IMPACT OF TRANSPORT TECHNOLOGIES IN SHAPING FUTURE CITIES TOWARDS SUSTAINABILITY

Soumyajit Dutta
Prof. Dr. Sanjay Gupta
School of Planning and Architecture, Delhi
Transport planning Department
Contents

• Aims and Objectives
• Methodology
• Sustainable Cities: Definition and Concept
• Mass Transit Technologies: Selection Procedure
• Transit technologies and Sustainable Cities
• Global Cities: Transit and Economy
• Systems in Indian Cities
• Sustainable Urban Mobility Index
• Case Study: Delhi
• Conclusion and Recommendation
Aim and Objectives

Aim

• Finding the impact of transit technologies in shaping future cities towards sustainability

Objectives:

• To review through literature interdependence of Transit and urban growth in sustainable cities.
• To develop a relationship between transit supply and ridership, per Km ridership, Economic, Social and Environmental development.
• To develop a Sustainable Urban Mobility Index for evaluating the Impact of Transit Systems in City.
• To assess the impact of metro in Delhi on physical, economical, social and environmental Development.
• To evaluate the alternate transit development strategies on case study area of Delhi for growing towards sustainable mobility.
Methodology

Finding the impact of transit technologies in shaping future cities towards sustainability

Transport and Economic Development
- Speed and Economy
- Population and Systems
- GDP and Speed
- City Size and Speed

Types and Form of the city
- Population
- Area
- Density
- Per Capita Income
- Economic Base
- Urban Form

Transit System Selection Procedure
- Topography
- Capacity
- Benefit
- Feasibility
- Adaptability
- Pre-condition for systems
- Political Influence
- Alternate Analysis

Systems Key Performance Indicators
- Population Served
- Urban Density Increased
- Percentage of Jobs in CBD
- Road Length / Capita
- Car VKT / Capita
- PT Service km / Capital
- PT Passenger-km / Capita
- Accessibility
- Speed
- Fare
- Per Km cost
- Cars / 1000 people
- Income per Capita
- GDP of the City
- Per Capita GDP
- Parking Spaces
- Environmental Impact
- Social Acceptance

Assessment of the impact of transport technology and service by Sustainable Urban Mobility Index (SUMI)

Interdependence of transport and urban form

Assessment of 97 world Cities
- Population
- Transit Modes
- System Selection
- System KPI Analysis
- Economic Base
- Urban Form

Checking on 9 Indian Cities
- Transit Modes
- System Selection
- System KPI Check
- Economic Base
- Urban Form

Analysis of Delhi Metro
- Temporal Land use of New Delhi
- Timeline of System Introduced
- Temporal data of change in Mobility
- Impact on Economy
- Impact on Mobility
- Impact on Land use
- Urban Sprawl Control
- Population Served
- Increase in Land Price

Analysis of New System Construction

Future Transport Systems in Delhi in future (2041, Master Plan Horizon Year)
- Spatial Growth
- Economic Growth
- Km of Metro Network
- Introduction of New Systems

Delhi Master Plan 2041 Vision on Transport
- Speed
- Catchment Area
- Ridership
- Served Population
- Total Network Density
- Sprawl Control

Analysis of Delhi Metro
Sustainable Cities: Definition and Concept

Attributes of a Sustainable Future Cities

- Dynamic technology ecosystem
- Talent
- Infrastructure
- Innovation Capabilities
- Quality of Life
- Market Transparency
- International Patents

Transport

- Promoting cycling and walkability
- Planning for local hubs
- Congestion charging
- Extensive provision of electric vehicle charging points
- Seamless travel

Dominating Transport System along the period of time

Urban Railway is the most dominating mode for the next half of a century along with Telecommunication

Comparison with World Cities

<table>
<thead>
<tr>
<th>Presence of Modes</th>
<th>Bus</th>
<th>Tram</th>
<th>LRT</th>
<th>BRT</th>
<th>Metro</th>
<th>Maglev</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>100%</td>
<td>14%</td>
<td>0%</td>
<td>29%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>100%</td>
<td>38%</td>
<td>38%</td>
<td>22%</td>
<td>97%</td>
<td>6%</td>
</tr>
</tbody>
</table>

