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GRAVITY MODELS FOR ESTIMATING INTER-DISTRICT PASSENGER AND COMMODITY TRIPS

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ABSTRACT: Two gravity models for predicting passenger and commodity movements among the old twenty districts of Bangladesh are developed in this study. It is assumed that, for road-based inter-district transportation, the commodity is solely transported by trucks, while the passengers use buses and other four-wheeled motorized vehicles for their desired trips. The gravity model for passenger movements is developed on the assumption that the travel resistance between any two districts is a function of travel time between them. The corresponding resistance factor for commodity movements is the truck operating cost. The models can estimate the number of inter-district daily trips for both passenger and commodity movements. The model calibration shows a complete match between the model results and the corresponding trips observed during the base year. The regression equations of travel resistance for both passenger and commodity movements developed using the model calibration outputs are significant at 5% level of significance. The models developed in this study are very simple and easy to use and require inputs that can be estimated reliably and easily.

KEY WORDS: Gravity model, trip distribution, transports modeling, model calibration.

INTRODUCTION

The transport sector plays an important role within any regional or national economy. A transport model that forecasts passenger and commodity transports between population centers, is essential in long-range planning and in advancing transportation efficiency. Road transport has become the principal mode of transport for the movements of commodity and passengers in Bangladesh. Railways and inland waterways, the other main transport modes, together account for less than half of the total motorized transport movements (Road Master Plan, 1991). It is envisaged that roads, which provide highly flexible and relatively low-cost transport, will continue to meet an increasing share of commodity and passenger transport demand in the future.

A number of transport studies have been undertaken during the last two decades in Bangladesh. The studies focussed on both rural and urban areas. The study reports showed that sophisticated transport models were used to forecast the travel between different activity centers. However, since most of the transport studies were foreign aided, the experts used models that were costly and required numerous

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parameter inputs which eventually lead to higher degrees of approximation for the model to be fitted in Bangladesh conditions. Therefore, simple gravity models for predicting both passenger and commodity movements among the major districts of Bangladesh are developed in this study, which require inputs that can be reliably and easily estimated.

THE STUDY AREA AND DATA COLLECTED

The study area considered in this research work is the portion of the nation's highway network that connects the old major twenty districts of Bangladesh (see Figure 1). The necessary data for the calibration of the gravity models are collected mainly from three transport studies - ITS (1985), SRIP (1991) and RMP (1991). The data collected are the number of daily trips between the old major twenty districts, road lengths, travel times, and commodity transport costs (i.e., truck operating cost) between the activity centers of the old twenty districts. The details of the data collected in this study can be found elsewhere (Hasan, 1993). It is to be noted here that the passenger trips are estimated from the number of trips made by bus, minibus, and light motorized vehicles, while the commodity trips are estimated from the number of truck trips.

CALIBRATION OF GRAVITY MODELS

The gravity model used to predict the passenger and commodity flow pattern between the old districts of Bangladesh is of the following form (Dickey, 1975)

$$T_{ij} = P_i \frac{A_j R_{ij}}{\sum_{j=1}^{n} A_j R_{ij}} \quad (1)$$

Where, T_{ij} = number of trips between distrcits i and j,
P_i = production of district i,
A_j = attraction of district j, and
R_{ij} = resistance factor for travel between districts i and j.

It is assumed during the model calibration that the resistance factors (R_{ij}) for travel between any two districts are travel time (t_{ij}) for passenger movements and transport costs (C_{ij}) for commodity movements (Hasan, 1993). Therefore, the resistance factors R_{ij} (see Equation 1) for passenger and commodity movements at the start of the calibration procedures are assumed to be of the following form

$R_{ij} = 1/t_{ij}^2$ for passenger movements, and
$R_{ij} = 1/C_{ij}^2$ for commodity movements.

The algorithms adopted for the calibration of the gravity models for both passenger and commodity movements are explained with a trip matrix presented in Table 1. Table 1 shows an example trip matrix with *m* number of origins and *n* number of destinations. The right most column of the trip matrix shows the number of trip productions of respective zones, while the bottom row shows the number of trip attractions of respective zones. The nine-step calibration procedure of the gravity models is as follows:

