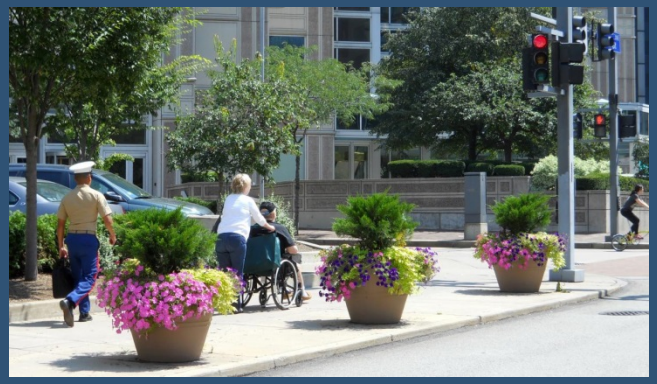
Charging Station Network Design for Electrified Vehicles in Urban Communities: *Reducing Congestion, Emissions, Improving Accessibility, and Promoting Walking, Bicycling, and use of Public Transportation*



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Wayne State University

Motivation

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- **Promise** of Electric Vehicles (EV):
  - **Diversification** of the transportation **energy feedstock**
  - **Reduction of greenhouse gas** and other emissions
  - Improving public health by improving **local air quality**

- **Direct and indirect policy incentives** for EV market share growth:
  - **Public charger availability** is an indirect policy incentive
    - **The most strongly related variable** among several socio-economic ones **to EV adoption** (Sierzchula et al., 2014)

- **Key decisions** for EV charging network infrastructure:
  - Number and location of charging service stations
  - Type of charging stations

Uncertainties and Data Analysis …

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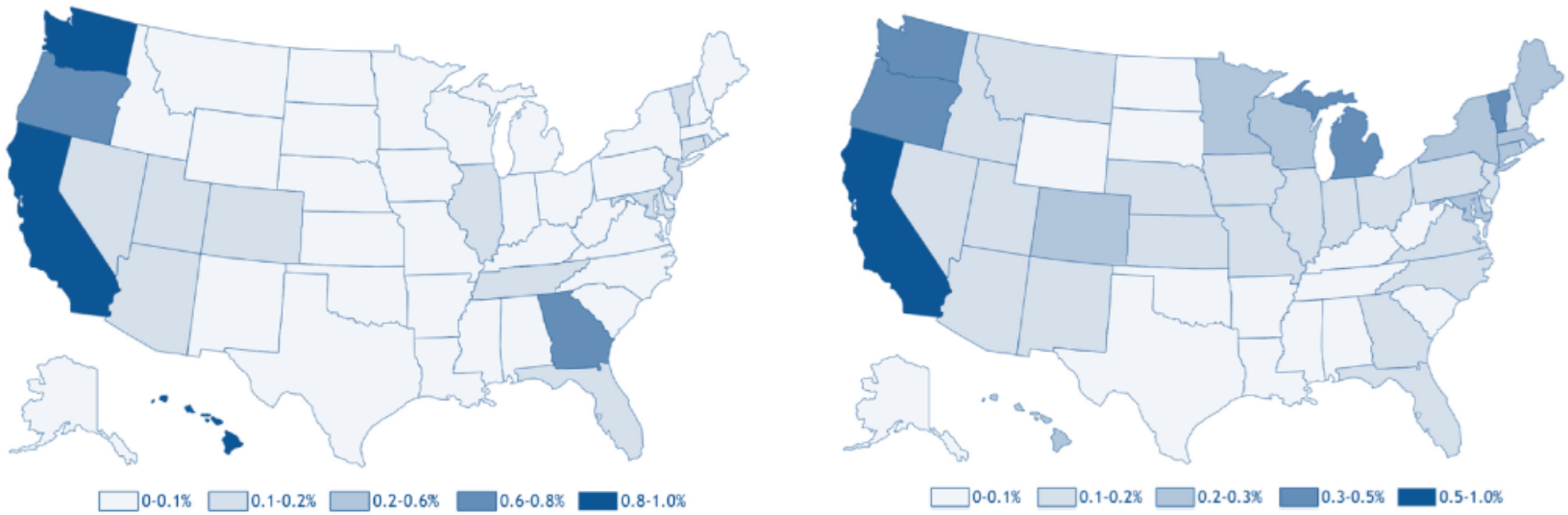

Cumulative 2010-2014 BEV market share (left) and PHEV market share (right) across the U.S.

