Urban Transport Research Journal

The Urban Mobility India (UMI) Research Symposium 2011

INSTITUTE OF URBAN TRANSPORT (INDIA)
The Urban Mobility research symposium 2011

The second research symposium on urban transport was organised on 3rd December 2011 at the fourth Urban Mobility India (UMI) Conference in Delhi. IUT sponsored this one day research symposium and IIT Delhi was given the responsibility to coordinate the same.

The symposium provided a platform to highlight the current research carried out by the academic and research institutes in urban transport, especially by the young researchers in masters and Ph.D. programmes. The purpose was to:

1. Encourage the young researchers working on the various facets of urban transport and provide opportunity for networking
2. Improve quality of research through peer review process,
3. Contribute towards the database compiled by the Institute of Urban Transport to identify gaps for future research funding

Young researchers (Undergraduate, Masters and Ph.D. level students) working in the area of urban transport were invited to submit abstracts online based on the work carried out by students as part of their academic or research program on the following six themes:

1. Accessibility and Safety
2. Public Transport
3. Transport and Environment
4. Urban land use and transport
5. Non-motorised transport
6. Traffic Management and Operations

Large numbers of academic institutes active in the area of urban transport research responded to the call for abstracts. The review and rating of abstracts were done by a panel of academic experts from the most reputed institutions of the country. The assessment of abstracts was done based on the following criteria:

- Originality
- Objectives: clarity and appropriateness
- Methodology: technical soundness
- Timeliness: in Indian context
- Usefulness: to researchers and practitioners
- Language

The technical sessions of symposium, which followed the inaugural session, were structured with oral presentations of 36 best abstracts selected. These were presented in six sessions, each session having 6 presentations for 20 minutes each including discussions. The presentations were followed by questions and answers by 2-3 panellists and open discussion from the floor. In addition to the presentations, 21 abstracts were selected for poster sessions.
The presentations were assessed by the session chairs during the course of technical sessions and based on that a list of ten best papers were selected for publication, which were again reviewed, amended and have been published in this Journal.

**List of Members of Review Panel for Rating Abstracts**

1. Dr V. Vasudevan, Dr Partha Chakravorty, *Indian Institute of Technology, Kanpur*
2. Dr Satish Chandra, *Indian Institute of Technology, Roorkee*
3. Dr Sanjay Gupta, *School of Planning and Architecture, New Delhi*
4. Dr Manjiri Akolkar, *Centre for Environment Planning and Technology, Ahmedabad*
5. Dr CSK Prasad, *National Institute of Technology, Warangal*
6. Dr R. Sivanandan, Dr S.Chella Rajan, *Indian Institute of Technology, Chennai*
7. Dr K.V. Krishna Rao, *Indian Institute of Technology, Mumbai*
8. Dr B. Maitra, *Indian Institute of Technology, Kharagpur*
9. Dr A.K. Sarkar, *Birla Institute of Technology, Pilani*
10. Dr C. Mallikarjuna, *Indian Institute of Technology, Guwahati*
11. Dr Ashish Verma, *Indian Institute of Science, Bangalore*
12. Dr K. RamchandraRao, *Indian Institute of Technology*
13. Dr G J Joshi, Dr Rakesh Kumar, *National Institute of Technology Surat*
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<thead>
<tr>
<th>S No</th>
<th>Name of Author</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Neera Jaiswal</td>
<td>Improving Accessibility for People with Disabiity in Public Transport: A Case of Ahmedabad</td>
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<td></td>
<td>EPT, Ahmedabad</td>
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<td>2.</td>
<td>Gaurav Harishchandra Pandey</td>
<td>Traffic Flow and Risk Assessment</td>
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<td>3.</td>
<td>Shraddha Jain</td>
<td>Assessment of BRTS in India</td>
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<td>CEPT, Ahmedabad</td>
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<td>SVNIT Surat</td>
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<td>5.</td>
<td>PRAGEEJA K</td>
<td>Alternative Strategies for Mass Transportation - An Indigenous Way</td>
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<td>NIT Calicut</td>
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<td>6.</td>
<td>Ravi Nashikkar</td>
<td>Impact of Bus Rapid Transit System on Socio-Economic Characteristic of Surat</td>
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<td>7.</td>
<td>Abdul Azizi</td>
<td>Disaggreggate Travel Behaviour and Transit Shift Analysis for a Transit Deficient Metropolitan City in India</td>
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<td>8.</td>
<td>Pranjali Chandraprakash Deshpande</td>
<td>Route Rationalisation of Public Transport Services: A Case of Pune</td>
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<td>9.</td>
<td>Rohit Singh Chouhan</td>
<td>Urban forest and its Significance in Mitigating Vehicular Pollution</td>
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<td>MANIT Bhopal</td>
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<td>10.</td>
<td>Ajinkya Vijay Kumar Mali</td>
<td>Spatio-Temporal Analysis of CO Emission At intersections: A Case Study of Mumbai</td>
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<td>11.</td>
<td>cheelavenkataravisankar</td>
<td>A Study On Air Pollution Management Due to Traffic Pollution on Urban Roads of Vizianagaram City</td>
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<td>Maharaja VijayaramGajapathi</td>
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<td>Raj College of Engineering, Vizianagaram,</td>
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<td>12.</td>
<td>Nibedita Dash</td>
<td>Defining A Sustainability Model for Developing Nation: Social, Economic and Ecological Perspective</td>
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<td>Indian Institute of Science,Bangalore</td>
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<td>13.</td>
<td>Satish Kumar Eerni</td>
<td>Forecasting Urban Sprawl and Traffic Conditions in Tiruchirappalli City</td>
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<td>NIT Tiruchirappalli</td>
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<td>15.</td>
<td>Yash K Hivarkar</td>
<td>Activity Based Planning for Pedestrian Traffic in SVNIT Campus</td>
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<td>Indian Institute of Technology Guwahati</td>
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<td>17.</td>
<td>Ramizraja Mohamadyasmin Munshi</td>
<td>Critical Review of Traffic Quality and Management for a Metropolitan CBD: A Case Study of Surat</td>
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<td>18.</td>
<td>Jasti Pradeep Chaitanya</td>
<td>Identification and Improvisation of Bottlenecks in an Urban Transportation Network by Speed Contour Technique</td>
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<td>20.</td>
<td>Arpan Mehar</td>
<td>Microscopic Traffic Flow Simulation of a Urban Road</td>
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# Urban Mobility India Conference cum Exhibition 2012 - Program

**Theme - “Smart Mobility”**

## DAY 1 (5th December 2012) – Research Symposium

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<td>Registration</td>
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<td>09:00 - 9:20</td>
<td><strong>OPENING SESSION</strong></td>
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<tr>
<td>09:00 - 09:05</td>
<td>Welcome Address by Shri S.K. Lohia, OSD(UT) and EO Joint Secretary, Ministry of Urban Development, Govt. of India</td>
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<tr>
<td>09:05 - 09:10</td>
<td>Introduction to the Symposium by IIT Madras</td>
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<td>09:10 - 09:20</td>
<td>Inaugural Address by Dr Sudhir Krishna, Secretary MoUD</td>
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<tr>
<td>09:20 to 10:20</td>
<td><strong>PLENARY SESSION: URBAN TRANSPORT - CHALLENGES AND SOLUTIONS</strong></td>
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<tr>
<td>09:20 - 9:30</td>
<td>Dr. Sanjay Gupta, Professor, School of Planning and Architecture, Delhi</td>
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<td>09:30 - 9:40</td>
<td>Dr. Jose Holguin-Veras, Rensselaer Polytechnic Institute, NY, USA</td>
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<td>09:40 - 09:50</td>
<td>Dr. P. K. Sikdar, President, Intercontinental Consultants and Technocrats Pvt. Ltd.</td>
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<tr>
<td>09:50 - 10:20</td>
<td>Discussion</td>
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<td>10:20 - 10:45</td>
<td>Tea &amp; Poster Session</td>
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### ORAL SESSIONS (10:45 - 12:45)

#### Oral Session 1: Research Paper Presentation
- Barriers In Fare Integration Of Public Transport Systems - Vijayshree Pednekar, H. M. Shivanand Swamy.
- Corridor Improvements Using Vissim Microscopic Simulation Tool - Ram Kumar, Prasad CSRK, Reith
- Estimating Perceived Inadequacy Of Public Transportation For A Residential Area In Jaipur - Krishna N. S. Behara, Shriniwas S. Arkatkar, Ashoke K. Sarkar,
- Flow Characteristics Of Heterogeneous Traffic With And Without Adherence To Lane Following - G. Sarishka, A. Gowri, R. Sivanandan
- Evaluation And Application Of Image Processing Sensors Under Indian Conditions - Jithin Raj, Sunny Raja Varma, Ramesh, V., Lelitha Vanajakshi
- Urban Walkability: The Urban Design Contribution - Anne Matan, Peter Newman

#### Oral Session 2: Research Paper Presentation
- Performance Evaluation Of City Bus Services For Tier-II Cities - Sreelakshmi R Pillai, N. Nawaz
- Mobile Vehicular Air Pollution Monitoring Using GIS, GPS And Sensor At Ambattur, Chennai - H. Prasad Raju, P. Partheeban
- Mode Choice Behavior Of Urban Dwellers For Commute To Work - Sreela, Jijn, Anjaneyalu
- Organizing The Role Of The Intermediate Public Transport (IPT) Sector: Focus On Autorickshaw Services - Taralshukla, Manjiri Akalkotkar
- Traffic Density Estimation On Urban Roads - Mahesh Kumar Gellaboina, Indhu Rajamohan, Gurumurthy Swaminathan And Vijendran Venkparao
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<tr>
<td>12:45 - 14:00</td>
<td>Lunch &amp; Poster Session</td>
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<td>14:00 - 16:00</td>
<td><strong>ORAL SESSIONS (14:00 - 16:00)</strong></td>
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<tr>
<td></td>
<td><strong>Oral Session 3: Research Paper Presentation</strong></td>
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<tr>
<td></td>
<td>• Spatial Analysis Of Road Transport System - Sreelekha.M.G., K.Krishnamurthy, Anjaneyulu MVLR</td>
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<td>• Enhancement Of Transit Ridership-A Case Study On Delhi Metro - S R S Sirisha, A K Sharma</td>
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<td>• Optimization Of Hyderabad Bus Network Using VISUM - Jayatheja A, Prasad CSRK And Markus Sator</td>
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<td>• Safety Evaluation Of An Uncontrolled Intersection Using Surrogate Safety Measures - P. Vedagiri, S.Shekhar Babu</td>
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<td>• Case Study Of The Auto-Rickshaw Industry In Mumbai - Emma Shlaes,Akshay Mani</td>
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<td>• Joint Models For Analysis Of Household Trip Frequency And Vehicle Ownership In Chennai City - G. Viswanath, Karthik K. Srinivasan</td>
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<td>• Demand Responsive Scheduling: A Methodology For Optimization Of Public Transport Operations - Sameep Arora, Prashant Bachu</td>
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<tr>
<td>16:00 - 16:30</td>
<td><strong>Oral Session 4: Research Paper Presentation</strong></td>
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<td>• Advanced Traveler Information Systems Qualitative Display Of Level Of Congestion Under Indian Conditions - Sai Vikas; Pavitra Tejaswi; Rini J G; Prabhas; Varaprasad</td>
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<td>• Coordinating City-Wide Multi-Modal Transit Services In Mumbai - Rahul Nair, Fabio Pinelli, Francesco Calabrese</td>
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<td>• Environmentally Sustainable Transport Performance Index For Residential Neighbourhoods - Megha, Sanjay Gupta</td>
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<td>• Car Restraint Policy For A Mega-City,Case Study - Delhi -Megha Aggarwal, Sanjay Gupta</td>
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<td>• Sustainable Approach In Vehicle Routing For Regional Solid Waste Transport System: MMR, A Case Study - G. S. Sasane., S. L. Dhingra, P. Vedagiri</td>
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<td>• Community Based Neighbourhood Accessibility Planning: A Case Of Malleshwaram, Bangalore - Sneha Rapur, Sylvia Prakash, Dult Karnataka</td>
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<td>• Performance Comparison Of A Radar Based Traffic Sensor - Smartsensor Hd For Indian And American Traffic Conditions - Ramesh, V., Jithin Raj, Leitha Vanajakshi, Shuo Wang, Anuj Sharma, Laurence Rilett</td>
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<th>Time</th>
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<tr>
<td>16:00 - 16:30</td>
<td><strong>Tea &amp; Poster Session</strong></td>
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<td>16:30 - 17:25</td>
<td><strong>PANEL DISCUSSION - AGENDA FOR RESEARCH IN URBAN TRANSPORT IN INDIA (16:30 - 17:25)</strong></td>
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<tr>
<td>16:30 - 16:35</td>
<td>Sri. Tara Shanker, MIT</td>
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<td>16:35 - 16:40</td>
<td>Dr. Gangopadhyay, Director, CRRI</td>
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<td>16:40 - 16:45</td>
<td>Mr. B.I. Singal, Director General, IUT</td>
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<td>16:45 - 17:15</td>
<td>Discussion</td>
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<tr>
<td>17:15 - 17:25</td>
<td>Conclusion - Dr. R. Sivanandan, IIT Madras</td>
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<td>17:25 - 17:30</td>
<td>Vote of Thanks - Ms. Kanika Kalra, Urban Transport Expert, IUT</td>
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### DAY 2 (6th December 2012)

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<tr>
<td>09:30 - 12:00</td>
<td><strong>INAUGURAL SESSION</strong></td>
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<td>09:30 - 09:35</td>
<td>Lighting of the Lamp</td>
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<td>09:35 - 09:40</td>
<td>Welcome Remarks by Shri S.K. Lohia, OSD(UT) and EO Joint Secretary, Ministry of Urban Development, Govt. of India</td>
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<tr>
<td>09:40 - 09:50</td>
<td>Address by Dr Sudhir Krishna, Secretary MoUD</td>
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<td>09:50 - 10:00</td>
<td>Release of manuals, booklets for Urban transport</td>
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<tr>
<td>10:00 - 10:15</td>
<td>Key note address; Ms. Susan Kurland, Assistant Secretary for Aviation and International Affairs, US</td>
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<td>10:15 - 10:30</td>
<td>Key Note address; Shri A.P. Mishra, Member Engineering, Railway Board</td>
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<tr>
<td>10:30 - 10:45</td>
<td>Key Note address; Shri A.K. Upadhyay, Secretary, Ministry of Road Transport and Highways (TBC)</td>
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<tr>
<td>10:45 - 11:00</td>
<td>Inaugural address by: Smt Deepa Dasmunsi, Honorable Minister of State for Urban Development</td>
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<tr>
<td>11:00 - 11:05</td>
<td>Vote of thanks - Mr R. K. Singh, Director (UT)</td>
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<td>11:05 - 12:00</td>
<td>Opening of the exhibition &amp; Tea/Coffee Break</td>
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#### PLENARY SESSION 1 - Role of Ministry of Railways; Suburban, Regional and Metro rail (12:00- 13:30)

**Chairman:** Shri A.P. Mishra, Member Engineering, Railway Board  
**Co-chair:** Shri Kul Bhushan, Member Electrical, Railway Boards (TBC)

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<tr>
<td>12:00 - 12:10</td>
<td>Rakesh Saksena, MD, Mumbai Railway Vikas Corporation</td>
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<td>12:10 - 12:20</td>
<td>Mr S Jayaseelan, Memeber Secretary, NCRPB</td>
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<td>12:20 - 12:30</td>
<td>Mr N.N. Kumar, Chief General Manager (PF), Chennai Metro</td>
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<tr>
<td>12:30 - 13:30</td>
<td>Discussion</td>
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<td>13:30 - 15:00</td>
<td>Lunch</td>
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#### PARALLEL SESSIONS (15:00 - 16:30)

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<th>Session IA: Institutional Development</th>
<th>Session IB: Financing with sustainable Transport Strategies</th>
<th>Round Table 1: Energy and Climate Change Issues</th>
<th>Round Table 2: S-BRT A smart way to move</th>
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</table>
| Chairman: Dr. Ramachandran, Ex Secretary (MoUD), Gol  
Co-chair: Shri S.P. Parihar, Principal Secretary, Govt. of MP (TBC)  | Co-chair: Mr Hemant Khanoria, Chairman, FICCI (TBC)  | Moderator: EBTC  | Chairman: Mr S.K. Lohia, OSD (UT) & EO JS., MoUD  
Moderator: Prof. Shivanand Swamy, Executive Director, CEPT University |
| Experience with UMTA under Executive Order - Ms Manjula, Commissioner, DULTA  | Urban Transport Fund-Case Study Rajasthan - Sh G.S. Sandhu PS UD& Housing Rajasthan  |  |  |
| Institutional Development of KOTI - Mr Choong Yeol (Peter) Ye, Vice President for Planning & Administration, The Korea Transport Institute  | TOD as a financing tool - Prof. Peter Newman, Professor of Sustainability, Curtin University, Australia  
Financing model for Buses - Mr PG Chandramohan, Special Director (Pricing & PCE), Ashok Leyland  |  |  |

Q&A / Open Discussion  
16:30 - 17:00 Tea/Coffee Break
### PARALLEL SESSIONS (17:00 - 18:30)

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<th>Session 2A: Parking</th>
<th>Session 2B: Improving Urban Road Safety</th>
<th>Round Table 3: Cities operating bus services - How can financial viability be improved</th>
<th>Round Table 4: IPT in Indian Cities</th>
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<tr>
<td>Chairman: Shri Praveen Kumar Tripathi, Chief Secretary, Govt. of NCT of Delhi</td>
<td>Chairman: Christine Bost, Vice-President of the Urban community of Bordeaux, mayor of Eizines (TBC)</td>
<td>Chairman: Mr O.P. Agarwal, Advisor, World Bank</td>
<td>Chairman: Ms Anuradha Bhawani, Country Head, Shell Foundation</td>
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<td>Co-chair: Shri Rahul Astana, Metropolitan Commissioner, Mumbai Metropolitan Region Development Authority (MMRDA) (TBC)</td>
<td>Co-chair: Prof. (Dr.) P.K. Sarkar, Professor, SPA, New Delhi</td>
<td>Moderator:</td>
<td>Moderator:</td>
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<tr>
<td><strong>Parking Policy - Case Study Delhi - Ms Anumita Roychowdhury, Executive Director, Policy Research &amp; Advocacy, Centre for Science and Environment</strong></td>
<td><strong>Design of Urban Roads to improve road Safety - Prof. Geetam Tiwari, IIT Delhi</strong></td>
<td><strong>Problems in Implementing to ensure Road Safety - Mr Satyendra Garg, Jt.CP (Traffic), New Delhi</strong></td>
<td><strong>Day 3 (7th December 2012)</strong></td>
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<tr>
<td><strong>Europe's Parking U-turn - Ms Shreya Gadepalli Regional Director, Institute for Transportation and Development Policy (ITDP)</strong></td>
<td><strong>Mechanized Parking - Mr. Pranav Poddddar, Suvidha Parklift, India</strong></td>
<td><strong>Developing Road Safety Policy for Road Engineering Departments - Dr. S.M. Sarin, Former Director, CRRI, India</strong></td>
<td><strong>Welcome Reception hosted by Hon’ble Minister of State (Urban Development)</strong></td>
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<tr>
<td><strong>Q&amp;A / Open Discussion</strong></td>
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### PARALLEL SESSIONS (09:30 - 11:00)

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<th>Session 3A: Mass Transit Systems - Technology</th>
<th>Session 3B: Use of New Technologies to Mitigate the Impact from Transport Related Air and Noise Pollution</th>
<th>Round Table 5: Complete street design and access to public transport</th>
<th>Round Table 6: JNNURM cities (SLBMs) - Experience with benchmarking</th>
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<tbody>
<tr>
<td>Chairman: Mr Mangu Singh, MD, DMRC</td>
<td>Chairman: Dr. S. Gangopadhyay, Director, CRRI</td>
<td>Moderator: Mr Christopher Kost, Technical Director, Institute for Transportation and Development Policy (ITDP)</td>
<td>Chairman: Mr S.K. Lohia</td>
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<tr>
<td>Co-chair: MD, Kochi Metro (TBC)</td>
<td>Co-chair: Louardi Bhougedada, Deputy Mayor of Dunkerque in charge of Urban renovation and Vice-president of the Urban Community of Dunkerque in charge of the Energy and the adaptation to the climate change (TBC)</td>
<td>Moderator: Mr B.I. Singal, Director General, IUT</td>
<td>Moderator: Mr B.I. Singal, Director General, IUT</td>
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<tr>
<td><strong>Mono Rail as a public transport system - Mr C.V. Kamesh, General Manager, Hitachi</strong></td>
<td><strong>Senior Expert, Cluster development, CEIPIMEONTE</strong></td>
<td><strong>Mitigating Air and Noise Impacts from Aviation - Mr Nicolas Duchene, Env-Isa, France</strong></td>
<td><strong>Experience with benchmarking</strong></td>
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<td><strong>Tramway revival in France and perspective for India - Ms Samira Israne, Public Affairs Manager for India &amp; Oceania, Directorate for European and International Affairs, France</strong></td>
<td><strong>Tramway revival in France and perspective for India - Ms Samira Israne, Public Affairs Manager for India &amp; Oceania, Directorate for European and International Affairs, France</strong></td>
<td><strong>Mitigating Air and Noise Impacts from Aviation - Mr Nicolas Duchene, Env-Isa, France</strong></td>
<td><strong>Chairman: Mr S.K. Lohia</strong></td>
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Parallely | 19:45 onwards | **Welcome Reception hosted by Hon’ble Minister of State (Urban Development)** | **Day 3 (7th December 2012)** | **Welcome Reception hosted by Hon’ble Minister of State (Urban Development)** |
### Plenary Session 2 - Code for urban roads (11:30 - 13:00)

**Chairman:** Shri A.K. Upadhyay, Secretary, Ministry of Road Transport & Highways  
**Co-chair:** Shri Rakesh Misra, Director General, Central Public Works Department (CPWD)

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<tr>
<td>11:30 - 11:40</td>
<td>Shri. Ashok Bhattacharjee, Director (Planning), Member Secretary/ UTTIPEC</td>
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<td>11:40 - 11:50</td>
<td>Dr Dinesh Mohan, IIT Delhi</td>
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<td>11:50 - 12:00</td>
<td>Dr L.R. Kadyali</td>
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<td>12:00 - 12:10</td>
<td>Dr D.P. Gupta</td>
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<td>12:10 - 12:20</td>
<td>Mr Patankar</td>
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<tr>
<td>12:20 - 13:00</td>
<td>Discussion</td>
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<td>13:00 - 14:30</td>
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### PARALLEL SESSIONS (14:30 - 16:00)

#### Session 4A: Mass Transit Systems
**Chairman:** Shri N Sivasailam, MD, BMRCL (TBC)  
**Co-chair:** NVS Reddy, MD, Hyderabad Metro

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<td>Planning and Scheduling Solutions for Public Transport Operations Optimization In the Indian context - Mr. Herve Beaudet, CEO Asia, Lumiplan</td>
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<tr>
<td>Precautions/ steps to be taken to ensure timely completion of large infrastructure projects - learning's from Delhi - Shri Jitendra Tyagi, Director (Works), DMRC</td>
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<tr>
<td>Public Transport: Accessible and Inclusive for disabled and the elderly - Anjlee Agarwal, Executive Director &amp; Access Consultant, Samarthyam</td>
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<tr>
<td>Q&amp;A / Open Discussion</td>
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#### Session 4B: Travel Demand Management
**Chairman:** Clotilde Tascon-Mennetrier, Vice-President of the Conseil Général d'Ile-et-Vilaine, in charge of International relations (TBC)  
**Co-chair:** Prof. SevaRam, Head Of Department (Transport Planning), SPA, New Delhi

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<td>Road Pricing in Urban Areas - Experience of Western Europe - Mr Arvind Kumar, Advisor, ministry of Transport &amp; Highways</td>
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<td>TDM - Singapore Case Study - Mr Mohinder Singh, Dean, LTA, Singapore</td>
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<tr>
<td>Q&amp;A / Open Discussion</td>
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#### Round Table 7: Difficulties in Enforcement
**Chairman:** Mr Satyendra Garg, Jt CP (Traffic), New Delhi  
**Moderator:** Dr Vinay Maitri, Prof, SPA, New Delhi

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<tr>
<td>Q&amp;A / Open Discussion</td>
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#### Round Table 8: Urban bus specification - the essentials
**Chairman:** Shri Anjum Parwez, MD, BMTC  
**Moderator:** Mr Ajai Mathur, MD, UMTC

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<thead>
<tr>
<th>Topic</th>
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<tr>
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<tr>
<td>Q&amp;A / Open Discussion</td>
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### 11:00 - 11:30 Tea/Coffee Break

