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

MEASURING MOBILITY POTENTIAL: A NOVEL METRIC TO QUANTIFY MOBILITY ENERGY PRODUCTIVITY (MEP) OF TRANSPORTATION SYSTEMS

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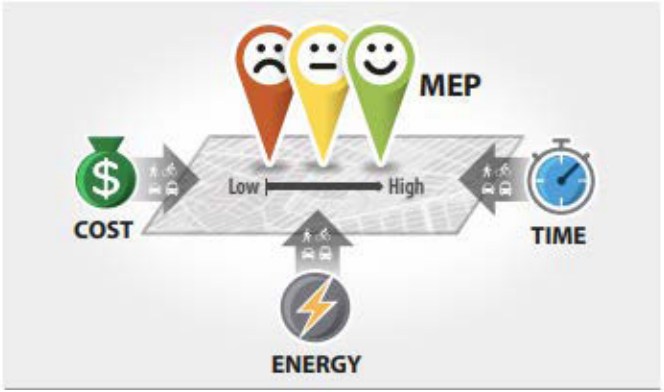
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Argonne NATIONAL LABORATORY · BERKELEY LAB · Idaho National Laboratory · NREL · OAK RIDGE National Laboratory

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
- How to create a metric that quantifies accessibility by all modes, while being cognizant of the costs associated with accessing opportunities?
  - Energy, Emissions, Dollars, Time
- Can we increase energy efficiency if we connect people better?
- Productivity = Mobility Benefits/Costs



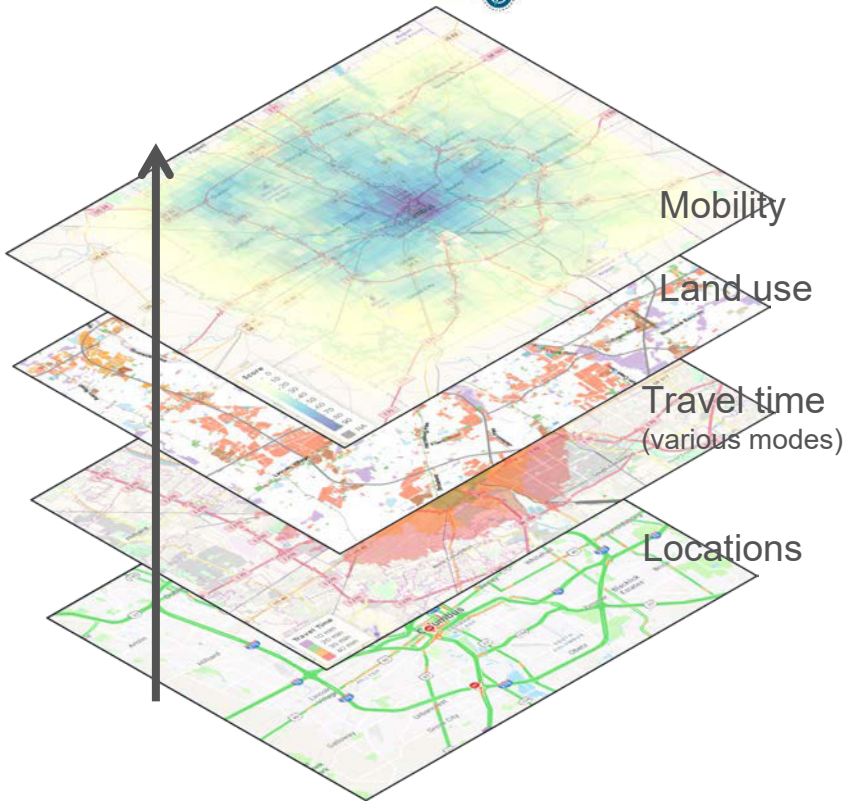
Mobility: The quality of a network or system to connect people to goods, services, and employment that define a high quality of life.

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

- **A**ccurately **reflects the efficiency** of accessing a variety of goods, services, and employment opportunities
- **B**ased on **established/accepted research**, yet supportable by available data
  - Prior work by Owen et al. 2014, Saunders et al. 2018
- **C**an be applied to **any mode** (car, walk, bike, transit, etc.)
- **D**etermined 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

