# A Comprehensive Approach to Measure the Efficiency of Freight Transport: Freight Mobility Energy Productivity (F-MEP) Metric

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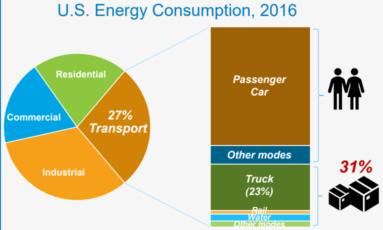
## MOTIVATION

### ❑ Current Freight Trend

U.S. Energy Consumption, 2016




Source: Transportation Energy Data Book: Edition 37.1 (Davis and Boundy, 2019)

- Small population (e.g., heavy vehicles are 5% of the registered vehicle population in the United States)
- 31% of the energy consumption in the transportation sector
- Emerging trends: electrification of power-train, automation, e-commerce, new delivery
- Travel modeling efforts to understand and forecast freight movement induced by the new trends

### ❑ Existing Freight Performance Metrics & the Need for Improvement

- Drawbacks of conventional freight metrics (e.g., truck-miles, ton-miles, or value-miles)
  - Too aggregated or unidimensional
  - Not capable of reflecting the combined effectiveness of networks
  - Little emphasis on **energy efficiency of freight transport** at system level
- Enable quantification of the changes in system efficiency with the introduction of these technologies

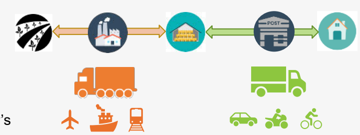
### ❑ Research Objective: Development of Freight Mobility Energy Productivity (F-MEP) Metric

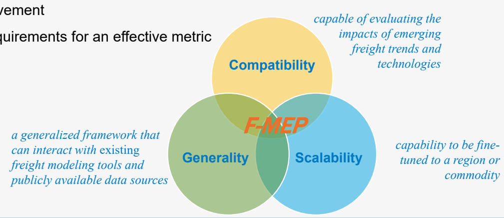
- Designed to **combine multiple dimensions (e.g., energy, cost, and time)** of freight performance into a single metric
- Focus on **between-city** freight movement
- Used as a planning or scenario analysis **tool for quantifying impacts of emerging technologies** on freight mobility

## METHODOLOGY

### ❑ Theoretical Background

- Accessibility theory: ease with which activities can be reached from a given place, using a given mode of transport
- Freight efficiency viewed from a shipper's perspective
- Fundamentally distinct characteristics between within, and between-city freight movement
- Requirements for an effective metric

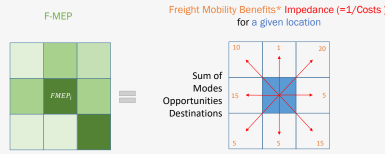



### ❑ Specification

- F-MEP of a location quantifies the efficacy of transporting a maximum amount of goods from a location to any other locations that have freight attractions; weights the efficacy by expenditure of time, money, and energy required to transport goods
- Formulation

$$FMEP_i = \sum_k \sum_c \sum_{j \neq i} B_{cj}(X)\, f^k_{c,ij}(Y)$$




$$f^k_{c,ij} = \exp(\alpha e_k + \beta p_k) \cdot r^{l_{ij}}_{ck} \cdot s_{ik}$$

*unit energy intensity ($/ton-mile)* ($e_k$); *weight fraction related to travel time (or distance)* ($r^{l_{ij}}_{ck}$); *unit logistics costs ($/ton-mile)* ($p_k$); *ease of shipping goods* ($s_{ik}$)

| | |
|---|---|
| $k$ | *mode* |
| α, β | *weighting factors <0* |

## IMPLEMENTATION

### ❑ Study Domain

- Mainland U.S. with FAF (Freight Analysis Framework) zonal structure
- Four modes for between-city freight: truck, rail, water, air

