Integrating housing and transport interactions: A strategic dynamic approach

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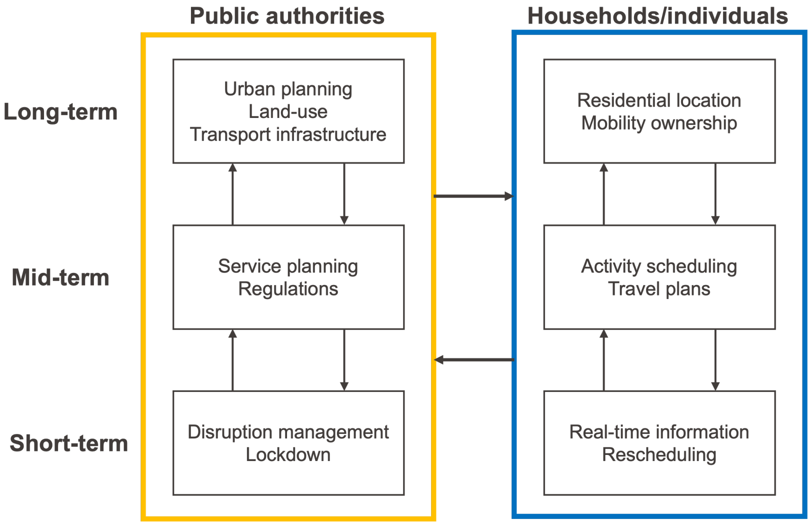
Overview

Urban systems and choices

- Think of an urban area where people are living in.
- In urban context, there are a combination of choices:
  - Different time horizons.
  - Choices of household/individuals.
  - Choices of public authorities.

Thus, there are various decisions made at different temporal, spatial, and hierarchical level.

Choices and decisions



Introduction

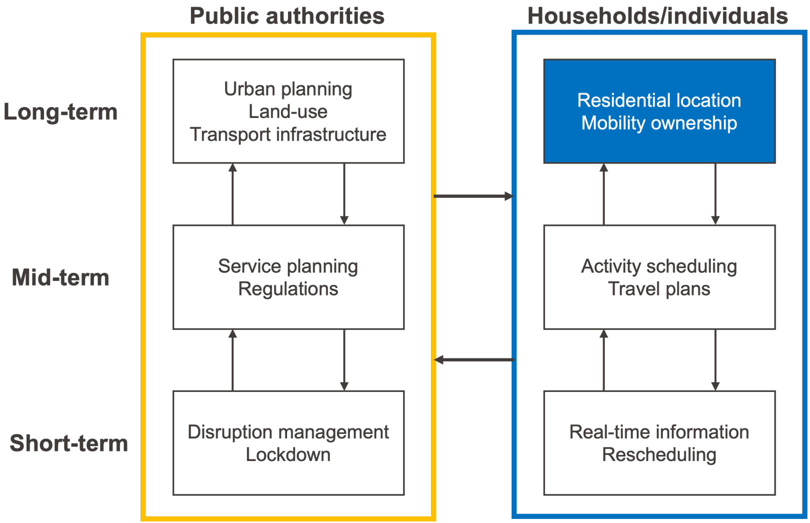
- **Challenges** stemming from the interplay of **transport** and **land-use** developments, such as:
    - Congestion,
    - Accessibility issues,
    - Increasing housing prices,
    - Housing shortage,
    - Relocation of residents.
- Effective urban/regional planning demands an **indicative tools** with capability to inform likely development **paths** under different scenarios, **over time**.

Thus, for a **structured policy decision-making process**, we need a **comprehensive model** accounting for these spatial and temporal interrelations over time.

