AN ESTIMATION OF INTER-ZONAL BUS DEMAND ON COLOMBO - KALUTARA TRANSPORT CORRIDOR

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ABSTRACT- In the past, it has been the practice to use demand estimation models widely, in transport planning studies. Models are important because transportation plans and their investment are based on what the model say about future passenger travel. Therefore the modal verification is required before the application. The transportation corridor includes, Colombo, Dehiwala, Moratuwa, Panadura and Kalutara travel zones. A traffic zone is taken as the area of the Divisional Secretary’s Division(DSD). This corridor carries a large share of daily bus passengers to the city of Colombo for various travel purposes. It is found that most of the trips are generated by the employed population and thereby it is taken as the main socio economic variable. Each year bus traveller demand towards the city of Colombo increases due to growth of new employee population. This indicated that about 97% of inter zonal bus passenger routes are terminated at Colombo.

The bus model was developed to estimate inter-zonal travel across this transportation corridor which is required to verify the model accuracy of predictors, since it was calibrated using the data from various surveys done during year 1996 to 1998.

The paper discusses (a) the preparation of inter-zonal origin – destination matrix and (b) the model verification process. It concluded that the model is performing at an acceptable level of predictive ability when tested on real demand observations.

BACKGROUND

The study concentrates on the 44 kilometre transportation corridor on the Galle Road, from Colombo to Kalutara. This corridor connects five traffic zones - Colombo, Dehiwala, Moratuwa, Panadura and Kalutara and extends a total area of 216 sq. kms. It is assumed that the traffic zone is the area of the Divisional Secretary’s Division. There are normal and intercity bus services that are operated by the cluster bus companies and private operators which serve all these zones. Each zone has a central bus stand that connects several intra-zonal bus routes. These routes are laid out to operate through the industrial zones located in these areas and facilitate better accessibility to the place of work. Therefore, there is a high daily bus passenger demand, between Colombo and Kalutara.

In 1997, the bus passenger travel in the Colombo – Kalutara transport corridor was estimated at 46,598 bus passengers per day (CMRSP,1997). Most of the buses have 42 passenger seats and have a newly furnished look with accessories to attract passengers such as radio/casettes, comfortable seats, good interior condition etc.. As a consequences a large number of passengers are attracted to private buses with respect to the Government operated cluster company buses. It is a fact that four private buses follow each CTB bus in this corridor and that an estimated 420 private buses operate per day. Therefore, Kumarage and Silva,( 2003) suggested that a priority lane for buses is required for this corridor in order to reduce traffic congestion and road accidents. In this respect, the bus passenger demand estimation is an important aspect in planning a better transportation system in this travel corridor.
The bus demand estimation model is developed to capture inter-zonal travel characteristics based on the data collected during the period of 1996 to 1998 by various transportation studies and published by Widanapathiranage and Kumarage (2003). In that model, the impedance to travel is expressed in a generalized form, which includes fare, waiting time, transfer time and travel time for the trip. The socio-economic variable of the employment population and the demographic variable of housing density are formulated in to the gravitational form of the model. It is calibrated to a 5% level of significance of the model variable with coefficient of correlation 72.1% and shown in equation (1). This indicated that these variables have been the primary determinant of the demand for inter-zonal travel together with an exponential form of the variable that represents direct travel between these zones.

$$B_{iK} = 0.255 \times \frac{E_{iK}^{0.860} \times e^{0.854BT}}{HD_{iK}^{0.197} \times BGC^{2.562}}$$

Where:
- $B_{iK}$ = Bus passenger trips between $i^{th}$ and $K^{th}$ zone per day in both directions.
- $E_{iK}$ = Product of employment of $i^{th}$ and $K^{th}$ zone.
- $HD_{iK}$ = Product of the housing density of $i^{th}$ and $K^{th}$ zone, where housing density is given as housing units per sq. km.
- $BGC$ = Generalized travel cost of bus in Rupees to travel between $i^{th}$ and $K^{th}$ zone given as, the sum of bus travel cost, waiting time cost and cost of invehicle travel time.
- $BT$ = Selected bus travel route between $i^{th}$ and $K^{th}$ zone is a direct or indirect.