Source: Vergis, S., Chen, B., 2015. Comparison of plug-in electric vehicle adoption in the United States: A state by state approach.

- US DoT:
  - **Share of vehicles** needing charging can reach **5%**
    - PHEV share would be ~ 2% and BEV ~ 3%
  - **3.5% of fleet** projected to be **full EV or PHEV** by 2022-2025
    - California Zero Emission Vehicles (ZEV) program considered in reference case
    - Adoption of ZEV program by nine additional states

Phase I Framework

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OD Pairs based on Household Survey

Driver Behavioral Characteristics

Distribution of final destination of drivers

Estimation of potential arrival pattern for parking locations (NHTS) and final destinations

Willingness to charge away from home and walking distance preference

Estimation of dwell time / required hours of charge

Uncertainty

Operational Constraints

Pass thru / community traffic and limited parking capacity

Stochastic Mathematical Model

Optimal locations and size of charging stations, and estimation of impact on livability metrics

Maximizes accessibility to public EV charging service!

Problem Description

Model for EV Charging Station Network Design

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- **Research Gap:**
  - Focus on large-scale state-wide networks and not on urban areas
  - Deterministic charging demand
    - Demand is quite stochastic in reality (varying by hour of day, weekday/weekend patterns, commute purpose, destination, etc)

- **Research Goal:**
  - Develop a **stochastic programming** approach to determine **location, type of chargers and capacity** of charging stations
    - Assess **community livability metrics**
      - Accessibility to charging service
      - Charging station utilization rate
      - Walkability
    - Account for **behaviors of EV drivers**
      - Willingness to walk
      - Willingness to pay
      - Willingness to use public charging stations

Assumptions:
- Public parking facilities
- Vehicle parking location
- Vehicle charging time

Computational Study: Case Study – Phase 1

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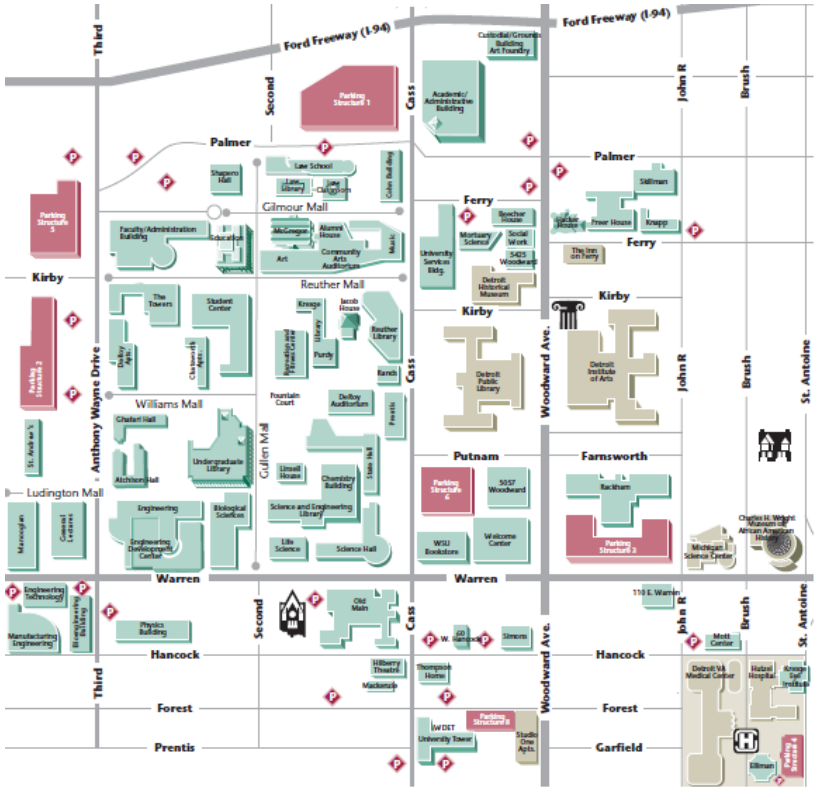
- **Setting**: Part of **Detroit Midtown**
  - Wide range of **employment types** (type of final destination) in this area
    - University faculties
    - Offices
    - Hospitals
    - Museums
  - Attracts a lot of traffic
  - 32 **parking lots** as potential locations for installing charging stations