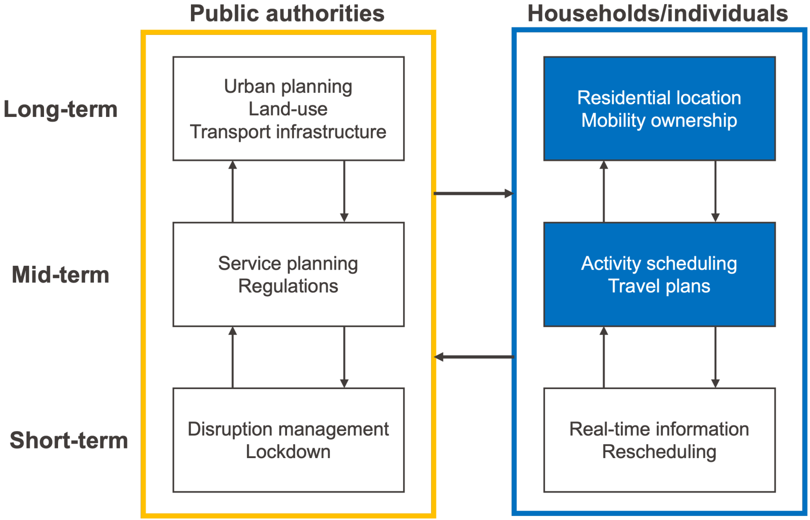
Motivation

- Case of Luxembourg; high economic development, population growth (migration, cross-borders), housing price, traffic.
- To address these challenges, understanding the **complex system** and **jointly** developing **housing** and **transport** developments, and their relevant **feedbacks** is required.
- Adding **spatial** dimension at canton-level into economic models, particularly integrating residential location and transportation endogenously in the model.
- An **efficient decision support** for potential **policy interventions**.

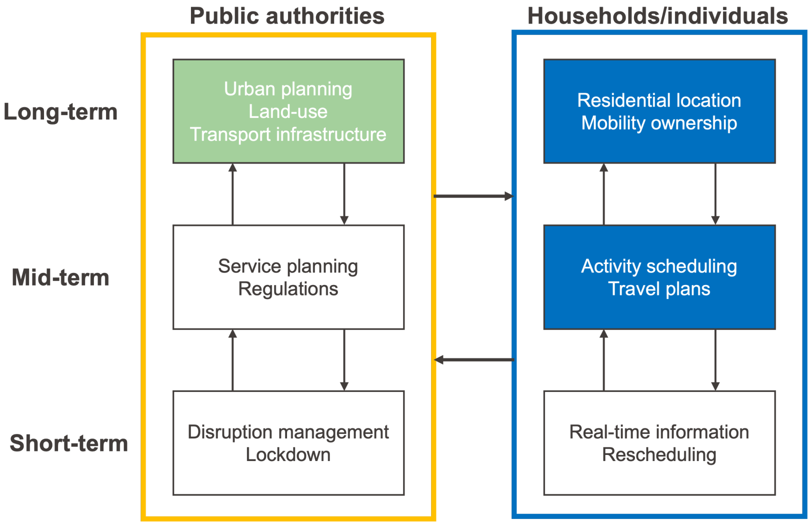
Choices and decisions



Choices and decisions



Choices and decisions



Literature review

- Land-use treated exogenously in traditional transport models.
- Multiple approaches to model transport across land-use models:

Model	Disaggregate	Aggregate
Static	• Discrete choice models (Bhat & Guo 2007, Ben-Akiva & Bowman 1998, Lerman 1976) • Ground-truth (Swisstopo)	• Spatial computable general equilibrium (Tscharaktschiew & Hirte 2012)
Dynamic	• Microsimulation (e.g., UrbanSim (Waddell 2002), ILUTE (SALVINI & MILLER 2005))	• Dynamic spatial equilibrium (Lennox 2023) • System dynamics (Pfaffenbichler et al. 2008) • Spatial interaction (Lopane et al. 2023) • Flow-based rules (e.g., Delta (Feldman & Simmonds 2014))

- *Static models do not model time evolution.*
- *Dynamic models simulate temporal feedback and trajectories.*

A Comparison of modelling approaches

Model	Disaggregate	Aggregate
Static	• + Captures heterogeneity. • + Useful for immediate impacts. • – No path evolution over time.	• + Suitable for equilibrium policy analysis. • – Ignores dynamics and temporal feedback.
Dynamic	• + Captures heterogeneity. • + Captures adaptive and path-dependent behaviour. • + Suitable for long-term scenarios. • – High model complexity. • – Long run times. • – Data-intensive.	• + Models macroeconomic trends and system-level feedback. • + Effective for strategic appraisal. • + Computationally efficient. • + Data requirement. • – Coarse spatial and social heterogeneity.

