OCTOBER 8, 2020

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

INTRODUCING A NOVEL METRIC TO QUANTIFY THE IMPACT OF SMART MOBILITY

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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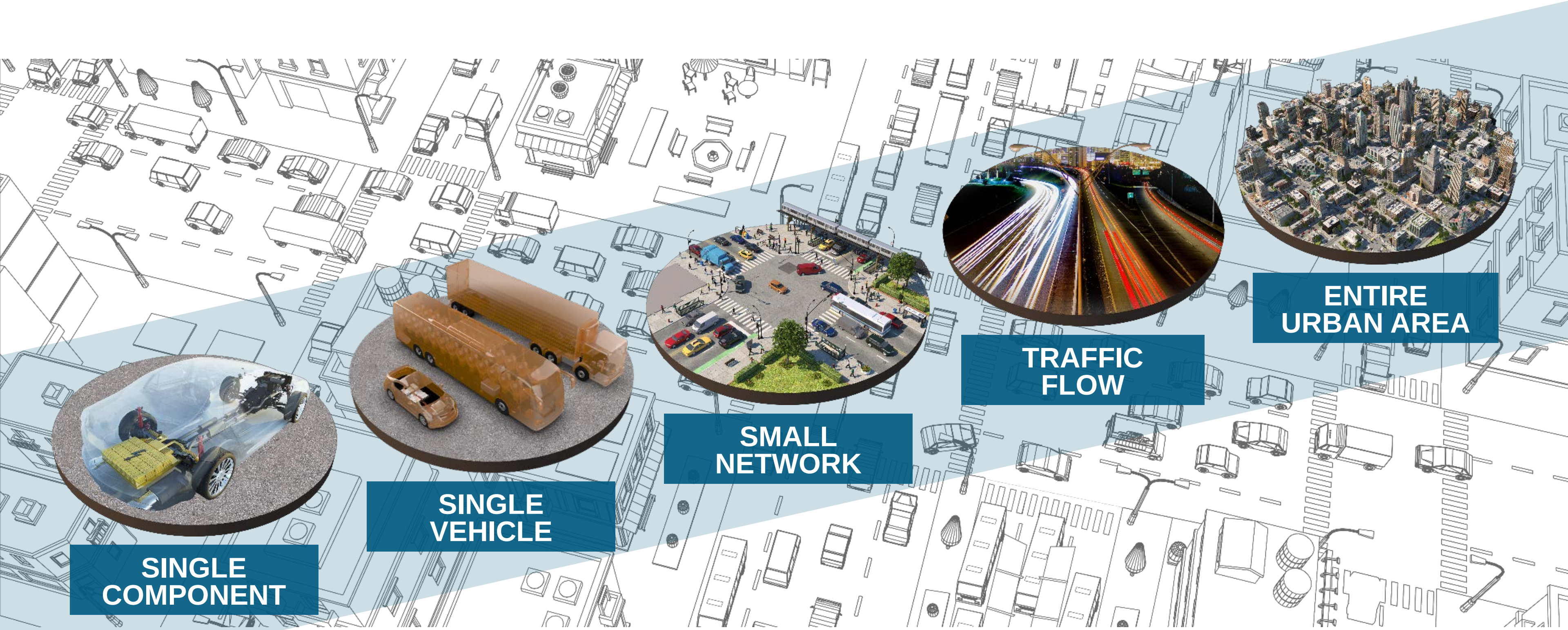
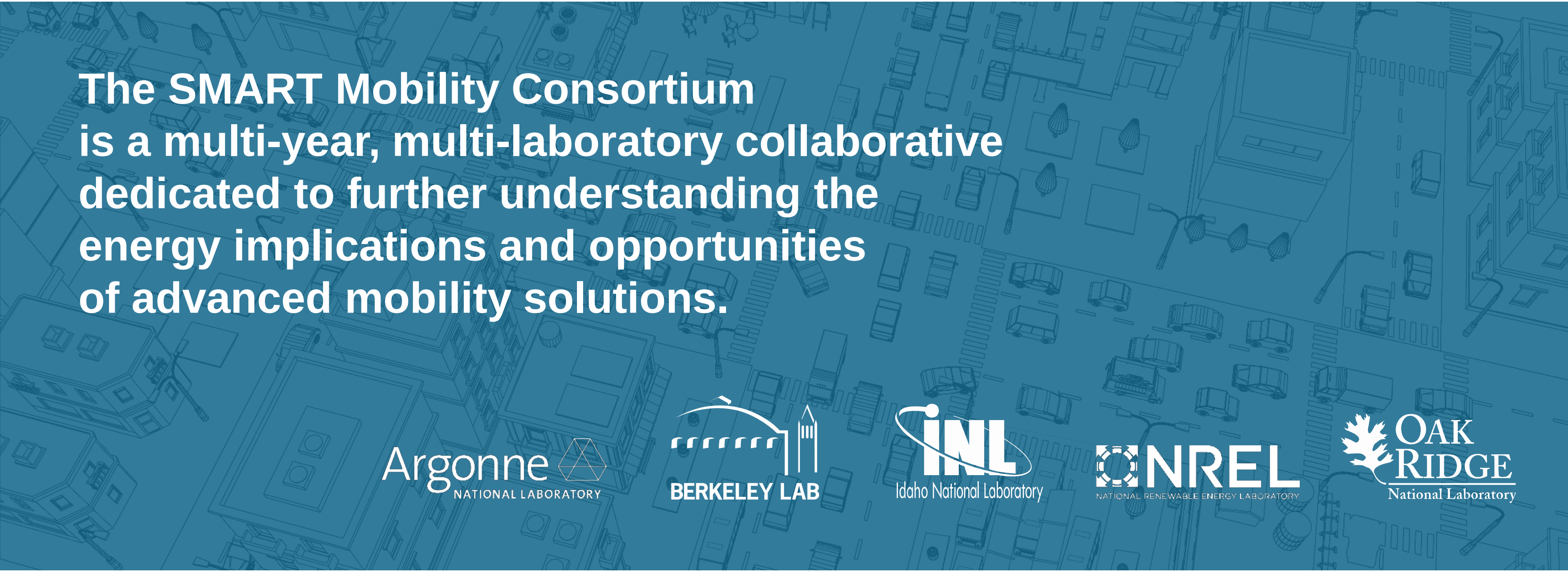
VTO SYSTEMS-LEVEL R&D



SMART MOBILITY CONSORTIUM



The SMART Mobility Consortium is a multi-year, multi-laboratory collaborative dedicated to further understanding the energy implications and opportunities of advanced mobility solutions.

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MOBILITY: CONNECTING PEOPLE TO OPPORTUNITY

The solutions we are developing will power the next transportation revolution, ushering in a new era of

SMART Mobility.

Mobility

The quality of a network or system to connect people to goods, services, and employment that define a high quality of life.

WORK

LEISURE

HEALTHCARE

SHOP & FOOD

EDUCATION

MEP CALCULATION

$$\text{MEP}_i = \sum_k \sum_t (o_{ikt} - o_{ik(t-10)}) \cdot e^{M_{ikt}}$$

$$M_{ikt} = \alpha \underline{e_k} + \beta \underline{t} + \sigma \underline{c_k}$$

energy time cost

Where

M_{ikt} is the modal weighting factor for opportunities accessed by mode k with travel time t from location i

e_k is the energy intensity (kWh per passenger-mile) of mode k

t is the travel time

c_k is the cost (dollar per passenger-mile) of using transportation mode k

$\alpha, \beta,$ and σ are weighing factors.

Mobility Energy Productivity (MEP):

The cumulative utility-weighted opportunity space for a geographically defined area.

$$o_{ikt} = \sum_j o_{ijkt} \cdot \frac{N^*}{N_j} \cdot \frac{f_j}{\sum_j f_j}$$

Where

o_{ijkt} [illegible] can be accessed by mode k within the travel time threshold t from the i^{th} pixel

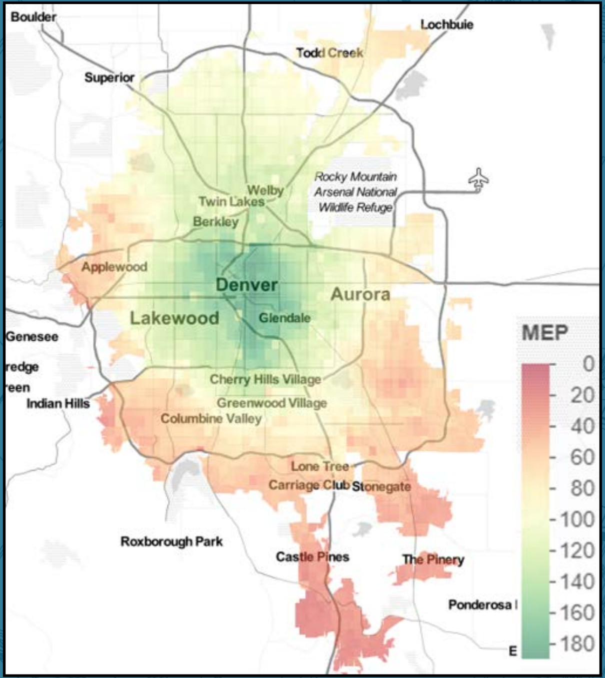
N^* is the total number of benchmark opportunities across multiple cities (for example, the number of meal opportunities)

N_j is the total number of opportunities of activity j (for example, [illegible] opportunities)

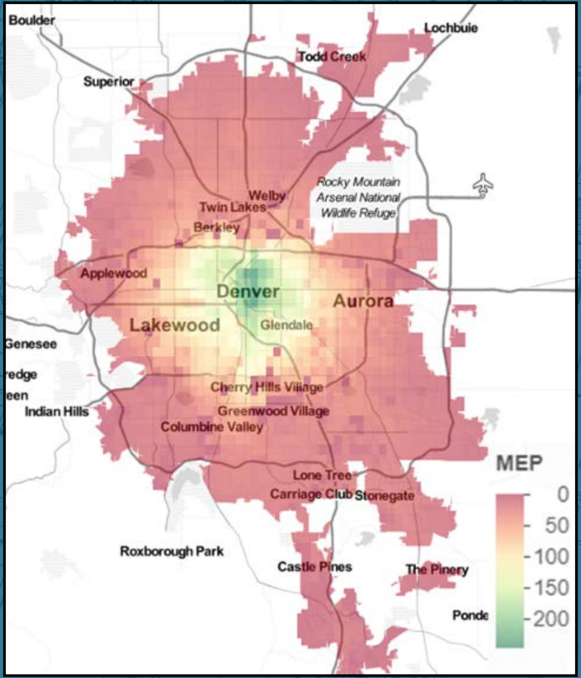
f_j [illegible] of activity j

o_{ikt} is the number of opportunities (normalized by a benchmark opportunity measure) that can be accessed by mode k within the travel time threshold t from the i^{th} pixel.

