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

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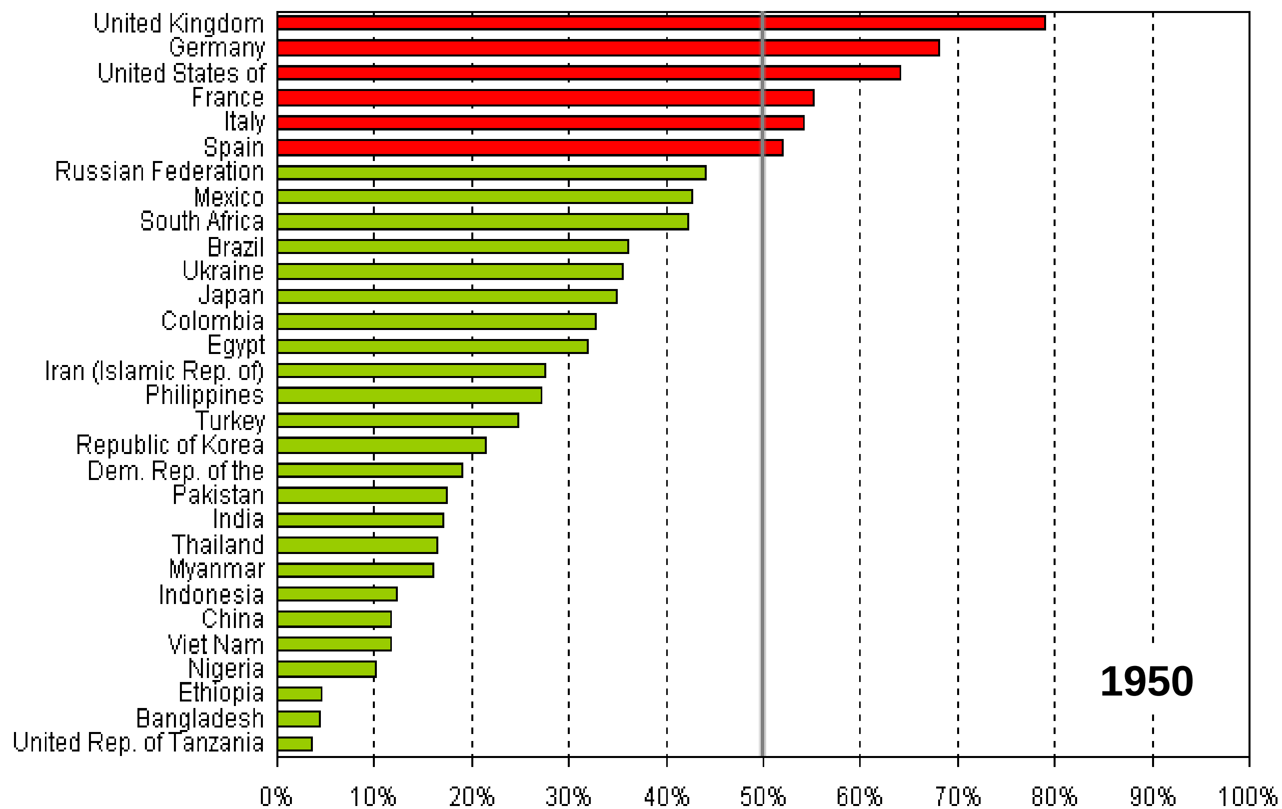
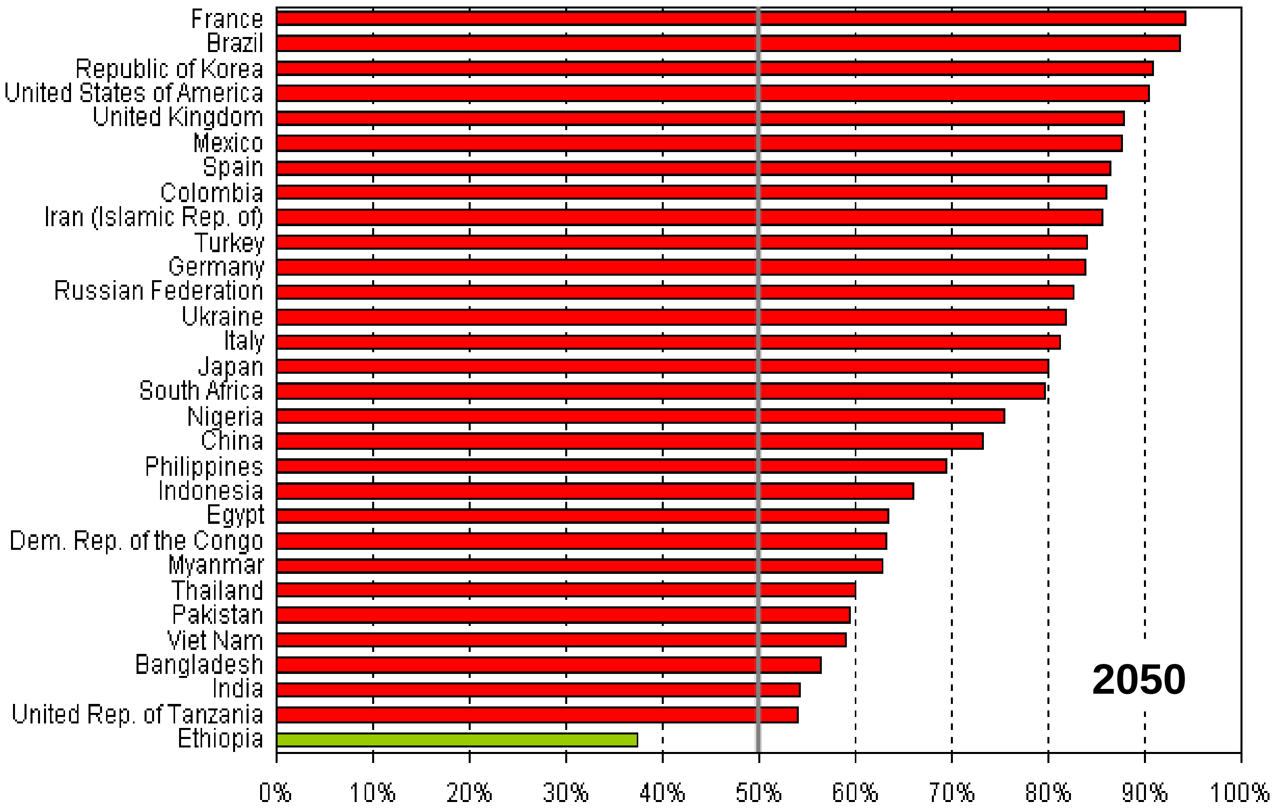
Background
Urbanization



