Modeling for Urban Goods Movement – a case study of Indian Cities

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by

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Workshop on
Urban Freight Transport: A Global Perspective

By
TSE/CE/IIT Bombay and Center of Excellence for Sustainable Urban Freight Systems, RPI, Troy, NY
What makes it important?

• Traffic congestion
• Environmental impacts
• Traffic accidents
• Terminal facilities
Goods movement pattern

- **Intra-city flows** – Flows whose origin and destination are within the city
- **Inter-city flows** - Flows whose one end (origin or destination) is within the city and other outside the city
- **Regional flows** - Flows whose both ends (origin and destination) are outside the city
Possible patterns of urban goods flows
Intra urban freight movement

• Goods movement is directly related to population and to understand that one must know the physical, economic, and social make up of the city

• Urban goods may be classified depending on its physical state, handling needs, modes of vehicles used, direction of movement etc., for analyzing the demands

• Whole problem of goods movement would not be solved all at once, but modeling framework can be flexibly adopted to make progress in small steps
Modeling framework
• Aggregate analysis of total establishments employing the aggregated parameters to yield trip rates may be adequate and useful for planning process
• Urban goods movement forecasting techniques must be developed in terms of fairly simple measures of economic activities
• Any modeling efforts should begin with the data collection relating to urban goods movements through primary surveys of consignment movements and supplementing them by secondary sources
Inter urban freight movement

• Situation in the case of inter urban freight movements has bright patches
• Consignment size and distance of haul are the most significant parameters in choosing the own transport, hired transport or railways for goods movement
• Firms owning transport generally utilized their own transport for medium and short hauls and preferred hired mode for long distance trips
Selection of cities for study

• Cities of varying sizes with respect to demography and economic activities
• Federation of Indian Chamber of Commerce and Industry (FICCI) proposal that classifying cities on the grounds of economy is an appropriate one as the urban economy structure has direct influence on the urban goods flows
Case Study Cities
Data collection

- Truck operator surveys
- Traffic counts at selected points in the city
- Outer cordon surveys
- Focal point surveys

Owing to the complexity of the goods movement, no single method of data collection could cover complete goods movement and its characteristics.
# Traffic survey stations in selected cities

<table>
<thead>
<tr>
<th>S.No.</th>
<th>City</th>
<th>Number of Traffic Survey Stations</th>
<th>Volume Counts</th>
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Outer cordon surveys

- Sample size between 6.8 to 100% depending upon the city was taken
- The following particulars of the sampled goods vehicle were collected
  1. Type of vehicle
  2. Origin of trip
  3. Destination of trip
  4. Land use at destination
  5. Type of commodity carried
  6. Quantity of commodity carried
<table>
<thead>
<tr>
<th>S.No.</th>
<th>City</th>
<th>Sample Size in Percentage of Outer Cordon Surveys in Cities</th>
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Goods focal point surveys

• Major goods focal points are industries, wholesale trade, ware houses, freight terminals.
• Goods focal point surveys are involved in identifying the extent of market in space and drawing a cordon line around these spaces.
• In most of the cities wholesale markets were concentrated at one place.
• Separate surveys were organized for each market in Delhi as different markets are located at different points.
<table>
<thead>
<tr>
<th>S.No.</th>
<th>City</th>
<th>Percentage of Vehicle Trips</th>
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</table>
Data collected in goods focal point surveys was:
1. Type of activity
2. Type of vehicle
3. Origin
4. Destination
5. Destination of land use
6. Type of commodity carried
7. Quantity of commodity carried
8. Average distance travelled in a day
Goods transport flows

• Magnitude of goods transport flows in each of the cities was determined by analyzing data collected through cordon surveys and focal point surveys.

• Volume of incoming vehicles and quantum of incoming goods increased with city size.

• Outgoing goods traffic was also found to be increasing with city size.
<table>
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Urban goods flow characteristics

- Commodity Classification is important to make the analysis manageable. Eight broad categories are listed
  1. Perishable food products
  2. Non-Perishable food products
  3. Beverages
  4. Industrial Inputs
  5. Industrial Outputs (Consumer Products)
  6. Building materials
  7. Industrial Outputs (Intermediate Products)
  8. Other Categories
Intercity Inbound flow characteristics

- Trucks and mini trucks are the major carriers of intercity inbound flows with more than 91% of goods moving by these vehicles.
- Building materials (28.9%), Industrial inputs (18.1%) and food products (16.7%) are the major constituents of the intercity inbound flows.
- Whole sale markets (35.8%) and retail markets (21.3%) are the major attractors of the inbound goods flows.
- The intercity inbound flows are dominated by heavy consignments with more than 55% consignments weighing more than 4 tonnes.
Mode split of intercity inbound goods flows

- Trucks: 83.5%
- LCVs: 7.9%
- Pedal Carts: 1.1%
- T. Trailors: 5.7%
- Animal Carts: 1.6%
- Hand Carts: 0.2%
Commodity wise composition of intercity inbound goods flows

