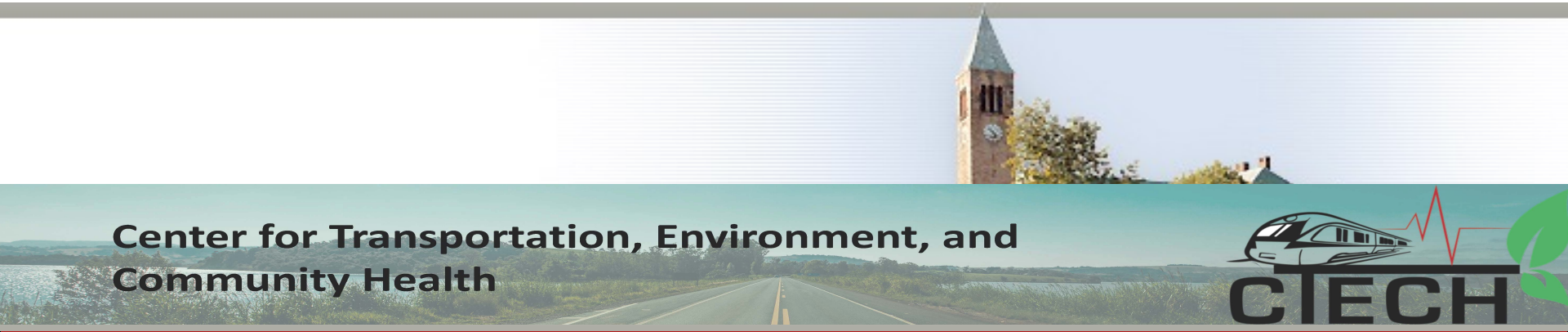
Urban Tech, Data Science, and Industry 5.0

for systems innovation at the nexus of urban infrastructure, climate/environment for smart and healthy communities

H. Oliver Gao, Cornell University, hg55@cornell.edu
Director, Center for Transportation, Environment, and Community Health (CTECH)

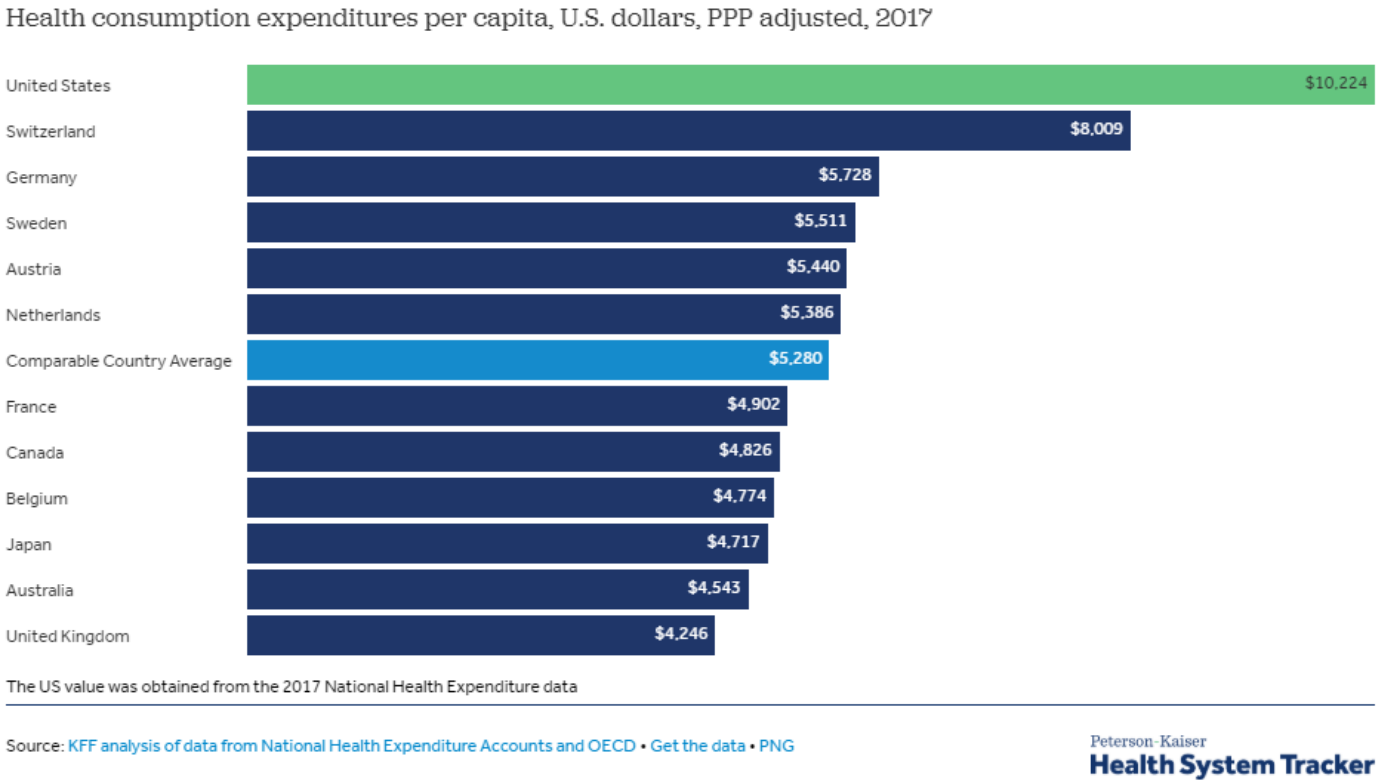


Two questions?

What is your most valuable asset?

Health Care

17% US GDP

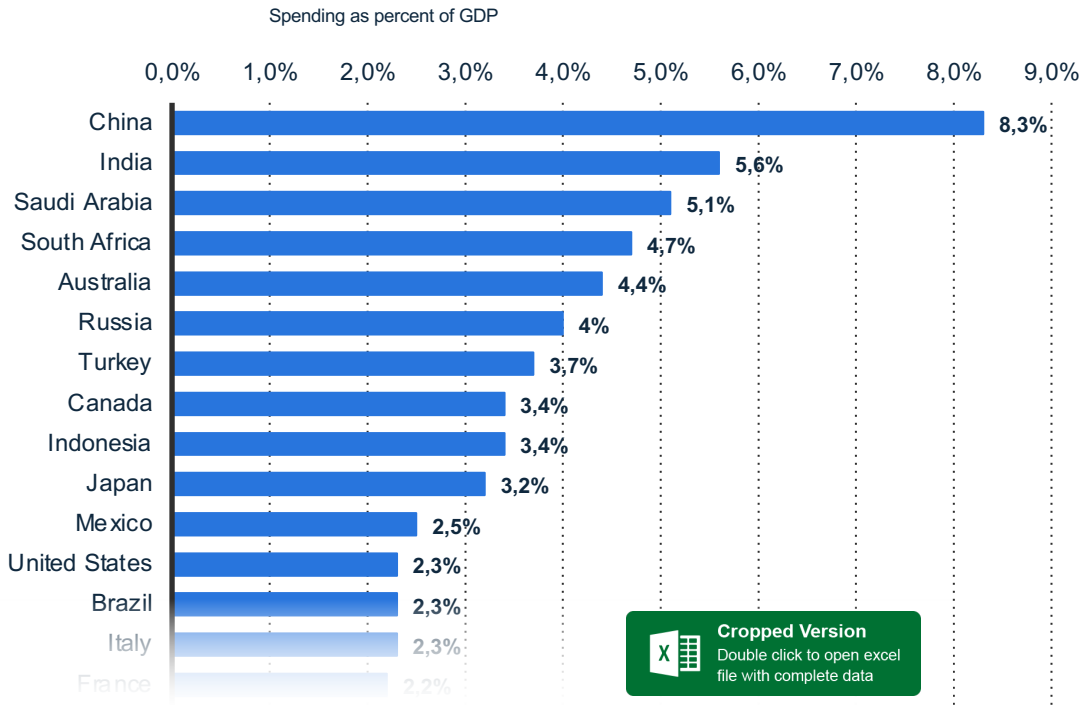


What is a nation's most valuable asset?

Infrastructure Expenditures

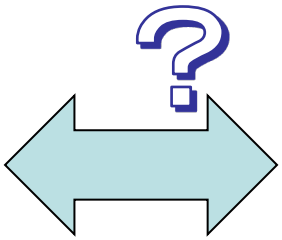
Annual average infrastructure expenditures as percent of GDP worldwide from 2010 to 2015, by country

Global annual spending on infrastructure as percent of GDP by country 2010-2015

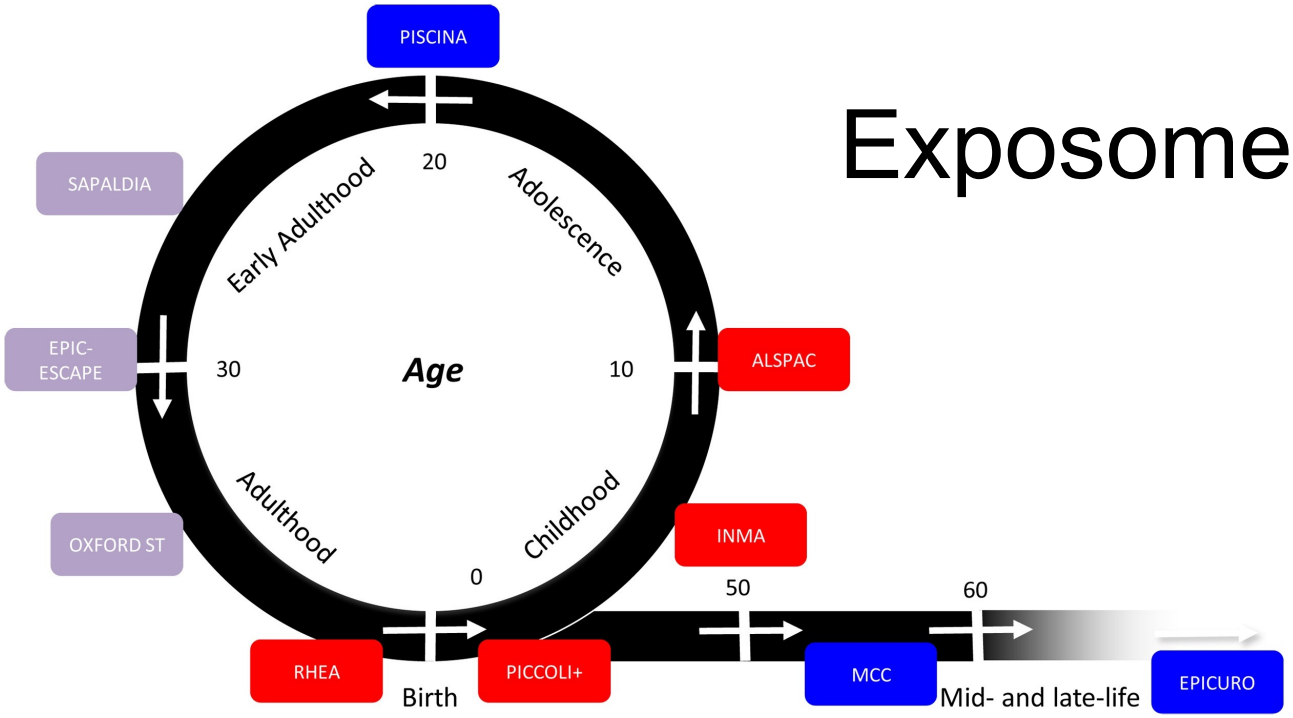


Note: Worldwide; 2010 to 2015
Further information regarding this statistic can be found on page 8.
Source(s): IHS; ITF; GWI; Deloitte; McKinsey; ID 566787

Your asset and the nation's most valuable assets



Health Factors: Genome, Phenome, and



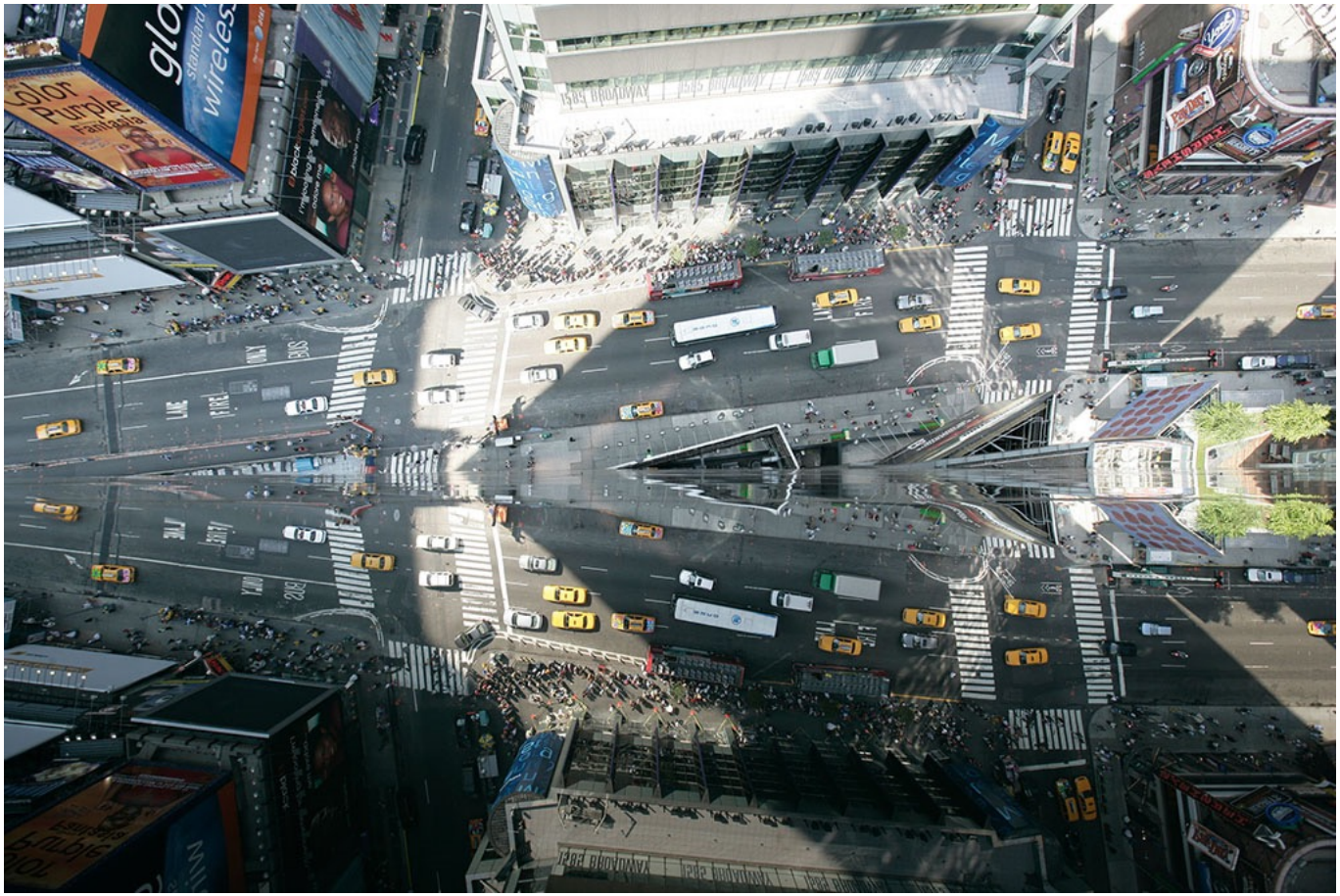
Exposome

The conceptual framework of Exposomics (life-long integration of cohorts)
(source: Vineis et. al., 2017, International Journal of Hygiene and Environmental Health)