### ❑ Input Variables

- *Freight mobility benefit,* $B_{cj}(X)$: tonnage by commodity obtained from FAF data
- *Unit energy intensity,* $e_k$: estimates by mode using Transportation Energy Book
- *Unit logistics cost,* $p_k$: estimates by mode using the 2016 U.S. business logistics costs
- *Ease of shipping goods* ($s_{ik}$): estimates by mode based on number of facilities related to a specific mode obtained from the Bureau of Transportation Statistics)

$$s_{ik} = \begin{cases} 1 & \text{if } k = truck \\ \dfrac{n_{ik}}{\max(n_{jk}, \forall j)} & Otherwise \end{cases}$$

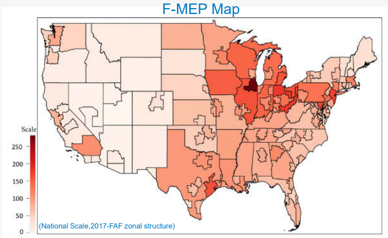
- *Weight fraction* $\left(r^{l_{ij}}_{ck}\right)$: obtained from FAF data with distance bins defined by FAF

## GENERALIZATION & SCALABILITY

### ❑ Ease of Application

- Input variables can be easily obtained from a freight model

F-MEP Map

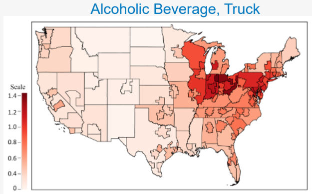



- Results are consistent with expectation: zones with high F-MEP
  - Are in the central United States and have relatively short distances to all other zones
  - Have good accessibility to all transportation modes, including ports
  - Are close to large freight demand markets in the Northeast
  - Are located near manufacturing centers that realize high shipping benefits.

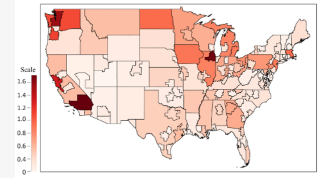
### ❑ Scalability

- Used to examine heterogeneity in opportunities (commodities) and modes
- Can be disaggregated to a single mode, a single commodity, or a single mode-commodity combination

Alcoholic Beverage, Truck



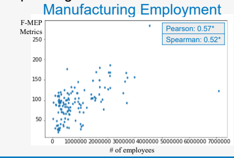

Electronics, Rail




## PROOF OF CONCEPT

- No similar metric accounts for time, energy, cost, and easy of shipping together: select freight-related employment as an indicator for freight mobility/productivity
- Correlation analysis between F-MEP scores and sector-specific employment for the corresponding zones.

Manufacturing Employment

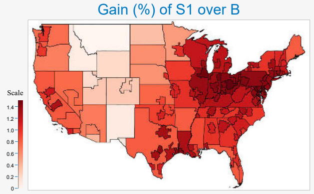



Logistics Employment

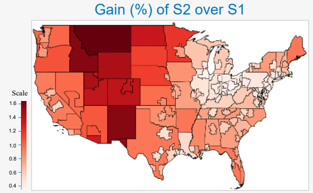

## COMPATIBILITY

- Demonstrates the capability of evaluating the impact of emerging technologies through hypothetical scenario analysis
- Long-haul truck electrification scenarios
  - B – Conventional truck with $e_{truck} = 0.0734$ \$/ton-mile
  - S1- Electrification of the powertrains with range constraints:
    - $e_{truck} = 0.0245$ \$/ton-mile for $l_{ij} \leq 500\ miles$
    - $e_{truck} = 0.0734$ \$/ton-mile for $l_{ij} > 500\ miles$
  - S2-Electrification of the powertrains without range constraints:
    - $e_{truck} = 0.0245$ \$/ton-mile for all $l_{ij}$

Gain (%) of S1 over B

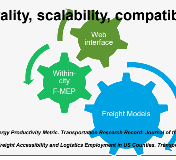



Gain (%) of S2 over S1




## CONCLUSION

- Develop a practical and holistic **metric for quantifying the performance of freight systems** from the shipper's perspective
- Show that the F-MEP meets the requirements (**generality, scalability, compatibility**)
- Future research
  - Interactive web-based visualization tool
  - Integration with freight demand modeling tools
  - Development of within-city F-MEP




***Key References***

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