Aggregate dynamic approach

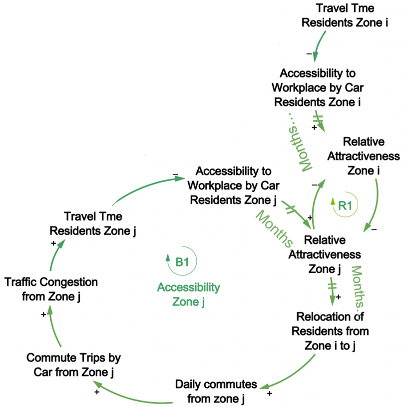
Model	Disaggregate	Aggregate
Static	• + Captures heterogeneity. • + Useful for immediate impacts. • – No path evolution over ti	• + Suitable for equilibrium policy analysis. • – Ignores dynamics and temporal feedback.
Dynam	scenarios. • – High model complexity. • – Long run times. • – Data requirement.	ic appraisal. • + Computationally efficient. • + Data requirement. • – Coarse spatial and social heterogeneity.

System thinking and Dynamic modelling
well-suited for complex systems that changes over time, due to their ability to model **feedback**, **delays**, and **dynamic adaptation**.

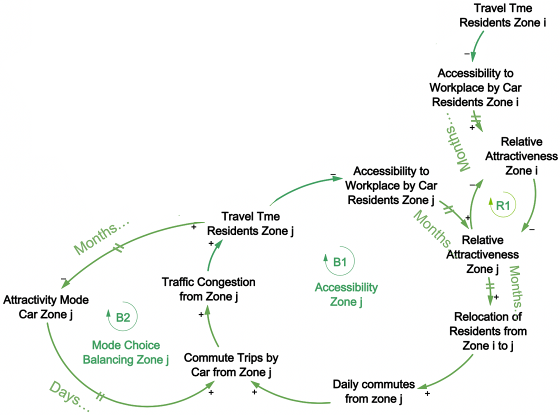
Causal loops

- Help tell a story about the system.
- Easily illustrates the mental model.
- Communicate the important feedbacks.

Causal loops in transport



Causal loops in transport



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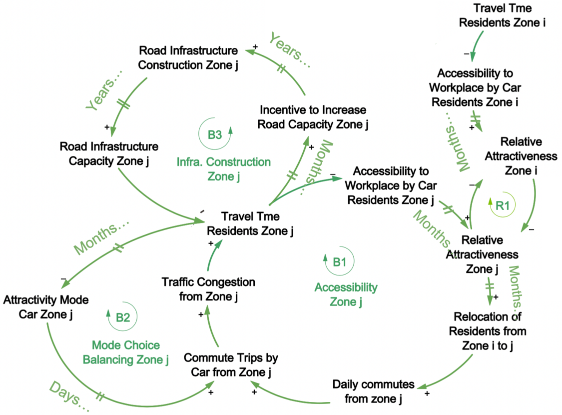

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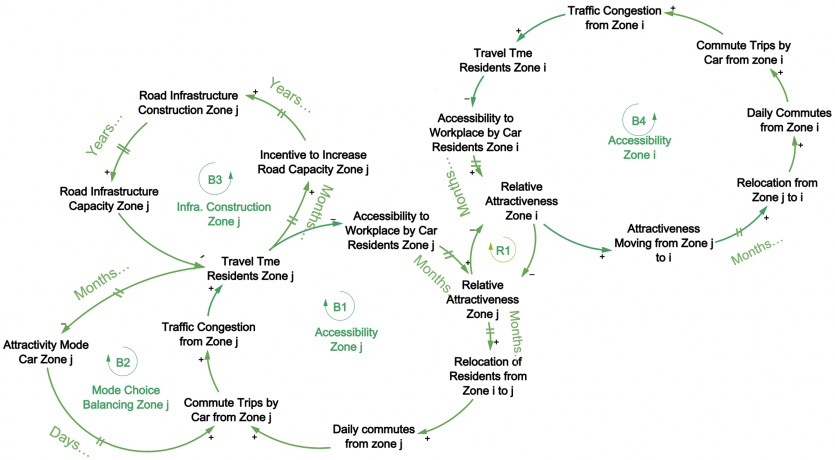