Exposome—Infrastructure/Transportation, and Health in Cities

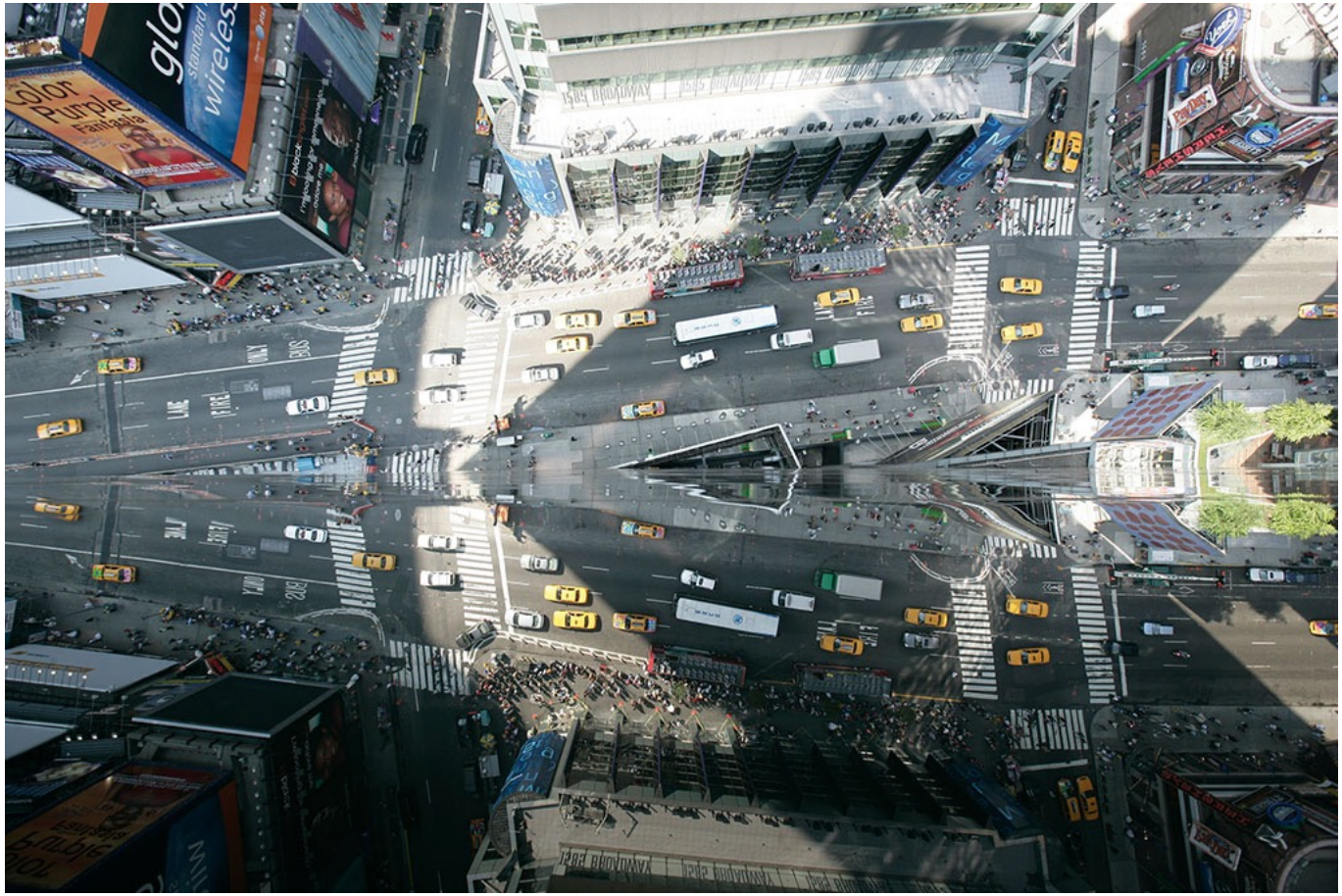
http://www.portstrategy.com/news101/administration/finance-and-investment/waking_up_to_exit_tariffs

Move closer



Building urban infrastructure for ants

Human life/health is shaped by infrastructure such as transportation



Transportation & Mobility at a Cost of Global Health

Transportation motorization caused 13.5 million disability-adjusted life-years and $53.8 billion of health-care costs worldwide (Ding et al., 2016; Goenka & Andersen, 2016).

Transportation increases ambient air pollution that kills three million people in the world every year (WHO, 2016a).

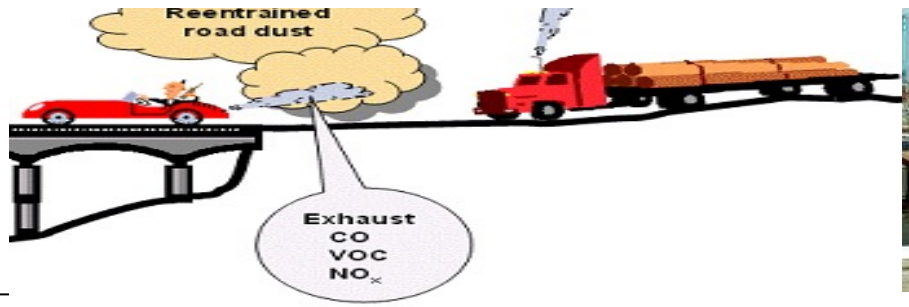
What's wrong?

What's the problem?

Paradigm is wrong: efficiency vs. sustainability

Physical Efficiency

Education and Practice are problematic: Disciplinary disconnection, sectorial silos

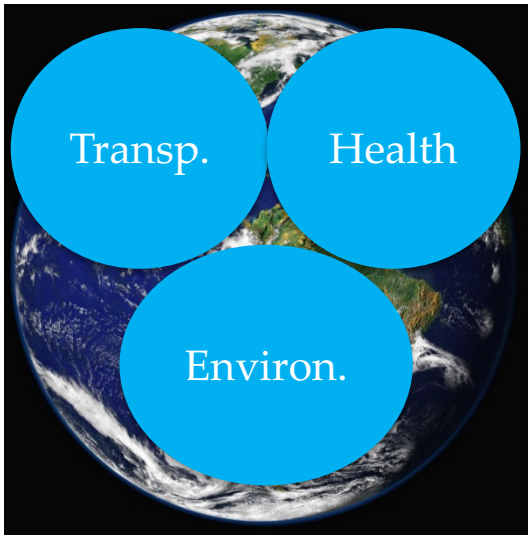


Can we fix the problems?

What shall we do, and must do?

System integrative infrastructure, transportation, environment & health planning, design, and management

Integrating Urban Infrastructure, Environment, and Community Health

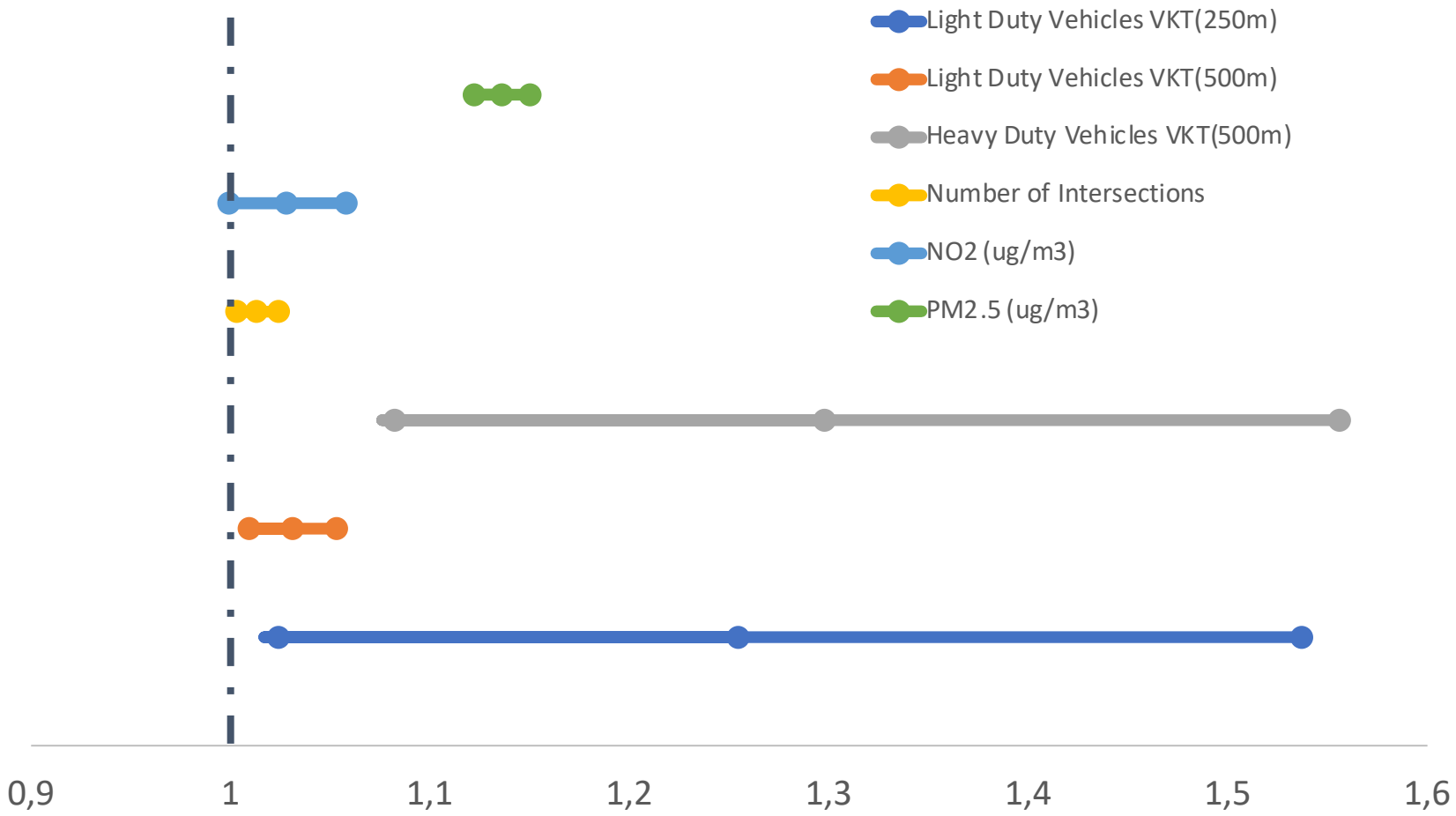


http://www.portstrategy.com/news101/administration/finance-and-investment/waking_up_to_exit_tariffs

Example: Infrastructure/Built Environment and Health

- 12,600 Heart Failure patients in New York City, 2012-2017
- Individual Covariates:
  - ✓ Age, gender, BMI, Education, Income, Smoking, Ethnicity
- Built Environment Covariates:
  - ✓ **Walkability**: Land Use Mix, #of Intersections, Retail Floor to Area Ratio (500 meter buffer)
  - ✓ **Air Pollution**: No2, PM2.5 Concentration (250 & 500 meter buffers)
  - ✓ **Accessibility**: Distance to the nearest: Park, Bus Station, Subway Station, Bike Facilities
  - ✓ **Traffic Exposure**: Light & Heavy VKT in 250&500 meters buffers
  - ✓ **Crime**: Housing Violations

What We have Found



OR of Death in HF Patients

Tayanary, Zhang, and Gao (2019)

Urban design and Mental Health: Transportation and Land Use Systems Impacts on Postpartum Depression Incidence

