JUNE 3, 2020

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

URBAN TRAVELER – CHANGES AND IMPACTS: MOBILITY ENERGY PRODUCTIVITY (MEP) METRIC

VENU GARIKAPATI
National Renewable Energy Laboratory
DOE Vehicle Technologies Office
2020 Vehicle Technologies Office Annual Merit Review

Project ID# eems057
Pillar(s): Urban Science

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

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

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

OVERVIEW

Timeline

- Project start date: 10/1/2017
- Project end date: 9/30/2019
- Percent complete: 100%

Budget

- Total project funding
  - DOE share: $850K
  - Contractor share: $0
- Funding for FY 2019: $500K

Barriers

- Lack of open and practical metrics to quantify energy productivity of mobility
- Need for new tools and core capabilities to determine the value and productivity derived from new mobility technologies

Partners

- SMART Mobility Laboratory Consortium
  - Argonne National Laboratory (ANL)
  - Lawrence Berkeley National Laboratory (LBNL)
- American Society of Civil Engineers (ASCE)
- Colorado Department of Transportation (CDOT)
- Ford Motor Company
- Dallas-Fort Worth International Airport

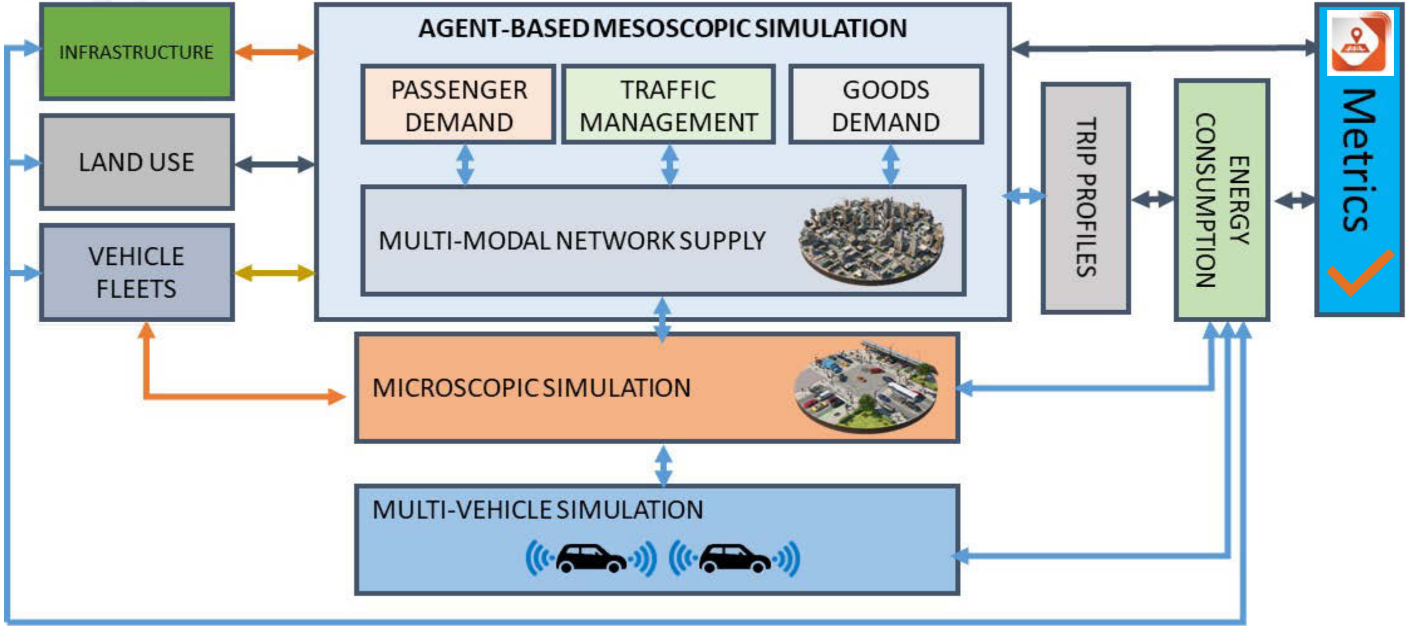
RELEVANCE

- **Overall Objective**
  - To create a scalable, open-source metric to quantify and compare energy productivity of mobility options provided by existing and emerging transportation options.
- **Objectives This Period**
  - Compute MEP scores for 100 U.S. cities
  - Finish development of beta version of the MEP code
  - Integrate the MEP calculation procedure with BEAM (Behavior, Energy, Autonomy, Mobility) and POLARIS (Planning and Operations Language for Agent-based Regional Integrated Simulation) workflow modeling processes
  - Engage external partners
    - Solicit feedback on MEP methodology
    - Use MEP for travel efficiency quantification outside SMART Mobility Consortium

- **Impact**
  - This metric serves as a unified lens through which research in the DOE–EEMS portfolio can be assessed
  - Being considered as a metric for the ASCE SMART City standard.

Development of the MEP metric is perfectly aligned with the EEMS program goal to "*develop new tools, techniques, and core capabilities to understand and identify the most important levers to improve the energy productivity of future integrated mobility systems.*"

RELEVANCE: RELATIONSHIP TO WORKFLOW MODELING



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.

MILESTONES

Month/Year	Description of Milestone or Go/No-Go Decision	Status
March 2019	Framework integration with BEAM/POLARIS	Complete
April 2019	Technical presentation on final MEP methodology	Complete
June 2019	Technical report on the framework for integrating MEP into BEAM and POLARIS	Complete
August 2019	MEP implementation for top 50 metropolitan areas in the United States	Complete
September 2019	MEP calculations for POLARIS and BEAM workflow scenarios	Complete

APPROACH: DESIRED PROPERTIES OF MEP 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. 2014. "Access Across America." *Transit* 4, no. 5.
- Saunders, Michael J., Tobias Kuhnimhof, Bastian Chlond, and Antonio Nelson Rodrigues da Silva. 2008. "Incorporating Transport Energy into Urban Planning." *Transportation Research Part A: Policy and Practice* 42, no. 6: 874–882.