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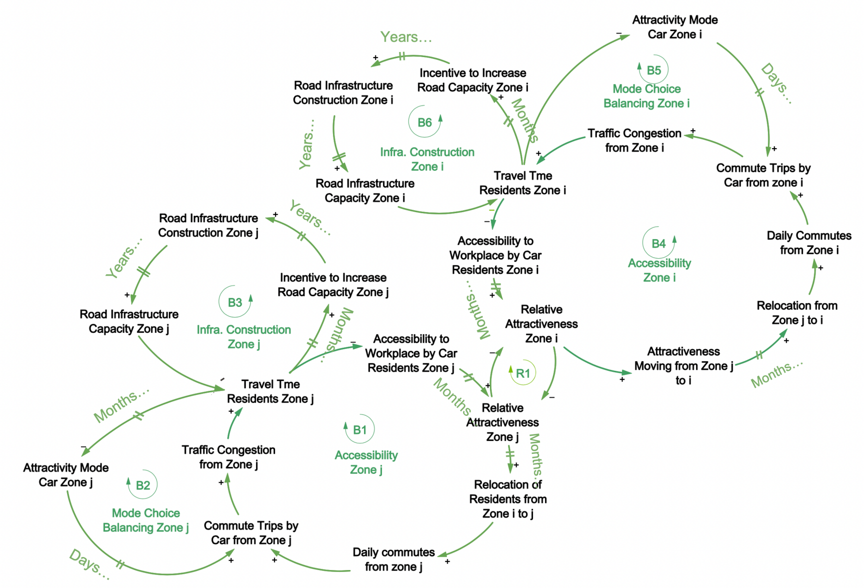
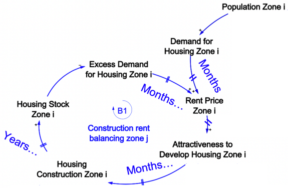


Causal loops in residential location



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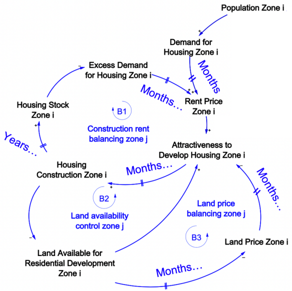

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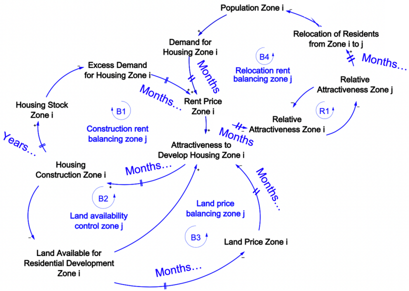

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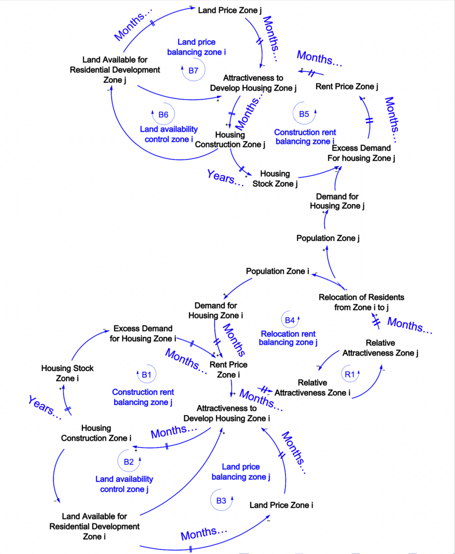

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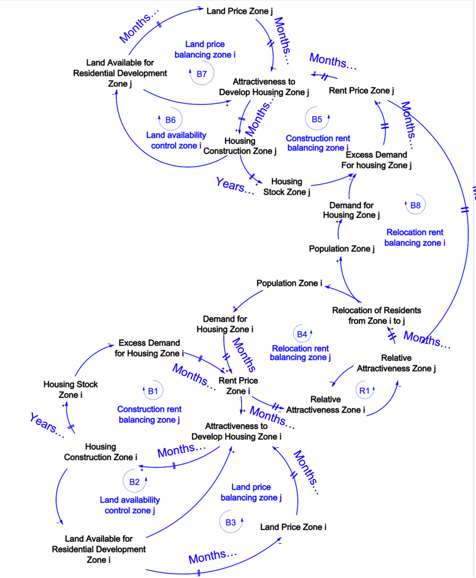