### 16:00 - 16:30 Tea/Coffee Break
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<thead>
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<th>PARALLEL SESSIONS (16:30 - 18:00)</th>
<th>PARALLEL SESSIONS (09:00 - 10:30)</th>
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<td><strong>Session 5A: Public Bus Transport</strong>&lt;br&gt;Chairman: Mr. Dinesh Mohan, Veolia Professor for Transportation Safety, Indian Institute of Technology (IIT) Delhi&lt;br&gt;Co-chair: Manjula, DULTA</td>
<td><strong>Session 6A: Ecomobility in Cities</strong>&lt;br&gt;Chairman: Dr. Sudhir Krishna, Secretary, MoUD&lt;br&gt;Co-chair: Shri. I P Gautam PS (UD), Gujrat</td>
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<td><strong>Session 5B: TOD</strong>&lt;br&gt;Chairman: Shri S.K. Srivastava, Vice-Chairman, DDA (TBC)&lt;br&gt;Co-chair: Dr PS Rana, Patron, IUT (TBC)</td>
<td><strong>Session 6B: Fuel technologies - State of Practice and advancement in India and learning’s from EU</strong>&lt;br&gt;Chairman: DG, SIAM (TBC) &lt;br&gt;Co-chair:</td>
</tr>
<tr>
<td><strong>Improving the Efficiency for Bus Transport in India</strong>&lt;br&gt;Shri. Sudhakara Rao, Executive Director, ASRTU</td>
<td><strong>Relevance of electric vehicles in Indian cities - current status and possible future scenario</strong> - DHI</td>
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<td><strong>Viable City bus in Small Cities</strong> - Mr N Manjunath Prasad, MD, KSRTC</td>
<td><strong>Sustainable transportation strategies for cities - Mr Marzio Bianchi, a Senior Technical Consultant, CEIPIEMONTE</strong></td>
</tr>
<tr>
<td><strong>Metro Bus Istanbul- Hayari Baracli, General Manager, General Directorate of IETT, Istanbul</strong>&lt;br&gt;Transit Oriented Development (TOD) - Study for Existing Metro Corridor between Chattarpur to Arjargah of Delhi Metro Project of Phase II - Mr Aditya Thakrar, Principal Consultant (Transport &amp; Technology), Capita Symonds India</td>
<td><strong>Ecomobility vision, approach and roadmap - City of Changwon - Mr. Kim, Director for the EcoMobility Division, City of Changwon, Korea</strong></td>
</tr>
<tr>
<td><strong>Assessment of innovative options for developing financially sustainable Urban Mass Transport Systems in India</strong> - Amber Dubey, Partner &amp; Head-North India Infrastructure Advisory, KPMG</td>
<td><strong>Influence of Fuels on Vehicle Design - Ms. Ratna Chatterjee, Chief Consultant, ARDMC</strong></td>
</tr>
<tr>
<td><strong>Financing Transit Oriented Development in India</strong> - Dr. Adnan Rahman, Director, International Division, Cambridge Systematics</td>
<td><strong>Round Table 9: Congestion Pricing</strong>&lt;br&gt;Chairman: Mr Mohinder Singh, Dean LTA&lt;br&gt;Moderator: Mr R.K. Singh, Director, MoUD</td>
</tr>
<tr>
<td>Q&amp;A / Open Discussion</td>
<td><strong>Round Table 10: Low-carbon Comprehensive Mobility Plans (LCMP)- Sustainable mobility with lower carbon emissions</strong>&lt;br&gt;Chairman: Mr B.I. Singal, Director General, IUT&lt;br&gt;Moderator: Mr Subhash Dhar, Senior Economist, UNEP Risoe</td>
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<td><strong>Q&amp;A / Open Discussion</strong></td>
<td><strong>Round Table 11: Cities Developing Metro Rail - Access and Feeder Services</strong>&lt;br&gt;Chairman: Mr K.K. Sharma, Advisor Chandigarh (TBC)&lt;br&gt;Moderator: Professor, Dr Geetam Tiwari</td>
</tr>
<tr>
<td><strong>Round Table 12: Hill cities - Planning for urban mobility in Hill cities</strong>&lt;br&gt;Chairman: Dr. A.R Sihag, Principal Secretary (Urban Development and Town &amp; Country Planning), Himachal Pradesh (TBC)&lt;br&gt;Moderator: Mr H.K. Gupta, DM (Traffic), HSRTC</td>
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20:00 onwards | Dinner

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<th>Positives and negatives of pursuing an Ecomobility approach - Kaohsiung, Taiwan - Mr Hung-Shen Lin, Senior Technical Specialist, Transportation Bureau, Kaohsiung City</th>
<th>Development of Alternative Fuel Engines - Prof. L. M. Das, IIT Delhi</th>
</tr>
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<tbody>
<tr>
<td>Accessibility to Jobs for the Urban Poor - A case study of Ahmedabad - Mr Talat Munshi, Associate Professor, CEPT University</td>
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Q&A / Open Discussion | Q&A / Open Discussion

| 10:30 - 11:00 | Tea/Coffee Break |

**Plenary Session 3 - Smart cities and ITS (11:00 - 12:30)**

**Chairman:** Minister of State (Urban Development)

**Co-chair:** Mr Arun Maira, Member Planning Commission (TBC)

| 11:00 - 11:10 | Mr Tilak Raj Seth, SEIMENS |
| 11:10 - 11:20 | Mr CN Raghupathi, VP and Head India business, INFOSYS |
| 11:20 - 11:30 | Mr Dhamodaran Ramakrishnan, Director, Smarter Planet Solutions, IBM |
| 11:30 - 12:30 | Discussion |

**VALEDICTORY SESSION (12:30 - 13:00)**

| 12:30 - 12:45 | Presentation of the summary of proceedings of the Conference - Ms Ishita Chauhan, Research Development Officer, IUT |
| 12:45 - 13:15 | Presentation of Urban Mobility Awards: Shri Kamal Nath, Hon'ble Minister for Urban Development |
| 13:15 - 13:25 | Valedictory Address by Shri Kamal Nath, Hon'ble Minister for Urban Development |
| 13:25 - 13:30 | Launch of UMI 2013 and Vote of Thanks by Shri B.I. Singal, Director General, Institute of Urban Transport (India) |
| 13:30 - 15:00 | Closing Lunch |
Urban Transport Research Journal
The Urban Mobility India (UMI) Research Symposium 2011

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Comparison of Environmental Impacts by Different Technologies of Bituminous Road Resurfacing on the Basis of Life Cycle Assessment 70
Vivek Arora, Geetam Tiwari, Kalaga Ramachandra Rao and Kirti Bhandari
Abstract

The speed of vehicles on the urban roads has become a matter of concern, as there are lot of accidents leading to fatalities. Speed management should be a central element of any road safety strategy which helps in achieving appropriate speeds taking into account the mobility, economic needs as well as safety and environmental requirements. The risk of crash involvement may be positively correlated with speed variation and higher vehicle speeds are generally correlated with increased crash severity. For given facility types, namely arterial and sub arterial roads, speed variance may be used as a safety surrogate in the development of a screening tool to classify safety conditions on urban streets. Intelligent Transportation System (ITS) tools help to provide a better measure of traffic management to reduce congestion, mortality rates and environmental impacts in Tiruchirappalli city.

Key Words: Speed, Accident, Traffic Management, ITS

1.0 INTRODUCTION

The prevailing traffic speed at any section of a roadway affects the quality of traffic at the time. Excessive speeds affect the severity of road traffic accidents, whereas crawling speeds in the urban environment is indicative of congestion. In efforts to decrease speed related accidents and fatalities on roads, several advanced speed management techniques have been investigated. These techniques include both in-vehicle control (Almquist et al.1991; Varhelyi and Makinen, 2001) and external vehicle control (Carsten and Fowkes, 2000). In the past decade, there has been an increasing interest in speed management techniques that take the advantage of Intelligent Transportation System (ITS).

1.1 Accident Statistics

Developing countries register the maximum number of road accidents in the world. India stands top in both fatal and non fatal accidents and the accident rates are alarming in India, at least 13 people die every hour in road accidents according to the report of National Crime Records Bureau. The fatal accidents are increasing at a high rate in the state of Tamil Nadu. The accident statistics for the past five years in Tamil Nadu are given below in Table 1.

Table 1: Number of accidents occurred in Tamil Nadu State during the past five years

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatal</th>
<th>Grievous Injury</th>
<th>Minor Injury</th>
<th>Non-Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>10055</td>
<td>4630</td>
<td>36262</td>
<td>4198</td>
</tr>
<tr>
<td>2007</td>
<td>11034</td>
<td>4498</td>
<td>39494</td>
<td>4114</td>
</tr>
<tr>
<td>2008</td>
<td>11813</td>
<td>4426</td>
<td>39193</td>
<td>4977</td>
</tr>
<tr>
<td>2009</td>
<td>12727</td>
<td>4448</td>
<td>39676</td>
<td>3943</td>
</tr>
<tr>
<td>2010</td>
<td>14241</td>
<td>4613</td>
<td>42320</td>
<td>3822</td>
</tr>
</tbody>
</table>

* M.Tech Scholar, NIT, Tiruchirappalli, Tiruchirappalli, Tamil Nadu -620015, India  e-mail: bazeeb4@gmail.com
** Associate Professor, NIT, Tiruchirappalli, Tiruchirappalli, Tamil Nadu -620015, India  e-mail: sams@nitt.edu
*** Professor, NIT, Tiruchirappalli, Tiruchirappalli, Tamil Nadu -620015, India  e-mail: moses@nitt.edu
**** Assistant Professor, NIT, Tiruchirappalli, Tiruchirappalli, Tamil Nadu -620015, India  e-mail: nisha@nitt.edu
1.2 Speed Management

Urban speed has become a widespread social problem as, at any time 50% of the drivers are above limits (European Conference of Ministers of Transport, October 2004). In order to bring the accident rates down, proper speed management techniques have to be implemented. Urban speed management includes the methods to slow down the fast moving vehicles through speed limits and enforcement and to physically separate the vulnerable road users from vehicles. Speed management is not necessarily about reducing speed but to a considerable extent it is about planning and designing the road layout and the road network in such a way that an appropriate speed is obtained (Greibbe et al, 1999). The vulnerable road user survives if hit by a vehicle at 30 kmph but get killed when the speed of vehicles is more than 45 kmph (Organization for Economic Co-operation and Development and European Conference of Ministers of Transport, January 2004). Innovative technology to automatically control speeds may eventually be an option to manage vehicle speeds in the horizon years.

2.0 APPROACH

Speed management is simply a way of adopting various methods such as legislation, road layout measures, enforcement, campaigns or advanced technology to help in regulating the speed of vehicles. In order to get a picture of the current traffic and safety situation, relevant data is usually collected to cover the road geometric parameters, accidents, traffic flow etc. The objective of the study is to determine the accident prone areas resulting from inappropriate speeding and bring out the possible traffic calming measures in aid with innovative technologies. Intelligent Transportation System technology is used to put forth an effective measure of traffic management for the study area.

3.0 STUDY AREA

Tiruchirappalli is located at latitude of 10.8050°N and longitude of 78.6856°E. The city corporation consists of network of National Highway, State Highway, Arterial and Sub-Arterial roads. The prime focus lies on the arterial and the sub-arterial network within the city. ArcGis is made use to digitise the major arterial and sub arterial roads in the city area using a satellite image of 2.5m resolution. The road attributes are fed into the GIS database management system. The digitised map of the arterial and sub arterial road network of Tiruchirappalli City under study is shown in Figure 1.

Figure 1 : Digitised map of road network under study in Tiruchirappalli City

4.0 METHODOLOGY

The objective of the study revolves around the need for speed management techniques in the urban road network and its evaluation. The study process can be categorised into the following steps:
4.1 Identification of Accident Prone Locations

The accident data for the arterial and sub arterial road network were obtained from Tiruchirappalli Traffic Control Zone. The accidents were analysed depending upon the frequency of accidents, spot locations, mode wise, time wise etc. for the selected roads under study. Depending on the majority of fatal accidents occurred during the past three years period, six roads have been identified for detailed examination. The accident spots at the midblock sections on these roads are categorised based on the frequency of accidents. The latitude and longitude for the accident spots are collected by means of GPS device and fed into the GIS database management system to rank the severity of crash spots.

4.2 Urban Volume Counts and Speed Measurements

Volume counts were carried out for the arterial and sub arterial during the peak hours of traffic by means of manual method and the peak hour of traffic is determined on each road. Spot speed measurements were carried out for the selected road network inclusive of arterial and sub arterial during the same period by stop watch technique. Followed by, off peak spot speed measurements were taken for six roads having higher speed rates during the peak hour traffic, eventually having the more number of accidents. Speed profiling is being carried out for the same six arterial roads having more number of accidents at the midblock sections. Speed profiling was done by means of Registration Number Plate method considering every hundred metres of the road way sections. Speed variance is determined in terms of 85th percentile speed and the crash severity analysis was carried out.

4.3 Proposed measure for Speed Management

The suitability assessment of effective traffic calming measure depends upon the traffic flow, geometric features, pattern of accident, area of control etc. In Urban road network, traffic calming measures like speed humps, arresters, flashing signs etc. proves less effective, which may in turn hinder the smooth passing of traffic. Innovative technologies have to be tried experimentally in collaboration with Tiruchirappalli City Corporation as well as the Traffic Police of the City to find out the feasibility of installation of these facilities for Speed Management in Tiruchirappalli City.

5.0 DATA AND ANALYSIS

5.1 Accident Studies

The review of road accidents inclusive of fatal and non fatal cases (Source: Tiruchirappalli Traffic Control Room) for the Tiruchirappalli city gives a clear indication of the rate at which the accidents are increasing year by year. Around 65% of the total accidents in Tiruchirappalli district are concentrated on the arterial and sub arterial roads of the city. This measure of accident rate in the urban centre is highly alarming and far from ideal as an indicator of relative safety as shown in Figure 2.
Accident data was collected for the past three years (2009 to 2011 till date) from Tiruchirappalli Traffic Control Zone. Around 69% of accidents occurred during the weekdays compared to holiday traffic. The data was analysed for 24 roads inclusive of arterial and sub arterial roads in Tiruchirappalli city. The occurrence of accidents are more prone during the off peak hours of traffic following the peak hour. The distribution of accidents for the urban road network during different hours of traffic is given in Figure 3.

Around 30% each of pedestrians and two wheelers form the victims of accidents. On the other hand, nearly 32% each of two wheelers and cars are the accused vehicles resulting in accidents. It has been found that more than 50% of fatal accidents are recorded in the six arterial roads that form a continuous network. The list of roads more prone to accidents includes Bharathidasan Road, Lawson's Road, EVR Puthur Road Thennur High Road, Thillai Nagar Main Road and Sastri Road.

Figure 4 gives the distribution of the fatal on the selected roads with respect to time of traffic. Road accidents leading to fatalities are mainly concentrated on the midblock sections of the roadway. The accident studies reveals that about 72% of accidents occurred at the midblock sections of the selected road network.

Figure 5 gives a clear indication of more young drivers’ involved in accidents in these roads.
5.2 **Volume and Speed Studies**

Volume and Speed studies form a key element in determining the prevailing traffic condition along with their geometric features. The volume counts and spot speed measurements were carried out on 24 roads during the peak hours of traffic. **Table 2** gives the list of roads along with the type, peak PCU/hr and v/c ratio.

![Figure 5: Distribution of fatal accidents according to age](image)

**Table 2: Volume Characteristics of Urban Road Network in Tiruchirappalli city**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Road Name</th>
<th>Type of Road</th>
<th>Peak PCU/hr</th>
<th>V/C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bharathidasan Road</td>
<td>Arterial</td>
<td>2547</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>Collector Office Road</td>
<td>Arterial</td>
<td>2453</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>Lawson’s Road</td>
<td>Arterial</td>
<td>4110</td>
<td>0.6</td>
</tr>
<tr>
<td>4</td>
<td>Puthur EVR Road</td>
<td>Arterial</td>
<td>2491</td>
<td>0.69</td>
</tr>
<tr>
<td>5</td>
<td>Puthur High Road</td>
<td>Arterial</td>
<td>1479</td>
<td>0.41</td>
</tr>
<tr>
<td>6</td>
<td>Salai Road</td>
<td>Sub-arterial</td>
<td>2569</td>
<td>0.97</td>
</tr>
<tr>
<td>7</td>
<td>Royal Road</td>
<td>Arterial</td>
<td>2567</td>
<td>0.64</td>
</tr>
<tr>
<td>8</td>
<td>Thillai Nagar Main Road</td>
<td>Arterial</td>
<td>4086</td>
<td>0.79</td>
</tr>
<tr>
<td>9</td>
<td>Thennur High Road</td>
<td>Arterial</td>
<td>4958</td>
<td>1.89</td>
</tr>
<tr>
<td>10</td>
<td>Gandhi Road</td>
<td>Sub-arterial</td>
<td>1859</td>
<td>0.8</td>
</tr>
<tr>
<td>11</td>
<td>Ammamandapam Road</td>
<td>Sub-arterial</td>
<td>1747</td>
<td>0.6</td>
</tr>
<tr>
<td>12</td>
<td>West Boulevard Road</td>
<td>Sub-arterial</td>
<td>2666</td>
<td>0.74</td>
</tr>
<tr>
<td>13</td>
<td>East Boulevard Road</td>
<td>Sub-arterial</td>
<td>887</td>
<td>0.3</td>
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<tr>
<td>14</td>
<td>Wellamandi Road</td>
<td>Sub-arterial</td>
<td>2940</td>
<td>0.58</td>
</tr>
<tr>
<td>15</td>
<td>Rockins Road</td>
<td>Sub-arterial</td>
<td>1441</td>
<td>0.68</td>
</tr>
<tr>
<td>16</td>
<td>Sastri Road</td>
<td>Arterial</td>
<td>2319</td>
<td>0.45</td>
</tr>
<tr>
<td>17</td>
<td>Annanagar Main Road</td>
<td>Arterial</td>
<td>1349</td>
<td>0.37</td>
</tr>
<tr>
<td>18</td>
<td>Heber Road</td>
<td>Sub-arterial</td>
<td>1896</td>
<td>0.98</td>
</tr>
<tr>
<td>19</td>
<td>Sub Jail Road</td>
<td>Sub-arterial</td>
<td>910</td>
<td>0.75</td>
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<tr>
<td>20</td>
<td>Reynold’s road</td>
<td>Arterial</td>
<td>1034</td>
<td>0.35</td>
</tr>
<tr>
<td>21</td>
<td>McDonald’s Road</td>
<td>Arterial</td>
<td>2195</td>
<td>1.15</td>
</tr>
<tr>
<td>22</td>
<td>Williams Road</td>
<td>Arterial</td>
<td>1592</td>
<td>0.66</td>
</tr>
<tr>
<td>23</td>
<td>Rajaram Road</td>
<td>Sub-arterial</td>
<td>1213</td>
<td>0.56</td>
</tr>
<tr>
<td>24</td>
<td>KK Nagar main Road</td>
<td>Arterial</td>
<td>2105</td>
<td>0.74</td>
</tr>
</tbody>
</table>
The roads having more accidents pronounce to have better level of services based on the v/c ratio obtained except for Thennur High Road where accidents are more concentrated on the intersections. The distribution of percentile speeds determined by spot speed measurements carried out during the peak hours of traffic are given in Table 3.

The six roads identified, based on more frequency of accidents recorded the maximum traffic speed. Hence off peak spot speed measurements were carried out along those roadway sections. It has been found that the mean speed on these roads have been increased by 20%.

5.3 Speed Profiles

Spot speed measurements are not sufficient enough to study the influence of speed variation on accidents. The profile of speed is estimated to positively correlate the effect of speed variance on crash rates. Speed profiling is being carried out on the selected roads by means of Registration Number Plate method. The operating speed is determined for every hundred metre of road section providing 30 samples for each mode of traffic. The speed profiles are generated in terms of 85th percentile speed with respect to distance measured. Figure 6 gives a measure of the speed distribution along the section of roadway.

<table>
<thead>
<tr>
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<td>Puthur High Road</td>
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<td>Salai Road</td>
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<td>33</td>
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<td>13</td>
<td>East Boulevard Road</td>
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<td>19</td>
<td>Sub Jail Road</td>
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<td>20</td>
<td>Reynold's road</td>
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<td>37</td>
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<td>McDonald's Road</td>
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<td>Williams Road</td>
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<td>41</td>
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<td>23</td>
<td>Rajaram Road</td>
<td>29</td>
<td>45</td>
<td>51</td>
</tr>
<tr>
<td>24</td>
<td>KK Nagar main Road</td>
<td>27</td>
<td>41</td>
<td>46</td>
</tr>
</tbody>
</table>
6.0 DISCUSSIONS

The analysis shows that the accidents are mainly concentrated on the midblock sections than the intersections. The geometric conditions on these roads and the v/c ratio obtained, gives a clear idea of steady and stable traffic flow conditions on the roadway sections. It is a widely-held belief that there is a connection between road safety and the variability of speeds on roads. Occurrence of accidents is mainly due to the variation in speed rather than excessive speeding at the midblock roadway sections. Speed distributions are cited that, if the spread of the distribution was reduced, safety would improve. The vehicular drivers need to be advised to maintain a steady state of speed without much acceleration or deceleration so that it would not much affect the smooth flow of traffic. Innovative technologies have to be taken into consideration for reminding in real time the vehicular driver regarding the speed limit to be maintained. Intelligent Transportation System technologies such as use of Speed cameras along with Number Plate Reader systems should be utilised to acquire the traffic speed data and provide them with the necessary driver feedback measures like variable message signs, voice messages to improve the efficiency of the system. The enforcement of RFID technology can also prove to be a major breakthrough that enables better management of information and to be delivered in real-time aspects. Future efforts have to be taken to model the speed profile of urban arterial and sub arterial sections by acquiring considerable amount of data. The impact of advisory mode of Speed management technique in prior to enforcement has to be evaluated on the arterial and sub arterial roads of Tiruchirappalli city.

7.0 ACKNOWLEDGEMENTS

We would sincerely like to acknowledge Ministry of Urban Development (MoUD), GOI for funding the research work and Indian Institute of Technology, Madras (IITM) for the valuable assistance in the work. We also like to thank Tiruchirappalli Traffic Control Zones for providing us with the necessary data that was helpful in the progress of work.
IMPACT OF STRATEGIES CHANGING THE INFRASTRUCTURE FOR NMV AND BUSES ON ACCESSIBILITY OF URBAN RESIDENTS

Deepty Jain *  Dr. Geetam Tiwari **

Abstract

The paper estimates the impacts of non-motorized transport and bus infrastructure improvement strategies on the accessibility of all users of transport system. Delhi - BRT corridor stretch of 5.8 km from Ambedkar Nagar to Moolchand flyover has been taken as a case study. Five scenarios addressing different strategies have been developed and evaluated to measure the impacts on total travel time savings by all users. The scenarios are: pre-BRT situation, minor improvements in infrastructure to improve speed of buses, implementation of Delhi-BRT corridor as in April 2008, further improvements in infrastructure of Delhi BRT corridor to increase speed of buses and improvement in road infrastructure to increase speed of other vehicles. As per the analysis, the existing Delhi-BRT corridor provides maximum benefits in terms of travel time saving. Improving infrastructure for other motorized vehicles results in travel time saving by 9% however, this benefit can be realized for short term only.

1.0 INTRODUCTION

Transport system users are diverse in terms of their socio-economic background having varying accessibility to modes and need for travel determining their travel patterns. In Indian cities, a large proportion of population lives in slums, for example in Mumbai approximately 54.1% of the population lives in slums, in Kolkata 32.5% and in Delhi 18.7%(Census of India 2001). This group of people cannot afford personal motorized vehicles (cars and two-wheelers) for transportation and subsidized bus systems are also expensive for them for daily commute(Mohan and Tiwari 2000). Their transportation needs are, thus, dependent on bicycling and walking, i.e. non-motorized transport (NMT). As such even in the megacities of India, 30% of the trips are made by NMT, 50% by public transport (PT) (both formal bus systems and informal bus systems, tempos) and rest are by Personal Motorized Vehicles (PMV) i.e. cars and motorized two wheelers(Wilbur Smith Associates 2008).

A transport infrastructure improvement project has varying impacts on different types of users. A project that is meant for improving mobility option for one type of user can indirectly distress the safety and accessibility for other. For example, construction of a flyover can result in increasing risk and discomfort to cyclists and provision of foot-over-bridge can result in increasing distance to be travelled by the pedestrian thereby decreasing accessibility.

Given the existing modal shares in Indian cities, a project resulting in improving speed of cars is likely to benefit a small group of society,though as a result of the project there might be negative impacts like detours, reduced speed, increased risk to accidents posed on larger group of transport users i.e. pedestrians, bicyclists and public transport users.

1.1 Policy concerns

National Urban Transport Policy (NUTP) states the need for improving transport infrastructure to move people rather than vehicles. The policy...
draws focus of transport planning towards providing safe access for pedestrians, bicyclists and public transport users to encourage the use of sustainable modes of transport (MoUD 2006).

Jawaharlal Nehru National Urban Renewal Mission (JnNURM) scheme taken up by central government of India provides financial assistance to urban local bodies to upgrade and provide adequate infrastructure services. For getting approval for transport projects under the scheme, the guidelines recommend that the transport infrastructure improvement schemes have to be in compliance with the NUTP. Under the scheme some of the transport infrastructure provision and upgradation projects have been taken up that include procurement of new buses, planning and optimization of bus routes, planning other supportive public transport systems, road widening, etc. Still, majority of projects are aiming to improve the mobility of PMV i.e. cars and motorized two wheelers (MTW) by constructing flyovers, un-signalized crossings and road widening programmes (Table 1).

Table 1: Approved share of projects cost by JNNURM

<table>
<thead>
<tr>
<th>Type of transport related projects</th>
<th>Additional Central Assistance committed (Rs in lakhs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRTS</td>
<td>219564</td>
</tr>
<tr>
<td>Bus procurement</td>
<td>22117</td>
</tr>
<tr>
<td>Other projects (roads, flyovers, ROB, etc.)</td>
<td>194463</td>
</tr>
<tr>
<td>Grand Total</td>
<td>436144</td>
</tr>
</tbody>
</table>

Source: (Jnnurm 2009)

In some cities public transport infrastructure projects like bus rapid transit (BRT) and Metro rail projects have been taken up. Even though, the detailed project reports of the projects specify appropriate infrastructure design for safe movement of pedestrians and bicyclists, there is reluctance in provision of infrastructure for the same during execution of the project (Tiwari and Jain 2010).

1.2 Objective

Though existing policies and strategies at national level emphasize to improve mobility, safety and accessibility of all city residents, still majority of the projects primarily aim to improve the speed of PMV on roads. The projects that are also related to public transport do not incorporate improvement of infrastructure for access modes like walk and bicycle. Thus a need is identified to understand the impacts of different types of infrastructure improvement projects on different users and the society as a whole. This would help in decisions making while selecting infrastructure improvement strategies in order to benefit majority of the people.

For the purpose, different strategies have been identified in the paper and evaluated on the basis of commonly used indicator of travel time savings by all the users of the transport system. A stretch of 5.8 km of Delhi BRT corridor from Ambedkar Nagar to Moolchand flyover, which has been operational since April 2008, is taken up as case study. Around the base case i.e. pre-BRT situation, four scenarios are developed discussing the varying impacts on the speeds of different modes as a result of different strategies. Traffic volume count in terms of persons travelling by each mode including pedestrian and cyclist has been considered to determine total travel time savings.
2 DESCRIPTION OF DELHI BRT CORRIDOR

The proposal for BRT was first mooted in Delhi in 1996. This recommendation was a part of a report “Delhi on the Move” submitted to the Central Pollution Control Board of India. The main motivation behind this proposal was to address the problem of growing road traffic injuries and fatalities and pollution in the city (Mohan et al. 1997). After examination of report by transport department of Delhi and a detailed discussion on the concept among experts and stakeholders in 2001, a committee was set up on sustainable transport chaired by the Chief Secretary of Delhi. In 2003, detailed feasibility report was prepared by RITES for implementing BRT on five selected corridors in Delhi (Tiwari and Jain 2010). Based on the comparative evaluation of daily bus passengers, availability of right of way (ROW) and number of road owning agencies, Ambedkar Nagar - ISBT, Kashmiri Gate was taken up as the first corridor for implementation. However, due to ROW constraints the implementation of BRT was restricted from Ambedkar Nagar to Moolchand flyover only.

