Hacia sistemas sustentables de movilidad urbana en el siglo 21: principios fundamentales y ejemplos

Programa de Capacitación para Jóvenes Profesionales en Planeamiento, Regulación y Gestión Pública del Transporte Urbano Metropolitano

Noveno Seminario de Actualización

Christopher Zegras
Assistant Professor, Transportation and Urban Planning
Massachusetts Institute of Technology

Contents

I. Metropolitan Mobility: Five Fundamental Principles

II. Sustainable Metropolitan Mobility: A Carbon Imperative?
   – Mobility = f (Built Environment)?
   – CO2_{urban mobility} = f (BE) in a developing city?
   – Examples: Santiago (Chile) and Jinan (China)
   – Implications
I. Metropolitan Mobility: Five Fundamental Principles

• 1. The Three I’s (Information, Intelligence, Integration)
• 2. Sustainability
• 3. Multi-Scale (from local to global)
• 4. Practical Innovation
• 5. Education

1. The Three I’s: Integration

• Modes
• Purposes, or end uses
• Hardwares and softwares
• Disciplines
• Analytic approaches
• Institutions and sectors
1. The Three I’s: Information

- Main challenge: *right* information into the *right* hands at the *right* time for the *right* purposes:
  - User decisions
    - *before* and *during* travel
  - Provider decisions
    - deployment; when travel is taking place
    - *accurate pricing* of the assets
  - Planning decisions
    - what to provide, when, and where
1. The Three I’s: Intelligence

Challenges
- Deploying data sources for improved tactical, operational, and strategic purposes
- Information overload risk
- Privacy, data ownership (and thus permitted use) and transparency (including for accountability).

1. The Three I’s: Intelligence

- Data-collection deployment
  - e.g., smart phones, and the like, for improved travel and activity surveys
- Data mining to extract higher level knowledge
- Data and computing to improve our predictive capabilities
  - short-, medium-, and long-term predictions
  - knowing what the system will do and how we can make it do it better.
1. The Three I’s: **Examples**

**CityMotion** (MIT Portugal Program)

• *Information* (data) from public/private sectors

• Large source of heterogenous data, compiled and “fused” by a university consortium to **demonstrate** the power of the fusion.

• Example: short-term traffic prediction tool using **DynaMIT** on Brisa toll-road

---

1. The Three I’s: **Examples**

Singapore MIT Alliance for Research and Technology: **Future Mobility** program:

1. information and communication technologies

2. advanced integrated microsimulation models (short-, medium-, long-term)

3. the policy, planning, institutional and financial framework necessary to use the information and knowledge **wisely**
2. Sustainability

• What are we trying to sustain?
  ➢ Accessibility

• Sustainable Mobility:

  Maintaining the capability to provide non-declining accessibility over time

• Accessibility = superior good.
  – Much (most?) of the developing world is accessibility poor
  – Improving accessibility, sustainably, is a fundamental development imperative

2. Sustainability

• How do we know we are moving in the right direction?

  The development and deployment of “metrics that matter”

• Standardized, meaningful, scale-able and operational performance measures
  – reflecting accessibility (in its multiple dimensions)
  – and life-cycle-based effects
    • based on full-cost accounting principles, etc., on the other.
3. Multi-Scale

- From Neighborhood to Metropolis to Regions
- Global Perspective Necessary
- North ↔ South
  - E.g., bus rapid transit (BRT)

4. Innovation

- Requires entrepreneurship
  - Again, South → North Lessons…
- Technology-enhanced/enabled
  - Combine “high”/“low” techs (Paris’ Velib)
  - capitalize on intermediate mode potential
  - revolutionize financial/incentive system
- “Distributed” knowledge infrastructures
  - Dynamic infrastructure management
  - Mobility brokers
- Barriers: digital divide; privacy concerns; data ownership; ‘opting out’
5. Education

- Need for new trans-disciplinary capabilities
- Cooperative Educational Models
- Next generation of professionals and ongoing capacity-building
- PCTU is a great example

3 Universities: IST-Lisboa, U. Coimbra, Porto

3 Domains: Management & Finance, Engineering, Policy & Regulation

3 Themes: Transportation systems, International context, Business models
In Sum: Metropolitan Mobility for 21st Century

- Information → Intelligence → Integration → Sustainability
- Multi-scale: collaborative networks and partnerships practical
- Innovations
- Education: of the next generation of global leaders