- **EV Market Share:** Two Cases
  - **Conservative:** (1%,2%) for (BEV,PHEV)
  - **Optimistic:** (2%,3%) for (BEV,PHEV)

Contribution – Phase 1

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- **Designing Community-Aware Charging Networks for EVs**
  - **Two-stage SP** model to determine **location** and **capacity** of public EV charging stations for communities to maximize access
  - Incorporation of **uncertainties** (EV demand flows, EV drivers' charging patterns, arrival and departure time, purpose of arrival to a community, walking preferences)
  - Adoption of **SAA** to solve two-stage model
  - Effective **heuristic** for **large-scale instances**
  - **Case study** (Detroit midtown area) and post-analysis framework
- **Designing Community-Aware Charging Networks for EVs**
  - **Exploration and Integration:** Called for data from several different sources to generate meaningful formulation and scenarios
  - Model presented to **SEMCOG**
  - **Computational Complexity:** Several hours for large scenario set
- **Presentations**
  - Manuscript was accepted in **IEEE Transactions on Intelligent Transportation Systems** (April 2018)
  - Presented:
    - INFORMS National Meeting, 2016

Computational Study: Insights

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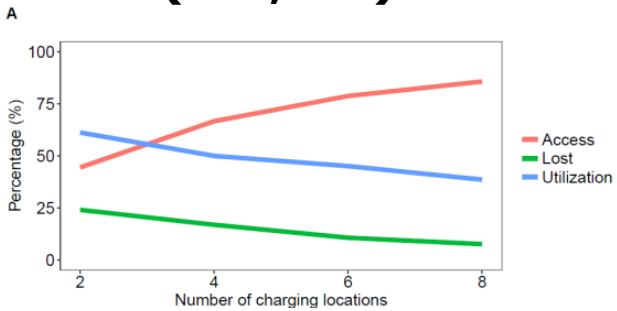
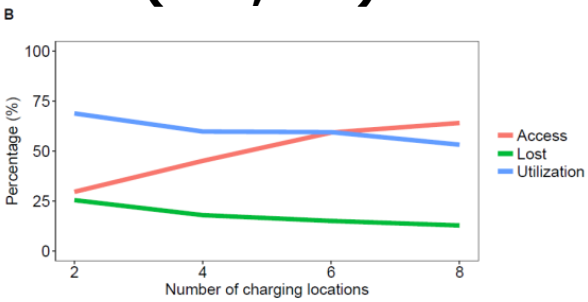
Percentage of accessibility, lost demand and charging utilization in A) (1%,2%) and B) (2%,3%) market shares.

(1%,2%)

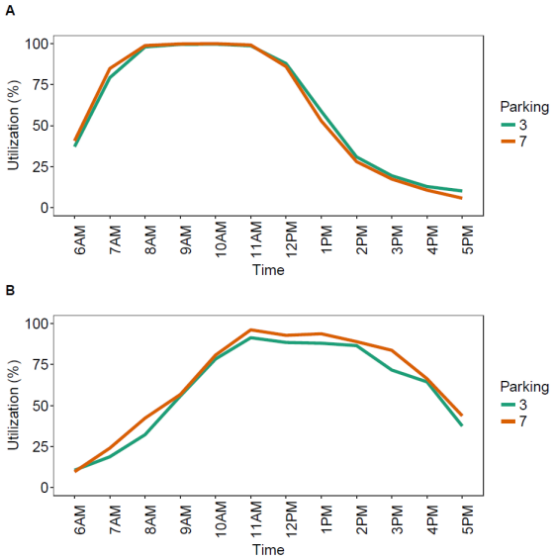


(2%,3%)

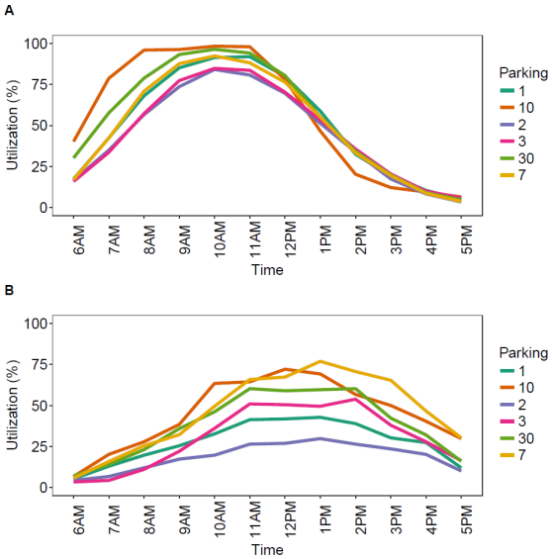


Average hourly utilization in A) weekdays and B) weekends in an optimistic case when p=2, left, and p=6, right.