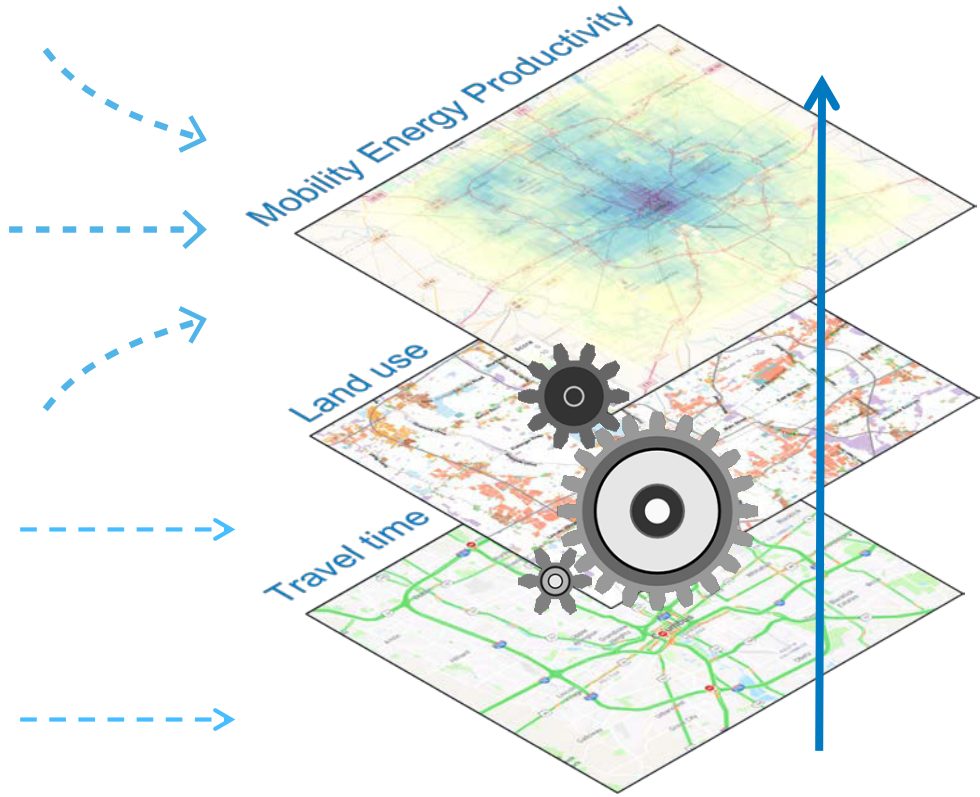
- Capital costs, operational costs
- Value of time

Land-Use Data

- Metropolitan Planning Organizations

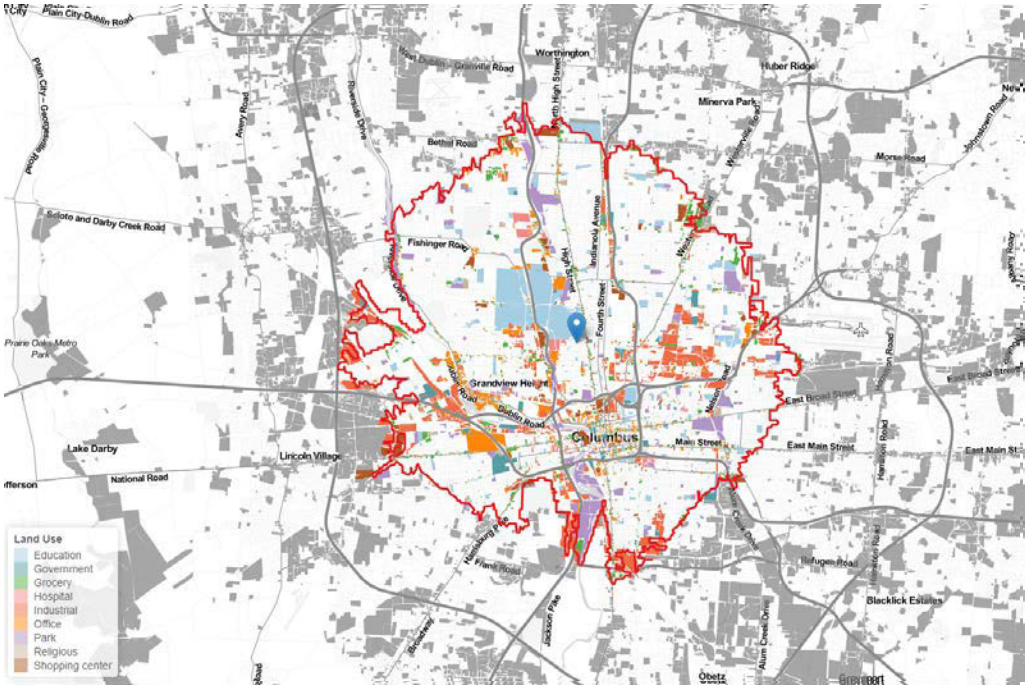
Travel Time and Isochrone

- 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*”



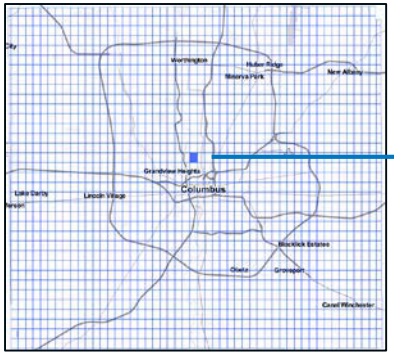
An example of opportunities accessible by biking

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.

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

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

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

$\beta = -0.08, \alpha = -0.5, \sigma = -0.5$

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.