Sources: United Nations, Siemens

- In 2025 29 Megacities (Population > 8 million) will have developed.
- In 2050, 70% of the world population is expected to be urban.

Background
Urbanization



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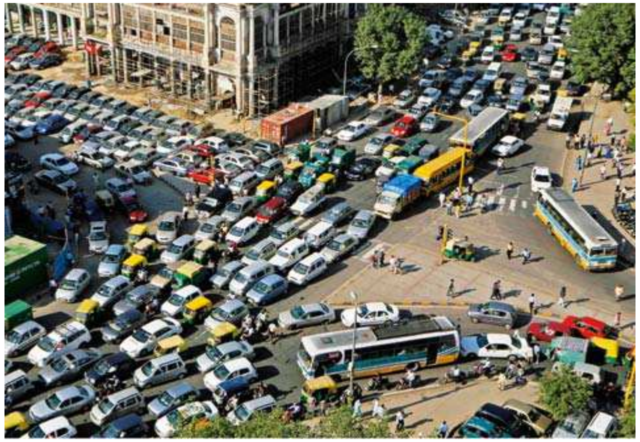
Background
Urbanization

Paris

Los Angeles

Shanghai



New Delhi

- 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

	Berlin	Hamburg	Aachen	Tokio	Mumbai
Population (centre/suburbs)	3,4 Mio / 3,5 Mio	1,7 Mio / 2 Mio	0,3 Mio / 0,8 Mio	13 Mio / 35 Mio	13 Mio / 20 Mio
Population density (Inhabitants / km²)	3.800	2.300	1.600	20.500	29.650
Cars per 1000 people	422	550	510	285	30
Cars per road km	250	240	200	420	600
Pop. per road km	590	440	390	1.470	20.000

Source: Pischetsrieder, B.: *Urbane Mobilität – Perspektiven für den Verkehr von Morgen,* Forum Elektromobile Stadt, Stuttgart, Jänner 2010