p =2 locations



p =6 locations



Outline for Phase II

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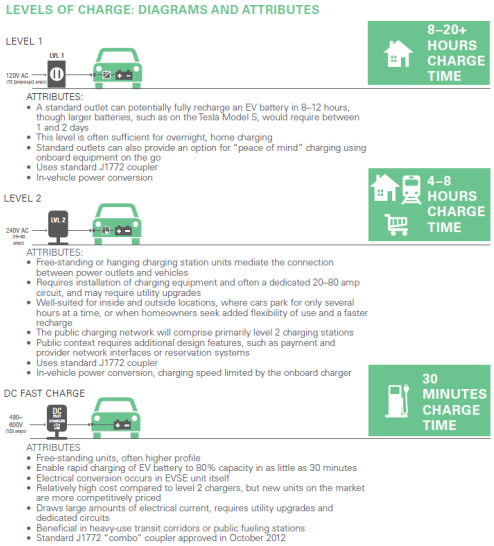
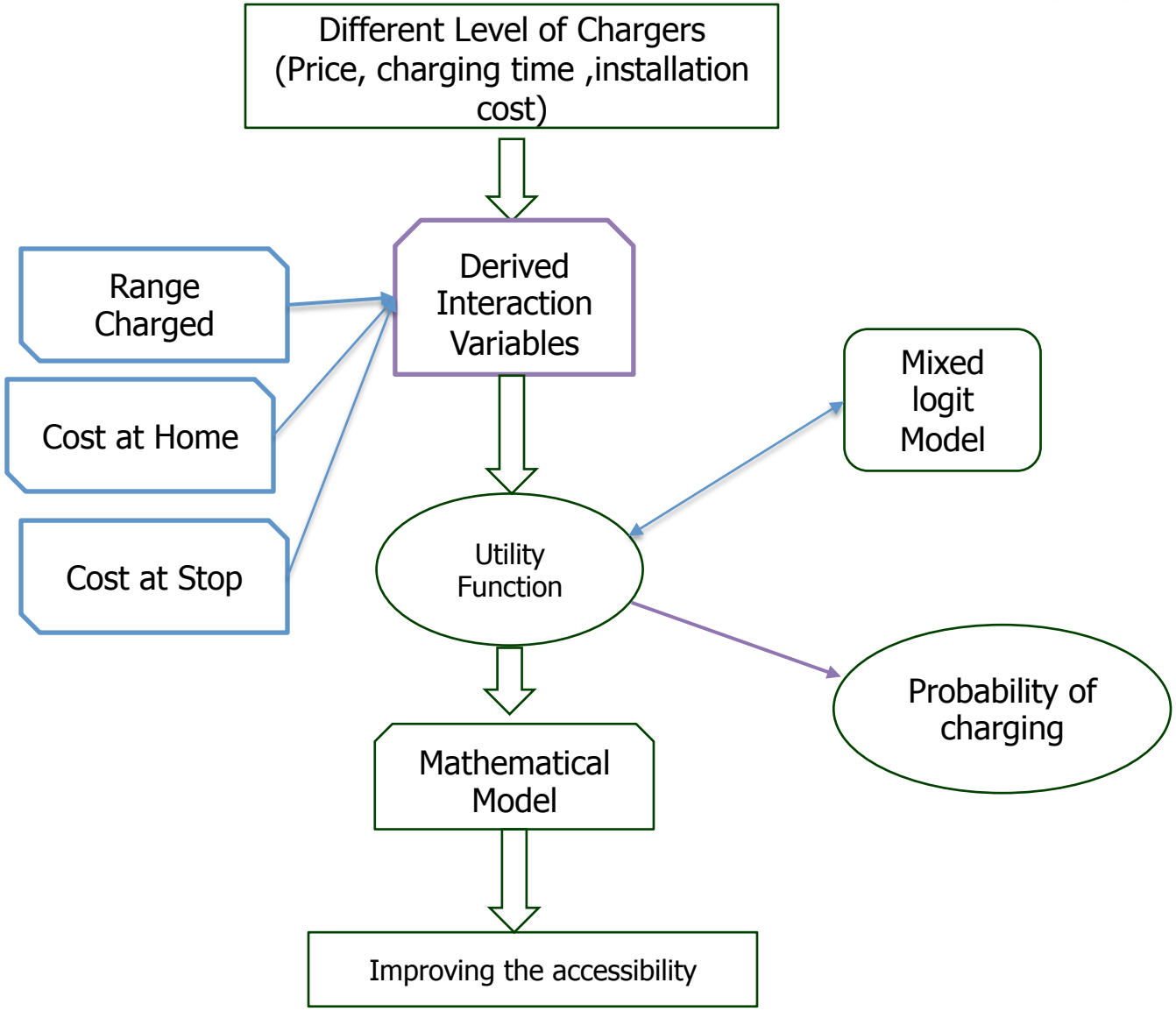
- Choice Modelling for Charger Types
  - Choice modeling approach captures the charging patterns for EV users and will lead to:
    - Accelerating the *adoption* of EVs
    - Better distribution of *budget* to charging infrastructures
    - Increasing the *mobility, accessibility*



