Urban mobility systems: complexity, models, and eco-rational choices

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Urban mobility systems: complexity, models, and eco-rational choices

Erice, May 10th, 2014

Outline

1. Urban mobility as a global challenge
2. Urban mobility as a complex system
3. Modeling urban mobility systems
4. Decision-making as a further layer of complexity
Outline

1. Urban mobility as a global challenge
2. Urban mobility as a complex system
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1. urban mobility as a global challenge

The (sometimes implied) roles of mobility

- Connect residences to workplaces/schools/shops, etc. (economic/territorial)

- Connect people (social)

- Allow urban metabolism
  - Input of goods (logistics)
  - Output of waste (waste management and reverse logistics)
1. Urban mobility as a global challenge

Cities are what their transportation systems allow them to be.
1. costs of urban mobility

- 20-30% of annual net **household income**

- 40% of GHG emissions in **urban atmosphere** result from fossil fuel driven vehicles

- 40% of **road accidents** occur in urban areas

- 25% of total **energy consumption** derives from urban transport systems
1. urban mobility as a global challenge

Challenge for the future

To combine adequate levels of accessibility and livability with a reduction of costs and externalities

- **Economic**
  - Productivity
  - Business activity
  - Employment
  - Tax burden
  - Trade

- **Social**
  - Equity
  - Human health
  - Community livability
  - Cultural and historic values
  - Public involvement

- **Environmental**
  - Pollution emissions
  - Climate change
  - Biodiversity
  - Habitat preservation
  - Aesthetics
1. Urban mobility as a global challenge

- Most of the world’s population lives in cities.
- Urbanized population passed the “symbolic threshold” of 50% in 2007 and going to exceed 60% in 2030.

1. Urban mobility as a global challenge
2. Urban mobility as a complex system
3. Modeling urban mobility systems
4. Decision-making as a further layer of complexity
2. Urban mobility as a complex systems

Complex, non-linear relationships

Interactions with activity and environmental systems
2. urban mobility as a complex systems

Supply system

*Transportation service performances for users*

- **Travel Times (walking, waiting, on boards)**
- **Reliability of travel times**
- **Fuel consumption**
- **Driving/Riding comfort**
- **Aesthetic quality of facilities**
- ...
2. urban mobility as a complex systems

Supply system

Capacity and Congestion

Congestion influences:
- average travel times
- dispersion of travel times (reliability)
- fuel consumption
- driving/riding comfort
- ...

Traffic Volumes
(# of vehicles / time interval)

Travel Time over a Link

Capacity
2. urban mobility as a complex systems

Complex, non-linear relationships

Interactions with activity and environmental systems

Travel demand is a “derived function” from the participation of people in activities or shipment of goods.
2. urban mobility as a complex systems

Demand system

Mode distribution

<table>
<thead>
<tr>
<th>City</th>
<th>Public Transport</th>
<th>Bike, Walking, other</th>
<th>Car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>10%</td>
<td>10%</td>
<td>80%</td>
</tr>
<tr>
<td>San Paolo</td>
<td>33%</td>
<td>33%</td>
<td>34%</td>
</tr>
<tr>
<td>Napoli</td>
<td>36%</td>
<td>17%</td>
<td>47%</td>
</tr>
<tr>
<td>Milano</td>
<td>40%</td>
<td>5%</td>
<td>55%</td>
</tr>
<tr>
<td>Londra</td>
<td>45%</td>
<td>20%</td>
<td>35%</td>
</tr>
<tr>
<td>New York City</td>
<td>50%</td>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>Tokyo</td>
<td>75%</td>
<td>20%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Legend:
- Public Transport
- Bike, Walking, other
- Car
2. urban mobility as a complex systems

Demand system

*Probabilistic choices*

Users choose among available alternatives according to different attributes (level of service, socio-economic, land use, etc.)

![Graph showing probability vs. difference of utility](image-url)
2. urban mobility as a complex systems

Complex, non-linear relationships

Interactions with activity and environmental systems

Urban mobility systems: complexity, models, and eco-rational choices

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2. Urban mobility as a complex system

Feedback loops

Short-term

New traffic light regulation

Supplemental text:

Urban mobility systems: complexity, models, and eco-rational choices

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2. Urban mobility as a complex systems

Feedback loops

Medium-term

New road/parking pricing scheme

[Diagram of urban mobility system with feedback loops and arrows indicating supply and demand components]
2. Urban mobility as a complex systems

Feedback loops

Long-term

New highway

INFRASTRUCTURES
VEHICLES
TECHNOLOGY
SERVICES
FARES
REGULATION

SUPPLY ELEMENT
CAPACITIES

CONGESTION

FLOWS ON MODAL
NETWORKS

TRAVEL DEMAND BY
TRANSPORTATION MODE

LEVEL, SPATIAL AND
TIME PATTERNS OF
TRAVEL DEMAND

TRANSPORTATION
SERVICE PERFORMANCES
(LOS)

