IMPACT ASSESSMENT OF SHORT-TERM MANAGEMENT MEASURES ON TRAVEL DEMAND

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Abstract:
Travel Demand Management (TDM) can be considered as the most viable option to manage the increasing traffic demand by controlling excessive usage of personalized vehicles. TDM provides expanded options to manage existing travel demand by redistributing the demand rather than increasing the supply. To analyze the impact of TDM measures, the existing travel demand of the area should be identified. In order to get quantitative information on the travel demand and the performance of different alternatives or choices of the available transportation system, travel demand model has to be developed. This concept is more useful in developing countries like India, which have limited resources and increasing demands. Transport related issues such as congestion, low service levels and lack of efficient public transportation compels commuters to shift their travel modes to private transport, resulting in unbalanced modal splits. The present study explores the potential to implement travel demand management measures at Kazhakoottam, an IT business hub cum residential area of Thiruvananthapuram city, a medium sized city in India. Travel demand growth at Kazhakoottam is a matter of concern because the traffic is highly concentrated in this area and facility expansion costs are pretty high. A sequential four-stage travel demand model was developed based on a total of 1416 individual household questionnaire responses using the macro simulation software CUBE. Trip generation models were developed using linear regression and mode split was modelled as multinomial logit model in SPSS. The base year traffic flows were estimated and validated with field data. The developed model was then used for improving the road network conditions by suggesting short-term TDM measures. Three TDM scenarios viz; integrating public transit system with feeder mode, carpooling and reducing the distance of bus stops from zone centroids were analysed. The results indicated an increase in public transit ridership and considerable modal shift from private to public/shared transit.

Keywords: travel demand management, four stage model, linear regression, modal shift, multinomial logit model

To cite this article:

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1. Introduction

Urban development and its related settlements are mostly connected to road transport planning and investments. A critical problem in most developing countries like India is the inadequacy of transport infrastructure, which is aggravated by increasing demands for intra city travel due to rapid growth in both population and employment. Poor mobility ruins several man hours in traffic congestion, road accidents, low speed, heavy vehicle density etc. This condition demands better planning and management of transportation facilities in a country. There is an enormous rise in the use of personalized modes due to increase in travel demand as well as commuter’s preference for personal comfort and convenience. These personalized vehicles will further cause deterioration in traffic and environmental conditions. This necessitates a travel mode shift from personalized vehicles like car to sustainable modes like walk/cycle for short trips and to public transport for long trips. In this scenario, Travel Demand Management (TDM) can be considered as the most viable option to manage the increasing traffic demand by controlling excessive usage of personalized vehicles.

Travel Demand Management takes advantage of the possibility of redistributing existing traffic demand by utilizing available infrastructure and facilities. With limited resources to devote for transportation infrastructure, TDM measures can offer more efficient transport solutions for people and goods which will help to ease the pressure on our congested roads, and make the whole sector more environmental friendly, safer, and cost efficient. In this respect, Travel Demand Management will help to bring about a truly sustainable and effective transport system. To analyze the impact of TDM measures, the existing travel demand of the area should be identified. In order to get quantitative information on the travel demand and the performance of different alternatives or choices of the available transportation system, travel demand model has to be developed.

The major focus of this study is to carry out methodological analysis to develop and execute transport modelling and apply travel demand management measures using the macro-simulation software CUBE. A travel demand model was developed for Kazhakoottam, an IT business hub of Kerala in India, using the conventional four stage method. Travel demand growth at Kazhakoottam is a matter of concern because the traffic is highly concentrated in this area and facility expansion costs are pretty high. The developed model was then used for improving the road network conditions by suggesting short-term TDM measures. Three travel demand management measures were analysed, viz; providing feeder modes to public transportation, carpooling and providing bus stops at less than 400 m from zone centroids. Improving alternative modes against personal modes and applying travel demand management measures would be the most cost-effective way to improve transportation at Kazhakoottam.

2. State of the Art

The most commonly cited objectives of TDM measures are efficiency in the use of resources; improved accessibility; environmental protection; and increased safety. Different possibilities should be considered to reach these objectives, which includes giving priority to public transit and non-motorized modes, providing feeder modes to public transportation, taxi share/ bike share, parking policies and pricing, fuel pricing etc.