- Multi-Modal Transportation for EV Network Design
  - Adding transportation modes (walking, Bicycling, Bus,…) to a network
  - Linking transportation networks
    - Link type
    - Node type

Choice Modelling - Framework



Utility Function – Choice Modelling

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- *Wen et al. (2015)* analyzed the charging choices of BEV owners based on a web-based survey in different parts of U.S.

- The choice model computes the volume flowing from demand sources to selected locations, requires to know EV driver preference data, namely the **utility** of drivers.

$$P(Charge) = e^{U_{it}} / \sum e^{U_{it}}$$

Where U_{it} is the utility of charging for respondent i under charging situation t

- The Choice decision was characterized by the following factors*: Charging price, maximum charging power, dwell time , distance to home, current electric range.*

- A **Mixed Logit Choice Model** was used to estimate those factors

Solution Approach

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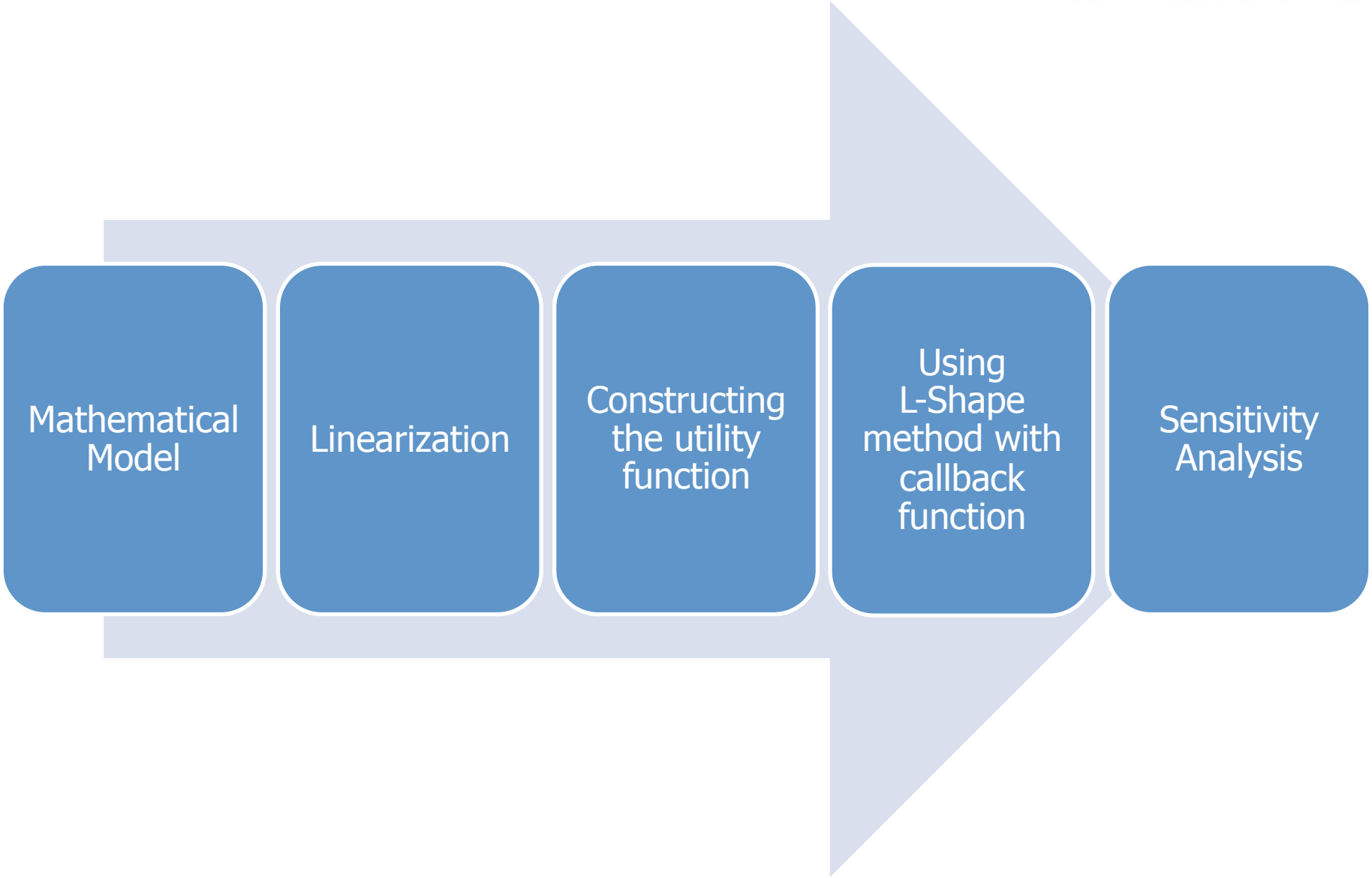