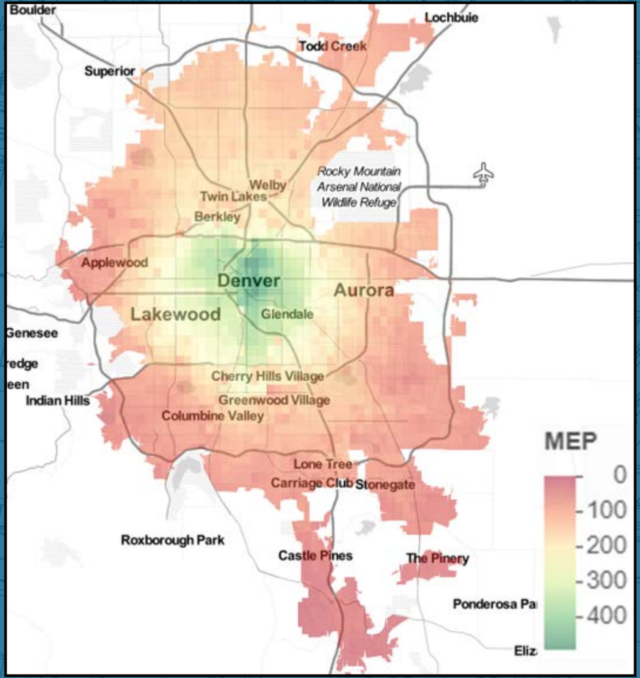
MEP EXAMPLE (DENVER, CO)



Car Only



Transit + Bike + Walk



All Modes

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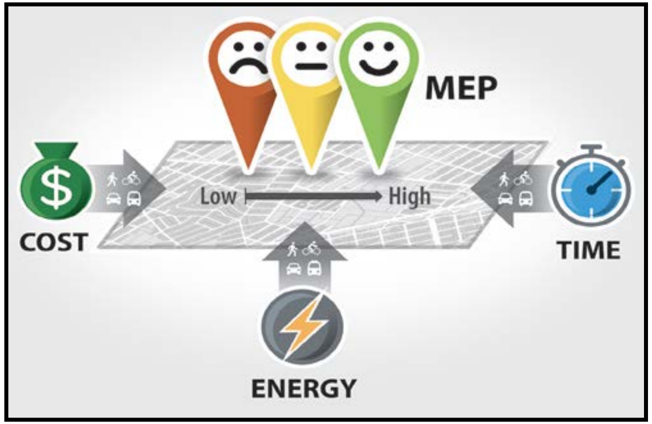
MOTIVATION

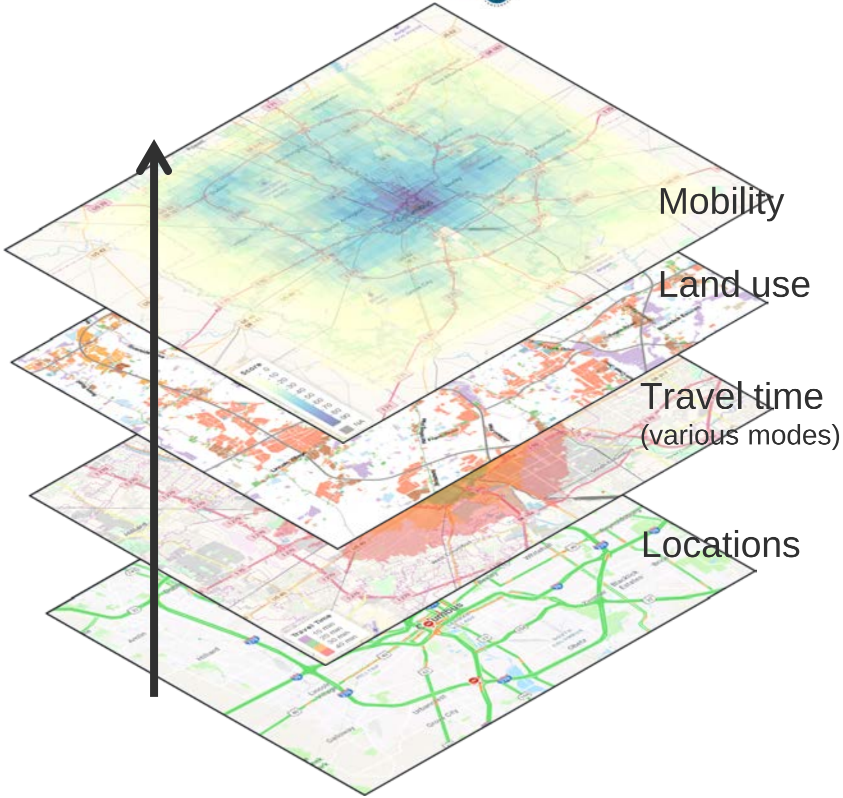
- Existing **transportation performance metrics** measure utilization or efficiency of road network
  - Vehicle miles travelled; Volume-to-capacity ratio
- **Accessibility metrics**, on the other hand, provide good information on accessible opportunities, but are often unimodal, and unidimensional
- A **combination of these facets** is required to answer questions such as
  - How does an **infrastructure investment** impact the mobility of a place or a region?
  - In what way does new and **emerging mobility technology** influence a community's overall mobility



Objective: Quantify the efficiency of a network or system to connect people to goods, services, and employment that define a high quality of life.

BACKGROUND

- Many ‘**siloed**’ metrics such as walk score, bike score, transit score, and average travel time index (by auto) are available to understand the mobility of a neighborhood
- Effectively **combine different modes into a holistic** metric
- Incorporate the **energy & cost** component as well as land-use information into the metric



Mobility Energy Productivity Metric = F (mobility weighted by [energy, cost, trip purpose])

PROPERTIES OF A GOOD METRIC

- Accurately **reflects the efficiency** of accessing a variety of goods, services, and employment opportunities
- Based on **established/accepted research**, yet supportable by available data
  - Prior work by Owen et al. 2014, Saunders et al. 2018
- Can be applied to **any mode** (car, walk, bike, transit, etc.)
- Determined by:
  - **Travel time**, as well as travel time reliability, to destinations
  - **Energy and monetary cost** of travel

- **Spatially scalable** (applied to a home, district, city, employer)
- **Data agnostic**: Can be applied using a wide variety of data sources
- Can compare:
  - Two **locations within a city** (downtown vs. suburb)
  - Two **planning strategies** (e.g., roadway extension vs. transit expansion)
  - Two **technologies** (e.g., electric vehicle penetration vs. automated vehicle penetration)

Owen, Andrew, David Levinson, and Brendan Murphy. "Access across America." *Transit* 4, no. 5 (2014).
Saunders, Michael J., Tobias Kuhnimhof, Bastian Chlond, and Antonio Nelson Rodrigues da Silva. "Incorporating transport energy into urban planning." *Transportation Research Part A: Policy and Practice* 42, no. 6 (2008): 874-882.

DATA SPECTRUM DRIVING THE METRIC

Energy Efficiency Measures

- Transportation Energy Data Book
- Other energy intensity studies

Travel Demand Data

- National Household Travel Survey (NHTS)

Cost Measures

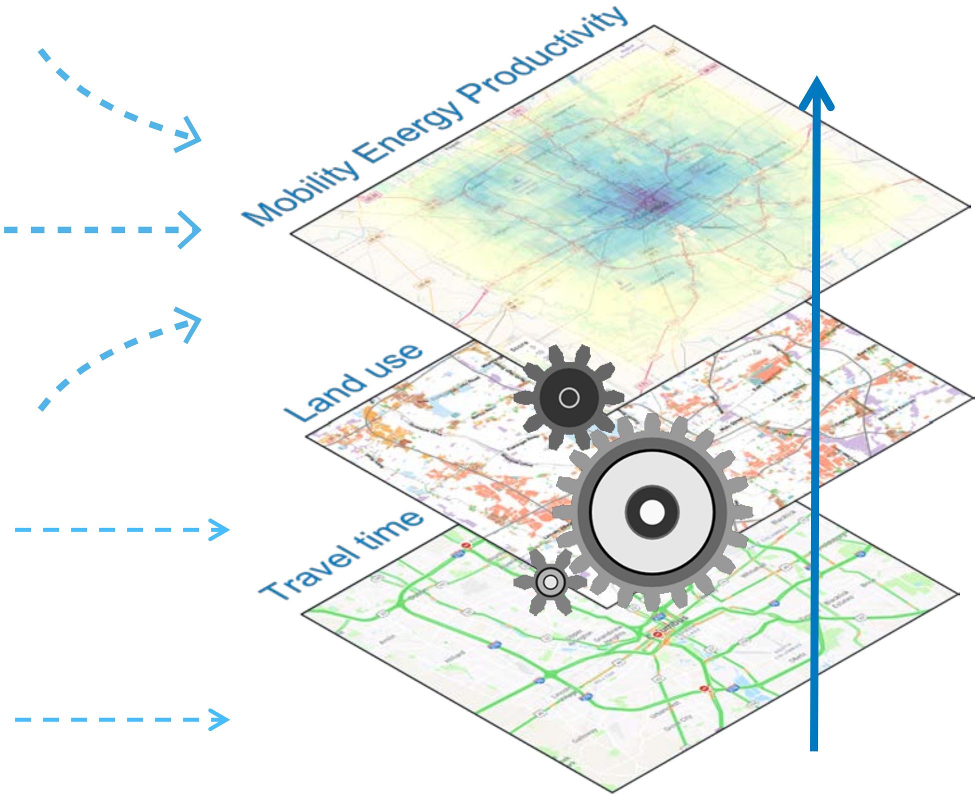
- Capital costs, operational costs
- Value of time