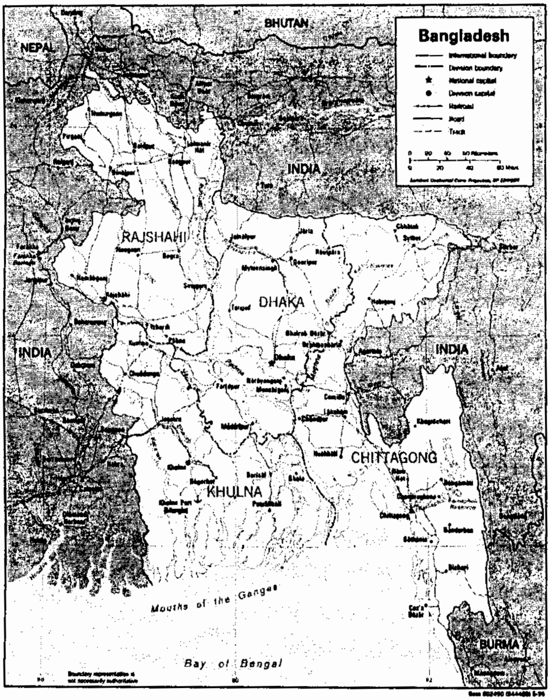

Fig. 1. The Study Area: Road Network Connecting Major Districts of Bangladesh

Step 1. Calculate P_i as,

$$P_i = \sum_{j=1}^{n} T_{ij}, \quad i = 1,2,3,\ldots, m$$

Table 1. An example trip matrix

Origin (rows) – Destination (columns)	1	2	3	....	n	Production
1	T_{11}	T_{12}	T_{13}	....	T_{1n}	P_1
2	T_{21}	T_{22}	T_{23}	....	T_{2n}	P_2
3	T_{31}	T_{32}	T_{33}	....	T_{32}	P_3
. . .	. . .	. . .	. . .	. . .	. . .	. . .
m	T_{m1}	T_{m2}	T_{m3}	....	T_{mn}	P_m
Attraction	A_1	A_2	A_3	....	A_n	

Step 2. Calculate A_j as,

$$A_j = \sum_{i=1}^{m} T_{ij}, \quad j = 1,2,3,\ldots\ldots,n$$

Step 3. Calculate T_{ij}^* as,

$$T_{ij}^* = P_i \frac{A_j b_j R_{ij}}{\sum_{j=1}^{n} A_j b_j R_{ij}}$$

where, $R_{ij} = 1/t_{ij}^2$ for passenger movements and $R_{ij} = 1/C_{ij}^2$ for commodity movements, and set $b_j = 1$ (b_j can be termed as an attraction adjustment factor for zone j).

Step 4. Calculate

$$A_j^* = \sum_{i=1}^{m} T_{ij}^*$$

Step 5. Compare A_j^* with A_j, if not equal, calculate $b_j = A_j/A_j^*$

Step 6. Continue steps 3 to 5 until

$$\frac{A_j^* \sim A_j}{A_j} \leq \lambda$$

where, λ is the acceptable limit of error.

Step 7. Compare T_{ij}^* with T_{ij}, if not equal, calculate

$$R_{ij}^{*} = R_{ij} \frac{T_{ij}}{T_{ij}^{*}}$$

Step 8. Calculate T_{ij}^* using R_{ij}^* calculated for each pair of i - j

Step 9. Continue steps 7 and 8 until

$$\frac{T_{ij}^{*} - T_{ij}}{T_{ij}} \leq \lambda$$

A computer program is written in C to perform the calculations involved in the calibration procedure. Setting an acceptable limit of error, λ as 1%, it is found that the inter-district passenger and commodity trips estimated by the calibrated gravity models match completely with the corresponding trips observed during the base year (1991). The calibrated gravity models for both passenger and commodity movements are as follow:

$$T_{ij} = P_i \frac{A_j b_j R_{ij}}{\sum_{j=1}^{20} A_j b_j R_{ij}} \qquad (2)$$

Where, T_{ij} = number of daily trips between districts i and j,
P_i = trip production of district i (trips/day),
A_j = trip attraction of district j (trips/day), and
b_j = attraction adjustment factor for district j (see Tables 2 and 3),
$R_{ij} = (t_{ij})^{-2.05}$ for passenger movements where t_{ij} is in hours, and
$R_{ij} = (C_{ij})^{-1.76}$ for commodity movements where C_{ij} is in thousand taka.

The above regression equations of travel resistance factors (R_{ij}) are significant at 5% level of significance and the R^2 values are 0.96 and 0.70 for passenger and commodity movement equations, respectively. Variations of R_{ij} with travel time and transport costs are shown in Figures 2 and 3, respectively. The attraction adjustment factors (b_j) for passenger and commodity movements among the old twenty districts, obtained from the calibration of the models, are given in Tables 2 and 3, respectively.

APPLICATION OF THE GRAVITY MODELS

The gravity models presented in this paper can be used to forecast the inter-district trips among the old twenty districts of Bangladesh. To forecast the number of daily trips, one needs to use Equation (2) along with the resistance factors (R_{ij}) and attraction adjustment factors (b_j). The attraction adjustment factors are given in Tables 2 and 3. The inputs needed for estimating inter-district trips are target year attraction (A_j) and production (P_i) of all districts in trips per day, inter-district travel times of bus and other 4-wheeled motorized vehicles for passenger movements, and inter-district truck operating costs for commodity transport.

