ESTIMATION OF ORIGIN DESTINATION TRAVEL MATRIX ON A CORRIDOR USING PASSENGER BOARDING, LOADING AND ALIGHTING COUNTS

Saman J. Widanapathiranage and Dr. Amal S. Kumarage

1Ph.D. Research Fellow, 2Professor, Department of Civil Engineering, University of Moratuwa, Moratuwa, Sri Lanka

1widanasj@civil.mrt.ac.lk, 2kumarage@sltnet.lk

1. INTRODUCTION

Transportation demand estimation modelling in Sri Lanka has developed after years of experimentation. The most common approach to modelling is based on zoning of the area concerned, and the identification of the travel network within this area, connecting the different zones. The resulting travel pattern is understood as trips made between each of these zones. These trips can be represented in the form of a matrix-referred to as the origin-destination matrix or OD matrix. The matrix thus describes the pattern of travel movements between a set of origin and destinations. Such O-D matrices are generally used as the basis for determining the requirements of the transport system such as road capacity, bus transit capacity etc. Developing these matrices is an extremely costly and time consuming task. For example, a bus passenger travel origin destination survey requires passenger household interviews and passenger or household counts.

Mondon and Hess (2003), used bus boarding and alighting counts to investigate the pedestrian safety and transit corridor capacity. Dantas et. al. (2001), developed a data base using bus passenger boarding and alighting counts to improve a bus route. LSC Consultants Inc.(2003), conducted a bus boarding and alighting passenger survey to develop a passenger loading profile in a bus route. This paper investigates a shorter approach to developing OD travel matrices using partial information such as passenger loading, boarding and alighting counts. This methodology is applied to the 44 kilometer transportation corridor on the Galle Road, from Colombo to Kalutara. This corridor connects five traffic zones - Colombo, Dehiwala, Moratuwa, Panadura and Kalutara, which covers an extent of 216 sq. kms. There are 15 routes connecting these zones as shown in Table 1.
Table 1. 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>100, 101, 154, 155, 167, 176, 400, 400/1, 430</td>
<td>100, 101, 400, 400/1, 430</td>
<td>100, 400, 400/1, 430</td>
<td>400, 400/1, 430</td>
<td></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></td>
</tr>
<tr>
<td>Moratuwa</td>
<td>100, 101, 155, 183, 400, 400/1, 430</td>
<td>100, 101, 155, 183, 400, 400/1, 430</td>
<td>100, 400, 183, 142, 430, 400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panadura</td>
<td>100, 101, 183, 400, 400/1, 430</td>
<td>100, 101, 183, 400, 400/1, 430</td>
<td>100, 400, 183, 142, 430, 400</td>
<td></td>
<td></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></td>
</tr>
</tbody>
</table>

There are normal and air-conditioned bus services operated by the state owned cluster bus companies and also numerous private operators serving all these zones. Each of these zones has a central bus stand from which there are intra-zonal bus routes. These routes are laid out through the industrial, commercial and residential zones located in these areas. The employed population in each zone determines to a large extent the travel that is generated and attracted to that travel zone which is mostly related to work and business purposes.

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 are relatively new. Since this is an important and busy corridor even a bus priority lane for this travel corridor has been suggested (Kumarage and Silva, 2003). In this respect, the development of bus passenger inter-zonal travel origin destination matrix is an important aspect in understanding the requirements for improving the transportation system on any corridor.

2. OBJECTIVES AND METHODOLOGY

The aim of this paper is to present (a) the theoretical approach and form for developing an OD travel matrix from partial data and (b) the application of this theoretical approach to formulate an OD matrix for the travel corridor selected.
2.1 Theoretical Approach & Formulation

In developing a general approach to formulate an OD matrix from partial data, 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 \( ED_{(n-1)}^{OD} \) at the end of zone (n-1) is illustrated in Figure 1.