Land-Use Data

- Metropolitan Planning Organizations

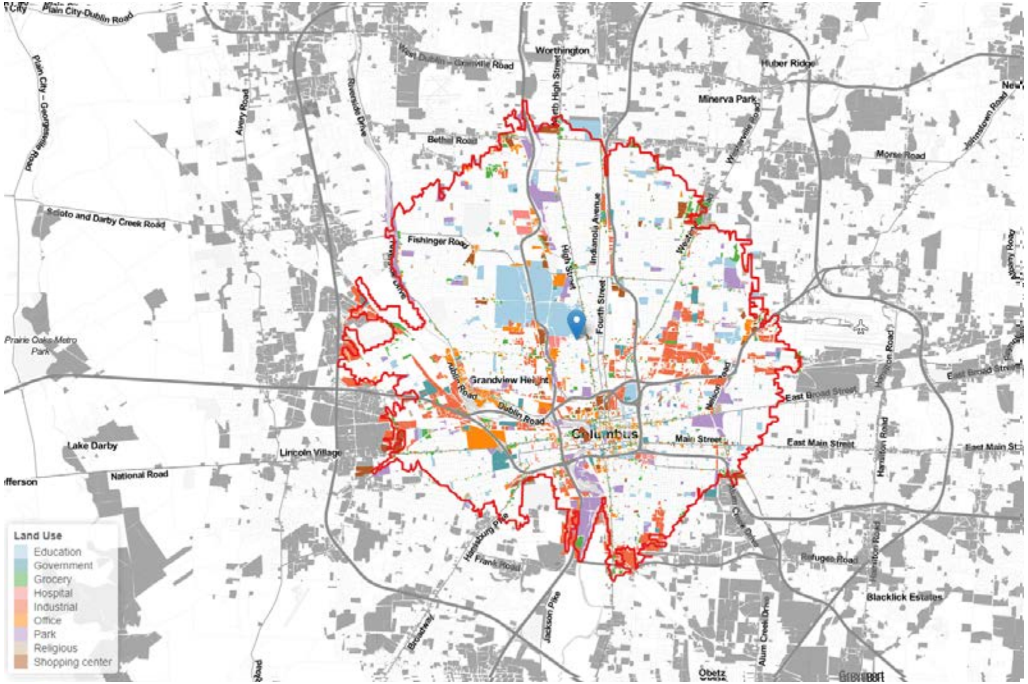
Travel Time and Isochrone

- Third-party isochrone APIs (e.g., HERE)
- GPS trajectory data (TomTom, INRIX)
- Travel Demand Models



ISOCHRONE

An isochrone is defined as “*a line drawn on a map connecting points at which something occurs or arrives at the same time*”



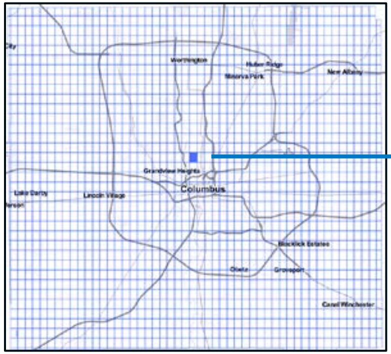
An example of opportunities accessible by biking

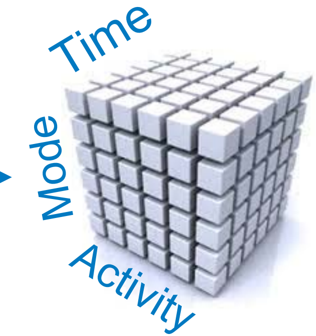
BASIC DATA ELEMENTS OF THE MEP METRIC

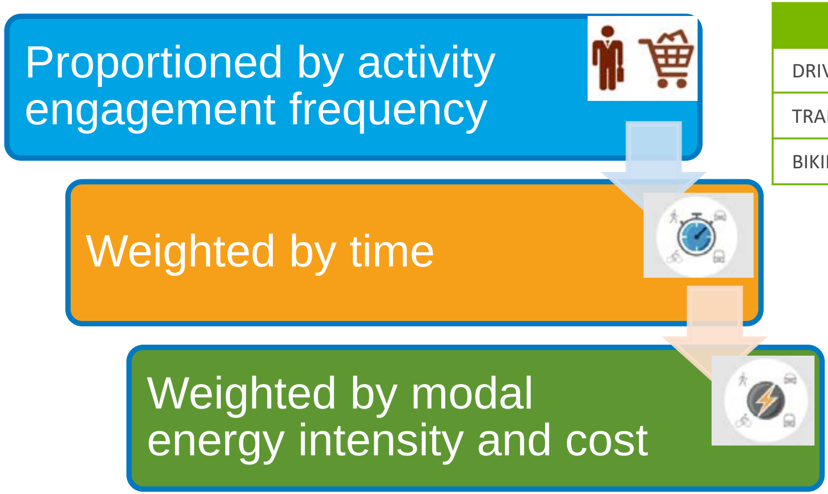
- **Quantify the number of opportunities** that people can reach within a certain travel time threshold via different transportation modes

- The opportunities measure is **weighted by the time, energy, and cost-efficiency** metrics of different transportation modes, as well as frequency of engaging in different types of activities.

MEP COMPUTATION: ILLUSTRATIVE







Proportioned by activity engagement frequency

Weighted by time

Weighted by modal energy intensity and cost

	WORK	SHOP	GROCERY
DRIVING	804,681	433	1,952
TRANSIT	24,628	8	109
BIKING	120,292	40	676

	CUMULATIVE OPPURTUNITIES
DRIVING	10,000
TRANSIT	680
BIKING	450

MEP
68

MEP COMPUTATION: EQUATION

$$o_{ikt} = \sum_j o_{ijkt} \cdot \frac{N^*}{N_j} \cdot \frac{f_j}{\sum_j f_j}$$

Where

o_{ijkt}	is the number of opportunities of activity j that can be accessed by mode k within the travel time threshold t from the i^{th} pixel
N^*	is the total number of benchmark opportunities across multiple cities (for example, the number of meal opportunities)
N_j	is the total number of opportunities of activity j (for example, number of shopping opportunities)
f_j	is the frequency that people access opportunities of activity j
o_{ikt}	is the number of opportunities (normalized by a benchmark opportunity measure) that can be accessed by mode k within the travel time threshold t from the i^{th} pixel.

$$\mathrm{MEP}_i = \sum_k \sum_t \left(o_{ikt} - o_{ik(t-10)}\right) \cdot e^{M_{ikt}}$$

$$M_{ikt} = \alpha e_k + \beta t + \sigma c_k$$

Where

M_{ikt}	is the modal weighting factor for opportunities accessed by mode k with travel time t from location i
e_k	is the energy intensity (kWh per passenger-mile) of mode k
t	is the travel time
c_k	is the cost (dollar per passenger-mile) of using transportation mode k

$\alpha, \beta,$ and σ are weighing factors.

MODAL WEIGHTS FOR ENERGY AND COST

Mode	Energy intensity (kWh/passenger-mile)	Capital and operational cost (dollar/passenger-mile)
Driving	0.90	0.48
Transit	0.65	0.85
Bike	0	0
Walk	0	0
Transportation Network Company	1.8	1.54
Paratransit	4.13	2.25

β = -0.08, α = -0.5, σ = -0.5

References

- Federal Transit Administration Office of Budget and Policy. 2016. *National Transit Summary & Trends*. Washington, D.C.: Federal Transit Administration.
- Davis, Stacy C., Susan E. Williams, and Robert G. Boundy. 2017. Transportation Energy Data Book: Edition 36. Oak Ridge, TN: Oak Ridge National Laboratory. ORNL/TM-2017/513.
- American Automobile Association (AAA). 2018. *Your driving costs: How Much are You Really Paying to Drive* (2018 Edition) Heathrow, FL: AAA Association Communication.
- ALG. 2016. The Road to 2030: Vehicle Production and Sales in the Autonomous Era. Santa Monica, CA: ALG.

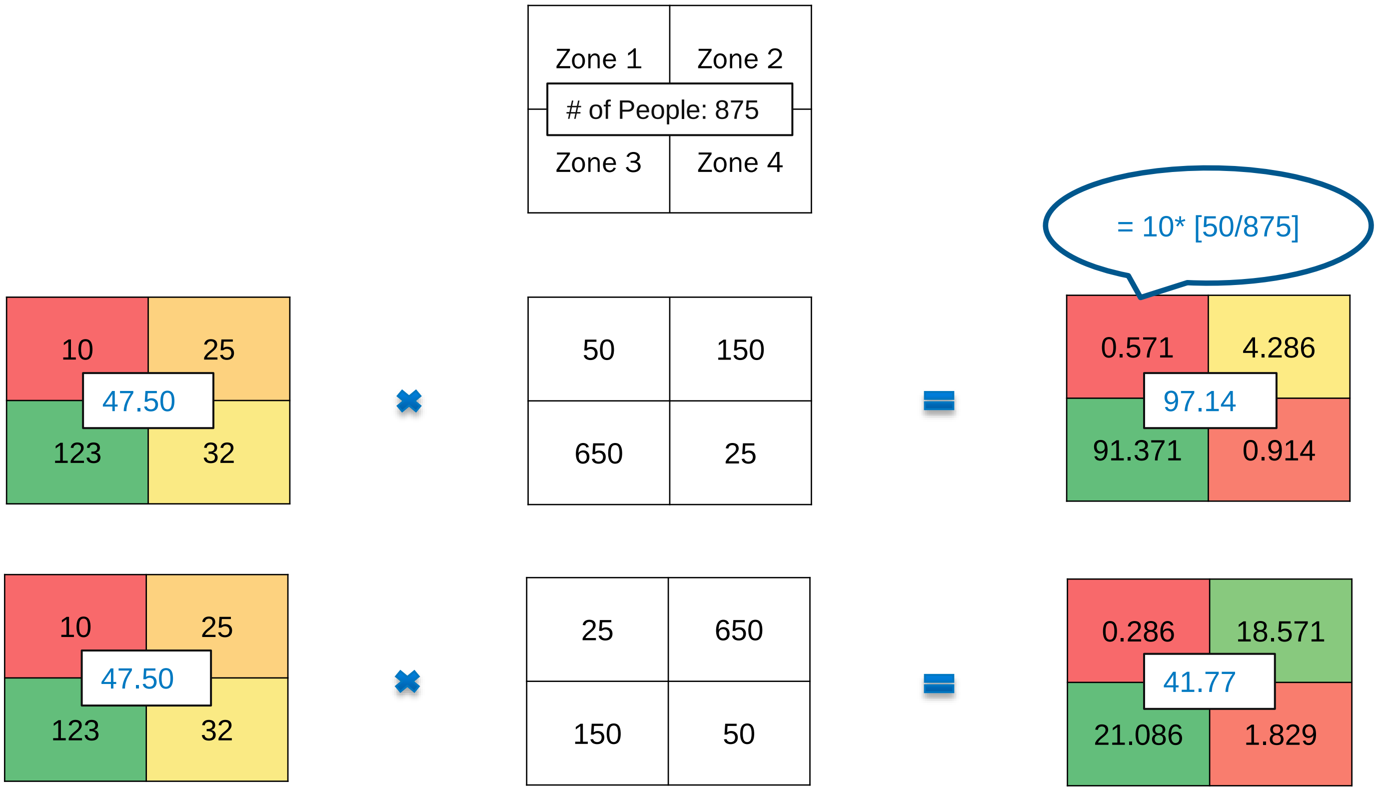
MEP APPLICATION

STANDALONE

MEP – COLUMBUS, OH

Leaflet | Map tiles by Stamen Design, CC BY 3.0 — Map data © OpenStreetMap

MEP: POPULATION DENSITY WEIGHTED SUMMATION FOR CITY-LEVEL AGGREGATION



Zone 1	Zone 2
Zone 3	Zone 4

# of People: 875

= 10* [50/875]