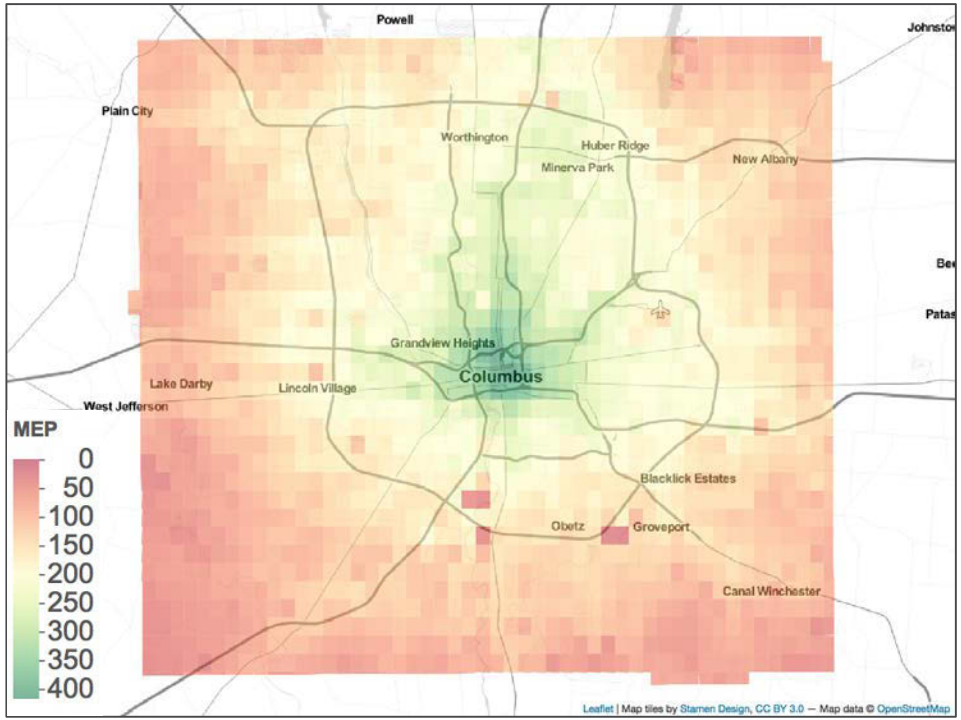
MEP APPLICATION

STANDALONE

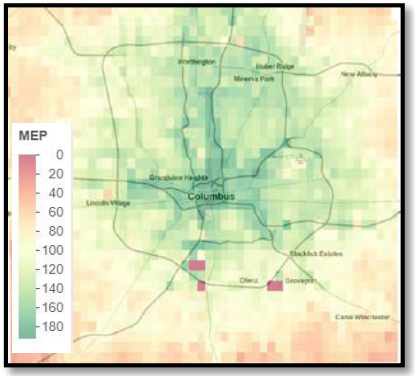
MEP – COLUMBUS, OH

POPULATION-WEIGHTED MEP COLUMBUS, OH

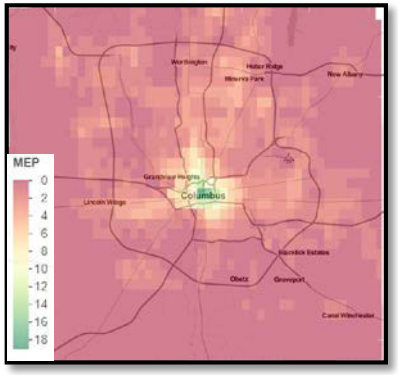
Population-density-weighted MEP metric: 198



