Using System Dynamics Analysis for Evaluating the Sustainability of “Complete Streets” Practices

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Background

Transportation infrastructure has a broad and long-lasting impact 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 system dynamics modeling to a generalized “complete streets” application.

- **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.
  - 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, system dynamics 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. Also, a given outcome variable may be influenced by a given input variable through more than one chain of intermediate variables, 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.

- **“Complete streets”** refers to any set of street-design practices that make a transportation corridor more accommodating to travel by multiple modes, including automobile travel, walking, cycling, and public transit. Benefits cited over the years of accommodating non-automobile transportation modes have included reduced transportation-related air emissions, greater physical activity, and greater transportation affordability. However, trade-offs may result. For example:
  - If the parcels of land bordering a transportation corridor have already been developed, the width of the corridor is unlikely to be increased. Therefore, greater accommodation of one mode of transportation is likely to decrease the amount of space available for travel by other modes.
  - Greater accommodation of a given mode is only beneficial in the presence of unmet demand for that mode.
  - Changing transportation behavior in a given area may produce changes in economic activity that, in turn, affect the natural environment.
  - When multiple transportation modes are used on a network, greater opportunities exist for them to come into conflict with one another.
  - There are many different ways “complete streets” design concepts can be implemented, including the use of different kinds of paving materials, different traffic control methods, and different numbers and widths of travel lanes or rights-of-way dedicated to any given mode or combination of modes. Each of the possible design schemes resulting from these choices costs a different amount of money to implement and maintain, uses a different amount of land, and produces a different amount of stormwater runoff, among other things.

This modeling outlines considerations to be accounted for by a given neighborhood within a larger metropolitan area contemplating a “complete streets” design approach. Some assumptions inherent in the model include:

- All values are taken to be averaged across the entire neighborhood, since system dynamics models are unable to show geographic variations.
- The model features input variables that describe either adjoining neighborhoods or the broader metropolitan area, for which information is assumed to be available.
- 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.

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:
“pt.” = “point”; “veh.” = “vehicle”; “GHG” = “Greenhouse Gases”; “rd.” = “road”; “Ave.” = “Average”; “#” = “number”;
“%” = “percent”; “w/” = “with”; “w/o” = “without”; “metro.” = “metropolitan”; “Trans.” = “Transportation”;
“ROW” = “Right-of-Way”; “com.” = “commercial”; “res.” = “residential”; “pop.” = “population”; “hr.” = “hour”;
“min.” = “minimum”; “max.” = “maximum”; “/” = “divided by” or “per”; “amt.” = “amount”

Summary of Topics Covered in the Model

- Usage Profile of Transportation Corridor Cross-Section (“Neighborhood” Streets) *(shown below)*
- Usage Profile of Transportation Corridor Cross-Section (Arterial Streets in the Neighborhood)
- Usage Profile of Transportation Corridor Cross-Section (Adjacent-Neighborhood Streets)
- Time Budgets and Monetary Budgets for Personal Travel
- Motor-Vehicle Traffic Impacts
- Public Transit Impacts
- Walking and Cycling Impacts *(shown to the right)*
- Land Use in the Neighborhood
- Effects on Household and Commercial Budgets
- 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

Photo courtesy of U.S. EPA,
http://www.epa.gov/livablecommunities/greencapitals.htm