10	25
123	32

47.50

✖

50	150
650	25

=

0.571	4.286
91.371	0.914

97.14

10	25
123	32

47.50

✖

25	650
150	50

=

0.286	18.571
21.086	1.829

41.77

POPULATION-WEIGHTED MEP COLUMBUS, OH

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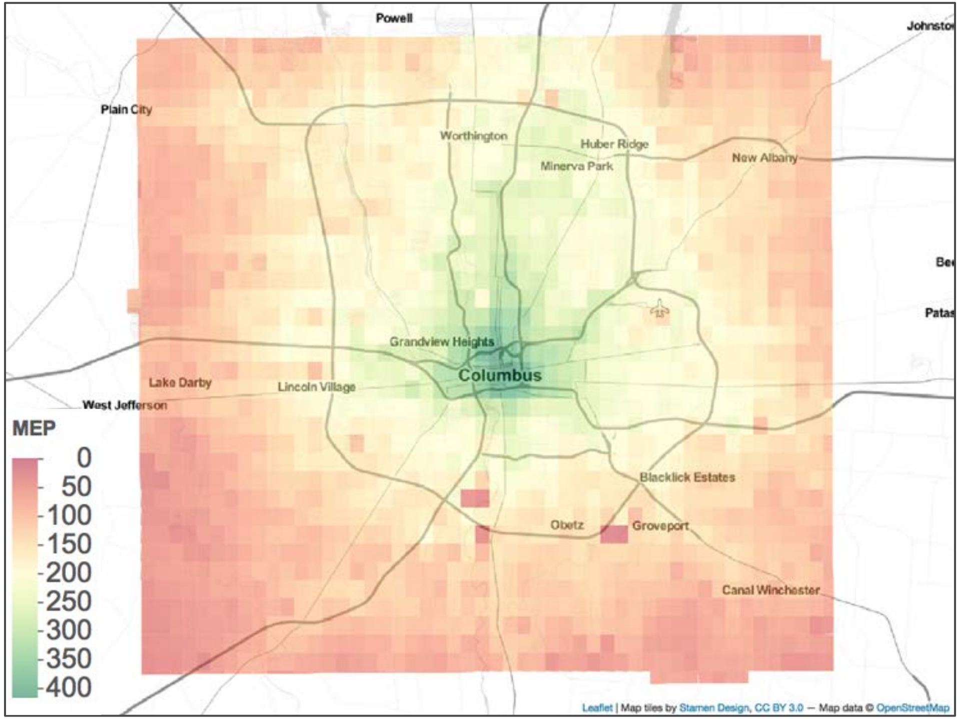
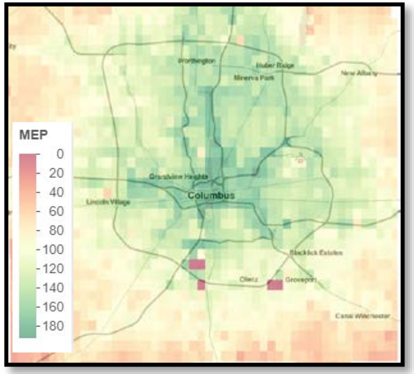
Population-density-weighted MEP metric: 198

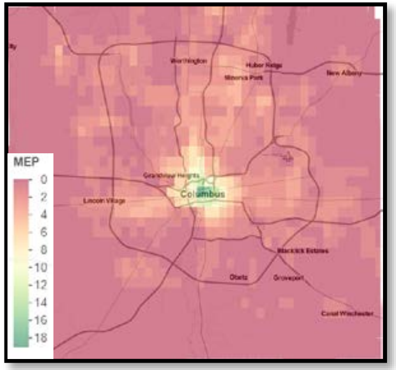


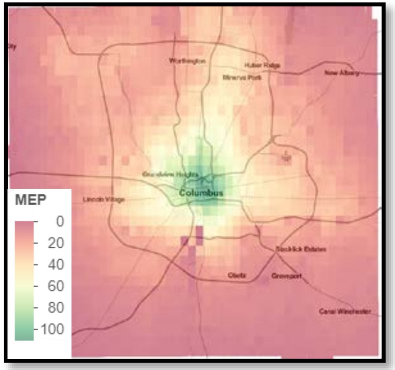
MEP MAPS BY MODE COLUMBUS, OH



Driving

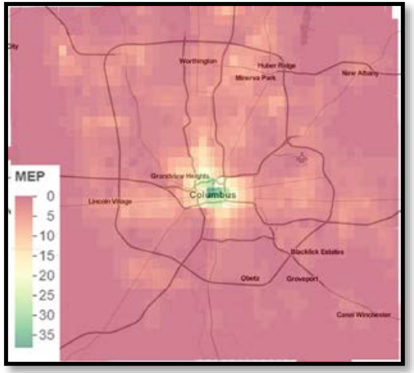
Transit





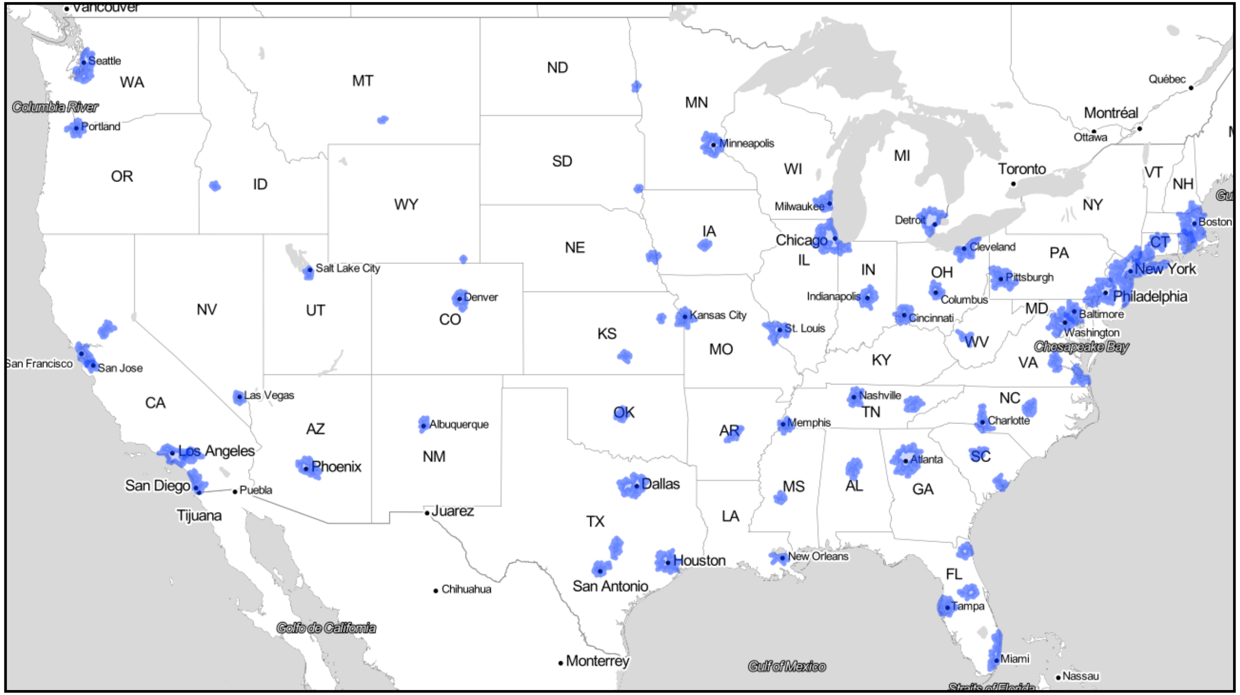
Bike

Walk

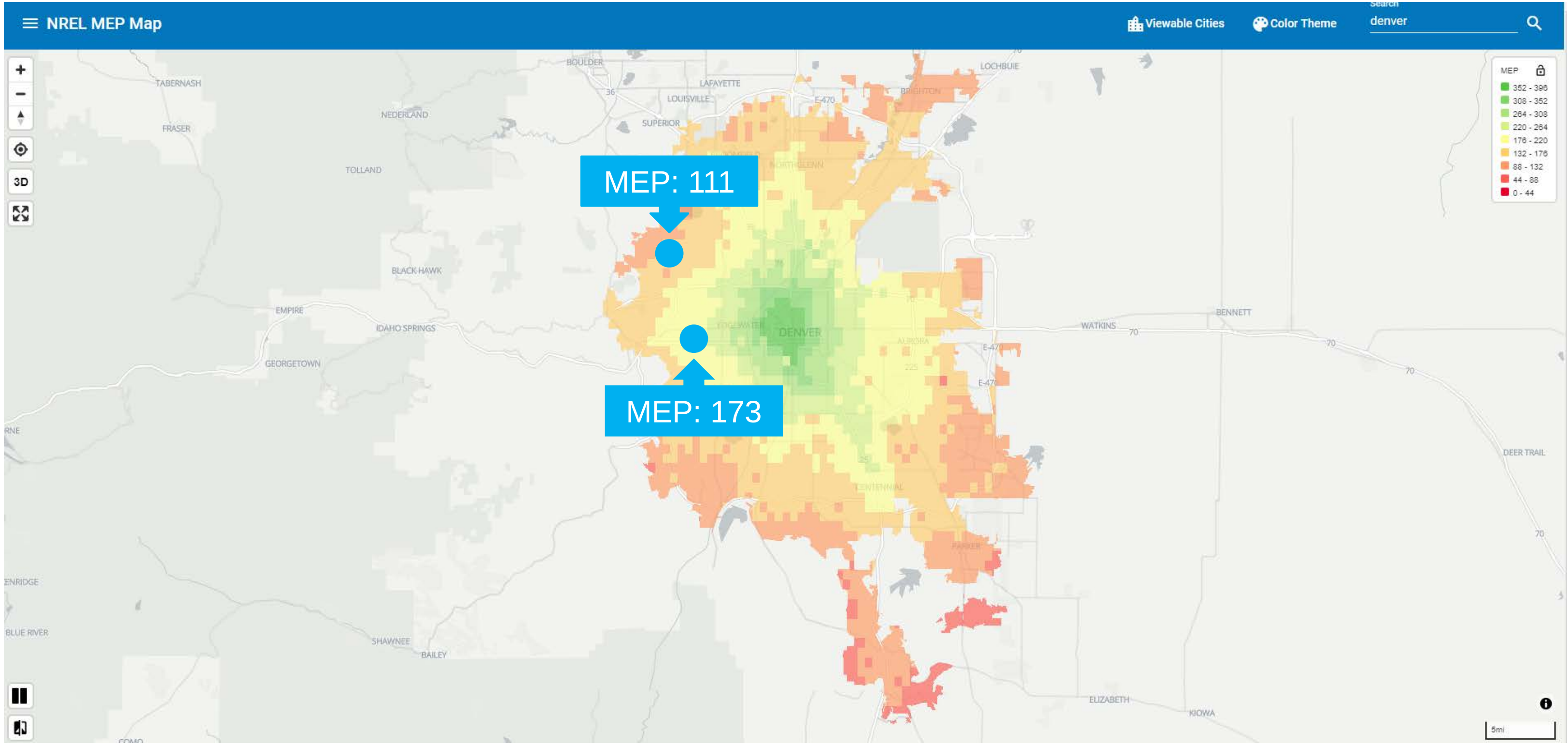


MEP COMPUTATION FOR VARIOUS CITIES IN THE U.S.

