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Systems-Dynamic Analysis for Neighborhood Study

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Abstract

Systems-dynamic analysis (or system dynamics (SD)) helps planners identify interrelated impacts of transportation and land-use policies on neighborhood-scale economic outcomes for households and businesses, among other applications. This form of analysis can show benefits and trade-offs of different strategies, but its complexity can make it unwieldy. This poster explains the process and the advantages and limits of using SD.

Key Points

Transportation and land use policies and projects can have broad and long-lasting impacts on the social, economic, and environmental conditions in a community. The interrelationships between factors affecting these three value areas are often complex and not well understood. System dynamics models can provide a tool for identifying and quantifying these relationships in order to determine the most sustainable policies and practices that also avoid unintended consequences. This poster provides an example of applying SD analysis to the economic mechanisms by which the transportation system and land use patterns in a given neighborhood affect decisions by households and businesses on whether to locate in that neighborhood and what travel behavior to engage in.

System dynamics is an approach to modeling the many interrelated causes and effects of a given quantifiable measure.

- Arrows are drawn between variables that have direct causal effects on each other.
- Mathematical formulas quantify these causal effects (when available, based on relevant research) and reflect either a positive or negative relationship.
  - In a positive relationship, an increase in variable A causes an increase in variable B and a decrease in variable A causes a decrease in variable B.
  - In a negative relationship, an increase in variable A causes a decrease in variable B and a decrease in variable A causes an increase in variable B.
- The result is a complex web of relationships.
  - One variable may influence another either directly or through some number of intermediate variables, revealing an outcome that might not otherwise be obvious.
  - Frequently, SD models include causal loops, wherein changes in a given variable ultimately lead to additional changes in the same variable on account of feedback effects from one or more of the other variables that the first variable influences. To mathematically model these causal loops requires use of a time dimension in the formulas.
  - A given outcome variable may be influenced by a given input variable through more than one chain of intermediate variables (that also have other inputs), with the result that a change in the input variable's value may produce a same-direction change in the outcome variable in some circumstances and an opposite-direction change in other circumstances.

The example modeling presented here outlines considerations to be accounted for by a given neighborhood within a larger metropolitan area. Some assumptions inherent in the model include:

- All values are taken to be averaged across the entire neighborhood, since SD models are unable to show geographic variations.
- The model features input variables that describe either adjoining neighborhoods or the broader metropolitan area, for which data is assumed to be available, either from empirical evidence or through parallel modeling.
- The design features of arterial streets passing through the neighborhood are regarded as distinct inputs from those of local-scale "neighborhood" streets (not designed to be traveled on for long distances or at high speeds), since different classes of roadways invite different sorts of travel behavior and are designed within different constraints.

The results of this modeling effort (and others like it) may be used by planners, engineers, and policy-makers to identify co-benefits and trade-offs not previously considered and to identify key inputs that currently lack data. The ensuing diagrams may also help determine whether, in a given scenario, the effect of a particular policy or project on a given outcome is significant relative to the effects of other model inputs. As may be seen here, there are many interrelated determinants of the transportation behavior and locational decisions of a neighborhood's households and businesses besides land-use patterns and transportation infrastructure. In practice, the model would need to be customized to reflect the context of the area of interest. Other outputs of the model (which may also serve as inputs) include measures of greenhouse gas emissions, local-government-budget impacts, traffic accident rates, impervious surface area, energy use, noise pollution, and air pollution. Note that many outcomes of significance to communities are not included in this example model, given the limitations of presenting in a poster format.