APPROACH: DATA SPECTRUM & PARALLEL IMPLEMENTATIONS

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

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

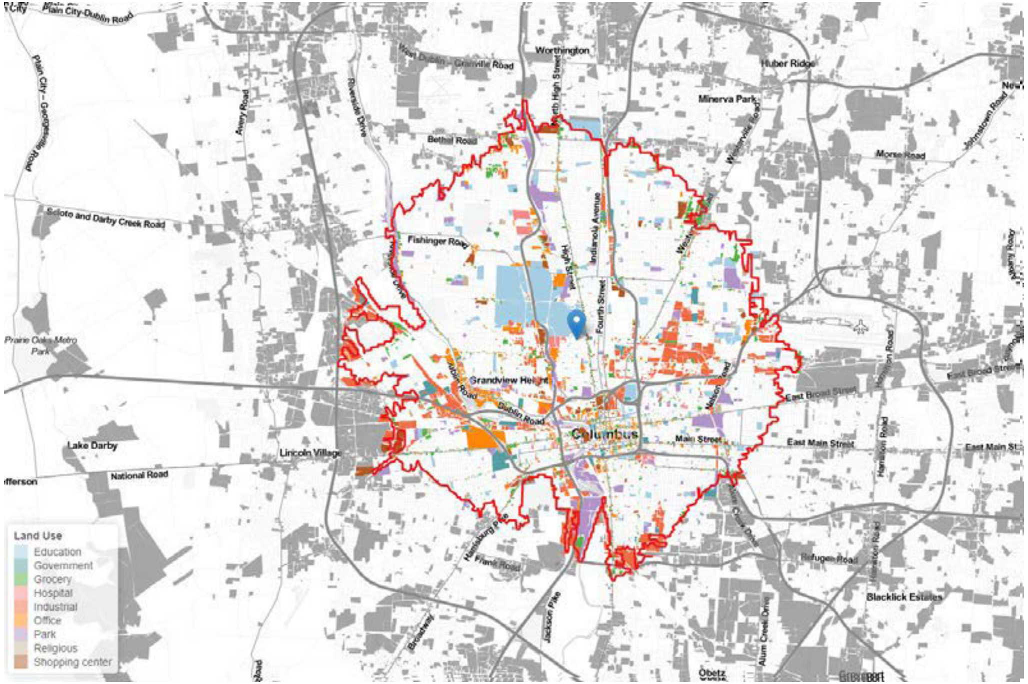
Travel Time and Isochrone
- Third-party isochrone APIs (e.g., HERE)
- GPS trajectory data (TomTom, INRIX)
- Travel Demand Models

The MEP package is implemented to compute baseline MEP scores in 100+ cities in the United States

The MEP package is being utilized to quantify impacts of various workflow scenarios being run in POLARIS and BEAM

