Using (big) data in urban transport research to improve energy projections: A case study of India

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Base Year Service Demand and Vehicle Stock Estimates

Source: ITEM (2014)
Personal passenger light vehicles
Drivers of demand

- **Structural effect**
- **Income effect**

Developed economies
Developing regions

Sources: Analysis of national and international databases, building on the information referenced in UNECE, 2012.
EIA: “Regional differences in China’s vehicle adoption reflect differences in income”
But, Vehicle ownership is also strongly influenced by policy (China)

Vehicle ownership per capita, 2002 → 2011

GDP per capita, current-year RMB

Ownership [veh/1000 capita]

Restrict vehicle ownership (1994)
Restrict vehicle use (2008-)
Source: ITEM (2014)
LDV and 2W ownership rates (2005 – 2050) - India

Source: ITEM (2014)
Modeling Comparison – Vehicle stocks (India)

Source: ITEM (2014)
Modeling Comparison – PKT by Mode (India)

Source: ITEM (2014)
Energy Intensity by mode in the Reference Scenario (India)

Model: GCAM, MESSAGE, MoMo, Roadmap

Source: ITEM (2014)
Modeling Comparison – Energy Use by Mode

Source: ITEM (2014)
Recommendations to improve future model projections

(Big) Data

- Vehicle ownership (demographic)
- Travel - Infrastructure constraints
- Travel - Urban vs rural
- Travel - Spatial patterns
- Cost and investment assumptions
- Travel per vehicle
- Heavy-duty focused topics
- Off-road
- Vehicle efficiencies
- Loads (especially in freight)

Model Improvemnet

- Policy shifts affecting behaviors
  - Urban vs rural
- Supply constraints (resources)
- Behavioral/structural shifts
- Freight activities/technology shift
- Demographic classes
- Modal shift analysis

Source: ITEM (2014)
Research motivation

- Energy and GHG emissions
  - Transportation energy use in India grows at the fastest rate, 5.1% per year on average, in the world, compared with the world average of 1.1% per year (EIA, 2013).
  - The transportation sector accounts for around 10% of India's total GHG emissions, with the largest share coming from road transport (EIA, 2013).

  - Moving people instead of cars
  - Encouraging integrated land use and transport planning
  - Encouraging greater use of public transport and non-motorized modes

- Huge uncertainties in estimating urban transport activities in India due to lack of reliable and detailed data
  - National-level studies point to the magnitude of transport problem, but all rely on scarce data and generous assumptions.
  - Very few city-level studies used household surveys to look at travel behavior and the influence of urban form.

- There is a need to know more about the interaction of urban structure (e.g. density, size, street network), travel activities, and energy use at city level.
Distribution of population by settlement size (1951-2011)

% urban                  15%      17%      18%      22%      26%      28%      31%

100%                      3%       1%       3%       4%       3%       4%       4%
                         2%       3%       3%       3%       2%       2%       3%
  90%                      10%      11%      4%       6%       7%       8%       9%
                         8%       8%       4%       6%       7%       8%       9%
  80%                      5%       8%       10%      9%       10%      9%       9%
  70%                      17%      18%      20%      12%      14%      16%      17%
  60%                      20%      21%      21%      22%      23%      24%      24%
  50%                      21%      21%      18%      19%      18%      17%      17%
  40%                      21%      19%      18%      15%      12%      10%       8%
  30%                      22%      17%      13%      10%       7%       5%       3%
  20%                      22%      17%      13%      10%       7%       5%       3%
  10%                      22%      17%      13%      10%       7%       5%       3%
  0%                       22%      17%      13%      10%       7%       5%       3%

- megacities (>10 million)
- booming cities (5 - 10 million)
- million-plus cities (1 - 5 million)
- cities (100,000 - 1 million)
- cities (<5,000 - 100,000)
- large villages (> 5,000)
- medium villages (2,000-5,000)
- small villages (1,000-2,000)
- hamlet (< 1,000)
- small hamlet (< 500)
Apply what we know about US/Europe to India?

Figure 4  Density Versus Private Vehicle Ownership (JICA 2011)

These three figures illustrate the relationships between population density and vehicle ownership, taking into account city size, per capita gross domestic product (GDP), and world region. The high R² values indicate strong relationships. This indicates that even in affluent cities, increased density reduces per capita vehicle ownership, which in turn leverages reductions in per capita vehicle travel.

