2-17-2017

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Using Fuzzy Cognitive Maps to Model Policy Issues in the face of Uncertainty and Limited Data

Portland State University Friday Seminar
February 17, 2017

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Outline

• Background on Fuzzy Cognitive Maps (FCM) and their usefulness for modeling issues involving uncertainty;

• The mathematical formulation of an FSDM and how it differs from common FCM models;

• Open source software for building and running an FSDM; and,

• Results of research with ODOT and OSU on modeling the potential effects of new transportation technologies and services using an FSDM.
Business as usual planning is no longer adequate

• Increasing ‘automobility’ is no longer a foregone conclusion;

• Disruptive technologies and services are emerging;

• EVs and more fuel efficient vehicles are making it necessary to pursue new revenue sources;

• Substantial environmental constraints are apparent

There is a lot of uncertainty about how things will play out.
Example of uncertainty about future vehicle miles traveled (VMT)

\[ \text{VMT} = \text{Number of Drivers} \times \text{Miles Per Driver} \]
Models enhance our ability to reason about the future even when there is uncertainty.

Everyone is a modeler to some extent.

In most cases we use mental models to help us reason.

We are accustomed to using mental models to reason about questions that involve uncertainty.

Due to our limited abilities to think in systems terms, our mental models are limited as well.

Differences in our mental models leads to conflict.

Computer models can “reason” about large systems in a consistent manner.

Proper use of computer models can help produce consensus.
Soft computing methods are useful for modeling systems involving uncertainty and imprecision

- Fuzzy cognitive maps (FCMs) describe causal systems as directed graphs.
- Nodes identify concepts of interest: values between 0 and 1.
- Edges show causal connections. Arrows point from cause to effect.
- Edge weights indicate magnitude and direction of causality.
  - Typically expressed as linguistic variables: e.g. low, medium, high.
  - Translated to fuzzy numbers or values between -1 and 1 (most common approach)
- Expert opinion commonly used in development.

Standard FCM math and its limitations

Fuzzy cognitive maps are neural networks with feedback.

**Issues**

- Weights relate the states of concepts rather than changes in state.
- Meaning of iteration is unclear.
- Meaning of the activation function is unclear.
- Need to invert concepts to avoid negative weights.
- Convergence can be a problem and results may not make sense.

If graph contains cycle(s), iterate to convergence (if it does converge).
Fuzzy System Dynamics Model (FSDM)

- Weights are similar to elasticities. Their meanings are clear.
- Sensitivity functions modify weights as a function of concept value.
- Causal concept(s) of interest are incremented in small steps.
- If model contains one or more cycles, calculations are iterated to convergence.
- Node values in range of 0-100 (% of maximum assumed real value)

\[
\Delta r = s_r \prod_{i}^{n} (s_c \cdot w_i \cdot \Delta c_i + 1) - 1
\]

\[
w = \frac{r'}{r} = \frac{c'}{c}
\]

\[
s_c = \text{causal sensitivity} \quad s_r = \text{receiving sensitivity}
\]
Running the FSDM

Causal concept(s) of interest are incremented in small steps.

• Elasticities relate small changes in cause to effect; and
• Large changes don’t happen immediately.

With each increment of the causal concept(s), if there are cycles (i.e. feedback loops), the model is iterated to convergence.

• Iterations calculate successive orders of effects.

Although time is not explicit in the model, it can be approximated by increments to causal concept(s) of interest.

Example: Effect of Density Change on Congestion
Steps for Creating a FSDM

• Define the concepts being modeled
  • Descriptive names (and abbreviations)
    • e.g. Relative auto capacity (RelAutoCap)
  • Meaning and, if possible, how measured
    • e.g. Freeway equivalent lane-miles of freeways and arterials per 1000 persons
  • Plausible range of values
    • e.g. 0.5 – 5.0

• Group the concepts into related sets to simplify model development and understanding, for example:
  • Transportation technologies and services
  • Travel behavior and outcomes

• Specify the causal relationships and direction of causality
  • Positive: increase causes increase
  • Negative: increase causes decrease

• Specify the relative magnitude of weights: VL, L, ML, M, MH, H, VH
  • VH: Mathematical identity relationships
  • H: Direct and immediate relationships
  • M: Causal variable is major determinant but effect depends on other factors too.

• Specify scenarios
  • Starting values of all concepts
  • Changes to values of causal concepts of interest.
Software for building and running FSDM models

- Demonstration to show how models are specified and run
- https://github.com/gregorbj/FSDM_GUI
Modeling the potential effects of new transportation technologies and services

• Autonomous vehicles
  • Owned autonomous vehicles
  • Shared autonomous vehicles
• Connected vehicles
• Intelligent infrastructure
• Mobile Technologies
• Demand-responsive transportation services
• Light-weight electric vehicles (e.g. electric bicycles)

• Research sponsored by the Oregon Department of Transportation
  • Project manager: Alex Bettinardi
• Research Team: Oregon Systems Analytics & Oregon State University
  • Brian Gregor (OSA)
  • Haizhong Wang (OSU)
  • Rachel Vogt (OSU)
Model of transportation technologies and services
Model of travel outcomes
Model of connections between technologies/services and outcomes
Testing the Travel Behaviors & Outcomes Sub-model

Double Density Scenario
Comparison with 47 Metropolitan Areas

Density vs. Congestion
Population Weighted Density
Percent of VMT in Congestion

Density vs. Vehicle Travel
Population Weighted Density
Per Capita VMT

Density vs. Speed
Population Weighted Density
Ratio of Congested vs. Uncongested Speed

Density vs. Auto Ownership
Population Weighted Density
% Having Access to More Than 1 Vehicle

Increase Road Capacity Scenario
Comparison with 47 Metropolitan Areas

Highway Capacity vs. Congestion
Relative Highway Capacity
Percent of VMT in Congestion

Highway Capacity vs. Vehicle Travel
Relative Highway Capacity
Per Capita VMT

Highway Capacity vs. Speed
Relative Highway Capacity
Ratio of Congested vs. Uncongested Speed

Highway Capacity vs. Auto Ownership
Relative Highway Capacity
Percentage of Households with 1 or Fewer Vehicles
Test of increasing capacity and increasing density
Test of increasing capacity and reducing autonomous vehicle cost
Conclusions

Models can be useful in every planning domain.

- We need simple models for policy development as well as complex models for project development.

It is useful to model systems for which there is uncertainty.

- Enforces consistency in reasoning.
- Helps form consensus.

FSDM is a promising modeling approach for policy matters that involve uncertainty.

- The process of model development helps bring rigor to policy discussions.
- Models can accommodate uncertainty.
- Can be easily modified to test different assumptions.
Next Steps

ODOT independent review underway

• Transportation futures model: evaluating model and developing and evaluating alternatives.
• Evaluating usability of FSDM software.

Improve documentation and awareness

• Publish in journals
• Other

More work needed to improve the method and model.

• Sensitivity function theory.
• Use fuzzy numbers for weights.
• Guidance on establishing weights.
Contacts and Acknowledgements

Contacts:

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Acknowledgements:

This research was partially supported through funding from the Oregon Department of Transportation and the Federal Highway Administration, U.S. Department of Transportation.