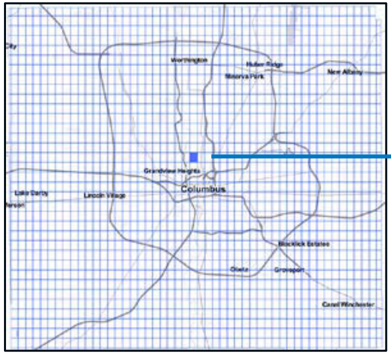
APPROACH: ISOCHRONE – EXAMPLE

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

APPROACH: MEP COMPUTATION – ILLUSTRATIVE



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

Proportioned by activity engagement frequency

Weighted by time

Weighted by modal energy intensity and cost

	CUMULATIVE OPPURTUNITIES
DRIVING	10,000
TRANSIT	680
BIKING	450

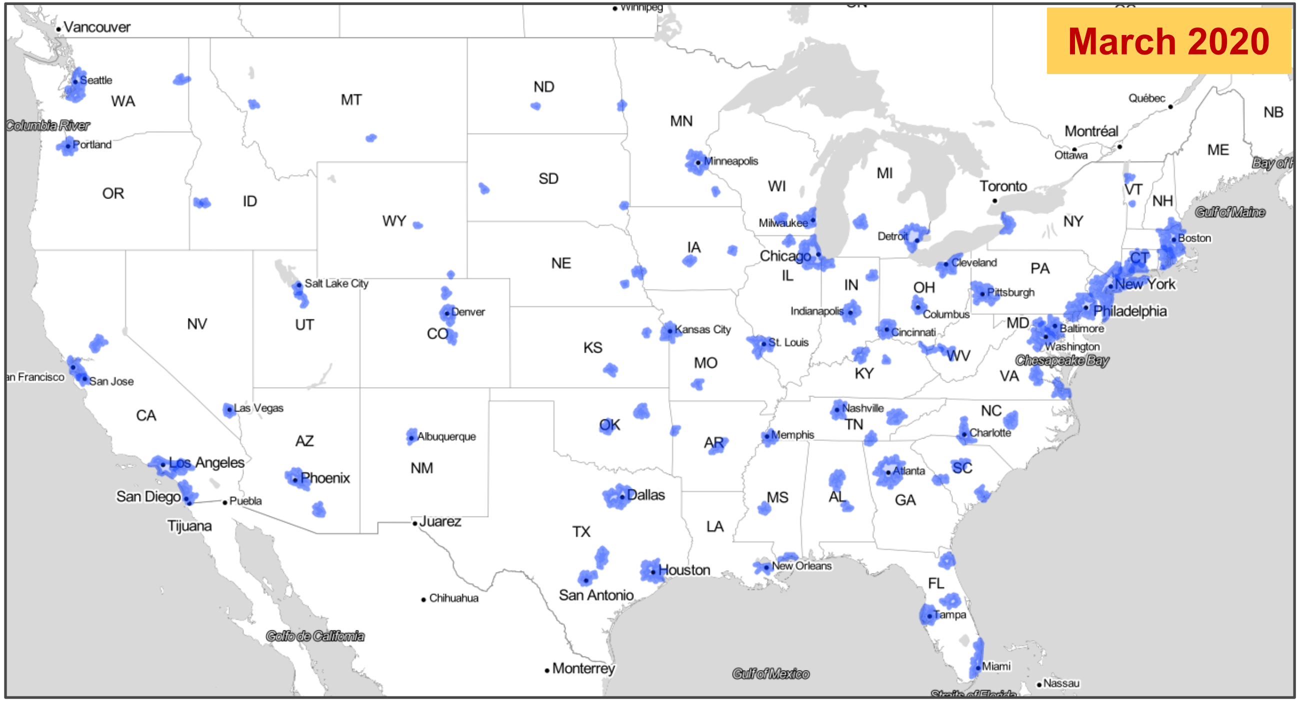
MEP
68

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: TWO IMPLEMENTATIONS

Data Input	Independent	Integrated with Workflow Modeling
Travel time isochrones	Third-party data sources	Travel models (BEAM/POLARIS)
Land-use data	Third-party data sources	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	Transportation Energy Data Book Sustainable Transport and Public Policy (2009)	Vehicle energy consumption models (SVTrip+Autonomie/RouteE)
Modal cost	P. Condon & K. Dow, A Cost Comparison of Transportation Modes (2009)	Travel models (BEAM/POLARIS)
Coefficients for energy and time (α, β)	$\alpha = -0.05$, $\beta = -0.08$	$\alpha = -0.05$, $\beta = -0.08$ (tagged for future research)

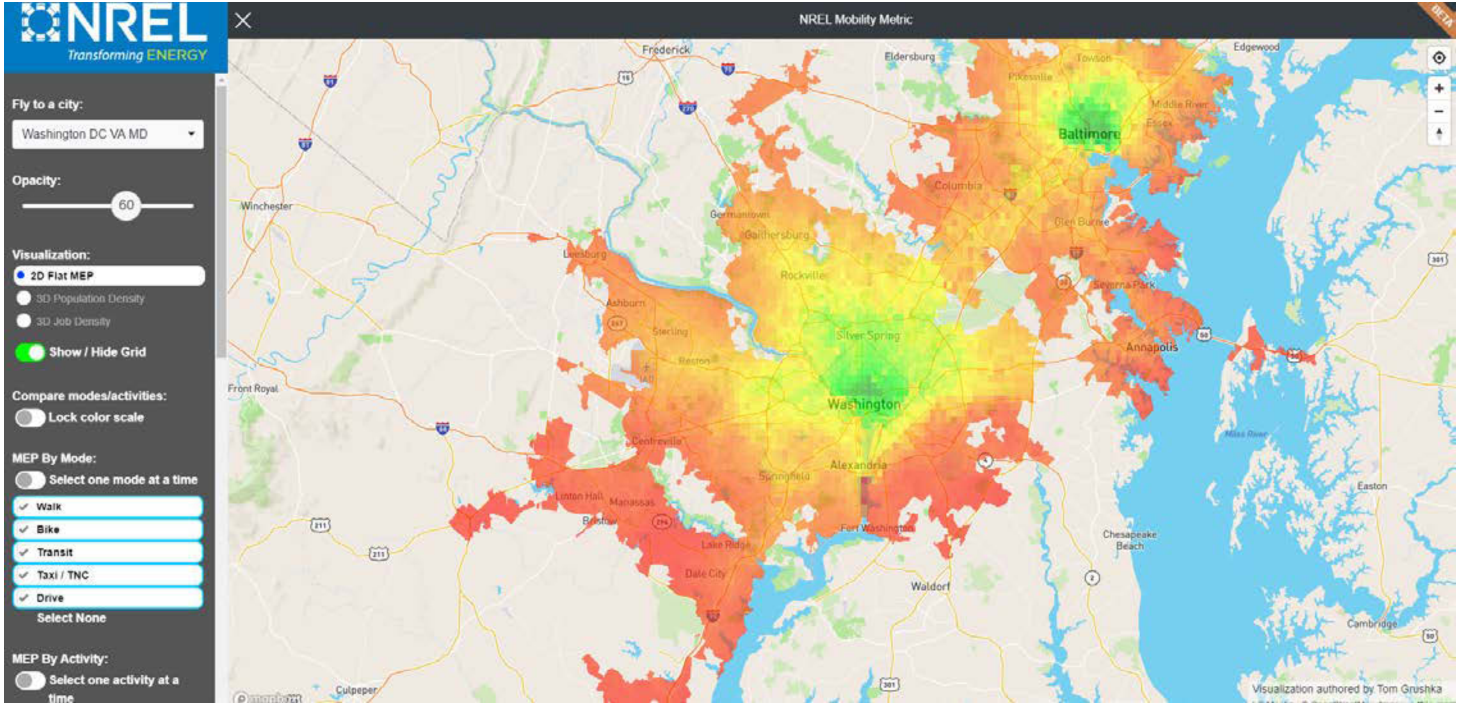
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