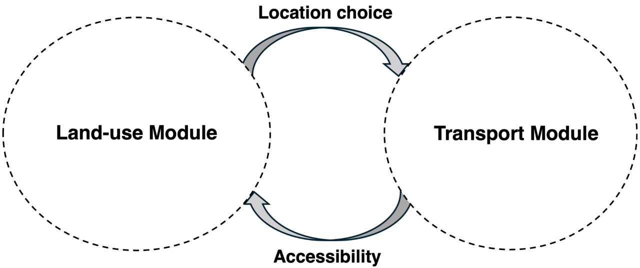
Scope

Can we have a framework that:

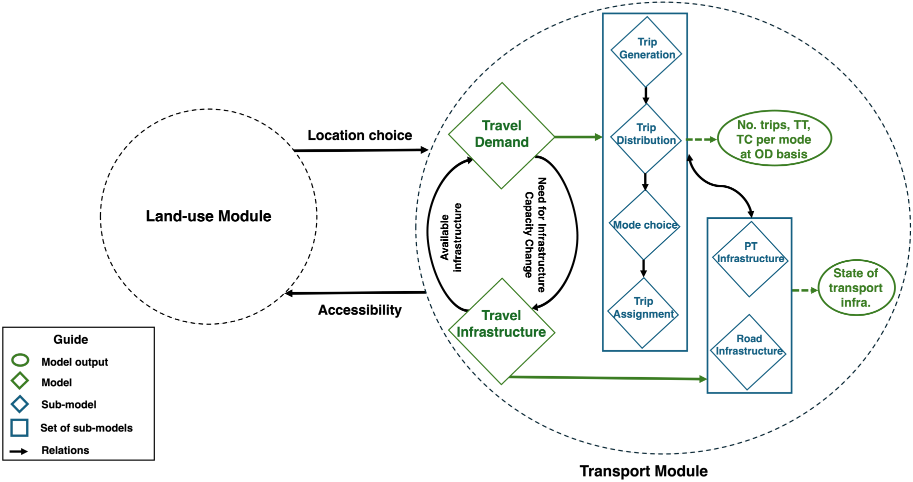
- Model both transport and land-use **endogenously** within the **same framework**.
- Capture **interaction** and feedback mechanisms **explicitly**.
- Connect **long- and short-term** choices.
- Handle **temporal leads and lags** between processes.
- **Dynamic** modelling, development **path over time**.
- Spatial granularity.
- Computationally **quick**.

Application: Serve to **understand system behaviour**, anticipate future trends and investigate consequences of **policy reforms**.

Integrated approach



Transport module



Travel demand model: Trip generation sub-model

- In trip generation, the **number of trips originating from each zone** is estimated.

$$T_i(t) = N^{\text{Empl}}(t)\ \lambda^{\text{Peak}}_{\text{Trip}}$$

- $T_i(t)$: number of morning peak-period commute trips originating from zone i at timestep t.
- $\lambda^{\text{Peak}}_{\text{Trip}}$: commute trip rate per employed individual during the morning peak on workday.
- $N^{\text{Empl}}(t)$: number of employed residents in zone i at time t.

Travel demand model: Trip distribution sub-model

- Generated trips are allocated to destination zones based on a gravity model.

$$T_{ij}(t) = T_i(t)\,\frac{A_j(t)\ \mathrm{FF}(\mathrm{GC}_{ij}(t))}{\sum_k A_k(t)\ \mathrm{FF}(\mathrm{GC}_{ik}(t))}$$

- $T_{ij}(t)$: number of morning peak commutes from origin zone i to j.
- $T_i(t)$: produced commute trips from i.
- $A_j(t)$: Attraction of destination zone j (number of jobs).
- $\mathrm{FF}(\mathrm{GC}_{ij}(t))$: Deterrence function for a trip from i to j, considering perceived generalised cost.