Four stage Urban Transportation Modelling System (UTMS) with trip generation, trip distribution, mode split and trip assignment continues to be the widely used method for simulating traffic volumes on transport networks in the planning of urban transportation systems (Kadiyali et al., 2009; Sheppard, 1995; Meyer et al., 2000). Trip generation modelling can consider either household as the unit of analysis (Badoe et al., 2004) or person-category model of trip generation (Supernak et al., 1983). The techniques generally used for trip generation modelling are cross classification, multiple regression analysis and trip rate analysis models (Ortuzar et al., 2001). McNally (2000) studied the conventional model of four stage travel forecasting and carried out trip generation modelling by classifying trips into three; Home based Work (HBW), Non-Home Based (NHB) and Home Based Other (HBO) trips. Various factors which affect the trip generation are land use, vehicle ownership, income, household size, density and type of development, availability of public transportation, and the quality of the transportation system, among other factors that represent the TAZs (Lan et al., 1973; Papacostas et al., 2001).

The trip distribution follows a gravity approach, which is widely used and fully meets the requirements of an up-to-date demand model (Mounir et al.,)
The friction factors can be provided as a look up table with a corresponding factor for each travel (NCHRP Report 365). Wilson (1998) studied the interaction between land use pattern and transportation network development. Trip distribution is mainly affected by the purpose of the trip, weight of each zone as well as the impedance between zones (Roy et al., 2003; Simini et al., 2012). Different trip distribution models were developed over past decades with greater accuracy. Machine Learning (ML) techniques like decision trees and random forests (Ghasri et al., 2017), support vector machine (Karim et al., 2019), neural networks (Pourrebrahimi et al., 2019), fuzzy logic, genetic algorithm (Kalica et al., 2003) and advanced data collection techniques were also applied in various scenarios.

Mode decision is constrained by factors such as vehicle ownership, availability of public transit, transit fare and personal/household-level factors (Pendyala, 2009; Cirill et al., 2010; Pendyala et al., 2005). The majority of travel mode choice studies have been focused on econometric theory of random utility maximization. It assumes that an individual’s choice is determined by the indirect utility of each alternative and the individual can choose the one that maximizes her/his utility level (Xiong et al., 2015). Various mode choice models were developed based on discrete choice models (Koppelman, 1983; McFadden et al., 2000; Hess et al., 2011) and its derivatives (Kitamura, 1990; Pendyala et al., 2000; Wainaina, 2003; Afandizadeh et al., 2010). Data mining methods and artificial intelligence were also employed to model behavioral process (Pendyala et al., 1998; Arentze et al., 2004; Xiong et al., 2013; Goulias, 1999; Ben-Akiva, 2010; Choudhury et al., 2010, Alex et al., 2019).

The various types of traffic assignment models available are incremental assignment, all-or-nothing assignment (AON), user equilibrium assignment (UE), capacity restraint assignment, stochastic user equilibrium assignment (SUE) and dynamic assignment. Many studies have been conducted in trip assignment problems (Kumar et al., 2014; Noeekel et al., 2009; Herawati, 2011; Paul, 2011). With this four-stage modelling, base traffic model can be developed. TDM measures will be applied and analyzed on the base traffic model to assess its impact.

The effectiveness of TDM measures in developing countries depends on many factors (Broaddus et al., 2009; Mahmood et al., 2009; Garling et al., 2007; Alonso et al., 2010; Vedagiri et al., 2009). Carpooling is a TDM measure which offers multiple benefits like congestion mitigation, reduced air and noise pollution, economic benefits, environmental benefits etc (Dewan et al., 2007; Suresh, 2016; Chintakayala et al., 2010). Most of the public policies often do not pay attention to long-term impacts on land use pattern and travel behavior. TDM supports public policy decisions to plan long and short-term transportation solutions more effectively.

3. Study Area and Data collection

The study area selected is Kazhakoottam ward of Thiruvananthapuram city, in the Kerala State; India. Kazhakoottam is an IT business centre cum residential area of Thiruvananthapuram city. This ward has a greater significance because the Technopark is located in this area. Technopark houses over 400 companies, providing jobs to over 58000 professionals and is still expanding with Technocity near Pallipuram. This can highly contribute to large number of trip attractions. Moreover, the Vikram Sarabhai Space Centre and Greenfield International Stadium are located in this area. In addition to its commercial activity, the growing population also demands provision of new traffic solutions which would handle future travel demand without controlling or regulating land use and economic growth.