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

Background

Income’s Effect on Car Ownership

- 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)

$$V_{it} = \gamma \theta e^{\alpha e^{\beta_i GDP_{it}}} + (1-\theta) V_{it-1}$$

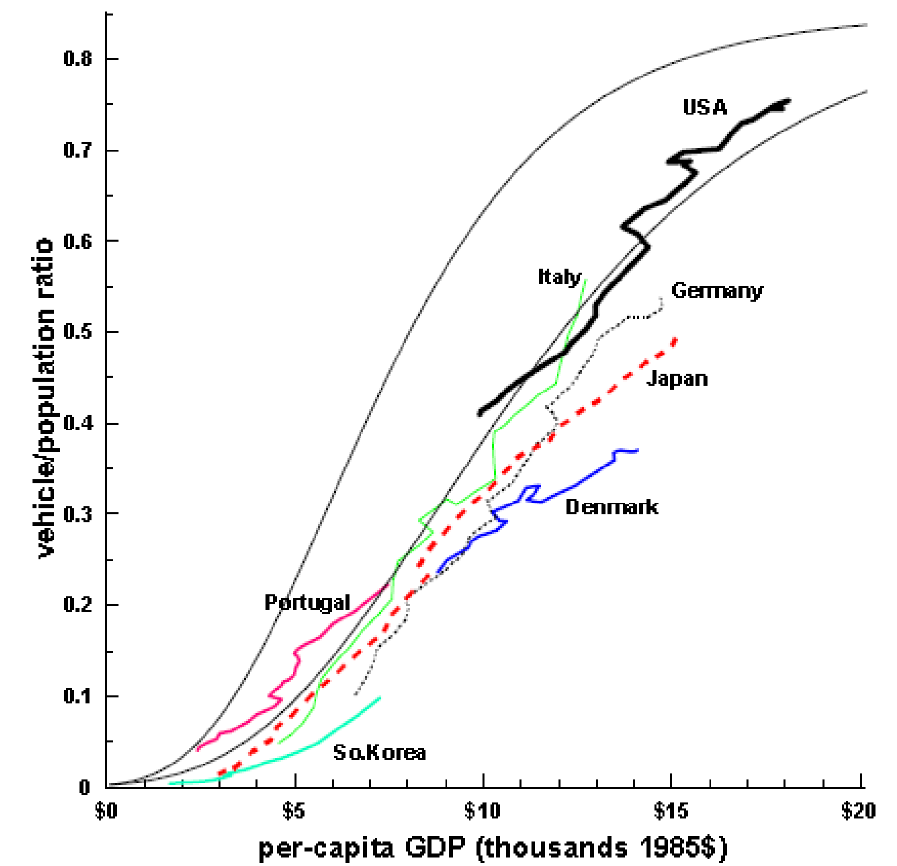
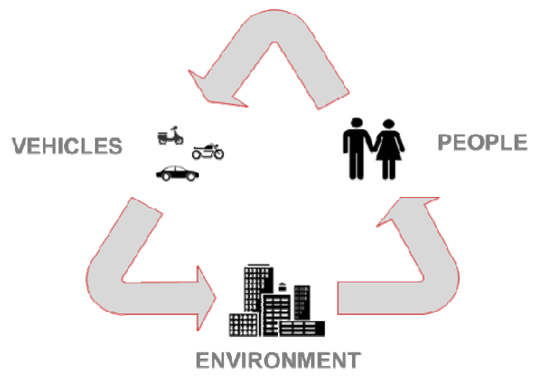


Figure 3.5. Long-run Gompertz Functions & Historical Data: 1960-92

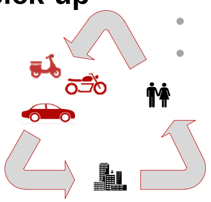
Income’s Effect on Car Ownership [Dargay, Gately 1997]

