Simulating Mobility in Cities: A System Dynamics Approach to Explore Feedback Structures in Transportation Modelling

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In 2025 29 Megacities (Population > 8 million) will have developed.

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Background
Urbanization

- Means of infrastructure
- Mobility cultures
- Economic performance
- Degree of motorization
- Availability of public transport
- Purchasing power of consumers
- etc.

- Worldwide, cities share difficulties to cope with augmented traffic volume, but local conditions are different …
### Background

#### Urbanization

<table>
<thead>
<tr>
<th>Berlin</th>
<th>Hamburg</th>
<th>Aachen</th>
<th>Tokio</th>
<th>Mumbai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (centre/suburbs)</td>
<td>3.4 Mio</td>
<td>3.5 Mio</td>
<td>1.7 Mio</td>
<td>2 Mio</td>
</tr>
<tr>
<td>Population density (Inhabitants / km²)</td>
<td>3.800</td>
<td>2.300</td>
<td>1.600</td>
<td>20.500</td>
</tr>
<tr>
<td>Cars per 1000 people</td>
<td>422</td>
<td>550</td>
<td>510</td>
<td>285</td>
</tr>
<tr>
<td>Cars per road km</td>
<td>250</td>
<td>240</td>
<td>200</td>
<td>420</td>
</tr>
<tr>
<td>Pop. per road km</td>
<td>590</td>
<td>440</td>
<td>390</td>
<td>1.470</td>
</tr>
</tbody>
</table>


- Worldwide, cities share difficulties to cope with augmented traffic volume, but local conditions are different …
Empirical research of historic data

Hypothesis: Car ownership levels are mainly dependant of income levels (measured in GDP per capita) and follow a s-curve shaped trajectory.

Gompertz-function to estimate future levels
- Saturation level (gamma) at 0.85 vehicles per capita
- Beta defines formature of the function
- Starting value (alpha)

\[ V_{it} = \gamma \theta e^{\alpha e^{B_i GDP_{it}}} + (1 - \theta) V_{it-1} \]
Research Objective
Dynamic Simulation of Scenarios

- Complex interaction between society, economy & mobility
  - Higher economic activity leading to more demand for mobility,
  - Higher motorization with rising incomes
  - Environmental pollution deteriorating quality of life -> demand for more sustainable solutions,…

- No simple cause-effect relationships
  - Occurrence of feedback loops
    - more traffic => more roads => more traffic => …
  - Time delays in information & product flows
    - Consumer awareness for new mobility options (e.g. car sharing schemes)
  - Different product life-cycles
    - Cars (7 yrs) – Public Transport (30 yrs)
  - Short term vs. Long-term effects
    - Reduced travel time ⇔ urban sprawl

- Need for scenario analysis with dynamic simulation
  » Improved understanding for system properties
  » Enabler for adequate mid- and long-term strategy development
  » Anticipation of future developments
Methodology
System Dynamics

- Modeling approach developed by Jay Forrester (MIT) identifying feedback loops and time delays as reasons for dynamic behavior in systems.
- No equilibrium model approach.
- First applications in the 1960’s: Urban Dynamics and Industrial Dynamics
- Best-known model: World3-Model (“Limits to Growth”)
- Simulation enabled (quantified) scenario analysis and policy development (e.g.: strategic management, public policy, operations research)
Model Structure
Different factors impact urban mobility

Means of Transport
- PV
  - Car
  - 2W
  - AT
  - IPT
- PT
  - Rail
  - Road
- NMT
  - Walk
  - Cycle

Infrastructure

Properties

Agents
- A1, A2, A3, ...
- Utility Functions & decision rules per population group
- Income, Age, Values, Expectations, ...

Economics
- Goods & Services
- GDP, ...

Land Use
- Housing Units
- Business Units ...

Legislation
- Emissions
- Charges...

Population
- Migration
- Households ...

Avg Speed
- Capacities
- Convenience
- Availability
- Costs
...
Model Structure
The System Dynamics framework

Trip distribution Sub-model
Model Structure
Advantages for Modelers

• **Scalable Design:**
  – Population Groups
  – Spatial Properties
  – Transport Modes

• **Elements of macroscopic transport modeling:**
  – 4-step algorithm
  – Gravitation model
  – Multinomial Logit

• **Dynamic feedbacks:**
  – Land use and transport infrastructure
  – Economic development and personal transport (motorization)
  – Environmental quality and mobility

• **Flexible (dynamic) framework conditions:**
  – Mode properties (cost, speed, comfort)
  – City tolls
  – Land use plans
  – Legislative measures
**VISUM Model**
- Activity chain – based transport model
- Integrated trip distribution/mode choice (VISEM)
- 198 Districts (118 + 80)
- 8 homogeneous groups of travellers
- 4 modes of transport (Bike, Walk, Public, Car)
- Including in-/outbound and through traffic for observed area

**VENSIM Model**
- 6 aggregate districts
- 3 agent groups (employed, non-employed, pupils)
- 3 modes of transport (non-motorized, public, car)
- Only traffic within observation area

Work in Progress