- The cohort of pregnant women from the Electronic Health Records of Weill Cornell Medicine and New York-Presbyterian Hospital from 2015 to 2017 are studied (N= 9,801). Individual Covariates:
  - ✓ Age, gender, BMI, Education, Income, Smoking, Ethnicity
- Built Environment Covariates:
  - ✓ **Walkability**: Land Use Mix, #of Intersections, Retail Floor to Area Ratio (500 meter buffer)
  - ✓ **Air Pollution**: No2, PM2.5 Concentration (250 & 500 meter buffers)
  - ✓ **Accessibility**: Distance to the nearest: Park, Bus Station, Subway Station, Bike Facilities
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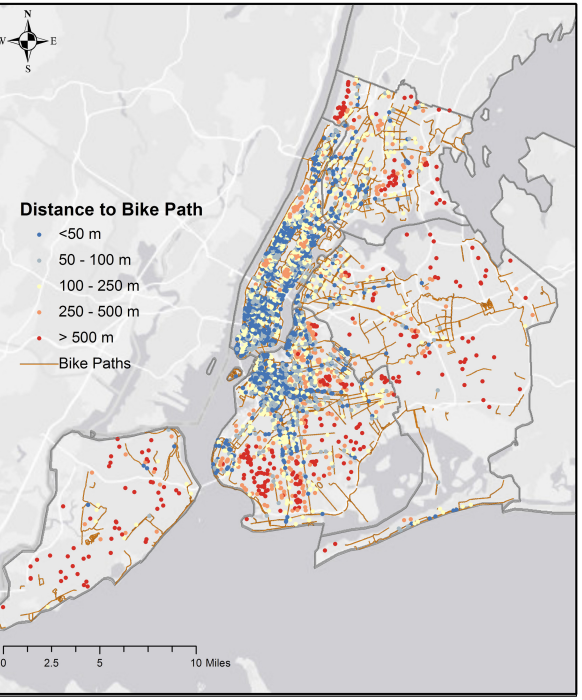

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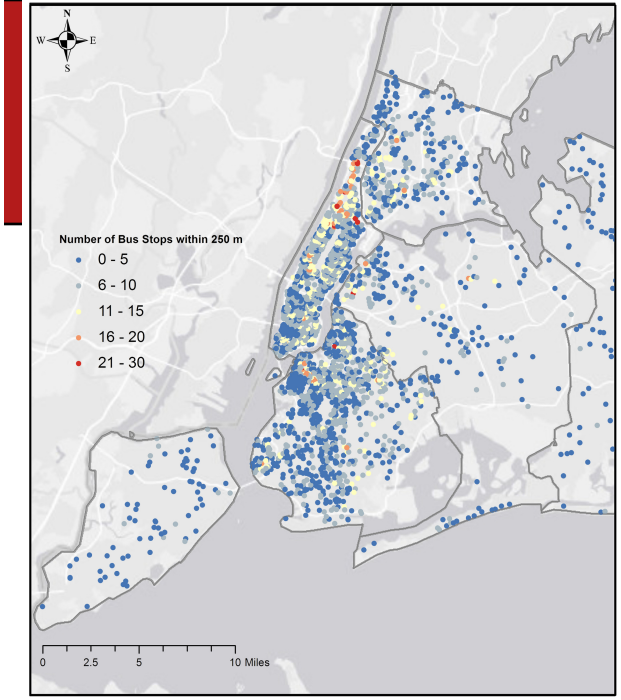
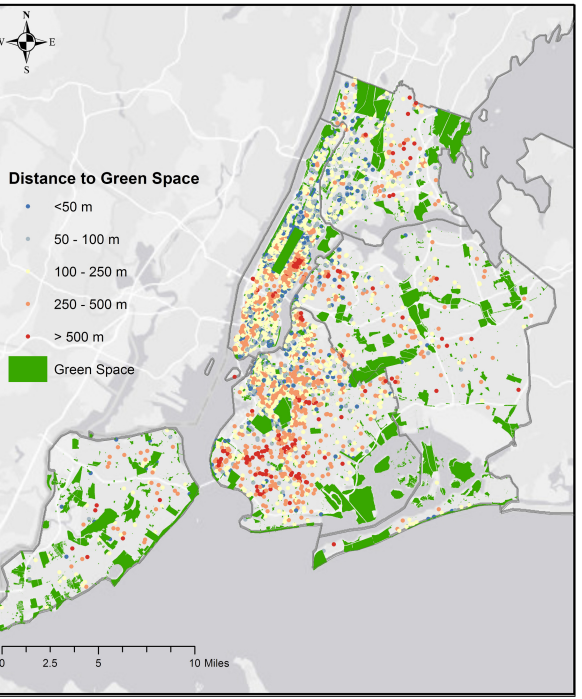
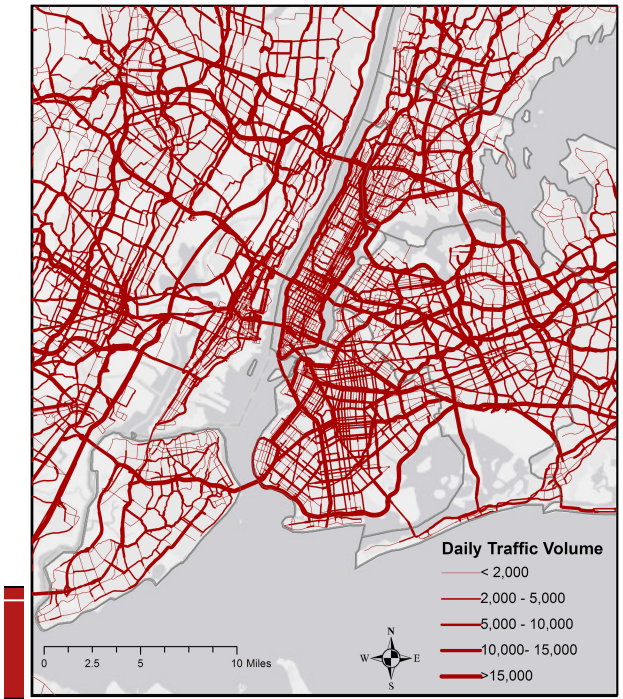


(b)

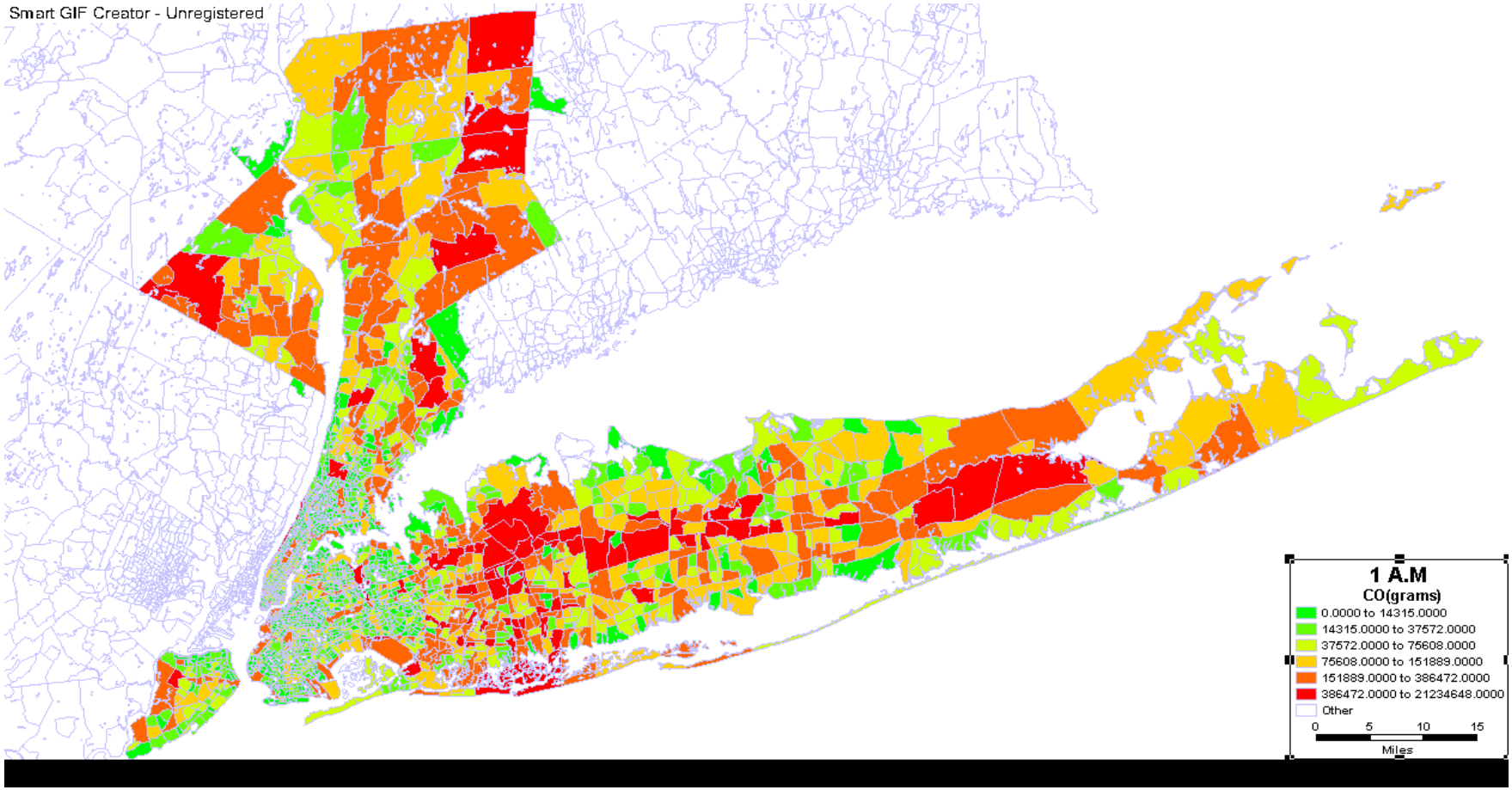




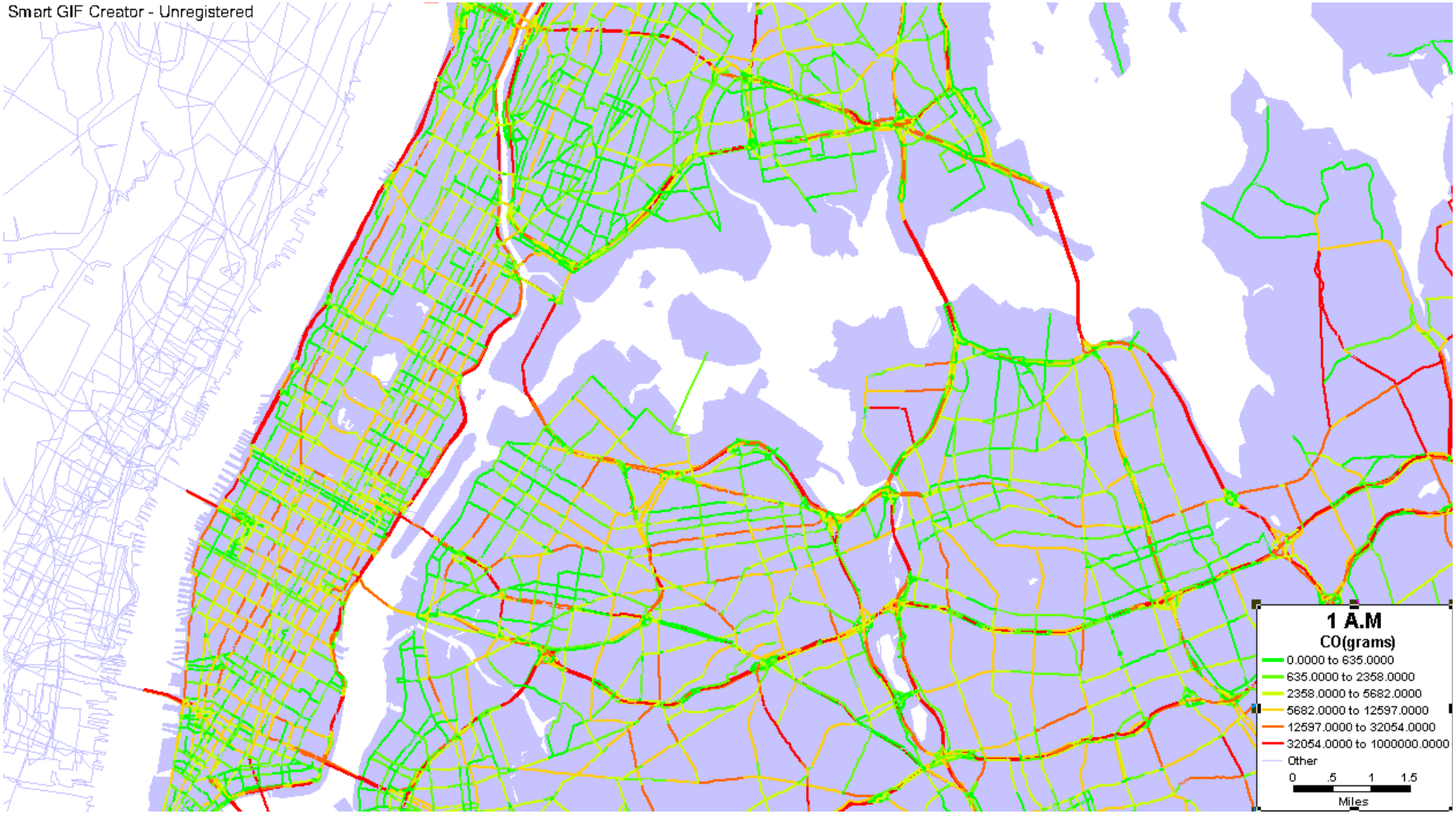
Significant Built Environment Factors On Postpartum Depression Incidence:

a) **Distance to Bike Path,**
b) **Number of Distance,**
c) **Distance to Green Space,**
d) **Daily Traffic Volume**