2.1 Design features

Delhi BRT corridor is an open system with dedicated lanes in the middle of the road allowing buses to enter or leave the corridor at intersections. The system is flexible adapting to the existing bus routes and requiring less interchanges as compared to a closed system. Dedicated lanes for buses are 3.3 m wide segregated from mixed traffic lane with the help of kerbs. To enhance safe movement of buses on the dedicated corridor rumble strips have been used allowing buses to overtake in case of problems. Staggered type bus stops have been provided before intersection at an average spacing of 500m. Wherever intersection spacing is more than 500 m, mid-block bus stops along with appropriate pedestrian crossings have been provided. The system has two parallel platforms at the bus stops on the near side of the junction. Each platform can accommodate 4-5 buses boarding and alighting simultaneously. Buses can move in platoon of 10 buses every 2 minutes if the signal cycle is kept at 2 minutes.

Appropriate intersection designs have been incorporated to minimize conflicts and enhance safe movement for all modes. The system is well integrated with other modes like walk, bicycle, cycle rickshaw and auto-rickshaw. Continuous 2m wide barrier free footpaths and 2.5m wide cycle tracks segregated from motorized vehicle traffic by kerbs, unpaved zone and green belt have been provided on both sides of the corridor. Special design features have been incorporated to reduce speed of motorized vehicles wherever side road meets the corridor. At intersections, appropriate holding areas for both bicyclist and pedestrians have been provided and raised zebra crossings have been provided for pedestrians. Parking has been provided near intersections for bicycles, cycle rickshaw and three wheelers. On street parking has also been provided for PMV at some locations.

2.2 Qualitative Performance of Delhi BRT corridor

Approximately, 9% of the total routes in Delhi pass through the BRT corridor with buses running at a frequency of 120 buses per direction in the peak hours (Table 2). Implementation of Delhi BRT corridor has resulted in increase in speed of buses from 12 km/hr to 18 km/hr and reduction in speed of motorized vehicles in mixed traffic lanes from 16 km/hr to 14 km/hr. At present, Delhi BRT corridor caters to the total demand of 13,500 pphpd. As per the analysis by Hidalgo, D. and Pai, M. (2009) Delhi BRT corridor performs fairly well in terms of achieved bus speeds and peak hour loads as compared to other full BRT systems in the world. Also, the accidents on the corridor have reduced to zero in 2009 from an average of 9 per year in pre-BRT condition (Hidalgo and Pai 2009).
3.0 **SCENARIOS FOR UNDERSTANDING IMPACTS**

Five scenarios have been developed referring to different strategies of improving transport infrastructure. Among the five scenarios the baseline scenario i.e. pre-BRT situation has been taken as the base case to understand the impacts of various strategies. The scenarios do not take into account the modal shifts that are likely to take place when different types of strategies are implemented.

**Scenario 1. Baseline scenario**

This is the do nothing scenario assuming the pre-BRT condition on the stretch of 5.8 km from Ambedkar Nagar to Moolchand flyover. This scenario is used to compare the impacts of other scenarios in terms of travel time savings. The determined speed on the corridor before implementation of BRT was 12 km/hr and 16km/hr for bus and other motorized vehicles, respectively. Taking into account the given speeds of vehicles on the corridor travel time by different modes is determined and total travel time by the society is computed based on the number of users of different modes.

**Scenario 2. Improvement in operation of buses**

In the scenario, appropriate footpaths and bicycle lanes are provided resulting in reduced conflict between buses and slow moving modes. This is likely to result in increased speed of buses however, not having impact on the speed of other motorized vehicles. Thus it is assumed that the speed of buses in the scenario will improve by 17% as compared to the baseline scenario.

**Scenario 3. Post-BRT scenario**

This scenario takes into account the resulted changes in speed of buses and motorized vehicles in dedicated and mixed traffic lanes, respectively, after the implementation of BRT system on the stretch of 5.8 km as given by Delhi Integrated Multi Modal Transit System Ltd (DIMTS). The speed of buses after implementation of the corridor has increased by 50% and speed of other motorized vehicle has reduced by 13%.

**Scenario 4. Further improvement in existing Delhi BRT system**

In the scenario further improvement in the existing Delhi BRT system is assumed by
providing dedicated signal phase for buses and reducing boarding and alighting time. The scenario is thus likely to result in increased average speed of buses by 67% and reduction in speed of other motorized vehicles in mixed traffic lane by 25% as compared to baseline scenario.

**Scenario 5. Improving infrastructure for motorized vehicles**

This scenario is based on the common strategy generally adopted resulting in increased speed of personal motorized vehicles on roads by developing unsignalized intersections, building flyovers and road expansion. Thus it is assumed that speed of other motorized vehicles on roads will increase by 25% as a result of road expansion and signal free junctions on road while not having any impact on the speed of bus.

Following table summarizes the scenarios developed for the study.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Impact on speed of bus</th>
<th>Impact on speed of other motorized vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline scenario</td>
<td>Pre-BRT condition on the stretch of 5.8 km</td>
<td>12km/hr</td>
<td>16km/hr</td>
</tr>
<tr>
<td>Improvement in operation of buses</td>
<td>Minor improvement in infrastructure</td>
<td>Increase in speed of bus by 17%</td>
<td>No impact</td>
</tr>
<tr>
<td>Post BRT scenario</td>
<td>Considering the existing impact of implementation of Delhi BRT corridor</td>
<td>Increase in speed of bus by 50%</td>
<td>Decrease in speed by 13%</td>
</tr>
<tr>
<td>Further improvement on BRT corridor</td>
<td>Considering operational improvements for buses</td>
<td>Increase in speed of bus by 67%</td>
<td>Decrease in speed of by 25%</td>
</tr>
<tr>
<td>Improving infrastructure for motorized vehicles</td>
<td>Road expansion and signal free junctions</td>
<td>No impact</td>
<td>Increase in speed by 25%</td>
</tr>
</tbody>
</table>

**4.0 RESULT AND ANALYSIS**

As per the data collected in 2008 by DIMTS on the Delhi bus corridor, modal share of NMT, bus and other motorized vehicles was 9%, 47% and 44%, respectively. Total travel time saving under different scenarios as compared to scenario 1 is calculated assuming the given modal share. The analysis clearly identifies the strategies that are beneficial for majority of people and the society as a whole. As per the analysis, Scenario 3 i.e. the existing impacts of Delhi-BRT corridor on speeds of bus and other motorized vehicles results in maximum travel time saving for the society as a whole. Even if infrastructure is improved for other motorized vehicles, i.e., three wheelers, MTW and cars resulting in increased speed by 25%, the total travel time saving by the society is 9% (Scenario 5) which is equivalent to Scenario 2 i.e. minor improvement in infrastructure to improve speed of bus. However, executing scenario 5 may require more investments as compared to the investments required in scenario 2. Also, Scenario 4 which is taking into account improving infrastructure to further improve speed of bus from the existing BRT corridor situation and resulting in reduced speed of other vehicles in mixed traffic lane does not have major benefits.
5.0 DISCUSSION

The analysis highlights the need for balance in imparting benefits to different users of the transport system. The research also highlights the need for evaluating impacts of strategy on all users of the system and society as a whole before decision making. As per the analysis, projects aiming to improve the speed of buses instead of other motorized vehicles have benefits in reducing travel time for the majority of the people.

However, it is to be noted that the study has not taken into account the modal shifts that are likely to take place with the implementation of different types of strategies. In various researches it has been shown that introduction of bus priority lanes or improvement of infrastructure for one type of mode induces trips for the mode depending on the difference in journey time using different modes (Vedagiri and Arasan 2009; Cascetta et al. 2011). As per the study by Vedagiri and Arasan (2009), if the percentage difference between bus and car journey time is 50% which is the case in Scenarios 3 and 4, then there is probability of 0.66 for car users to shift to bus. Similarly, improving speed of other motorized modes can also result in increasing its use. However, as use of other motorized vehicles will increase in future it is likely to result in reduced speed in long term. Hence, improving infrastructure for other motorized vehicles does not have long term benefits.

If the likely modal shifts under each scenario had been taken into account, then the impacts of improving infrastructure for bus system would have been larger than estimated. Improving infrastructure for buses not only has short term benefits of travel time savings but also has long term benefits of attaining both
environmental and social sustainability.

### 6.0 CONCLUSION

The paper has evaluated different scenarios in terms of travel time savings as compared to the travel time in Scenario 1 by all the users of the system, i.e., buses and other motorized vehicles on Delhi-BRT corridor stretch of 5.8 km from Ambedkar Nagar to Moolchand flyover. The five scenarios included the situation of the corridor before implementation of BRT, minor improvements in infrastructure to improve speed of buses, implementation of Delhi-BRT corridor, further improvements in infrastructure of Delhi BRT corridor to increase speed of buses and improvement in infrastructure to increase speed of other vehicles.

As per the analysis, implementation of Delhi BRT corridor on the stretch of 5.8 km has resulted in total time saving of 15% by all the users of the system as compared to 9% travel time saving by improving infrastructure to increase speed of other vehicles. The analysis shows that well planned small investments in infrastructure can benefit majority of the people having long term effects.

The research highlights the need for including the impacts of a project or strategy on all the users of the transport system before decision making. Also, the research emphasizes the current strategies being taken, aiming to relieve congestions from roads and increasing average speed of vehicles do not have both short term and long terms benefits for the society.

### References

A SUSTAINABLE APPROACH OF MODELLING REGIONAL SOLID WASTE TRANSPORT SYSTEM: MUMBAI METROPOLITAN REGION A CASE STUDY

Gajanan Sasane *  Sunder Lal Dhingra **  Perumal Vedagiri ***

Abstract

Many developing countries like India are facing serious problem of day by day increasing quantity of solid waste and related aspects like poor efficiency of solid waste transport and collection. Municipal Corporations spends millions of rupees annually on the collection and transportation of solid waste and employs thousands of persons and vehicles to do it. It clearly implies that if cost of operation of vehicles and crews can be reduced in small quantities, it will result into substantial total savings over a number of years. Sustainable transportation is of great importance in today's world, due to concerns regarding the environmental, economic, and social impacts of transportation systems. Considering these important aspects, this study develops a performance-measurement-based system for the regional solid waste transportation to evaluate and achieve sustainable transportation.

This paper particularly deals with the estimation of economical sustainable indicator performance measures of regional solid waste transport system for which Mumbai Metropolitan Region (MMR) is taken as study area. The most encouraging result obtained is the average solid waste cost/ton, which is Rs.439.5 and actual transport cost for solid waste transport is 697.7/ton at present in Mumbai(MCGM).

Key Words : Sustainable Transportation, Vehicle Routing, GIS, Solid Waste

1.0 INTRODUCTION

Generation of solid waste is a natural consequence of human life. Removal of that solid waste is consistent with improved quality of life. Initially, solid waste management techniques aimed simply to eliminate solid waste from the vicinity of habitable areas as a means of maintaining public health. After realizing the hazards of uncontrolled disposal, measures were devised and implemented mainly through sanitary land filling. Global efforts are now in force to reorient solid waste management systems toward sustainability. Asian countries are deeply involved in this transition. However, the degree of attention paid to sustainability varies from country to country and is correlated with economic status. From ancient time human beings has been using the available resources on the earth for their daily need and developing new things for better life. The solid waste is nothing but the spill over of these resources. The solid waste produces due to activities like domestic, industrial, trade etc. and all these solid waste contributes to the municipal solid waste. As the population was small and the amount of land available for assimilation was large the disposal of solid waste did not pose a significant problem in early times. But, the past century has seen anenormous growth of population especially in the urban areas, and also a rapid increase in per capita production of refuse in terms of weight and volume. In India, every citizen discards on an avg. 700 gms of solid wastes per day. The collection and transportation of solid wastes contributes nearly 80% of the total cost of the solid waste management(George, 1991). If a small percentage of collection and
transportation cost is reduced by proper utilizations of vehicles and human resources and efficient planning (routing, scheduling), it will result in to substantial total saving over number of years (George, 1991).

The collection, transportation and disposal of municipal solid waste can be classified as a "logistic management problem" (Bodin et al., 1983). The routing decision involves demandsto be satisfied by each vehicle and which route to be follow by each vehicle. These decisions should be made to minimize the cost of operating the vehicle fleet. Principal cost items include fuel, personnel and vehicle depreciation. These costs are usually large and highly sensitive to how routing decisions are made. An effective planning of "logistic" involves strategic, tactical and operational planning. Operational planning involves various decisions relating to routing and scheduling of vehicles. Staffing of such vehicles with crews requires ongoing attention on day-to-day basis. There has been wide gap between generation of solid waste, its storage, collection and transportation. All these functions must be in-synchronization with 95-100% efficiency level, and then only a city can be clean and worth living (George, 1991).

2.0 REGIONAL SOLID WASTE TRANSPORT SYSTEM (RSWTS)

The word regional gives an idea about the inclusion of all urban local bodies (ULB's) in it. Thus, the regional system interpret the integration of ULB’s to work as regional system. The regional solid waste transport system has three key elements: a) Solid waste transport from individual collection demand points to check post (Ward-level) b) Check-post point (Ward) to Transfer Station (TS) and c) Transfer station (TS) to Regional landfill (RLF) site. 

Figure 1 interprets the routing environment of RSWTS.

3.0 TRANSFER STATION (TS)

A Transfer Station (TS) is defined as a solid waste processing site where solid waste is transferred from one vehicle to another vehicle or storage device for temporary storage, until transferred to a permanent disposal site approved by the solid waste management authority. At TS, the solid waste comes in smaller trucks where it is compacted and loaded on larger trucks or trailers for transporting it to RLF.
4.0 REGIONAL LANDFILL (RLF) SITE

Landfill site is a place for the disposal of solid waste materials by burial and is the oldest form of solid waste treatment. Many landfills are also used for solid waste management purposes, such as the temporary storage, consolidation and transfer, or processing of waste material. As name indicates, regional landfill site is identified for the burial of solid waste for regional solid waste management system.

5.0 SUSTAINABILITY, BASIC ASPECTS AND NEED

Jeon and Amekudzi(2005) stated that sustainability is an increasingly important issue in transportation system. Services provision is evident in congested highway systems in urban areas, results in declining air quality and respiratory health. Therefore there is need for improved and more equitable access to basic social and economic services in several areas around the world.

Sustainable transportation is of great importance in today's world, due to concerns regarding the environmental, economic, and social impacts of transportation systems. Sustainable transportation can be considered as an expression of sustainable development in the transportation sector. Therefore, there is a need to integrate sustainable transportation concerns into the activities of transportation agencies. In particular, it is important to develop methodologies that address and evaluate sustainable transportation within the regular transportation planning paradigm.

6.0 ELEMENTS OF TRANSPORTATION SYSTEM SUSTAINABILITY

Based on the findings from the literature review one can conclude that a sustainable transportation system is one which incorporates impacts of relative economic, social and environmental parameters. Thus, the three essential dimensions of transportation system sustainability could be considered to be economic sustainability, environmental sustainability, and social sustainability.

7.0 SELECTED SUSTAINABILITY PERFORMANCE MEASURES AND THEIR EVALUATION

This study attempts to evaluate a feasible numbers of performance measures shown as in Table 1 within the scope of this study. In other words, the performance measures actually evaluated to capture the sustainability goals and objectives of the regional solid waste transport system (RSWTS). Follow which the details of estimation of selected performance measures of sustainability indicators are given.

➢ Environmental Sustainability Indicators

For the calculation of total daily emissions for a particular year, emission rates estimated for the corresponding year will be used.

➢ Social Sustainability Indicator

Social equity can be captured by equity of exposure to emissions and public health is represented by exposed population to emissions. These measures are designed to compare the coincidence or proximity of people to air pollutants such as Carbon Monoxide (CO), Volatile Organic Compound (VOC) and NOx. As a surrogate for population exposure, population density by Traffic Analysis Zone (TAZ) is multiplied by the daily average emissions density, and the values are summed across the entire region. Higher human impact indexes indicate that high population density and high pollution density are more likely to occur in the same proximity (FHWA, 2004). The spatial equity indexes are derived by ordering 1031 TAZs from the highest to lowest emission densities and plotting the cumulative percentage of total land area against the cumulative percentage of pollutants (FHWA, 2006). Emission densities are calculated by dividing total emissions contained by the land acre of each TAZ, assuming that each TAZ is exposed to the amount of VOC and NOx emissions resulting from the transportation links located within a particular TAZ. The higher the
Table 1: Selected Sustainability Indicators

<table>
<thead>
<tr>
<th>Sustainability Dimension</th>
<th>Goals and Objectives</th>
<th>Performance Measures</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Sustainability</td>
<td>Minimize Greenhouse Effect</td>
<td>CO₂ emissions</td>
<td>Gram/day</td>
</tr>
<tr>
<td></td>
<td>Minimize Air Pollution</td>
<td>*VOC emissions</td>
<td>Gram/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOx emissions</td>
<td>Gram/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO emissions</td>
<td>Gram/day</td>
</tr>
<tr>
<td>Social Sustainability</td>
<td>Increase Safety and Security</td>
<td>Exposure to *VOC</td>
<td>Gram/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exposure to NOx</td>
<td>Gram/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exposure to CO</td>
<td>Gram/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equity of *VOC exposure</td>
<td>Spatial Equity Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equity of NOx exposure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equity of CO exposure</td>
<td></td>
</tr>
<tr>
<td>Economical Sustainability</td>
<td>Maximize Economic efficiency</td>
<td>Avg. solid waste transport Travel Time</td>
<td>Mins</td>
</tr>
<tr>
<td></td>
<td>Improve System Performance</td>
<td>Solid Waste Mobility Cost</td>
<td>Cost/ton</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Solid Waste Transport</td>
<td>Ton/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Daily Solid-Waste mobility</td>
<td>Total veh-km travelled/ day</td>
</tr>
</tbody>
</table>

*VOC-Volatile Organic Compound

Index is, the greater the spatial equity that can be achieved.

**Economical Sustainability Indicators**

Calculating average solid waste transport travel time involves finding link traffic volume. Then with the help of the link traffic volume, solid waste transport travel time is found out. For finding solid waste mobility cost per ton, first the VOC/km is found out, and then with the help of per day quantity of solid waste per ton, the mobility cost of solid waste is found out. For calculating average total solid waste transport per day solid waste quantity is taken into consideration. Daily solid waste mobility is total veh-km travelled in a day.

8.0 STUDY AREA CHARACTERISTICS

The Mumbai Metropolitan Region (MMR) extends over an area of 4355 sq.km and comprises of seven municipal corporations and thirteen municipal councils. Presently all these ULBs work independently for solid waste management in their jurisdictions. Mumbai is the biggest contributor of solid waste in the region. Following details shows MMR’s corporations and councils forecast of Municipal Solid Waste (MSW) generation (RCUES 2008)

- Seven Corporations
  - Mumbai
II. Bhiwandi-Nazampur
III. Kalyan-Dombivali
IV. Mira-Bhayandar
V. Navi Mumbai
VI. Thane
VII. Ulhasnagar

➢ Forecast of MSW Generation in year for seven corporations -
   I. 2009 - 10684 Tons/day
   II. 2034 - 22370 Tons/day
   III. 2060 - 48242 Tons/day

● A-Class Councils
   I. Ambernath
   II. Kulgaon-Badlapur
   III. Navghar-Manikpur
   IV. Nalasopara
   V. Virar

➢ Forecast of MSW Generation in year for A-Class Councils -
   I. 2009 - 278 Tons/day
   II. 2034 - 583 Tons/day
   III. 2060 - 1256 Tons/day

● B & C Class Councils
   I. Alibaug
   II. Karjat
   III. Khopoli
   IV. Panvel
   V. Matheran
   VI. Pen
   VII. Uran
   VIII. Vasai

➢ Forecast of MSW Generation in year for B & C Class Councils -
   I. 2009 - 154 Tons/day
   II. 2034 - 323 Tons/day
   III. 2060 - 696 Tons/day

9.0 PLANNING FOR SOLID WASTE TRANSPORT SYSTEM FOR STUDY AREA

The vehicle routing for municipal refuse collection and transportation, and fleet size determination are attempted in two phases. In Phase-I (Macro-level Planning) the whole planning is structured for transportation of solid waste from TS to RLF site, and it will include planning for routing of solid waste vehicles and finding optimum distribution cost and fleet size to satisfy the each TS requirement. In Phase-II (Micro-level Planning) the study will concentrate on solid waste transport from individual collection demand points to check post (Ward-level) and routing of vehicles and finding optimum distribution cost and fleet size, for transportation of solid waste from different wards to transfer station. In this paper only phase-I (Macro-level) is discussed. For phase-1 with the help of TransCAD the routing is done with considering all possible route options from each TS to each RLF. For finding minimum distribution cost, linear programming model is developed and solved with the help of CPLEX optimization tool. Total 20 ULB’s are identified in study area and at each ULB one TS is planned.

10.0 PHASE-1 (MACRO-LEVEL)

ANALYSIS

VEHICLE OPERATING COST (VOC) ANALYSIS

While the costs of road construction and maintenance consume a large proportion of national budgets, the costs borne by the road using public for vehicle operation and depreciation are even greater. It is therefore important that road policies take account of total
transportation costs. The cost of owning and operating vehicle due to its use on roads is called the Vehicle Operating Cost (VOC). VOC has two components, variable cost and fixed cost. Variable costs may be subdivided into two categories: Distance related components like, (i) fuel consumption, (ii) spare parts, (iv) tyre wear (v) lubricants (vi) maintenance labour cost etc. Time related components, like, (i) depreciation (ii) value of the passenger's time (iii) wages of the crew etc. Fixed cost includes the capital cost, registration fees, insurance, road permit charges, road and other taxes. For all possible route options from each TS to each RLF VOC/km is found out.

11.0 METHODOLOGY FOR FINDING LINK TRAFFIC VOLUMES

The peak hour public transport passenger matrix is assigned to the public transport network, which includes buses and intermediate Public Transport (IPT) routes on the road network. The public transport assignment is based on generalized time, which is a combination of In-Vehicle Travel Time (IVTT), Waiting Time (WT), No of Transfers (TR), Fare and Discomfort in time units. The parameters of this generalized time are obtained from Stated Preference Survey. The public transport assignment is done by assigning the peak hour Origin-Destination (OD) matrix on to the network. After performing the public transport assignment, the assigned flows across the screen lines are compared with the observed flows. Highway assignment carried out for peak hour, preloading the highway network with peak hour public transport and commercial vehicle flows. The daily public transport loadings are factored by the peak hour flow to daily flow ratios to obtain the peak hour public transport flows. These are converted to Passenger Car Unit's (PCU's) by using appropriate passenger-to-Passenger Car Unit (PCU) conversion factors. These peak-hour public transport (bus and IPT) and commercial vehicle flows in terms of PCU's are is preloaded on to the highway network before loading the private vehicle passenger OD matrices. The private vehicle passenger matrices are converted into peak hour PCU units, by using appropriate regional peak hour ratios and passenger-PCU conversion factors, based on observed occupancies at screen lines. A user equilibrium procedure based on generalized cost (sum of vehicle operating cost and time cost) trips is performed on the revised network, and the next iteration of private traffic assignment is carried out by taking the bus, taxi, auto and truck flows as preloads. This iterative process between PT and private vehicle traffic assignment is repeated until there is no appreciable change in the link loadings and link costs. Three skims namely the highway time, highway travel cost and highway distance are obtained from the loaded network. The skims obtained are used for calibrating the gravity model and the modal split-model. The process of distribution, modal split and assignment is repeated till the OD matrices become stable. This exercise is performed with CUBE, which is a transportation planning software package. This exercise is done for the greater Mumbai region. The rest MMR region link volumes are determined with the help of the Comprehensive Transportation Study (CTS) report and 24-hours classified traffic volume survey which carried out nearby all RLF sites.

12.0 METHODOLOGY FOR DETERMINATION OF TRAVEL TIME

The link traffic flow is taken from travel demand model developed for MMR. With the help of link traffic flow, speed of multi axel vehicle is estimated using speed flow relations for multi axel vehicle, which are developed for different type of roads (SP-30). Then the travel time is found out with the help of distance from TS to RLF. Following details shows the speed flow relations for different road types taken from manual on economic evaluation of highway projects in India (SP-30).
<table>
<thead>
<tr>
<th>Road type</th>
<th>Plain Terrain</th>
<th>Rollin Terrain</th>
<th>Hilly Terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Lane</td>
<td>SF5:VMAV = 39.718 - 0.0313*Q</td>
<td>SF11:VMAV = 36.253 - 0.0313*Q</td>
<td>SF17:VMAV = 27.773 - 0.0313*Q</td>
</tr>
<tr>
<td>Intermediate lane with earthen shoulders</td>
<td>SF23:VMAV = 43.974 - 0.0156*Q</td>
<td>SF29:VMAV = 40.464 - 0.0156*Q</td>
<td>SF35:VMAV = 31.873 - 0.0156*Q</td>
</tr>
<tr>
<td>Two Lane with Earthen Shoulders</td>
<td>SF41:VMAV = 49.808 - 0.0070*Q</td>
<td>SF47:VMAV = 47.830 - 0.0101*Q</td>
<td>SF53:VMAV = 38.798 - 0.0101*Q</td>
</tr>
<tr>
<td>Two Lane with Paved Shoulders</td>
<td>SF59:VMAV = 51.770 - 0.0052*Q</td>
<td>SF65:VMAV = 49.576 - 0.0052*Q</td>
<td>SF71:VMAV = 43.027 - 0.0052*Q</td>
</tr>
<tr>
<td>Four lane with Earthen Shoulders</td>
<td>SF77: VMAV = 52.425 - 0.0093*Q</td>
<td>SF83: VMAV = 48.670 - 0.0093*Q</td>
<td>SF89: VMAV = 39.479 - 0.0093*Q</td>
</tr>
<tr>
<td>Four lane with paved Shoulders</td>
<td>SF95: VMAV = 52.425 - 0.0063*Q</td>
<td>SF101: VMAV = 48.993 - 0.0063*Q</td>
<td>SF107: VMAV = 40.350 - 0.0063*Q</td>
</tr>
</tbody>
</table>

Where,

\[ Q \quad = \quad \text{Volume of traffic in PCUs/hour} \]
\[ V_{MAV} \quad = \quad \text{Speed of Multi Axle Heavy Commercial Vehicles in km/hour} \]

*Figure 2: Vehicle routing strategy for transfer station to RLF*
Determination of vehicle routes on a network is the major problem in the design of an efficient collection and transportation service. A route represents the sequence of streets traversed by vehicle. Often vehicle must call at certain number of nodes in the transportation network or must go through specifically determined branches in the network. The routing decision involves determining which of the demands will be satisfied by each vehicle and what route each vehicle will follow in servicing its assigned demand. These decisions should be made to minimize the cost of operating the vehicle fleet. Principle cost items include fuel, personnel and vehicle depreciation. These costs are usually large and highly sensitive to how routing decisions are made. For routing of vehicle for transport of solid waste from TS to RLF all probabilities of routing are covered as shown in Figure 2.