The defined study area was divided into 13 Traffic Analysis Zones (TAZs), which includes 8 internal zones (Fig. 1) and 5 external zones. The total population of Kazhakoottam ward area in 2011 was 36,264 based on Census Data 2011. The projected population of this area for the year 2019 is 42,792. The rapid growth of population and commercial activities in the area affects the traffic condition in a worst manner. During the peak hours, the area is witnessing severe congestion and longer travel time. The increasing travel demand at Kazhakoottam is a matter of concern because facility expansion costs in the area is pretty high. TDM measures would be the most cost-effective way to improve transportation facilities in such a situation because it redistributes the traffic demand without insisting infrastructure supply.
Data collected for this study includes socio-economic, employment, road inventory, highway network characteristics, land use and Origin-Destination data. Socio-economic data was collected by home interview survey. The main objective was to collect household information, personal information and activity-travel information. Household information included location of the household, type of dwelling unit, household size and vehicle ownership. Personal information included gender, age, occupation, type of employment, place of occupation and monthly income. The gender wise distribution of the sample data collected shows that the study area has almost equal distribution of male and female population. About 34% of the population falls under the age group of 26-45, of which majority were workers. 35% of the population have full time job. Vehicle ownership details showed that 46% of households had two wheelers followed by 32% having four wheelers. These two modes contribute a major share of the vehicle distribution. Activity-travel information consists of the activities and trips made by each individual of the household. It includes the origin, destination, mode of travel, travel cost, travel distance, travel time, frequency of trips, trip purpose, vehicle ownership and their willingness to shift to public/ shared transit modes. Data were collected for selected households in each zone and a total of 1461 samples were taken. Employment data were collected by classifying the buildings in the study area under five categories as shown in Table 1.

### Table 1. Employment Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Type of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Government/Private offices</td>
</tr>
<tr>
<td>Type 2</td>
<td>Hotels and restaurants</td>
</tr>
<tr>
<td>Type 3</td>
<td>Shops</td>
</tr>
<tr>
<td>Type 4</td>
<td>Educational institutions</td>
</tr>
<tr>
<td>Type 5</td>
<td>Places of worship, other recreational centres</td>
</tr>
</tbody>
</table>

Road inventory survey was conducted to assess the physical condition and characteristics of roads within the study area, so as to identify traffic bottlenecks and constraints. It assesses potential capacity and identifies the extent for future development. Road inventory data included the details about the road network such as length, lane width, shoulder width, number of lanes, one way/two-way, parking availability and median type. The highway network characteristics collected for the study included traffic speed, traffic volume counts and capacity of road links. Video-graphic method was adopted and the traffic flows obtained were converted into equivalent Passenger Car Units (PCU) by using conversion factors as suggested by Indian Roads Congress, IRC SP 41.
4. **Travel Demand Modelling**

Travel demand modelling using CUBE software was done which consists of network formation and four stage model development. Each stage is discussed in the following subsections.

4.1. **Network formation**

The road network and traffic analysis zone map were digitalized using ArcGIS and QGIS Software. The highway network thus created was converted to .NET file in CUBE software and all the necessary link attributes were assigned to it. The socio-economic data which include household data and employment data for the study area were organized into the Traffic Analysis Zones or TAZs. The digitized road network in ArcGIS is shown in Fig. 2, in which all major roads are included.

4.2. **Trip generation**

The production and attraction values for the study area were estimated for three different trip categories, viz., Home-Based Daily (HBD) trips, Home-Based Other (HBO) trips and Non-Home-Based (NHB) trips. The trip production and attraction models were developed using Multiple Linear Regression (MLR). The trip production and attraction models obtained are given in Table 2 and 3 respectively. These trip generation models, along with zonal data and total external-internal trips, were given as input to obtain trip end matrix. CUBE script used is shown in Fig.3.

The output of the trip generation step was the trip ends in each zone by trip category as given in Table 4. The values in each cell represent the number of trips produced and attracted for all the three trip categories in the study area. The total trip ends are shown in Table 5. It shows that maximum number of trip productions is from Zone 8. This is due to the fact that the IT centre, Technopark is located in this zone and it is attracting maximum number of trips. It is also found that maximum number of attractions is from the same zone.

![Fig. 2 Digitized Road Network in Arc GIS](image-url)
Table 2. Trip production Models

<table>
<thead>
<tr>
<th>Production Equations</th>
<th>Adj. R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBD = -5.538 + 1.003 Age ( (20-55) ) + 1.587 HH (_2) + 0.382 HH (_3) - 2.048 HH (_3)</td>
<td>0.987</td>
</tr>
<tr>
<td>HBO = 28.138 - 12.687 Age (<em>{&lt;5}) + 1.466 Age (</em>{5-55}) + 2.722 HH (<em>{3}) - 0.271 Age (</em>{20-55})</td>
<td>0.799</td>
</tr>
<tr>
<td>NHB = -0.724 - 0.357 HH (<em>2) - 0.409 Age (</em>{5-20}) + 0.662 TW availability</td>
<td>0.746</td>
</tr>
</tbody>
</table>

where:

Age \(_{<5}\) = Persons with age group less than 5,

Age \(_{5-20}\) = Persons with age group 5 to 20,

Age \(_{20-55}\) = Persons with age group 20 to 55,

Age \(_{5-55}\) = Persons with age group greater than 55,

HH \(_2\) = Household having only 2 members,

HH \(_3\) = Household having only 3 members,

HH \(_{3}\) = Household having greater than 3 members,

TW availability = Two-wheeler availability

Table 3. Trip Attraction Models

<table>
<thead>
<tr>
<th>Attraction Equations</th>
<th>Adj. R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBD = 20.867 + 7.771 Type1 + 5.661 Type4 + 2.019 Type3</td>
<td>0.878</td>
</tr>
<tr>
<td>HBO = 20.085 + 7.473 Type1 + 2.741 Type3</td>
<td>0.834</td>
</tr>
<tr>
<td>NHB = 0.231 + 0.438 Type1 + 1.723 Type2 + 0.974 Type5</td>
<td>0.921</td>
</tr>
</tbody>
</table>

where:

Type1 to type 5 are the employment categories as given in Table 1.

RUN PGM=GENERATION PRNFILE="C:\Users\Jim\Desktop\Thesis\Cube_files\TMGEN00A.PRN"
MSG=Trip Generation
FILEI ZDATI2 = "C:\Users\Jim\Desktop\Thesis\External trips\External Trips (1) .dbf"
FILEI ZDATI1 = "C:\Users\Jim\Desktop\Thesis\Cube_files\zone\ZONE\SHIPPING.dbf"
FILEO PAO[1] = "C:\\USERS\\JIM\\DESKTOP\\THESES\\CUBE\FILES\\TRIPS\ENDED.DAT",
;DBF: Z=zone field name
;TXT: Z=zone field location, var=field location, var=field location ....
PARAMETERS ZONES = 13

PROCESS PHASE=ILOOP
IF (I<=8)
;calculate productions by purpose
P[1] = -5.538 + 1.587*zi.1.HH + 1.003*zi.1.Age\(20-55\) + 0.382*zi.1.HH - 2.048*zi.1.HH>3
P[3] = 0.724 - 0.357*zi.1.HH - 0.409*zi.1.Age\(_{5-20}\) + 0.662*zi.1.TW availability
;calculate attractions by purpose
A[1] = 20.867 + 7.771*zi.1.Type1 + 5.661*zi.1.Type4 + 2.019*zi.1.Type3
A[3] = 0.231 + 0.438*zi.1.Type1 + 1.723*zi.1.Type2 + 0.974*zi.1.Type5
ELSE
P[4] = 1*zi.2.eitrips
ENDIF
ENDPROCESS
;adjust zonal attractions so total attractions match total productions
PHASE=ADJUST
ENDPROCESS
ENDRUN

Fig.3 Trip generation script in CUBE network
4.3. Balancing trip ends

The trip productions and attractions should be balanced before the trip distribution stage as there should be only two ends of a trip. The trip attractions were adjusted so that total productions and attractions are equal. The factor for balancing was calculated using the equations (1) to (3). The balanced trip ends obtained is shown in Table 6.

\[
\text{Factor} = \frac{\text{CT}_{\text{p}} \sum A_z}{z}
\]  

(1)

\[
\text{CT}_{\text{p}} = \sum P_x + \sum P_E - \sum A_E
\]  

(2)

\[
A_z = \text{Factor} \times A_z
\]  

(3)

\[A_x = \text{Trip attractions at each zone (by purpose)}\]

\[\text{CT}_{\text{p}} = \text{The total of productions}\]

\[P_x = \text{Trip productions for each zone}\]

\[P_E = \text{Trip productions at each external station}\]

\[A_x = \text{Trip attractions at each external station}\]

\[A_z = \text{Balanced Trip Attractions}\]

P1, P2 and P3 represents trip productions and A1, A2, A3 represents trip attractions for the three trip categories HBD, HBO and NHB. P4 and A4 represent trip ends for external trip purposes. The values in each cell represent balanced trip production and attraction numbers in each zone. Total balanced productions and attractions were obtained as 32,657.

### Table 4. Trip Ends before Balancing

<table>
<thead>
<tr>
<th>Zones</th>
<th>Production</th>
<th>Attraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBD</td>
<td>HBO</td>
<td>NHB</td>
</tr>
<tr>
<td>HBD</td>
<td>HBO</td>
<td>NHB</td>
</tr>
<tr>
<td>HBD</td>
<td>HBO</td>
<td>NHB</td>
</tr>
</tbody>
</table>