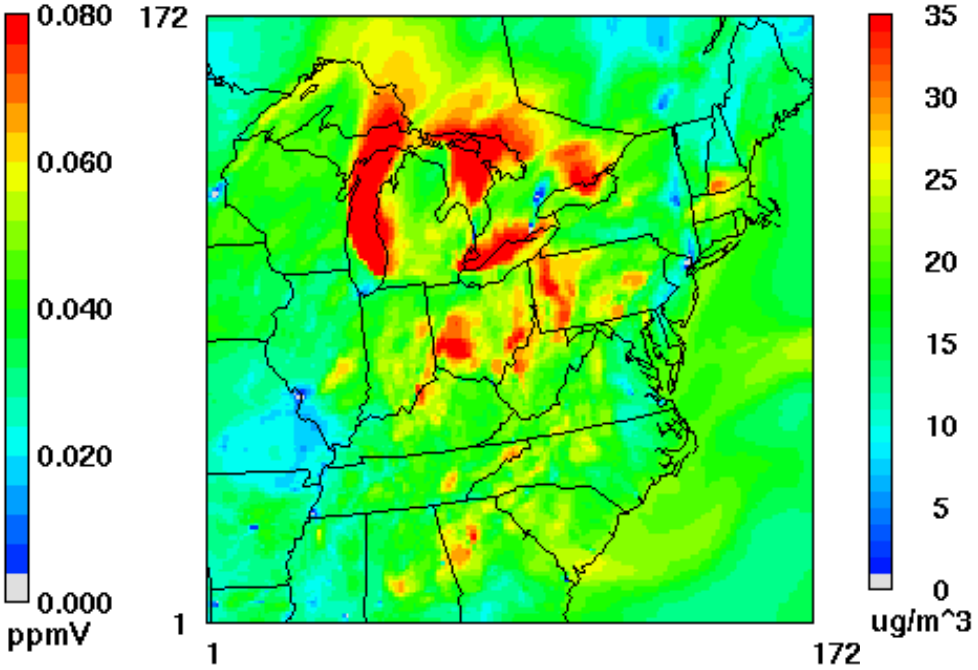
Future Mobility: the 3 Revolutions: Transportation Emissions Modeling in NYC



Transportation Emissions Modeling in NYC-Link based emissions

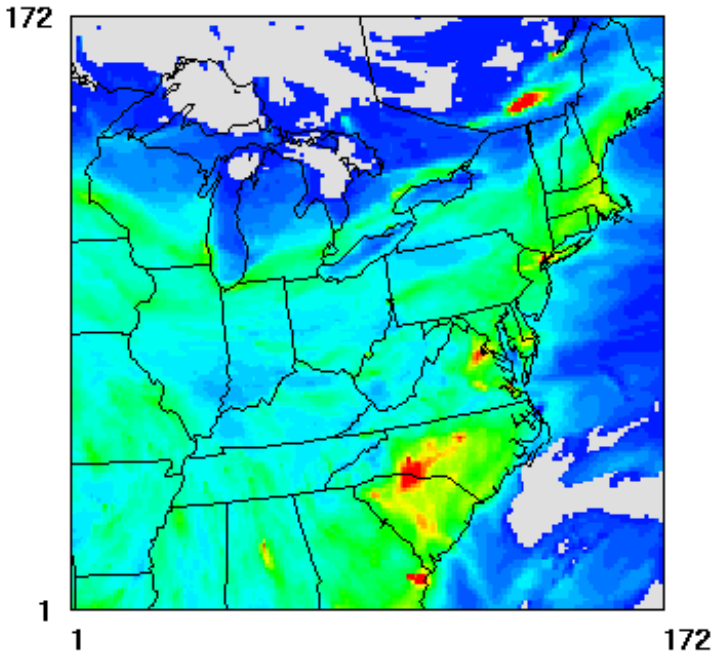


O3



July 1,2002 5:00:00
Min=0.000 at (93,112), Max=0.135 at (45,113)

PM2.5



January 1,2002 5:00:00
Min= 0 at (138,28), Max= 64 at (129,145)

Quantifying the Health Costs of Air Pollution toward Optimal Policy Decision Making for Infrastructure, Environment, and Health

We have built NYC into Testbeds.

We can do the same for any city to evaluate any policy, any technology

Information Technology for Behavior Change

Informatics and Behavior Intervention for Healthy Living in Smart Cities

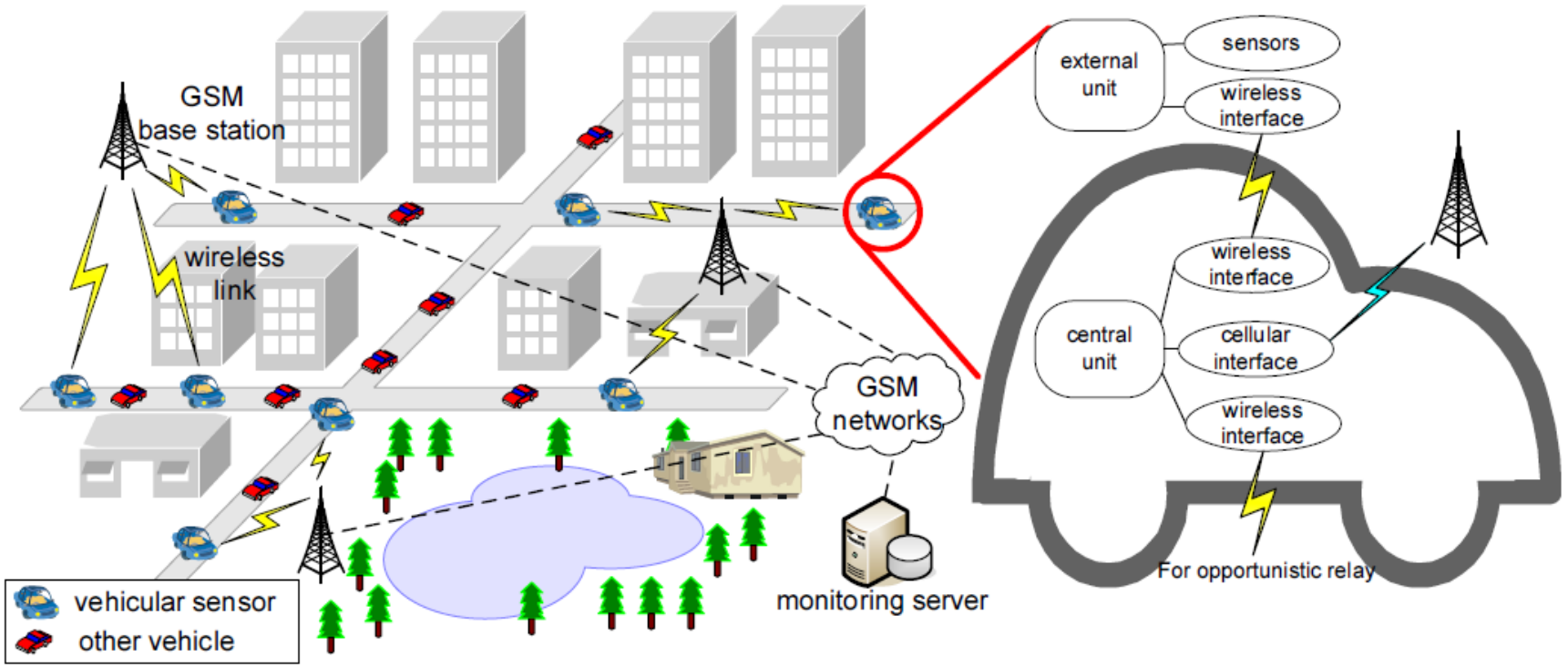
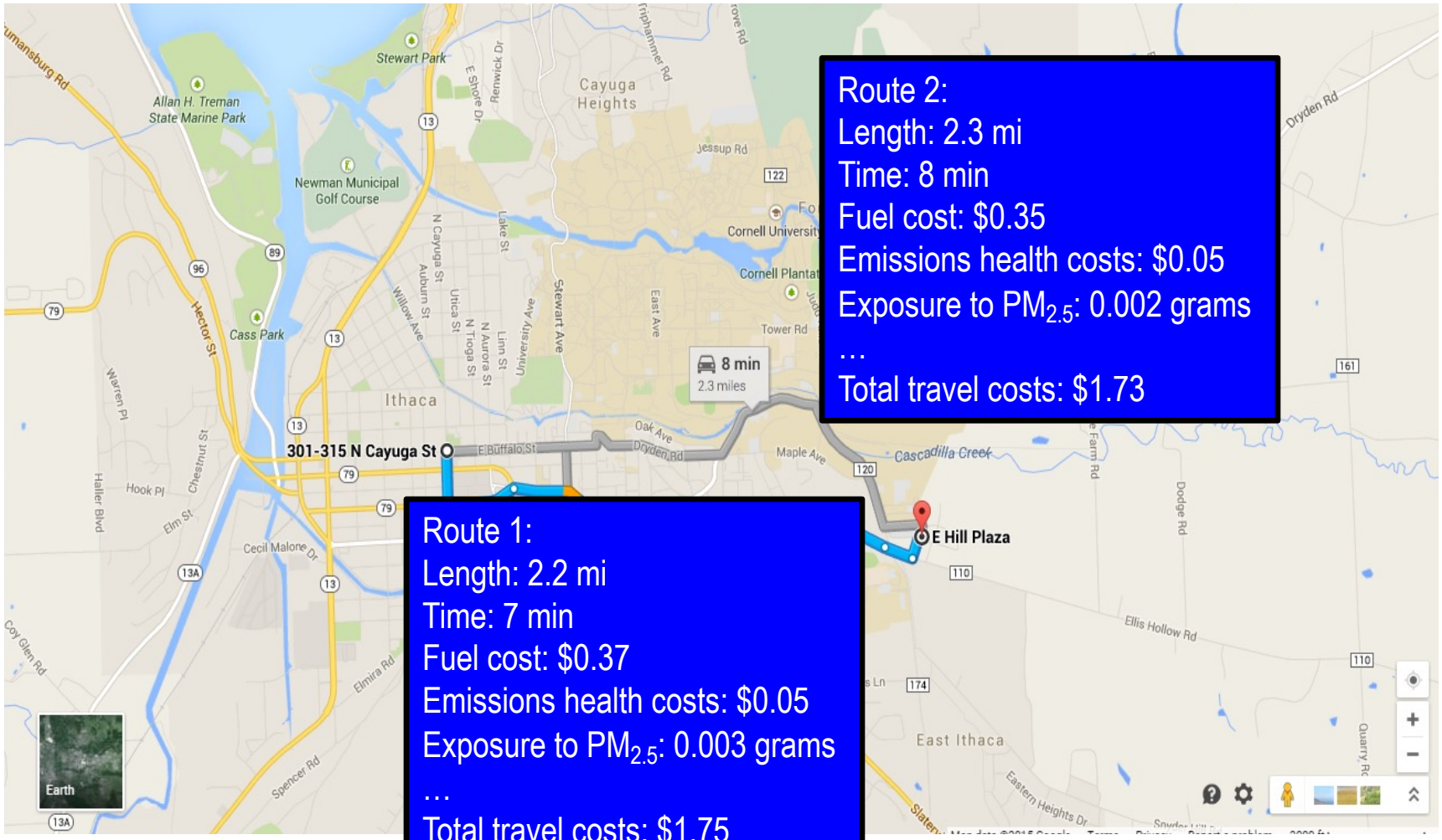


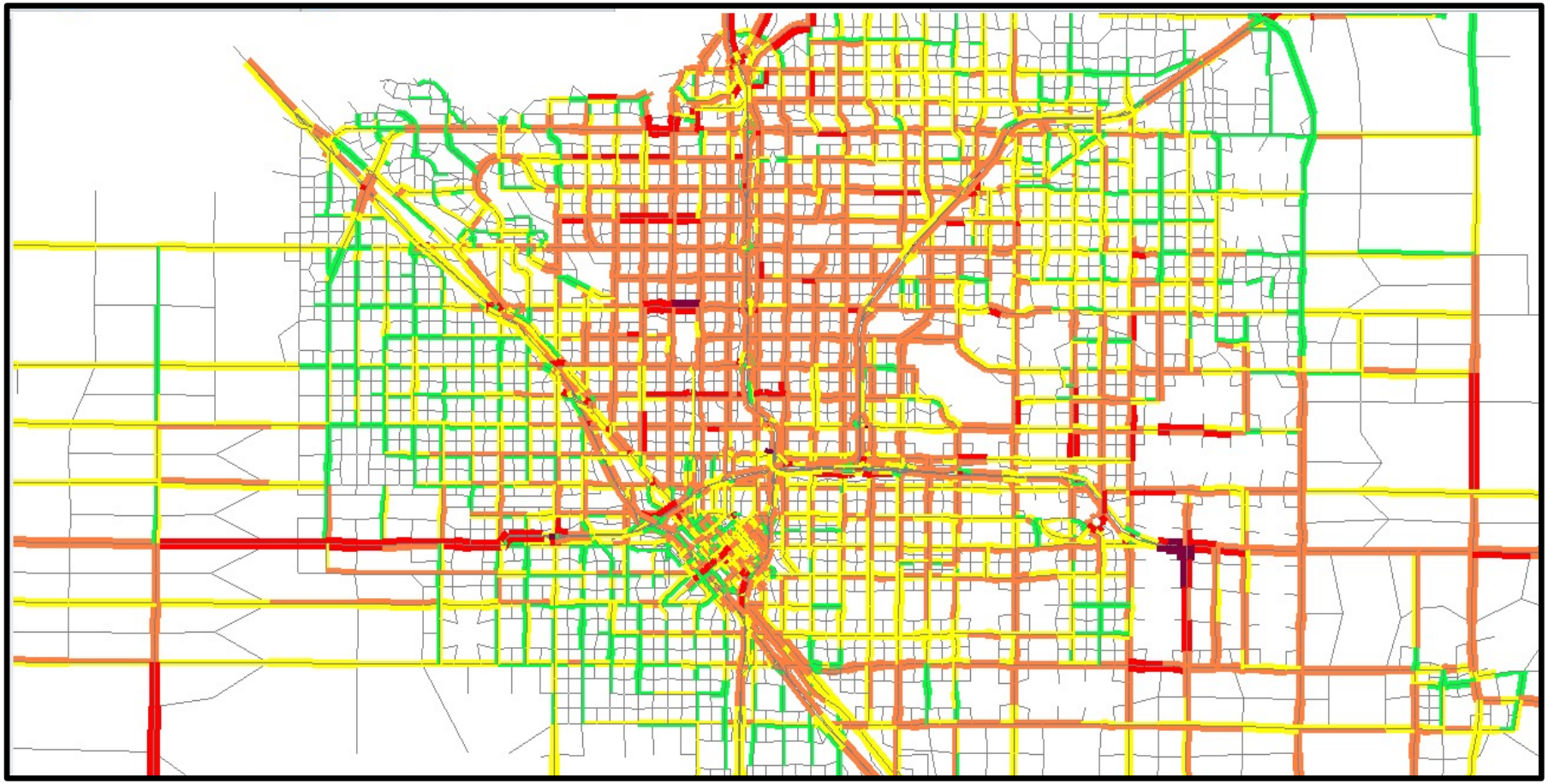
Fig. 1: The proposed VSN architecture for micro