MEP Standalone Application



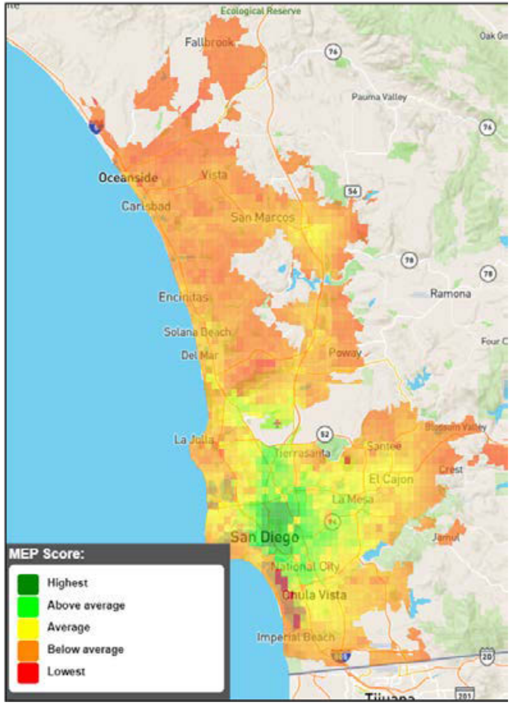
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

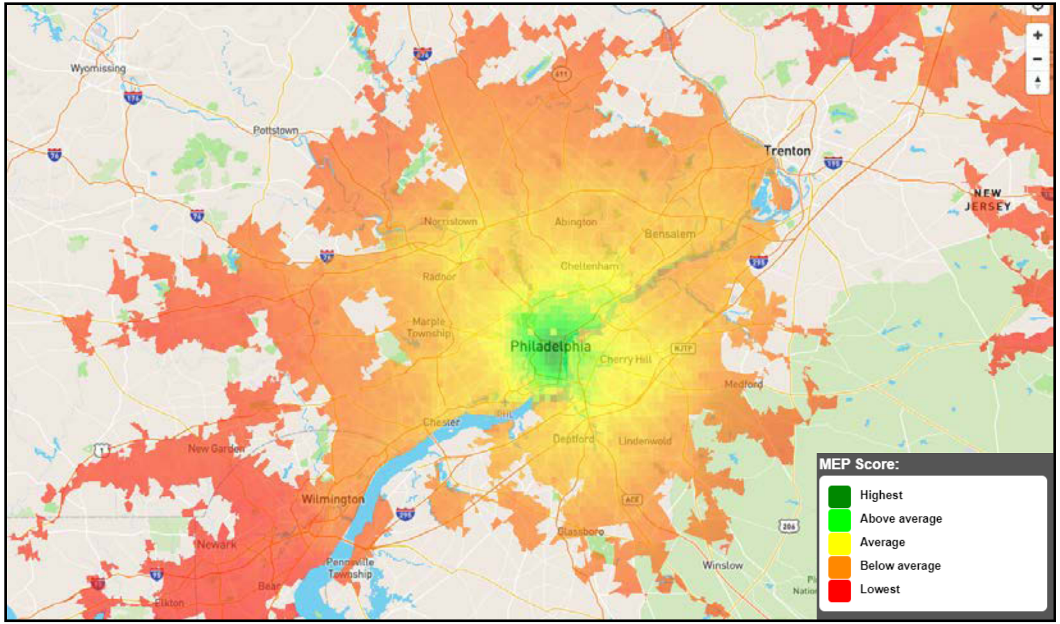
MEP Web Application Prototype



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

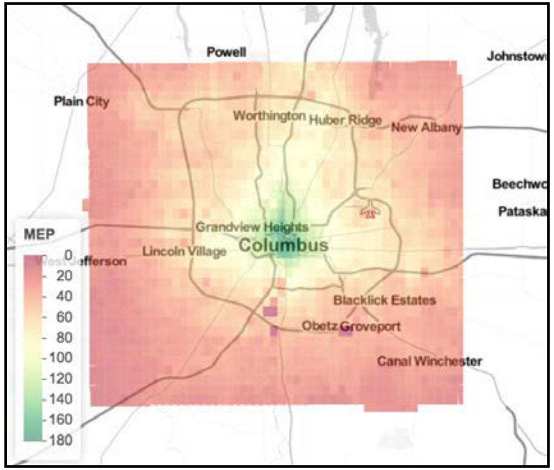
MEP Standalone Application



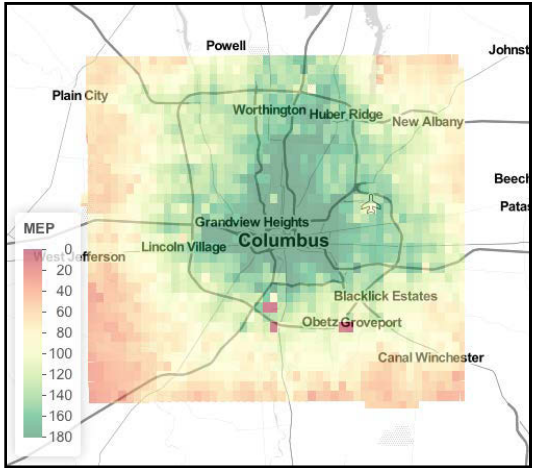


MEP – ILLUSTRATIVE SCENARIO ANALYSIS VEHICLE ELECTRIFICATION

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



Before



After

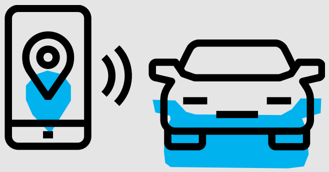
Caveats:

- 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

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Integration with Workflow Modeling Process

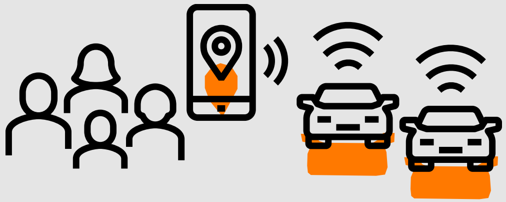
HIGH SHARING, PARTIAL AUTOMATION (A)



Tests new technology's ability to increase use of **multimodal travel. Partial automation** is assumed on highways.