- I.O. (Intermediaries): 9.4%
- Building Materials: 29.9%
- I.O. (Finish Products): 5.7%
- F.P. (non perishables): 16.7%
- F.P. (Perishables): 8.4%
- F.P. (beverages): 7.3%
- I.I. (Raw Materials): 18.1%
- Others: 5.4%
Intercity inbound goods flows destined to different land uses

- Residential: 11.0%
- Transport Terminals: 10.0%
- Ware House: 6.0%
- Industry: 15.8%
- Retail Trade: 21.3%
- Whole Sale Trade: 35.8%
Intercity inbound goods flows as per consignment size
Intercity Outbound flow characteristics

- The dominant carriers of Intercity Outbound flows are trucks (70%) and mini trucks (18%)
- The major constituents of outbound flows are food products, industrial outputs and industrial raw materials
- Whole sale trade (52.4%), industries (23.1%), transport terminals (17.6%) are the major generators of outbound flows from the cities
- Intercity outbound flows are also dominated by heavier consignments with more than 4 tonnes accounting for 44.4% of the total consignments
Mode split of intercity outbound goods flows
Commodity wise composition of intercity outbound goods flows
Intercity outbound goods flows destined to different land uses

- Whole Sale Trade: 52.4%
- Industry: 23.1%
- Ware House: 6.9%
- Transport Terminals: 17.6%
Intercity outbound goods flows as per consignment size
Regional flow characteristics

• The proportion of through traffic in a city is found to be dependent more on its locations with respect to trunk routes

• The industrial raw materials (24.4%), building materials (16.9%) and food products (16.1%) are found to be major constituents of the through flows
Intra-city flow characteristics

- The major generators of intracity goods flows are wholesale markets and warehouses with a contribution of 62% of total intracity flows.
- Retail trade is found to be the major attractor (39.4%) of the intracity flows.
- Trucks carry 45% and mini trucks carry 16% of the goods transported within the city.
- Slow moving vehicles constitute 70% of the intracity goods vehicle trips and carry about 40% of goods transported in cities.
- Non-Perishable food products (21.3%), industrial raw materials (20.6%), building materials (17.4%) and intermediate industrial outputs (16.5%) are the major contributors of Intracity flows.
Mode split of intracity goods flows
Intracity goods flows originating from different land uses

- Whole Sale Trade: 55.4%
- Industry: 18.7%
- Transport Terminals: 19.4%
- Ware House: 6.5%
Commodity wise composition of intracity goods flows

- I.O. (Intermediaries): 16.5%
- I.O. (Finish Products): 5.6%
- I.I. (Raw Materials)
- Others: 1.8%
- Building Materials: 17.4%
- F.P. (non perishables): 20.3%
- F.P. (Perishables): 11.6%
- F.P. (beverages): 5.2%
• The average consignment size of intracity flows ranged from 0.5 tonnes to 2 tonnes and also the average consignment size of different commodities varied widely
• The average distance of haul varied with city size and it is found to increase with the city size
• As expected the average trip length of trucks was higher and they also carried heavier consignments
• Trucks accounted for 40.8% of the tonne kilometers made in the cities and is followed by LCVs with 18.8%
• Fast moving vehicles contributed to about 30% of the vehicle km while the slow moving vehicles contributed to more than 70% of the vehicle km while the slow moving vehicles contributed more than 70% of the vehicle kilometers made in urban areas
Intracity veh-km made by different vehicles
Intracity tonne-km made by different vehicles
Urban Goods Transport Demand Modeling

• Input – Output model
Goods demanded by each sector of economy from all other sectors of economy can be determined but non-availability of Input – Output tables in terms of commodities makes the use of model difficult

• Sequential model
Similar to urban passenger transport planning modeling with certain variations in the specifics of the models
• Variables Selection

Urban goods flows = f(Population, Industrial Workers, Workers in Trade and Commerce)
Proposed modeling approach

Sequential Flow Models

• Intercity Inbound Vehicle Trips Model

  Vehicle trips = -233+0.00102(Pop)+59.6(PIW)

  where,

  Pop = Population of city
  PIW = Industrial workers as % of total workers

• Intercity Inbound Goods Flows Model

  Flow in tonnes = -556+0.00736(Pop)+281.1(PIW)
• Intercity Outbound Vehicle Trips
  Vehicle trips = -417+.00139 Pop

• Intercity Outbound Goods Flows
  Flow in tonnes = -3242+.00913 Pop

• Intracity Outbound Vehicle Trips
  Vehicle trips = -1814+.00510 Pop
  Vehicle Kilometers = -19251+.0394 Pop

• Intracity Outbound Goods Flows
  Flow in tonnes = -3167+.0077 Pop
  Tonne Kilometers = -46109+.0846 Pop
## Commodity Flow models

### Intercity Inbound flows

<table>
<thead>
<tr>
<th>Dependent Variable in Tonnes Y</th>
<th>Constant Term C</th>
<th>Regression Coefficient</th>
<th>Degrees of Freedom</th>
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<tbody>
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<td>0.00098 (5.84)</td>
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<td>119.6</td>
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<td>Food Products (Beverages)</td>
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<td>0.00120 (3.52)</td>
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<td>0.0011 (11.96)</td>
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<td>Building Materials</td>
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<td>Industrial Outputs (Intermediaries)</td>
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### Note:
1) P. I. W = Industrial workers as percentage of total workers.
2) Figures in brackets indicate 't' statistic.
Outbound flows