Figure 3  Average Daily Vehicle-miles Per Capita (Kuzmyak 2012, Figure 76)

Increased density reduces vehicle mileage even in relatively new cities such as Phoenix, Arizona.

Figure 2  Annual Vehicle Miles per Person by Population Density

Source: 2009 NHTS. Population density data was appended to the NHTS files from the Nielsen-Clariitas annual demographic update. See www.clariitas.com/MarketPlace/Default.jsp.
Note quite the same story: Urbanization (%) and household car ownership (%) in India.
### Methods for Estimating VKT/PKT

<table>
<thead>
<tr>
<th>Source of VMT data</th>
<th>Applications</th>
<th>Limitations in Indian context</th>
</tr>
</thead>
<tbody>
<tr>
<td>travel survey</td>
<td>Detailed information on VKT estimates, eg. vehicle odometer readings and model year, household self-reported annual VKT, and daily VKT during a designated 24-hour period</td>
<td>India does not have a national survey or any systematic record of travel behavior at national and regional level.</td>
</tr>
<tr>
<td>traffic count</td>
<td>Monthly and yearly VKT by roadway functional classes and vehicle types nationally and by state</td>
<td>Few traffic count from permanent automatic traffic counts and short-period traffic counts in India</td>
</tr>
</tbody>
</table>
| vehicle odometer readings | • Precise estimate of VKT for each vehicle type  
• In some US states, odometer information can be accessed from vehicle registration or emissions inspection checks. | Lack of regular vehicle inspections where the average distance travelled by the vehicles is determined |
| GPS-based travel survey | • More information about route choice, speed, and path  
• Addressing underreporting and nonresponse issue                                                                                           | GPS-based survey is expensive and small-scale.                                                     |
| land use model          | Use land use-based trip generation factors to estimate vehicle trips and then multiply the trips by average trip lengths to calculate VKT      | Useful only at a small scale, such as a metropolitan area where land use information are complete and accurate |
| fuel consumption        | • often used to validate data obtained from bottom-up method  
• VKT is estimated from information about fuel supply and fuel consumption as derived from estimates of kilometers driven per fuel liter for typical types of vehicles | appropriate only at a very large regional scale, where it would be less risky to assume that cars were driven in the same region where they were refueled. |
Explore the use of “big data” to collect two categories of information:

1. *urban structure and development* such as via remote sensing and measures of the road network, and
2. *travel patterns and activity* information such as traffic and congestion, as geospatially explicit as possible across multiple timescales (decades, annual, daily, and hourly).

Better quantify how these two categories of behavior influence each other over multiple temporal and spatial scales.
Urban data sources

- Conventional urban data
  - Satellite images
    - Mapping urban expansion, physical attributes
  - Census data, traffic counts, travel surveys, etc
    - time-consuming, labor-intensive, costly, and restricted to scope and scale, inaccessible

- Urban big data
  - massive amounts of data for cities that reflect city spatial-temporal dynamics about people, their movement, and activities.
  - Examples: public transit smart card data, mobile phone data, location-based social media data, real-time information (Google Traffic, Waze, Bing Maps)
    - Short times, fine spatial scales
    - Occurrence as a byproduct
    - Presence in everyday urban life
    - Available to researchers
Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object.

Spatial and temporal pattern of urban expansion

- Classification: urban/non-urban
- Area of urban land (km2)
- Compare rates of urban expansion
- Connect the patterns to population data
## Landsat satellite image: Chennai urban growth

The administrative area of Chennai Metropolitan Area (CMA) is 1189 km².

<table>
<thead>
<tr>
<th>Year</th>
<th>1991</th>
<th>2001</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (person)</td>
<td>5.2 million</td>
<td>7.0 million</td>
<td>8.7 million</td>
</tr>
<tr>
<td>Population density (person/km²)</td>
<td>4373</td>
<td>5887</td>
<td>7317</td>
</tr>
<tr>
<td>At least one car (% HH)</td>
<td>8.2%</td>
<td>13.2%</td>
<td></td>
</tr>
</tbody>
</table>

Source: India Census

Map scale: 1:150,000
Rapid urban growth: Jaipur 2001 - 2011

2.3 million (2001) 6% households who have at least one car in 2001
3.1 million (2011) 12% households who have at least one car in 2011
OpenStreetMap (OSM): Infrastructures of Mobility