- Indian cities are predominantly moving on Bus and Metro in available for cities with more than **5 million population**.
- Medium capacity transit systems such as tram, Monorail are absent except for Calcutta and Bombay
# Mass Transit Technologies: Selection Procedure

## Factors In Choosing a Type of Public Transport Technology

### COST
- 1) CAPITAL COSTS (Infrastructure and Property costs)
- 2) OPERATING COSTS
- 3) PLANNING COSTS

### PLANNING AND MANAGEMENT
- 1) PLANNING AND IMPLEMENTATION TIME
- 2) MANAGEMENT AND ADMINISTRATION

### DESIGN
- 1) SCALABILITY HOMOGENEITY
- 2) FLEXIBILITY
- 3) DIVERSITY VERSUS

### PERFORMANCE
- 1) CAPACITY
- 2) TRAVEL TIME/SPEED
- 3) SERVICE FREQUENCY
- 4) RELIABILITY
- 5) COMFORT AND SAFETY
- 6) CUSTOMER SERVICE
- 7) IMAGE AND PERCEPTION

### IMPACTS
- 1) ECONOMIC IMPACTS
- 2) SOCIAL IMPACTS
- 3) ENVIRONMENTAL IMPACTS
- 4) URBAN IMPACTS
Transit technologies and Sustainable Cities

Average City Speed and Metro Network Length

City Size wise Mass Transit Modes Availability

Modes Availability and City Form

0% - 20% 20% - 40% 40% - 60% 60% - 80% 80% - 100%
Global Cities: Transit and Economy

**GDP Per capita PPP Regression American Cities**

- **R² = 0.5957**

**Average Speed (KMPH) with Urban Population in Asian and Latin American Cities**

- **R² = 0.6648**

**American Cities Average City Speed and Urban Population Density**

- **R² = 0.5891**

**Average Speed (KMPH) with Population Density**

- **R² = 0.5655**
## Systems in Indian Cities

### Metro System Efficiency Across India

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>City</th>
<th>Population in Million</th>
<th>Opening</th>
<th>Network length</th>
<th>Stations</th>
<th>Lines</th>
<th>Avg. station distance (m)</th>
<th>Avg. line length (KM)</th>
<th>Stations per line</th>
<th>Daily ridership</th>
<th>Ridership per km</th>
<th>Length per resident in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bangalore</td>
<td>10.60</td>
<td>15-Sep-11</td>
<td>42.3</td>
<td>40</td>
<td>2</td>
<td>1085</td>
<td>21.1</td>
<td>20.5</td>
<td>400000</td>
<td>9457</td>
<td>6.2</td>
</tr>
<tr>
<td>2</td>
<td>Bombay</td>
<td>21.00</td>
<td>11.4</td>
<td>2253</td>
<td>31.9</td>
<td>24</td>
<td>700000</td>
<td>23570</td>
<td>2</td>
<td>405107</td>
<td>35536</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Calcutta</td>
<td>15.00</td>
<td>24-Oct-84</td>
<td>29.7</td>
<td>24</td>
<td>1</td>
<td>1219</td>
<td>29.7</td>
<td>24</td>
<td>2761000</td>
<td>11553</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Delhi</td>
<td>18.70</td>
<td>24-Dec-02</td>
<td>239</td>
<td>172</td>
<td>8</td>
<td>1366</td>
<td>22.9</td>
<td>400000</td>
<td>1366</td>
<td>11553</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>Hyderabad</td>
<td>6.80</td>
<td>28-Nov-17</td>
<td>29.8</td>
<td>24</td>
<td>2</td>
<td>1296</td>
<td>14.9</td>
<td>12.5</td>
<td>220000</td>
<td>7383</td>
<td>4.7</td>
</tr>
<tr>
<td>6</td>
<td>Jaipur</td>
<td>3.06</td>
<td>03-Jun-15</td>
<td>9.6</td>
<td>9</td>
<td>1</td>
<td>1200</td>
<td>9.6</td>
<td>9</td>
<td>17649</td>
<td>1839</td>
<td>3.3</td>
</tr>
<tr>
<td>7</td>
<td>Kochi</td>
<td>0.90</td>
<td>17-Jun-17</td>
<td>18</td>
<td>16</td>
<td>1</td>
<td>1200</td>
<td>18</td>
<td>16</td>
<td>45000</td>
<td>2500</td>
<td>6.6</td>
</tr>
<tr>
<td>8</td>
<td>Lucknow</td>
<td>3.30</td>
<td>05-Sep-17</td>
<td>8.4</td>
<td>8</td>
<td>1</td>
<td>1200</td>
<td>8.4</td>
<td>8</td>
<td>67000</td>
<td>7977</td>
<td>3.3</td>
</tr>
<tr>
<td>9</td>
<td>Madras</td>
<td>7.00</td>
<td>29-Jun-15</td>
<td>47.4</td>
<td>38</td>
<td>3</td>
<td>1317</td>
<td>15.8</td>
<td>13</td>
<td>900000</td>
<td>1899</td>
<td>6.6</td>
</tr>
</tbody>
</table>