Atkinson Center for a Sustainable Future

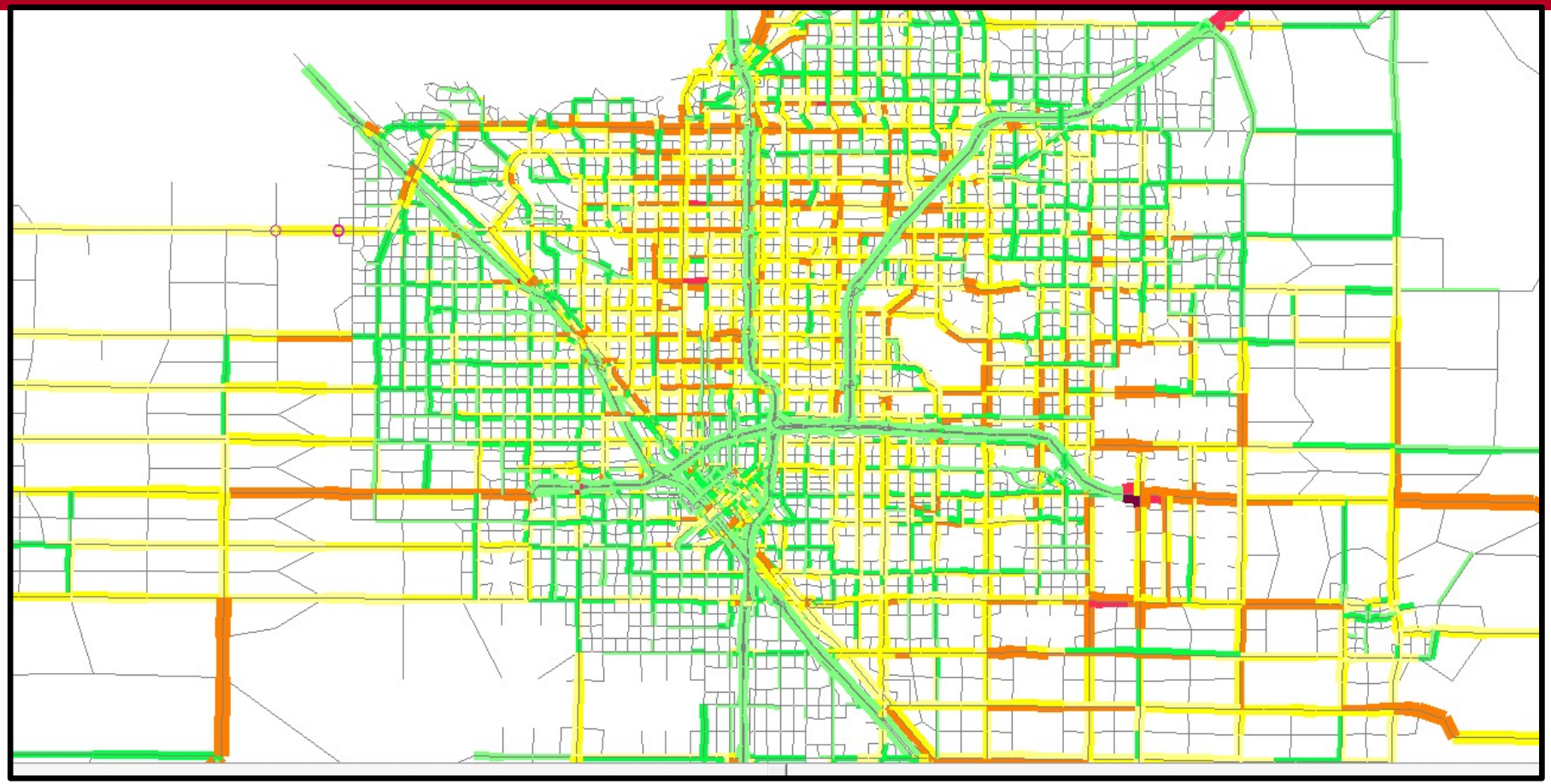
Better informed travelers make heathier decisions



Traffic behavior before



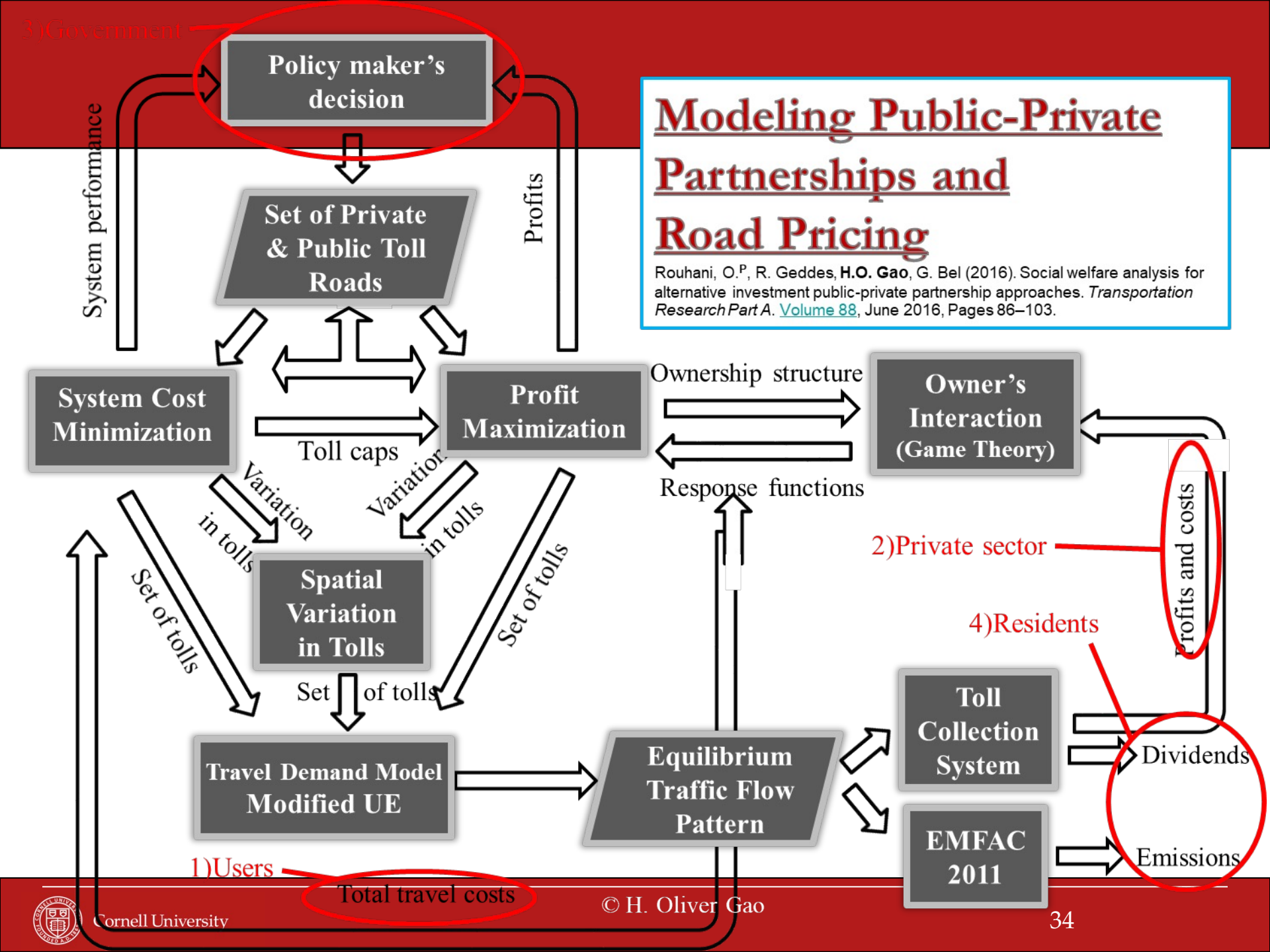
Traffic behavior after



Omid M. Rouhani, H. Oliver Gao (2014), An advanced traveler general information system for Fresno, California, Transportation Research Part A, 67, 254–267

Infrastructure Policy, Finance, and Health

Picture Source: www.komonews.com


3)Government
Policy maker's decision
System performance
Profits
Set of Private & Public Toll Roads
System Cost Minimization
Profit Maximization
Toll caps
Ownership structure
Response functions
Owner's Interaction (Game Theory)
Variation in tolls
Variation in tolls
Set of tolls
Set of tolls
Spatial Variation in Tolls
Set of tolls
2)Private sector
Profits and costs
4)Residents
Travel Demand Model Modified UE
Equilibrium Traffic Flow Pattern
Toll Collection System
Dividends
EMFAC 2011
Emissions
1)Users
Total travel costs
Modeling Public-Private Partnerships and Road Pricing
Rouhani, O.P, R. Geddes, H.O. Gao, G. Bel (2016). Social welfare analysis for alternative investment public-private partnership approaches. Transportation Research Part A. Volume 88, June 2016, Pages 86–103.

Model and Findings

Flexible PPP

Government

- Social choice fun.: $f(c, v)$
- Blind on c, v
- Designing a mechanism satisfying BIC and IIR with payment p_l^i and p_o^j

Private parties

- Decision t
- Private type c_i
- $u_l^i(d(t, f), c_i) - p_l^i(t, f)$

The publics

- Decision f
- Knowing t
- Private type v_j
- $u_o^j(d(t, f), v_j) - p_o^i(t, f)$

Stage 0

- Government designs mechanism (M, g)

Stage 1

- Private parties make decision

Stage 2

- The publics make observation
- The publics make decisions
- The designer makes decision d and receives payment p

Brian Huang and H. Oliver Gao (2019)

Math form

$$\max_{\substack{\mathbf{p}(\mathbf{t},\mathbf{f}):\\ \mathbf{t}\in\mathbb{T}\\ \mathbf{f}\in\mathbb{F}}} \quad \mathbf{E}_{c,v}\left[\sum_i u_l^i(\mathbf{t_c}, \mathbf{f}^*_{\mathbf{v},\mathbf{t}}|\mathbf{c}) + \sum_j u_o^j(\mathbf{t}, \mathbf{f}_{\mathbf{v},\mathbf{t}}|\mathbf{v})\right]$$

Obj. fun.
Maximizing social welfare

$$s.t. \quad \mathbf{E}_{\mathbf{v},\mathbf{c}^{-i}}\left\{I_l^i(\tau_c^i, \tau_{\mathbf{c}^{-i}}^{-i}, \mathbf{f}^*_{\mathbf{v},\tau_c}) - \Omega(c, \mathbf{f}^*_{\mathbf{v},\tau_c}) - p_l^i(\tau_c^i, \tau_{\mathbf{c}^{-i}}^{-i}, \mathbf{f}^*_{\mathbf{v},\tau_\mathbf{c}})\right\}$$

$$\geqslant \mathbf{E}_{\mathbf{v},\mathbf{c}^{-i}}\left\{I_l^i(t, \tau_{\mathbf{c}^{-i}}^{-i}, \mathbf{f}^*_{\mathbf{v},\tau_c}) - \Omega(c, \mathbf{f}^*_{\mathbf{v}},\ldots\right\}$$

$$\forall\, i = 1,\ldots,M,\ t \in T^i,$$

$$\mathbf{E}_{\mathbf{v}-j}\left\{-p_o^j(\tau_\mathbf{c}, \phi_{\mathbf{v}-j}^{-j}, \phi_v^j) - I_o^j(\tau_\mathbf{c}, \phi_{\mathbf{v}-j}^{-j}, \phi_v^j) -\right.$$

$$\geqslant \mathbf{E}_{\mathbf{v}-j}\left\{-p_o^j(\tau_\mathbf{c}, \phi_{\mathbf{v}-j}^{-j}, f) - I_o^j(\tau_\mathbf{c}, \phi_{\mathbf{v}-j}^{-j},\ldots\right\}$$

$$\forall\, j = 1,\ldots,N,\ \mathbf{c} \in \mathbb{C},\ v \in V^j,\ f \in F^j,$$

Constraints 1 & 2
Bayesian incentive compatibility

$$\mathbf{E}_{\mathbf{v},\mathbf{c}^{-i}}\left\{I_l^i(\tau_c^i, \tau_{\mathbf{c}^{-i}}^{-i}, \mathbf{f}^*_{\mathbf{v},\tau_c}) - M(c, \mathbf{f}^*_{\mathbf{v},\tau_c}) - p_l^i(\tau_c^i, \tau_{\mathbf{c}^{-i}}^{-i}, \mathbf{f}^*_{\mathbf{v},\tau_\mathbf{c}}) - U_l^i\right\} \geqslant 0$$

$$\forall\, i = 1,\ldots,M,\ c \in C,$$

$$\mathbf{E}_{\mathbf{v}-j}\left\{-p_o^j(\tau_\mathbf{c}, \phi_{\mathbf{v}-j}^{-j}, \phi_v^j) - I_o^j(\tau_\mathbf{c}, \phi_{\mathbf{v}-j}^{-j}, \phi_v^j) -\right.$$

$$\forall\, j = 1,\ldots,N,\ \mathbf{c} \in \mathbb{C},\ v \in V^j,$$

Constraints 3 & 4
Interim individual rationality

Brian Huang and H. Oliver Gao (2019)

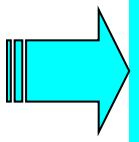
Conclusion: Mega-Ton Problems Require "Mega-Ton Solutions"

Max ObjTrans(X1, X2, ..., Xn)

Subject to:

Efficiency, Equity, Energy & Environ

Reliability, ... constraints.