- An open and freely available database of geographic data
- As of December 2014, the content is edited by 1.9 million volunteer participants across the world.
- Timely updated and highly consistent with other data sources in large urban areas of India
- The main key for classifying the street network is “highway” tag, with values directly related to road hierarchy (e.g. “motorway”, “trunk”, “primary”, “secondary”, “tertiary”, “residential”) and with values directly related to mode (e.g. “cycleway”, “footway”, “pedestrian”).
OpenStreetMap (OSM): Infrastructures of Mobility

- OSM considers streets and paths designed for non-motorized modes
- Connect to land use and population information
OpenStreetMap (OSM): road density

- A circle is drawn around each raster cell center (10m X 10m) using the search radius (100m).
- The length of the portion of each line that falls within the circle is multiplied by its Population field value (number of lanes for each class).
- These figures are summed, and the total length is divided by the circle's area.

<table>
<thead>
<tr>
<th>ROAD TYPE</th>
<th>weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways and links</td>
<td>6</td>
</tr>
<tr>
<td>Trunk roads and links</td>
<td>6</td>
</tr>
<tr>
<td>Primary roads and links</td>
<td>4</td>
</tr>
<tr>
<td>Secondary roads and links</td>
<td>4</td>
</tr>
<tr>
<td>Tertiary roads and links</td>
<td>2</td>
</tr>
<tr>
<td>Local roads</td>
<td>1</td>
</tr>
</tbody>
</table>
OpenStreetMap (OSM): road density

Road density (km/km²)
- 0
- 0.01 - 10
- 11 - 20
- 21 - 25
- 26 - 30
- 31 - 40
- 41 - 80
- 81 - 100
- 110 - 330
Vehicle ownership vs. road density

Weighted road density in 2014 and % household having at least one car, jeep, and van in 2011, district level, n=640

City expand

GDP

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Real-time Google Traffic

- Red for significant congestion, yellow for minor slow-downs, and green for free-flowing traffic
- Access to Google traffic layers using Google Maps application programming interfaces (APIs)
- Google zoom level=13 for all four cities and a bounding box with latitude and longitude is used to capture traffic images for each city.
- An image processing software is used to differentiate the color (green, yellow, and red) of pixels using “rule-based feature classification”.

Traffic

Fast  -  Slow

Live traffic  ○  Typical Traffic

Access to Google traffic layers using Google Maps application programming interfaces (APIs)

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Live traffic  ○  Typical Traffic
Frequency of traffic flow over 24-hour with interval of 30 mins

Tues Jan 27, 2015
Delhi: road density and traffic intensity
Mumbai: road density and traffic intensity
Bangalore: road density and traffic intensity
Chennai: road density and traffic intensity
# Summary urban data sources

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<th>Applications</th>
<th>Limitations</th>
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<tr>
<td>Remote sensing</td>
<td>Area of urban/built-up area</td>
<td>Coarse spatial resolution</td>
</tr>
<tr>
<td>Census, government documents, travel survey</td>
<td>Social-economic indicators</td>
<td>Not timely updated, time consuming, costly, extensive labor work</td>
</tr>
<tr>
<td>OpenStreetMap (OSM)</td>
<td>Road network and Point of Interest (POI); a basis for building multimodal urban network model</td>
<td>May not be representative, digital divide</td>
</tr>
<tr>
<td>Real-time traffic (Google traffic)</td>
<td>Visualize traffic information. Can be used to map where and when traffic congestion happens in cities</td>
<td>No specific information about number of vehicles on the roads, and speeds.</td>
</tr>
<tr>
<td>Social media data (Twitter and Facebook)</td>
<td>mapping urban activity and mobility</td>
<td>May not be representative if information is biased by self-selection</td>
</tr>
</tbody>
</table>

**Decades**

**Annual**

**Daily**

**Hourly**

**Minutely**

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SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS
Connecting Urban Research to VMT?

- Characterize urban land use expansions of selected cities (e.g. urban, suburban, hybrid) in the last decade or two
- Use road network analysis to estimate the change of road density associated with urban expansion
- Estimate the levels of travel (VMT) associated with urban expansion
  - Road capacity analysis
  - Traffic flow analysis
- Project future urban expansion (based on historical rates of urban expansion) and future VMT changes
Thank you!