II. Sustainable Metropolitan Mobility

A carbon imperative in the developing world?
### Accessibility

**how do we “get” it?**

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>Effect on Accessibility (all else equal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>Improved with more links, faster or cheaper service</td>
</tr>
<tr>
<td>Spatial distribution of “opportunities”</td>
<td>Improved if proximity of opportunities is increased</td>
</tr>
<tr>
<td>Individual (personal/firm) characteristics</td>
<td>Improved with physical, mental, economic ability to take advantage of opportunities</td>
</tr>
<tr>
<td>Quality of opportunities</td>
<td>Improved with more, or better, opportunities within same distance/time</td>
</tr>
<tr>
<td>Information and communications technologies (ICTs)</td>
<td>Improved with more, more rapid, and more ‘realistic’ connections</td>
</tr>
</tbody>
</table>

---

**Why focus on developing urban areas?**
The Urbanizing Developing World…the current paradigm does not scale…

By 2030

~2 billion new residents

\[ \times \]

~3,000 vkm/person/year

~6 trillion additional vehicle kms/yr

~600 billion additional liters of gasoline/yr

or

~1.4 billion tonnes of CO2 annually
• GDP per capita explains “only” about 40% of variation
  – suggests an elasticity of about 1 (0.95; 0.66-1.22)
• Density, primate city, national rail and road network, and exports explain another 30%
### Urban Transport GHGs

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Choice</strong></td>
<td>(grams / liter)</td>
</tr>
<tr>
<td>- Fuel Type</td>
<td></td>
</tr>
<tr>
<td>- Engine Type</td>
<td></td>
</tr>
<tr>
<td>- Vehicle Age</td>
<td></td>
</tr>
<tr>
<td>- Temperature</td>
<td></td>
</tr>
<tr>
<td>- Altitude</td>
<td></td>
</tr>
<tr>
<td>- Built Environment</td>
<td></td>
</tr>
<tr>
<td>- Etc.</td>
<td></td>
</tr>
<tr>
<td><strong>Fuel Intensity</strong></td>
<td>(liters / pkm)</td>
</tr>
<tr>
<td>- Engine Type</td>
<td></td>
</tr>
<tr>
<td>- Vehicle Load</td>
<td></td>
</tr>
<tr>
<td>- Vehicle Age</td>
<td></td>
</tr>
<tr>
<td>- Congestion Levels</td>
<td></td>
</tr>
<tr>
<td>- Capacity Mix</td>
<td></td>
</tr>
<tr>
<td>- Built Environment</td>
<td></td>
</tr>
<tr>
<td>- Etc.</td>
<td></td>
</tr>
<tr>
<td><strong>Mode Share</strong></td>
<td>(% pkm)</td>
</tr>
<tr>
<td>- Income</td>
<td></td>
</tr>
<tr>
<td>- Motorization</td>
<td></td>
</tr>
<tr>
<td>- Infrastructure</td>
<td></td>
</tr>
<tr>
<td>- Service Provision</td>
<td></td>
</tr>
<tr>
<td>- Relative Costs</td>
<td></td>
</tr>
<tr>
<td>- Built Environment</td>
<td></td>
</tr>
<tr>
<td>- Etc.</td>
<td></td>
</tr>
<tr>
<td><strong>Activities</strong></td>
<td>(pkm = trips x kms)</td>
</tr>
<tr>
<td>- Population</td>
<td></td>
</tr>
<tr>
<td>- Demographics</td>
<td></td>
</tr>
<tr>
<td>- Income</td>
<td></td>
</tr>
<tr>
<td>- Economy</td>
<td></td>
</tr>
<tr>
<td>- Built Environment</td>
<td></td>
</tr>
<tr>
<td>- Etc.</td>
<td></td>
</tr>
</tbody>
</table>

### Travel Behavior (TB) = f (BE)?

**Something new?**
Travel Behavior (TB) = f (BE)?

Theoretically, ambiguous net effects

- BE influences net utility for user
  - Disutility: costs of travel (including perceived)
  - Utility: potential activity destinations

- Example, If BE → TT↓, then i might
  a) Increase activity time,
  b) Choose alternative (more-preferred) destinations,
  c) Schedule additional non-home activities.

- b) and c) would result in increased total travel,
  - consistent with the idea of constant travel time budgets
  - (empirical challenge: typically available travel survey data…)

TB = f (BE)?