Solution Approach: Notation

- **Sets**

J: *Set of parking lots, indexed by* $j \in J$

$J\uparrow*$ (j): Set of parking lots in a specific distance from parking lot $j \in J$

T: Set of time slots $t \in T$

N: Set of charging types $n \in N$

A: Set of all activity types, indexed by $a \in A$ Γ:Set of arrival and departure times, indexed by $\gamma(t) \in \Gamma$ containing time slot $t \in T$

- **Fixed Model Parameters**

mber of **candidate locations** for installing charging stations

Ω:Set of scenarios

l_j :Capacity of charging stations j

- **Scenario Dependent Parameters**

$d_{\gamma(t),j,a}(\omega)$:**Demand** with arrival and departure time of $\gamma(t) \in \Gamma$ for a given $t \in T$ for ***activity*** *type* ***a*** that are **willing to park** their vehicle in **location** $j \in J$, in a **scenario** $\omega \in \Omega$

- **First-Stage Decision Variables**

x_j :1 if **location** $j \in J$ is selected for installing charging stations.

$z_{n,j}$: *Number of charging type n in location j*

- **Second-Stage Decision Variables**

$y_{\gamma(t),n,j}(\omega)$:Proportion of demand with arrival and departure time of $\gamma(t) \in \Gamma$ for a given $t \in T$ *of charging typen from drivers who are willing to charge their vehicle in parking lot j* in scenario $\omega \in \Omega$

Solution Approach: Model (use choice model)

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- **First-Stage Model**

$$Max\ f(x,z)=E[\varphi(x,z,\omega)]$$

p locations for installing charging stations:

$$\sum_{j\in J} x_j \le p$$

Charging capacity in each location:

$$\sum_{n\in N} z_{n,j} \le k_j x_j \quad \forall j\in J$$

Feasible set for the binary first-stage variables:

$$x_j \in \{0,1\}, z_{n,j} \in \mathbb{Z}, \forall j\in J, n\in N$$

- **Second-Stage Model**

$$\varphi(x,z,\omega)=Max \sum_{t\in T,\gamma(t)\in\Gamma,j\in J,n\in N,a\in A} y_{\gamma(t),n,j}(\omega) * d_{\gamma(}$$

Supply-demand balance:

$$\sum_{\gamma(t)\in\Gamma,n\in N,a\in A} y_{\gamma(t),n,j}(\omega) * d_{\gamma(t),j,a}(\omega) \le z_{n,j} \quad \forall j$$