Research Objective
Dynamic Simulation of Scenarios



- **3W-CNG-Hatchback**
- **4W-Diesel-pick-up**
- **Electric-2W**
- **…**

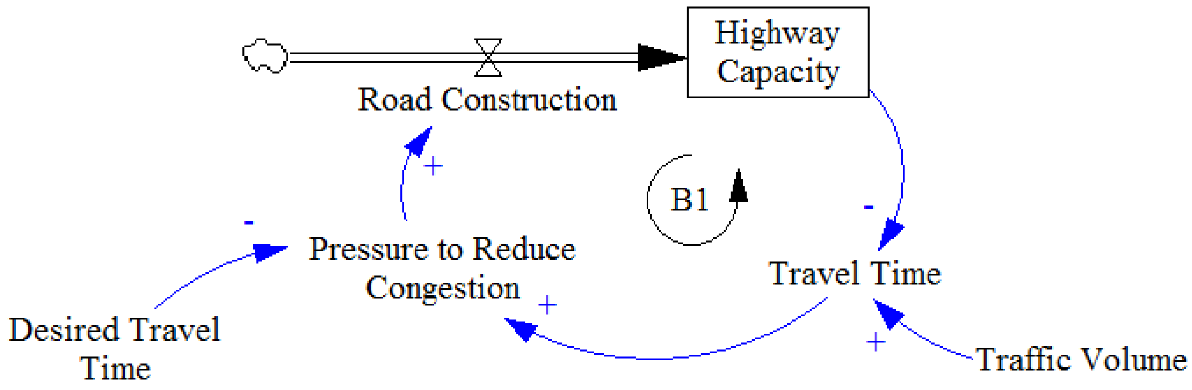
- Travel demand
- Demographics
- Avg. Income
- …



- **City toll (yes/no)**
- **Fuel price scenarios**
- **Infrastructures 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

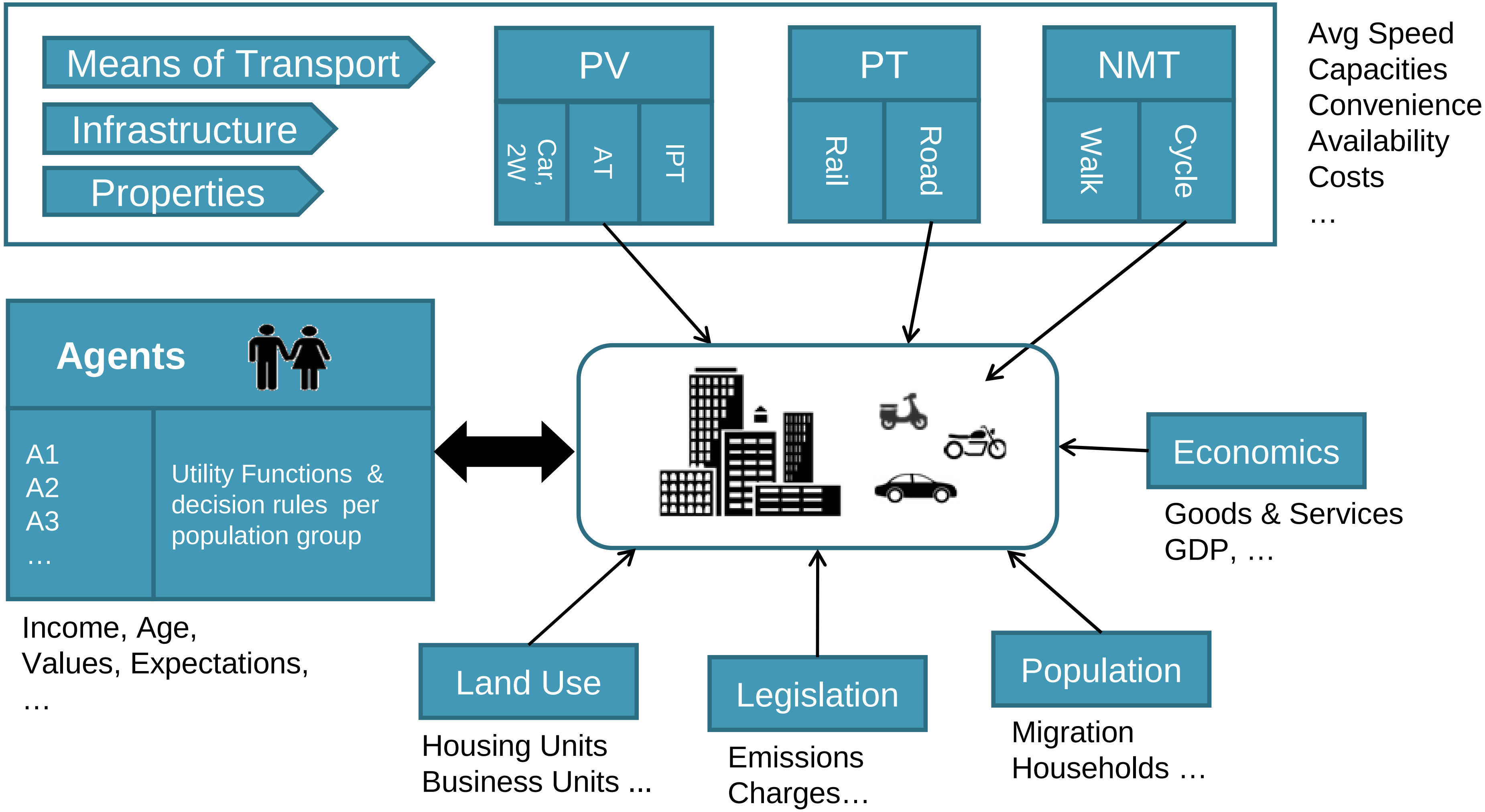
Methodology
System Dynamics



- 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)