### Table 5. Total trip ends

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Trip Types</th>
<th>Total Trip Ends</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HBD Trip Productions</td>
<td>18,382</td>
</tr>
<tr>
<td>2</td>
<td>HBO Trip Productions</td>
<td>12,233</td>
</tr>
<tr>
<td>3</td>
<td>NHB Trip Productions</td>
<td>20,424</td>
</tr>
<tr>
<td>4</td>
<td>HBO Trip Attractions</td>
<td>20,245</td>
</tr>
<tr>
<td>5</td>
<td>NHB Trip Attractions</td>
<td>10,482</td>
</tr>
<tr>
<td>6</td>
<td>NHB Trip Attractions</td>
<td>3,002</td>
</tr>
</tbody>
</table>

### Table 6. Trip Ends after Balancing

<table>
<thead>
<tr>
<th>Z</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2824</td>
<td>934</td>
<td>256</td>
<td>300</td>
<td>1036</td>
<td>221</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1860</td>
<td>2185</td>
<td>170</td>
<td>417</td>
<td>2195</td>
<td>1141</td>
<td>198</td>
<td>870</td>
</tr>
<tr>
<td>3</td>
<td>2094</td>
<td>1151</td>
<td>204</td>
<td>2103</td>
<td>988</td>
<td>216</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1627</td>
<td>1116</td>
<td>336</td>
<td>2079</td>
<td>972</td>
<td>318</td>
<td>829</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1499</td>
<td>1862</td>
<td>1959</td>
<td>2978</td>
<td>2034</td>
<td>249</td>
<td>1295</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2061</td>
<td>948</td>
<td>336</td>
<td>2123</td>
<td>1123</td>
<td>322</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3169</td>
<td>1959</td>
<td>278</td>
<td>3078</td>
<td>2234</td>
<td>226</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3247</td>
<td>2423</td>
<td>400</td>
<td>2987</td>
<td>2507</td>
<td>440</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.4. Trip distribution

In the trip distribution step, the trips generated from each TAZ were allotted to all other TAZs in the study area. Doubly constrained gravity model was used for developing the trip distribution model. The gravity model is given in equation (4):

\[T_{ij} = P_i \times \frac{A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij}}
\]

(4)

where:

- \(T_{ij}\) = No. of trips from zone i to zone j,
- \(P_i\) = No. of trip productions in zone i,
- \(A_j\) = No. of trip attractions in zone j,
- \(F_{ij}\) = Friction factor relating to spatial separation between zone i & j,
- \(K_{ij}\) = Trip distribution adjustment factor between zone i to zone j.

The inputs to the trip distribution include balanced trip end matrix obtained from trip generation stage, highway skim matrix and friction factors. The output matrix gave the number of trips distributed from one zone to another for all the trip purposes.

#### 4.4.1. Skim matrix

The zone to zone skim matrix or travel impedance matrix is one of the important inputs to the trip distribution step. It represents the shortest path from one zone to another. The CUBE script for travel impedance matrix is shown in Fig. 4 and the skim matrix is shown in Table 7.
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4.4.2. Friction factors

The friction factors are parameters used in the gravity model to account for travel time separation between zones. The friction factors attempt to show the effect of travel time or impedance on trip making. These factors were calculated using the gamma function given in equation (5). The values of a, b and c for initial friction factors are given in Table 8 (NCHRP Report 365)

\[ F_{ij} = a \times t^b \times e^{ct} \]  

(5)

where:

- \( t \) = travel impedance (time in minutes)
- \( a, b, c \) = model parameters

The trip length frequencies obtained from the initial friction factors were compared with the observed trip frequencies from the OD survey. The calibrated friction factors considered are shown in Table 9 (NCHRP Report 365). The friction factors were adjusted until the trip length frequencies from the model matches the observed average trip length frequencies from the survey.
### Table 9 Synthetic Friction Factors

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>HBD</th>
<th>HBO</th>
<th>NHB</th>
<th>Ext</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25214</td>
<td>126632</td>
<td>196293</td>
<td>25214</td>
</tr>
<tr>
<td>5</td>
<td>14936</td>
<td>10979</td>
<td>15601</td>
<td>14936</td>
</tr>
<tr>
<td>10</td>
<td>7972</td>
<td>2811</td>
<td>37763</td>
<td>7972</td>
</tr>
<tr>
<td>15</td>
<td>4280</td>
<td>1041</td>
<td>1331</td>
<td>4280</td>
</tr>
<tr>
<td>20</td>
<td>2303</td>
<td>449</td>
<td>551</td>
<td>2303</td>
</tr>
<tr>
<td>25</td>
<td>1241</td>
<td>210</td>
<td>248</td>
<td>1241</td>
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<tr>
<td>30</td>
<td>669</td>
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<td>118</td>
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<td>35</td>
<td>361</td>
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<td>58</td>
<td>361</td>
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<td>40</td>
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<tr>
<td>45</td>
<td>105</td>
<td>15</td>
<td>15</td>
<td>105</td>
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<tr>
<td>50</td>
<td>57</td>
<td>8</td>
<td>8</td>
<td>57</td>
</tr>
<tr>
<td>55</td>
<td>31</td>
<td>4</td>
<td>4</td>
<td>31</td>
</tr>
<tr>
<td>60</td>
<td>17</td>
<td>3</td>
<td>2</td>
<td>17</td>
</tr>
</tbody>
</table>