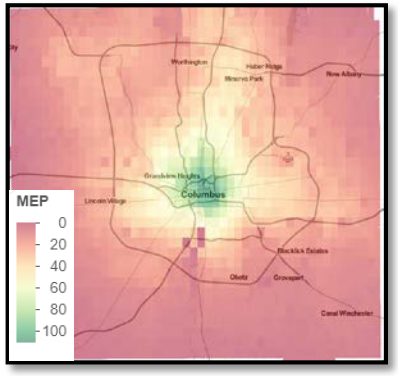
MEP MAPS BY MODE
COLUMBUS, OH



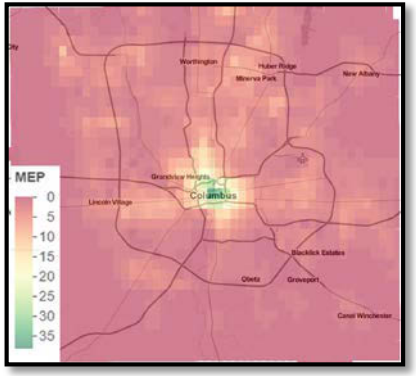
Driving



Transit



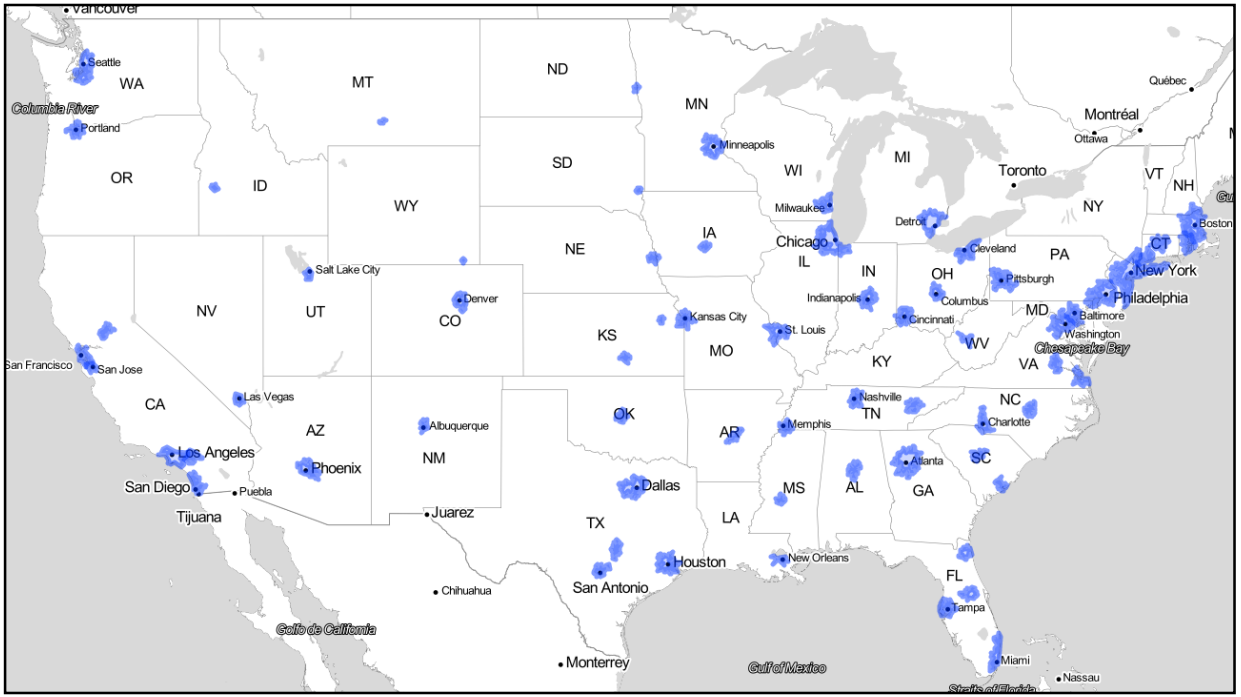
Bike



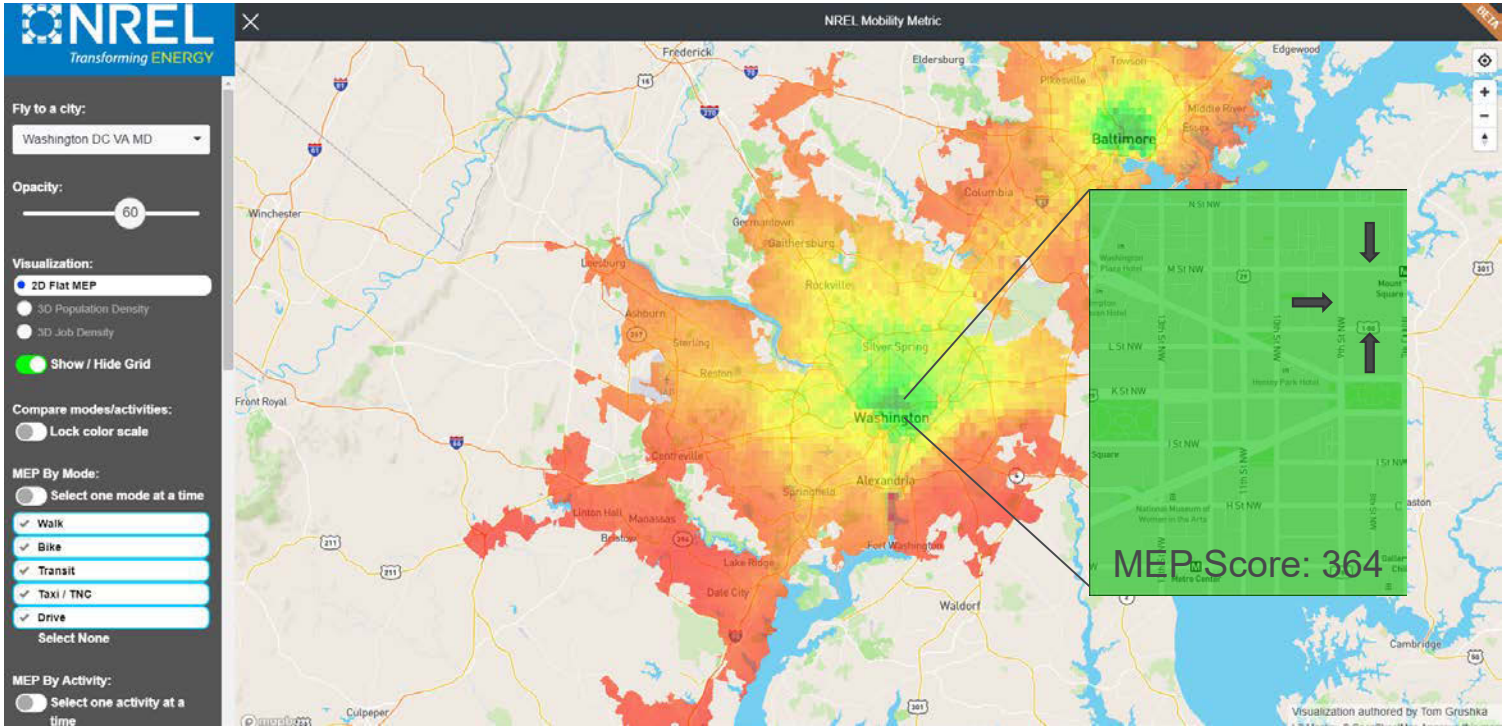
Walk

MEP COMPUTATION FOR VARIOUS CITIES IN THE U.S.

