Toxic Materials Transportation Security

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April 1, 2011

Project Description

Goal:

> *develop and implement a mathematical model to estimate the road transportation of industrial chlorine.*

The project is done by the Towson University Applied Mathematics Laboratory; sponsored by the Chemical Security Analysis Center.

Presentation outline

- About AML
- Description of data
- Structure of the model
- Results; challenges

Project Description

Applied Mathematics Laboratory

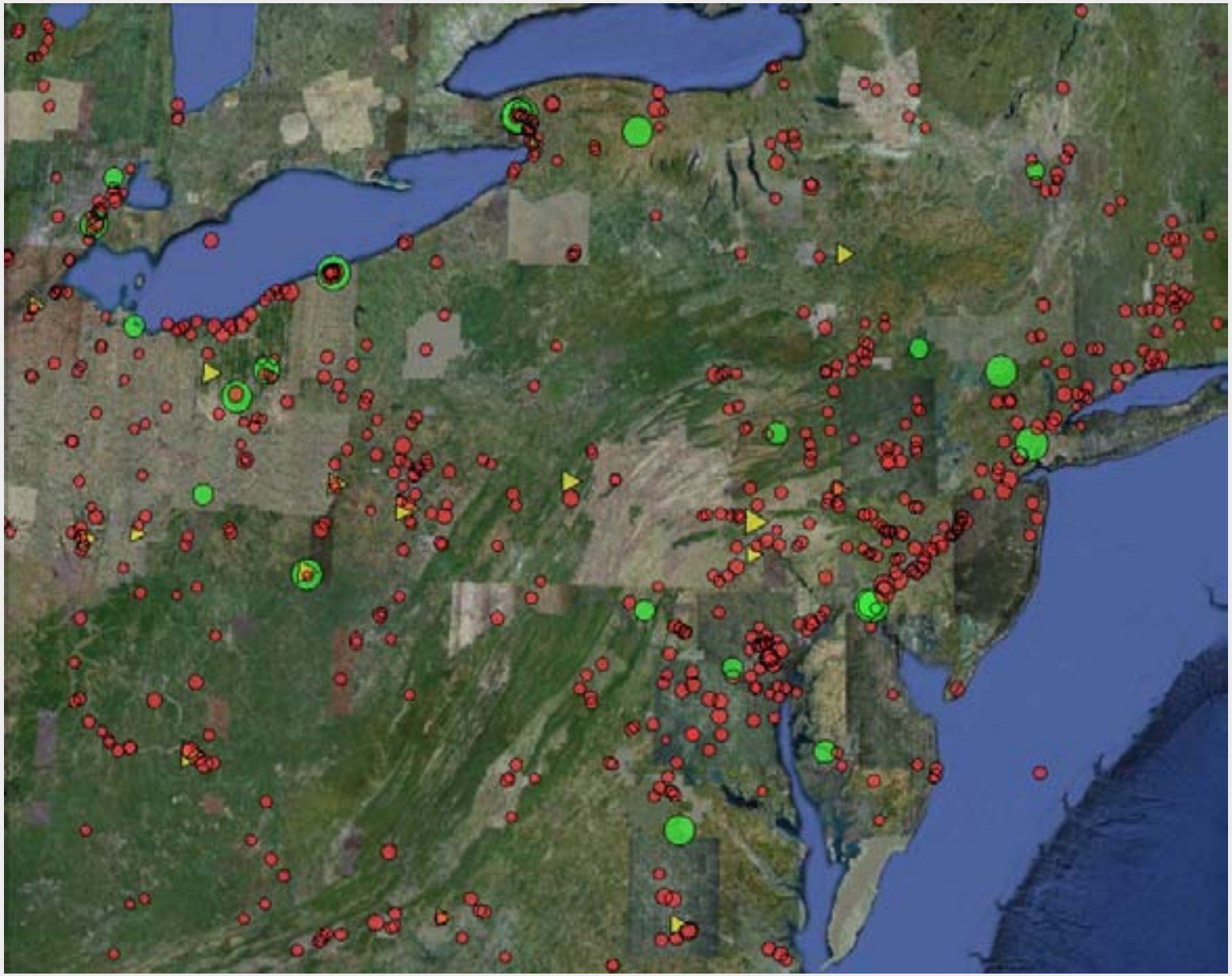
- established in 1980
- team of 3-6 students working on applied projects under direction of two faculty members
- past sponsors: National Institute of Justice; Carroll Area Transit Systems; Baltimore City Fire Department
- current project is sponsored by Chemical Security Analysis Center