13.0 MODEL DESCRIPTION

The objective is to find optimum distribution cost and fleet size for satisfying the solid waste transport need at each TS. For routing the TransCAD tool is used, then at each OD (Origin-Destination) pair of TS to RLF all possible routes are identified and highlighted in GIS map of study area (MMR).

Assumptions

1. The solid waste at each of the ULB are assumed to be concentrated at a given spot called 'Transfer Station' (TS).
2. The total quantity of solid waste produced per day in each ULB is known.
3. The minimal distance from each of TS to each RLF site is known.

14.0 MODEL FORMULATION FOR MINIMUM DISTRIBUTION COST

With the help of basic aspects of operation research a mathematical model for optimum solid waste distribution cost is developed.

Objective function

\[ \min z = \sum_{j=1}^{J} \sum_{i=1}^{I} C_{ij} X_{ij} \]  

s.t.  

\[ \sum_{j=1}^{J} X_{ij} = S_{i}, \quad i = 1, 2, 3 \ldots 20 \]  

\[ \sum_{i=1}^{I} X_{ij} = d_{j}, \quad i = 1, 2, 3 \]  

\[ X_{ij} \geq 0, \quad \forall j \in J \]  

Where,

\[ X_{ij} \] = Amount of Solid waste to transport from \( i \) to \( j \)
\[ C_{ij} \] = Transportation Cost/trip from Transfer Station \( i \) to RLF \( j \)
\[ S_{i} \] = Solid Waste supply from Transfer station \( i \)
\[ d_{j} \] = allocated supply for destination \( j \)

Index Set

\( I \) Transfer Stations, \( i \in I, i = 1, 2, 3 \ldots 20 \)
\( J \) Landfill Sites, \( j \in J, j = 1, 2, 3, \ldots \)

Equation (1) represents the formulation for minimizing the distribution cost over origin \( i \) i.e. TS and to destination \( j \) i.e. Regional Landfill (RLF) site. Equation (2) represents the supply constraint which signifies that total solid waste quantity coming over whole day at TS \( i \) and transported on same day to RLF \( j \) should be equal which satisfies that whatever solid waste is gathering at TS is totally transported to the RLF, this helps to avoid the storage of solid waste at TS. Equation (3) is demand constraint which signifies that total solid waste transporting to RLF should be less than or equal to the per day demand at RLF. This constraint is used to signify that if it happen that most of TS's are nearby particular RLF, then the formulation will send all solid waste to only near one RLF site and will ignore the other RLF site's if any, but this constraint...
help to make sure that all solid waste is not going to concentrate on particular RLF, and after demand at particular RLF is satisfied the formulation will look for next nearby RLF. This is to confirm that even the aim is to minimize distribution cost it should to take care that the system should work in feasible way and should also consider the congestion and over demand supply aspects. Equation (4) signifies non-negative constraint. Solution Technique.

The model developed is a linear programming formulation. The formulation solved using 'ILOG CPLEX' tool. The important aspect of this model is, it's not only gives the optimum solution for satisfying the demand with optimum cost and quantity but it also signify the destination to be choose to transport solid waste from particular TS to particular RLF. The model input includes supply matrix, demand matrix and cost matrix. Supply matrix includes quantity of solid waste to be transported from each TS, demand matrix includes the specified demand at each RLF site and the cost matrix includes the Vehicle Operating Cost (VOC)/trip from each TS to each RLF. In study area we have twenty origin stations (TS's) and three destination stations (RLF sites). We got per ton solid waste transport cost around Rs.439.5 and if compared with the present per ton solid waste transport cost is 697.7/ton at present in Mumbai(MCGM). These results promote to adopt such inception planning initiatives for system which will enhance the system effectiveness and economic efficiency, The collection and transportation of solid wastes contributes nearly 80% of the total cost of the solid waste management, so If a small percentage of collection and transportation cost is reduced it will result in to substantial total saving over a number of years.

16.0 RESULTS AND DISCUSSION

There are numerous definitions are available of sustainable development in literature but the most recommended and famous is "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). This paper mainly shows the details about estimation of selected performance measures for economical sustainability parameters of RSWTS. The most encouraging result obtained is the average solid waste cost/ton which is Rs.439.5 and actual transport cost for solid waste transport is 697.7/ton at present in Mumbai(MCGM). These results promote to adopt such inception planning initiatives for system which will enhance the system effectiveness and economic efficiency, The collection and transportation of solid wastes contributes nearly 80% of the total cost of the solid waste management, so If a small percentage of collection and transportation cost is reduced it will result in to substantial total saving over a number of years.

17.0 FUTURE WORK

The next part of study consists of the micro-level planning, and the sustainability assessment of RSWTS. Then it is planned to use the Taguchi Method for impact analysis of combination of indicators (Economical, Social and Environmental) on system sustainability, which is very popular method for design of experiments and analysis. Taguchi method is a technique for designing and performing experiments to investigate processes where the output depend on may factors (variable or inputs) without having to tediously and uneconomically run an entire process of using all combinations of variables or inputs. Taguchi method have been successfully applied and proven in many industrial and commercial applications. By identifying controllable variables and varying them in specific trials, one variable
is found that has the greatest individual impact. Taguchi method may be used to reduce experimental time and at the same time produce sufficient information. Also MCDM approach will be considered for developing preference criteria for sustainability indicators (Economical, Social and Environmental).

18.0 ACKNOWLEDGEMENT

Thanks to Mr. Rakesh Kumar, Director, Ms. Shruti Nair, Mr. Sandeep Taide from National Environmental Engineering Research Institute (NEERI), Mumbai and Mr. Shrote from Mumbai Metropolitan Region Development Authority (MMRDA) for providing vital information related to this study, also thanksto Mr. Alok Patel, Research Scholar from IEOR department, IIT Bombay for his guidance regarding optimization techniques.

References

EXPLORING THE SUSTAINABLE TRANSPORTATION INDICATORS
BY COMPARING TWO NEIGHBOURHOODS:
A CASE STUDY OF AHMEDABAD CITY

Hemangi Dalwadi  *  Manjiri Akalkotkar  **

Abstract

The Concept of Sustainable Transportation at neighbourhood scale is important to enhance safety and accessibility issues. Such issues are addressed by understanding the socio-economic, physical and travel characteristics of neighbourhood. Numerous problems encountered at macro-city scale are results of cumulative consequences of poor planning at micro (neighbourhood) level therefore it is important to amalgamate the sustainable principles for a livable neighbourhood.

The aim of research is to examine the sustainable transportation indicators by comparing two neighbourhoods in Ahmedabad. It traces the relationship between three factors which are land use, travel activity and overall accessibility. A guiding principle has been developed for neighbourhood by integrating factors to obtain the desired objective.

Key words: Sustainable transportation Indicators, Neighbourhood, Land use, travel activity, accessibility.

1.0 INTRODUCTION

1.1 Background

India is experiencing faster and more intense urbanization with uncontrolled and unplanned growth. Such unplanned and uncontrolled growth leads to the development of sprawl on the peripheral limit of an urbanized area. Development of such growth results into low density settlements and decentralized pattern of suburban growth. The sprawl can be developed as residential or commercial centres. Such land uses attract or generate trips to fulfil their needs that indirectly increase travel distance, increase in use of private vehicles, increase in congestion, pollution. This may lead to decrease in quality of life and safety issues for commuters as well as pedestrians and non-motorized vehicles (NMV). To avoid such issues, unplanned urban growth should be controlled through some growth management strategies. There are various growth management strategies which have been evolved over years by different terminologies such as Traditional Neighbourhood Development (TND), Transit Oriented Development (TOD), New Urbanism, Smart growth, Compact city and Sustainable city. All these growth management strategies are applied at various spatial levels (i.e., regional, city, neighbourhood and street level). In this paper, examination of sustainable transport factors and the application of the indicators are assessed only at neighbourhood level.

The Sustainable Transport Neighbourhood is endowed with convenient and easy accessibility to basic amenities. It also focuses on safety for both pedestrian and motorised vehicle. Such parameters are important to consider to develop livable community which attracts the people to visit, work or live as compared to complex mobility system within the neighbourhood.

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1.1 Research problem
What is the effect on city growth by amalgamating and implementing the Sustainable transportation indicators at neighbourhood level?

1.2 Need of study
Ahmedabad is projected to grow from 4.5 million in 2001 to 5.5 million in 2011 (CEPT University and Urban Mass Transit Company Ltd. 2011). The urban form of the city shows a typical dispersed growth with improper mix of land use. As the city lacks efficient public transport system and physical infrastructure to support access to transport, it has resulted into people preferring private vehicles. The existing part of the city has issues of traffic congestion, lack of footpath, unsafe access to services, etc. which has impacts on transit accessibility.

Various theories based on neighbourhood development and the sustainable transport are available but the combination of both and its application are not documented when it comes to Indian cities. Therefore this research is focused on exploration of the indicators of Sustainable Transportation System Indicators at the neighbourhood level and validate the sustainability level.

1.3 Research objective
1. To identify key factors that support sustainable transportation at neighbourhood level. (from literature study)

2. To analyze the interrelationship between the factors (i.e. land use, travel activity and overall accessibility) with the help of indicators at neighbourhood level for Ahmedabad city. (analyzed from case of Ahmedabad city)

1.4 Expected Results
- Evolved methodology to analyze the indicators to meet sustainability level.
- Formulate guiding principle to make sustainable transportation neighbourhood.

2.0 LITERATURE STUDY
2.1 Sustainable Development
"Sustainable Development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). There is growing interest in the concepts of sustainability, livability, sustainable development and sustainable transport (Litman Todd, 2011). Sustainability is about integrating and balancing economical, social and environmental aspects which has impacts for a long term. It also maintains a distinction between growth (increased quantity) and development (increase quality) (Litman Todd, 2008).

2.2 Sustainable Transport Neighbourhood
Neighbourhoods are said to have a high degree of local self-sufficiency if most of goods, services and activities people access frequently are located within a walkable distance. This reflects a suitable combination of land use density, mix, employment and transport options that respond to the demand of the people residing in that area. Sustainable transportation neighbourhood is one that is accessible, safe, environmentally friendly and affordable by all (ECMT, 2004).

2.3 Justification of selected factors for Sustainable Neighbourhood
The literature illustrates nine factors (i.e., travel activity, air pollution emission, noise pollution, traffic risk, economic productivity, accessibility, land use impacts, equity, transport policy and planning) which define sustainable transportation system in terms of social, economic and environmental aspects. Out of these, factorssuch as travel activity, landuse and accessibility are essential and are
interrelated with each other while physical planning of neighbourhood. As through literature study it has observed that sustainable transport is more concerned with transport and land use interrelationships, because transportation systems shape land use and development opportunities. To support the transportation system and land use, accessibility based planning plays important role to make a sustainable transport system by reducing the transport issues such as congestion, improper accessibility to public transport services, unprovided with basic amenities, etc.

Therefore study is focused and limited to only three factors out of nine i.e. Land use impact, travel activity and overall accessibility.

3.0 METHODOLOGY

To evaluate the sustainability level and to understand the relationship between the three factors, two neighbourhoods were compared with each other in terms of social demography and physical and travel characteristics. The data was collected with respect to the parameters needed for evaluation. The data was compiled through primary and secondary sources. The primary data was collected through household survey and land use observation survey. Stratified random sampling method was used to conduct household survey to collect socio-economic data and travel characteristics. Sampling size was decided based on limitation of time, manpower and information available. Therefore, only 2% samples were collected from each individual neighbourhood (i.e. total 400 samples from both neighbourhood). Whereas land use observation survey was done to collect information related to physical features of a neighbourhood.

3.1 Study Area Delineation - Selection Criteria

Neighbourhoods was delineated based on the major road network and the individual identity of the area. In case of Ahmedabad, two neighbourhood were selected based on the following criteria, they are:

1. Both the neighbourhoods have similar socio-economic characters (i.e. income level vehicle ownership, etc).
2. Location parameter (one is located in city centre and another is located away from the city centre)
3. Developed neighbourhoods (Old development and Newly developed area).
4. Similar in size (4 sq km area)

| Neighbourhood 1 (Navrangpura) | Neighborhood 2 (Jodhpur) |

Figure 1: Delineation of Neighbourhoods
4.0 EVALUATION PARAMETERS AND RESULTS

The survey information was used as indicator to check the sustainability level in terms of availability and accessibility of services. This would help to know whether the basic amenities are available and if it is available then is it accessible with the sufficient street network connectivity and also comprehend trip pattern of individual neighbourhood.

4.1 Socio-economic Characteristics

- The study reveals that monthly income of people living in Navrangpura ranges from INR 50,000 to INR 1,00,000, while the people living in Jodhpur has income level ranging from INR 30,000 to INR 50,000. Navrangpura has about 43.5% households in the above range while Jodhpur has about 40.7%. In this case the difference is not too much, so it can be considered at same level.

- Both the neighbourhoods have 62% to 64% ownership of two wheelers which says that use of two wheelers is higher compared to other modes.

4.2 Physical Characteristics

4.2.1 Road Network Analysis and its connectivity

- By evaluating the indicators it has been observed that, Jodhpur has fewer missing links compared to Navrangpura (missing links means incomplete network).

- The intersection density indicates Navrangpura has better intersection density (i.e.71.8/sqkm) compared to Jodhpur (52.5/sqkm). As per literature study intersection density should be greater or equal to 66/sq km. Greater the intersection density, greater the connectivity of the network. Whereas intersection density was calculated as below,

\[
\text{Intersection density} = \frac{\text{Total No. of Intersection}}{\text{Total area (sqkm)}}
\]  

- But after computing the street connectivity,

\[
i.e. \text{Street connectivity Index} = \frac{\text{Total No. of links}}{\text{Total No. of nodes}}
\]

- The ratio of links vs. nodes should be minimum 1.4 for good connectivity and for better connectivity 1.6 is required (Division of Planning, 2009). These ratios in case of Navrangpura was 1.3 and Jodhpur was 1.4, which defines that Navrangpura has less connectivity than Jodhpur.

- The ratio of street connectivity also depends on the number of culs-de-sac, which is calculated as follow,

\[
\frac{\text{Ratio of cul-de sac}}{\text{Total No. of Intersections}} = \frac{\text{Total No. of Intersections}}{\text{Total No. of Intersections+Total No. of culs-de-sac}}
\]

- According to literature the ratio should be between 0 to 1 and desired index should be over 0.75. Here, the ratio of both neighbourhoods is 0.8, which means both neighbourhoods are well connected.

4.2.2 Land use and its demography:

- The study shows that Navrangpura comprises of good mix of land use with FSI 2.5. In this neighbourhood population density is quite lower compared to Jodhpur. This is due to 12.5% of commercial land use and 10% of mixed land use including institution, public spaces and commercial areas.

- Both neighbourhoods have high potential to increase population density with increase in FSI along the major...
transit corridor. The strategy of Transit Oriented Development (TOD) along the transit corridor should be applied to increase the employment and population density with ease of access to major transit corridors.

4.2.3 Public Transport Services:

- It has been observed that, Navrangpura facilitates good public transportation service as compared to Jodhpur. It is because the ratio of availability of Public transport per 1000 people in Navrangpura is 2.2 whereas in Jodhpur the ratio is only 0.7 which means that Navrangpura is well facilitated by public transportation services. This ratio is calculated as follows,

\[
\text{Availability of Public transport} = \frac{\text{Total No. of buses}}{\text{Total population}} \times 1000
\]  

- But the accessibility to services is lower due to inconvenience to passengers to travel during peak hours; it is time consuming and facility provided is not accessible within walkable distance. Therefore services are not used efficiently. Hence commuters are more comfortable to travel in private vehicles rather than public transport.

- In Jodhpur the services are not so efficient and reliable as compared to Navrangpura due to newly developed area and less frequency of buses.

- Navrangpura has about 47.5% of mixed land use (including 12.8% open spaces) and Jodhpur has 42.6% (including 14.2% open spaces).

- Navrangpura consists of about 12% commercial centres (like offices, shopping centres, etc) therefore more trips are attracted. It increases the need for public transportation or alternative mode.

4.2.4 Conclusion of physical characteristics and sustainability level of neighbourhoods

The following table depicts the summary of both the neighbourhoods, the indicators are measured by assessing Levels of Service (LOS). LOS was calculated as defined in the Ministry of Urban Development (MoUD) service level benchmarking document initiated by Government of India, whereas the indicators such as street connectivity (refer eq.2) and public transport availability (refer eq.4) was derived through literature study. After examining the level of service of each individual indicator, a simple additive method is used to evaluate the sustainability level described in Table 1, so that it get simplified and easy to calculate and judge the sustainability level of both the neighbourhoods.

4.3 Travel characteristics

4.3.1 Daily Trip characteristics

Mode split and trip destination were examined to know the daily travel pattern. The two wheeler usage was maximum because unsafe, improper accessibility and comfort matters in case of individual neighbourhood observed. Figure 2 interprets that in Navrangpura trips made are generally less than 2 km while in Jodhpur it ranges from 2 to 8 km for work or education purpose. It is because location of Navrangpura is within city centre with 35% of attraction centres (i.e., institution, commercial and mixed use) and 30% of residential whereas Jodhpur is located away from city centre having 40% of residential and 20% of attraction centres. The difference in location reflect land use, average trip length and vehicle kilometer travel. The average trip lengths computed for Navrangpura and Jodhpur are 4.23 km and 5.13 km respectively. Similarly the VKT/day in Jodhpur is more (51.4 km/day) compare to Navrangpura (41.4 km/day) because of major commercial activities (like offices, institute) happening in the city centre. Hence Navrangpura, having trip destination nearer which ultimately results in lesser Vehicle Kilometre Travelled (VKT).
<table>
<thead>
<tr>
<th>Indicators</th>
<th>Navrangpura</th>
<th>Jodhpur</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Road Network Analysis and its connectivity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Road Network Pattern and Completeness</td>
<td>LOS 2</td>
<td>LOS 2</td>
</tr>
<tr>
<td>2. Road Density</td>
<td>LOS 1</td>
<td>LOS 2</td>
</tr>
<tr>
<td>3. Street connectivity</td>
<td>LOS 3</td>
<td>LOS 2</td>
</tr>
<tr>
<td>4. Road safety</td>
<td>LOS 3</td>
<td>LOS 2</td>
</tr>
<tr>
<td><strong>B. Land use and its demography pattern</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Population Density</td>
<td>LOS 4</td>
<td>LOS 3</td>
</tr>
<tr>
<td>2. Mixed Land use</td>
<td>LOS 2</td>
<td>LOS 3</td>
</tr>
<tr>
<td>3. Intensity of Development along transit corridor</td>
<td>LOS 4</td>
<td>LOS 4</td>
</tr>
<tr>
<td><strong>B. Land use and its demography pattern</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Service Coverage of Public transportation</td>
<td>LOS 1</td>
<td>LOS 2</td>
</tr>
<tr>
<td>2. Availability of Public transportation /1000 population</td>
<td>LOS 1</td>
<td>LOS 1</td>
</tr>
<tr>
<td>3. Level of comfort in Public transportation</td>
<td>LOS 4</td>
<td>LOS 3</td>
</tr>
<tr>
<td>4. Pedestrian Infrastructure (% of footpath covered)</td>
<td>LOS 3</td>
<td>LOS 4</td>
</tr>
</tbody>
</table>

Both the neighbourhoods having same overall level of service but Navrangpura acts better in terms of availability and accessibility of services. Only Improvement is need in accessibility and comfort as compared to Jodhpur.

**NOTE:**
* MoUD Service Level Benchmarking and Connectivity Index theory was considered for evaluation of indicators in form of level of service which has derived through literature study. Whereas,
  - LOS1 – Excellent service
  - LOS2 – Good, but can be better
  - LOS3 – Needs improvement
  - LOS4 – Worst condition

---

Figure 2 : Percentage Trip distribution with distance (km)
The comparison is done to observe whether the location parameter makes any difference in the nature of trips, choice of mode and will also reflect on the vehicle kilometre travel and trip length.

4.3.2 Occasional Trip Characteristics

There are two types of occasional trips made, such as:

1. Social/Recreation trip - made once in a week or once in month
2. Irregular trips - Trips which can be made on daily basis to fulfil their own needs or a community willing to visit such places on regular basis.

The irregular trips made to amenities were identified from surveys to know the basic needs of people. It has been observed that people residing in both the neighbourhoods are likely to visit three basic amenities like markets, religious places and parks in their day to day life. About 39-59% people visited religious places, 27-33% visited parks and 19-28% visited markets. It has observed from survey that such places people are more willing to travel by walk if it is located less than 400 to 500m. Similarly, the survey also interprets that proper accessibility to transit network could also encourage to use the public transport mode for their regular trips.

The Amenities were measured in two ways:

- **Availability of Amenities**: Whether the amenities were available within average walking distance.
- **Accessibility to Amenities**: If it is it accessible or not in terms of providing footpaths, safety and comfort.

4.3.3 Conclusion for occasional trip characteristics within the neighbourhood

* Parks:

In terms of Availability, Jodhpur has 72 parks, located at an average distance of 0.93km between two parks, which is good enough to access within the walkable distance.

In terms of Accessibility through the survey it has been concluded that people are willing to walk up to a distance of 0.44 km from their origin. So the capacity of one park serves the buffer area of 0.25km to 0.50 km.

* Religious Places

By comparing the parameter both neighbourhood are different in terms of location availability and accessibility. People visit religious centres at an average distance of 0.4 km by walk. The travel frequency is about 2 to 3 times a week or during some religious festivals. Here the density doesn't make any difference. The numbers of religious centres are same in both neighbourhoods but the location distribution of centres varies. In Navrangpura it is well distributed whereas in Jodhpur the religious places are so close to each other that this number does not serve the entire neighbourhood.

Table 2: Summary sheet for occasional Trip characteristics within the Neighbourhood

<table>
<thead>
<tr>
<th>Amenities within the Neighbourhood</th>
<th>Navrangpura</th>
<th>Jodhpur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Available</td>
<td>Accessible</td>
</tr>
<tr>
<td>Parks</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Religious place</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Market</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Bus stops</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Note:
Available: - The amenities are spatial distributed within the neighbourhood and number of amenities that serves the population.
Accessible:- The amenities which are accessible within buffer of 250 and 500m
Market

In terms of Availability, Navrangpura is not serving the whole neighbourhood as compared to Jodhpur. In Navrangpura door to door facilities are available and about 20% of population utilized this service. But such facilities are not economically useful for everyone because the prices for commodities are quite higher than the regular market prices. Such facilities are not satisfactory to middle and lower income groups.

Bus stop

Availability and accessibility to bus stop is important for sustainable transport neighbourhood. Firstly to check the availability of bus stop, requisite number of bus stops is calculated by computing bus stop density which is number of bus stops per sqkm. From survey it has observed that the location of bus stop should be accessible within the average walkable distance of 250m. Therefore, for calculation, a buffer area of 250m has been considered which depicts that 1 bus stop servers about 0.196 sq km (i.e. buffer area of 250m) which means minimum 5 bus stops per sqkm are required. In Jodhpur, bus stop density is 2.3 while in Navrangpura it is 7.3 which is quite good compared to Jodhpur.

But now in terms of accessibility, In Navrangpura, transit stops are accessible within walkable distance of 250 to 500m whereas it is not so in Jodhpur area. The availability and accessibility of public transportation services are related to public transport indicators described in physical characteristics indicators. It has observed from surveys that, Navrangpura facilitates good services but it is inconvenient to travel in buses during peak hours and also poor pedestrian facilities encourage the commuters to use private vehicles rather than public transport. Therefore shorter distance trips are done by two wheelers. In that case Navrangpura is far better than Jodhpur as in Navrangpura, bus stop density and service coverage of public transport are better but accessibility to PT is not efficient which decrease in ridership.

5.0 CONCULSION

- Socio economic characteristic does have impact on the individual's ability to afford motorized vehicles and its usage. For example, Less average family income leads more number of 2-wheeler ownership in Indian cities compared to other developed countries where two- wheeler ownership is not distinct.

- Indicators of physical characteristics (i.e. road network connectivity, land use and public transportation services) and travel characteristics (i.e. VKT, trip length, mode split, trip frequency, availability of services) are interdependent on each other to choose the individual travel pattern and travel modes.

- Complete road network connectivity, road safety, public transport service coverage encourages the use of public transportation or non motorized vehicles, results into reduction in emission from vehicles as the Vehicle Kilometre Travel (VKT) reduces to make neighbourhood sustainable in term of environment aspects

- Minimal accidents contributes to good hierarchy and street connectivity with mixed of land use

- Mix of land use and accessibility to transit has impact on an individual's decision to use public transport.

- Basic amenities located within distance of 250 to 400 m is defined as accessible neighbourhood (i.e. park, religious place, bus stop, etc).

- Both neighbourhoods can sustain increased in residential density and employment density, hence further exploration is needed for increase of FSI.

5.1 Recommendation

For appropriate physical planning at neighbourhood scale following points are recommended

- Complete road network pattern is requisite with maintained hierarchy of street to
segregate pedestrian and motorized vehicle movement

- Desired Street connectivity index should be 1.6 or minimum 1.4 for good network connectivity.
- The occurrences of cul-de-sac and dead ends should be eliminated.
- Higher FSI (about minimum 4 to 5) should be investigated along transit corridor with mixed land use to generate employment and population density within the neighbourhood.
- The amenities provided should be distributed spatially within neighbourhood preferably in a smaller pockets (example. Parks should be located at every 300 to 400m).
- Spaces for informal activities like pan shop, vendors, etc should be provided along with the amenities, so that, such informal activities doesn't encroached on footpath and parking spaces.
- Providing parking spaces near to parks and temples should be avoided.

The above recommendation would help to achieve compactness, proper accessibility, promote equity, safety and provide public services also at macro scale.