\[
\begin{align*}
\sum_{k=1}^{n-2} B_k^{OD} & \quad LD_{(n-1)}^{OD} \quad B_{n-1}^{OD1} \\
A_k^{OD} & \quad A_{n-1}^{OD1} \quad A_{n-1}^{OD2} \\
\sum_{k=1}^{n-2} A_k^{OD} & \quad A_{n-1}^{OD1} \quad A_{n-1}^{OD2} \\
\sum_{k=1}^{n-2} B_k^{OD} + B_{n-1}^{OD} & \quad LD_{(n-1)}^{OD} \quad B_{n-1}^{OD1} \\
\sum_{k=1}^{n-2} A_k^{OD} + A_{n-1}^{OD1} & \quad A_{n-1}^{OD1} \quad A_{n-1}^{OD2} \\
\sum_{k=1}^{n-2} A_k^{OD} + A_{n-1}^{OD1} & \quad A_{n-1}^{OD1} \quad A_{n-1}^{OD2} \\
\end{align*}
\]

Figure 1: A Bus Route Crossing n\(^{th}\) Zones (Traveling from O to D)

Where:
- \( LD_{(n-1)}^{OD} \) = The total bus passenger loadings observed at a roadside loading observation point located within (n-1)\(^{th}\) zone from origin \( o \) to destination \( d \).
- \( ED_{(n-1)}^{OD} \) = The inter-zonal bus passenger demand between the (n-1)\(^{th}\) zone and n\(^{th}\) 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 \( d \).
- \( \sum_{k=1}^{n-2} B_k^{OD} + B_{n-1}^{OD} \) = The cumulative bus passenger boardings up to the roadside loading observation point (LSP).
- \( \sum_{k=1}^{n-2} A_k^{OD} + A_{n-1}^{OD1} \) = 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 n\(^{th}\) zone given in equation (1) estimates the average number of bus
passengers who would be traveling across the (n-1)\textsuperscript{th} zonal boundary ($ZB_{n-1}$) when a bus moves from origin $o$ to destination $d$.

\[
IPT_{n-1}^{OD} = \sum_{K=1}^{n-2} B_{K}^{OD} - \sum_{K=1}^{n-2} A_{K}^{OD} + B_{n-1}^{OD} + B_{n-1}^{OD} - A_{n-1}^{OD} \tag{1}
\]

In estimating the total passenger demand at the (n-1)\textsuperscript{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 (2),

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

Similarly, equation (3) 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,

\[
ED_{(n-1)}^{DO} = \left\{ 1 - \frac{B_{n-1}^{DO} - A_{n-1}^{DO}}{ \sum_{K=1}^{n-2} B_{K}^{DO} - \sum_{K=1}^{n-2} A_{K}^{DO} + B_{n-1}^{DO} + B_{n-1}^{DO} - A_{n-1}^{DO} - A_{n-1}^{DO} } \right\} \cdot LD_{(n-1)}^{DO} \tag{3}
\]

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,

\[
\begin{bmatrix}
T_{11} & T_{1n} \\
T_{21} & \cdots & T_{2n} \\
\vdots & \vdots & \vdots \\
T_{(n-1)1} & \cdots & T_{(n-1)n} \\
T_{n1} & \cdots & T_{nn}
\end{bmatrix}
= \begin{bmatrix}
0 & \alpha_{12}ED_{1}^{OD} & \cdots & \alpha_{1(n-1)}ED_{1}^{OD} & \alpha_{1n}ED_{1}^{OD} \\
\alpha_{21}ED_{1}^{DO} & 0 & \cdots & \alpha_{2(n-1)}ED_{2}^{OD} & \alpha_{2n}ED_{2}^{OD} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
\alpha_{n1}ED_{1}^{DO} & \alpha_{n2}ED_{2}^{DO} & \cdots & 0 & \alpha_{n(n-1)}ED_{n}^{DO} \\
\alpha_{n1}ED_{1}^{DO} & \alpha_{n2}ED_{2}^{DO} & \cdots & \alpha_{n(n-1)}ED_{n}^{DO} & 0
\end{bmatrix}
\]
Where: \( T_{ij} \) is the estimated inter-zonal passengers travel between \( i^{th} \) zone and \( j^{th} \) zone. 
\( (i = 1,2,\ldots,n) \) and \( (j = 1,2,\ldots,n) \); \( \alpha_{12}, \alpha_{13}, \alpha_{14} \ldots \ldots \alpha_{n(n-1)} \) are the factors that are derived from the bus passenger boardings and alightings counts on the bus route as shown below,

\[
\alpha_{ij} = P_{ij} \cdot \frac{A_j}{\sum_{m=1}^{n} B_m} \tag{4}
\]

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 \( d \).