### 4.4.3. Trip distribution process

The trip ends obtained from trip generation step and highway skim matrix obtained from the network, which is the measure of travel cost between each pair of zones in terms of time and distance and the friction factors were provided as the input to the CUBE software. The CUBE script for trip distribution is given in the Fig. 5.

The output matrix in Table 10 shows the number of trips distributed from one zone to another for HBD trips. The trips were found decreasing as the distance between zones increases. The increased number of trips distributed in certain zones was due to increased activity in those particular zones.

```plaintext
RUN PGM=DISTRIBUTION
PRNFIL="C:\Users\Jiri\Desktop\Thesis\Cube_files\TMGEN00B.PRN" MSG=’Trip Distribution’
; ----- specify input p & a file and los file
FILEI ZDATI[1]= {PAlQ},
Z=#1, P1=#2, P2=#3, P3=#4, P4=#5, A1=#6, A2=#7, A3=#8, A4=#8
FILEI MATTI[1]= {MAT1},
FILEO MATO[1]= {MAT0},
MO=1-5, NAME={matnames}
; ----- setup friction factor lookup tables, input from file

LOOKUP FILE = "[LOOKI.LQ]",
INTERPOLATE=Y, NAME=FF,
LOOKUP[1]=1, RESULT=2,
LOOKUP[2]=1, RESULT=3,
LOOKUP[3]=1, RESULT=4,
LOOKUP[4]=1, RESULT=5
; ----- setup the working p’s and a’s
; ----- get the los matrix into work matrix 10
MW[10] = ML1.1
; ----- do 4 gravity models, each followed by a frequency summation
GRAVITY PURPOSE=1, LOS=MW[10], FFACTORS=FF
GRAVITY PURPOSE=2, LOS=MW[10], FFACTORS=FF
GRAVITY PURPOSE=3, LOS=MW[10], FFACTORS=FF
GRAVITY PURPOSE=4, LOS=MW[10], FFACTORS=FF

(prt3) FREQUENCY VALUE=EMW=1 BASEMW=10, RANGE=1-100
(prt3) FREQUENCY VALUE=EMW=2 BASEMW=10, RANGE=1-100
(prt3) FREQUENCY VALUE=EMW=3 BASEMW=10, RANGE=1-100
(prt3) FREQUENCY VALUE=EMW=4 BASEMW=10, RANGE=1-100
; ----- get a comparison report on last iteration
(prt2) REPORT ACOMP=1-4, ITERATIONS=99
ENDRUN
```

Fig. 5. CUBE Script for Trip Distribution
For example, the number of trips distributed to zone 8 was found to be more because it has a greater number of business centres. The trip length distribution curve was obtained for all the three trip categories and is shown in Fig. 6. The trip length frequency for HBD and HBO were obtained as 15 to 20 minutes and for NHB, it was 5 to 10 minutes.

Table 10. Trip Distribution for HBD trips

<table>
<thead>
<tr>
<th>Zones</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>778</td>
<td>276</td>
<td>380</td>
<td>203</td>
<td>148</td>
<td>241</td>
<td>362</td>
<td>435</td>
</tr>
<tr>
<td>2</td>
<td>323</td>
<td>348</td>
<td>287</td>
<td>134</td>
<td>97</td>
<td>159</td>
<td>242</td>
<td>270</td>
</tr>
<tr>
<td>3</td>
<td>408</td>
<td>259</td>
<td>314</td>
<td>164</td>
<td>119</td>
<td>192</td>
<td>302</td>
<td>336</td>
</tr>
<tr>
<td>4</td>
<td>253</td>
<td>141</td>
<td>190</td>
<td>233</td>
<td>126</td>
<td>186</td>
<td>304</td>
<td>195</td>
</tr>
<tr>
<td>5</td>
<td>148</td>
<td>82</td>
<td>110</td>
<td>101</td>
<td>449</td>
<td>215</td>
<td>225</td>
<td>168</td>
</tr>
<tr>
<td>6</td>
<td>269</td>
<td>149</td>
<td>200</td>
<td>167</td>
<td>242</td>
<td>319</td>
<td>410</td>
<td>305</td>
</tr>
<tr>
<td>7</td>
<td>437</td>
<td>245</td>
<td>339</td>
<td>295</td>
<td>273</td>
<td>442</td>
<td>635</td>
<td>503</td>
</tr>
<tr>
<td>8</td>
<td>519</td>
<td>270</td>
<td>374</td>
<td>187</td>
<td>201</td>
<td>325</td>
<td>498</td>
<td>874</td>
</tr>
</tbody>
</table>