Most populous city in each state plus a few other cities of interest



MEP – PROTOTYPE WEB APPLICATION

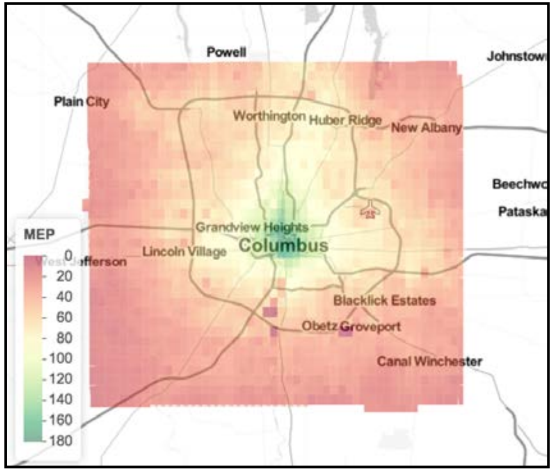


MEP: 111

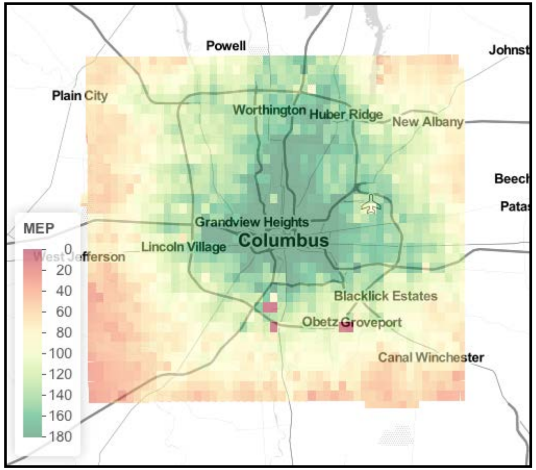
MEP: 173

MEP – ILLUSTRATIVE SCENARIO ANALYSIS VEHICLE ELECTRIFICATION

- What if MPG of vehicles is increased by 200% (MPG of cars increased from 25 in the baseline to 75 in the scenario)?



Before



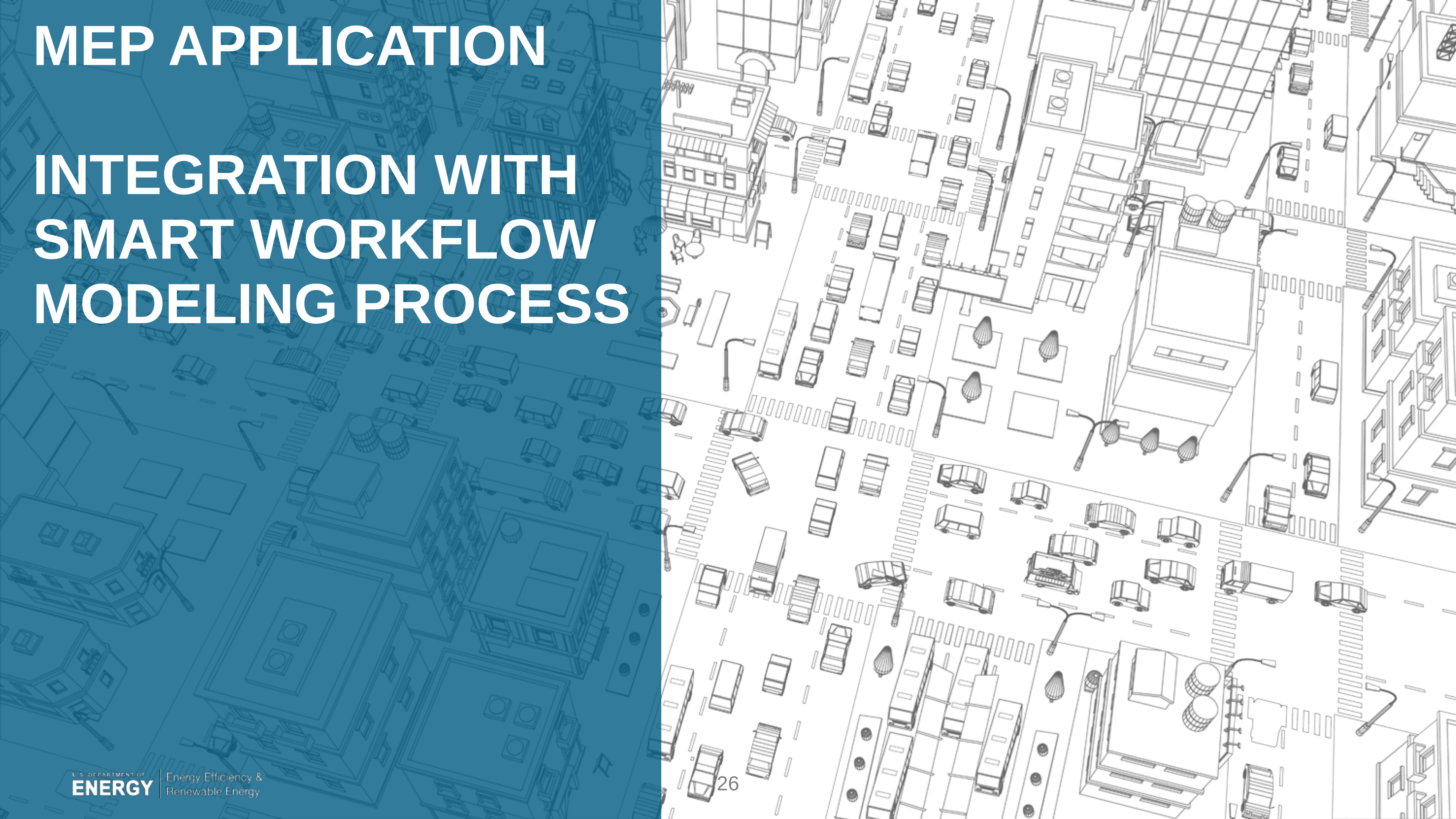
After

Caveats:

- The scenario analysis does not account for any secondary effects of MPG increase
- Such effects may be captured by linking the MEP metric with travel demand models

MEP APPLICATION

INTEGRATION WITH SMART WORKFLOW MODELING PROCESS



SMART
WORKFLOW MODELING PROCESS

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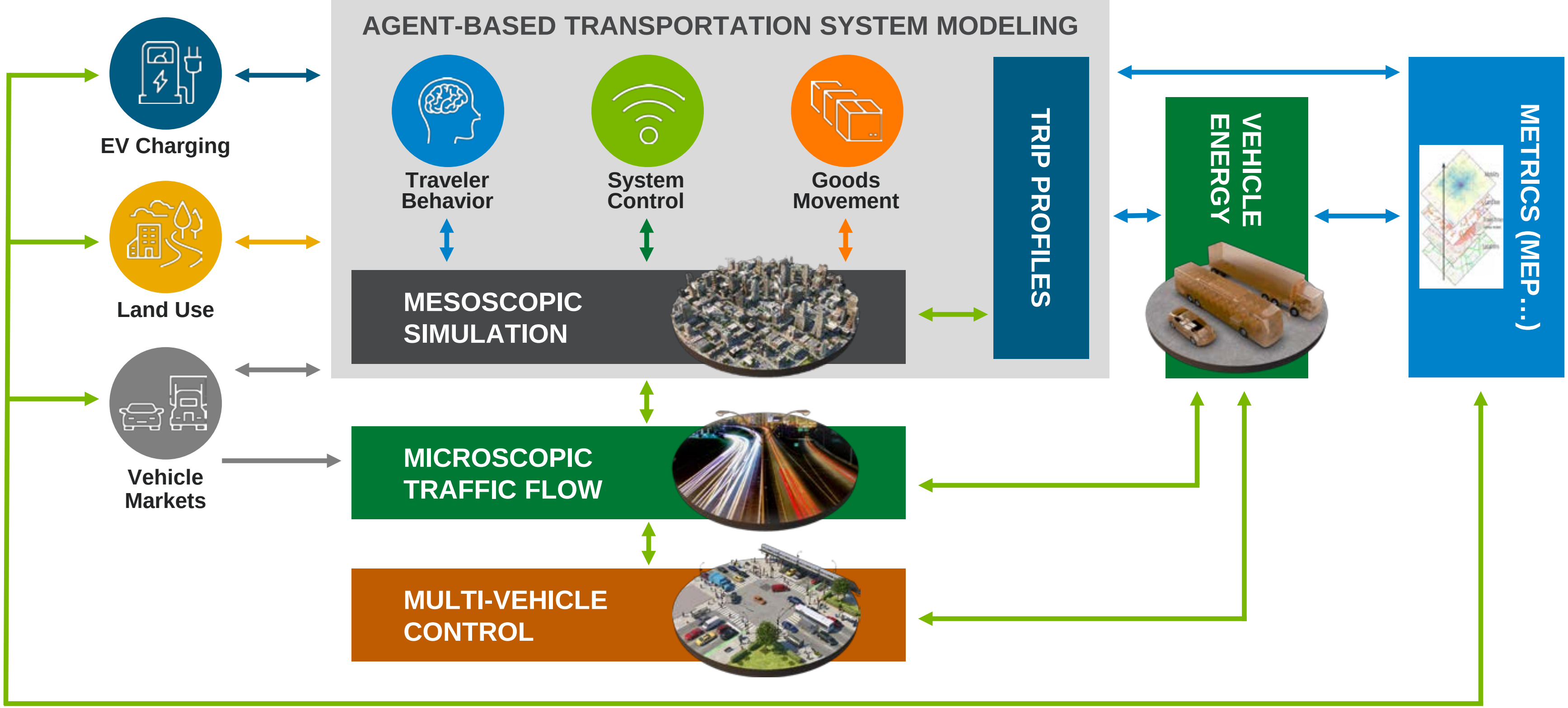