### Relationships in Indian Cities

- **Daily Ridership vs. Network Length**
  - $y = 437317\ln(x) - 930632$
  - $R^2 = 0.8184$

- **Ridership per KM vs. Network Length**
  - $y = 785.68x^{0.3582}$
  - $R^2 = 0.7329$

- **Daily Ridership vs. Per Capita Network Length**
  - $y = 10068x^2 - 47492x + 104079$
  - $R^2 = 0.9569$
Sustainable Urban Mobility Index

- **Sustainable Urban Mobility Index (SUMI)** is a framework of indicators for the assessment of urban transport systems and mobility and services in a city. The indicators and SUMI can help summarize, track and compare state of urban transport performance in a city. SUMI can serve as a useful tool for cities to assess the ability to move a city on a mass transit mode. It consists of Population, Area, Population Density, GDP PPP, Per Capita GDP, Average Speed (Kmph), Network length, Stations, Lines, Avg. station distance, Avg. line length, Stations per line, Daily ridership, Ridership per km, Length per resident in mm, Usage, Stations per Lakh Population, Network Density.

- It is derived from Sustainable Urban Transport Index (SUTI)

**Methodology:** For SUMI both methods were tested using partly hypothetic yet realistic data. The test showed that the SUMI results (ranking of cities) in some cases could be affected by the choice of aggregation method. Based on the similar argument as for the HDI it was decided to apply the geometric mean for aggregation.

\[
\text{Index, } I_i = \frac{(i_i - i_{\text{min}})}{(i_{\text{max}} - i_{\text{min}})}, \quad \text{SUMI Base, General Index, } J_1 = \sqrt[n]{I_1 \times I_2 \times I_3 \times \ldots \times I_n}, \quad \text{SUMI Base, } K_i = \sqrt[8]{J_1^{1/8} \times J_2^{1/8} \times J_3^{1/8} \times J_4^{1/8} \times J_5^{1/8}}
\]

- \[SUMI_i = \frac{K_i \times 100}{K_{\text{max}}},\]
  1. \[I_i = \frac{(i_i - i_{\text{min}})}{(i_{\text{max}} - i_{\text{min}})}\]
  2. \[I_{\text{area}} = \frac{(\text{area}_{\text{London}} - \text{area}_{\text{min}})}{(\text{area}_{\text{max}} - \text{area}_{\text{min}})} \text{ or } \left(\frac{671 - 90}{8000 - 90}\right) = \left(\frac{581}{7910}\right) = 7.3\]
  3. \[J_i = \sqrt[n]{I_1 \times I_2 \times I_3 \times \ldots \times I_n}, \quad \text{or } J_{\text{City}} = \frac{3}{2}\sqrt[3]{I_{\text{area}} \times I_{\text{population}} \times I_{\text{population density}}} \quad \text{or } J_{\text{City}} = 17.7\]

- \[SUMI_i = \frac{K_i \times 100}{K_{\text{max}}}\]