Fig. 6. Trip Length Frequency Distribution Curve

4.5. Modal split

In the third step, the mode split models were developed in the form of Multinomial Logit models. The modes considered for the study were car, two-wheeler, three-wheeler and bus. The total time taken for travel was considered as the independent variable and modes were taken as the dependent variables. Bus was considered as the reference category. The utility equations were developed in SPSS Software. The utility equations are given in equations (6), (7) and (8).

\[ U(TW) = 0.506 - 0.032 \times \text{time}, \quad (6) \]

\[ U(AUTO) = 1.265 - 0.075 \times \text{time}, \quad (7) \]

\[ U(CAR) = 0.679 - 0.003 \times \text{time} \quad (8) \]

CUBE script for mode split is given in Fig. 7. The output of the mode split stage was in person trips by mode.

The OD matrix of the person trips by different modes such as car, two-wheeler, auto-rickshaw and bus were obtained. This was converted to vehicle trips by dividing with average occupancy factors for each mode. The average occupancy factors were taken from IRC-SP 30. The friction factors were adjusted until the trip length frequencies from the model matched the observed average trip length frequencies from the survey. The OD matrix of the person trips by different modes such as car, two-wheeler, auto-rickshaw and bus were obtained. This was converted to vehicle trips by dividing with auto occupancy factors for each mode. The auto occupancy factor used is given in Table 11. The obtained vehicle trips for each mode were multiplied with PCU values. The PCU values used for car, two-wheeler, three-wheeler and bus were 1, 0.5, 0.8 and 3.5. The final OD matrix in vehicle trips determined from this matrix is shown in Table 12.

Table 11. Average Occupancy Factors

<table>
<thead>
<tr>
<th>Mode</th>
<th>Auto Occupancy Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>4.8</td>
</tr>
<tr>
<td>Two-Wheeler</td>
<td>1.5</td>
</tr>
<tr>
<td>Autorickshaw</td>
<td>1.76</td>
</tr>
<tr>
<td>Bus</td>
<td>43</td>
</tr>
</tbody>
</table>

Table 12. Final OD Matrix

<table>
<thead>
<tr>
<th>Zones</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>668</td>
<td>164</td>
<td>282</td>
<td>120</td>
<td>75</td>
<td>130</td>
<td>194</td>
<td>242</td>
</tr>
<tr>
<td>2</td>
<td>191</td>
<td>886</td>
<td>316</td>
<td>99</td>
<td>51</td>
<td>98</td>
<td>151</td>
<td>179</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>298</td>
<td>281</td>
<td>108</td>
<td>62</td>
<td>104</td>
<td>212</td>
<td>253</td>
</tr>
<tr>
<td>4</td>
<td>144</td>
<td>101</td>
<td>120</td>
<td>519</td>
<td>74</td>
<td>117</td>
<td>306</td>
<td>124</td>
</tr>
<tr>
<td>5</td>
<td>76</td>
<td>47</td>
<td>60</td>
<td>67</td>
<td>737</td>
<td>133</td>
<td>135</td>
<td>101</td>
</tr>
<tr>
<td>6</td>
<td>145</td>
<td>95</td>
<td>108</td>
<td>107</td>
<td>138</td>
<td>366</td>
<td>425</td>
<td>181</td>
</tr>
<tr>
<td>7</td>
<td>229</td>
<td>151</td>
<td>226</td>
<td>294</td>
<td>150</td>
<td>439</td>
<td>686</td>
<td>358</td>
</tr>
<tr>
<td>8</td>
<td>281</td>
<td>177</td>
<td>266</td>
<td>119</td>
<td>110</td>
<td>188</td>
<td>356</td>
<td>1353</td>
</tr>
</tbody>
</table>

4.6. Trip assignment

All or nothing assignment technique was used to assign trips to the network in this study. It is assumed in this technique that the travel time on links does not vary with link flows. According to this method, a trip maker will choose that route which minimizes his/her travel time between a particular origin and destination pair. The input provided for this step was highway network and O-D matrix. CUBE script is shown in Fig. 8. The travel time was chosen as path cost to assign trips. The trip assignment output, which is the volume count in each link is shown in Fig. 9. The congested links are shown as thick lines.
Fig. 7. CUBE Script for Mode Split
It was found from the four step model that several road links near the Kazhakoottam intersection were congested. FCI Road and Kumizhikara road were found to be congested even though the traffic volume in these roads is comparatively low. This can be attributed to the fact that these roads have low capacity to carry its existing traffic volume, especially during the peak hours. The congested links were identified as NH66, Kazhakoottam to AJ hospital road, Kazhakoottam – Menamkulam road, Kazhakoottam- Kulathoor road, FCI Road and Kumizhikara Road.