A1 - Low-technology case, business as usual (BAU)
A2 - High-technology (VTO targets)

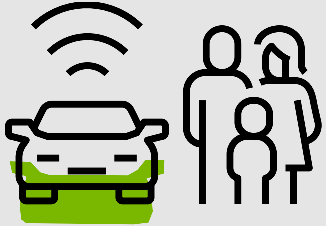
HIGH SHARING, HIGH AUTOMATION (B)



High usage of fully automated driverless vehicles, ride-hailing, and multimodal trips. As a result, **private ownership has decreased** and **e-commerce has increased**.

B1 - Low-technology case (BAU)
B2 - High-technology (VTO Targets)

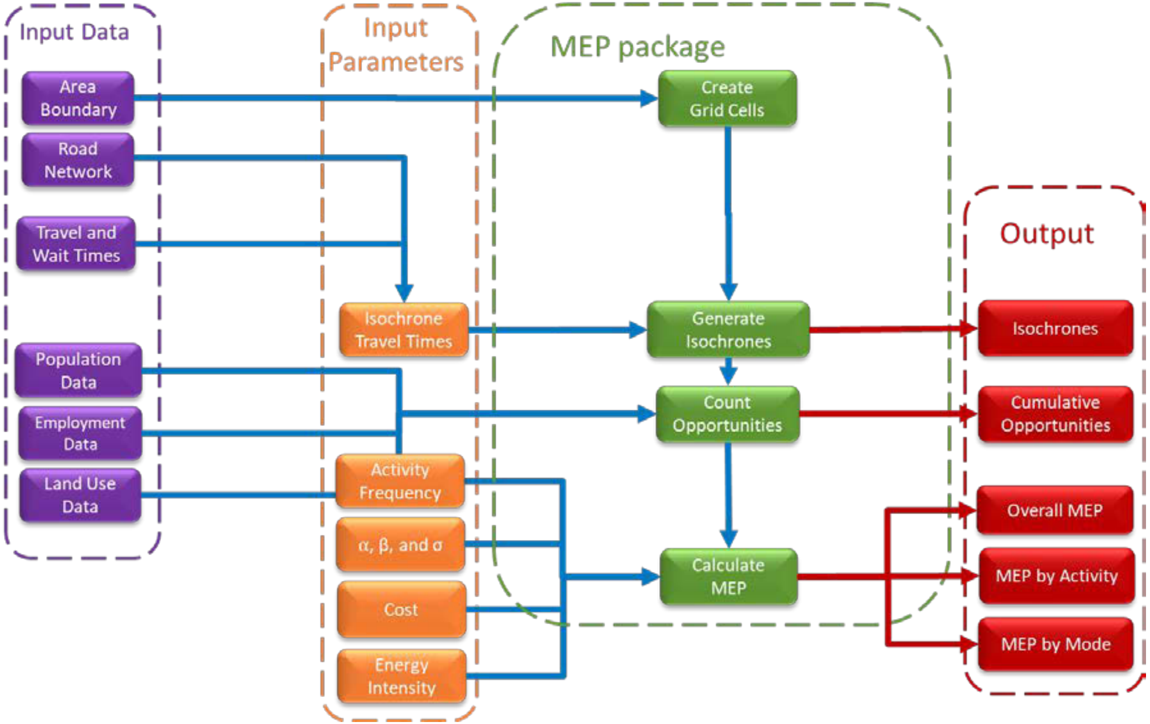
LOW SHARING, HIGH AUTOMATION (C)



Fully automated, privately owned driverless vehicles are affordable and dominate. Leads to **low ride-sharing** and an more urban sprawl, while **e-commerce has increased.**

C1 - Low-technology case (BAU)
C2 - High-technology (VTO targets)