Summary of Topics Covered in the Example Model

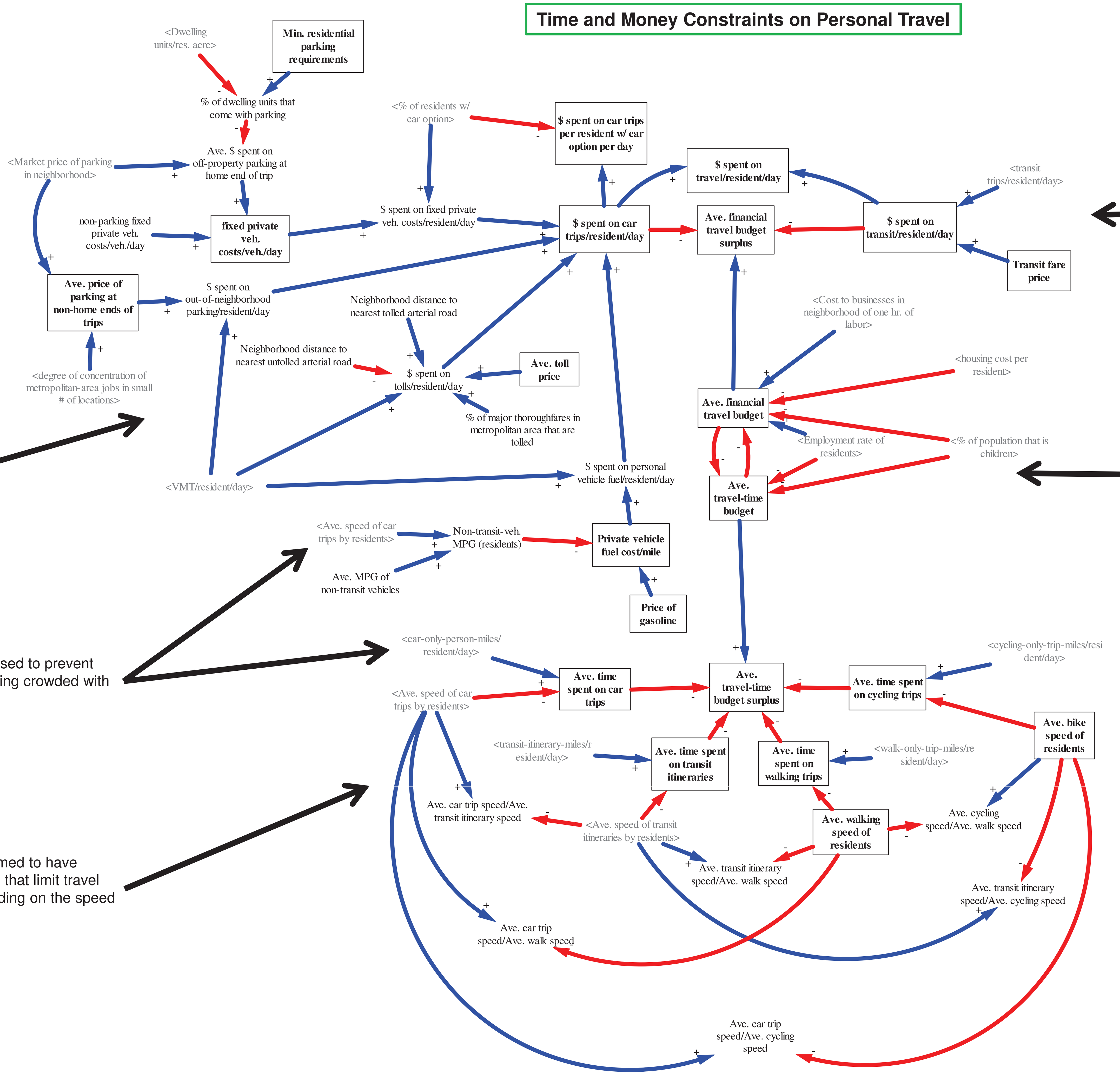
- Usage Profile of Transportation Corridor Cross-Sections
- Time and Money Constraints on Personal Travel (*shown*)
- Motor-Vehicle Traffic Impacts
- Public Transit Impacts
- Walking and Cycling Impacts
- General Household and Commercial Budgetary Considerations
- Land Use in the Neighborhood
- Neighborhood Parking Supply
- Traffic Accident Rates
- Greenhouse Gas Emissions
- Neighborhood Energy Use
- Traffic Noise Zones
- Local/Regional Air Pollution and Near-Road Air Pollution
- Impervious Surfaces in the Neighborhood
- Effects on Local Government Budgets