Unclear pathways of effects

Transport-Efficient Neighborhood

Transport-Efficient Behavior
TB = f (BE)?
Unclear pathways of effects

Transport-Efficient Neighborhood

Transport-Efficient Preferences

Transport-Efficient Behavior
TB = f (BE)?
Unclear pathways of effects

Transport-Efficient Neighborhood

Transport-Efficient Preferences

Transport-Efficient Behavior
TB = f (BE)? Unclear pathways of effects

TB = f (BE)? Empirical Evidence

Challenges to generalizability include variations in:
- Scale of analysis
- Types of BE measures used
- Travel behavior data used
- Analytical approaches and control variables employed; and,
- Ultimate outcomes measured
  - e.g., trip frequencies, mode choices, distances, etc.
Measuring the Built Environment: “What zone do you live in?”

TB = f (BE)? Empirical Approaches

“Vector” representation of the BE, e.g.:
- Density
- Diversity
- Design
- Relative Location

➢ But, these variables are, in reality, limited
➢ And, maybe the “whole > ΣParts”?
Empirical Precedents: USA?

- Doubling of future development densities
  - Up to 60 mn new DUs by 2030
  - 1-8% reduction in CO2 versus BAU

Examples from two (very?) different developing urban contexts

**Santiago Chile**
- data provided by SECTRA
- analysis with G. Hunter (MCP)

**Jinan, China**
- travel data collected by Shandong Univ.
- analysis with Y. Jiang (MCP/MST)
### A few stats

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Santiago</th>
<th>Jinan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (persons/hectare)</td>
<td>61</td>
<td>65</td>
</tr>
<tr>
<td>Urban pop. (mn)</td>
<td>~5.5</td>
<td>~4</td>
</tr>
<tr>
<td>Avg Home Size (m²)</td>
<td>71</td>
<td>68</td>
</tr>
<tr>
<td>HH Auto Own Rate</td>
<td>42% (2001)</td>
<td>31% (2006)</td>
</tr>
<tr>
<td>Public Mode Share</td>
<td>33%</td>
<td>16%</td>
</tr>
<tr>
<td>GDP/Capita (AAGR 90-08)</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>Gini Coefficient</td>
<td>52</td>
<td>42</td>
</tr>
<tr>
<td>Gasoline/Capita (liters)</td>
<td>149</td>
<td>45</td>
</tr>
<tr>
<td>US$ Gas/Diesel per ltr</td>
<td>109/86</td>
<td>69/61</td>
</tr>
</tbody>
</table>

### Examples from two (very?) different developing urban contexts

**Santiago Chile**
- data provided by SECTRA
- analysis with G. Hunter (MCP)

**Jinan, China**
- travel data collected by Shandong Univ.
- analysis with Y. Jiang (MCP/MST)
Santiago’s Emerging Middle Class

Sources: Derived from SECTRA, 1992; 2002

Santiago’s Auto Ownership & Use

Source: derived from SECTRA, 2002
Santiago’s Transport CO₂ Emissions (2000)

Sources: Univ. de Chile, 2002; Metro 2002; DICTUC, 2004

Santiago’s Passenger Transport: Mode Share vs. GHG Share
Santiago: Previous Analysis

HH Motor Vehicle Ownership (# vehicles) = \( f (\text{HH Characteristics, Urban Form, Urban Design}) \)

Selection bias and endogeneity

Motor Vehicle Use (VKM/day) = \( f(#\text{ vehicles, HH characteristics, urban form, urban design}) \)

Results: Elasticities of Auto VKT

Zegras, 2010.
But, what about CO2, accounting for all travel modes?

- Distance to CBD effect falls
  - Reduced auto VKT still requires travel by other (motorized) modes
- Metro effect disappears
  - Strange result given Metro’s relative “CO2-cleanliness”
- Combined effect of land use mix, CBD distance, residential density, street layout (share 4-way intersections) = income effect
  - Elasticity of CO2 = ~0.37
- Models still being refined
  - Including for joint effects and underlying modal substitutions.

Examples from two (very?) different developing urban contexts

**Santiago, Chile**
- data provided by SECTRA
- analysis with G. Hunter (MCP)

**Jinan, China**
- travel data collected by Shandong Univ.
- analysis with Y. Jiang (MCP/MST)
## Neighborhood Typologies in Jinan