The travel demand model developed using the CUBE software was validated by comparing the simulated volume obtained from the model and the observed volume from the study area. The errors in simulated volume on all the roads are obtained below 20%. This shows that the developed model is good.
5. Impact of Travel Demand Management (TDM) Measures

In order to analyse the impact of TDM measures, a public transit line file was coded to the assigned network in CUBE. All the necessary details like route, stops, headway, delays, speed etc. were given in the public transit route file. Non–transit legs were also generated after assigning public transit. Three travel demand management measures were analysed.

a) Providing feeder modes to public transportation.

b) Carpooling.

c) Limiting the distance between zone centroids and bus stops to 400m.

5.1. Providing feeder modes to public transportation

In this scenario, share taxi was considered as a feeder mode to public transportation. The combination of feeder mode and public transport was taken as the fifth choice for mode in the analysis. The variation in three influential variables were analysed. In-vehicle Travel Time (IVTT), Out-Vehicle Travel time, and Generalised cost. The generalized cost function was given in equation (9).

\[
\text{Generalized Cost} = (0.5 \times \text{Time}) + (0.00151 \times \text{Distance}) + \text{Base Fare}
\]  

It was observed that the mode split for public transport increased from 2.2% to 8.4%, implying that around 25.88% of passengers would shift to public transportation if feeder connectivity were provided.

5.2. Carpooling

The modal split output obtained from the four-step model showed that there is a higher mode share of cars in zone 8 compared to other zones, having its origin and destination within zone 8. Hence an analysis was made to assess the impact of introducing carpooling to this particular zone. A roadside vehicle occupancy survey was carried out to identify the average occupancy of cars within that zone. The average occupancy was found to be 2.13. As per IRC-SP-30, the auto occupancy factor for car is 4.8. The following assumptions were made in view of assessing this scenario

i. 50% of the people are willing to change from Single Occupancy Vehicle (SOV) to carpooling.

ii. The average occupancy of cars considered in carpooling is 4.8.

Considering the above factors, the change in mode share was analysed. The resultant mode split showed that there was an increase of 16.32% shift from private cars to public/shared transit.

5.3. Limiting the distance between zone centroids and bus stops to 400 m

For analyzing this scenario, the distance of intercity bus-stop from the zone centroid is taken into consideration. Among the 8 zone centroids, three of them are within 400m from the bus stop. The remaining 5 zone centroids are more than 400m. The distance of these bus-stops was limited to 400m and the corresponding change in modal share was analysed. It was observed that when the distance was reduced, there is an increase of 12.88% modal shift from private to public transportation.

6. Conclusion

The major output of this study is a methodological analysis to develop and execute transport modelling and application of travel demand management measures using the macro-simulation software CUBE. The method considers the construction of a set of parameters that can be applied in evaluating TDM measures and examines its efficiency in terms of passenger benefits. From a practical point of view, the aim of the method is to establish opportunities for better connectivity to public transport systems and encouraging passengers to shift from private modes to public transport. Beyond the reported results, this study also highlighted the essential need for data and variables, in order to predict travel patterns and to design efficient transportation systems.

The study area was divided into eight TAZs. It was found that the major factors affecting trip productions were number of commuters in the study area, vehicle ownership and age. The trip attractions were influenced by factors such as total employment opportunities in the region and type or category of employment. Trip generation model showed that the trips between commercial/employment zones and residential zones were high. The result from the model shows that seven road links near Kazhakoottam intersection were congested. Validation results showed that the difference between simulated volume and actual volume for most of the roads was obtained below 20%. This shows that the model is
accurate. Three travel demand management measures were considered. It was observed in all the three TDM scenarios, that there is an increase in modal shift from private vehicles to public transportation. When share taxi was introduced as a feeder mode to public transportation, there was an increase of 25.88% in modal share of public transit. In the case of carpooling, the increase in modal shift to shared transit was 16.32%. In the case of limiting the distance of bus-stops from zone centroids to 400m, an increase of 12.88% in the modal share of public/shared transit was observed. The demand management measures analyzed in the study thus proved that the developed model system is effective to analyze the impact of various short term TDM measures by policy makers before implementation.

Acknowledgements
The authors are grateful to Transportation Engineering Research Centre (TRC), College of Engineering Trivandrum, funded by Government of Kerala, for sponsoring the project.

References
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