ACCESSIBILITY
- active
- passive

LEVEL AND LOCATION
OF ECONOMIC ACTIVITIES

NUMBER AND LOCATION
OF HOUSEHOLDS BY TYPE

SPACE AVAILABILITY BY
AREA AND TYPE

ACTIVITY SYSTEM

ENERGY CONSUMPTION
POLLUTANTS
VISUAL INTRUSION

ENVIRONMENTAL IMPACTS

DEMAND

SUPPLY

TRANSPORTATION SYSTEM

Urban mobility systems:
complexity, models, and eco-rational choices

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2. urban mobility as a complex systems

Complex systems

- Dynamic and “with memory”
- Nested sub-systems
- Relationships are non-linear
- Relationships contain feedback loops
- Produce emergent phenomena

Sociotechnical systems

- Containing technological subsystems and components that are central to its performances
- Having societal/political/economic relevance and impacts
2. urban mobility as a complex systems

Differences with other city lifeline systems
1. Urban mobility as a global challenge
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4. Decision-making as a further layer of complexity
3. Modeling urban mobility systems

Alternative assumptions in transportation systems simulation (*Levels of representation*)

- **Time representation**
  - $d_{OD}$ vs. $t$
  - Within-day static
  - Within-day dynamic

- **Space representation**
  - Discrete (links)
  - Continuous

- **Users representation**
  - Continuous fluid
  - Discrete units

- **Users response**
  - Driving behavior (car-following, lane changing, merging, look-ahead, etc.)
  - Route choices (pre-route, en-route, etc.)
  - Other demand dimensions
## 3. modeling urban mobility systems

### Supply models for road systems

*Levels of detail*

<table>
<thead>
<tr>
<th>Flow Representation</th>
<th>Performance Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate (explicit capacity)</td>
<td>Disaggregate</td>
</tr>
<tr>
<td><strong>Continuous</strong></td>
<td><strong>Macro-simulation</strong></td>
</tr>
<tr>
<td>Space</td>
<td>Space</td>
</tr>
<tr>
<td>Discrete</td>
<td>Continuous</td>
</tr>
<tr>
<td><strong>Discrete</strong></td>
<td><strong>Meso-simulation</strong></td>
</tr>
<tr>
<td><strong>Micro-simulation</strong></td>
<td></td>
</tr>
</tbody>
</table>

Demand models

Choice dimensions

Travel demand is the result of travelers’ choice behavior over several dimensions, e.g.

- **Strategic choices**
  - activity participation
  - trip frequency
  - activity time
  - destination
  - mode/service

- **Tactical choices**
  - driver behaviour
  - departure time
  - path choice/adjustment
3. modeling urban mobility systems

Demand models
Activity-based models

Schedule

Tours

Trips

Source: Bowman (1998)
3. modeling urban mobility systems

Demand models

Random Utility Models

Decision maker \( n \) selects the alternative \( i \) with the highest perceived utility \( U_i^n \) among the available alternatives \( J^n \) in the choice set \( C^n \)

\[
U_i^n = V_i^n + \varepsilon_i^n = \sum_{h=1}^{M} (\beta_h \cdot X_{hi}^n) + \varepsilon_i^n \quad \forall i \in C^n = \{1, ..., J^n\}
\]

\( V_i^n = \sum_{h=1}^{M} (\beta_h \cdot X_{hi}^n) \)

is the systematic utility expressed as a function (e.g. a linear-in-parameter specification) of \( M \) observable variables \( X_{hi}^n \) such as expected travel times, costs, etc.

\( \varepsilon_i^n \)

random utility component

\[
P(j) = P(U_j \geq U_i | \forall i \neq j) = P(\varepsilon_i \leq (V_j - V_i) + \varepsilon_j | \forall i \neq j) = \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{(V_j - V_i) + \varepsilon_j} f(\varepsilon) \cdot d\varepsilon
\]
3. modeling urban mobility systems

Assignment models

Framework
3. modeling urban mobility systems

Assignment models – CONGESTED NETWORKS

Equilibrium

DEMAND MODEL

OD demand flows
Path/Departure time choice model
Path Flows (h)
Path cost (g)
Path Performances Model
Network Flow Propagation Model
Link flows (f)

SUPPLY MODEL

Dynamic Process

DEMAND MODEL

Cost Updating Model
O-D Flows
Expected Path Cost
Path / Departure Time Choice Model
Path Flows
Actual Path costs

SUPPLY MODEL

Network Flow Propagation Model
Link Performances Model
Link Flows
Link Performance Model