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: WORKFLOW INTEGRATION

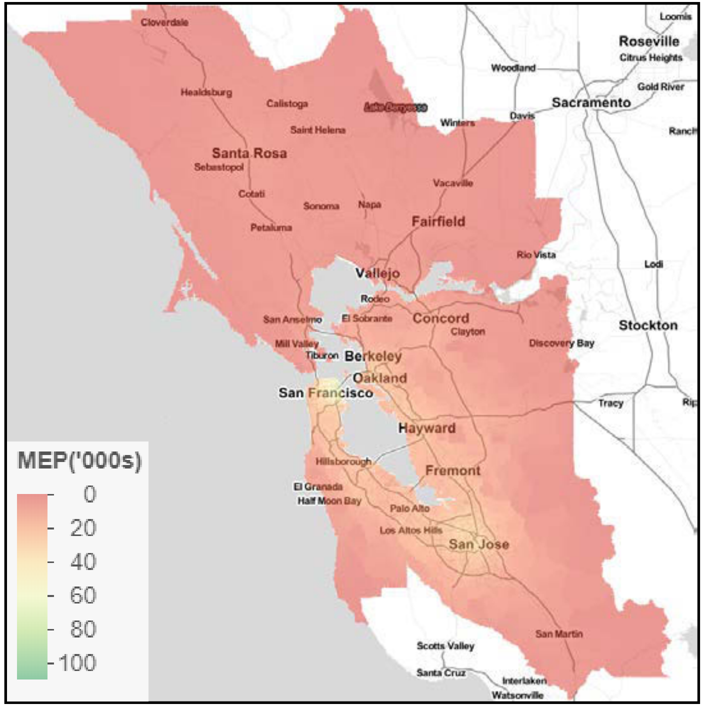


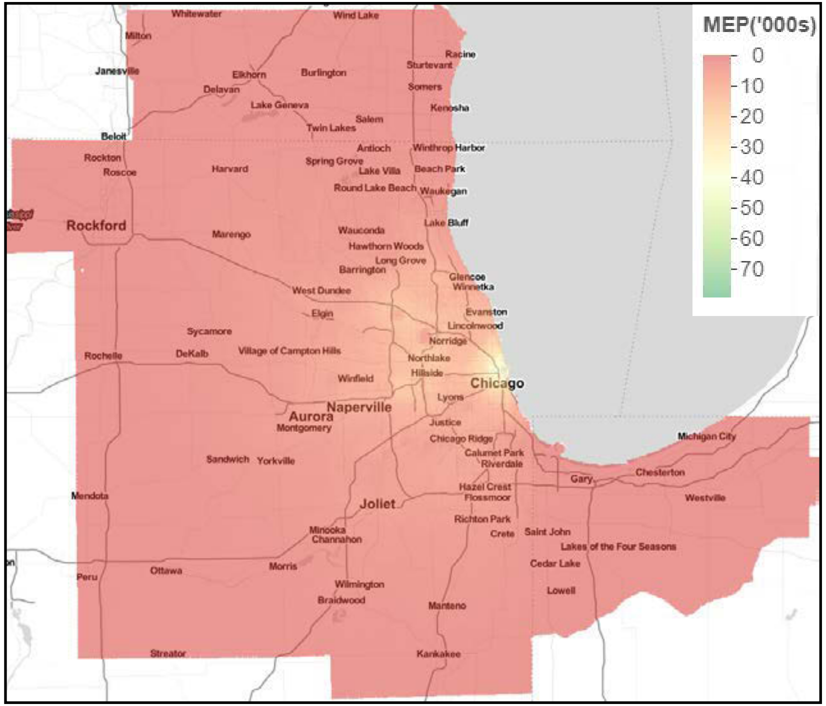
The MEP tool is utilized to quantify impacts of various workflow scenarios run in POLARIS and BEAM

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

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

Workflow Modeling: Sample Outputs





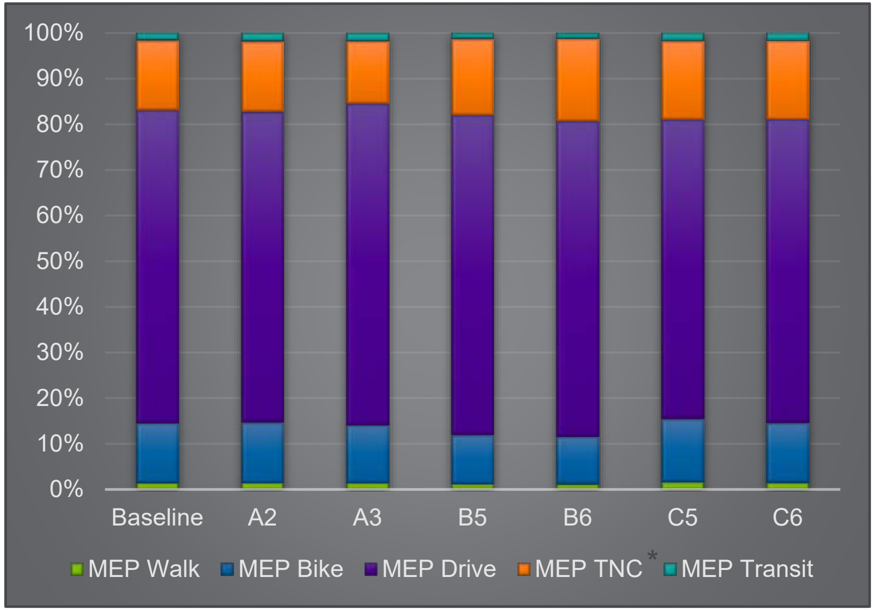
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

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

Workflow Implementation using BEAM

MEP Values (% Change from Baseline)

MEP Split by Mode



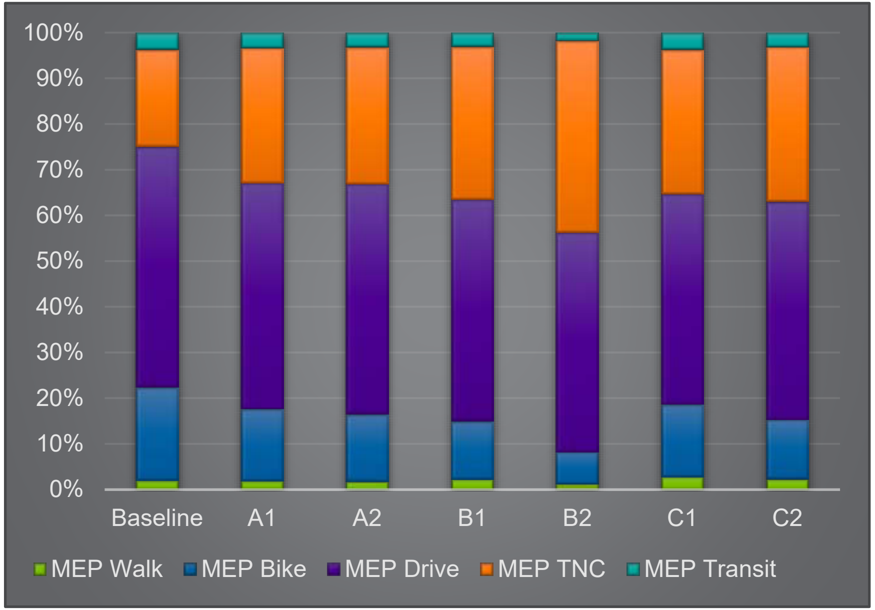
*TNC – Transportation Network Companies like Uber & Lyft