The employed population determines to a large extent the travel that is generated and attracted to that zone which is mostly related to work and business purposes. The housing density represents a transportation interaction characteristic and the variable that represented to capture existing direct bus service shows, bus passenger demand doubled in these routes in contrast to indirect travel routes. It may be the high waiting and transfer time that are considered for the calculation of generalized cost of travel for the indirect routes. The predictors of this model indicate that if the product of employee population increases by 10%, then bus passenger inter-zonal travel increases by 5.8 % and thereby the growth of primary variables result in increases of daily bus passenger demand. These results are estimated based on the data in 1998 and the variables of bus demand model at year 2004 are estimated using the growth factors. The growth factors are taken as 6% of the employed population and 10% of housing density per year. It also assumes that the bus generalized cost remained unchanged. In this approach there is a high percentage of error accumulated in the model predictors. Therefore, to maintain the acceptable level of accuracy of the predictors, a verification stage of the modelling is required to test the model.

**OBJECTIVES AND METHODOLOGY**

The aim of this paper is to present (a) an approach for the formulation of an origin-destination matrix using partial data of passenger loading, boarding and alighting counts and (b) the result of a model verification process for the bus model that was developed for inter-zonal passenger demand estimation for a chosen transport corridor.

Dantas et. al.(2001), collected bus boarding and alighting data to improve a bus route capacity. LSC Consultants Inc, (2003) collected bus boarding and alighting counts to develop a bus loading profile of a route. Prethika et.al. (2001), collected bus passenger boardings and loadings
data in a route to develop a bus operational schedule. In this study, boarding and alighting partial data are collected to develop a OD matrix. The estimation of O-D matrix for inter-zonal travel requires two type of data. In the first instance boarding and alighting counts are required and secondly, roadside passenger loading counts are also required. The bus passenger loading data collected in 2003 are available at the Transportation Engineering Division of the Civil Engineering Department. The data were collected at strategically selected locations at the traffic zones. There are 15 bus routes connecting these zones as shown in Table 2. Four roadside loading observation locations are selected such a way that the maximum number of bus routs can observed at the observation point. The average loading observations that are collected according to the bus passenger occupancy and bus size categories are shown in Table 1.

Table 1. Passenger Occupancy in Buses

<table>
<thead>
<tr>
<th>Bus Size</th>
<th>Mean Passenger Load by Level of Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Empty</td>
</tr>
<tr>
<td>&lt; 20 Seats</td>
<td>2</td>
</tr>
<tr>
<td>20-29 Seats</td>
<td>4</td>
</tr>
<tr>
<td>30-39 Seats</td>
<td>5</td>
</tr>
<tr>
<td>Over 40 Seats</td>
<td>6</td>
</tr>
</tbody>
</table>

The occupancy survey of bus passengers is somewhat difficult as there are a large number of standing passengers at the time of observation. The estimations are done in such a way that the bus size and the level of loading is observed as against counting the actual numbers as in Table 1. The bus boarding and alighting survey were done by traveling observers on a number of individual buses operate in bus routes are given in the Table 2.