AGENT-BASED TRANSPORTATION SYSTEM MODELING

EV Charging

Land Use

Vehicle Markets

Traveler Behavior

System Control

Goods Movement

MESOSCOPIC SIMULATION

MICROSCOPIC TRAFFIC FLOW

MULTI-VEHICLE CONTROL

TRIP PROFILES

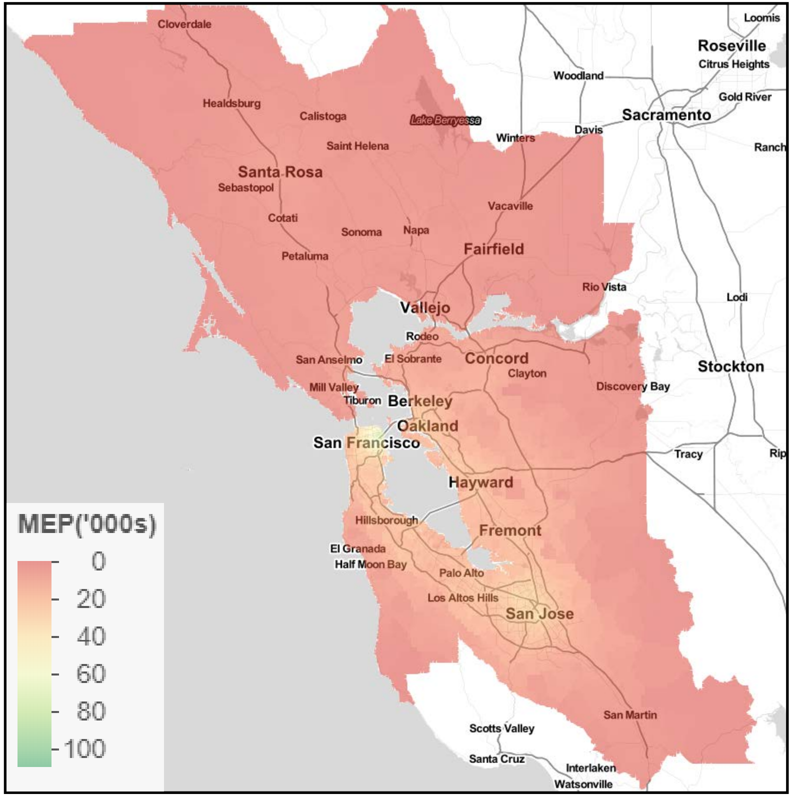
VEHICLE ENERGY

METRICS (MEP…)

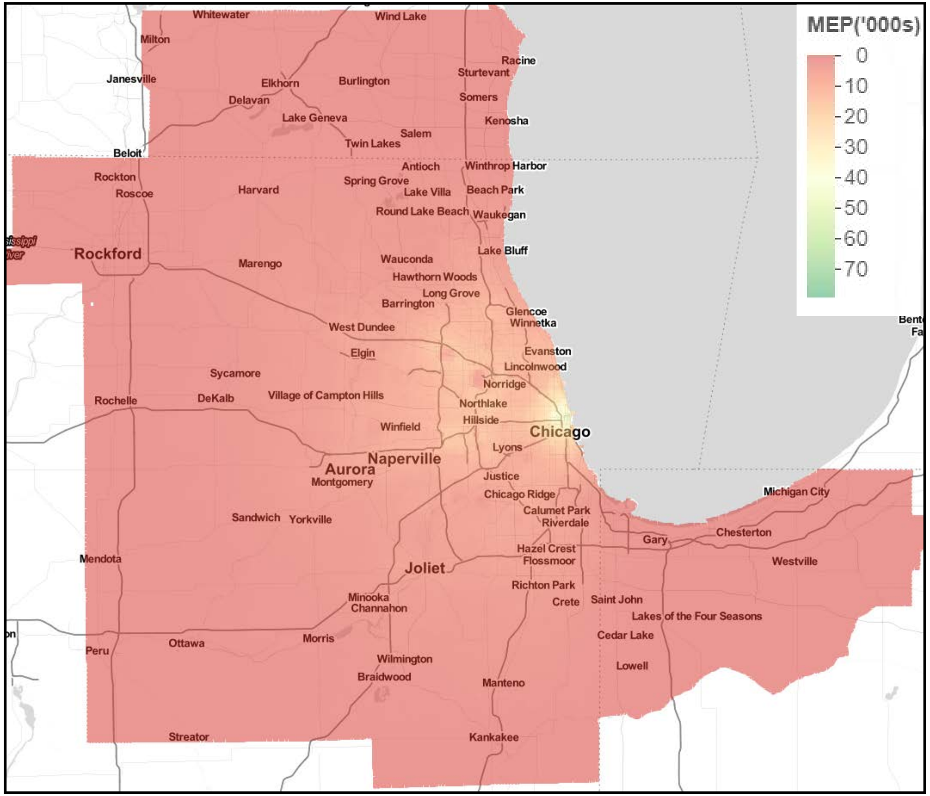
DATA SOURCES

Data Input	Independent	Integrated with Workflow Modeling
Travel time isochrones	Third-party data	Travel models (BEAM / POLARIS)
Land-use data	Third-party data	Land-use Model (UrbanSim)
Employment data	Longitudinal Employer-Household Dynamics Data (2015)	Land-use Model (UrbanSim)
Trip frequencies	2017 National Household Travel Survey	NHTS / Travel model (BEAM / POLARIS)
Energy intensity	ORNL Transportation Energy Data Book (Stacy et al. 2017) Sustainable Transport and Public Policy (Banister 2009)	Vehicle energy consumption models (SVTrip+Autonomie / RouteE)
Modal cost	A Cost Comparison of Transportation Modes (Condon and Dow 2009)	Travel models (BEAM / POLARIS)
Coefficients for time, cost, and energy	α, σ = -0.05, β = -0.08	α, σ = -0.05, β = -0.08

