Using System Dynamics for Automated Vehicle Impact Assessment

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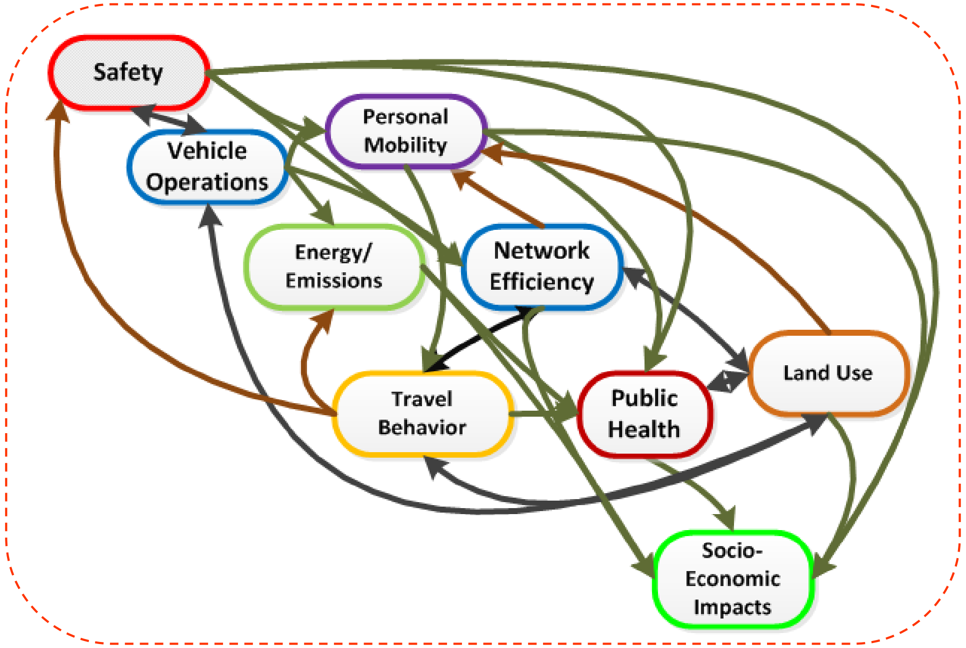
Disclaimer

Statements made during this presentation are opinions of the speaker and do not represent official positions of the U.S. Department of Transportation.

AV impacts are complex

The problem: assessing impacts will not be easy, and the stakes may be high.

- **There will be far reaching impacts across many areas, and across multiple time-frames**



- **Multiple highly complex systems are involved**

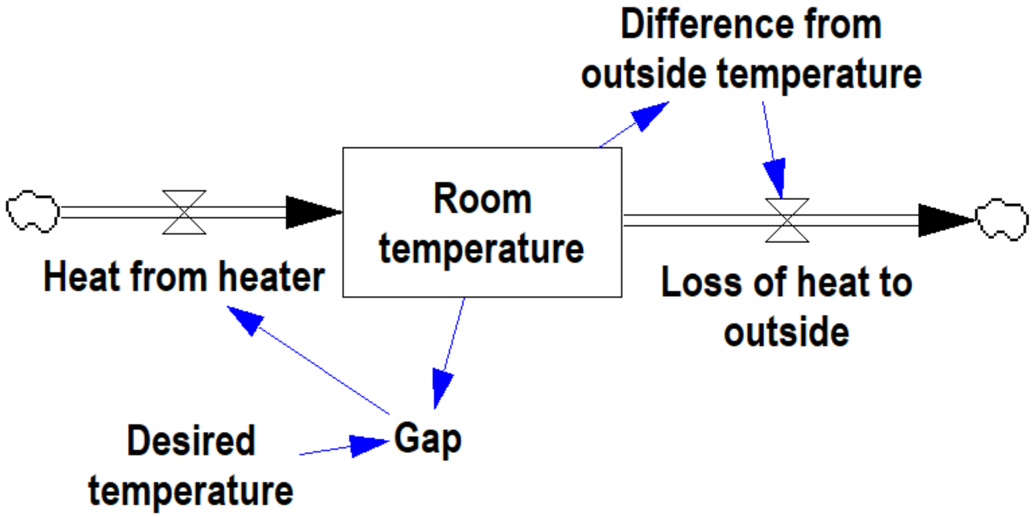
  *(complex interactions both **within** and **among** these systems)*