The research conclude by defining the neighbourhood that serves basic facilities, with safer and easy accessible by walk or non-motorized vehicle with a good mix of land uses, such neighbourhood can be defined as Sustainable transport neighbourhood. An individual indicator does not create a sustainable community. The amalgamations of indicators are important due to interdependence between the indicators

5.2 Limitation

- To check the sustainability of neighbourhood, land use, travel activity and overall accessibility are only indicators which are focus to achieve the sustainable transportation neighbourhood.
- The evaluation of physical sustainability is done on bases of benchmarking (Minister of Urban Development and literature study).

5.3 Way Forward

The application of schematic proposal for both neighbourhood (Navrangpura and Jodhpur) based on recommendation can be looked forward to plan sustainable transportation neighbourhood.

Further it would help to frame intervention policy to attract more population and jobs. This may serve as a deterrent to people and companies to locate at the outskirts of the city, leading to sprawl. The study clearly indicates that the Ahmedabad city neighbourhoods have land use and street pattern that is conducive for the sustainable neighbourhood with some minor policy intervention.
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Abstract

Basic needs of pedestrians are not recognized as a part of the urban transport infrastructure improvement projects in Delhi. Rather, an ever increasing number of cars and two wheelers implicate the construction of large numbers of flyovers to facilitate signal free movement for motorized vehicles, exposing pedestrians to a greater risk. This paper describes the statistical analysis of pedestrian risk and risk taking behavior while crossing the road at foot of flyover. Construction of flyovers increased the risk and inconvenience to pedestrians. Results indicate that absence of signals and uninterrupted flow of motorized vehicle make pedestrians behave independently, leading to no influence of predictor variables such as sex and age of the pedestrian, whether they are alone or in a group and type of conflicting vehicle on their risk taking behavior. From logistic regression, it is found that about 99% pedestrian were crossing the road at foot of flyover with the gap size less than the adequate gap size. At foot of flyover, about 50% pedestrians cross the road within 10 second of waiting.

Keywords: Pedestrian risk; Flyover; Gap size; ANOVA; Logistic regression

1.0 INTRODUCTION

Walking is the most sustainable and most used mode of transportation in Indian cities. As per the accident data, among all road users in Delhi, the one who are most exposed to risk are the pedestrians. Pedestrian deaths in Delhi are about four times the national average. Figure 1 shows the share of pedestrian fatalities of total in Delhi from 2001 to 2009 (Delhi Police, 2009) and it indicates that the pedestrians are the largest shares in total fatalities and the share remains the same over the years, which is about 50% of the total fatalities.
By virtue, pedestrians are the most vulnerable and the ongoing infrastructure improvement projects in Delhi are making them even more vulnerable. It is therefore important to study pedestrian behavior in order that the risk faced by them can be minimized while the transportation facilities are improved for motorized traffic. Pedestrians are mainly exposed to risk when crossing a road in urban areas as non-crossing accidents generally represent a small proportion of pedestrian accidents (Duncan et al. 2002; Lassarre et al. 2007). A common phenomenon in Delhi is that pedestrian fights for space on roads, because of a lack of safe and convenient pedestrian paths and crossings. In Delhi, a significant investment has been made for the construction of flyovers to increase the speed of motorized vehicles, to reduce their delay, and to make arterial roads in Delhi signal free. A public transport user is also a pedestrian during their ingress /egress trips. Pedestrians and public transport users together form the largest group of road users. After the construction of flyovers bus stop locations are also shifted away from the intersection to the foot of the flyover, increasing the walking distance for bus commuters by at least 400 m. Thus, Bus commuters after alighting from the bus and the other pedestrians if wish to go on the other side, cross the road straight ahead to reduce their walking distance and time. Pedestrians are exposed to higher risk while crossing the road at foot of flyover because of very high speed of motorized vehicles. Although a pedestrian sometime has the option of crossing the road at foot of flyover using the subway/footover bridge but most often they do not use it. Rather, they prefer to cross the roads on the surface. Rasanen et al. (2007) and Tanaboriboon and Jing (1994) confirmed this by comparing signalized intersection pedestrian crossings to overpass and underpass counterparts and found that pedestrians preferred signalized at-grade crossings to overpass or underpass crossings.

It should be noted that at foot of flyover, traffic signals are not provided. As a consequence, there is no safe signal for pedestrian, rendering all crossings to be unsafe. Thus, at foot of flyovers pedestrians who cross the road on the surface always face a risk. This paper describes the statistical analysis of pedestrian risk and risk taking behavior while crossing the road at foot of flyover of Delhi, India. This study will contribute to the literature in several ways. First, it will help to understand the risk and road crossing behaviour of pedestrians at foot of flyover. Earlier studies have not attempted to quantify the risk faced by pedestrians after providing free flow facilities to motorized vehicles. Also, this study jointly examines the impact of influencing variables to provide a better estimate of pedestrian variables and risk taking behaviour.

2.0 OBJECTIVES OF THE RESEARCH

This study aims to define and quantify the risk and risk taking behavior of pedestrian at the foot of flyover in Delhi, India. The study has four objectives: (1) To define the pedestrian risk (2) to evaluate the effect of demographic parameters of pedestrian (sex and age), whether they are alone or in a group, and type of conflicting vehicles on their accepted gap size and waiting time behaviour (3) to quantify the risk to pedestrian in terms of gap accepted by them (4) pedestrian waiting time analysis and evaluation of the correlation between waiting time of pedestrian and their accepted gap size.

3.0 DATA COLLECTION

To quantify the risk to pedestrian and observe the risk taking behaviour of pedestrian, data have been collected by video recording at two pedestrian crossings near foot of Panchsheel Park and Munirka flyover during the morning peak hours (8:30 - 9:30). A total of 200 pedestrians were analyzed at both the locations, all of them committed an unsafe crossing.
3.1 Site Characteristics

Foot of Panchsheel Park and Munirika flyovers were chosen for the study. At foot of flyovers, pedestrians were observed waiting at both sides of the road to cross with fast and uninterrupted flow of traffic from the flyovers. Some pedestrians were found running across to cross the road. Site characteristics are as follows:

I. Panchsheel Park

- Subway (underpass) is present at both sides near to the foot of the flyover but most often pedestrian do not use it. Rather, they prefer to cross the roads on the surface.
- Metro station is also present at both sides of the road. Metro commuters cross the road by the underpass metro station.
- Bus stops are present both side of the foot of flyover and most commuters weave through the moving traffic to board the bus or after alighting from the bus.
- A school is present near the foot of flyover that also causes the pedestrian density in the area.

II. Munirika

- Munirka market is present at one side of the road and vegetable market (Sabzi Mandi) with some other shops on the other side cause lots of activity in the area. Thus, a very high pedestrian volume in the area crosses the road at foot of the flyover. Due to presence of market both side, some pedestrians carrying heavy things while crossing the road.
- Despite of heavy pedestrian volume in the area, subway or any other pedestrian crossing facility is not provided at the foot of the flyover.

3.2 Videotaping, coding and interpreting the videotape data

Data have been collected by video recording at the pedestrian crossing near foot of flyovers during the morning peak hours (8:30 - 9:30) when vehicular and pedestrian flow was the maximum. The camera was placed at the foot of the flyover, facing the median. The crossing behavior of pedestrians was noted by reviewing the video tapes. A high quality digital camera was used to collect all the relevant information of pedestrian and vehicular traffic at each instant.

Each pedestrian was viewed in slow motion by progressing the tape. The tape was viewed many times to code all of the relevant information for pedestrians and vehicles. Two sets of variables were coded for each pedestrian. The first set describes the pedestrian's attributes and movements. The coded attributes include sex, age group, and type of pedestrian (single or in a group). The movement information includes the time of arrival at the intersection, time when crossing begins, time of arrival and departure from the median, and time at which crossing is completed. The second set describes the vehicle's attributes and movements that include type and speed of conflicting vehicle and gap between two consecutive conflicting vehicles. From a single camera, full pedestrian crossing could not be observed clearly. Hence all half crossings were analyzed in the study.

4.0 METHODOLOGY

As the foremost step to study, pedestrian risk has been defined. Afterwards, two-tailed independent t-tests and Levene's tests were performed to check the equality in mean and variance of rejected and accepted gap sizes and waiting time of pedestrian at two selected locations. A four way analysis of variance (ANOVA) was designed on the data to test the statistical significance of the influencing variables (sex and age of pedestrian, whether...
they are alone or in group, and type of conflicting vehicle) on the pedestrian gap acceptance and waiting time behaviour.

Adequate gap size to cross the foot of flyover was determined. Logistic regression was fitted using the different gap sizes faced by the pedestrians. It is the probability of crossing the road by a pedestrian in an available gap size (in sec). Gap size (in sec) is defined as the difference between the time when each pedestrian arrives at a crossing and each conflicting vehicle enters at the crosswalk. The length of the first gap size faced by pedestrian is calculated as the difference between the arrival time of pedestrian and the first conflicting vehicle. And the later gap sizes faced by pedestrian are calculated as the difference between the arrival times of two consecutive vehicles. This gap is the available gap size to the pedestrian. If a pedestrian accepts the available gap size (i.e., crosses the road within that gap), then it is called an accepted gap size; otherwise it is called a rejected gap size. Pedestrian waiting time analysis has been done. Also, to see the dependence of pedestrians’ gap acceptance behaviour on their waiting time, correlation analysis has been done.

5.0 RISK TO PEDESTRIAN

The risk faced by pedestrians while crossing the road has been defined in different ways. In common life, risk is used as a very broad concept including both the probabilities of an unwanted event as well as the consequences of this event (Ekman 1996). The risk exposed to pedestrians depends upon road crossing conditions that include presence and location of zebra crossings (Keall 1995), signal cycle time for pedestrians (Tiwari et al. 2007), speed of the conflicting vehicles (Pasanen 1991), type of conflicting vehicle, intersection geometry (Lee and Abdel-Aty 2005), waiting time at different points of the intersection(Carsten et al., 1998; Tiwari et al., 2007) and planning and design of subways/foot over bridges (Rasanen et al., 2007; Tanaboriboon & Jing 1994). Previous research shows that the risk taking behaviour of pedestrian also depends on the pedestrian characteristics like age and sex of pedestrian (Hamed 2001; Moyano Diaz 2002; Oxley et al. 1997; Rosenbloom and Wolf 2002; Yagil 2000), whether they are alone or in group (Rosenbloom 2009).

6.0 DATA ANALYSIS

6.1 Mean and variance of the data set at two locations

Before analyzing the significance and relationship of influencing variables on pedestrian risk taking behaviour, we need to check whether there is a significance difference in the risk taking behaviour of pedestrians at two locations: foot of Panchsheel and Munirika flyover. Gap sizes rejected and accepted by pedestrian and waiting time of pedestrians are the important measures of pedestrian risk taking behaviour. Mean and variance of rejected and accepted gap sizes and waiting time of pedestrian were observed at two locations from the recorded data. To check whether mean and variance of the data set at two locations are statistically similar or not, two tailed independent t-test and Levene’s test have been performed. Table 1 summarizes the findings. Levene’s test tests the hypothesis that variance in groups are equal. The results show that for rejected and accepted gap sizes and waiting time of pedestrian, Levene’s tests are insignificant (at 95% C.I.) i.e. variance in the data of rejected and accepted gaps and waiting time of pedestrian are statistically equal. Hence, to check the equality of means two tailed t-value is observed by assuming that the variances of two dataset are equal for all the three variables. Results indicate that t-tests are insignificant (at 95% C.I.) for all three variables. It shows that mean rejected and accepted gap size and mean waiting time of pedestrian are statistically similar at two locations.
Table 1: Mean and variance of rejected gap, accepted gap and waiting time of pedestrian

<table>
<thead>
<tr>
<th>Location</th>
<th>Rejected gap analysis</th>
<th>Accepted gap analysis</th>
<th>Waiting time analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Rejected Gap (in Sec)</td>
<td>SD</td>
<td>Levene's Test</td>
</tr>
<tr>
<td>Panchsheel</td>
<td>2.02 (*n=224)</td>
<td>1.8</td>
<td>F= .001 (sig)</td>
</tr>
<tr>
<td>Munirika</td>
<td>2.21 (*n=801)</td>
<td>1.77</td>
<td>F= .001 (sig)</td>
</tr>
</tbody>
</table>

There is a no significance difference in the risk taking behaviour of pedestrians at two locations. Thus, for further analysis two data sets have been merged.

6.2 Variables in the model

To analyze the road crossing behavior of pedestrian, predictor variables were extracted from the recorded videos. The following variables were categorized into broad groups from their appearance manually by the data analysts: (1) Gender of pedestrian: male and female, (2) Age group of pedestrian: children, young adult, middle aged and old aged, (3) Type of pedestrian: single normal, in a group, handicapped and with children/ heavy luggage, (4) Type of conflicting vehicle: Heavy vehicle, Light commercial vehicle, Car, Motorized two wheeler and Motorized three wheeler.

It is observed that males were involved in more road crossings than females. At both the locations, we found that those who were involved in road crossings comprise about 75% males and the rest were females. Further we noticed that those who were involved in road crossing primarily consist of young adults and the middle aged people (approximately 90%).

For the analysis, the following categories of the predictor variables were excluded from the data set due to insufficient sample size: children from the category age, handicapped and with children/ heavy luggage from the category type of pedestrian and light commercial vehicle from the category type of conflicting vehicle.

6.3 Pedestrian gap acceptance behaviour and their waiting time

To test the statistical significance of the influencing variables on the pedestrians' gap acceptance and waiting time behaviour, a four way analysis of variance (ANOVA) was designed on the data. The dependent variables were the gap size (in sec) accepted and waiting time faced by the pedestrians. The independent variables were sex and age of pedestrian, type of pedestrian (whether they are alone or in group), and type of conflicting vehicle. The results of the ANOVA are summarized in Table 2. Table 2 lists the sources of variation in the ANOVA including F statistics and their associated P values.

Table 2: Results of ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Accepted gap size</th>
<th>Waiting time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F Statistics</td>
<td>P- Value</td>
</tr>
<tr>
<td>Model</td>
<td>1.818</td>
<td>0.017*</td>
</tr>
<tr>
<td>Sex</td>
<td>1.403</td>
<td>0.238</td>
</tr>
<tr>
<td>Age</td>
<td>0.688</td>
<td>0.561</td>
</tr>
<tr>
<td>Type of pedestrian</td>
<td>0.029</td>
<td>0.865</td>
</tr>
<tr>
<td>Type of conflicting vehicle</td>
<td>0.817</td>
<td>0.486</td>
</tr>
</tbody>
</table>
Table 2 shows that both the ANOVA models were significant at the .05 level. All main factors' (sex, age, type of pedestrian, and type of conflicting vehicles) effects were insignificant at 95% confidence level. Realistically, pedestrian's gap acceptance and waiting time behaviour are not absolute. It is a function of many other parameters, such as sex and age of the pedestrian, whether they are alone or in a group and type of conflicting vehicle. But in the present case, both the ANOVA models statistically proved that these parameters are insignificant to determine the gap acceptance and waiting time behaviour of pedestrian at foot of flyover (at 95% CI). This can be attributed to the fact that at foot of flyover only those pedestrian cross the road who can take a high risk or if they are in haste (to catch the bus on the other side etc.) while the others go to the intersection and cross road safely. At the foot of flyover, traffic signals are not provided. As a consequence, there are no safe signals, rendering all crossings unsafe. The absence of signals and uninterrupted flow of motorized vehicle make pedestrians behave independently, leading to no influence of independent variables on their risk taking behavior.

6.4 Adequate gap size for pedestrian crossing at foot of flyover

Gap size available to pedestrian is considered to estimate risk to pedestrian at foot of flyover. Adequate gap size \( t \) to accommodate safe crossing for pedestrian at foot of flyover is determined as:

\[
t = \frac{d}{v} + s
\]

(1)

Where, \( d \) = Width of the one way crosswalk (starting point to median) at foot of flyover (4 lanes at both the locations i.e. 14 m), \( v \) = Average walking speed of pedestrian (1 m/s), and \( s \) = pedestrian start-up time before crossing, seconds (standard value = 2 sec).

By equation (1), value of adequate gap size \( t \) is obtained 16 sec. Thus, 16 sec is considered as the minimum safe gap size for pedestrian to cross the road at the selected locations.

6.5 A Probabilistic model for pedestrian's risk taking behavior

Both speed and distance of conflicting vehicles are judged at a time by the pedestrians while crossing the road. Therefore, gap size which represents the unit of time by which the vehicle will reach the crossing line of pedestrian is considered as a parameter to define risk to pedestrian.

Under the binary discrete choice framework, the probability of pedestrians' road crossing decision is seen as a choice between two alternatives, s/he starts crossing and s/he still does not decide to cross. Let \( P_i \) be the probability of crossing the road by a pedestrian. Under the binary Logistic regression \( P_i \) is related to predictor variable \( X_i \) (gap size faced by a pedestrian) in a non-linear way as:

\[
P_i = \frac{1}{1 + \exp(-\beta_0 - \beta_1 X_i)}
\]

(2)

Where \( \beta_0 \) is the intercept (the value of the criterion when the predictor is equal to zero) and the independent variables weighted by their parameters, \( \beta_1 \) is. SPSS statistical software was used for the analysis.

From the Logistic regression analysis for the recorded data, the value of intercept (\( \beta_0 \)) is obtained -4.139; value of Logistic regression coefficient (\( \beta_1 \)) for the gap size parameter is obtained 0.549; gap size parameter is found highly significant to determine the probability of road crossing by pedestrian (sig value: 0.00); value of chi-square is obtained is 488.271 (sig value 0.00). The chi-square statistics indicate that the logistic regression model is statistically significant. The value of Nagelkerke R square is 0.558, indicating that model is good enough to predict the outcome variable. Table 3 and Figure 2 show that how the probability of crossing for the pedestrians varies with the gap size.
Table 3: Probabilities of road crossing at different gap sizes

<table>
<thead>
<tr>
<th>Gap size</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of road crossing (%)</td>
<td>4.5</td>
<td>12.5</td>
<td>30</td>
<td>56.2</td>
<td>79.4</td>
<td>92</td>
<td>97.1</td>
<td>99</td>
</tr>
</tbody>
</table>

Table 3 and Figure 2 clearly show that about 99% pedestrian were crossing the road at foot of flyover with the gap size less than the adequate gap size i.e. 16 second (from the previous section). From Figure 2 it is clear that at foot of flyover, if the gap size is small (varies from 0-4 seconds) the probability of crossing is low. But when the gap size is between 5-16 seconds the probability of crossing increases linearly and finally after the gap of 16 sec the probability of crossing for the pedestrians become almost 1. So, 16 sec is assumed as the Critical Gap i.e. a gap after which almost every gap is accepted by pedestrian.

7.0 WAITING TIME ANALYSIS

In the section above, it is statistically proven that the sex and age of pedestrian, whether they are alone or in a group, and type of conflicting vehicle are not the influencing variables for the waiting time behaviour of pedestrians at foot of flyover. Thus waiting time analysis has been done by considering all type of pedestrians. From the data of 200 pedestrians, it was observed that 99 pedestrians (49.5%) crossed the road between the waiting time 0-10 second, 35 (17.5%) pedestrians crossed between the
waiting time 10-20, 48 pedestrians (24%) crossed between the waiting time 20-30, and 18 pedestrians (9%) crossed between the waiting time more than 30 seconds. To see the correlation between the waiting times of the pedestrians at the starting point of crossing and the gap accepted by them, a sample of 200 waiting time faced by the pedestrians at foot of flyover was taken into account. Correlation analysis was insignificant at the 0.05 level i.e. there was no direct correlation found between waiting time of pedestrian and gap size accepted by them at foot of flyover. This can be attributed to the fact that waiting time of pedestrian is very less at foot of flyover. Most of the pedestrians cross the road without waiting because of the continuous flow of traffic.

8.0 CONCLUSION

Flyovers provide short-term benefits to private motorized vehicles at the cost of increased traffic hazards and inconvenience to other road users. It also encourages people to use cars and two wheelers and move away from public transport, walking and bicycling that result in more vehicles, congestion and pollution on the roads. Results indicate that mean and variance of risk taking behaviour of pedestrians at two locations of foot of flyovers are significantly similar. None of the variables, viz. sex and age of pedestrian, whether they are alone or in group, and type of conflicting vehicle parameters, was found to significantly contribute to determine the pedestrian risk taking behaviour at foot of flyover. At foot of flyover a pedestrian who can take a high risk or if s/he is in haste crosses the road while the others go to the intersection and cross road safely. From logistic regression, it is found that almost all the pedestrian were crossing the road at foot of flyover with the gap size less than the adequate gap size. At foot of flyover, about 50% pedestrians cross the road in less than 10 sec of waiting. Thus, there is no correlation found between the waiting time and gap size accepted by a pedestrian. This study highlights human behaviour and risk taking owing to road geometry and operations. Traffic engineers and safety planners while designing flyover must ensure safe and convenient pedestrian crossings.
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CORRIDOR MANAGEMENT USING SERVICE LEVEL BENCHMARKS

Pradeep Kumar D. * CSRK Prasad **

Abstract

Due to tremendous increase of road traffic with increase in population, vehicle ownership and individual mobility, there is a growth in traffic congestion, delays and accidents. The present transportation infrastructure is inadequate to cater to this traffic. In order to alleviate these problems, corridor management is necessary. Complete monitoring and understanding corridor enable us to know deficiencies in the transportation. One of the such approach is Service Level Benchmarking (SLB). Level of Service for study area (Visakhapatnam) is found using the concept of SLBs (MoUD). Public Transport, Pedestrian Infrastructure, Non-Motorised Transport, ITS facilities, Travel speeds, Road Safety, Parking facilities, Pollution levels, Land Use Transport Integration are the parameters considered to find the Overall LOS of the city’s urban transport. The current service level benchmarking concept is commented which enables us to make necessary changes in it. Visakhapatnam is addressed with adhoc measures to improve the performance of urban transport.

Key Words: Corridor Management, Service Level Benchmarks, Level of Service

1.0 INTRODUCTION

Traffic congestion and safety issues continue to be increasing concerns to both the traveling public and transportation agencies. There is a need to encourage public transport instead of personal vehicles. This requires both an increase in quantity as well as quality of public transport and effective use of demand as well as supply-side management measures. Pollution, Heterogeneous traffic, slow moving traffic, high density of pedestrian traffic in urban streets due to high density of population, the very wide variety of traffic units with their great disparity of size and speed creates a number of problems and areas of conflict.

A corridor is defined as: "A broad geographic band, connecting population and employment center, served by various transportation modes, within which passenger and freight travel, land use, topography, environment and other characteristics are evaluated for transportation purposes" (Corridor Management Hand book, Vermont Agency of Transportation, 2005).

The term corridor management refers to the practice of identifying and implementing a mutually supportive set of strategies to maintain and enhance access, mobility, safety, economic development, and environmental quality along the transportation corridor.

Benchmarking is an important mechanism for Urban Local Bodies (ULBs) and utilities in identifying performance gaps and effecting improvements through best practices, ultimately resulting in better services to people. To facilitate comparison between cities and changes in performance over time, it is important that the performance levels are monitored against set benchmarks. SLBs are defined in this context.

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2.0 NEED FOR STUDY

The increase in traffic has generated demand to provide better transport facilities and services to the public. The main challenges to be faced are to provide these services through the congested, dense urban areas. Air pollution, Noise, Congestion and accidents are much more severe in India than those in other countries. All the vehicles in Indian cities are mainly disadvantaged by congested conditions. Buses are travelling in an extremely congested, narrow street, with no separate lanes and have to fight in heterogeneous traffic. To address the urban transport challenges faced in India, corridor management techniques can be applied. The ultimate aim of any corridor management study is to improve the mobility of the corridor within the available facilities using corridor management strategies.

In this policy, performance of the study corridor is evaluated and best management strategies are suggested which addresses the current problem. Ministry of Urban Development suggested a policy Service Level Benchmarks to evaluate the overall level of service of the corridor dealing for the improvement of the sustainability of the public transport, improving Non-motorized safety, pedestrian and parking facility, ITS, land use areas.

3.0 LITERATURE REVIEW

Generally, the performance of a transport corridor is evaluated based on the capacities and volumes on different links, speeds and delays along the corridor. This will enable to evaluate the performance of a given corridor and subsequently to suggest remedial measures for improvements. It is evaluated based on three perspectives.

➢ Infrastructure
➢ Quality of Service
➢ Movement of passengers and vehicles.

Ministry of Urban Development (2009) published a Handbook on Service level Benchmarks for Urban Transport for the performance evaluation of Urban Transport. Accordingly, all cities under JNNURM are advised to undertake the process of service level benchmarking. In addition, the initiative will facilitate development of Performance Improvement Plans using information generated by the benchmarking. After much deliberation, the benchmarks, their definitions, means of measurement, frequency and reporting, etc. were finalized. The Handbook of Service Level Benchmarks can be found in the website of Ministry of urban development.

Typically, four levels of service (LOS) have been specified, viz. ‘1’, ‘2’, ‘3’, and ‘4’ with ‘1’ being highest LOS and ‘4’ being lowest to measure each identified performance benchmark. Therefore, the goal is to attain the service level 1.

Various Corridor Management Handbooks published by US, UK, Department of Transportation were referred. Transportation management solutions given by different authors in India and around the world were also referred.

4.0 STUDY METHODOLOGY

The study methodology for the project work through which the transportation management study would be completed for the selected area is listed below:

➢ Physical inventory of the corridors in the study area
➢ Traffic data collection, Secondary Data Collection
➢ Evaluating the Corridor using Service Level Benchmarks By MoUD
➢ Performance Report for all the parameters chosen
➢ Suggest the best Management Measures

4.1 Service Level Benchmarks Designed By Ministry of Urban Development, India

Benchmarking values are given by Ministry of Urban Development (Service Level
Corridor Management Using Service Level Benchmarks

Benchmarks Handbook, 2009) for the following services.

a. Public Transport in a city
b. Pedestrian Infrastructure facilities
c. Non-Motorized Transport facilities
d. Usage of Integrated Transport System (ITS) facilities
e. Travel speed along major corridors
f. Road Safety
g. Availability of parking facilities
h. Pollution levels
i. Land Use Transport Integration
j. Financial Sustainability of Public Transport

5.0 STUDY AREA

Visakhapatnam is a fast developing port city, with a population of 20,15,120 (Census, 2011) and a land area of 540 square kilometres, and Andhra Pradesh’s second largest urban agglomeration in population. On account of rapid industrialisation with the growth of Steel, petroleum and refining and fertilizers, there has been significant migration into the city. With the formation of “Greater Visakhapatnam” in 2005 the city’s development is set for a quantum leap.

The city has radial form of road network development. NH- 5 and NH - 43 and the State Highways connect the city to the vast hinterland. Around 7.88 % of the total area is covered by roads, 2.13% by railways and 0.85% by the Port authorities.