Multidisciplinary Systems Approaches, and Solutions!!!

Engineering

Natural Science

Social Science

Technology

Human Behavior

…

Conclusion: Mega-Ton Problems Require "Mega-Ton Solutions"

$$\text{Max } \text{ObjTrans}(X1, X2, \ldots, Xn)$$

Subject to:

Efficiency, Equity, Energy & Environ

Reliability,...constraints.

Multi-Sector Planning and Design for Smart and Healthy Communities!!!

Government, Industry, Academia

Infrastructure (transportation, power and utility, water, etc.)

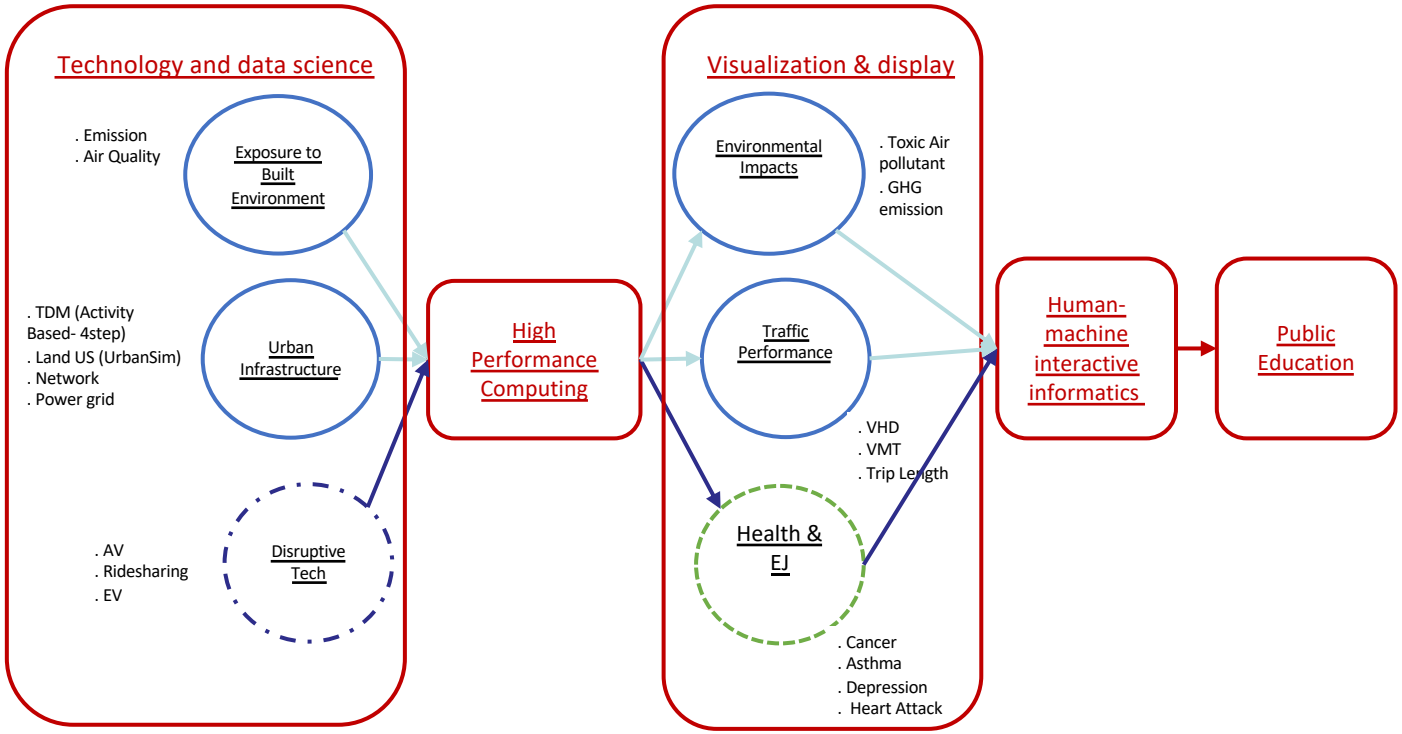
Environment/Energy

CTECH Open Labs

Advanced Technology, Data Science, AI and Informatics, and Digital Twin

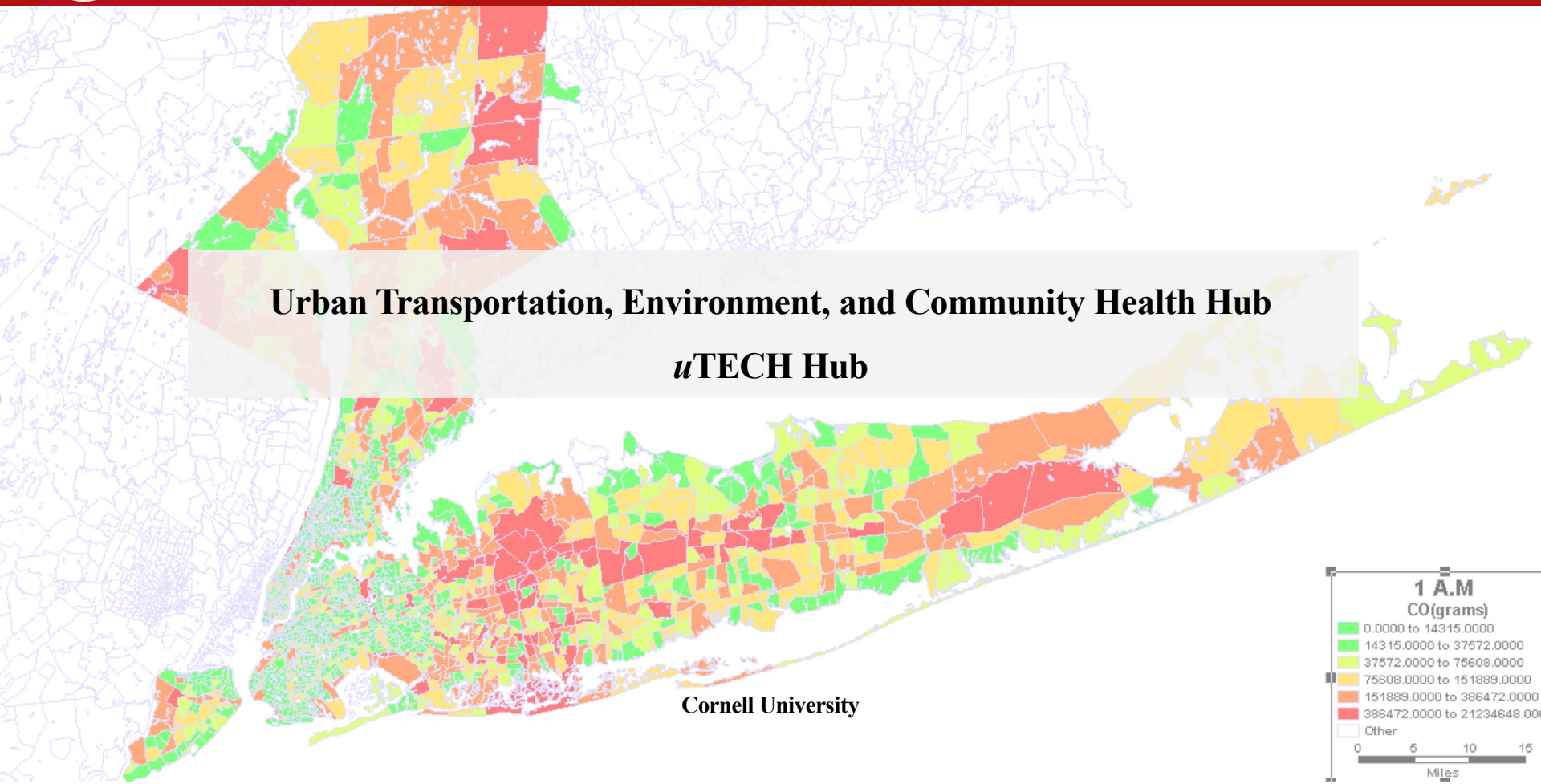
Building Smart and Healthy Communities in Urban and Rural Settings

CTECH Sustainable Urban Planning Tool (SUPT)



Urban Transportation, Environment, and Community Health Hub

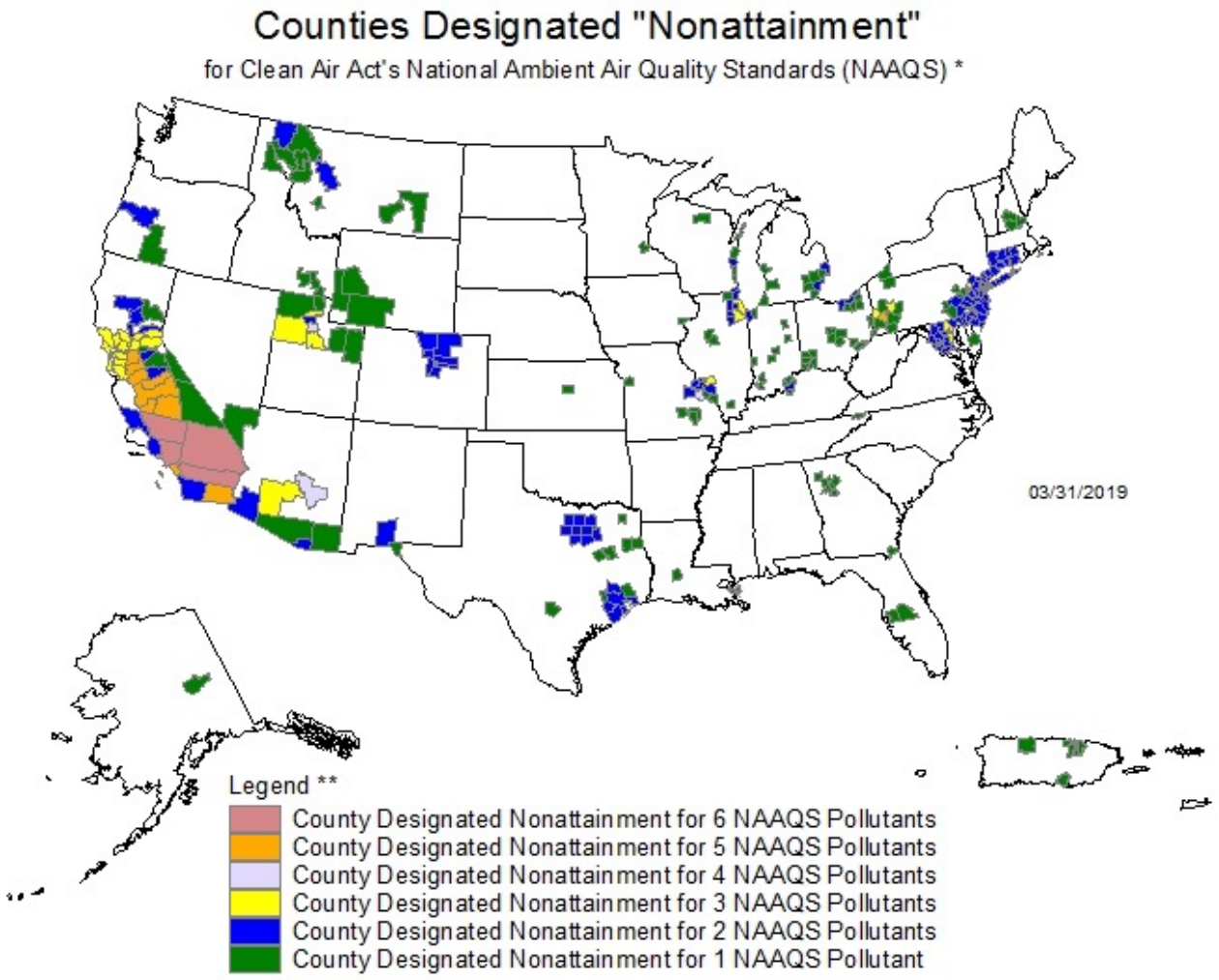
*u*TECH Hub



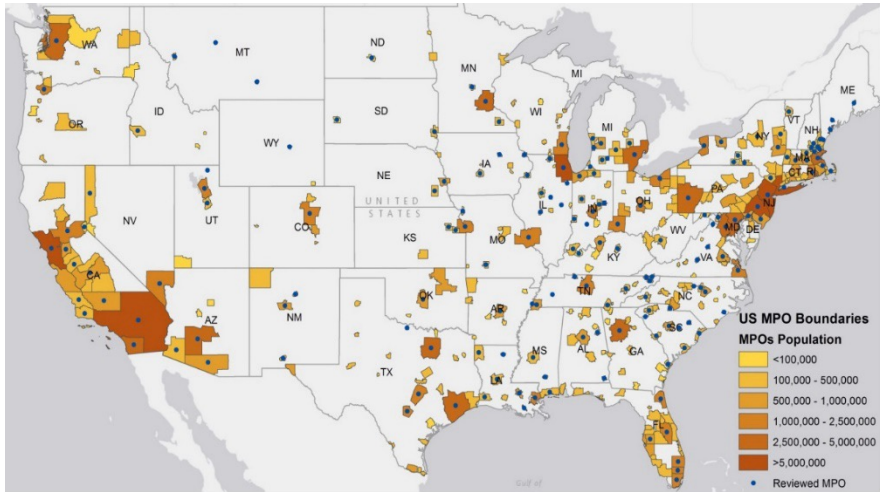
Cornell University

Existing Market Need

There are 120 Areas across the country in the Nonattainment areas with the 2010 population of 132,503.