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<th>Sl. No.</th>
<th>Dependent Variable in Tonnes Y</th>
<th>Constant Term C</th>
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<td>-86.1</td>
<td>0.00035 (10.22)</td>
<td>0.889</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>Industrial Outputs (Intermediaries)</td>
<td>-353.5</td>
<td>0.00135 (11.99)</td>
<td>0.917</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>Others</td>
<td></td>
<td>No Significant Relationships were observed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Figures in brackets indicate 't' statistic.
Intracity flows

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Dependent Variable in Tonnes Y</th>
<th>Constant Term C</th>
<th>Regression Coefficient Population A1</th>
<th>2 R</th>
<th>Degrees of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Food Products (Non-Perishables)</td>
<td>-889.5</td>
<td>0.00169 (10.26)</td>
<td>0.890</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Food Products (Vegetables)</td>
<td>-64.5</td>
<td>0.00048 (8.36)</td>
<td>0.843</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Food Products (Beverages)</td>
<td>-113.9</td>
<td>0.00027 (10.64)</td>
<td>0.899</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Industrial Inputs (Raw Material)</td>
<td>-139</td>
<td>0.00095 (14.3)</td>
<td>0.942</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>Industrial Outputs (Finished Products)</td>
<td>-630</td>
<td>0.00123 (18.54)</td>
<td>0.963</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>Building Materials</td>
<td>-975</td>
<td>0.00189 (9.84)</td>
<td>0.882</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>Industrial Outputs (Intermediaries)</td>
<td>-387</td>
<td>0.00119 (17.65)</td>
<td>0.960</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>Others</td>
<td>No Significant Relationships were observed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mode Split Models

• Regression analysis was conducted with percentage of consignments of a given category, going by a designated mode, as dependent variable and the size of consignment and length of haul as independent variable

• Linear and exponential forms of functions are established
• Linear Models
  PCS 1 = 96.33 - 2.83 L
  PCS 2 = 85.15 - 4.96 L
  PCS 3 = 36.42 - 3.94 L

• Exponential Models
  PCS 1 = 3.78 L^{0.859}
  PCS 2 = 14.91 L^{0.589}
  PCS 3 = 24.53 L^{0.486}

Where,
L = Haulage length in km
PCS 1 = % of consignment < .5 tonnes by slow moving Vehicles
PCS 1 = % of consignment <1 & >.5 tonnes by slow moving Vehicles
PCS 1 = % of consignment <2 & >1 tonnes by slow moving Vehicles
• Validation of Demand Models

Data generated in Hyderabad is used to validate the models. Estimated and observed trips are matching closely
Strategy for goods transport facility planning

• Quantum of goods categorized commodity wise must be known for planning terminal facilities more rationally and efficiently

• Standardize the total requirements of various types of commodities and flows for given population and percentage of industrial workers in city as it is cumbersome to use large number of models practically
Facilities Required In Goods Terminals

• Docking and loading/unloading area
• Fuel and servicing stations
• Office spaces
• Parking spaces
• Covered storage space for handling goods
• Lodges and dormitories
• Shops selling motor spares
Spacing Required

- Assuming that loading / unloading takes place from 8.00 am to 8.00 pm and loading / unloading time per intercity truck is 2 hours and for intracity truck is one hour

Number of spaces = (Number of trips/Working hours )*Time required for loading
Time series techniques for forecasting truck traffic

• Spectral analysis which include line spectrum and power spectrum are required to check whether time series models are suitable for the data sets

• Two types of models – ARMA and ARIMA
  1. Auto Regressive Moving Average
  2. Auto Regressive Integrated Moving Average
• Auto Regressive Moving Average Model

\[ u_t = \sum_{j=1}^{m1} \phi_j y(t-j) + \sum_{j=1}^{m2} \phi_j w(t-j) + C + w(t) \]
• ARIMA model is given by

\[ u_t = y_t - y_{t-d} = \sum_{j=1}^{m_1} f_j y(t-j) + \sum_{j=1}^{m_2} q_j w(t-j) + C + w(t) \]
Where,
Y(t), t=1,2,...n is the series being modeled
M1 is the number of AR parameters
Fj is the jth AR parameter
M2 is the number of MA parameters
Qj is the jth MA parameter
C is a constant and
{w(t)=1,2,...n} is the residual series
• Model selection is based on two criteria
  1. Maximum likelihood rule
  2. Minimum mean square error
• Model is validated for the data available in Mumbai Metropolitan region
• Utilizing time series models weekly truck traffic on national highways 3, 4 and 8 and L.B.S road at Vashi, Mulund(E), Dahisar and Mulund(W) in Mumbai Metropolitan region were modeled
• Complexities associated with the urban goods transport analysis and modeling do not permit comprehensive planning of the transport system

• Development of planning methods is inhibited by the absence of urban goods movement data and the inadequate knowledge of the urban goods transport needs
Thank You