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Workflow Implementation using POLARIS

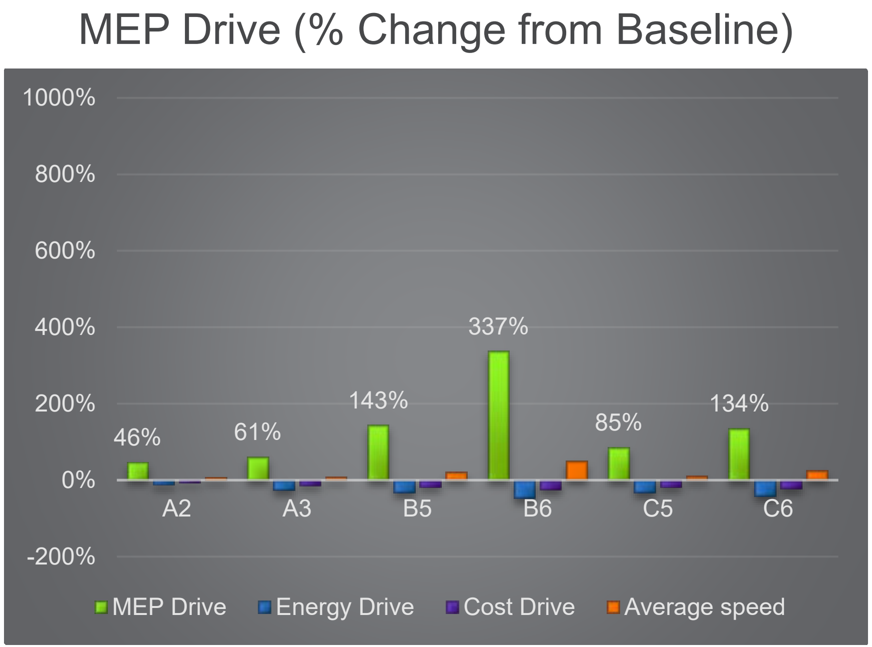
MEP Values (% Change from Baseline)

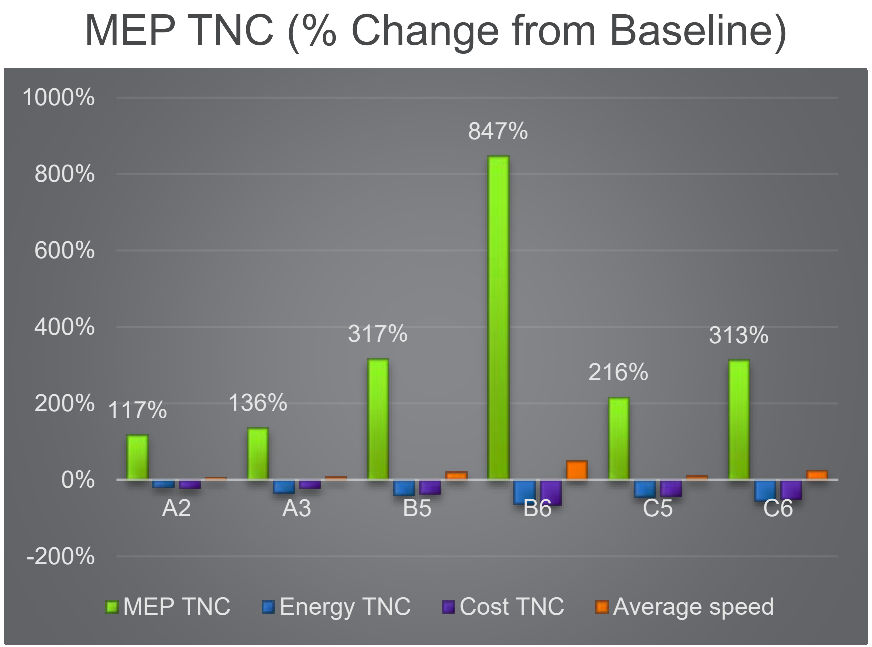
MEP Split by Mode



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Workflow Implementation using POLARIS





RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

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

The project team thanks all the reviewers for the overwhelmingly positive feedback on our work.

- Q1: Please provide more information on the quantification of energy and costs, including scope. Do costs include just user costs, or also infrastructure? Do it include life cycle costs?
  - While the project team would like to be as comprehensive as possible in considering inputs required to compute the metric, we also want to be pragmatic in making sure that we have scalable and continuous data sources to compute the metric. In that vein, we have tried to include costs that are readily accessible, citable, and continuously available. Thus, we include costs as the one 'realized' by the user (i.e., capital + operating costs for car; fare for transit; etc.). That said, we will make every effort possible to capture life-cycle costs in the future iterations of the metric.
- Q2: Multi-modal transportation does appear to be currently comprehended. Implementation of this capability is vital to understanding how MEP will change with adoption of TNCs and other disruptive technologies.
  - This is an aspect that the team has tagged as an important addition to the metric. We have made progress in capturing other modes (e-scooter–transit–walk), but additional time and resources are required to incorporate multi-modal / inter-modal trips into the metric. This proposed this to VTO as an enhancement to the existing metric.
- Q3: How MEP would change under different transportation investment or technology adoption scenarios.
  - While last year's AMR presentation could only showcase preliminary results from Chicago and San Francisco implementations of the workflow, this year's AMR presentations (this one, as well as connected presentations from ANL and LBNL) showcase MEP results for a spectrum of scenarios covering automated, electrified, and shared mobility.