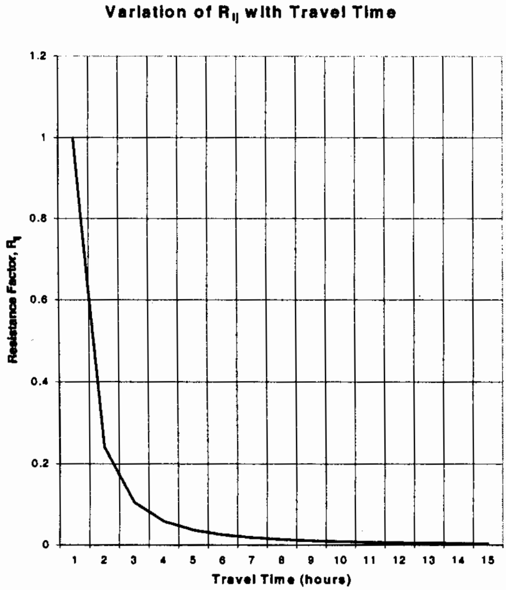

Fig. 2. Variation of R_{ij} with Travel Time for Passenger Movements

Table 2. Attraction adjustment factor b_j for passenger movements between the old twenty districts of Bangladesh

District	b_j for passenger movements	District	b_j for passenger movements
Chittagong	1.186775	Barisal	2.929699
Chittagong Hill Tracts	0.854324	Jessore	0.569406
Comilla	0.686657	Khulna	1.066793
Noakhali	1.371084	Kushtia	0.942806
Sylhet	2.953246	Patuakhali	1.897565
Dhaka	0.892701	Bogra	1.091377
Faridpur	1.246937	Dinajpur	2.534634
Jamalpur	1.593255	Pabna	0.763561
Mymensingh	1.046865	Rajshahi	1.239324
Tangail	0.816109	Rangpur	0.892670

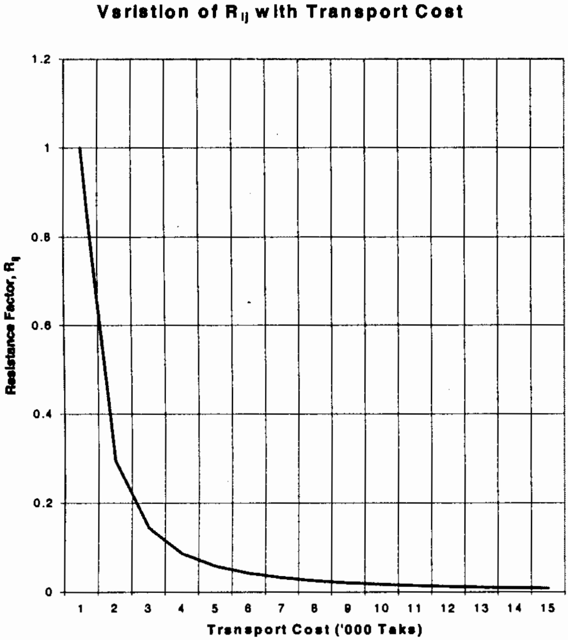

Fig. 3. Variation of R_{ij} with Transport Cost for Commodity Movements

Table 3. Attraction adjustment factor b_j for commodity movements between the old twenty districts of Bangladesh

District	b_j for commodity movements	District	b_j for commodity movements
Chittagong	2.469072	Barisal	3.172040
Chittagong Hill Tracts	0.259721	Jessore	0.527990
Comilla	0.413508	Khulna	1.216003
Noakhali	0.702893	Kushtia	0.692357
Sylhet	2.588268	Patuakhali	0.688916
Dhaka	1.116696	Bogra	1.346616
Faridpur	1.738256	Dinajpur	2.690704
Jamalpur	1.481896	Pabna	0.868120
Mymensingh	0.756153	Rajshahi	1.381994
Tangail	0.461700	Rangpur	0.985814

CONCLUSIONS

Gravity models for passenger and commodity transportation between the major twenty districts of Bangladesh are presented in this paper. The calibrations of gravity models shows that the models can estimate the base year inter district trips completely. The travel resistance factors are considered to be function of travel time and transport cost for passenger and commodity movements, respectively. The regression analyses show that the travel resistance equations are significant at 5% level of significance and they have reasonably high R^2 values. The attraction adjustment factors of all districts needed for using the gravity models are also presented. The gravity models developed in this study are simple and easy to use since the data needed to use the gravity models can be estimated or can be obtained from the field easily with reasonable accuracy. One of the major advantages of gravity models is its ability to predict trips between any two zones even when there are structural changes in the network in the form of constructing new road sections. Since Bangladesh is a developing country and structural changes are very common, it is expected that the models developed in this study can be used as a powerful tool by transport planners and national policy makers.

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