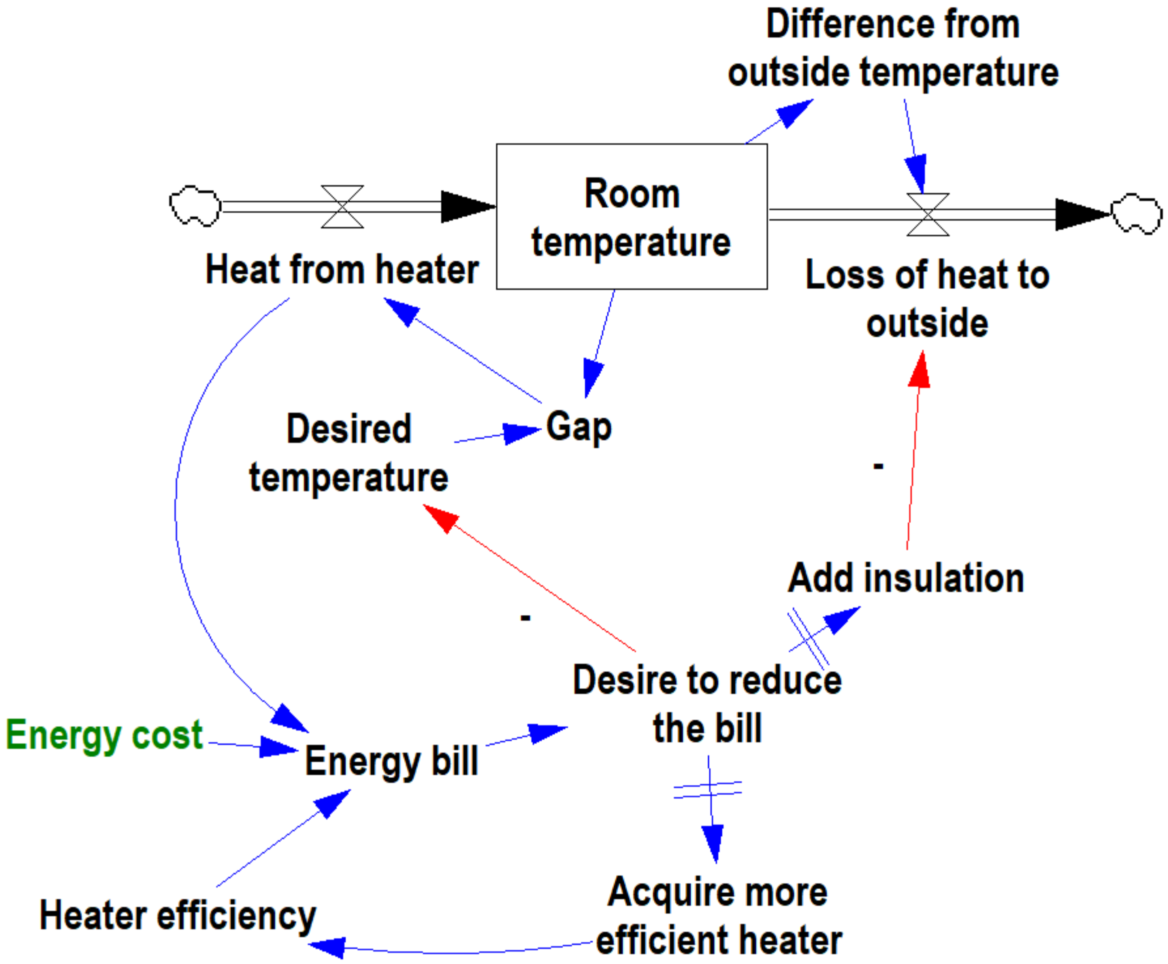
highway operations + land use + public transit + freight + etc…