Public transport comprises buses, which are used by 20% of the total commuters in the city

The city’s transportation requirement is met by the following modes of transport

➢ Bus transport is the major public transport with modal share of 20%
➢ Three seated autos acting as the Para transit contributing to nearly 15% of the transport demand.
➢ Private vehicles comprising two and four wheelers.

The public transport is taken care by APSRTC. The traffic regulation has been the responsibility of the police department. The NHAI, R&B etc, are the other agencies that contribute to the facilitation of transport system

6.0 DATA COLLECTION AND ANALYSIS

The surveys undertaken for the measurement of Level of Service of each of the Benchmark identified are as follows. The specific surveys are carried out on key public transport corridors, major roads and arterial roads and aggregated to give the overall level of service of the city. This also includes secondary data from different secondary sources. The type of data collected and surveys carried out are described below:

6.1 Primary Surveys:

➢ Journey Speeds & Level of Comfort of Public Transport. (By physically travelling through buses in Peak and Non-Peak hours in all routes)
➢ Speeds of Private Transport - ( By Moving Car Method )
➢ Waiting Time for Passengers at Bus stops (Frequency Distribution of passengers waiting at different times at different bus stops in the city)
➢ Physical Inventory Data (Foot path Condition and Existence)
➢ Parking Spaces Count (Parking Allowance in the city and fees)
➢ Waiting time for pedestrians at signalized intersections (Video graphic Surveys at intersections)

6.2 Secondary Data

➢ Pollution Level Data (AP Pollution Control Board)
➢ Accident Data from police records (Police Station)
➢ Public Transport Details (APSRTC depot)
➢ Land Use and Population Data (GVMC, Visakhapatnam)
The following analyses are carried out.

➢ Overall Level of Service using Service Level Benchmarks, MoUD.
➢ Performance Report of all parameters considered.

➢ Causality Analysis to identify the problems in the corridors.
➢ Suggesting Better management measures

Results for Level of Service for Visakhapatnam are presented in **Tables 1 to 9**.

### Table 1: Overall LOS of Public Transport city wide

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of Organized Transport System in Urban Area</td>
<td>80.11%</td>
<td>1</td>
</tr>
<tr>
<td>Extent of Supply Availability of Public Transport</td>
<td>0.35 per 1000</td>
<td>3</td>
</tr>
<tr>
<td>Service Coverage of Public Transport in the city</td>
<td>0.78 km/sqkm</td>
<td>2</td>
</tr>
<tr>
<td>Average Waiting Time of Public Transport</td>
<td>19.24 sec</td>
<td>2</td>
</tr>
<tr>
<td>Average Level of Comfort in Public Buses</td>
<td>0.93</td>
<td>1</td>
</tr>
<tr>
<td>% of Fleet as per Urban Bus Specification</td>
<td>100.00%</td>
<td>10</td>
</tr>
<tr>
<td>Calculated LOS of Public Transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall LOS of Public Transport city wide</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 2: Overall LOS of Travel Speeds along Major Corridors City wide

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Speeds of Motorized Vehicles</td>
<td>28.87 kmph</td>
<td>2</td>
</tr>
<tr>
<td>Travel Speeds of Public Transport Vehicles</td>
<td>18.30 kmph</td>
<td>2</td>
</tr>
<tr>
<td>Calculated LOS of travel Speeds along Major Corridors</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Overall LOS of travel Speeds along Major Corridors</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 3: Overall Level of Service of Pedestrian Facilities

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signified Intersection Delay (%)</td>
<td>36%</td>
<td>2</td>
</tr>
<tr>
<td>Street Lighting (Lux)</td>
<td>7.5 Lux</td>
<td>2</td>
</tr>
<tr>
<td>% of City covered with footpaths</td>
<td>43.58%</td>
<td>3</td>
</tr>
<tr>
<td>Calculated LOS of Pedestrian Facilities</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Overall LOS of Pedestrian Facilities</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>
Table 5: Overall Level of Service of Integrated Land Use Citywide

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Density</td>
<td>53.31/sqkm</td>
<td>4</td>
</tr>
<tr>
<td>Proportion of Non-Resident Area along major Transit Corridors</td>
<td>15 %</td>
<td>2</td>
</tr>
<tr>
<td>Intensity of Development Citywide</td>
<td>1.00</td>
<td>3</td>
</tr>
<tr>
<td>Intensity of Development along major Corridors</td>
<td>1.75</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 6: Overall LOS of Road Safety

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality Rate for Lakh Population</td>
<td>14 persons</td>
<td>4</td>
</tr>
<tr>
<td>Fatality Rate for Pedestrians and NMT users</td>
<td>35.78%</td>
<td>2</td>
</tr>
<tr>
<td>Calculated LOS of Road Safety</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Overall LOS of Road Safety</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Table 7: Overall LOS of Pollution Levels of the City

<table>
<thead>
<tr>
<th>Location</th>
<th>Gnanapuram</th>
<th>Seethammadhara</th>
<th>Police</th>
<th>Auto Barracks</th>
<th>Average Nagar</th>
<th>LOS of City</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2 (ug/m³)</td>
<td>14.6</td>
<td>7.2</td>
<td>9.5</td>
<td>9.7</td>
<td>10.25</td>
<td>1</td>
</tr>
<tr>
<td>NO2 (ug/m³)</td>
<td>26</td>
<td>18.7</td>
<td>23.5</td>
<td>18.7</td>
<td>21.725</td>
<td>1</td>
</tr>
<tr>
<td>SPM (ug/m³)</td>
<td>200.3</td>
<td>176.3</td>
<td>196.4</td>
<td>144.7</td>
<td>179.7</td>
<td>1</td>
</tr>
<tr>
<td>RPM (ug/m³)</td>
<td>99.6</td>
<td>88.8</td>
<td>89.7</td>
<td>72.7</td>
<td>87.7</td>
<td>3</td>
</tr>
</tbody>
</table>

Calculated LOS of Pollution Levels City Wide 6

Overall LOS of Pollution Levels City Wide 2

Table 8: Overall LOS of Financial Sustainability of Public Transport

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent of Non fare Revenue</td>
<td>1.27689</td>
<td>4</td>
</tr>
<tr>
<td>Staff / bus ratio</td>
<td>5.44959</td>
<td>1</td>
</tr>
<tr>
<td>Operating Ratio</td>
<td>1.02898</td>
<td>3</td>
</tr>
<tr>
<td>Calculated LOS of Financial Sustainability of Public Transport</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Overall LOS of Financial Sustainability of Public Transport</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
Table 9: Performance Report

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LOS (SLB, MoUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Transport</td>
<td>1</td>
</tr>
<tr>
<td>Pedestrian Infrastructure</td>
<td>2</td>
</tr>
<tr>
<td>NMT facilities</td>
<td>4</td>
</tr>
<tr>
<td>ITS facilities</td>
<td>4</td>
</tr>
<tr>
<td>Travel Speeds</td>
<td>2</td>
</tr>
<tr>
<td>Availability of Parking Spaces</td>
<td>3</td>
</tr>
<tr>
<td>Road Safety</td>
<td>3</td>
</tr>
<tr>
<td>Pollution Levels</td>
<td>2</td>
</tr>
<tr>
<td>Integrated Landuse Transportation</td>
<td>3</td>
</tr>
<tr>
<td>Financial Sustainability of PT</td>
<td>3</td>
</tr>
</tbody>
</table>

The city does not have Non-Motorized Tracks or facilities at present situation. Therefore, the NMT coverage is zero. Hence, the LOS of the facility is taken as 4.

Though in the city of Visakhapatnam, the buses and bus stations are proposed to have ITS, Passenger Information Systems, and GPS in the buses, they are not implemented. Therefore, City is said to have no ITS facilities. Hence, Level of Service for ITS facilities is taken as 4.

7.0 MANAGEMENT MEASURES

General management measures suggested are explained in detailed below. The measures are suggested such that they are easily executable, economical and effective, which could increase the mobility of traffic flow and ensure the smooth and safe travel for the road users and the pedestrians.

- Availability of Bus per 1000 population is 0.35. Hence, the bus fleet is to be increased.
- Service Coverage of public Transport is found to be satisfactory,
- Waiting Times of Passengers at Bus stops is found to be high in the routes 17B (Old Post office to Bheemili), 540 (MVP to Simhachalam), 400M (Gajuwaka to Complex), 38J, 38D, 52V (Sagar Nagar to Collector Office), and 52S which is more than 30 minutes. Hence, Service frequency through these routes has to be increased.
- Commuters using Public Transport are only 20%. It can be increased by attracting people to Public Transport by installing A/C, video coaches and maintaining perfect schedules.
- Non- Fare Revenue is very low. It is to be increased by advertising on buses etc., which reduces the ticket fare.
- All the buses are to be equipped with GPS. Bus Stops should have Passenger Information System and Integrated Ticketing System
- Foot Paths coverage over the city is not adequate. The existing footpaths are in poor condition and needs replacement, especially, at VUDA Children Complex, Waltair Depot to Appughar, Jagadamba to Complex needs new footpaths. It is likely that footpath coverage is to be increased to 80%.
- Waiting Time of Pedestrians at Signalised intersections can be reduced by constructing Subways or foot over bridges.
Constructions to be taken place at all the crossings on NH5, JagadambaJn, and Asilmetta Jn.

- Non-Motorized Vehicle Tracks are to be constructed parallel to existing roadway by a separating median. Interchanges are to be provided with NMT parking.

- Travel Speeds of Motorized Vehicles are around 30 kmph. Lane Discipline is to be introduced to increase the vehicle speeds. Proper signage and markings should also be done for this.

- Daba Gardens Road, Jagadamba to Complex Roads carry vehicles with speeds less than 20kmph. Hence, carriageway widths are to be increased.

- Travel Speeds of Public Transport are around 20kmph. Exclusive Lanes for Buses is a better option to increase the speeds of the buses.

- On-Street Parking fare is to be increased to discourage the use of personal vehicles. Parking fee is to be collected on hourly basis and high fare to be collected at CBD areas. At JagadambaJn, Complex, CMR central High parking fare is to be collected.

- It is important that road accidents are to be reduced by 50%. It is observed that accidents are increased from 1217 (2009) to 1312 (2010). Strict Enforcement is to be implemented to make the road users follow the traffic rules.

The service level benchmarks were developed to understand the deficiencies in the corridor. This can be an effective technique to manage a corridor as the surveys required, data requirements are fixed and no biased judgment of level of service calculations are possible.

8.0 COMMENT ON SERVICE LEVEL BENCHMARKS, MOUD

MOUD Service Level Benchmarking is biased towards metro cities and may not be a right approach for medium-sized cities for the performance monitoring.

In Public Transport System, One of the parameter is Presence of Organized Public Transport System. But many of the cities in India do not have organized public Transport System. Bus Stops Spacing are not considered. Service Coverage of Public Transport should vary between high density areas to low density areas. The whole city is considered as a single unit. The main mode is Intermediate Public Transport (autos). They are not considered at all.

Improvement in one of the Service adversely affects other parameter. For Example, Synchronized signals are recommended all over the city, which results in increase of pedestrian delays. The minimum width of the footpath is prescribed as 1.2 mts in which two people can walk side by side. But where pedestrian flow is high, this may not be sufficient and causes problems. Pedestrians Conflict points with the drive ways were ignored. Pedestrians’ crossings at mid blocks where FOBs are to be provided are totally ignored.

Quality, Maintenance of foot paths (Height of Kerb, Guard Rails) were not considered. NMV Tracks, CCTVs, GPS, PIS Integrated Ticketing System pertains to only metro cities and not commonly seen in India.

This method is more concentrated over Signalized Intersections. Unsignalized Intersections and roundabouts where still traffic is being controlled were ignored. Only the figures of the fatality rate were taken into consideration. Reasons are to be identified and necessary measures are to be implemented. Delays at the Intersections to the vehicles are not considered.

This method strictly encourages on street paid Parking facilities. Instead, Off Street parking, multi storied parking is to be encouraged. Higher parking charges at CBDs and higher
parking charges for bigger vehicles should be implemented. Journey Speed is the only performance measure for motor vehicles. Extensive surveys are required to be done. An authority is to be set up to completely monitor each city from time to time.

Average Bus Stop Spacing, Commuters using Public Transport, Commuters using Autos, Street Lighting, Condition of Footpath, Volume-Capacity Ratio, Accident Rate are the parameters that are to be introduced for better understanding of the corridor. Including all the neglected parameters in the service level benchmarks and redesigning them would give better understanding of the urban transport performance level of the city.

9.0 CONCLUSIONS

The results obtained with service level benchmarks gave a better idea of complete monitoring of the performance of urban transport in a city. A complete monitoring from time to time should take place to know the deficiencies in the urban corridors. The measures that are to be taken to overcome the deficiencies in present transportation system are discussed. Therefore, SLB concept can be an effective tool in identifying the performance gaps in Urban Transport. All the JNNURM Cities should take up the Service level benchmarking exercise. Finding the LOS of each parameter individually for each corridor and summing up to the whole city enable to manage the corridor effectively.
FINANCING URBAN PUBLIC TRANSPORT SYSTEMS - AN 'ECONOMIC FIRM' APPROACH
Pradeep Singh Kharola *

Abstract
Financing public transport systems is a challenge in reconciling between affordability and quality of service, particularly in the developing world. There exists substantial literature on financing transport systems, but seldom has this sector been viewed in its totality. Focus has been either on principles of fare determination or inducting private capital or realising revenues from the real estate potential etc. Presented in this paper is a holistic approach which treats the public transport system as an 'economic firm'.

Any typical 'economic firm' uses four basic factors of production and the firm pays for each one of these, consumes them and produces goods (or services), for sale. The public transport activity could also be modelled as an 'economic firm' as it also requires the basic factors of production and converts them into 'transportation services'. There are however some basic differences. First, the transportation firm does not own the first factor of production - the road space. Second, the transport utility does not have the flexibility to determine price of its services. Third, the public transport system generates positive externalities, whose benefits it normally cannot reap.

This paper analyses the options available for funding the different factors of production. It emphasises a holistic approach that caters to funding all the factors of production.

Key Words: user charges, externalities, funding transport

1.0 INTRODUCTION
1.1 Financing Urban Transport Systems- The Basic Problem

Urban public transport systems, the world over, present a multi-dimensional challenge - for governments to provide an appropriate policy framework, for planners to design a system which harmonises accessibility and affordability needs of citizens, for financial economical analysts to balance the economical and financial costs and benefits and for managers to run the system effectively. The public transport systems present a contrasting picture in the developed and the developing world, Table 1.

Despite the differences mentioned in Table 1 there are certain common issues which cut across both developed and developing countries:

- The rapid growth of personalized modes of transport coupled with urban sprawl is decreasing the patronage of public transport and hence their viability.
- Financial support to public transport systems from budgetary grants is being curtailed there are other competing demands.
- Focus is on internalizing both positive and negative externalities.
- The contribution of fare box revenues to operating costs is either static or declining.
- There are few incentives to the public transport utilities to increase internal efficiencies.

The complexities of public transport systems do not lend themselves to straightforward solutions. Interventions are required on the
In the policy front, the legal environment requires changes, new institutional arrangements have to be established, the capability of the organizations as well as individuals staffing these organizations needs to be enhanced, a slew of measures that would give priority to public transport are required to be put in place, modern technology needs to be resorted to, the quality of services needs to be improved followed by sustained marketing efforts and last but not the least the operational efficiencies have to be increased. An underlying necessity for undertaking these measures is the requirement of financing. One of the important causes of the unsatisfactory state of public transport systems in the developing world has been inadequate investments coupled with poor internal generation of resources.

The conventional approach for funding transportation systems in cities has been that the public transport infrastructure has to be funded by the city or the provincial governments from their general revenues and the public transport utilities have to sustain themselves on the fare box revenues.

### 2.0 AN ECONOMIC FIRM APPROACH

An economic firm is defined as an organization that procures various factors of production (labour, capital, raw materials, entrepreneurship) and produces goods and/or services for sale for maximising profits. The price charged for the 'goods or services' brings revenue to the firm so as to pay up for the factors of production and earn a reasonable profit. The transport activity could also be modelled as an 'economic firm' as it also uses all the factors of production to generate 'transportation services' for which a 'fare' is charged. The transportation sector has two broad components - road and the road users - and each can be analysed as an economic firm.

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### Table 1: Contrasting Features of Public Transport

<table>
<thead>
<tr>
<th>S.No</th>
<th>Characteristics/Parameter</th>
<th>Developed City</th>
<th>Developing City</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GDP</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Population</td>
<td>Generally manageable</td>
<td>Very high</td>
</tr>
<tr>
<td>3</td>
<td>Population growth</td>
<td>More or less stable</td>
<td>High growth rates</td>
</tr>
<tr>
<td>4</td>
<td>Compliance to rules</td>
<td>Very high</td>
<td>Low</td>
</tr>
<tr>
<td>5</td>
<td>Economic equality</td>
<td>Generally homogeneous population</td>
<td>Very heterogeneous population</td>
</tr>
<tr>
<td>6</td>
<td>Subsidy on public transport systems</td>
<td>Highly subsidised</td>
<td>Virtually no subsidies</td>
</tr>
<tr>
<td>7</td>
<td>Informal sector</td>
<td>A force to reckon with</td>
<td>Virtually absent</td>
</tr>
<tr>
<td>8</td>
<td>Autonomy to city governments</td>
<td>Very strong city governments</td>
<td>Weak city governments</td>
</tr>
<tr>
<td>9</td>
<td>Capacity to manage</td>
<td>Good capacity in all fields</td>
<td>Weak capacities within organisations</td>
</tr>
<tr>
<td>10</td>
<td>Population density</td>
<td>Medium to low-difficult to plan public transport</td>
<td>High-ideally suited for public transport systems</td>
</tr>
<tr>
<td>11</td>
<td>Availability of Finances</td>
<td>Adequate</td>
<td>Starved of funds</td>
</tr>
<tr>
<td>12</td>
<td>Use of Technology</td>
<td>Use modern technology</td>
<td>Use outdated technology</td>
</tr>
</tbody>
</table>
2.1 Economics of Roads

The provisioning of road space, regulating traffic and providing other support infrastructure have never been viewed as economic activities. Urban roads are usually provided without levy of any user charge—they are treated as 'free goods'. Indeed, in India providing and maintaining roads is the primary duty of a municipal government. Thus expenses towards construction and maintenance of roads are to be met through the general revenues of the municipal government. National governments and provincial governments also finance development of roads.

The 'invisible hand theory' propounded by Adam Smith stipulates that in a free market, the price of a commodity would so adjust such that the demand equals supply and the allocation of resources for production and consumption of different commodities will be in a manner which is the most optimum for society. This theory can be applied to production and consumption of road space. The road space is created (produced) by the city governments at a cost and the creation of road space follows the traditional upward facing 'supply curve'. There is a demand for road space that follows the traditional downward sloping demand curve. If the road users were charged for the road usage, the 'invisible hand' should have ensured the optimal utilisation of the road space by different users. However, the real scenario for road is far too complex as explained below:

a. It is difficult to quantify the extent of road space used by a consumer. There are concepts such as PCU - Passenger Car Units - etc. which come close to the idea of road space utilization, but even they are not perfect measures.

b. Utilization of road space creates externalities. In conventional economic theory the goods consumed by a person have utility only for that person. Externalities such as pollution, congestion and accidents impose a cost on others.

c. Unlike other goods, transportation services generally do have substitutes. There may be different modes of transport, but the need for a person to move is basic and has to be fulfilled (exceptions - travel for pleasure). Thus curtailing the demand for travel is not an available option. If the transport services were to be left totally to the market forces, the economically weaker sections would lose access to transport and consequently lose their livelihoods.

2.2 The Economics of the Road Users

The second component of the transportation activity is the road users. These road users could be grouped into two categories - those who use road through their own vehicles and secondly those who use road through public transport. Each user behaves like an economic firm and he/she is willing to pay as long as the value he derives from the service is more than the cost he/she incurs on it.

2.3 The Economics of Using a Personalised Vehicle

As stated above, a person would use his/her car as long as the utility he derives from such usage is more than the costs he incurs on it. The various costs which a car user incurs can be broadly categorized into three groups:

a. Initial or one-time costs - these include the payment made by the vehicle owner at the time of purchase.

b. Periodic costs - these include payments which the vehicles owner has to make periodically - annual tax, interest and annual maintenance charges.

c. Usage costs - these include -costs which a user incurs for each usage - fuel costs, parking charges and tolls.

The case of a motor cycle and a car was examined. The basic cost of the car/motor cycle, the Central Excise, the Sales Tax on vehicle and the Lifetime Motor Vehicle Tax are
one time levies and could be clubbed as the initial or one-time costs. The amount spent on fuels depends on the actual usage and therefore has been taken as the usage cost (there are no tolls in Indian cities and also the parking levies are very low). Items of expenditure such as annual insurance premium, annual servicing charges are included under the category of periodical expenses. The usage cost for a motor cycle comes to Rs 1.25/km and for a car it is Rs 5/ km.

An economist uses the concept of total costs. But there is a difference between the perceptions of an economist and a car user. A car user works on the presumption that the capital costs as well as the periodic costs are sunk costs. These costs may have a bearing upon the decision to own a car but these costs certainly would have no bearing on deciding on the extent of car usage. It is the usage cost which by and large is the fuel cost that is most important for a user. Thus factors governing ownership of cars/motor cycles are different from those that govern their usage. Levies like VAT on vehicles impact the decision of a person to own a car/motorcycle but not the decision to use the car/motor cycle. Therefore if usage of road space by cars and motor cycles is to be influenced then manipulating road usage costs is a better tool rather than tax on vehicles.

The Economics of a Public Transport System

The economic theory cannot be applied straightaway to the public transport utility for the following reasons:

i. Unlike a general economic firm, the transportation firm does not own the first factor of production - the road space.

ii. The transport utility does not have a choice of determining the price of its services. Because of reasons of equity, the fares are usually determined by a governmental
authority. The transportation utility has to buy the factors of production at market prices but it cannot charge a market price for its services.

iii. The public transport system generates positive externality, whose benefits it normally cannot reap; extension of transport system to any area raises the value of real estate in that area. The benefits go to the residents and also to local bodies which can now mobilize more taxes from these properties.

3.0 THE CONCEPT OF ROAD USAGE CHARGES

The cars and scooters demand road space. The road space is supplied by the city government. As the supply of road space is limited, the demand for road space needs to be adjusted in a manner such that it equals the supply. The price of the road usage should be so adjusted that the demand equals the supply.

A car or motor cycle owner merely looks at his/her marginal costs to decide on whether to use the vehicle or not. Higher the marginal cost lesser the number of car/motor cycle users on roads. This is explained by the diagram shown in Fig 1. The downward sloping line AB represents the demand for the usage of car/motorcycle. The upward sloping curve CD represents the marginal cost of a road user. The two curves intersect at point M and this is the equilibrium position. But this may not be desirable from environmental and social point of view and the desired equilibrium may require lesser vehicles on road. This could be achieved by shifting the marginal cost curve of a road user upwards. This upward shift is given effect through imposition of a road usage charge which increases the marginal cost of a road user and the equilibrium shifts to a point N which is leftward of point M and thereby the number of vehicles on the roads is reduced. However there are certain problems with this concept. Firstly, the demand for road usage varies from road to road and also from time to time. This makes it difficult to have a uniform price for the road usage. Secondly, the more important challenge is how to collect this variable road price from the users.

4.0 ROAD USAGE CHARGES FOR CARS AND MOTOR CYCLES

There are very few examples of proper usage charges for the road users. However the users pay in a number of indirect ways - through taxes on purchase of vehicles, taxes on fuels, impact fees and betterment levies. Moreover these levies are not administered with a view to regulate the vehicles on road rather than an aim to generate revenues for the government.

There are institutional issues which further complicate the financing of urban road infrastructure. In the developing countries, the city governments are weak as a result a large number of governmental agencies have been established each looking after one limited aspect of public transport. This fragmented approach is another reason why road usage charges have not become a reality in the developing countries.

Cities have, in the past tried to levy some sort of road usage prices on the road users. Urban road pricing has been implemented in some specific sites in France for building tunnels and urban motorways with different levels of success, whilst in other countries it has been used for restricting access to central districts. Different types of systems are prevalent. Some cities have defined a ‘cordon area’ and any vehicle entering the cordon area is levied a charge. Some cities charge based upon the time spent inside a defined area. In some cases, only certain roads are tolled.

5.0 ROAD USAGE CHARGES FOR PUBLIC TRANSPORT UTILITIES

Another issue which arises is what should be the user charge that should be levied for the public transport system. As mentioned earlier, since the demand for travel to work is a basic necessity, an alternate means of travel has to
be provided to the people who give up their cars/ motor cycles and also to those people who cannot afford a car or motor cycle. This brings in the public transport system. Although economic theory would dictate levy of road usage on public transport vehicles also but as stated earlier, there are issues of equity involved and therefore fares in public transport systems have to be kept at affordable levels. Moreover it has been established that the externalities caused by a bus are much less per passenger - as compared to car or a scooter. For example the CO emission in gm/passenger km for a two wheeler is 4.50 whereas for a bus it is 0.26 . Similar is the case for other externalities. Therefore there is no case for levy of road usage charges on the public transport vehicles. A public transport utility spends on fuel, capital, staff, taxes and various consumables. The public transport utilities are getting their funds from the fare box, subsidies by city or provincial governments and also through other non-traffic sources. The fare box revenues contribute 60% to 100% of the total funds i-flow to a transport utility. It is generally understood that the public transport systems make losses and therefore they need to be subsidized. However a closer examination of the fund flow in the public transport systems reveals an anomalous situation. The public transport systems are heavily taxed. These taxes are in the form of tax VAT on the purchase of buses, taxes on fuels, other levies imposed by the provincial governments etc. if all these are added up they constitute a significant part of the cost of operations. In India it is estimated that all the losses of the public transport utilities put together stands at about 20% of their gross income and on the other hand the total burden of taxes is to the extent of 20% of the total costs. This is indeed an anomalous situation that on the one hand the public transport systems are taxed heavily and on the other they are subsidized.

6.0 INTERNALISING THE EXTERNALITIES

The user charge mechanism can be a good instrument to internalize the externalities caused by the car users. This would mean that road usage levies if appropriately fixed could subsume the levies to internalize the externalities. The economics of internalizing the externalities could very well be explained by the diagram in figure 1. The curve CD represents the marginal cost curve of the car user, and the curve CE represents the marginal total costs (including the social costs the car user imposes on the system). Without any additional levy the equilibrium will be struck at point M. But the desirable equilibrium is at point N. Therefore there has to be an additional levy on the car user such that his marginal costs curves shifts upwards and coincides with curve CE.