Available Data

An EPA dataset details 4,291 major chlorine facilities:

Facility Name	Belmont Water Treatment Plant
Chemical Name	Chlorine
Quantity (lbs)	60000
CAS Number	7782-50-5
Facility Lat Dec Degs	39.999720
Facility Long Dec Degs	-75.219190
number of tanks	1
NAICS Code	22131
NAICS DESCRIPTION	Water Supply and Irrigation Systems
FacilityStr1	4300 Ford Road
FacilityStr2	
Facility City	Philadelphia
Facility State	PA
Facility Zip Code	19131
Facility ID	3
EPA Facility ID	333
LEPC	100000041821
Feat Desc	Philadelphia LEPC Process Unit

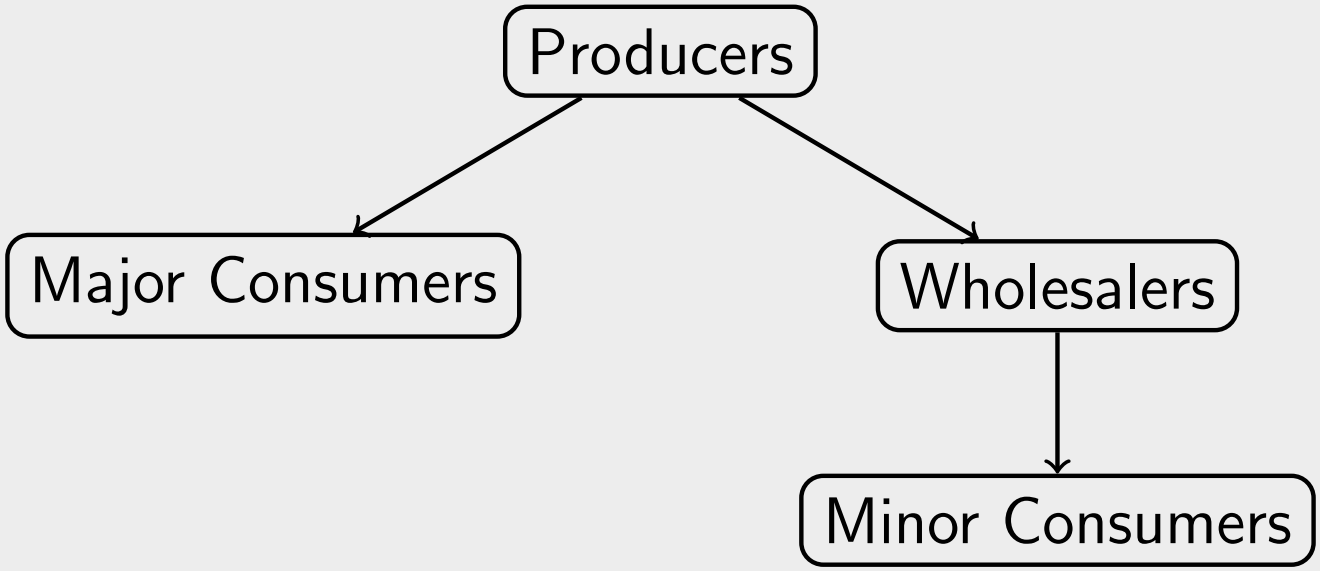
Available Data



Model Design

Model *the entire* network.
Assumptions:

- large consumers and wholesalers are supplied by rail (or barge);
- "minor" consumers are supplied by road from wholesalers, but not from producers.



Model Set-up

In addition to the assumptions about network structure, we assume:

- supply/demand is proportional to storage capacity;
- cost of transportation is proportional to route distance;
- efficient market hypothesis: transportation is done in a cost-minimizing way.