### Table: Sustainable Urban Mobility Index (SUMI)

<table>
<thead>
<tr>
<th>City Index ( (J_1) )</th>
<th>Transit System Index ( (J_2) )</th>
<th>Overall Transport Index ( (J_3) )</th>
<th>Economic Index ( (J_4) )</th>
<th>Environmental Index ( (J_5) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Network length</td>
<td>Average Trip Length</td>
<td>GDP PPP</td>
<td>CO</td>
</tr>
<tr>
<td>Population</td>
<td>Lines</td>
<td>Motorised PCTR</td>
<td>Per Capita GDP</td>
<td>HC</td>
</tr>
<tr>
<td>Population Density</td>
<td>Avg. station distance</td>
<td>Average Speed (Kmph)</td>
<td>Private Modal Split</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>Avg. line length</td>
<td>Total VKT</td>
<td>PT Modal Split</td>
<td>PM10</td>
</tr>
<tr>
<td></td>
<td>Daily ridership</td>
<td>Private VKT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ridership per km</td>
<td>Vehicle Hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Length per resident in mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Usage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stations per Lakh Population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Network Density</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case Study: Delhi

<table>
<thead>
<tr>
<th>Year</th>
<th>Delhi Metro in KM</th>
<th>Total Built-up Area of Delhi (Sq.KM)</th>
<th>Built-up area Percentage</th>
<th>Total Built-up within Present network coverage area</th>
<th>Built-up within 1km</th>
<th>Coverage of NCT Area by Metro</th>
<th>Coverage of NCT Built-up Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
<td>456</td>
<td>30.87</td>
<td>220</td>
<td>35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003</td>
<td>22</td>
<td>518</td>
<td>35.13</td>
<td>245</td>
<td>35</td>
<td>3.5</td>
<td>6.8</td>
</tr>
<tr>
<td>2008</td>
<td>74</td>
<td>617</td>
<td>41.79</td>
<td>268</td>
<td>139</td>
<td>15.7</td>
<td>22.6</td>
</tr>
<tr>
<td>2011</td>
<td>190</td>
<td>692</td>
<td>46.88</td>
<td>308</td>
<td>230</td>
<td>23.4</td>
<td>33.3</td>
</tr>
<tr>
<td>2014</td>
<td>193</td>
<td>757</td>
<td>51.26</td>
<td>330</td>
<td>247</td>
<td>23.4</td>
<td>32.7</td>
</tr>
<tr>
<td>2015</td>
<td>212</td>
<td>807</td>
<td>54.65</td>
<td>336</td>
<td>252</td>
<td>25.7</td>
<td>31.3</td>
</tr>
<tr>
<td>2016</td>
<td>212</td>
<td>830</td>
<td>56.26</td>
<td>339</td>
<td>254</td>
<td>25.7</td>
<td>30.6</td>
</tr>
<tr>
<td>2019</td>
<td>343</td>
<td>867</td>
<td>58.71</td>
<td>363</td>
<td>363</td>
<td>30.9</td>
<td>41.9</td>
</tr>
</tbody>
</table>

From 2011-12 to 2014-15 the extension of metro was stalled. Average growth of Delhi Metro Ridership was adjusted as 12.5 increase per year.

\[ y = 0.097\ln(x) - 0.2656 \]

\[ R^2 = 0.9936 \]
Case Study: Delhi

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario</th>
<th>Options</th>
<th>Country</th>
<th>City</th>
<th>City Index</th>
<th>Transit System Index</th>
<th>Overall Transport Index</th>
<th>Economical Index</th>
<th>Environmental Index</th>
<th>SUMI Base</th>
<th>SUMI</th>
<th>Percentage Development of SUMI from BAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>Present</td>
<td>343 KM</td>
<td>India</td>
<td>Delhi</td>
<td>32.9</td>
<td>19.1</td>
<td>46.1</td>
<td>7.4</td>
<td>60.6</td>
<td>26.8</td>
<td>57.0</td>
<td>0%</td>
</tr>
<tr>
<td>2041</td>
<td>BAU</td>
<td>460 upto Phase IV</td>
<td>India</td>
<td>Delhi</td>
<td>45.3</td>
<td>21.9</td>
<td>27.1</td>
<td>22.3</td>
<td>25.7</td>
<td>26.4</td>
<td>56.2</td>
<td>0%</td>
</tr>
<tr>
<td>2041</td>
<td>Metro Enhancement</td>
<td>604 KM of Metro</td>
<td>India</td>
<td>Delhi</td>
<td>45.3</td>
<td>24.2</td>
<td>47.3</td>
<td>38.3</td>
<td>44.3</td>
<td>40.4</td>
<td>85.8</td>
<td>53%</td>
</tr>
<tr>
<td>2041</td>
<td>Urban Rail System</td>
<td>683 KM of Urban Rail</td>
<td>India</td>
<td>Delhi</td>
<td>45.3</td>
<td>31.6</td>
<td>53.2</td>
<td>35.1</td>
<td>53.6</td>
<td>44.1</td>
<td>93.8</td>
<td>67%</td>
</tr>
</tbody>
</table>