- **Major uncertainties and lack of data regarding:**
  - Technology performance → *Will the technology perform as expected?*
  - Policy response → *What could drive policy responses, and will those responses be effective/timely?*
  - Human behavior → *How will individuals/families use automated vehicles?*
  - New business models → *How will businesses use automated vehicles?*
  - *(note: even more uncertainty emerges when cooperation among vehicles—cooperative driving automation—is considered)*

System dynamics

Applies ideas from control systems theory to complex technological, social and economic problems.





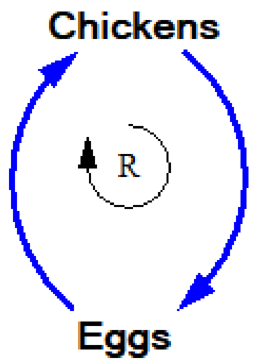
$$T_{i+1} = T_i + H_i - L_i$$

H_i = *positive constant, if Desired temp. > Room temp.*

0 otherwise

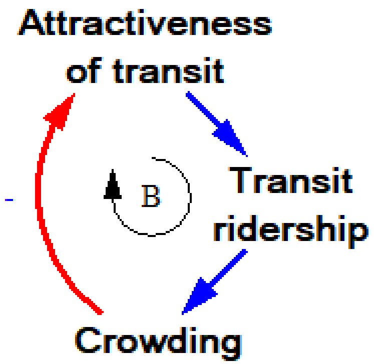
See https://systemdynamics.org/what-is-system-dynamics/

Basic constructs in system dynamics



Reinforcing Loop

- Exponential growth or decline
- “Going viral”
  - New product taking over a market as more people learn about it
  - Epidemic



Balancing Loop

- Reaches an equilibrium, perhaps with oscillation
- Examples
  - Congestion on a road
  - Limits on food in an ecosystem

Stock and Flow

- Stock = accumulation of something
- Flow = change in the accumulation
- Examples
  - Firm’s cash on hand
  - Fleet size
  - Persons familiar with automated vehicles
  - OEM technical knowledge
  - Refueling infrastructure
  - Population in a region

System dynamics (SD) is a higher-level strategic modeling tool

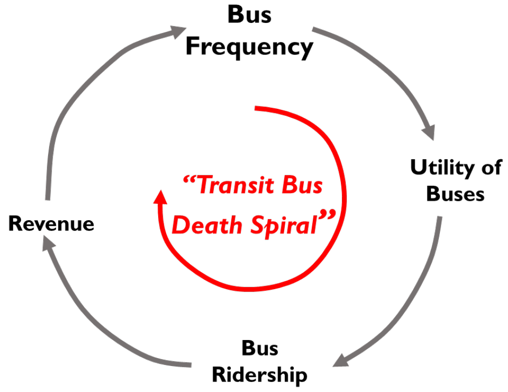
- Uses known causal relationships to model complex systems
  - Simple processes can be taught to stakeholders
  - Reusable building blocks (modules) of system effects can be assembled easily into larger models
- Quickly identifies key **system impacts**, including:
  - ***Vicious/virtuous cycles*** *and other feedback effects*
  - *Potential* ***tipping points***
  - ***Unintended consequences****, etc.*
- Produces **highly aggregated, very fast models**. Unlike region-specific transportation models, SD is not highly detailed or computationally intensive and can be run quickly, to explore a large scenario-space.
- Outputs include:
  - Qualitative analysis—Useful tool for communications and outreach and for identifying data needs and modeling gaps
  - Quantitative analysis—can be used with real-world data or scenario-based assumptions.