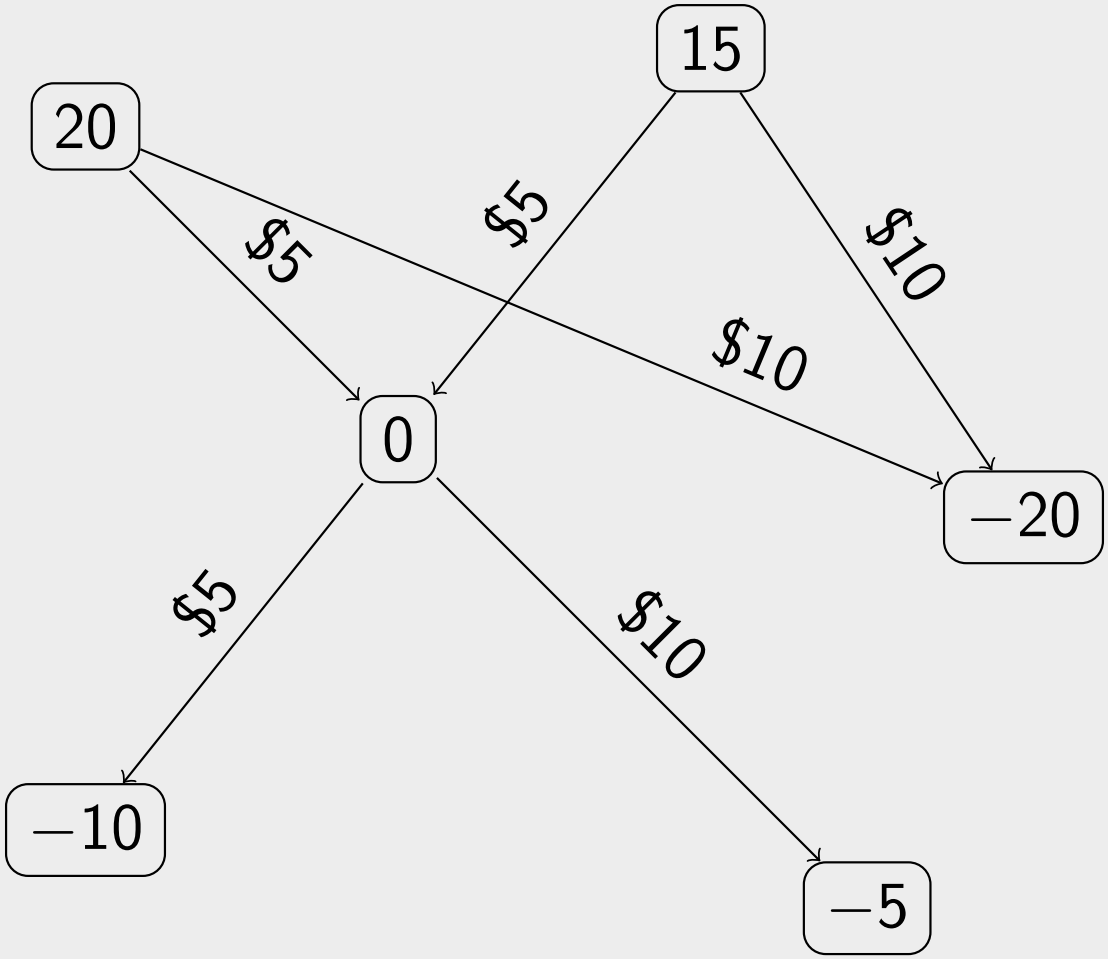
Implementation

Mathematical problem:

- find the "network flow" that minimizes the total cost of transportation;
- analyze sensitivity of solutions to changes in cost;
- find a way to deal with the sensitivity.