50 DOTs & 408 MPOs



Corporations

Politics & Policy

Climate Costs Rise as Amazon, Retailers Compete on Fast Delivery

'The problem isn't buying online—it's how the delivery is implemented and how packages come to our door.'

By LEILA ABBOUD & CAMILLA HODGSON, FINANCIAL TIMES
December 24, 2019

amazon

DOORDASH

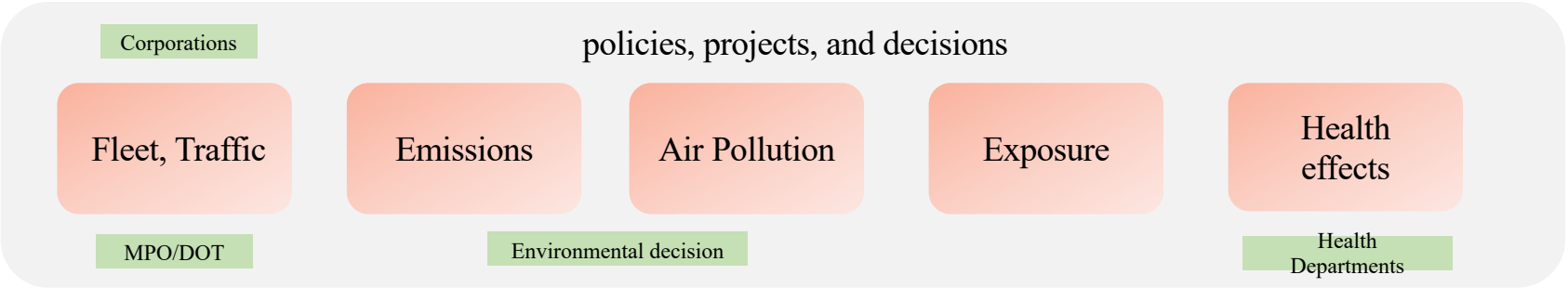
Delivering Shipment Zero

Shipment Zero is Amazon's vision to make all Amazon shipments net zero carbon, with a goal of delivering 50% of shipments with net zero carbon by 2030.

Quantifiable environmental and health impact?

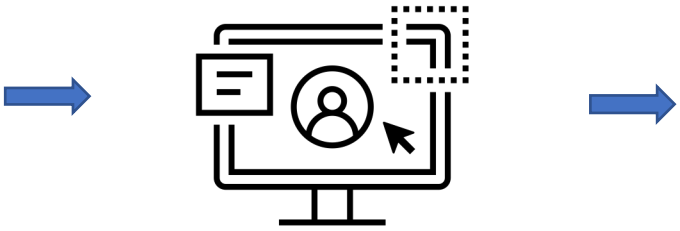
How do people know if organizations/entities are really carbon-zero?

*u*TECH Hub



Government agencies
- Policy-making
- Conformity requirements
- Budget (Financial/Emission)

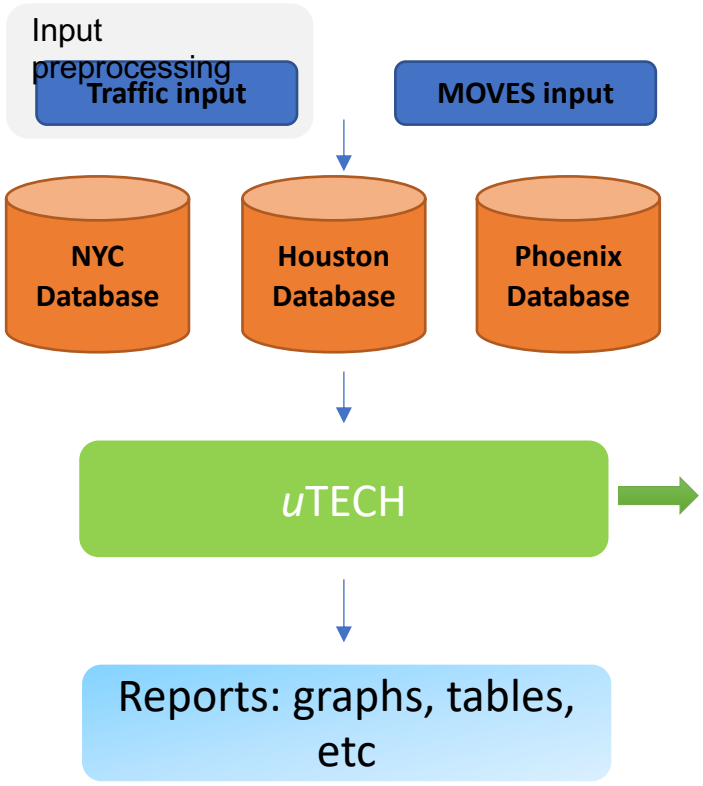
Corporations
- Zero carbon goals
- Traffic data

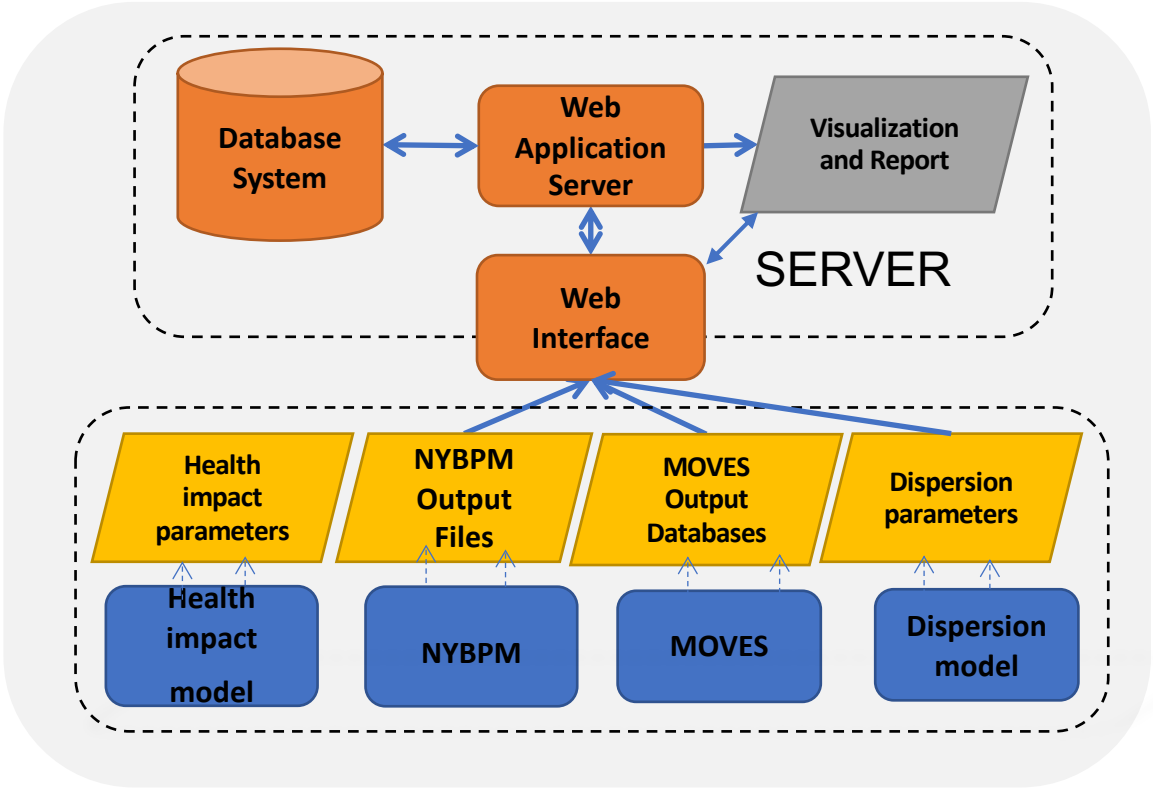


One integrated platform!

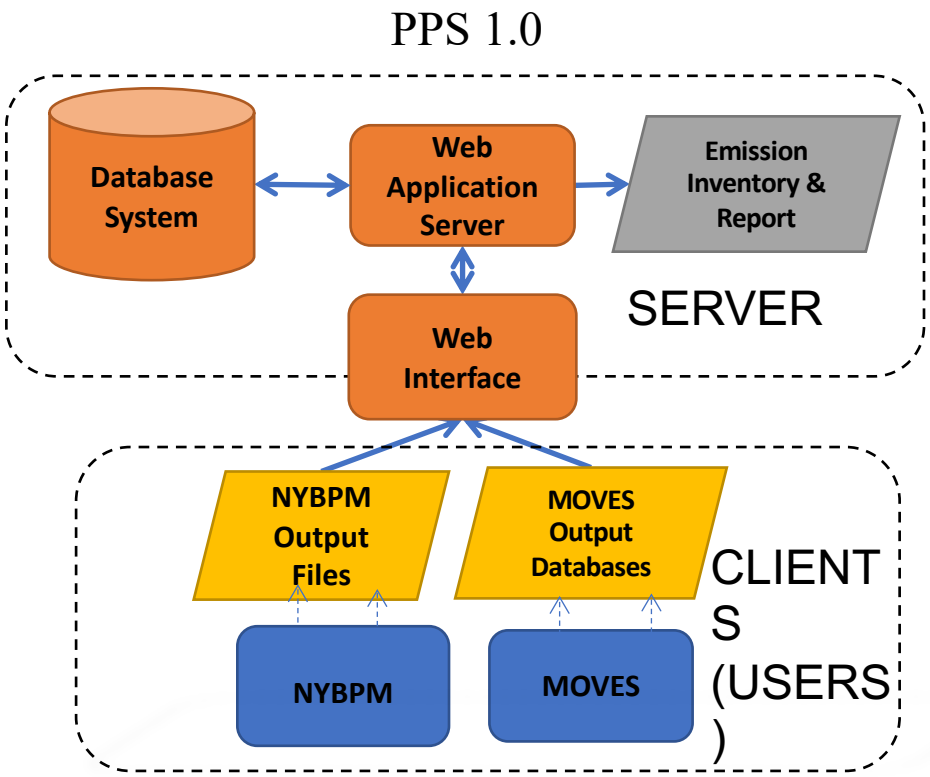
Informative Results

uTECH


Input preprocessing
Traffic input
MOVES input
NYC Database
Houston Database
Phoenix Database
uTECH
Reports: graphs, tables, etc


Database System
Web Application Server
Visualization and Report
SERVER
Web Interface
Health impact parameters
NYBPM Output Files
MOVES Output Databases
Dispersion parameters
Health impact model
NYBPM
MOVES
Dispersion model

Main Update for PPS 1.0



Vertical extension

Vision of uTECH: A secure modern web application

Application Update:

- Database system: MySQL
- Main platform: .NET → Node.JS (Typescript+React)
- Backend language: C# → Python
- Visualization: Only tables → Table download + interactive charts/maps

New Modules:

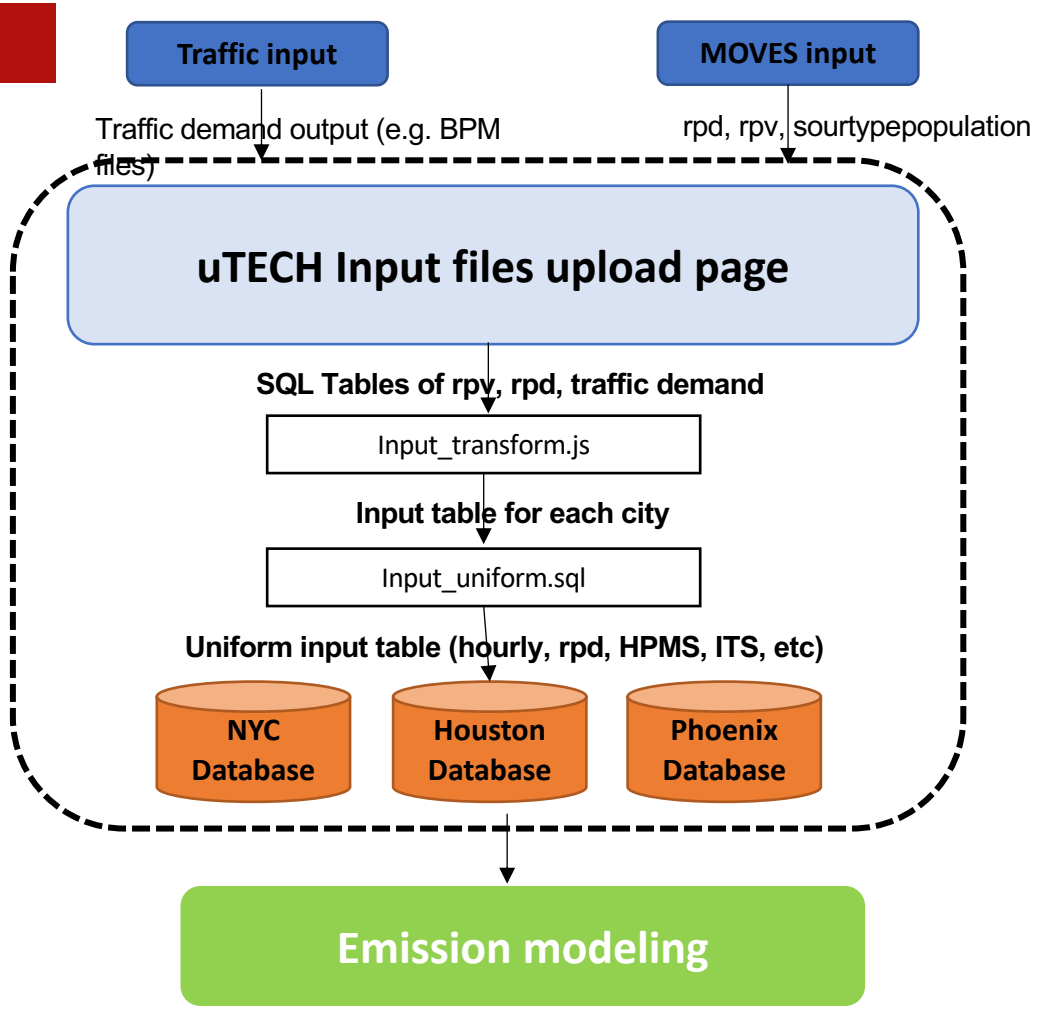
- Dispersion models
- Health impact (PPS-Health)
- Reports page (articles/tables/graphs)