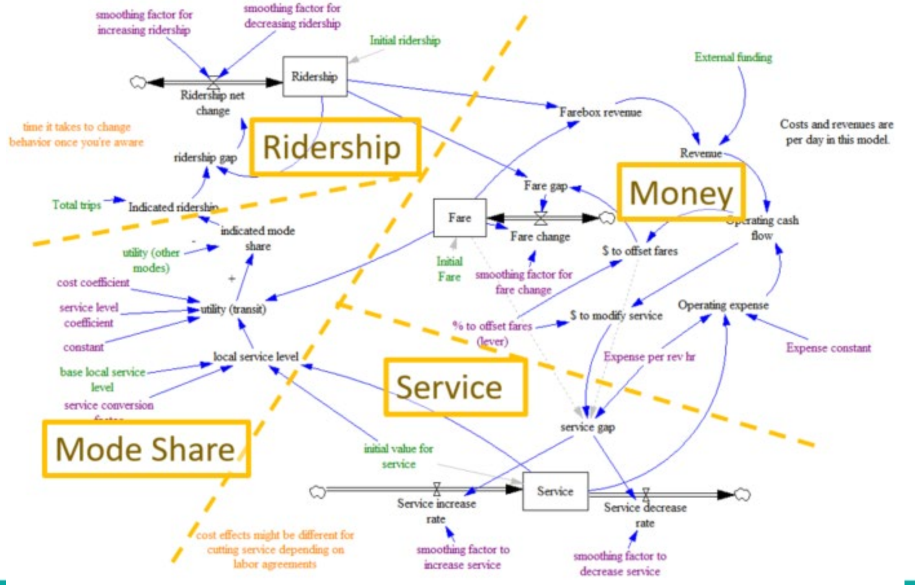
from linear thinking:

Cause: → ***Effect:***

Bus frequency → utility of buses
Utility of bus → bus ridership
Bus ridership → revenue
Revenue → bus frequency

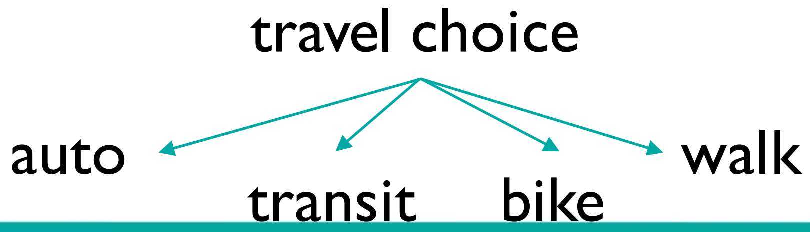
to systems-thinking:





Building blocks for SD transportation models

1. Technology adoption: Consumer adoption of a new product, via word-of-mouth and other influencing factors
2. Business models: Business provision of a service, relying on the availability of factors of production, how customers pay, and profitability
3. Competition: What mode does the traveler choose?



Building blocks for SD transportation models

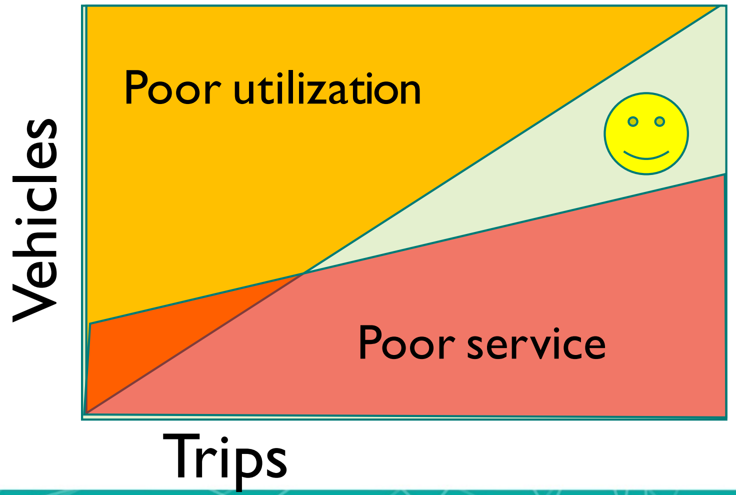
4. Reinforcing effects of services and users, where greater usage of a service justifies adding more service and/or higher quality service
5. Balancing effects of use: Congestion effects, where as something is used more (e.g., road space), its use becomes less desirable
6. Long term dynamics
   - Vehicle ownership
   - Land use (residential relocation)