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

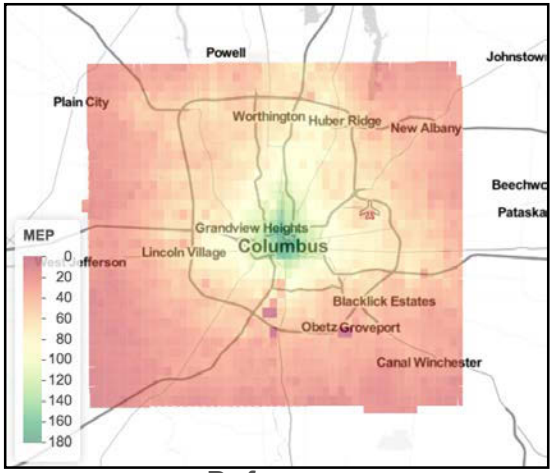


MEP – PROTOTYPE WEB APPLICATION

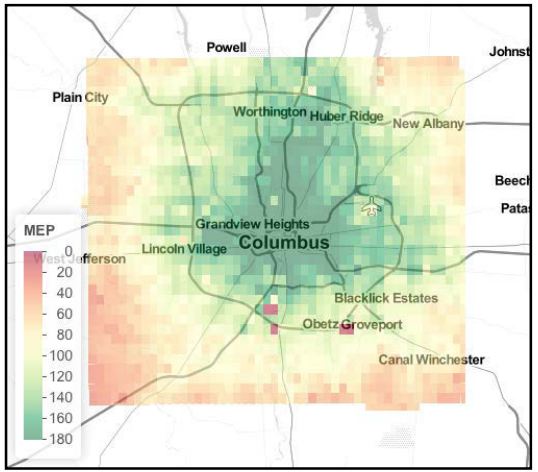


MEP – ILLUSTRATIVE SCENARIO ANALYSIS VEHICLE ELECTRIFICATION

- 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

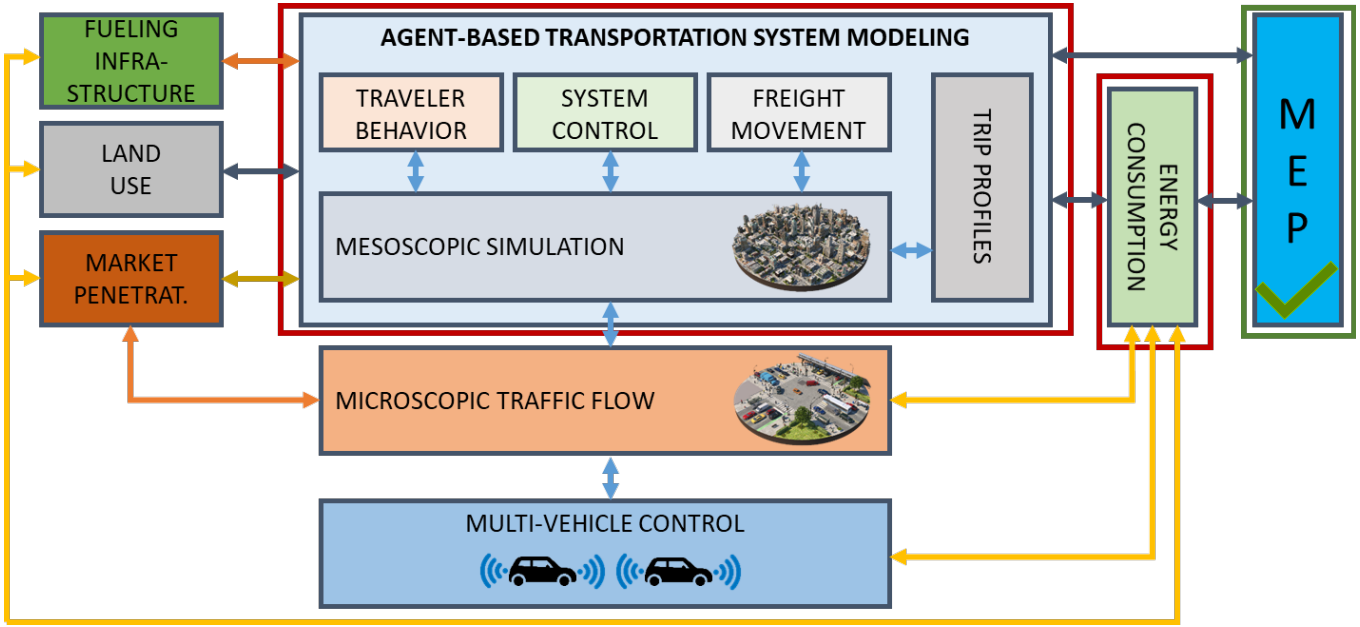
Caveats:

- 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

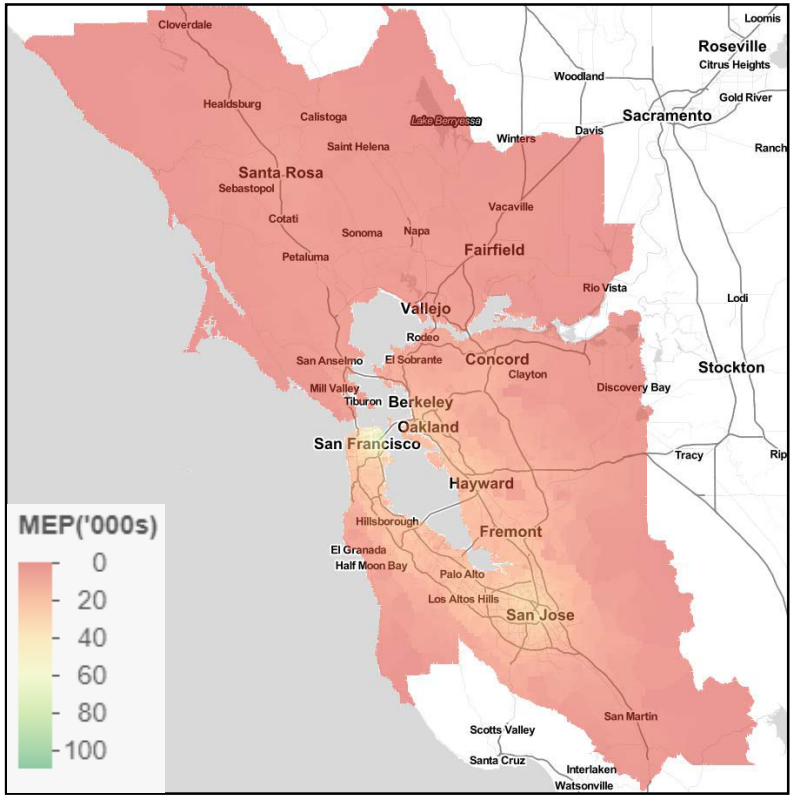


The MEP metric will capture the impact of emerging technologies and land-use patterns on accessibility—including impacts on travel time, energy usage, and the cost of different modes of transportation.