SAMPLE OUTPUT: SAN FRANCISCO

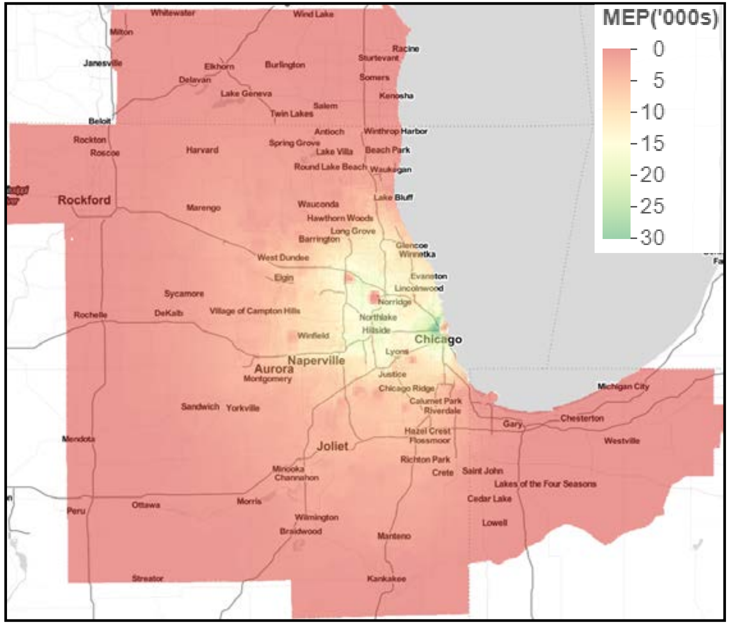


SAMPLE OUTPUT: CHICAGO



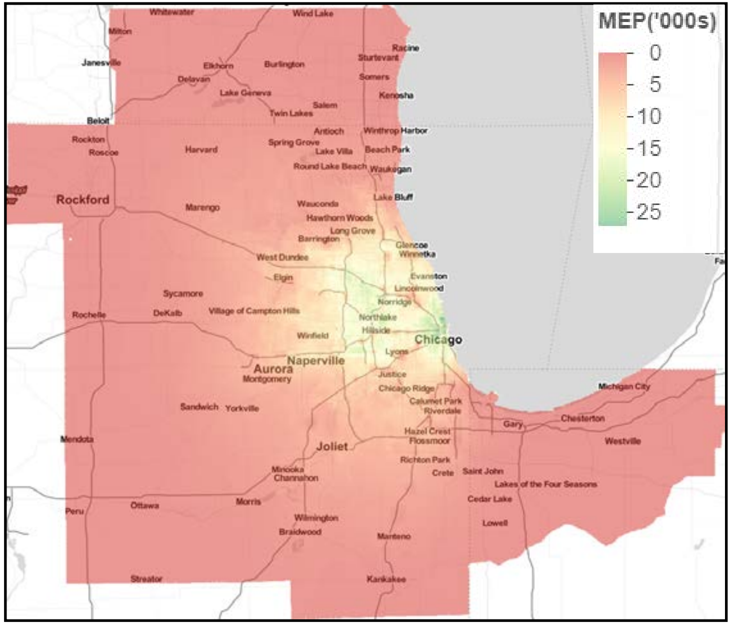
CHICAGO MEP: ONLY TIME-WEIGHTED

Overall MEP: 9675



Mode A
Average Network Speed: 32.54 mph
Average Wait Time: 0 minutes

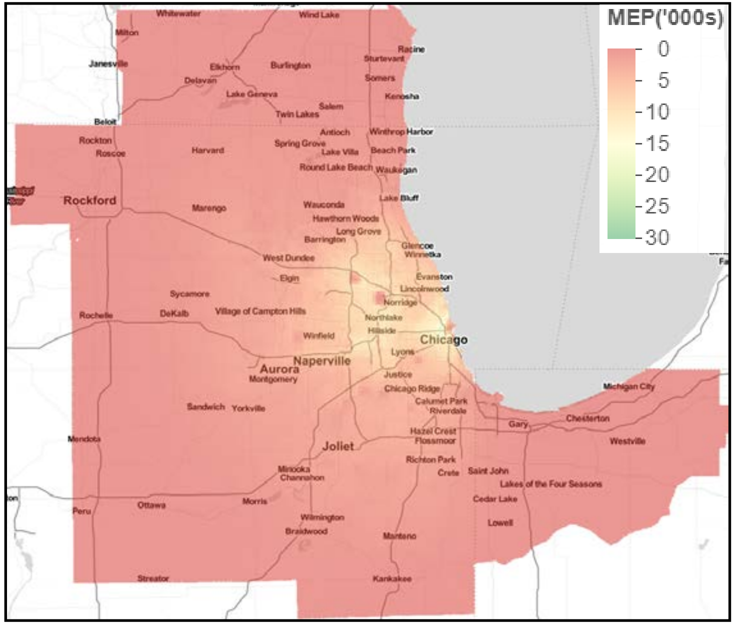
Overall MEP: 8792



Mode B
Average Network Speed: 32.54 mph
Average Wait Time: 4.7 minutes

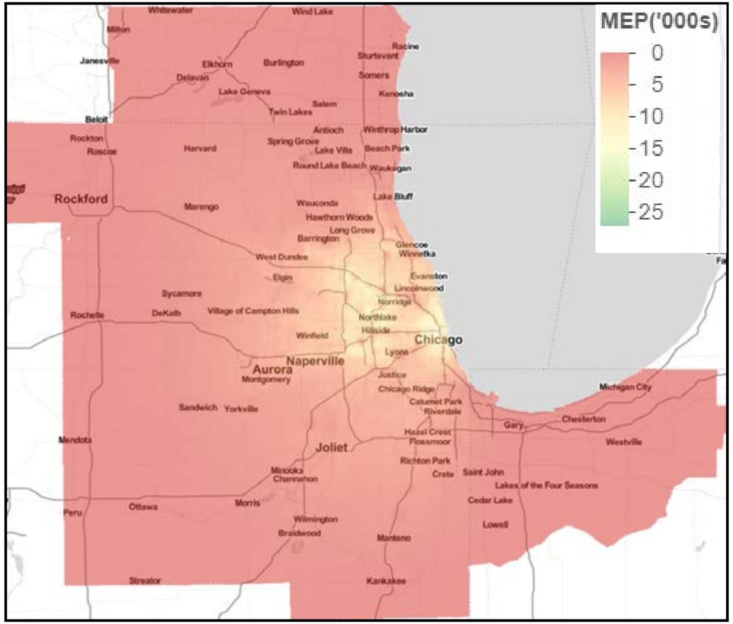
CHICAGO MEP:
TIME-, AND ENERGY-WEIGHTED

Overall MEP: 5579



Mode A
Energy Intensity: 1.10 kWh/passenger-mile

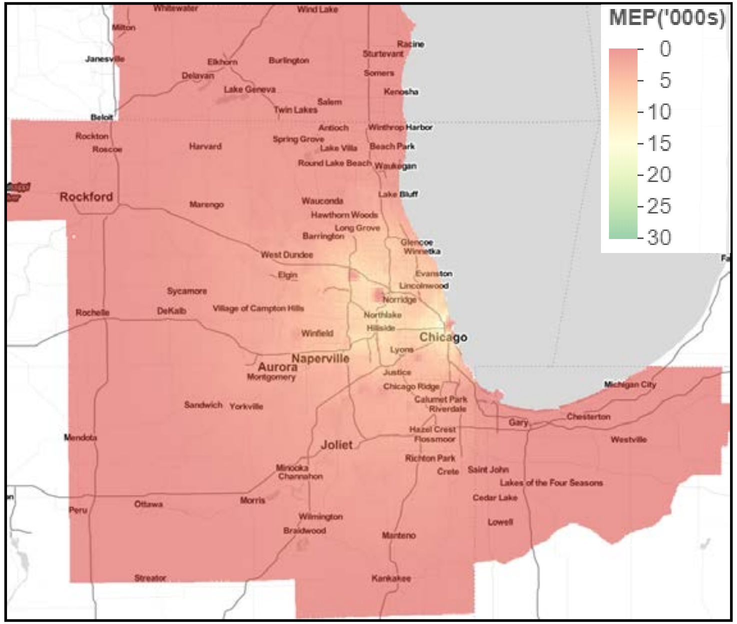
Overall MEP: 5256



Mode B
Energy Intensity: 1.03 kWh/passenger-mile

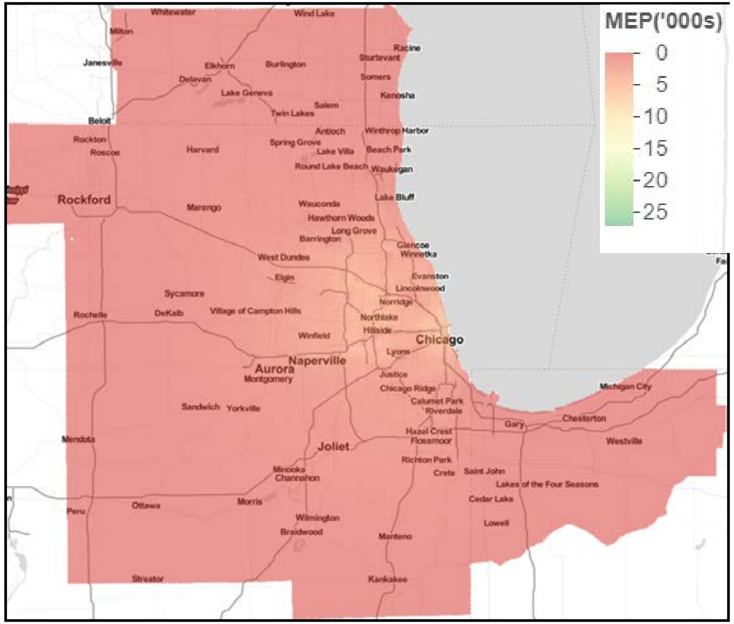
CHICAGO MEP:
TIME-, ENERGY-, AND COST-WEIGHTED

Overall MEP: 5111



Mode A
Cost: $0.18/passenger-mile

Overall MEP: 2191

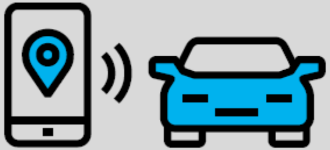


Mode B
Cost: $1.75/passenger-mile

MEP APPLICATION TO WORKFLOW SCENARIOS

A world of

HIGH SHARING, PARTIAL AUTOMATION (Sharing)



New technology enables people to significantly increase the use of **transit, ride-hailing** and **multi-modal travel. Partial automation** is introduced and is primarily used on the highway.

HIGH SHARING, HIGH AUTOMATION (SAV)

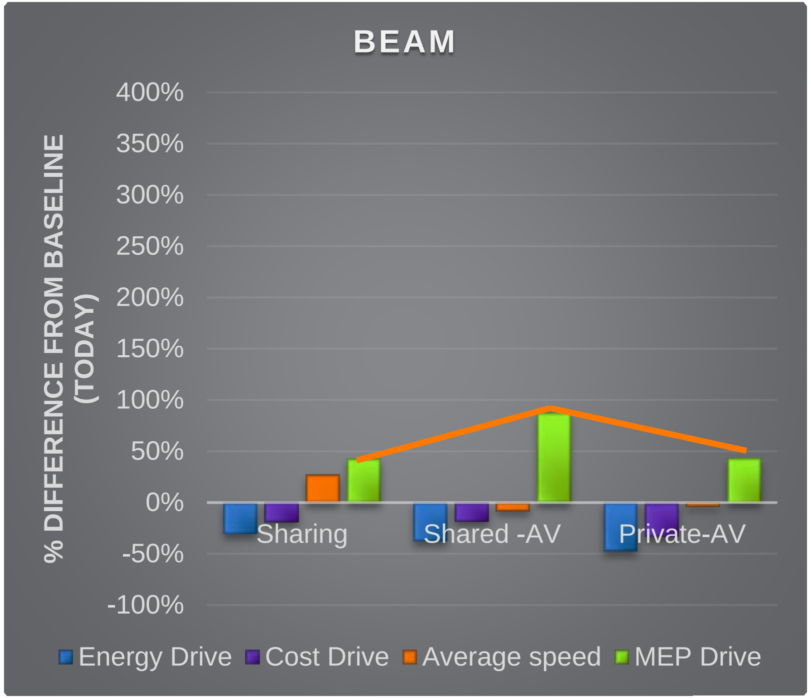
Technology has taken over our lives, enabling **high usage of fully automated driverless vehicles, ride-hailing and multi-modal trips**, which are convenient and inexpensive. As a result, **private ownership has decreased** and **e-commerce has increased**.

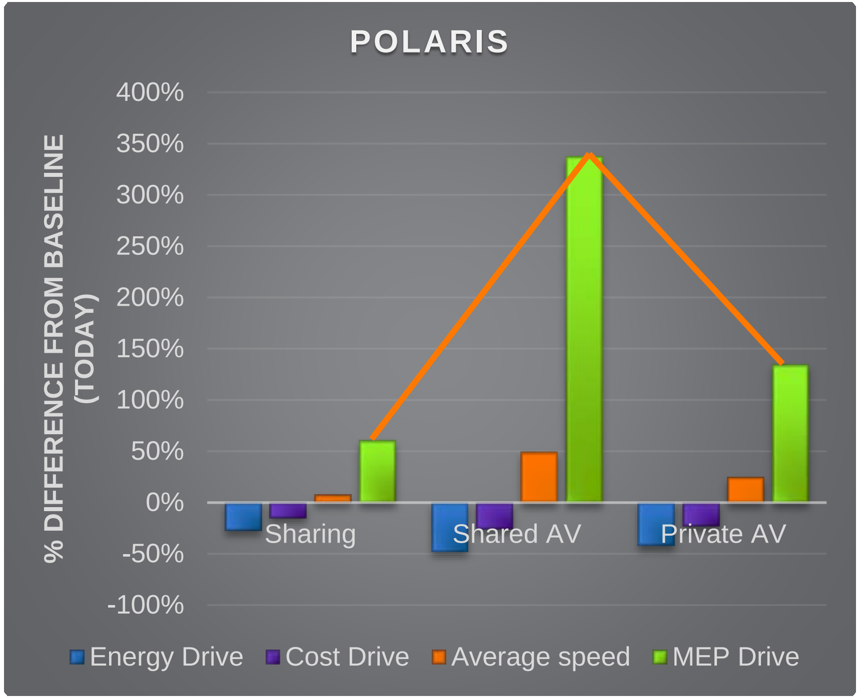
LOW SHARING, HIGH AUTOMATION (Private-AV)

Fully automated privately owned driverless vehicles dominate the market. The ability to own AVs leads to **low ride-sharing** and an expansion of urban/sub-urban boundaries, while **e-commerce has increased.**