Table 2: Inter- Zonal Bus Travel Routes Between Colombo and Kalutara

<table>
<thead>
<tr>
<th>Zones</th>
<th>Colombo</th>
<th>Dehiwala</th>
<th>Moratuwa</th>
<th>Panadura</th>
<th>Kalutara</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombo</td>
<td></td>
<td>100,101,154, 155,167,176, 400,400/1,430</td>
<td>100, 101, 400, 400/1, 1, 430</td>
<td>100, 400, 400/1, 430</td>
<td>400, 400/1, 430</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>100,101,154, 155,167,176, 400, 400/1, 430</td>
<td>100,101,155, 183 400, 400/1, 430</td>
<td>100,183 400, 400/1, 430</td>
<td>400, 400/1, 430</td>
<td>400, 400/1, 430</td>
</tr>
<tr>
<td>Moratuwa</td>
<td>100, 101, 400, 400/1, 430</td>
<td>100, 101, 155, 183, 400, 400/1, 430</td>
<td>100, 101, 400, 400/1, 430, 400, 400/1, 430, 400, 400/7, 430</td>
<td>400, 142, 430, 400, 400/1, 430</td>
<td>400, 400/1, 430</td>
</tr>
<tr>
<td>Panadura</td>
<td>100, 400, 400/1, 430</td>
<td>100, 183, 400, 400/1, 430</td>
<td>100, 400, 400/1, 183, 142, 430</td>
<td>400, 400/1, 400/1, 430</td>
<td>400, 400/7, 430</td>
</tr>
<tr>
<td>Kalutara</td>
<td>400, 400/1, 430</td>
<td>400, 400/1, 430</td>
<td>400, 400/1, 430</td>
<td>400, 400/1, 430</td>
<td>400, 400/7, 430</td>
</tr>
</tbody>
</table>
A group of trained enumerators were used for this purpose. Two enumerators were assigned to a bus to collect these data during peak and off-peak period of the day. The surveying period was set at 13 hours on a day starting at 6.00 hours and ending at 19.00 hours depending on the data requirement.

In developing a general approach to formulate an OD matrix from partial data such as passenger loadings, boardings and alightings, it is assumed that there are \( n \) number of traffic zones across which a bus route or corridor operates. The inter-zonal travel demand from origin to destination \( (ED_{(n-1)}) \) at the end of zone (n-1) is illustrated in Figure 1.

**Figure 1. A Bus Route Crossing \( n \)th Zones (Traveling from O to D)**

Where: 
- \( LD_{(n-1)} \) = The total bus passenger loadings observed at a roadside loading observation point located within (n-1)th zone from origin \( o \) to destination \( d \).
- \( ED_{(n-1)} \) = The inter-zonal bus passenger demand between the (n-1)th zone and nth zone from origin \( o \) to destination \( d \).
- \( B_{n-1}^{OD2} \) = Bus passenger boardings in the (n-1)th zone from roadside observation point(LSP) to the zonal boundary (ZB \( n-1 \)) for the direction of origin \( o \) to destination \( d \).
- \( A_{n-1}^{OD2} \) = Bus passenger alightings in the (n-1)th zone from roadside loading observation point(LSP) to the zonal boundary (ZB \( n-1 \)) from origin \( o \) to destination \( d \).

\[
\sum_{k=1}^{n-2} B_{k}^{OD} + B_{n-1}^{OD1} = \text{The cumulative bus passenger boardings up to the roadside loading observation point (LSP).}
\]

\[
\sum_{k=1}^{n-2} A_{k}^{OD} + A_{n-1}^{OD1} = \text{The cumulative bus passenger alightings up to the roadside loading observation point(LSP).}
\]

The first step is to calculate a difference of cumulative passenger boardings to cumulative passenger loadings. It is determined the inter-zonal passenger travel \( (IPT) \) between the (n-1)th zone and the nth zone given in equation (2) estimates the average number of bus passengers who would be traveling across the (n-1)th zonal boundary (ZB \( n-1 \)) when a bus moves from origin \( o \) to destination \( d \).
\[ IPT_{n-1}^{OD} = \sum_{K=1}^{n-2} B_{K}^{OD} - \sum_{K=1}^{n-2} A_{K}^{OD} + B_{n-1}^{OD} + B_{n-1}^{OD} - A_{n-1}^{OD} - A_{n-1}^{OD} \]  

(2)