### Typologies: Basic Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Traditional</th>
<th>Grid</th>
<th>Enclave</th>
<th>Superblock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking (lots/100 HHs)</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>Entry Interval Dist.(m)</td>
<td>218</td>
<td>107</td>
<td>148</td>
<td>730</td>
</tr>
<tr>
<td>Green Coverage</td>
<td>0%</td>
<td>12%</td>
<td>17%</td>
<td>31%</td>
</tr>
<tr>
<td>Land Use Mix</td>
<td>0.23</td>
<td>0.32</td>
<td>0.37</td>
<td>0.07</td>
</tr>
<tr>
<td>Building Function Mix</td>
<td>0.33</td>
<td>0.34</td>
<td>0.38</td>
<td>0.04</td>
</tr>
<tr>
<td>Population Density (persons/km2)</td>
<td>34,000</td>
<td>37,500</td>
<td>43,500</td>
<td>46,000</td>
</tr>
<tr>
<td>Household Density (households/km2)</td>
<td>12,500</td>
<td>19,000</td>
<td>19,500</td>
<td>16,000</td>
</tr>
<tr>
<td>FAR</td>
<td>1.2</td>
<td>1.7</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Average Building Height (floors)</td>
<td>2.2</td>
<td>5.5</td>
<td>5.3</td>
<td>10.1</td>
</tr>
</tbody>
</table>
Transportation Energy: MJ/Person

Vehicle Ownership: Income and Typology
Jinan: Analytical Approach

- 9 neighborhoods, 4 typologies
  - Approx. 300 HHs per neighborhood
- For the moment, only MJ (not CO2…yet)
- Again, 2-stage models
  - Vehicle ownership
  - Total transportation use

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect on Auto Own</th>
<th>Effect on Energy Use via Car Own.</th>
<th>Effect on Energy Use via All Veh. Use</th>
<th>Combined Effect on Energy Use (MJ/HH/Wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Grid</td>
<td>-24%</td>
<td>-75</td>
<td>-55</td>
<td>-130</td>
</tr>
<tr>
<td></td>
<td>-30%</td>
<td>-86</td>
<td>-30</td>
<td>-116</td>
</tr>
<tr>
<td>Enclave</td>
<td>-31%</td>
<td>-86</td>
<td>-21</td>
<td>-107</td>
</tr>
<tr>
<td>2x Dist. to City Center</td>
<td>-8%</td>
<td>-18</td>
<td>+42</td>
<td>+23</td>
</tr>
<tr>
<td>On BRT Corridor</td>
<td>-4%</td>
<td>-6</td>
<td>+29</td>
<td>+22</td>
</tr>
<tr>
<td>Double Income</td>
<td>+12%</td>
<td>+31</td>
<td>+15</td>
<td>+46</td>
</tr>
<tr>
<td>Have Company Car</td>
<td></td>
<td></td>
<td>+562</td>
<td>+562</td>
</tr>
<tr>
<td>Own Motorcycle</td>
<td>-8%</td>
<td>-14</td>
<td>+76</td>
<td>+61</td>
</tr>
<tr>
<td>Own E-Bike</td>
<td>-10%</td>
<td>-13</td>
<td>-23</td>
<td>-36</td>
</tr>
<tr>
<td>Own Bike</td>
<td>-10%</td>
<td>-10</td>
<td>-29</td>
<td>-40</td>
</tr>
</tbody>
</table>
Is the BE associated with lower urban transportation CO2 emissions?

- YES, with combined effects at least as strong as the income effect

- And, interestingly, income effect is closely comparable across the 2 settings examined
  - Jinan: 0.35-0.48 (MJ); Santiago: 0.37
  - How does this compare to the global national averages?

• Does the BE cause lower urban transportation CO2 emissions?
  – Cannot say based on our analyses

• What about effects on total transportation emissions?
$\text{CO}_2_{\text{urban transport}} = f(\text{BE}),$ so?

- Is BE the most cost-effective mitigation measure?
  - Again, cannot tell from our analyses
  - But, technology alone will not likely get us where we need to be by 2030…

- What about the carbon offsets market?
  - Behaviorally based efforts
  - Integrated models have too much uncertainty
  - “Statistics-based” approaches have not yet convinced the relevant powers (CDM Board)

$\text{CO}_2_{\text{urban transport}} = f(\text{BE}),$ so?

- Has transportation been held (unfairly) to a higher standard?
  - E.g., uncertainties, “leakage”, etc.
  - Some quantification challenges are not inherent to transport alone
CO$_2$ urban transport *quo vadis*?

- Challenge too large for the current project-based offset approach?
  - Across-ASIF suite of interventions may be most necessary

- Sectoral and/or programmatic CDM still face fundamental challenges
  - Baseline establishment, leakage, verification, additionality, accountability, etc.

- Advanced ICTs *could* help in modeling, monitoring & verification
  - And additional behavioral change

CO$_2$ urban transport *quo vadis*?

- Carbon tax: where for art thou?