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Assignment models

Equilibrium models
- Fixed demand
- Elastic demand

Dynamic process models
- Deterministic processes
- Stochastic processes

More details in:
3. modeling urban mobility systems

Transport-Land Use Interaction Models

- Mode choice satisfaction
- Residents/worker ratios per zone
- Workers per zone
- Residents per zone
- Houses price
- Total number of jobs in Services
- Activities occupation
- Total number of jobs in Commerce
- Mode choice satisfaction
- Residential Surfaces N. of houses Zonal characteristics

DEMAND MODELS
- level, spatial-distribution, modal split
- O-D matrices by mode and purpose
- Supply Networks

ASSIGNMENT MODEL
- Input data
- Output data
- Level of service
- Zonal Accessibility
- N. of jobs per zone
- N. of houses
- Zonal characteristics
- Residential Surfaces

SERVICES LOCATION MODEL
- jobs in Services per zone
- jobs in basic activities per zone
- jobs in Comm. per zone

COMMERCE LOCATION MODEL
- Total number of jobs in Commerce
- Total number of jobs in Services
- Total number of jobs in Commerce
1. Urban mobility as a global challenge
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4. decision-making in urban mobility

Decisions related to urban mobility

- **Transport Infrastructures**
  - Building
  - Upgrading, ...

- **Transport Services**
  - Timetables
  - Fares, ...

- **Vehicles & technologies**
  - Fleet composition
  - ITS deployment and operation, ...

- **Regulations**
  - Land use regulation
  - Market regulation (e.g. Liberalizations)
  - Air quality regulations, ...

- **Activity locations**
  - Public facilities (e.g. hospitals)
  - Economic activities (e.g. shopping malls)
4. decision-making in urban mobility
4. decision-making in urban mobility

Decision-making on urban mobility can be very difficult:

- Several decision-makers and stakeholders
- Strong and contrasting interests
- Public visibility

Mobility planning is a “wicked” problem (Rittel and Webber, 1973)

1. No definitive problem formulation
2. No stopping rule
3. Not true-or-false solutions
4. No ultimate optimality test
5. “One-shot operation”
6. No enumerable set of potential solutions
7. Unique problems
8. Each problem is a symptom of another problem
4. decision-making in urban mobility

Eco-rationality

**Eco-rationality**: acting in the best possible way considering people’s health (pollution/welfare) and environment’s benefits (pollution)

Many transport policies (choices) are widely accepted as sustainable (ecological) but they are not necessary eco-rational
4. decision-making in urban mobility

Examples of potential irrationalities
Restricting the use of cars may increase congestion, energy consumption, and pollution

Case study: Naples (Italy)

<table>
<thead>
<tr>
<th>Population (ISTAT 2010)</th>
<th>GDP per capita (ISTAT and Istituto Tagliacarne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≈ 0.96 MIL. inhab.</td>
<td>≈ 34 thousand €</td>
</tr>
</tbody>
</table>
4. decision-making in urban mobility

Examples of potential irrationalities
Limited Traffic Zones (LTZs)

**Objectives**
- Reduce traffic congestion
- Reduce traffic emissions (CO2 and PM10)

**Impacts**
- - 5% traffic congestion
- + 10% traffic fuel consumption
- + 5% GHG emission (equiv. CO2)
- + 11% fine particles emission (PM10)

Increase in paths length
4. decision-making in urban mobility

Examples of potential irrationalities
Advanced Traveler Information System

Providing descriptive information to drivers may increase congestion and travel times

LOW CONGESTION

TOTAL TRAVEL TIME REDUCTIONS

HIGH CONGESTION

TOTAL TRAVEL TIME REDUCTIONS

Providing descriptive information to drivers may increase congestion and travel times.
4. decision-making in urban mobility

Examples of potential irrationalities
Advanced Traveler Information System

Not-informed users may be better-off that informed ones

LOW CONGESTION

HIGH CONGESTION

AVERAGE TRAVEL TIME REDUCTIONS

-5% 0% 5% 10% 15% 0 10 25 50 75 90 100

Market Penetration

AVERAGE TRAVEL TIME REDUCTIONS

-5% 0% 5% 10% 15% 0 10 25 50 75 90 100

Market Penetration
4. decision-making in urban mobility

Examples of potential irrationalities
Building new roads may increase congestion and pollution

“Black Holes” theory in highway investments

- Road networks are designed for peak period loads
- If congestion occurs...we build more lanes!
- But transportation/land-use systems are dynamic
- If you make it easier to travel, people will travel longer distances
- Concept of “Latent Demand”

Public pressure to add capacity
Capacity added
Travel is easier
Average trip length increases
Number of trips rises
Further congestion
Highway congestion
Thank you for your attention!
basic references

Reference papers