In estimating the total passenger demand at the \((n-1)\)th zonal boundary\((ZB_{n-1})\), further adjustments are required to estimate the number of boardings and alightings between the roadside loading observation point and the boundary. This can be given by equation (3),

\[ ED_{(n-1)}^{OD} = \left\{ 1 + \frac{B_{n-1}^{OD} - A_{n-1}^{OD}}{\sum_{K=1}^{n-2} B_{K}^{OD} - \sum_{K=1}^{n-2} A_{K}^{OD} + B_{n-1}^{OD} + B_{n-1}^{OD} - A_{n-1}^{OD} - A_{n-1}^{OD}} \right\} \times LD_{(n-1)}^{OD} \]  

(3)

Similarly, equation (4) is derived to estimate the total inter-zonal passenger demand at the same boundary when traveling from destination zone \(d\) to origin zone \(o\) is given as,

\[ ED_{(n-1)}^{DO} = \left\{ 1 - \frac{B_{n-1}^{DO} - A_{n-1}^{DO}}{\sum_{K=1}^{n-2} B_{K}^{DO} - \sum_{K=1}^{n-2} A_{K}^{DO} + B_{n-1}^{DO} + B_{n-1}^{DO} - A_{n-1}^{DO} - A_{n-1}^{DO}} \right\} \times LD_{(n-1)}^{DO} \]  

(4)

In this estimation, it was assumed that the roadside loading observation point was situated ahead of the zonal boundary. For this type of arrangement the generalized form of origin to destination travel matrix for the given bus route can be illustrated as,

\[
\begin{bmatrix}
T_{11} & T_{1n} \\
T_{21} & \cdot & T_{2n} \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
T_{(n-1)1} & \cdot & T_{(n-1)n} \\
T_{n1} & T_{nn}
\end{bmatrix} = \begin{bmatrix}
0 & \alpha_{12} ED_{1}^{OD} & \ldots & \alpha_{1(n-1)} ED_{1}^{OD} & \alpha_{1n} ED_{1}^{OD} \\
\alpha_{21} ED_{1}^{DO} & 0 & \alpha_{23} ED_{2}^{OD} & \ldots & \alpha_{2n} ED_{2}^{OD} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
\alpha_{n1} ED_{1}^{DO} & \alpha_{n2} ED_{2}^{DO} & \ldots & 0 & \alpha_{n(n-1)} ED_{n-1}^{DO} & 0
\end{bmatrix}
\]

Where: \(T_{ij}\) is the estimated inter-zonal passengers travel between \(i\)th zone and \(j\)th zone. \((i = 1,2,\ldots,n)\) and \((j = 1,2,\ldots,n)\); \(\alpha_{12}, \alpha_{13}, \ldots, \alpha_{1(n-1)}\) are the factors that are derived from the bus passenger boardings and alightings counts on the bus route as shown below,
\[ \alpha_{ij} = P_{ij} \left( \frac{A_j}{\sum_{m=1}^{n} B_m} \right) \] .................................................(5)

where \( P_{ij} \) = the ratio of all passengers who alighted in zone \( j \) to the passengers who boarded from zone \( i \) to travel up to zone \( j \) is expressed as a percentage. In this study, the value for \( \alpha_{ij} \) was investigated based on experience of the route boardings and alightings pattern.

\( A_j \) = Bus passenger alighting in the \( j^{th} \) zone.

\[ \sum_{m=1}^{n} B_m \] = The cumulative bus passenger boarding up to destination \( d \).

As an example, the above approach is used to estimate the inter zonal travel for bus route number 101 from Colombo zone to Moratuwa Zone. The zones that cross this section are Zone 1, as the Colombo DSD, Zone 2, as the Dehiwala DSD and Zone 3, as the Moratuwa DSD. The box 1 is given how this can be done.

**Box 1: Estimation of Inter-zonal Bus Passenger Travel on Moratuwa- Colombo Bus Route (Route Number 101)**

In the Moratuwa- Colombo bus route, the roadside passenger loading observation points were located at Maliban Junction (LSP1) and Bambalapitiya (LSP2). In this example, the observation points were situated ahead to the zonal boundary. The observed average daily passenger demands were 11,341 and 13,442 for the Moratuwa to Petah direction and 7,950 and 11,304 for the direction of travel from Petah to Moratuwa. The summary of passenger boardings and alightings counts on this route are shown in Table 3.