2.2 Data Collection

In order to calibrate the above matrix and to estimate the OD flows, two type of data are required. In the first instance boarding and alighting counts are required and secondly, roadside passenger counts are also required at selected locations.

The estimation of total bus passenger travel from origin \( o \) to destination \( d \) and destination \( d \) to origin \( o \) at the roadside observation point is done in such a way that the bus size and the level of loading are observed as against counting the actual numbers. 
The bus boarding and alighting surveys were done by traveling observers on a number of individual buses representing the bus corridor.

2.3 Application to Colombo-Kalutara Corridor

This above approach is used to estimate the inter-zonal travel for the travel corridor. The first step is to determine approximate values for the parameters \( \alpha_{ij} \). The corridor is made up of five zones and 15 bus routes serving different zonal pairs as shown in Table 1. The following example given in Box 1 illustrates how this can be done.
Box 1: Estimation of Inter-zonal Bus Passenger Travel on Moratuwa- Colombo Bus Route (Example Route Number 100)

In the Moratuwa- Colombo bus route, the roadside passenger loading observation points were located at Bambalapitiya (LSP1) and Maliban Junction (LSP2). The observed average daily passenger demands were 8,813 and 4,435 for the Colombo to Moratuwa direction and (b) 6,384 and 4,998 respectively for the direction of travel from Moratuwa to Colombo travel. The summary of passenger boardings and alightings counts on this route are shown in Table 2.

Table 2. Passenger Boardings and Alightings Counts (Bus Route Number 100)

<table>
<thead>
<tr>
<th>Location</th>
<th>From Moratuwa to Colombo</th>
<th>From Colombo 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>86</td>
<td>42</td>
</tr>
<tr>
<td>LSP - 1</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Dehiwala zonal limit</td>
<td>49</td>
<td>48</td>
</tr>
<tr>
<td>LSP – 2</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Colombo zonal limit</td>
<td>15</td>
<td>59</td>
</tr>
</tbody>
</table>

Calculation 1: Travel from Colombo to Moratuwa.

\[
ED_{\text{Colombo}}^{DO} = \left[ 1 - \frac{(31 - 26)}{(31 + 82 - 36 - 26)} \right] \times 8813 = 7949 \text{ Passengers per day.}
\]

\[
ED_{\text{Dehiwala}}^{DO} = \left[ 1 - \frac{(11 - 25)}{(82 + 31 + 28 + 11 - 36 - 26 - 33 - 25)} \right] \times 4435 = 6375 \text{ Passengers per day.}
\]

Assuming the \( P_{(\text{Colombo to Dehiwala})} \) is 80 %. Then we can estimate,

\[
\alpha_{\text{Colombo-Dehiwala}} = 0.8 \times \left( \frac{33 + 25}{165} \right) = 0.281
\]

Inter zonal travel (\( T_{ij} \)) (Colombo-Dehiwala) = 2234 Passengers per day / \( T_{(\text{Dehiwala-Moratuwa})} = 660 \) Passengers per day / \( T_{(\text{Colombo-Moratuwa})} = 5715 \) passengers per day.
Calculation 2: Travel from Moratuwa to Colombo.

\[
ED_{\text{Moratuwa}}^{OD} = \left[ 1 + \frac{(11 - 10)}{(86 + 11 - 42 - 10)} \right] \times 4998 = 5109 \text{ Passengers per day.}
\]

\[
ED_{\text{Dehiwala}}^{OD} = \left[ 1 + \frac{(25 - 28)}{(86 + 11 + 49 - 25 - 42 - 10 - 28 - 48)} \right] \times 6384
\]

= 5939 Passengers per day.