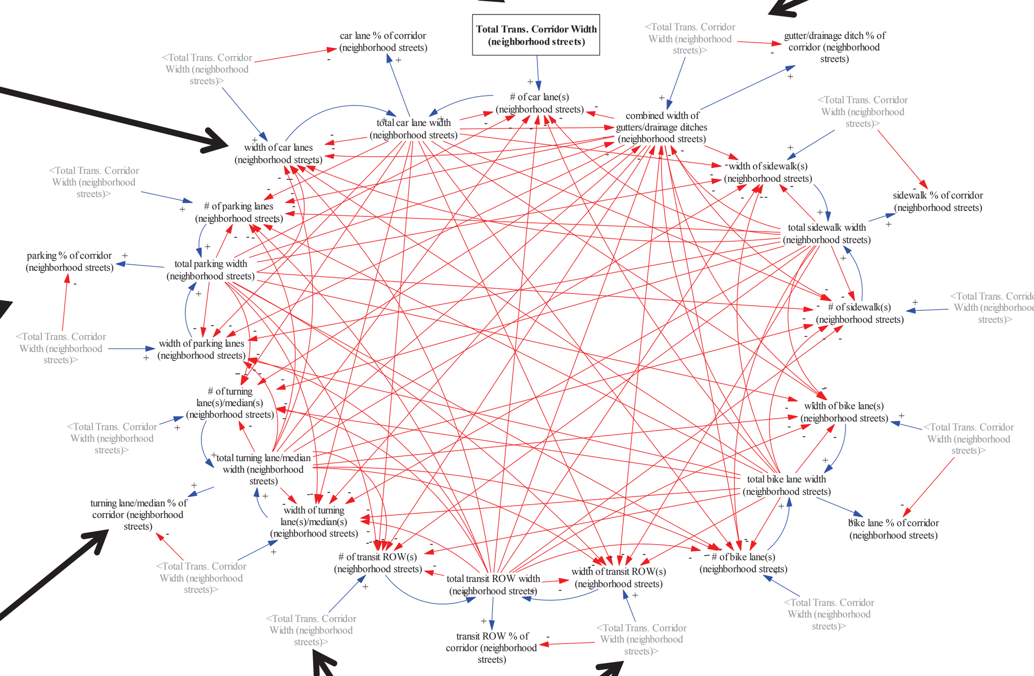
Close-Up Views of Selected Model Sections

Usage Profile of Transportation Corridor Cross-Section (“Neighborhood” Streets)

The sum of the widths of all of the modal uses of the transportation corridor cannot exceed the corridor’s total width (widening the overall corridor is often impossible)

Space needs to be reserved for gutters and/or drainage ditches

The wider each travel lane is, the fewer lanes can be accommodated



Parking lanes may be used to separate travel modes, improving safety and traffic flow

Adding turning lanes and medians reduces regular traffic lanes, but may improve traffic flow and safety

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

****Increasing the amount of space used for any mode reduces the space available for all other modes (car lanes, bike lanes, sidewalks, public transit ROWs)****