Choice modeling constraint

$$y_{\gamma(t),n,j}(\omega) \le e_u y_{\gamma(t),n,a} \quad z_{n,j} / \sum_{j\in J,n\in N} e_u$$
$$y_{\gamma(t),n,a} \quad z_{n,j} \quad , t\in T, \gamma(t)\in\Gamma, j\in J, a\in A, n\in N$$

Demand assignment to parking lots:

$$\sum_{j\in J} y_{\gamma(t),n,j}(\omega) \le 1 \quad t\in T, \gamma(t)\in\Gamma, a\in A, n\in N$$

$$y_{\gamma(t),n,j}(\omega) \ge 0 \quad \forall \gamma(t)\in\Gamma, j\in J, t\in T, n\in N$$

Preliminary Results

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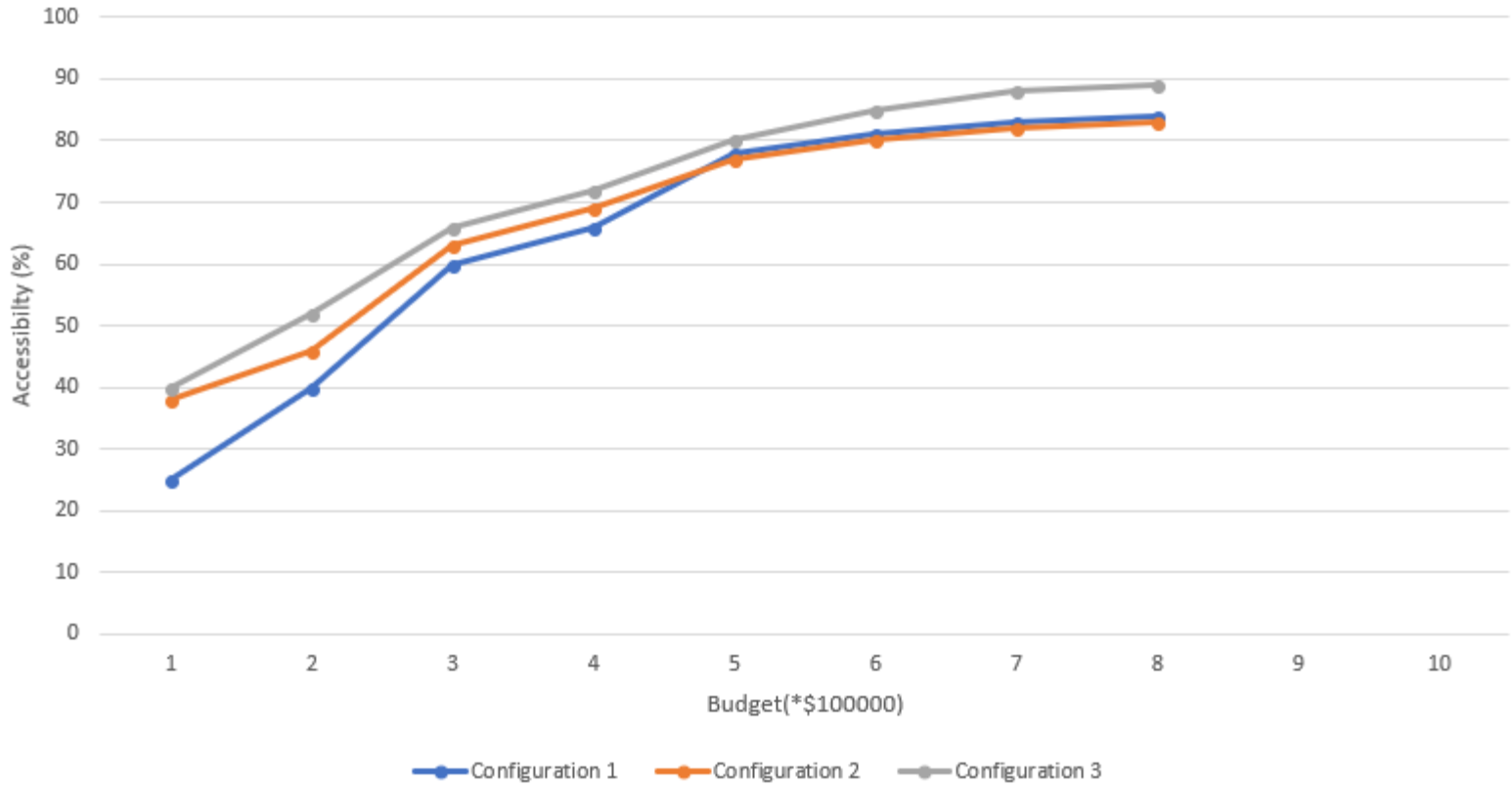
Configuration 1: only level 3 charger