Assuming the \( P_{(\text{Moratuwa to Dehiwala})} \) is 60%. Then we can estimate,

\[
\alpha_{\text{Moratuwa-Dehiwala}} = 0.6 \times \left[ \frac{(10 + 48)}{186} \right] = 0.187
\]

Similarly, \( T_{(\text{Moratuwa-Dehiwala})} = 955 \text{ Passengers per day} / T_{(\text{Moratuwa-Colombo})} = 4154 \text{ Passengers per day} \) and \( T_{(\text{Dehiwala-Colombo})} = 1785 \text{ Passengers per day} \).

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.

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

The results and the percentage error of the observations with respect to the model predictors are given in the column 4 and 5 of Table 4, respectively.

3. VALIDATION WITH ESTIMATES BUS DEMAND ESTIMATION MODEL

These estimates were validated using model outputs from an inter-zonal travel demand model (Widanapathiranage and Kumarage, 2003) are given in column 3 of Table 4. This model uses impedance to travel expressed in a generalized form, which includes fare, waiting time, transfer time and travel time for the travel. The socio-economic variable of employment population and the demographic variable of housing density are formulated in to the gravitational form of the model as shown in Equation 7. The model has been calibrated using 438 cases of inter zonal travel observations in the Colombo Metropolitan Region and returned a multiple correlation coefficient or Rsquare of 72.10%.

\[
B_{ij} = 0.255 \times \frac{E_{ij}^{0.860} \times e^{0.854BT}}{HD_{ij}^{0.197} \times BG^{2.562}}
\]  \( \text{equation (7)} \)

Where: \( B_{ij} \) = Bus passenger trips between \( i^{th} \) and \( j^{th} \) zone per day in both directions.

\( E_{ij} \) = Product of employed population residing in \( i^{th} \) and \( j^{th} \) zone.
\[ HD_{ij} = \text{Product of the housing density of } i^{th} \text{ and } j^{th} \text{ zone, where housing density is given as housing units per sq. km. The housing unit defined as a single occupant or multi occupant permanent house in the zone.} \]

\[ BGC = \text{Generalized travel cost of bus in Rupees to travel between } i^{th} \text{ and } j^{th} \text{ zone given as, the sum of bus travel cost, waiting time cost and cost of in-vehicle travel time.} \]

\[ BT = \text{Selected bus travel route between } i^{th} \text{ and } j^{th} \text{ zone is a direct (1) or indirect (0). In this corridor, all are the direct travel routes.} \]

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

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>2004 (Verification Year)</th>
<th>% error Based on Model Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>From Zone</td>
<td>To Zone</td>
<td>Model Estimates</td>
</tr>
<tr>
<td>Colombo</td>
<td>Dehiwala</td>
<td>49,305</td>
</tr>
<tr>
<td>Colombo</td>
<td>Moratuwa</td>
<td>27,290</td>
</tr>
<tr>
<td>Colombo</td>
<td>Panadura</td>
<td>12,543</td>
</tr>
<tr>
<td>Colombo</td>
<td>Kalutara</td>
<td>6,234</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>Moratuwa</td>
<td>10,157</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>Panadura</td>
<td>7,896</td>
</tr>
<tr>
<td>Dehiwala</td>
<td>Kalutara</td>
<td>2,783</td>
</tr>
<tr>
<td>Moratuwa</td>
<td>Panadura</td>
<td>24,134</td>
</tr>
<tr>
<td>Moratuwa</td>
<td>Kalutara</td>
<td>4,215</td>
</tr>
<tr>
<td>Panadura</td>
<td>Kalutara</td>
<td>9,421</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

The paper has successfully demonstrated that the theoretical formulation of a method of calculating travel OD matrix from partial information of loading, boarding and alighting counts can lead to acceptable estimates of inter zonal trip estimates. This has been verified with model estimates for the corridor using a travel demand estimation model. This enables alternatively a high level of estimation of inter zonal travel in a corridor where a number of bus routes ply within a number of different travel zones. This method enables estimation of such travel with minimal survey observations that save both funds and time.

5. REFERENCES