Walking and Cycling Impacts

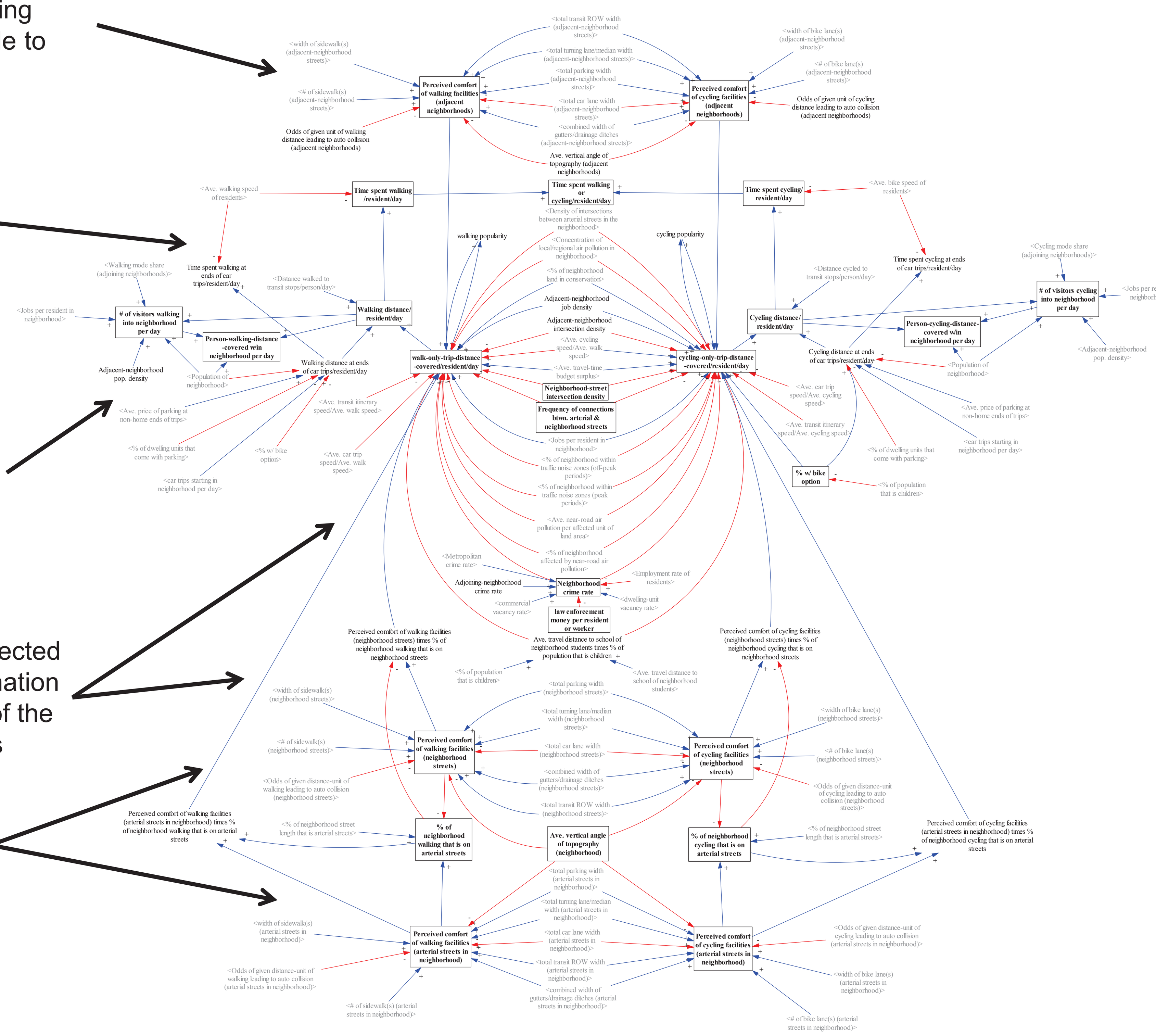
People are more likely to walk and cycle in a given neighborhood if adjoining neighborhoods are also amenable to walking and cycling

Overall walking and cycling totals come from both single-mode and multi-mode trips

For some purposes, it is better to measure overall walking and cycling by residents, regardless of where they do their walking and cycling; for other purposes, it is better to only measure walking and cycling within the neighborhood, regardless of whether the walkers and cyclists are residents or not

Walking and cycling rates are affected by street-design variables, destination accessibility, and other aspects of the natural and human environments

Residents’ walking and cycling behavior is affected by the characteristics of both arterial and non-arterial transportation corridors



Conclusions

The results of this modeling effort may be used by planners and engineers to identify trade-offs and co-benefits not previously considered and to identify key inputs they do not yet have data for. These diagrams may also help determine whether, in a given scenario, the effect of “complete streets” on a given outcome is significant relative to the effects of other inputs to the model. In practice, the model would need to be redesigned to reflect the context of the place where it is applied. Transportation-corridor design features are among many interrelated determinants of the transportation behavior of a neighborhood’s residents and workers, including local land-use patterns. Also of great significance are the inputs (and outputs) of traffic speeds, traffic volumes, accident rates, the parking supply, and the degree to which the neighborhood and the metropolitan area are served by public transit, all of which are affected by “complete streets” practices. Other outputs of the model (many of which are also inputs) include greenhouse gas emissions, economic impacts, local-government-budget impacts, impervious surface area, energy use, noise pollution, and air pollution. Note that many outcomes of significance to sustainability are not included in this example model, given the limitations of presenting these results in a poster format.

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