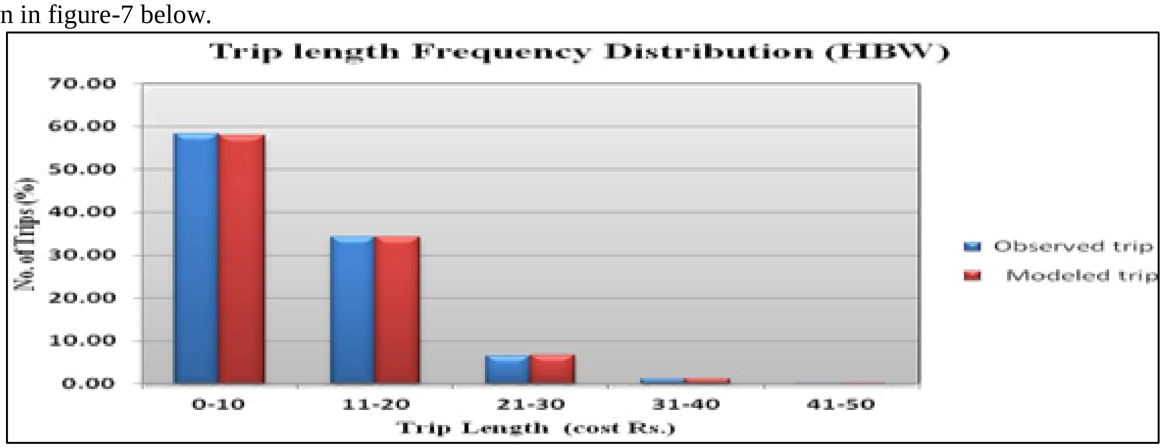

Fig. 7: TLD for HBW trip (Travel Time)

The travel cost in Rs. for observed and simulated trips is as shown in figure-8

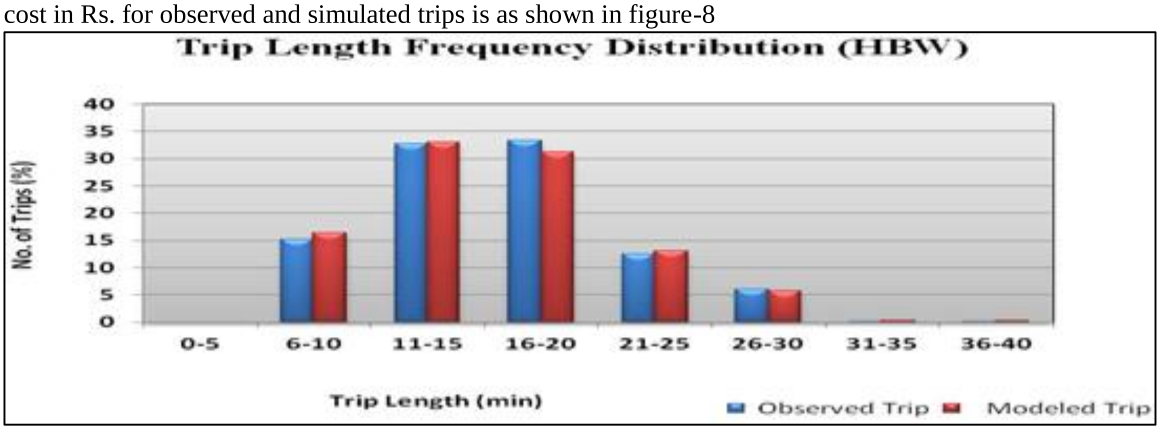

Fig. 8: TLD for HBW trip (Travel Cost)

V. CONCLUSION

The Highest preferred or selected mode of trip is 2W with 43% of total trips. Considerable trips with 18% model share are made by walk. Average trip rate observed is 2.2 trips per person per day. From trip length frequency distribution of observed trips and simulated/modeled trips, it is concluded that the modeled trips are close to observed trips and the difference between observed and simulated trips is not more than 3 %. The average trip length in terms of travel time is 15.6 minutes for HBW. The average trip length in terms of travel distance is 1.72 km for HBW. Calibration parameters of Gravity model is 0.65 for travel distance, 1.05 for travel time and 0.33 for travel cost.

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