New functionality:

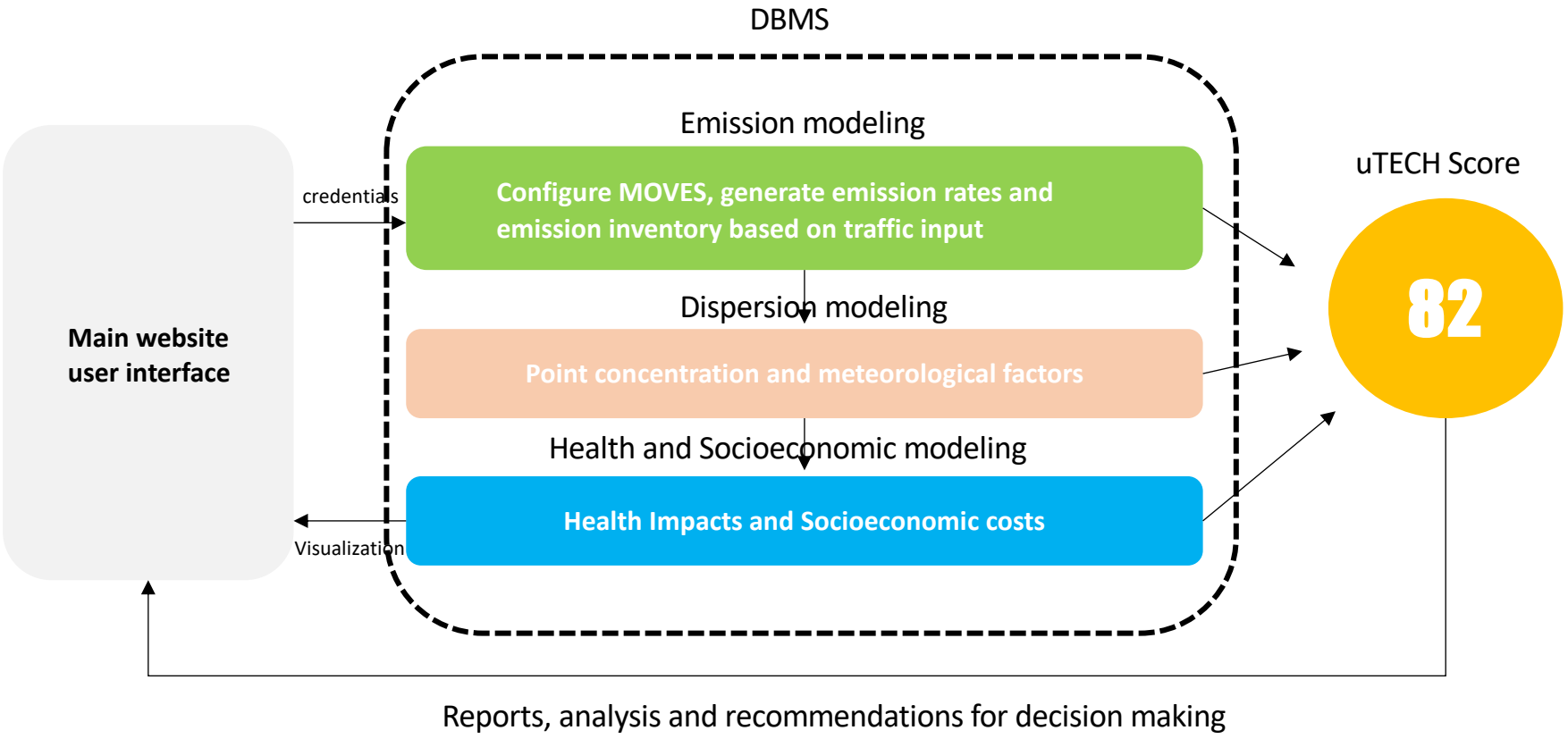
- Model configurations
- Version control: Git, separate user and test versions

Input processor

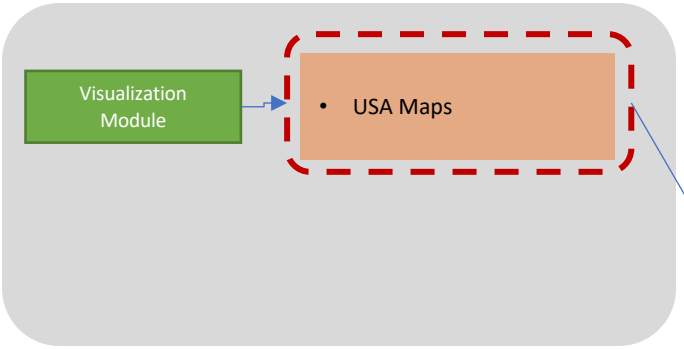
We implement an **input processor** after the input files are uploaded onto our website and extract uniform columns of data from each city's input and store them into their corresponding city database.



Framework


DBMS
Emission modeling
Configure MOVES, generate emission rates and emission inventory based on traffic input
Dispersion modeling
Point concentration and meteorological factors
Health and Socioeconomic modeling
Health Impacts and Socioeconomic costs
credentials
Visualization
Main website user interface
uTECH Score
82
Reports, analysis and recommendations for decision making


Climate Actions in Transportation (CAT)
Developing Data-driven Decision Support System/Dashboard for Climate Action Plans

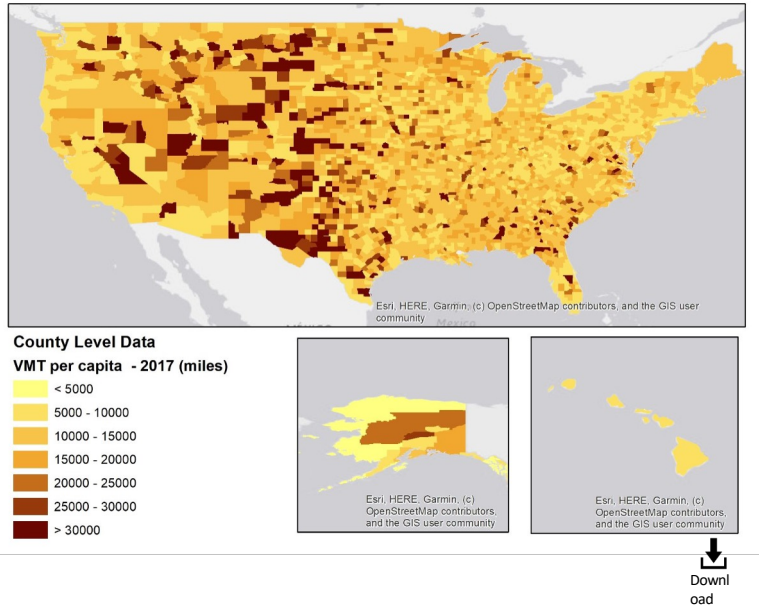


County level visualization

- Creating a place for county level data on firebase including data for
  - Emission (running moves for GHG emission for the entire US)
  - Other metrics for clean transportations (developed by Micah)
- Generating maps based on users' selection of metrics and years

❖ Map
❖ Tables
❖ Summary statistics

- ❑ **GHG emission for past, now, and future**
- ❑ Car mode share
- ☑ Vehicle Miles Traveled (VMT)
- ❑ Vehicle Population
- ❑ PM2.5
- ❑ Methane
- ❑ CO
- ❑ N^2O
- ❑ NO^x
- ❑ SO^2
- ❑ Percent of residents using public transit to commute
- ❑ Fatalities from vehicle accidents
- ❑ Average trips in a single day



Modeling the Transportation and Climate Initiative

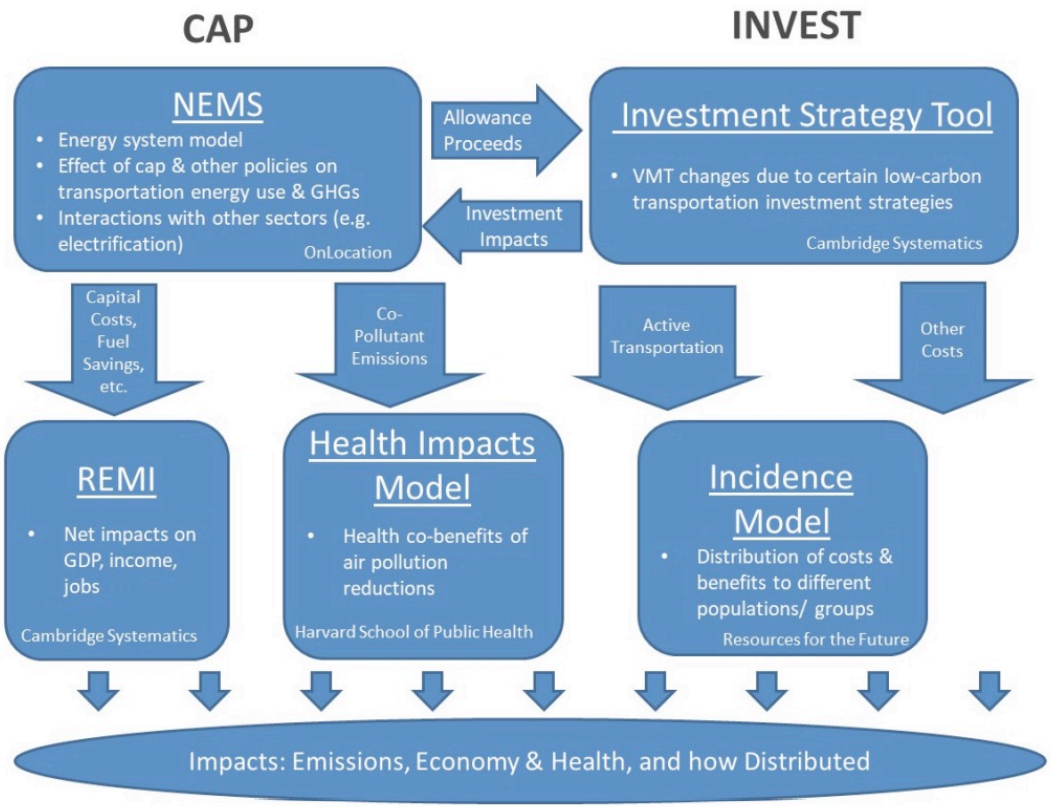
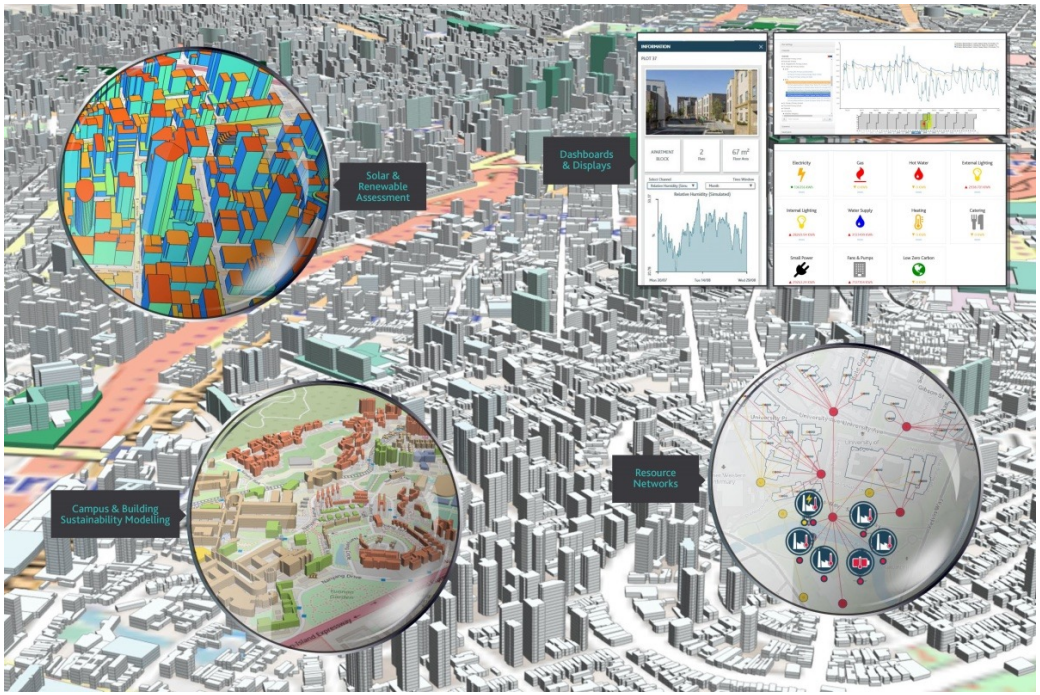


Figure: Diagram illustrating respective roles for each modeling tool and interrelationships.
https://www.mjbradley.com/

Digital twin technology to put sustainability at the heart of smart and healthy communities



Center for Transportation, Environment, and Community Health

CTECH