Travel demand model: Mode-choice sub-model

- Mode choice is modelled using a Logit specification.

$$T_{ij}^{m}(t) = T_{ij}(t)\,\frac{e^{V_{ij}^{m}(t)}}{\sum_{m'} e^{V_{ij}^{m'}(t)}}$$

- $T_{ij}^{m}(t)$: number of morning peak commuters from zone i to j by mode m.
- $T_{ij}(t)$: number of morning peak commute trips from zone i to j.
- $V_{ij}^{m}(t)$: utility of mode m for that OD, considering perceived travel time and cost.

Travel demand model: Trip assignment sub-model

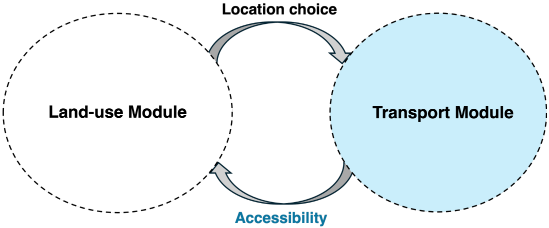
- Trips are studied at the corridor level.
- *Assumption*: there is one corridor between each origin and destination pair.

Transport module: Transport infrastructure development model

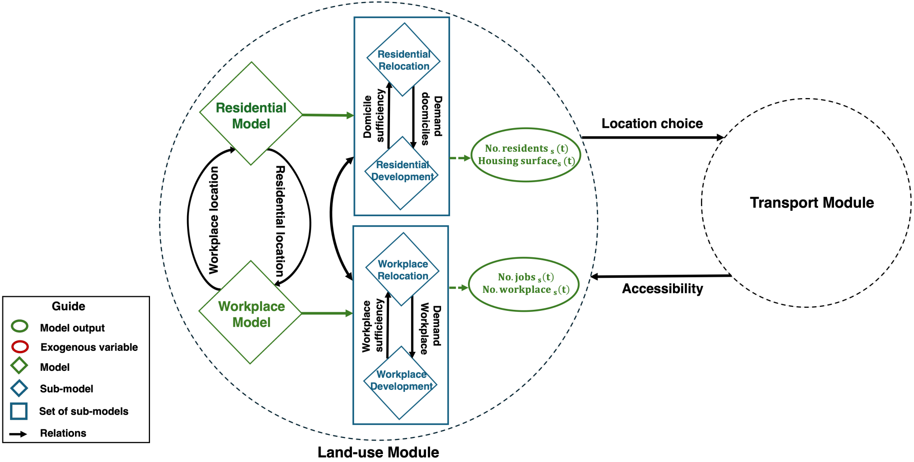
- It uses aggregate speed-flow relationships, based on transport planning manuals (Highway Capacity Manual), for each origin-destination movement.
- The decision to increase the transport infrastructure capacity is determined with a set of rules based on the speed at morning peak and number of commutes.

Transport module: output

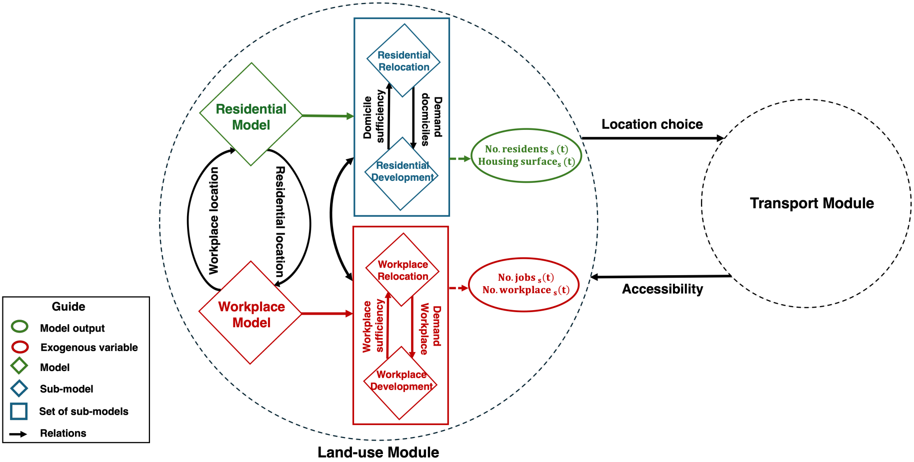
The output of the transport module at each timestep is the transport flows at an origin-destination basis by each mode, travel times and cost between each origin-destination pair, as well as transport infrastructure, which links the transport module back to the land-use module through accessibility.