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

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

The project team thanks all the reviewers for the overwhelmingly positive feedback on our work. Only questions that need a response are included here.

- Q4: Suggest that engagement of Metropolitan/Transportation Planning Organizations (MPO/TPO) would have provided better opportunities across the MEP metric discussion.
  - The research team fully agrees. Since last AMR, we have demoed the metric to MPOs and DOTs in Florida, Delaware, California, Virginia, and Canada (to name a few). We are in active discussions with several of these entities to integrate the metric into their transportation planning processes.
- Q5: Of the future research topics were proposed by the presenter, which are most important, and what are the overall impact of implementing the improvements.
  - While there are many aspects to consider in enhancing the metric, we have identified the following four as the key aspects to mature the metric. We would also like to note that we identified these enhancements based on feedback from DOE, as well as industry-, city-, and state-level stakeholders:
    - Conducting extensive research on coefficients used for time, energy, and cost
    - Incorporating multimodal trips and mode usage considerations in MEP calculation, as well as better basis for combing MEP across modes (currently simply additive)
    - Adding consideration of additional factors (e.g., emissions, safety)
    - Moving from a static MEP quantification to a (min-max) range-based quantification

  We will be sure to elaborate on the impact of working on these enhancements during the AMR presentation this year.

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

COLLABORATIONS AND COORDINATION WITH OTHER INSTITUTIONS

- SMART Mobility Consortium Laboratory Partners: LBNL, ANL, Idaho National Laboratory (INL), and Oak Ridge National Laboratory (ORNL)
- Additional Collaborations:

Collaborators	Type	Extent
American Society of Civil Engineers (ASCE)	Government	Designating MEP as a SMART City metric
Colorado DOT	Government	Plans to integrate MEP into the Statewide Travel Model
Ford	Industry	Adopt and enhance the MEP metric
Commutifi	Industry	Collaborate to integrate the MEP metric into their commute score platform
Dallas-Fort Worth International Airport	Industry	Adopt MEP in the context of airports
Delaware DOT, Florida DOT, Virginia Clean Cities Coalition, SanDiego Association of Governments	Government	In various stages of discussion to integrate the MEP metric into transportation planning processes
University of Maryland, Carnegie Mellon University, Colorado State University, University of Michigan	University	Adopting MEP in various contexts

REMAINING CHALLENGES AND BARRIERS

- Addressing concerns regarding **mode summation and mode integration**
  - While the first iteration of the metric computes a mobility potential field, methodological enhancements are required to make sure that the MEP calculations reflect modal usage in a location more realistically.

- **Standardization of MEP inputs and outputs**
  - The initial integration of the MEP metric into workflow implementations using POLARIS and BEAM revealed the need for standardizing input data formats into the metric. Also, because the MEP calculation presents results in a numeric score as well as a visual map, careful consideration is need to standardize the outputs generated from the metric.

- Research on **time, energy, and cost coefficients** in the MEP calculation

PROPOSED FUTURE RESEARCH

- Methodological enhancements
  - Conducting **extensive research on coefficients** used for time, energy, and cost
  - Incorporating **multimodal trips** and mode usage considerations in MEP calculation
  - Adding consideration of **additional factors** (e.g., emissions, safety)
  - Moving from a static MEP quantification to a (min-max) **range-based quantification**

- MEP calculations customized to **individual specific** socio-demographic and trip characteristics
  - Location-based and person-based

- Add **intercity/long-distance travel** considerations into MEP
  - Different types of modes (bus, rail, air), methods, and data sources

- Development of MEP **visualization and interaction platforms**
  - To provide modelers, VTO, and external stakeholders with an easy way to explore the impacts of specific scenarios on MEP scores

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

MEP UPDATES

- Integration of MEP code with agent-based models POLARIS and BEAM – **Accomplished!**
- Open-source MEP code development – **Beta version ready**
  - Approximately 101 cities for which MEP is computed
- MEP web application – **Beta version ➔ Production grade**
- MEP as one of the ASCE Smart City standards – **Pre-standard publication started**
- Interest in incorporating MEP in transportation planning processes
  - Colorado, Florida, Virginia, Delaware, and Canada!

SUMMARY

- **Objective**: To develop a comprehensive metric that provides a way to measure the quality of mobility, taking time, energy, and cost of modes into consideration. Such a metric will not only help quantify mobility in the current day, but will also provide an avenue to measure improvement in mobility with time and/or technological advancement.

- **FY 2019** efforts focused on:
  - Enhancing the MEP metric methodology
  - Tightly integrating with POLARIS and BEAM and developing a generic plug-in module to work with outputs from any travel demand model
  - Applying the metric to 50 metropolitan areas across the United States.

- **Future Research** aims to tackle methodological enhancements and develop complementary aspects to the current MEP metric.

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

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding was provided by the DOE Vehicle Technologies Office (VTO) under the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Laboratory Consortium, an initiative of the Energy Efficient Mobility Systems (EEMS) Program. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.
NREL/PR-5400-76572

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

Argonne NATIONAL LABORATORY · BERKELEY LAB · Idaho National Laboratory · NREL · Oak Ridge National Laboratory

TECHNICAL BACK-UP SLIDES

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: 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.

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

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

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.

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

MEP STANDALONE APPLICATION