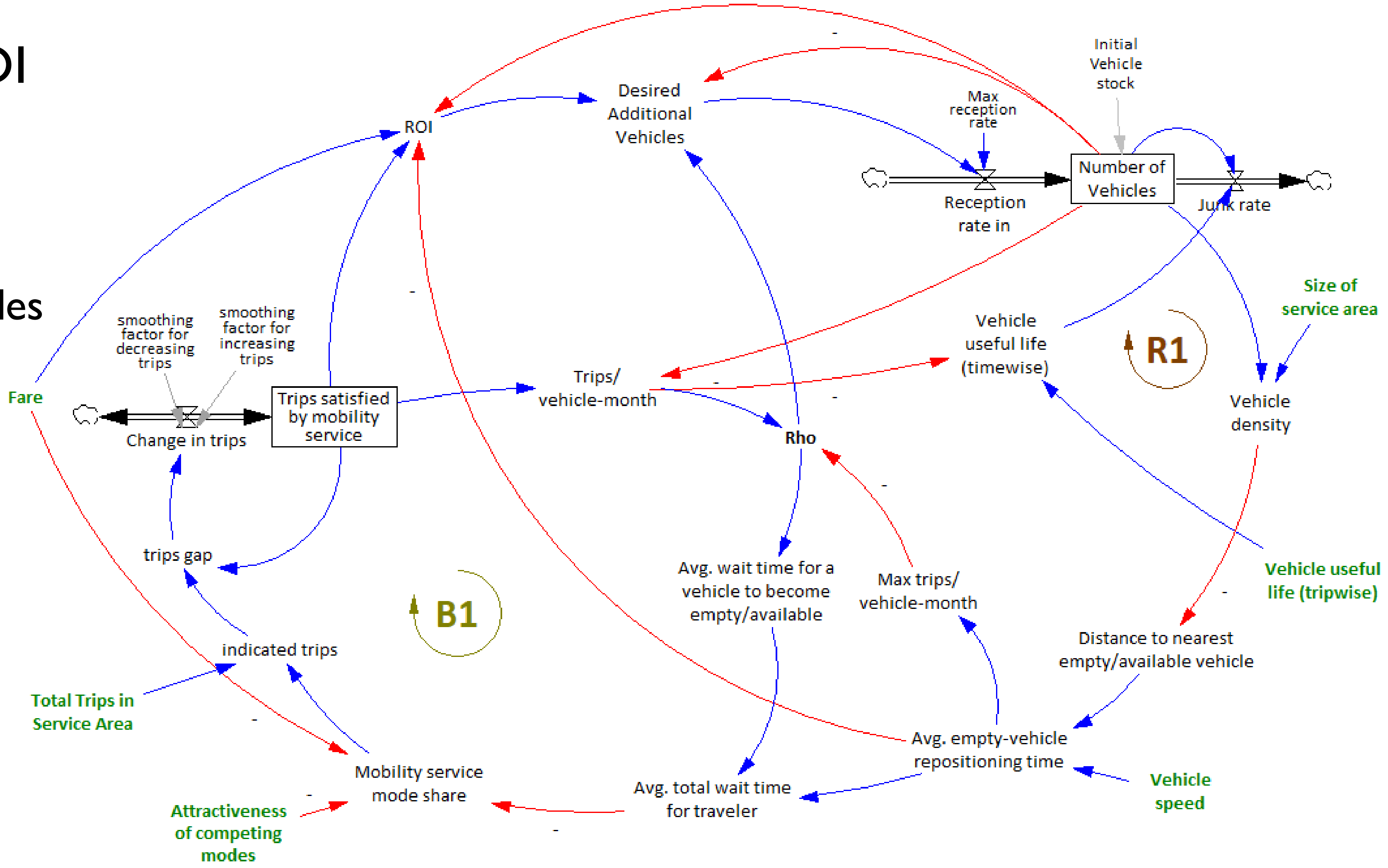
Photo source: Volpe

Photo source: FHWA

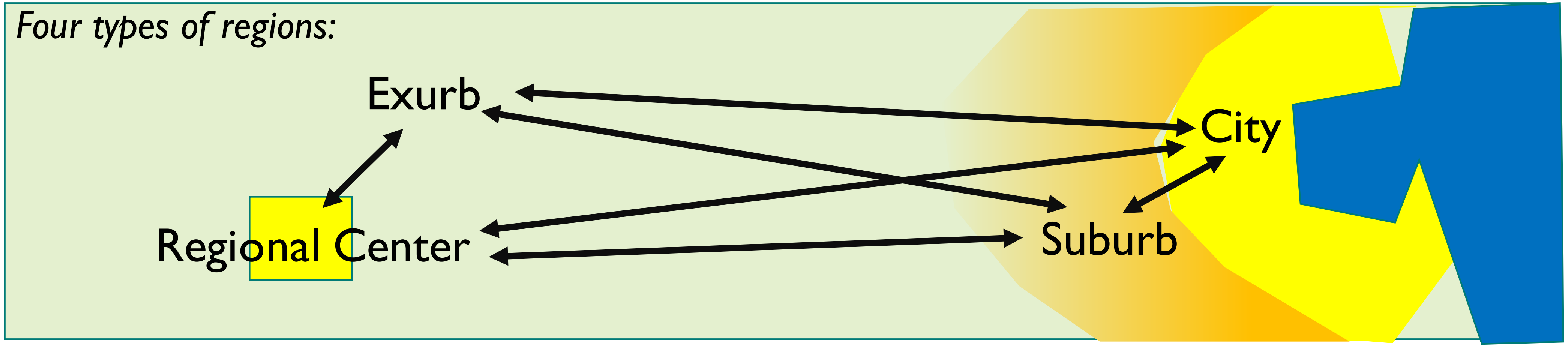
Short term dynamics: a shared vehicle service