Land-use module



Land-use module



Residential relocation sub-model

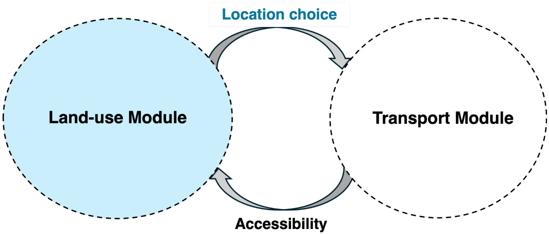
- The residential relocation sub-model models the relocation of residents within the zones in the area through 3 steps:
  - The **out-migration of residents** is estimated for each zone.
  - The out-migration residents are **pooled** over all the zones.
  - The movers are **distributed** within residential zones based on a **logit model** considering the characteristics of the destination such as perceived rent prices and accessibility to workplace.

Residential development sub-model

- The development decision is based on the following factors:
  - demand for housing,
  - achievable rent,
  - availability of land for construction.
- The new housings would be ready to domicile after an externally defined **time lag** of construction time.

Land-use module: output

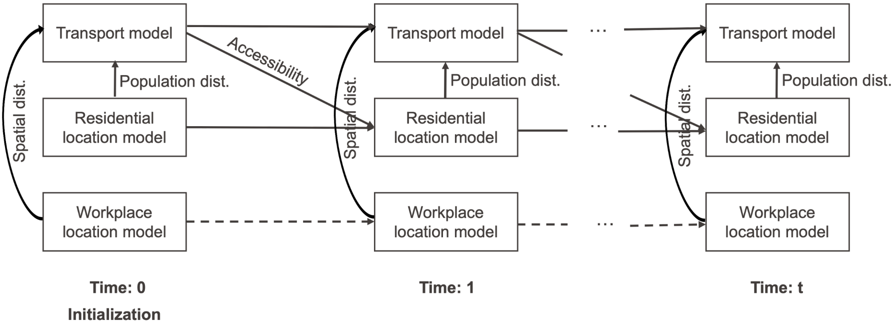
The output of the land-use module in each timestep is the spatial distribution, which links the land-use module back to the transport module.



Specification

- Dynamic model.
- Spatial: discrete urban zonal level.
- Time-step: days.
- Development path over time.

Stepping through time...



Case study: Luxembourg

Data sources:

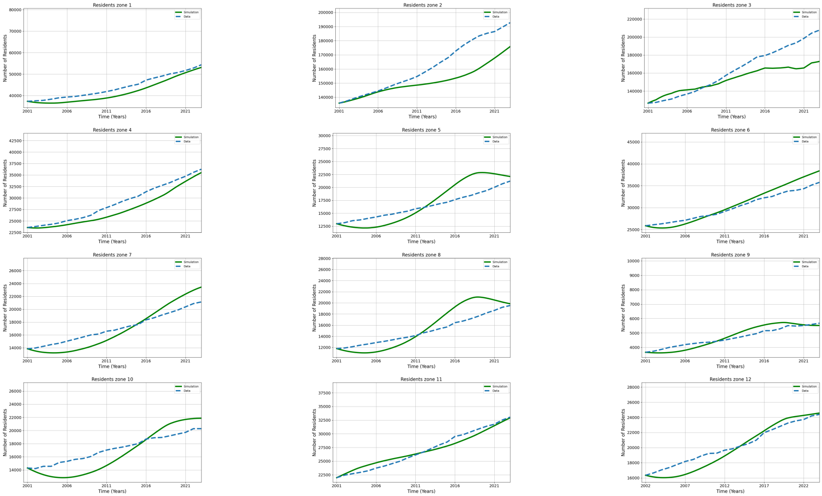
- Census and IGSS: demographic data.
- Mobility observatory and census: travel data.
- Housing observatory: developments, prices, land use.

Model setup:

- Spatial resolution: 15 zones (12 cantons + 3 cross-border).
- Daily time step.
- Parameters calibrated/estimated to match observations.
- Time period: 2001 to ... (e.g., 50 years).