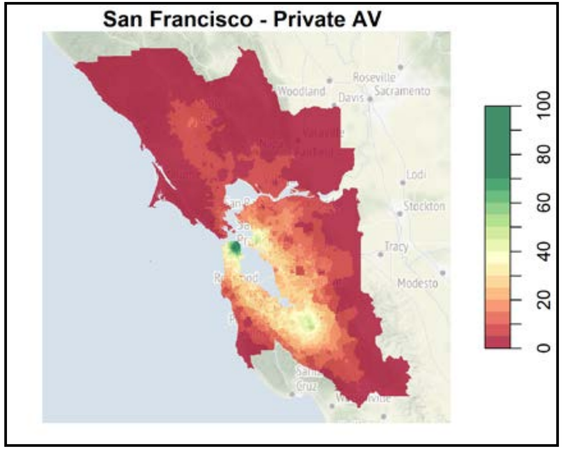
RESULTS ACROSS WORKFLOWS

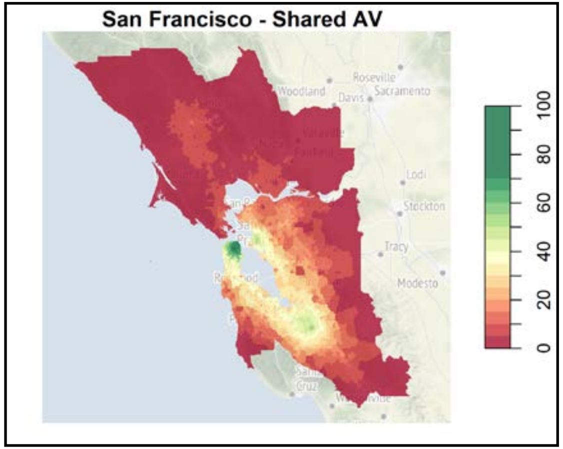
Similarities and Differences

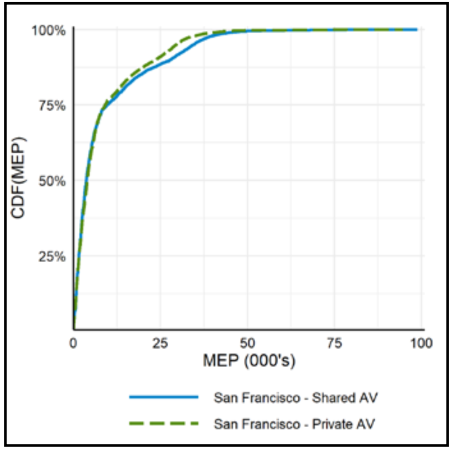




BEAM (SAN FRANCISCO) WORKFLOW



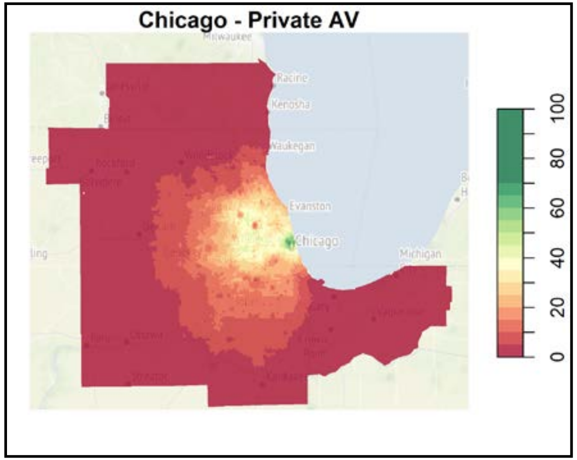




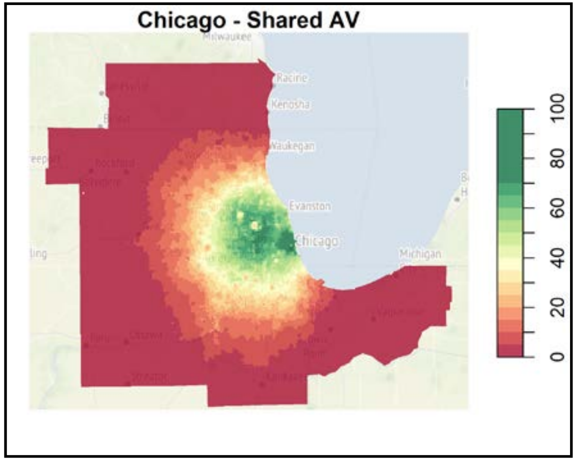
*MEP value shown in ‘000s

MEP improvement between Private-, and Shared-AV scenarios exists but to a lesser magnitude, as **increased congestion** (particularly in the Private-AV scenario) **offsets the assumed vehicle efficiency improvements**.

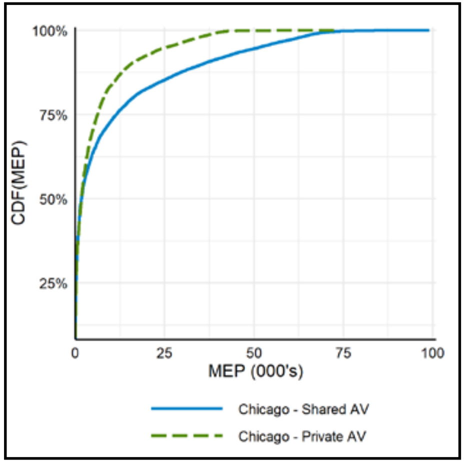
POLARIS (CHICAGO) WORKFLOW



Chicago - Private AV



Chicago - Shared AV



*MEP value shown in ‘000s

MEP improvement between Private-, and Shared-AV scenarios is significant owing to a combination of **decreased congestion** (due to increased system efficiency) and **assumed vehicle efficiency improvements**.

NEXT STEPS

- MEP enhancements
  - Development of **multi-modal isochrones** (e.g., car-transit-walk trips)
  - Compute **MEP score as a range,** as opposed to a single value, for a location
- Customizing MEP calculations for **individual specific socio-demographic** and trip characteristics
- MEP interactive dashboard
- Exercising **MEP metric for additional cities** through workflow implementations
  - Austin, Detroit, Atlanta, and more…

Any proposed future work is subject to change based on funding levels.

THE MEP TEAM!

Ambarish

Chris

Rob

Stan

Venu

Yi

*Tom Grushka and others…

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

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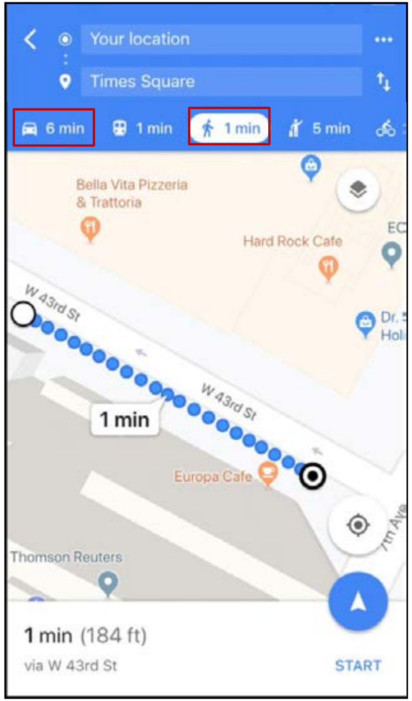
FIND THE LOCATION(S)!



Your location

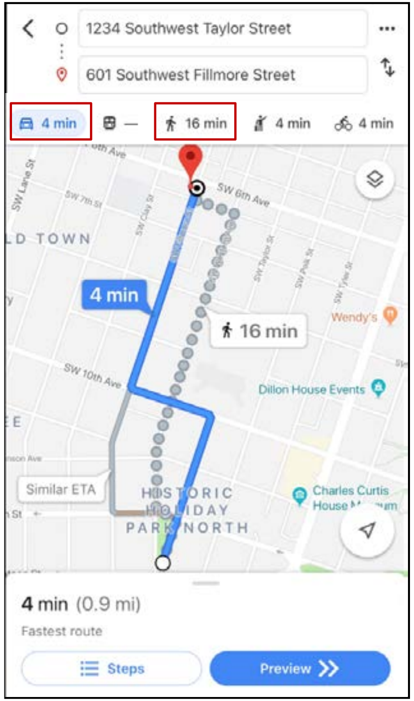
Times Square

1 min (184 ft)

via W 43rd St

Times Square, NY

Topeka, KS



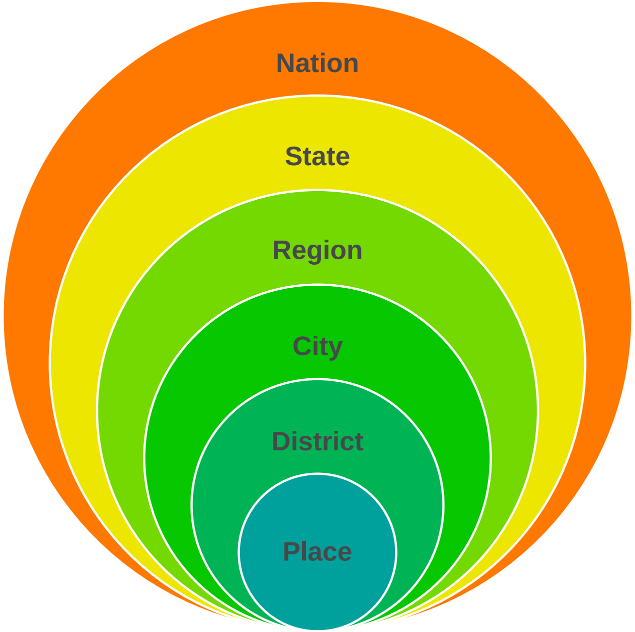
1234 Southwest Taylor Street

601 Southwest Fillmore Street

4 min (0.9 mi)

Fastest route

CONCEPTUAL DEVELOPMENT OF THE METRIC



- A metric that is **easy to scale spatially**, as different contexts might need the metric computed at different scales

- The MEP metric can be **customized by different weighting parameters** at the local level (activity distributions in Columbus might be different from than in Chicago), and then **aggregated by population**

POTENTIAL USES OF THE MEP METRIC

City/State/National level

- Key performance metric for projects based on improvement in MEP

City Level

- Integrate into urban planning for future scenario testing

City Level

- Use to assess competing investments in mobility/transportation/infrastructure services (city level)

MEP UPDATES

- Integration of MEP code with agent-based models POLARIS and BEAM – **Results available in DOE SMART Mobility Workflow Capstone Report**
- MEP journal article – https://journals.sagepub.com/doi/full/10.1177/0361198119848705
- Open-source MEP code development – **Alpha version ready**
- MEP web application – **Beta version ready**
  - ~108 cities for which MEP is computed
- MEP as one of the ASCE Smart City standards – **In Consideration**
- Interest in incorporating MEP in transportation planning processes
  - Colorado, Florida, and Delaware!