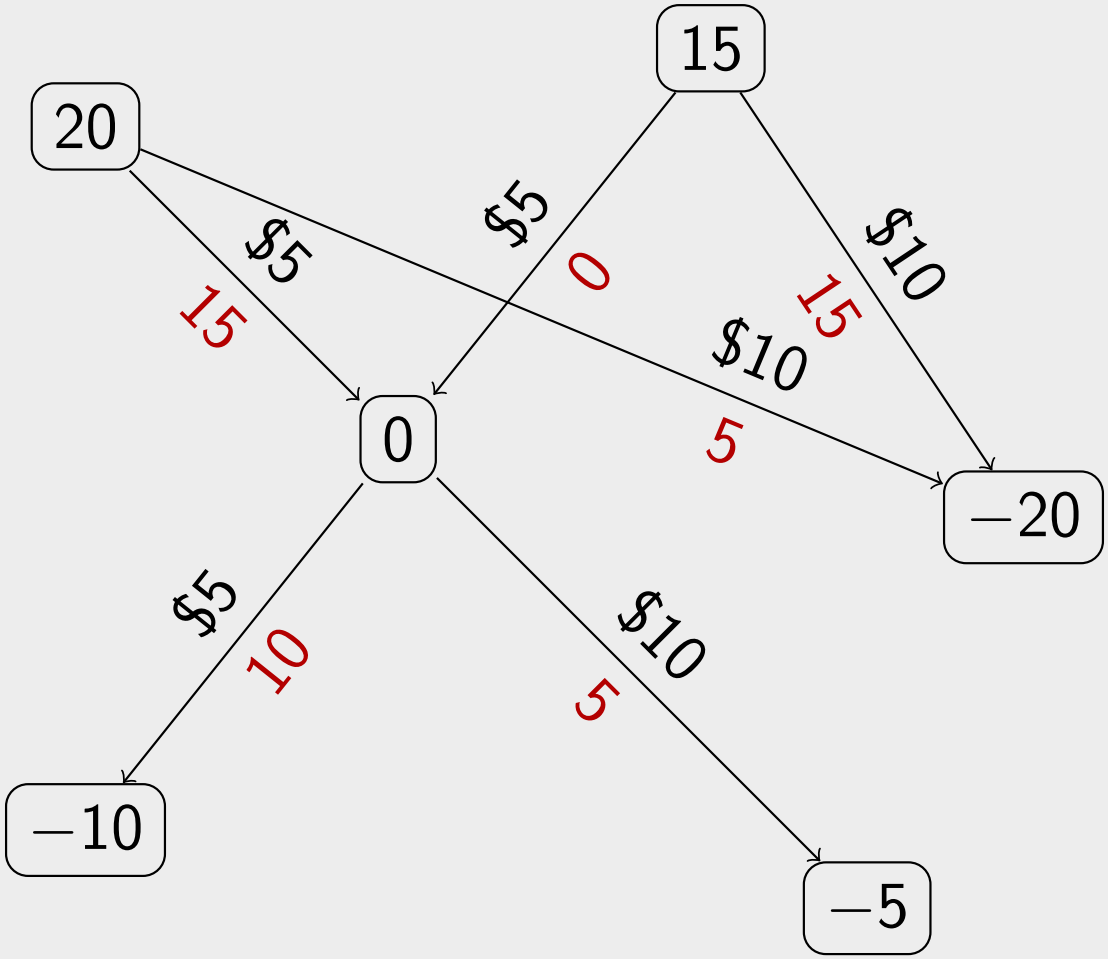
Example

A network with different cost-minimizing flows:



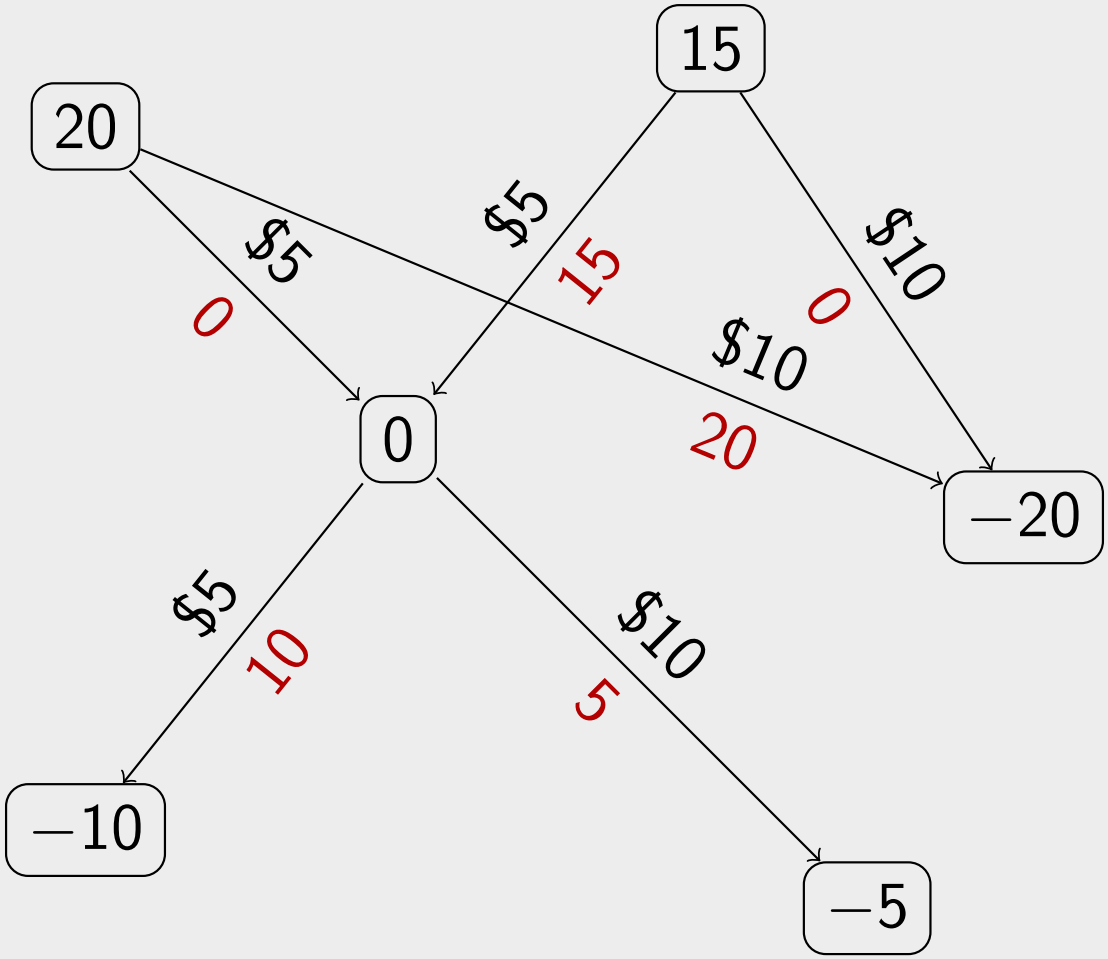
Solution 1

A network with different cost-minimizing flows:
Total minimized cost : $375



Solution 2

A network with different cost-minimizing flows:
Total minimized cost : $375



Implementation

The approach:

- Take the route costs to be random variables with the mean proportional to the route length;
- For each set of route costs, solve the cost-minimization problem, record the results;
- Compile the results from multiple trials into flow distributions for each route.

Questions:

- Can a cost-minimization problem be solved fast enough?
- What types of distributions, for each route, do we get?

Implementation

Software used:

- `sqlite`, a "light" database to store the inputs and results
- `mcf`, a Minimum Cost Flow solver (free software for academic use)
- `python`, a scripting language
- Google Earth, to visualize data and results
- ESRI routing service

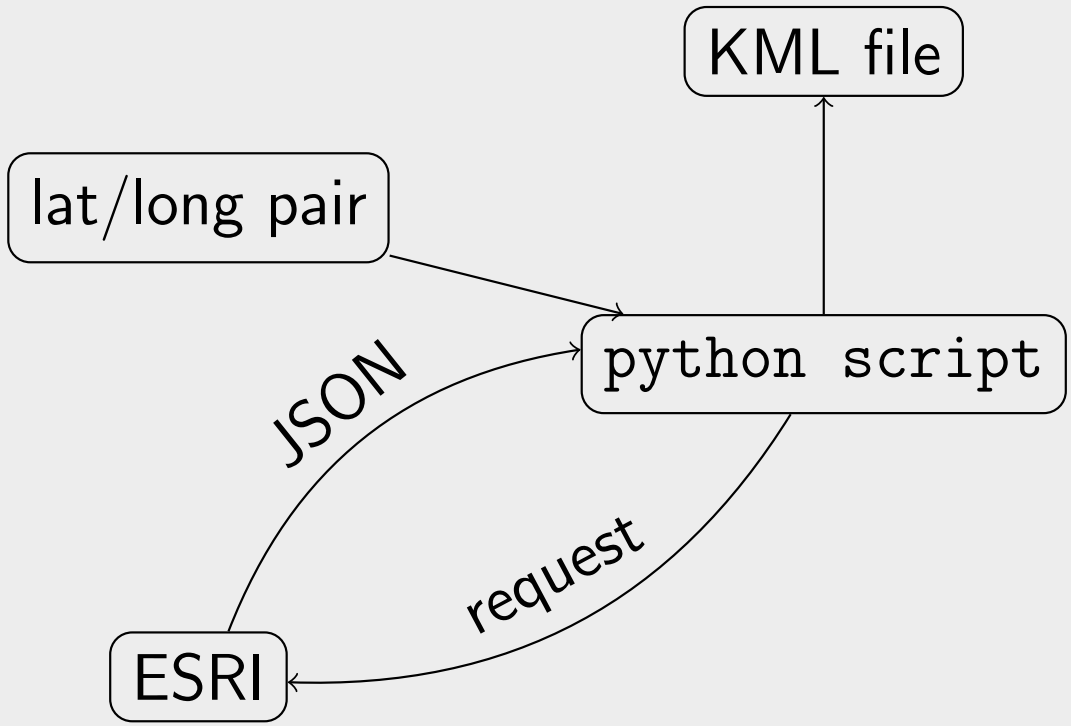
Implementation

Network: more than 4,000 nodes; more than 500,000 routes.
Minimum cost flow problem is solved fast: about 4 seconds per trial.
Visualization remains the biggest challenge:

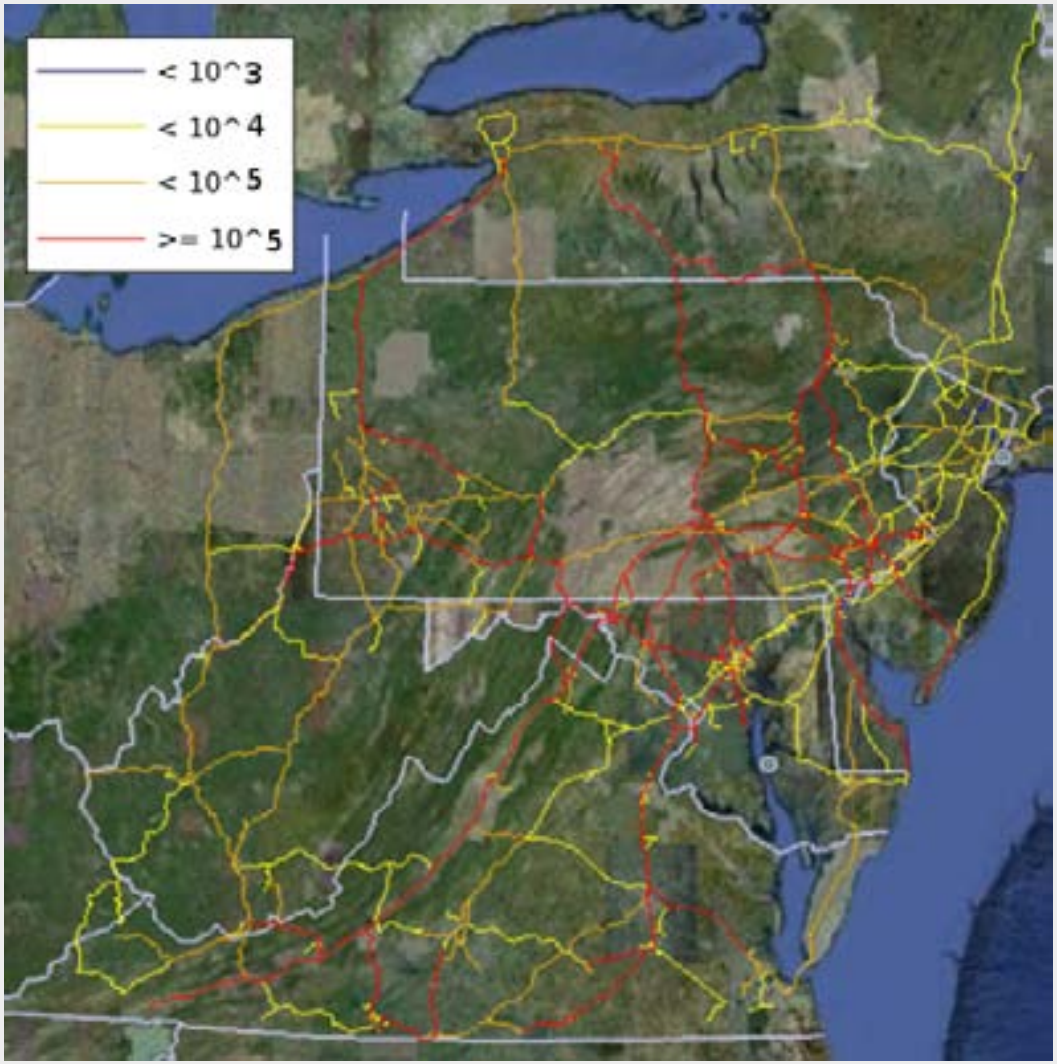
- How to display a single solution?
- How to display the distribution of solutions for a route?

Visualization

- Server hosted by Economic and Social Resource Institute
- Produces driving route from a pair of latitude/longitude coordinates.



Results



Results

What are the distribution types?

Distribution type	% of routes
Zero flow	64%
Bi-modal	35%
Non-zero constant	0.7%
Other	0.3%

Zero: no shipment in any of the trials;
Bi-modal: either no shipment or a fixed amount shipment;
Non-zero constant: shipment of a fixed amount in all trials.

Future directions

- Include risk assessment in the model;
- Better visualization of solutions;
- Provide ways to adjust the model;
- What are other questions that can be answered?