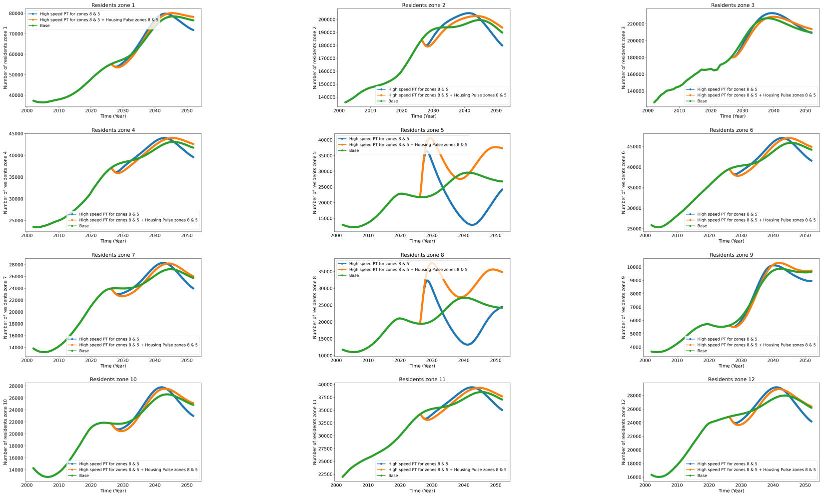
* *Source: Luxembourg Institute of Socio-Economic Research (LISER)*

Calibration



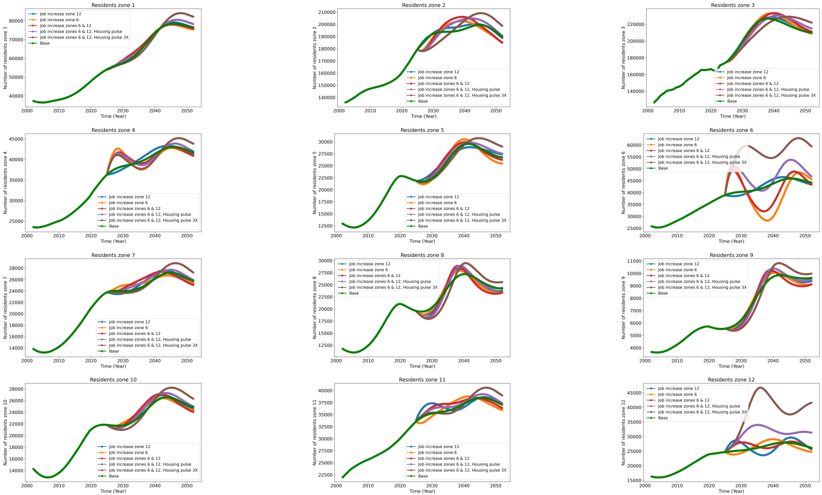
Time series of residents in 12 internal Luxembourg cantons

Example scenarios – Highspeed PT in Clervaux and Wiltz



Time series of residents in 12 internal Luxembourg cantons – Highspeed PT scenario

Example scenarios – Job increase in Diekirch and Remich



Time series of residents in 12 internal cantons in Luxembourg – Job increase scenario

Summary

- Motivation: decision support tool, with systematic view of land use and mobility patterns, to assess the long-term impact of transport and land use policies.
- Use system dynamics mapping and modelling.
- Support data-driven planning, while remaining computationally efficient.
- Main advantages of the framework:
  - Integrated design.
  - Computationally efficient.
  - Dynamic model.
  - Reproducible
  - Flexible.
  - Easy to understand.
  - Policy combinations.

Key takeaways

- Cross-national application.
- Daily modelling timesteps.
- The approach balances sufficient detail to support evidence-based planning while remaining computationally efficient.
- Link discrete choice modelling with systems thinking and system dynamic modelling for improved calibration.

To conclude

Future work:

- Define and assess policies with different KPIs (welfare, equity, cost-benefit, etc).
- Economic aspects; time value of money and inflation.
- Model fits can be improved further.
- Probabilistic modelling.
- Other choice complexities; e.g., buying or renting for satisfying residential demand.

Acknowledgment

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Thank You!

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