**Table 3. Passenger Boardings and Alightings Counts (Bus Route Number 101)**

<table>
<thead>
<tr>
<th>Location</th>
<th>From Moratuwa to Petah</th>
<th>From Petah to Moratuwa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average passenger Boardings</td>
<td>Average passenger Alightings</td>
</tr>
<tr>
<td>Moratuwa zonal limit</td>
<td>55</td>
<td>16</td>
</tr>
<tr>
<td>LSP1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Dehiwala zonal limit</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>LSP2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Colombo zonal limit</td>
<td>36</td>
<td>64</td>
</tr>
</tbody>
</table>
Calculation 1: Travel from Moratuwa to Petah.

\[
ED_{\text{Moratuwa}}^{DO} = \left[1 - \frac{(4 - 5)}{4 + 15 - 5 - 16}\right] \times 11,341 = 5671 \text{ Passengers per day.}
\]

\[
ED_{\text{Dehiwala}}^{DO} = \left[1 - \frac{(10 - 20)}{(10 + 22 + 4 + 55 - 20 - 22 - 5 - 16)}\right] \times 13,442
\]

= 18,243 Passengers per day.

Assuming the \( P(\text{Moratuwa to Dehiwala}) \) is 90 %. Then we can estimate,

\[
\alpha_{\text{Moratuwa-Dehiwala}} = 0.9 \times \left[\frac{4 + 22}{127}\right] = 0.184
\]

Inter zonal travel \( T(\text{Moratuwa-Dehiwala}) = 1043 \text{ Passengers per day} / T(\text{Moratuwa-Colombo}) = 4628 \text{ Passengers per day} \) and \( T(\text{Dehiwala-Colombo}) = 13,615 \text{ Passengers per day.} \)

Calculation 2: Travel from Petah to Moratuwa.

\[
ED_{\text{Colombo}}^{DO} = \left[1 + \frac{(25 - 17)}{(25 + 78 - 17 - 42)}\right] \times 11,304 = 13,359 \text{ Passengers per day.}
\]

\[
ED_{\text{Dehiwala}}^{DO} = \left[1 + \frac{(65 - 20)}{(65 + 102 + 25 + 78 - 20 - 61 - 17 - 42)}\right] \times 7950
\]

= 10,702 Passengers per day.

Assuming the \( P(\text{Colombo to Dehiwala}) \) is 95 %. Then we can estimate,

\[
\alpha_{\text{Colombo-Dehiwala}} = 0.95 \times \left[\frac{20 + 61}{299}\right] = 0.257
\]

\( T(\text{Colombo-Dehiwala}) = 3,433 \text{ Passengers per day} / T(\text{Dehiwala-Moratuwa}) = 776 \text{ Passengers per day} / T(\text{Colombo-Moratuwa}) = 9,926 \text{ passengers per day.} \)

The analysis was carried out for each of the other bus routes and estimates were thereafter made using the summation of all the \( T_{ij} \) travels as shown in equation (6) relevant to the travel from origin \( o \) to destination \( d \) to obtain the inter-zonal bus demand \( TT_{ij} \) for that zonal pairs.

\[
TT_{ij} = \sum_{j=1}^{n} T_{ij} \quad \text{------------------------------------------(6)}
\]

The results are shown in column 3 of Table 4 together with the model prediction at year 2004 and 2006. Widanapathiranage and Kumarage (2003) mentioned that this model could be applied to transport planning studies. In order to verify this statement, the predictions of the model at
year 2004 are compared with the inter-zonal travel observations and calculated the percentage error with respect to the observations as shown in the column 5 of Table 4.

Table 4. Comparison of Predicted and Observed Inter-zonal Travel.