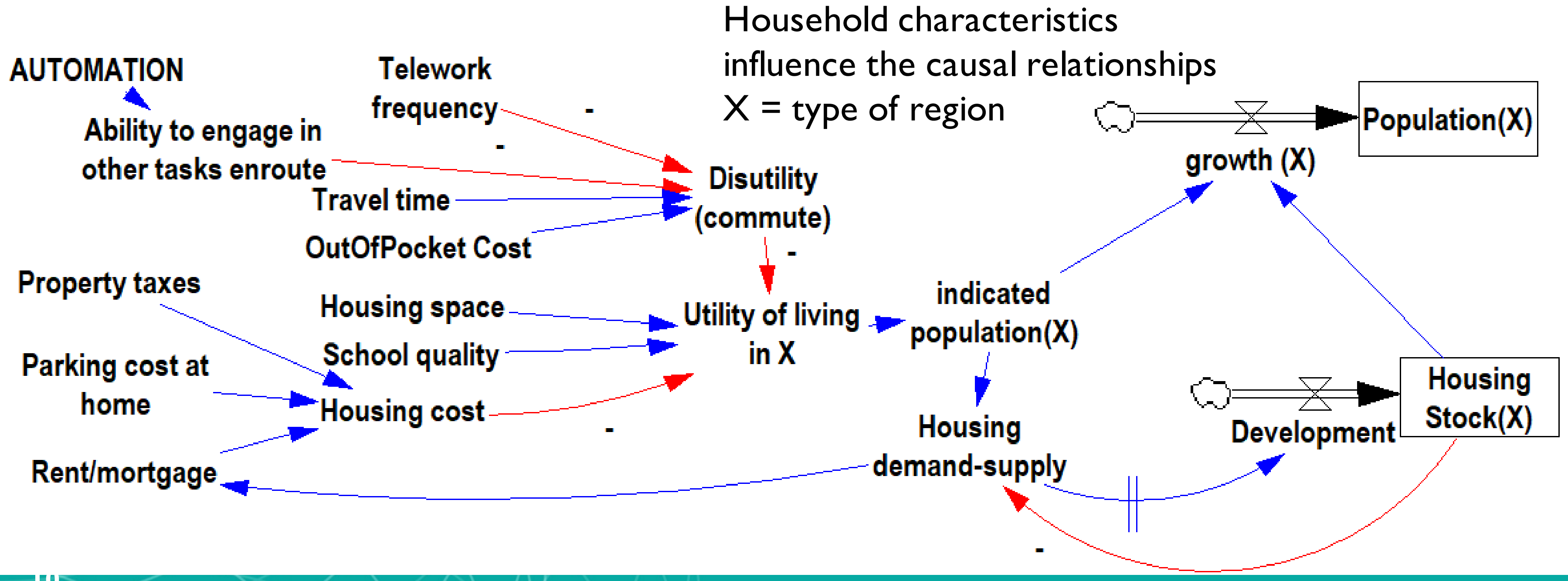
- Too many vehicles?
  - Poor utilization and ROI
- Too few vehicles?
  - Poor service with high
    - empty repositioning miles
    - traveler wait time