7.0 MODALITIES FOR LEVY OF USER CHARGES

An efficient way of reducing the urban traffic would be a system which calculates the toll for each trip on a kilometre basis. Earlier such systems were not possible but with the rapid advances of Information Technology such systems are possible. Use of SMART cards, Radio Frequency Technologies etc. in conjunction with reading/writing devices installed at vantage points could perform this task. Adoption of these technologies by the developing countries would take some more time. Meanwhile alternate methodologies for levying road usage charges could be worked out.

7.1 Fuel tax as a substitute for user charges

There are both Central and State levies on vehicle fuels. Of the total price of fuel the levies account for 25 to 35% of the price. Although the purpose of such taxes is to mobilise revenue for the government, taxes on fuel directly impact the vehicle usage cost and therefore could be a potent tool for controlling road space usage. As the fuel consumed is also proportional to the pollution generated as well as the size of the vehicle such taxes would bring in an element of equity.
There are some problems associated with the use of fuel taxes as a substitute of road usage charges. Road usage charges should be dependent on the demand for road usage and the extent to which it needs to be controlled. This varies from road to road and even has diurnal variations. Moreover there are certain essential services vehicles which should not be charged the road usage charges. Even the public transport vehicles should not be charged the road usage charges. The fuel tax does not distinguish between the different types of road users and to that extent treats all vehicles uniformly at the cost of equity. However there could be mechanisms where the essential services vehicles could be exempted from the levy of fuel tax or the fuel tax paid by them could be reimbursed later. It is important to note that the high rate of various taxes are one of the important reasons for the financial non-viability of public transport systems in India. Besides, as compared to other modes of transport, the levies on the public transport system are quite inequitable.

8.0 CAPTURING OTHER STREAMS OF REVENUES

Transport activity can generate many streams of revenue apart from the fare box revenue. These streams can be grouped into the following major categories:

a. Revenue from increased value of land in the vicinity - betterment levy and impact fees.
b. Non traffic revenue from buses
   i. Advertisement revenue.
   ii. Parcel and freight services.
   iii. Lease from properties like bus stands.
   iv. Provision of certain value added services.
c. Traffic related fines and penalties
d. Realistic parking charges.
e. Pollution related levies.
f. Revenues from roadside facilities

At present in most cities the abovementioned streams exist but are collected and appropriated by different agencies resulting in a very sub optimal situation. Therefore it is very much necessary that convergence is achieved among all these revenue streams.

9.0 INTEGRATING THE FUNDING SYSTEM THROUGH CREATION OF A FUND

The traditional approach has been that urban public transport is the responsibility of the bus company which operates buses in the city. Apart from running the buses or trains, provisioning of urban public transport requires planning and providing for roads, regulating traffic on roads, arranging for support infrastructure like pedestrian facilities, planning and managing complementary modes of transport - bicycles, para-transit modes, parking etc., managing the demand for public transport, use of appropriate financial tools to ensure that public transport systems are affordable on the one hand and viable on the other and above all ensuring that the long term city development plan and the transportation plan converge. All these activities are undertaken by a multitude of independent agencies (Table 2).

The fragmented responsibilities come in the way of financial integration. So far the funding of the road infrastructure and the funding of the public transport buses has been dealt with as two separate activities. At the city level for best results the two should be treated as an integrated activity. This integration could be achieved through the mechanism of creation of a city transport fund. All proceeds from the transport related activities should be credited to this fund. A study by Wilbur Smith Associates has come to a conclusion that urban transport needs a huge investment and has recommended the establishment of a dedicated transport fund.
Table 2: Multiplicity of authorities dealing with transport in Indian cities

<table>
<thead>
<tr>
<th>S.No</th>
<th>Cities</th>
<th>Delhi</th>
<th>Bengaluru</th>
<th>Mumbai</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Overall responsibility for public transport</td>
<td>Union Govt. as well as State Govt.</td>
<td>State Govt.</td>
<td>Municipal Govt.</td>
</tr>
<tr>
<td>2</td>
<td>Traffic regulation</td>
<td>Delhi Police</td>
<td>Bengaluru Police</td>
<td>Mumbai Police</td>
</tr>
<tr>
<td>4</td>
<td>City planning</td>
<td>Delhi Development Authority</td>
<td>Bangalore Development Authority</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Construction of roads and maintenance</td>
<td>Municipal Corporation of Delhi, New Delhi Municipal Committee, Delhi Development Authority</td>
<td>Municipal Corporation of Bengaluru, State Public Works Department, Bengaluru Development Authority</td>
<td>Municipal Corporation of Mumbai</td>
</tr>
<tr>
<td>6</td>
<td>City planning</td>
<td>Delhi Development Authority</td>
<td>Bengaluru Development Authority</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Fiscal policies</td>
<td>Union and State Govt.</td>
<td>Union and State Govt.</td>
<td>Union and State Govt.</td>
</tr>
<tr>
<td>8</td>
<td>Travel demand management</td>
<td>No specified agency</td>
<td>No specified agency</td>
<td>No specified agency</td>
</tr>
</tbody>
</table>

10.0 THE WAY AHEAD

The above analysis leads to several findings and remedial actions as listed below:

a. There are many streams of revenue flow from the urban transport sector. These include revenues from the road infrastructure as well as revenue streams from the public transport system. In order to adopt a holistic approach for funding of the transport system in a city all these revenue streams should be converged into a single fund.

b. Tax on fuel should be so adjusted that it comes close to road usage charges. To start with, adjusting fuel taxes and subsuming the other taxes on transport into fuel taxes could be good first step. The fuel tax paid by the public transport vehicles should be reimbursed to them.

c. Economic principles dictate that ultimately the tax streams should be substituted by a charge on road usage. The road usage charges should be fixed in a way that they ensure adequate revenues for the government to at least fund the transport sector on the one hand and represent a fair price to the road users so as to optimize the usage of road space on the other.

d. All revenue streams from transport should be converged into a fund to be used for development of transport activities.

e. Public transport systems should be freed from the tax burden and also no road usage charge to be levied on them.

f. The multiplicity of agency which exists at present at the city level with each agency dealing with only aspect of the transport system should be subsumes into an integrated transport agency. This agency would undertake urban transport planning, supervise regulation and lay down principles for transport funding.
11.0 SCOPE FOR FURTHER STUDY

The paper establishes the need for levying a road usage charge, following the economics principles. A more rigorous analysis could be done with actual data from a city to drive home the principle. Further studies are also possible on how to have a variable tax on fuels which could substitute for actual levy of road usage charges. Although Electronic Road Pricing (ERP) systems have the capability of levying road usage charges at varying rates on different roads, these devices are expensive and their widespread use, especially in developing countries, would take some more time. Further research is possible to evolve affordable mechanisms to collect road usage charges.

12.0 CONCLUSIONS

This paper concludes that road usage charges, if levied, serve dual purposes - one of mobilizing resources for the city government and two to regulate the number of vehicles on roads. It has also been established that taxes on ownership of vehicles, though bringing substantial revenues, do not have any impact on the demand for vehicle use. Therefore it has been concluded that ownership based taxes should be replaced by usage based levies.

The most important conclusion that emerges from the analysis in this paper is that funding of road infrastructure as well as funding of public transport systems should not be viewed as two distinct activities as there is an integral link between the two. Therefore it has been suggested that the surplus generated in the road infrastructure sector should be used to fund the public transport system. Last but not the least, there is a need to converge all the revenue streams as also to subsume all the different agencies under one agency which in turn would do planning for transport, supervise regulation of transport activities and lay down principles of funding the transport activity.

References


Delhi on the move. 2005. Future Traffic Management Scenarios. TRIPP, Indian Institute of Technology, Delhi India

Abstract

Research attempts on time headways have focused mainly on light and heavy-tailed distributions such as exponential, Gamma, Erlang, lognormal and weibull. The problem with these distributions is that they do not provide a good fit in right tail region. It is very important to model tail data effectively, as tails contain significant proportion of data. In addition to this, researchers have mainly employed Chi-square and Kolmogorov-Smirnov goodness-of-fit tests. Both of the tests have discrepancies viz. Chi-square test is distribution free and Kolmogorov-Smirnov test is based on one point deviation. Therefore in this paper power law based distributions have been proposed as they offer better tail fit than light and heavy tailed distribution. Two robust goodness-of-fit tests namely Cramer-Von Mises and Anderson-Darling and three penalty functions Schwarz, Akaike and Hanna-Quinn information Criteria's are used to evaluate fit of distributions. A multi-level strategy for selection of the distribution with best fit based on combination of above tests penalty functions is proposed. It was found from the study that time headways follow power law. Pareto-2 distribution was found to model time headway data in all the three regions(lower left tail, middle portion and right tail) up to a flow level of 1500 vph better than all the other distributions statistically and none of the singular probability distribution offers a better fit in higher flow ranges above and around 1900vph.

Key Words: Power law, Pareto-2, Extreme value, Penalty function, Cramer-Von Mises test

1.0 INTRODUCTION

Vehicular time headway is a vital factor in the determination of level of service, roadway capacity and many more traffic characteristics such as safety, signal time adjustment etc. It is the basic building block of simulation model as it serves the purpose of generation of vehicle.In this context, the present study focuses on accurate modeling of time headways under heterogeneous traffic condition.

Several researchers have attempted to fit the time headway into suitable probability distributions, both under homogeneous and heterogeneous traffic conditions. A review of literature shows that mostly probability distributions such as exponential distribution, normal distribution, log-normal distribution, Gamma distribution and Erlang distribution which are either light-tailed or heavy tailed have been used to model time headways. These distributions though offer a good fit in the middle region, do not do so in tail regions. Previous research has not been oriented in this direction as none of the researchers have performed tail fit test say for example, Anderson-Darling goodness-of-fit test. To overcome this problem few researchers have tried power law based analysis taking inspiration from computer networks, where a lot of work has been done on data-pocket inter arrival time modeling (Ulanovs and Petersons, 2002; Willinger and Paxson, 1998).In spite of availability of large volume of research literature in the field of time headways, there are some issues which are yet to be addressed.

1. Firstly, very few researchers have examined power law form of traffic pattern, but none of the author has proposed any distributions for the same.
2. Secondly, research attempts have confined themselves to either Chi-square or Kolmogorov-Smirnov (K-S) goodness-of-fit tests. Both the tests have some inherent discrepancies, which may lead to false observations. Chi-square goodness-of-fit test is a distribution free test, i.e., its critical values do not depend upon the distribution being tested. Kolmogorov-Smirnov test is based on the greatest difference between the empirical and theoretical cumulative distribution function (CDF). Therefore there is a possibility of a distribution being declared unfit when the greatest difference at a certain point is more than its critical value, regardless of its good fit at other data points.

3. Finally, none of the authors have examined the nature of fitted distribution particularly in the right tail region. Usually, the data in the right tail is merged with the upper level bins or have been considered insignificant. Also, none of the authors have performed Anderson-Darling test for testing of distribution fit in tail region.

Therefore to address these discrepancies, this paper makes an attempt to thoroughly examine time headways with the help of advance models and tests for accurate overall modeling.

2.0 LITERATURE REVIEW

Headway distributions have been an area where an extensive research has been carried out. Many researchers have proposed light tailed distributions for modeling time headways. Katti and Pathak (1985) proposed negative exponential for a flow level less than 500 vehicle per hour (vph) and shifted negative exponential for flows between 500 vph and 1000 vph. Kumar and Rao (1998) studied negative exponential distribution for flow ranges varying from low to moderate levels. Al-Ghamdi (2001) proposed exponential, shifted exponential and Erlang distributions, established boundaries of flow such as low traffic (less than 400 vph), medium traffic (400 to 1200 vph) and high traffic (more than 1200 vph) and conducted chi-square goodness-of-fit test. Arasan and Koshy (2003) found that negative exponential distribution fits well for all the traffic flow ranges under heterogeneous flow conditions based on chi-square goodness-of-fit test.

Many people have proposed heavy tailed distributions for medium to higher flow ranges as it gives better fit than any light tailed distributions in these ranges. Ramanayya (1980) found exponential, shifted exponential and lognormal fit well for the flow levels less than 500 vph, 500 to 650 vph and more than 650 vph respectively. Yin et. al (2009) modeled time headway data for peak and non peak hour at two lane and three lane road. They found lognormal distribution better under non peak hour and log logistic distribution under peak hour based on Kolmogorov-Smirnov goodness-of-fit test.

Some researchers have studied power law form of traffic flow pattern. Meng and Khoo (2009) found traffic pattern to be self similar and proposed time headway data to follow power law than exponential distribution. Helbing and Tilch (2009) studied "high flow states" in freeway traffic and found them to follow power law. Kanagaraj et. al (2011) studied the class-wise distribution of time headways under heterogeneous condition and proposed generalized extreme value distribution for higher flow rates based on two sample Kolmogorov-Smirnov test.

A review of literature on headways clearly shows that both light tailed and heavy tailed distributions offer a good fit to headway data only when the data in the right tail is condensed or merged with higher class intervals. Such a loss of information can be prevented if power law based distributions would be used which has been one of the main objectives of this paper.
3.0 DATA COLLECTION

Vehicular time headway data were collected from two locations in India: one on a rural highway near Bangalore city and the other on an urban arterial in the city of Chennai. The first set of observation was made on the National Highway (NH) 48, starting from Bangalore to Mangalore (southern part of India), for 7 consecutive days. The second set of observation was made on Anna salai, Chennai. Both the stretches are four-lane divided carriageways with a width of 7.5 m in one direction. The whole width of the carriageway was used to collect inter arrival times of vehicles, since there is no strict enforcement of lane-based driving in India. A video camera was mounted on the roadside, opposite to the reference point to capture the moving traffic continuously across the reference point. The video-captured traffic data, for each of the flow levels was transferred to computer to extract the required time headway data of vehicles. The video of traffic flow was played in the computer, using software known as AVIDEMUX, at 0.125 times the actual speed, which facilitated observation of vehicle arrivals in a convenient manner. The time headway (time gap between successive vehicle arrivals at the reference point) was noted considering the entire width of the road. The slow-motion-headway (0.125 times the actual speed) values were then divided by 8 to obtain the actual time headways in milliseconds. This method facilitates easy and accurate extraction of headway data pertaining to the observed traffic-flow conditions.

4.0 POWER LAW

A power law is a special kind of mathematical relationship between two quantities. When the frequency of an event varies as a power of some attribute of that event (e.g., its size), the frequency is said to follow a power law. When a histogram of the data plotted on logarithmic horizontal and vertical axes (log-log scale) can be approximated using a straight line equation, then it is said to follow a power law.

The power law distributions are heavy tailed distributions and are capable of modeling data in tail region with higher accuracy as compared to the distributions which follow central limit theorem and Markovian process (Asmussen, 2003). To examine whether the time headway data follow a power law or not, based on linear form as mentioned in equation 1, rank frequency plot of the observed headway data for a flow range of 550 vph to 4100 vph are plotted on log-log scale. The graphs for different volume levels are shown below in Figure 1.

![Figure 1: Rank frequency plot of time headway on log-log scale](image-url)

(a) Flow level: 1020 vph  
(b) Flow level: 4100 vph
From figures 1(a) and 1(b), it can be noted that the data points plotted on the log-log scale follow a linear form. Similar observations were found for flow range 550 vph, 1473 vph and 1959 vph. So it can be concluded that time headway data collected under heterogeneous for different traffic volume follow a power law.

5.0 GOODNESS-OF-FIT TESTS

Goodness of fit tests can be classified into two class; tests which are based on probability density function (PDF) and tests based on cumulative distribution function (CDF). The Chi-square test is based on PDF, whereas Kolmogorov-Smirnov (K-S), Cramer-Von Mises and Anderson-darling tests are based on CDF. Detailed description of each test along with their merits and demerits are explained below in different sections.

5.1 Kolmogorov-Smirnov test:
The K-S test is a CDF based test and known as "distance test". The K-S statistics is defined as equation 1.

\[ D = \text{Maximum of all } D^+ \text{ and } D^- (\ ? 0); \text{ for } i = 1,\ldots, n \]  

Where \( D^+ = F_n - F_0 \) and \( D^- = F_0 - F_{n-1} \) for every data point \( X_i \). 

\( F_n \) is empirical CDF and \( F_0 \) is theoretical CDF.

It may happen that for a same data set, a particular distributions theoretical CDF closely follow empirical CDF for most of the data point except at few points. Then, as per K-S test the maximum deviation will be reported and considered for selection of distribution. Furthermore it may also happen for the same data set that other distributions theoretical CDF does not follow closely the empirical CDF for most of the data points, but its maximum deviation is less as compare to first case. So as per K-S test second distribution will be chosen. For example consider the case of figure 2. Theoretical distribution closely follow empirical distribution except at point 'A' and 'B' and if deviation at this point is more than critical value, then distribution will be discarded regardless of its good overall fit. Hence, it is very clear that K-S test does not take into account overall fit and could be misleading in some cases. A better solution to this problem will be to conduct some test which account over all deviation, integrates it and gives a final result so that better decisions can be made regarding selection of distributions.

5.2 Cramer-Von Mises test

This test is also based on CDF. It is very much similar to K-S test except the fact that instead of maximum deviation, it makes use of overall deviation by integrating the area between theoretical CDF and Empirical CDF (Shaded area as shown in figure 2). The test statistic

Figure 2: Graph of empirical and theoretical CDF
is defined as equation 2.

\[ \omega^2 = \int_{-\infty}^{\infty} [F_n(x) - F^*(x)]^2 dF^*(x) \]  \hspace{1cm} (2)

Where \( \omega^2 \) = Cramer-Von Mises statistic value

\( F_n(x) \) = Empirical CDF

\( F^*(x) \) = Theoretical probability distribution CDF

This statistic will be reduced to following form for one sample test

\[ \omega^2 = \frac{1}{12n} + \sum_{i=1}^{n} \left\{ \frac{2i-1}{2n} - F(x_i) \right\}^2 \]  \hspace{1cm} (3)

From figure 2, it is clear that Cramer-Von Mises test takes into account the total deviation and hence, can be considered as the best goodness-of-fit test.

5.3 Anderson-Darling (A-D) test

A-D test is also a CDF based test and is considered as one of the robust test among all known goodness-of-fit test. It is distribution specific test which assign more weightage to tail. The critical value of A-D statistics depends upon the particular distribution being considered. It is not possible to explain the statistics for all the distributions. A particular case for log-normal distribution is shown below as one example.

\[ AD = \sum_{i=1}^{n} \frac{1-2i}{n} \left\{ \ln(F_o[z_i]) + \ln(1 - F_o[z_{n+1-i}]) \right\} - n \]  \hspace{1cm} (4)

Where AD= Anderson-Darling statistic value

\( F_o \) = Log- Normal Distribution

\( Z_i \) = Sorted log-standarize values

Since A-D test is mainly used to evaluate the fit of distribution in the tail region, it may not be solely used as a single judging criteria for selecting the most suitable distribution. It may be better to use it as complementary to Cramer-Von Mises test.

5.4 Schwarz Information criteria (SIC)

SIC is mainly known as a penalty function, which takes in- to accounts number of parameter to be estimated and maximum likelihood value to check for over fit. The SIC statistics (Schwarz, 1978) is defined as equation 5.

\[ SIC = k \ln(n) - 2 \ln(L_{\text{max}}) \]  \hspace{1cm} (6)

Where, \( n \) = number of observation

\( K \) = number of parameters to be estimated

\( L_{\text{max}} \) = maximized value of likelihood function for estimated probability-distribution

While modeling data, it is possible to increase the likelihood by adding parameters, but doing so may result in over fitting. The SIC resolves this problem by introducing a penalty term to represent the number of parameters used in the model. SIC is the most strict penalty function. Hence, lower value of SIC implies either fewer explanatory variables, better fit, or both. Akaike Information criteria (AIC) (Akaike, 1974) and Hannan-Quinn Information criteria (HQIC)(Hannan and Quinn, 1979)penalty functions are also similar in all respects to SIC except for the fact that they are lesser strict in applying penalty.

6.0 FORMULATION OF A STRATEGY FOR SELECTION OF DISTRIBUTION

Based on merits and demerits pertaining to different goodness-of-fit tests and penalty functions, it can be inferred that a single independent criteria/test for selection of the best fitted distribution may not be appropriate. Hence, based on these facts a strategy comprising of hierarchy of steps for the selection of the best distribution is devised as follows:

**Step 1:** Perform Cramer-Von Mises goodness-of-fit test for the given distributions and select the distributions for the next step, which satisfy this test.
Step 2: Perform Anderson-Darling (AD) goodness-of-fit test for distributions selected from step 1 to evaluate the fit in the tail region. Select the distributions, which satisfy this test.

Step 3: Apply all three penalty functions (SIC, AIC and HQIC) for the selected distributions from step 2.

Step 4: Finally, select the distribution, which has minimum penalty value among all three information criteria. If penalty values of distributions are very close to each other, select the distribution based on better overall fit (lowest C-V-Modified) and tail fit (lowest A-D statistics value). In the case, when two or more distributions qualified after step 3 with very close C-V-Modified and A-D values, trade-off can be made.

7.0 DATA ANALYSIS AND RESULTS

For accomplishing the objectives of the present study, nine different distributions, namely, negative exponential, Gamma, Weibull, Lognormal, Erlang, Pareto-2, Extreme Value minimum, Extreme value maximum and Log-logistic were used to fit the headway data, extracted for varying flow levels. The statistical validity of each of the models were tested using the strategy developed above.

The statistics for different tests and penalty functions for all nine distributions over different flow levels are depicted in Tables 1 through 3.

### Table 1: Results of Goodness-of-fit tests for traffic flow of 550 vph

<table>
<thead>
<tr>
<th>Distribution</th>
<th>C-V</th>
<th>K-S</th>
<th>A-D</th>
<th>SIC</th>
<th>AIC</th>
<th>HQIC</th>
<th>C-V-M</th>
<th>A-D critical</th>
<th>AD*</th>
<th>OSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td>0.07</td>
<td>0.03</td>
<td>0.54</td>
<td>3138.58</td>
<td>3134.27</td>
<td>3135.95</td>
<td>0.07</td>
<td>0.54</td>
<td>0.54</td>
<td>0.17</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.09</td>
<td>0.03</td>
<td>0.51</td>
<td>3143.73</td>
<td>3135.14</td>
<td>3138.48</td>
<td>0.09</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weibull</td>
<td>0.09</td>
<td>0.03</td>
<td>0.52</td>
<td>3144.17</td>
<td>3135.57</td>
<td>3138.92</td>
<td>0.09</td>
<td>0.53</td>
<td>0.53</td>
<td>0.19</td>
</tr>
<tr>
<td>Pareto-2</td>
<td>0.06</td>
<td>0.03</td>
<td>0.50</td>
<td>3144.89</td>
<td>3136.29</td>
<td>3139.63</td>
<td>0.06</td>
<td>2.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erlang</td>
<td>0.07</td>
<td>0.03</td>
<td>0.54</td>
<td>3146.76</td>
<td>3138.16</td>
<td>3139.63</td>
<td>0.07</td>
<td>0.54</td>
<td>0.54</td>
<td>0.17</td>
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<tr>
<td>Log-logistic</td>
<td>0.21</td>
<td>0.05</td>
<td>2.55</td>
<td>3196.47</td>
<td>3187.87</td>
<td>3191.22</td>
<td>0.21</td>
<td>0.66</td>
<td>2.55</td>
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<tr>
<td>Log-normal</td>
<td>0.63</td>
<td>0.05</td>
<td>4.30</td>
<td>3214.88</td>
<td>3206.28</td>
<td>3209.62</td>
<td>0.63</td>
<td>0.75</td>
<td></td>
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</tr>
<tr>
<td>EV#-Max</td>
<td>0.31</td>
<td>0.04</td>
<td>2.27</td>
<td>3328.80</td>
<td>3320.21</td>
<td>3323.55</td>
<td>0.31</td>
<td>0.76</td>
<td>2.29</td>
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</tr>
<tr>
<td>EV-Min</td>
<td>9.55</td>
<td>0.28</td>
<td>52.32</td>
<td>3949.40</td>
<td>3944.14</td>
<td>3944.14</td>
<td>9.57</td>
<td>0.76</td>
<td>52.77</td>
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### Table 2: Results of Goodness-of-fit tests for traffic flow of 1479 vph

<table>
<thead>
<tr>
<th>Distribution</th>
<th>C-V</th>
<th>K-S</th>
<th>A-D</th>
<th>SIC</th>
<th>AIC</th>
<th>HQIC</th>
<th>C-V-M</th>
<th>A-D critical</th>
<th>AD*</th>
<th>OSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td>0.34</td>
<td>0.05</td>
<td>2.14</td>
<td>5577.21</td>
<td>5571.92</td>
<td>5573.89</td>
<td>0.34</td>
<td>2.15</td>
<td>0.00</td>
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</tr>
<tr>
<td>Gamma</td>
<td>0.39</td>
<td>0.04</td>
<td>2.11</td>
<td>5582.64</td>
<td>5572.06</td>
<td>5576.00</td>
<td>0.39</td>
<td>0.75</td>
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</tr>
<tr>
<td>Weibull</td>
<td>0.36</td>
<td>0.05</td>
<td>2.12</td>
<td>5584.24</td>
<td>5573.66</td>
<td>5577.60</td>
<td>0.36</td>
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</tr>
<tr>
<td>Pareto-2</td>
<td>0.26</td>
<td>0.06</td>
<td>2.21</td>
<td>5582.49</td>
<td>5571.91</td>
<td>5575.85</td>
<td>0.26</td>
<td>2.49</td>
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<td></td>
</tr>
<tr>
<td>Erlang</td>
<td>0.34</td>
<td>0.05</td>
<td>2.14</td>
<td>5587.50</td>
<td>5576.92</td>
<td>5580.87</td>
<td>0.34</td>
<td>2.15</td>
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<tr>
<td>Log-logistic</td>
<td>0.43</td>
<td>0.04</td>
<td>5.75</td>
<td>5683.14</td>
<td>5672.56</td>
<td>5676.50</td>
<td>0.43</td>
<td>0.66</td>
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<tr>
<td>Log-normal</td>
<td>1.51</td>
<td>0.05</td>
<td>10.85</td>
<td>5727.32</td>
<td>5716.74</td>
<td>5720.66</td>
<td>1.52</td>
<td>0.75</td>
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</tr>
<tr>
<td>EV#-Max</td>
<td>0.63</td>
<td>0.04</td>
<td>4.61</td>
<td>6103.50</td>
<td>6092.93</td>
<td>6096.87</td>
<td>0.63</td>
<td>0.76</td>
<td>4.63</td>
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<tr>
<td>EV-Min</td>
<td>33.33</td>
<td>0.32</td>
<td>178.99</td>
<td>8180.54</td>
<td>8169.96</td>
<td>8173.90</td>
<td>33.35</td>
<td>0.76</td>
<td>179.93</td>
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</table>
Table 3: Results of Goodness-of-fit tests for traffic flow of 1959 vph

<table>
<thead>
<tr>
<th>Distribution</th>
<th>C-V</th>
<th>K-S</th>
<th>A-D</th>
<th>SIC</th>
<th>AIC</th>
<th>HQIC</th>
<th>C-V-M</th>
<th>A-D critical</th>
<th>AD*</th>
<th>OSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td>2.49</td>
<td>0.07</td>
<td>13.84</td>
<td>3514.71</td>
<td>3509.13</td>
<td>3511.18</td>
<td>2.49</td>
<td>13.90</td>
<td>0.00</td>
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</tr>
<tr>
<td>Gamma</td>
<td>2.34</td>
<td>0.07</td>
<td>13.28</td>
<td>3518.96</td>
<td>3507.80</td>
<td>3511.90</td>
<td>2.35</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weibull</td>
<td>2.22</td>
<td>0.06</td>
<td>13.00</td>
<td>3501.09</td>
<td>3489.94</td>
<td>3494.03</td>
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<td></td>
</tr>
<tr>
<td>Pareto2</td>
<td>1.70</td>
<td>0.07</td>
<td>11.48</td>
<td>3426.15</td>
<td>3415.00</td>
<td>3419.09</td>
<td>1.70</td>
<td>2.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erlang</td>
<td>12.40</td>
<td>0.28</td>
<td>38.26</td>
<td>3527.24</td>
<td>3516.09</td>
<td>3520.19</td>
<td>12.41</td>
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</tr>
<tr>
<td>Log-logistic</td>
<td>1.33</td>
<td>0.05</td>
<td>11.65</td>
<td>3471.21</td>
<td>3460.06</td>
<td>3464.15</td>
<td>1.33</td>
<td>0.66</td>
<td>11.65</td>
<td></td>
</tr>
<tr>
<td>Log-normal</td>
<td>3.74</td>
<td>0.09</td>
<td>21.20</td>
<td>3528.59</td>
<td>3517.44</td>
<td>3521.53</td>
<td>3.75</td>
<td>0.75</td>
<td></td>
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</tr>
<tr>
<td>EV#-Max</td>
<td>0.77</td>
<td>0.05</td>
<td>5.61</td>
<td>4376.05</td>
<td>4364.90</td>
<td>4368.99</td>
<td>0.77</td>
<td>0.76</td>
<td>5.64</td>
<td></td>
</tr>
<tr>
<td>EV-Min</td>
<td>85.64</td>
<td>0.43</td>
<td>422.12</td>
<td>9081.09</td>
<td>9069.93</td>
<td>9074.03</td>
<td>85.68</td>
<td>0.76</td>
<td>424.03</td>
<td></td>
</tr>
</tbody>
</table>

Note: C-V: Cramer-Von Mises statistic; K-S: Kolmogorov-Smirnov statistics; A-D: Anderson-Darling statistics; SIC: Schwarz information criteria; AIC: Akaike information criteria; HQIC: Hannan-Quinn information criteria; C-V-M: Modified Cramer value; AD*: Modified AD value; OSL: Observed significance level.