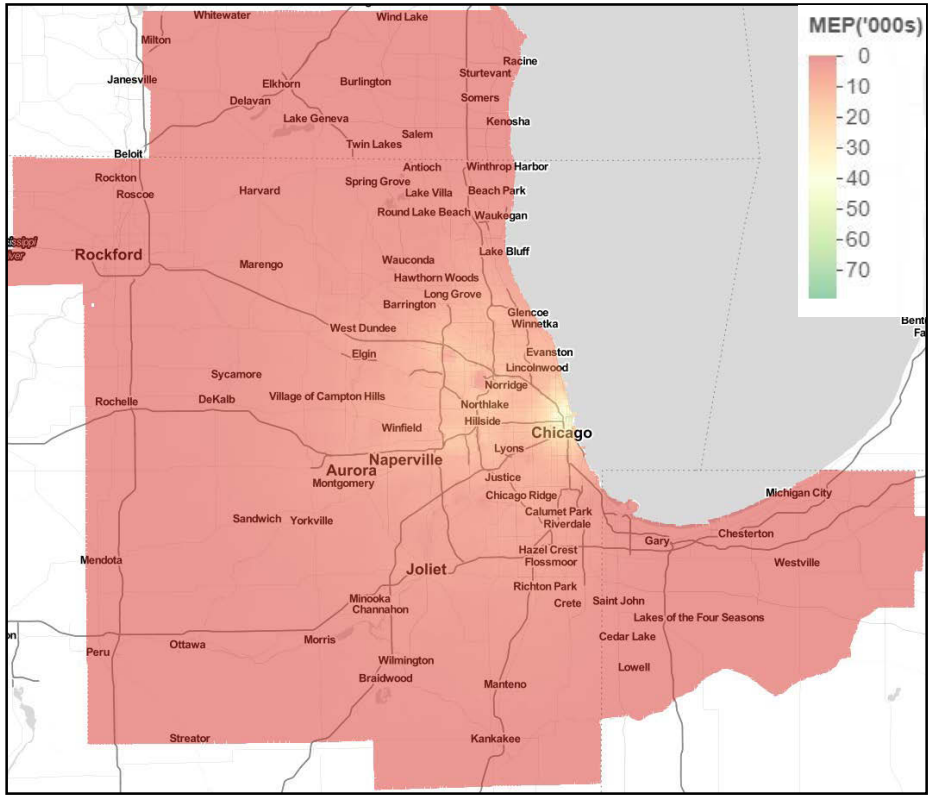
DATA SOURCES

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

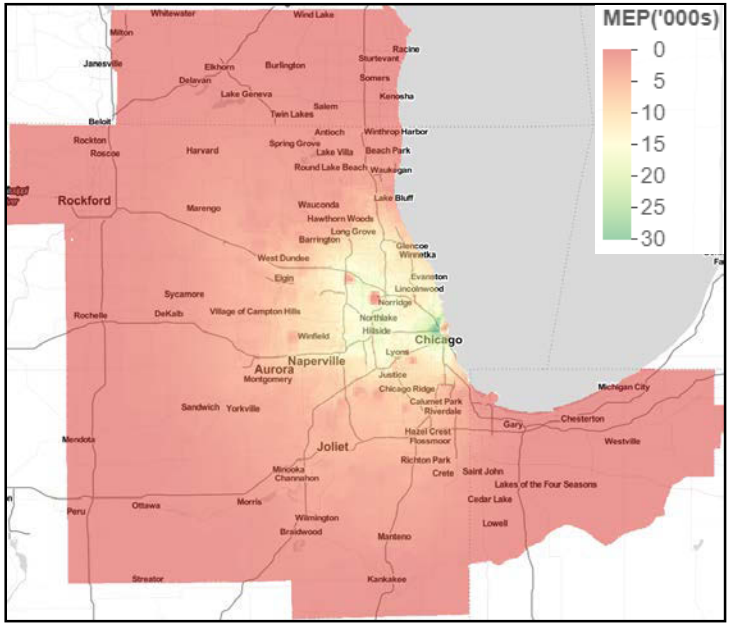


SAMPLE OUTPUT: CHICAGO



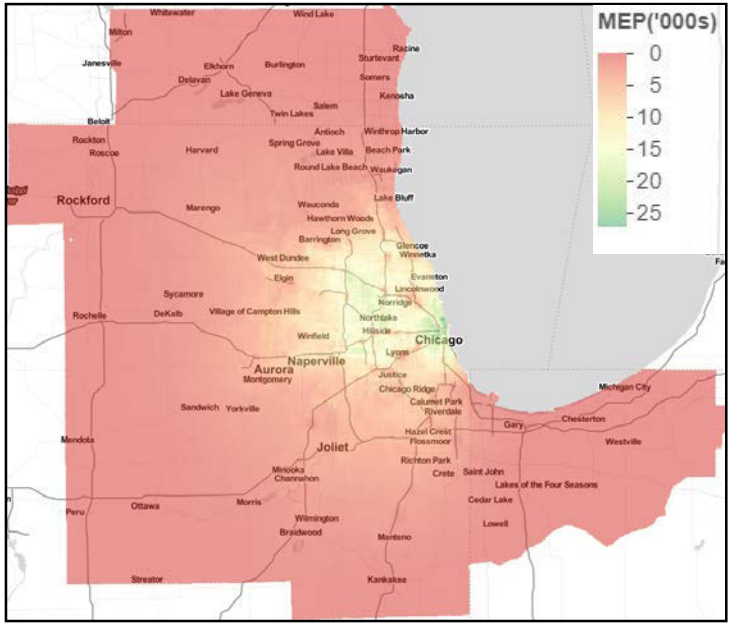
CHICAGO MEP: ONLY TIME-WEIGHTED

Overall MEP: 9675



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

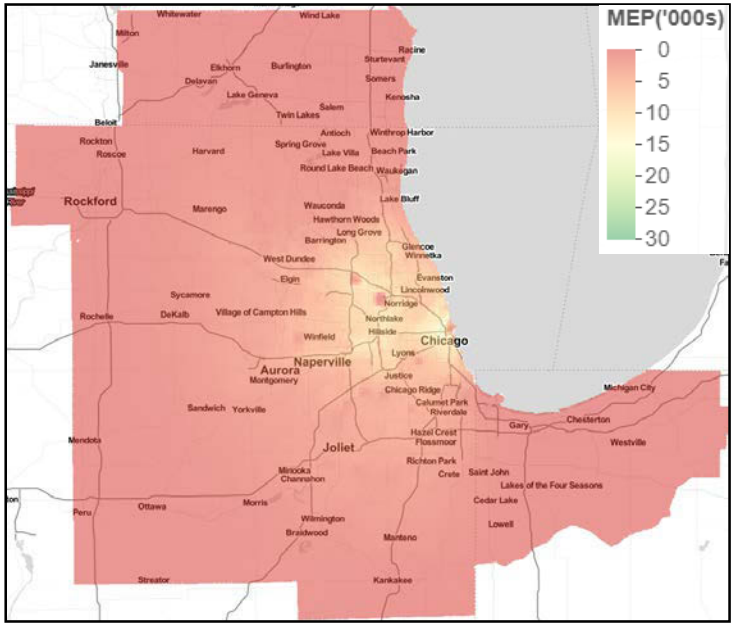
Overall MEP: 8792



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

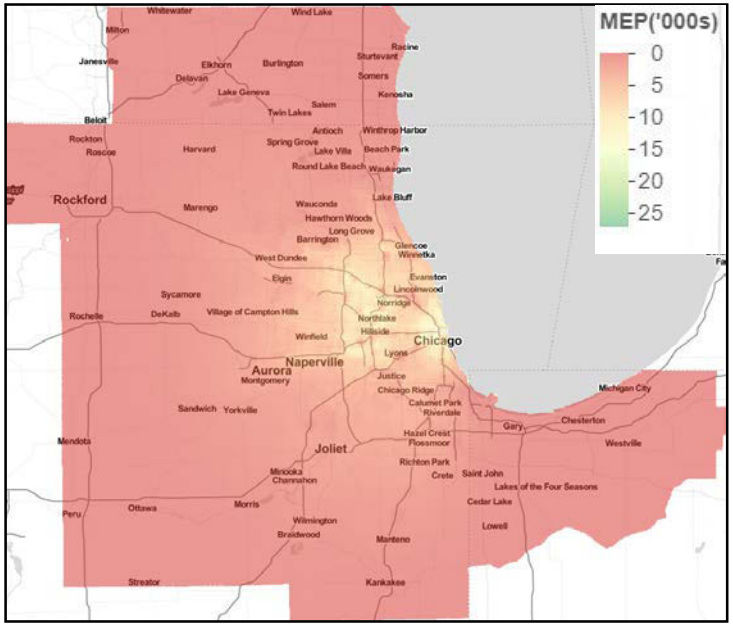
CHICAGO MEP:
TIME-, AND ENERGY-WEIGHTED

Overall MEP: 5579



Mode A
Energy Intensity: 1.10 kWh/passenger-mile

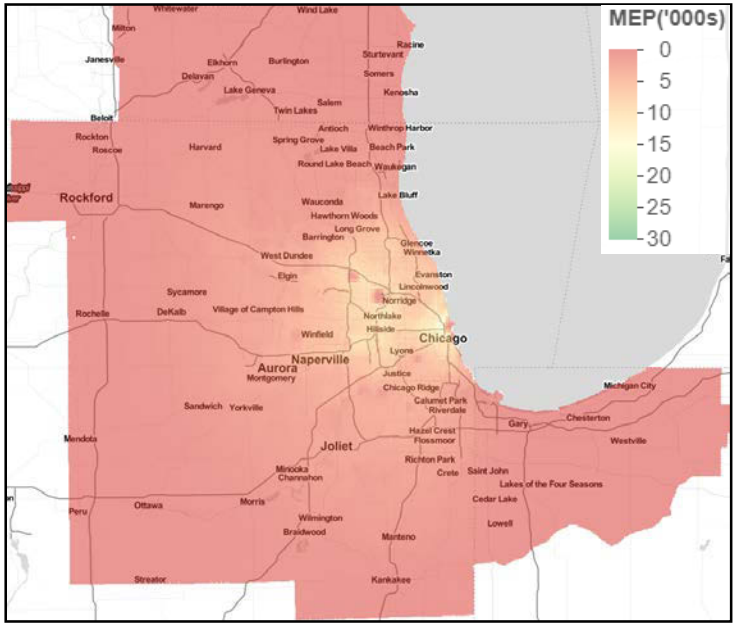
Overall MEP: 5256



Mode B
Energy Intensity: 1.03 kWh/passenger-mile

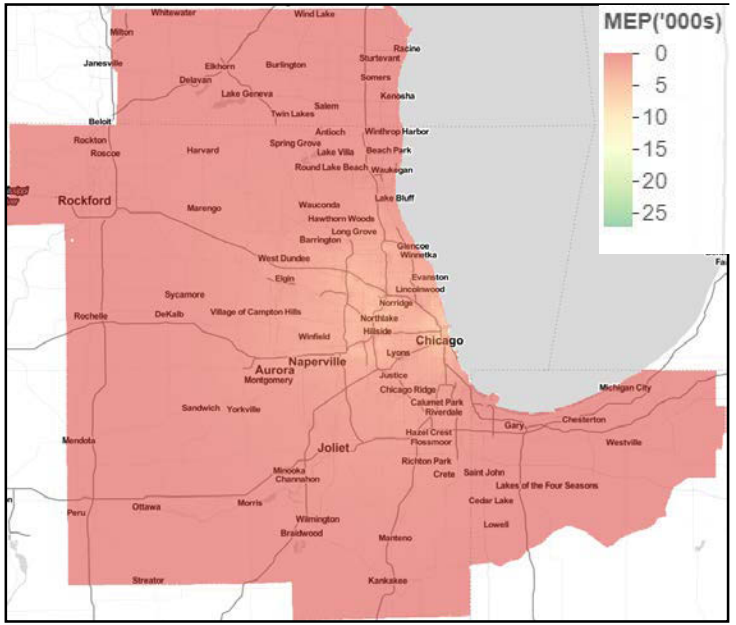
CHICAGO MEP: TIME-, ENERGY-, AND COST-WEIGHTED

Overall MEP: 5111



Mode A
Cost: $0.18/passenger-mile

Overall MEP: 2191



Mode B
Cost: $1.75/passenger-mile

MEP UPDATES

- Integration of MEP code with agent-based models POLARIS and BEAM – **First iteration completed**
- MEP journal article – https://journals.sagepub.com/doi/full/10.1177/0361198119848705
- Open-source MEP code development – **Alpha version ready**
  - ~68 cities for which MEP is computed
- MEP web application – **Beta version ready**
- MEP as one of the ASCE Smart City standards – **Pre-standard publication soon**
- Interest in incorporating MEP in transportation planning processes
  - Colorado, Florida, Virginia, Delaware, and Canada!

NEXT STEPS

- **Correlation** with other transportation metrics
- Customizing MEP calculations for **individual specific socio-demographic** and trip characteristics
- Development of **multi-modal isochrones** (e.g., car-transit-walk trips)
- Extending the methodology to quantify **MEP scores for significant travel generators/attractors** such as universities, airports, or major employers
- Compute **MEP score as a range,** as opposed to a single value, for a location

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