**MODAL SPLIT COMPARISON**

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario</th>
<th>Options</th>
<th>Cost in Crore Rupees</th>
<th>Per KM Cost in Crore Rupees</th>
<th>Increase in SUMI Index</th>
<th>Cost per SUMI Index Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>Present</td>
<td>BAU</td>
<td>460</td>
<td>46800</td>
<td>400</td>
<td>-0.8</td>
</tr>
<tr>
<td>2041</td>
<td>Metro Augmentation</td>
<td>BAU</td>
<td>604</td>
<td>104400</td>
<td>400</td>
<td>28.8</td>
</tr>
<tr>
<td>2041</td>
<td>Urban Rail System</td>
<td>Urban Rail System</td>
<td>683</td>
<td>100320</td>
<td>295</td>
<td>36.8</td>
</tr>
</tbody>
</table>

**SUMI for top 10 Cities 2041**

- New York: 94
- Seoul: 94
- Delhi: 88
- London: 87
- Paris: 82
- Osaka: 74
- Moscow: 74
- Chicago: 74
- Tokyo: 73
- Singapore: 73

**Metro**

- Fleet Required: 9660
- 57242
- 29239
- Vehicle KM: 162Lakh
- 328Lakh
- KM Required: 456
- Modal Split: 30% 5% 4%
- 14%
- 17%
- 30%
- Users/Ridership: 63lakh 10.6Lakh 8.5Lakh 29Lakh 36Lakh 63Lakh

**Metro Enhancement**

- Fleet Required: 9660
- 45793
- 21929
- Vehicle KM: 115Lakh
- 251Lakh
- KM Required: 608
- Modal Split: 30%
- 4%
- 3%
- 10%
- 13%
- Users/Ridership: 63Lakh
- 8.5Lakh 6.3Lakh 21Lakh 27Lakh 85Lakh

**Urban Rail System**

- Fleet Required: 9660
- 34344
- 14619
- Vehicle KM: 104Lakh
- 212Lakh
- KM Required: 684
- Modal Split: 30%
- 3%
- 2%
- 9%
- 11%
- Users/Ridership: 63Lakh
- 6.3Lakh 4.3Lakh 19Lakh 23Lakh 95Lakh
Conclusion and Recommendation

**Recommendation**

- Urban Rail System needs to given the top priority in Large Cities like Delhi
- Rail based systems are essential to achieve sustainability in large cities as seen in the global sustainable cities as well as in India
- Rail based transport impacts the city in terms of physical extent, economic extent as well as social enhancement
- There is a straight relationship between per capita network length and usage of Systems
- As the Network Length Increases, the Ridership per KM increases
- The average speed of a city is directly impacting the Per Capita GDP of a City
- To increase ridership, a whole network has to be created, a single corridor
- Multimodality increases efficiency of each system
- Alternate scenarios to be developed and right system and network has to be implemented

**Proposal for 2041 Delhi**

460 KM Metro Network was as considered upto Phase IV, plus **223 Kms LRT Network** according to BAU Traffic Assignments, PPHPDT over 20 thousands for New LRT

Target PT Modal Split 75%

**Way Forward**

- SUMI can be further developed
- Weightage (Power) of different criteria may be considered statistically
- Proper weightage of Metro, BUS, BRT, LRT and Trams has to be calculated. In this study capacity of the systems are considered as their weightage