7.1 Interpretation of results:

A brief description is given below to help readers understand interpretation of various tests and how to apply these tests to evaluate the fit of distributions.

1. The critical value for Cramer-Von Mises test at 5% significance level is 0.461. The critical values for the K-S test are 0.0456, 0.034, 0.028, 0.024 and 0.017 respectively for 550, 1020, 1479, 1959 and 4100 vph.

2. In the case of Cramer-von Mises test, the modified Cramer values have been obtained using Cramer-Von Mises statistic as suggested by Stephens (1970) and compared against the critical value for evaluation of distribution fit.

3. In the present study, the parameters of all distributions were estimated using observed data; hence an adaptiv KS test procedure was used. As per this adaptive KS test procedure, the test was conducted at a significance level of significance (?) of 0.05 but KS statistics were compared with the critical value at a level of significance ? = 4*? = 4*0.05 = 0.2 (Romeu, 2003).

4. In the case of A-D test each distribution has its unique way of determining statistics value. The detailed and comprehensive analysis can be found in (Romeu, 2003; D'Agostino, 1986; Arshad et. al, 2003). For distributions which have been used in this paper, a general discussion is presented which is as follows. Exponential and Weibull distributions are evaluated based on observed significance level (OSL). If OSL is more than 0.05, the distribution is said to be statistically significant. Gamma, Pareto-2, Erlang and Lognormal distributions have been evaluated directly by comparing calculated A-D statistic value against their corresponding critical values. Finally Log logistic and Extreme value distributions are evaluated by calculating modified A-D value (AD*). If AD* is less than AD critical value distribution, is said to be significant (D'Agostino, 1986).

8.0 DISCUSSIONS

All the fitted distributions are evaluated for their fit at various flow levels as per the strategy formulated for choosing the best-fit distribution. In the case of flow level 550 vph (Table 1), Exponential, Gamma, Weibull, Pareto-2, Erlang, Extreme value maximum and Log logistic distributions are selected in step 1, as they satisfy the Cramer test. All these distributions selected from step 1 qualify for step 3, as they satisfy A-D test criteria. In step 3, the distribution with minimum penalty among
three information criteria will be chosen as the best fit distribution and hence exponential distribution is selected as the best fit distribution. Whereas a closer look at both goodness-of-fit tests reveals that Pareto-2 has better overall fit as per Cramer test and better tail fit as per A-D test. In addition to this, penalty value difference between these two distributions is also not too high. So, one can choose Pareto-2 distribution as the best distribution for a flow level of 550 vph. It is also worth mentioning that one can chose other distribution based on the interest, as these tests and penalty functions offers lot of flexibility. Similar observations were made for flow levels of 1020 vph and 1479 vph where Pareto-2 was found to be the best-fit distribution.

The lacuna (single point deviation calculation) pertaining to K-S test as mentioned earlier can be observed from distributions statistic value. In the case of 550 vph flow level, K-S test discards log-logistic and lognormal distribution (calculated K-S value is more than critical value) whereas Cramer-Von Mises test approves it. So K-S test results could be misleading in some cases and hence may be ignored. It is also very important to show the differences on final result based on the adaptive K-S test. It must be used, when distribution parameters are derived from the data set, otherwise it may lead to false result, which can be witnessed by referring Table 1. For the flow level of 550 vph, lognormal distribution has calculated K-S value 0.05. As per adaptive K-S test, critical value is 0.04, which indicates that lognormal is not able to model data. If normal K-S test is applied, critical value will be 0.057 and hence lognormal distribution can pass goodness-of-fit test. Hence, it is very important to use appropriate kind of test based on situation at hand.

For the flow levels of 1959 and higher, no distribution satisfies the formulated strategy and hence, no distribution may be applicable to be chosen as the best fit distribution.

9.0 FINDINGS

Following are the important findings of study:

1. Vehicular time headway data under heterogeneous traffic conditions follow a power law. It indicates that traffic has long term memory dependence in contrast to no memory associated with central limit theorem and Markovian process.

2. Cramer-Von Mises test is better as compared to the Kolmogorov-Smirnov test, as it accounts for the total deviation rather than one point maximum deviation. Anderson-Darling test is better for testing the fit of distribution in the tail region. Three penalties namely Schwarz, Akaike and Hannan-Quinn information criteria helps in preventing against over-fitting.

3. The strategy formulated for selection of the best-fit distribution is comprehensive as it accounts for each of the aspects of fit. Cramer-Von Mises test checks overall fit, Anderson-Darling test checks tail region fit and finally penalty functions checks over fitting of distributions.

4. Pareto-2 distribution proves to be better than any other distribution in modeling time headway data up to a flow range of 1500 vph (lower volume levels). No distribution is significant around or over a flow level of 1950 vph (higher volume levels), although Extreme value maximum distribution is comparatively better than other distributions. So it can be concluded that no singular model distribution is capable of modeling time headway above and around 1950 vph and hence composite distributions should be utilized.
References


Abstract

The use of recycled Hot Mix Asphalt (HMA) is the non-conventional way to rehabilitate the flexible pavements. However, there are energy consumption concerns, because of an extra heating unit to effectively blend the recycled materials.

To analyse and compare the environmental impacts of road rehabilitation techniques, quantitative method, Life Cycle Assessment (LCA) has been used.

This study performed life cycle inventory of both traditional and recycling methods to evaluate the eco-burden presented. The results can provide a foundation for choosing least eco-burdened rehabilitation technique for flexible pavements.

It is observed that by using Hot In Place Recycling(HIPR), the environmental impacts can be reduced by 45% to 55%. If this technology is adopted for rehabilitation of major arterial roads of Delhi, the energy use can be reduced up to 586 million MJ, while CO2 emissions can be mitigated by 31 thousand tons, conserving water by 606 thousand kilo litres, along with a saving of INR 162 million, in next three to seven years.

**Key Words:** Environmental impact, road rehabilitation, carbon footprint, hot in place recycling, GHG emission.

1.0 INTRODUCTION

Increasing energy cost and environmental concerns have encouraged the development of using pollution free, recyclable engineering materials that consume less energy to manufacture. Generally there is a vast amount of materials used in rehabilitating a roadway.

The use of recycled HMA is the non-conventional way to rehabilitate the flexible pavements. There are energy consumption concerns regarding the use of the recycling because an extra heating unit has to be installed to effectively blend the recycled materials. Presently, several models and systems for assessing environmental impacts of road construction have been developed. However, most of the models are subjective, which make it difficult to provide in-depth and comparable results. In addition, they often serve as post-construction evaluation tools for determining the acceptance of completed work rather than pre-construction evaluation tools to support decision-makers.

Thus, quantitative methods, such as life cycle assessment (LCA), are increasingly being used to analyse the environmental impact of road construction activities, help decision-makers identify major environmental impact factors and make environmentally friendly construction plans in the early stages of construction. This paper presents a general framework for integrated life cycle assessment of environmental impact for road rehabilitation and applies it to the reconstruction phase for a particular road stretch in New Delhi. This study
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intends to perform life cycle inventory of both traditional and recycling methods to evaluate the eco-burden presented. The results can provide a foundation for decision making regarding the choice of least eco-burdened rehabilitation technique for flexible pavements.

2.0 OBJECTIVES OF THE STUDY

- Identifying and quantifying the life cycle inventories involved in the process of different technologies of bituminous road resurfacing.
- Studying the environmental impacts of these inventories.
- Quantifying the savings on eco-burdens with conventional versus Hot Recycling Technique.
- Assessing the energy and eco burden saving on account of an informed decision regarding technologies to be used for bituminous road resurfacing on the roads of Delhi city.

3.0 GOAL

The goal of the study is to come up with a methodology for life cycle assessments of road reconstruction. Also

- to identify and quantify the sub-components which describe a road reconstruction process.
- to design a model structure for the road reconstruction process based on the identified sub-components.
- to simulate a road reconstruction process on LCA software, for assessment of eco-burdens.

4.0 SCOPE OF THE STUDY

- The scope of the study is limited to the rehabilitation of bituminous roads by conventional and HIPR technologies.
- Projects at two different locations in Delhi shall be taken up as case study.
- The functional unit has been kept as per kilometre lane length of road.
- The processes involved have been shown in the flow diagram.
- The eco-burden comparison between technologies shall also be performed.

5.0 BACKGROUND AND LITERATURE REVIEW

An extensive literature review was carried first to understand the concept of Life Cycle Assessment and Hot in Place Recycling technology of rehabilitation of bituminous roads. The process of setting up an LCA model was generalised and charted out from the various research papers, reports etc. The review was then streamlined to construction related literature where the various stages and processes involved in road rehabilitation were identified. From similar LCA studies done around the world and coordinating with Indian literature, process identification was carried out. A software PaLATE (Pavement Life-cycle Assessment Tool for Environmental and Economic Effects) was also identified for carrying out the LCA.

The following is a summary of the various concepts picked up and their application to the given problem.

6.0 LIFE CYCLE ASSESSMENT

The goal of LCA is to compare the full range of environmental damages assignable to products and services and to be able to choose the least burdensome one. The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence. The sum of all those steps - or phases - is the life cycle of the product. Common categories of assessed damages are global warming (greenhouse gases), acidification, smog, ozone layer depletion, eco-toxicological and human-toxicological pollutants, desertification, land use as well as depletion of minerals and fossil fuels.
7.0 LCA USES AND TOOLS

Based on a survey of LCA practitioners carried out in 2006 (Cooper and Fava 2006), most life cycle assessments are carried out with dedicated software packages. 58% of respondents used GaBi software, 31% used SimaPro and 11% a series of other tools. According to the same survey, LCA is mostly used to support business strategy (18%) and R&D (18%), as input to product or process design (15%), in education (13%) and for labeling or product declarations (11%).

8.0 HOT IN-PLACE RECYCLING

The objective of hot in-place recycling (HIR) of structurally sound asphalt pavements is to restore (renew) the existing aged, cracked, worn, or rutted asphalt surface course to the same quality (or better) as a new hot-mix asphalt overlay, in a cost-effective manner (Button et al., Emery and Terao 1992). Current HIR processes have evolved through continuous technical and quality improvements, particularly in heating and mixing systems.

The HIR process option is particularly attractive in terms of the renewal depth achieved and full recycling of the old asphalt concrete (recovery of aggregate and asphalt cement).

9.0 COSTING

A comparison of typical baseline estimated costs for two recycling processes with a conventional asphalt overlay process was carried out by Sorenson and Siddon (2000), who showed a cost saving of about 43%. According to study done by CRRI on Delhi roads the cost of 40mm overlay with HIPR comes to INR 130/m², instead of INR 155/m² with conventional resurfacing which reflects a net saving of around 16% (CRRI, 2003).
Based on the LCA ground rules with definition of the LCA parameters, the above mentioned processes were considered for the life cycle inventory of both HMA and RAP.

10.0 METHODOLOGY

**Literature Review** - It includes reviewing the existing LCA tools worldwide, to know and understand more about the earlier studies of experience and knowledge in the field of environmental impacts of road construction/rehabilitation.

1. **Goal definition** - The main goal of this project is to study and compare the environmental impact of road rehabilitation activities in conventional and HIPR technology, by inducing the life-cycle perspective.

2. **Process identification** - The flow chart at Figure 1 includes the slightest details of all the stages and components of life-cycle of construction activities for both technologies of road rehabilitation, right from the mining, transportation of raw material to final laying and compaction of HMA.

3. **Data Collection** - Life cycle inventory data was collected from the literature and software for transportation of the materials, material production, machinery used for production and associated energy use. Two different road rehabilitation projects have been evaluated and relevant actual data collected, one at MayurVihar and the other at Rohini, in New Delhi, for both the technologies.

4. **System Boundaries** - The boundaries and limitations of the study have been identified and data is processed accordingly.

10.1 **Functions and work stages**

The analysis included all the significant life-cycle stages covering the production and transportation of materials, their placement in the road structures and the use of the construction machinery. The situation after the use of the construction, was not included in the analysis because the use in both the technologies is similar and no point in comparing them. Those stages of road construction and use that have no significance for the comparison of constructions were ruled out of the analysis. These include:

- Site clearance,
- Functions associated with road use (e.g. lane markings, the installation and use of traffic signs and lights),
- Regular or seasonal maintenance (e.g. snow ploughing)
- Traffic emissions.

10.2 **Environmental loadings**

The environmental loadings assessed as being essential during the life cycle of road constructions were selected on the basis of the case studies for inclusion in the analysis. The included environmental loadings were the following:

1. Use of resources: natural materials, water, energy and fuel consumption
2. Atmospheric emissions: carbon dioxide (CO2), nitrogen oxides (NOx), sulphur dioxide (SO2), particles and carbon monoxide (CO)
3. Leaching into the ground: heavy metals
4. Other loadings: Hazardous waste generation, Human toxicity etc.

10.3 **Other Boundaries**

1. **Functional units**: In this study, a one-kilometre-long and one lane (3.5m) wide section of the road construction was selected as the functional unit. In other practical cases the entire construction can also be the functional unit.

2. **Period of analysis**: In this study, one full cycle of resurfacing has been considered, which is same for both the cases.
3. **Machines and equipment:** The loadings caused by the manufacture of work machines and lorries and by the maintenance of machines were excluded from the analysis. The manufacture and transportation of blasting materials and fuels were also excluded.

4. **Situation after use:** It was assumed in the analysis that the usage would be similar in both cases, use after construction is not examined in this study.

5. **Landfill disposal:** As the analysis period is kept at 5 years in both the cases, and after that relaying of wearing course is adopted, the landfill disposal is not required in both the cases.

6. **Analysis of the collected data** - It includes analysing the practical data for fuel and energy usage at each and every stage of both technologies in the PaLATE software.

7. **Impact Analysis** - The aim is to convert the inventory results into a form that can be more easily interpreted and compared.

### 10.4 Data Collection

The data was collected for two locations, one at MayurVihar and the other at Rohini, Delhi. The data was collected in a structured format, wherein it is requested to provide energy use information applicable to mainly three road construction processes used in the course of rehabilitating by two types of technologies. The three processes are hot-mix asphalt mixing (Permanent and/or portable); material hauling activities; and heavy equipment use. The two road rehabilitation technologies are as follows:

(i) **Conventional hot mix rehabilitation.**

(ii) **Hot in place recycling rehabilitation.**

For each road type, the functional unit is a lane-kilometre with a width of 3.50 m. The rehabilitation is limited to resurfacing. The details of the projects considered are as under:

- **Project:** Resurfacing of KN KatjuMarg, Rohini by HIPR technology.
  
  **Client:** PWD, Delhi

- **Road length:** 3.65 km
- **Lanes:** 6
- **HIPR machinery:** AR2000, Martec (Technology), Hitachi (Manufacturer) (3rd Generation)
- **Ratio of old and fresh bituminous mix:** 65:35
- **Milling depth:** 35mm
- **Resurfacing thickness:** 50mm

- **Data provided by:** M/s TelconEcoroad Resurfaces Pvt. Ltd. (TERPL)(Agency)

- **Project:** Resurfacing of road no. 113 in MayurVihar by HIPR technology.
  
  **Client:** PWD, Delhi
  
  **Road length:** 0.65 km
  
  **Lanes:** 6
  
  **HIPR machinery:** R4500, Wirtgen India Pvt. Ltd. (3rd Generation)
  
  **Ratio of old and fresh bituminous mix:** 55:45
  
  **Milling depth:** 25mm
  
  **Resurfacing thickness:** 40mm
  
  **Data provided by:** Wirtgen India Pvt. Ltd. (Agency)

These two projects with conventional resurfacing at similar locations were considered and their data was also collected from the respective agencies.

### 11.0 DATA ANALYSIS

The data collected has been analysed using an excel based software PaLATE, developed by Dr. Arpad Horvath, University of California at Berkeley.

The Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE) utilises a life-cycle assessment framework that draws on engineering, environmental, and economic information and data to evaluate the use of virgin and recycled materials in the construction and maintenance of pavements that use different percentages of virgin and recycled materials in the sub grade/sub base and wearing course layers.

### 11.1 Modeling

PaLATE is built on extensive data collection, analysis, and modeling efforts. It uses the state-
of-art LCA model, and it is a robust yet flexible modeling framework. Robustness is achieved through the inclusion of all relevant roadway engineering factors coupled to the most significant environmental variables known today. Flexibility is achieved through the design of the model and transparency of the programming and user interface.

It provides default values for most of the variables in the model, but at the same time left it open to the users to add their own numbers if they deem them more accurate or relevant than those provided by PaLATE.

11.2 User Interface

User input is needed on many variables, decisions need to be made many times during the software use, but this is the price of being comprehensive. The user is required to have familiarity with pavement construction activities in order to go through the set of options required in the analysis. However, the degree to which the user interacts with PaLATE varies, e.g., the tool provides a set of default parameters that may or may not be accepted by the analyst.

11.3 Tool Structure

PaLATE uses an LCA approach to model the environmental effects of road initial construction and maintenance. The user defines the design of the pavement, which results in a given type and volume of construction materials and its source (hauling distance), a given combination of construction activities, and a set of prescribed maintenance activities.

Environmental effects of using recycled materials depend on the characteristics of the equipment used to recover the materials, and the hauling of materials between processing facilities and the construction site. Energy use and air emissions are based on typical productivity, fuel consumption rate, and the engine size of the equipment used in each recycling activity.

Productivity values for the equipment used in the various activities and processes modeled by PaLATE were obtained from equipment manufacturers, and it is possible that actual values differ from the ones represented in the tool.

Hauling distances are key factors for the environmental effects arising from the use of recycled materials.

11.4 Data Analysis

The collected data was used with PaLATE software to assess the eco-burdens. Table 1 represents various eco-burdens with respect to conventional and HIPR technologies comparatively.

<table>
<thead>
<tr>
<th>Table 1 : Comparative Eco-burdens assessed by collected data at RohiniSite</th>
</tr>
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<tbody>
<tr>
<td>Maintenance</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td>Total</td>
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<td></td>
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<tr>
<td>Total</td>
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<tr>
<td>Legend:</td>
</tr>
</tbody>
</table>

*GWP= Global Warming Potential
12.0 IMPACT ANALYSIS AND CONCLUSIONS

This research tries to utilize the life cycle assessment to evaluate the environmental impact of rehabilitating pavement using different technologies. Two technologies - traditional resurfacing and HIPR - are investigated. These two technologies are applied for milling/overlaying one lane-kilometer asphalt pavement with a thickness of 4/5 cm. Using the mix ratio of each material and information from inventory analysis, the eco-burden for each scenario is calculated based on the database provided in PaLATE software.

![Figure 2: Comparative assessments of environmental impacts.](image)

The HIPR technology seems to be a tool of sustainable rehabilitation of bituminous roads, as the material production accounts for approximately 90% of total eco-burden.

The assessment done by PaLATE software of the data collected from various projects indicates that every lane-km of road resurfacing by HIPR technology over conventional resurfacing, results in:

- approximately 45% to 55% reduction on all accounts of eco-burden is achieved through HIPR technology over conventional resurfacing.
- There have been minor differences observed between different locations and different machinery of application of HIPR
- 300 thousand MJ of energy is saved.
- 326 kilo litres of water is saved.
- 17 tons of CO$_2$ emission is mitigated.
- at least 16% of cost saving.
- reuse of aggregates and bitumen at the rate of approximately 50%, contributes to the sustenance of natural resources, considerably.

The analysis of this research indicates that the use of new technologies such as HIPR is the key to lower the eco-burden of rehabilitation works of bituminous roads. But there are not enough specifications developed for these new technologies and this is one area which needs to be catered urgently before we leap on to the sustainable rehabilitation processes which are equally sound on quality front as well.
12.1 Application on Delhi Roads

In November 2002, the Govt. of NCT Delhi entrusted the task of evaluation of a network of about 750 kms of roads within the jurisdiction of PWD and MCD to Central Road research Institute (CRRI). The main objective of the study was to evaluate the existing condition of the roads in Delhi and to suggest the needed improvement to provide higher levels of serviceability by regular and timely maintenance with the usage of modern technologies.

CRRI studied all PWD roads (30 m wide and more) and MCD roads of ROW 35m and above, with the length more than 2kms. For HIPR, wide and long road stretches are preferable. These studied roads shall stand a good chance of candidature for resurfacing with HIPR, provided other conditions are met, like they should not have:

1) Excessive amount of sub grade failures: The report indicates satisfactory sub grade at most of the locations.
2) Mat thickness of less than 3 inches: Generally not the case in Delhi major roads, as these are overlaid every five years.
3) Wide cracking: Few roads indirectly reported to be in bad condition.
4) Low oil content - less than 4%: Negligible roads wearing course layer found to be having less than 4% binder content.
5) Poor or soft aggregates: Aggregates were found to be of satisfactory quality.
6) Large aggregates - larger than ¾” in diameter: Not the case for wearing course, as 12.5mm maximum size of aggregates used for Dense Bituminous Concrete (DBC) or Bituminous Concrete (BC).
7) Evidence of Stripping: Found at some stretches.

But on the whole, CRRI has recommended the treatment in two stages, first is for preventive maintenance wherever required and the second, periodical maintenance. In periodical maintenance, in more than 50% cases, CRRI has recommended BC or DBC layer of 30-40mm every 3 to 7 years. Conservatively, even if we consider 50% of cases to be fit for HIPR i.e., 1850 lane-km with an average overlay of 35mm, the eco-burden and economic savings would be:

These results conclude:

- Saving of energy usage to the tune of 586 Million MJ.
- Conserving water by 606 Thousand of kilo litres.
- Carbon Footprint is reduced by 31 Million Kgs.
- Thus, a case of Clean Development Mechanism (CDM) can be persuaded which could create additional source of income.

Also
- Considering the conservative estimation of 16% cost saving only, INR 162 Million are saved every cycle of preventive maintenance, say, every 5 years on average.
- Non-utilisation of virgin aggregate comes to 200 thousand cum of natural resources saved.

### Table 2: Environmental Loading for considered Delhi Roads (1850 lane-km)

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<tr>
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</thead>
<tbody>
<tr>
<td>Materials Production</td>
<td>1,01,81,25,633</td>
<td>52,02,07,948</td>
<td>12,06,751</td>
<td>6,56,280</td>
<td>51,784</td>
<td>26,981</td>
</tr>
<tr>
<td>Materials Transportation</td>
<td>14,05,91,987</td>
<td>5,82,87,060</td>
<td>90,721</td>
<td>37612</td>
<td>10,511</td>
<td>4,357</td>
</tr>
<tr>
<td>Processes (Equipment)</td>
<td>98,64,625</td>
<td>41,41,005</td>
<td>3636</td>
<td>1527</td>
<td>740</td>
<td>311</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,16,85,82,246</strong></td>
<td><strong>58,26,36,013</strong></td>
<td><strong>13,01,107</strong></td>
<td><strong>6,95,438</strong></td>
<td><strong>63,035</strong></td>
<td><strong>31,650</strong></td>
</tr>
<tr>
<td><strong>Savings</strong></td>
<td><strong>58,59,46,233</strong></td>
<td><strong>6,05,672</strong></td>
<td><strong>31,385</strong></td>
<td></td>
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</tbody>
</table>
References


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