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>2004 (Verification Year)</th>
<th>% Error of Model</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>From Zone</td>
<td>To Zone</td>
<td>Obs.(TT ij)</td>
<td>Pred.</td>
</tr>
<tr>
<td>Colombo</td>
<td>Dehiwala</td>
<td>68,952</td>
<td>49,305</td>
</tr>
<tr>
<td>Colombo</td>
<td>Moratuwa</td>
<td>31,515</td>
<td>27,290</td>
</tr>
<tr>
<td>Colombo</td>
<td>Panadura</td>
<td>7,858</td>
<td>12,543</td>
</tr>
<tr>
<td>Colombo</td>
<td>Kalutara</td>
<td>4,871</td>
<td>6,234</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>Moratuwa</td>
<td>8,618</td>
<td>10,157</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>Panadura</td>
<td>8,047</td>
<td>7,896</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>Kalutara</td>
<td>2,545</td>
<td>2,783</td>
</tr>
<tr>
<td>Moratuwa</td>
<td>Panadura</td>
<td>35,927</td>
<td>24,134</td>
</tr>
<tr>
<td>Moratuwa</td>
<td>Kalutara</td>
<td>3,675</td>
<td>4,215</td>
</tr>
<tr>
<td>Panadura</td>
<td>Kalutara</td>
<td>9,106</td>
<td>9,421</td>
</tr>
</tbody>
</table>

(Where: Obs = Actual observations, Pred = Model predictions)

Table 4 shows the predictions at year 2004 and 2006 are randomly varying with respect to the observations. This may be the effect of the growth factors that are assumed for the traffic zones. It indicated that the employed population after the base year is not uniformly distributed across this corridor. The statistical abstracts have shown that the housing density in Kalutara and Panadura has been growing significantly. As a result the passenger demand towards Kalutara, Panadura traffic zone shows a significant variation with respect to the actual observations. However, the prediction of 2006 can be adjusted in accordance to the error distribution of the year 2004 travels.

CONCLUSIONS

The main conclusions that are reached in this study are;

- A Bus passenger Origin-destination travel matrix is estimated successfully using the partial data such as the passenger loadings, boardings and alightings of buses that are operated on this travel corridor.
- The bus model is based on gravitational form and can capture the interaction between the main two variables (ie. The effect of one on the other). The accuracy of these variables depends on the accuracy of the model predictions.
- The model performs at an acceptable level of predictive ability when tested on real demand observations.

REFERENCES


ANNE/TEXTURE

The List of Inter-zonal Bus Travel Routes Between Colombo – Kalutara Transport Corridor.

<table>
<thead>
<tr>
<th>Route No.</th>
<th>From</th>
<th>To</th>
<th>Route No.</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Moratuwa</td>
<td>Petah</td>
<td>167</td>
<td>Dehiwala</td>
<td>Totalaga</td>
</tr>
<tr>
<td>100</td>
<td>Panadura</td>
<td>Petah</td>
<td>176</td>
<td>Karagampitiya</td>
<td>Hettiyawatta</td>
</tr>
<tr>
<td>101</td>
<td>Moratuwa</td>
<td>Petah</td>
<td>183</td>
<td>Panadura</td>
<td>Nugegoda</td>
</tr>
<tr>
<td>102</td>
<td>Angulana</td>
<td>Kotahena</td>
<td>400</td>
<td>Aluthgama</td>
<td>Colombo</td>
</tr>
<tr>
<td>142</td>
<td>Moratuwa</td>
<td>Panadura</td>
<td>400.1</td>
<td>Kalutara</td>
<td>Colombo</td>
</tr>
<tr>
<td>154</td>
<td>Angulana</td>
<td>Kiribathgoda</td>
<td>400.7</td>
<td>Panadura</td>
<td>Kalutara</td>
</tr>
<tr>
<td>155</td>
<td>Soysapura</td>
<td>Hettiyawatta</td>
<td>430</td>
<td>Mathugama</td>
<td>Colombo</td>
</tr>
<tr>
<td>155</td>
<td>Mt.Laviniya</td>
<td>Muttakkuliya</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>