Close-Up View of Selected Example-Model Section

Private vehicle costs include fuel, parking, tolls, and fixed costs of ownership

Shadow variables, used to prevent the diagram from being crowded with too many arrows

Individuals are assumed to have "travel time budgets" that limit travel by all modes, depending on the speed of each mode



Spending on public transit and spending on private automobile travel are traded off

People make tradeoffs between time spent traveling and money spent on travel

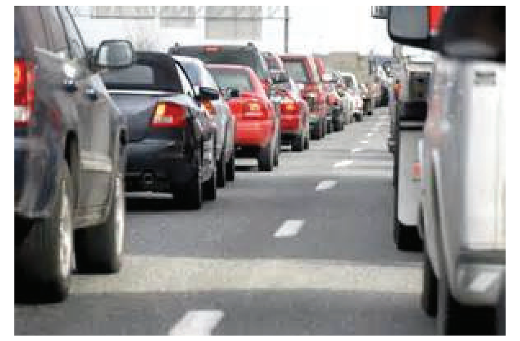


Photo courtesy of U.S. EPA, http://www.epa.gov/otaq/tier3.htm, accessed March 5, 2014

KEY TO THE DIAGRAMS:

Blue Arrow (→)	Direct positive causal relationship (+)
Red Arrow (→)	Direct negative causal relationship (-)
<Grey Text in Angle Brackets>	"Shadow" variable that affects one part of the model but whose own inputs are shown in a different part of the model
Bold Text in a Box	Input or output variable of special interest

Abbreviations:
"veh." = "vehicle"; "VMT" = "Vehicle-Miles Traveled"; "GHG" = "Greenhouse Gases"; "MPG" = "Miles per Gallon"; "Trans." = "Transportation"; "ROW" = "Right-of-Way"; "rd." = "road"; "pt." = "point"; "metro." = "metropolitan"; "com." = "commercial"; "res." = "residential"; "pop." = "population"; "Ave." = "Average"; "#" = "number"; "%" = "percent"; "$" = "money"; "ft." = "foot" or "feet"; "w/" = "with"; "w/o" = "without"; "&" = "and"; "hr." = "hour"; "min." = "minimum"; "max." = "maximum"; "/" = "divided by," "per," or "or"; "amt." = "amount"

Conclusion

A particular neighborhood's per-capita contribution to greenhouse gas emissions, other air emissions, water pollution, and habitat loss, as well as the degree of people's exposure to harmful emissions, are all dependent upon what behavior residents, business owners, and land developers are motivated to engage in. System dynamics models such as this one serve to map out the many contributing factors to these motivations, with particular behaviors ultimately changing the conditions that led people to choose those behaviors in the first place. In this way, effective policy interventions may be discovered and tested both for side effects and for the magnitudes of their impacts. For example, as may be seen in the diagram on this poster (which represents just one small part of a much larger conceptual model), individual travelers have both time budgets and monetary budgets for their travel activities, the sizes of which are influenced by the amount of time and money they must budget for other things and the amount of time and money they have to begin with. Since some modes of transportation are faster than others and some modes are cheaper than others, people try to satisfy their travel needs using a combination of modes that will not result in either their travel time budget or their monetary travel budget being exceeded, depending upon their trip frequencies and the necessary distances between their origins and destinations. Various characteristics of local and regional land-use patterns and transportation networks influence the trip distances and frequencies characterizing people's travel needs and the speed and cost-effectiveness of any given travel mode which influence the amounts and types of vehicle fuel used in the area (and hence the amounts and types of vehicle emissions in the area) and the amount of impervious transportation infrastructure that it is appropriate to build.