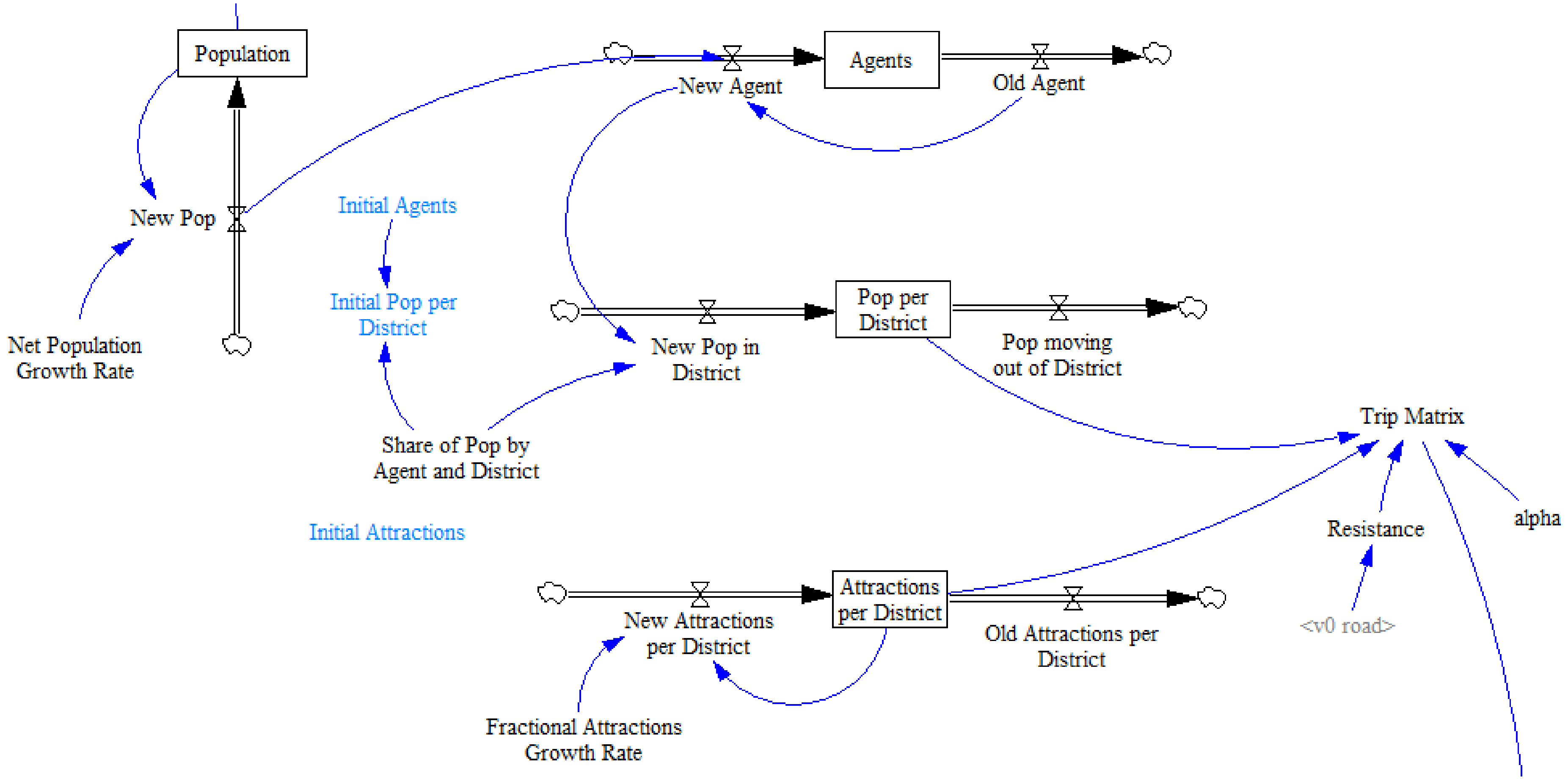
Model Structure

Different factors impact urban mobility



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

Work in Progress

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