Long term dynamics: land use





An increase in telework and automation may have a similar effect: both make long commutes less onerous

Outcomes to date: SD has been a powerful communications and engagement tool

1. Helped planners and modelers "speak the same language" regarding complex changes to transit demand and land use
2. Provides a way to structure collaborations with stakeholders from multiple disciplines
3. It can be a useful strategic tool for rapid analysis of any complex system, especially hard-to-quantify socio-technical systems
4. Can complement other strategic tools, such as VisionEval
5. Can be applied at various levels
   - Communications and engagement tool
   - Structuring thinking with your team, clients and stakeholders—enabling a "systems-thinking" approach
   - Rigorously modeling causal relationships
   - Quantitative models

For more information

- Transport Research Arena conference paper from a 2019 workshop in Leeds, UK: *Rakoff et al, Building Feedback into Modelling Impacts of Automated Vehicles: Developing a Consensus Model and Quantitative Tool (April 2020)* https://rosap.ntl.bts.gov/view/dot/48969
- Webinar, sponsored by the Zephyr Transport Foundation, that included a group model building exercise on road safety: *A System Dynamics Perspective for Transportation Planning Under Uncertainty (May 2020)* Slides and recording: https://zephyrtransport.org/events/2020-may-learning-system-dynamics/
- Report that includes modeling of the proxy modes of ridehailing (user response) and dockless bike share (vehicle utilization): *Berg, Ian, Hannah Rakoff, Jingsi Shaw and Scott Smith: System Dynamics Perspective for Automated Vehicle Impact Assessment, (FHWA-JPO-20-809) (July 2020)* https://rosap.ntl.bts.gov/view/dot/49813
- Report from our work with transport planning organizations in the U.S. to apply system dynamics to planning, with a focus on transit: *Automated Vehicle Impacts on the Transportation System: Using system dynamics to assess regional impacts (March 2021)* https://rosap.ntl.bts.gov/view/dot/55247/
- Webinar, sponsored by the Zephyr Transport Foundation, that summarized our work with transport planning organizations in the U.S.: *System dynamics for strategic planning under technological uncertainty (April 2021)* https://zephyrtransport.org/events/2021-04-21-system-dynamics-applications/
- Presentation from the 18th TRB Planning Applications Conference. *Rakoff, Hannah, Alex Bettinardi: Testing a system dynamics approach for modeling mode shift and equity under uncertainty (June 2021)*