Configuration 2: only level 2 charger

Configuration 3: All three levels of chargers



Outline for Phase II

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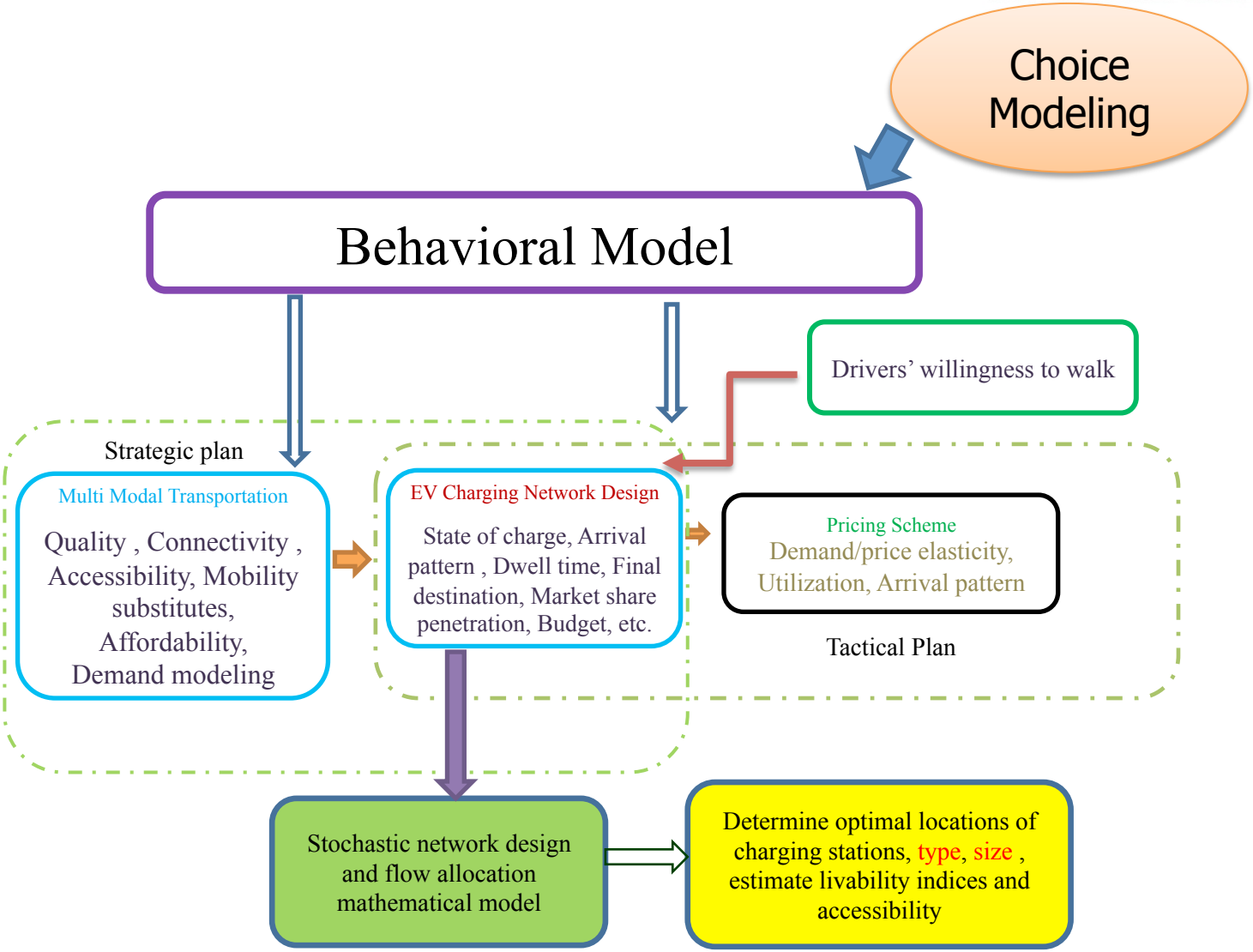
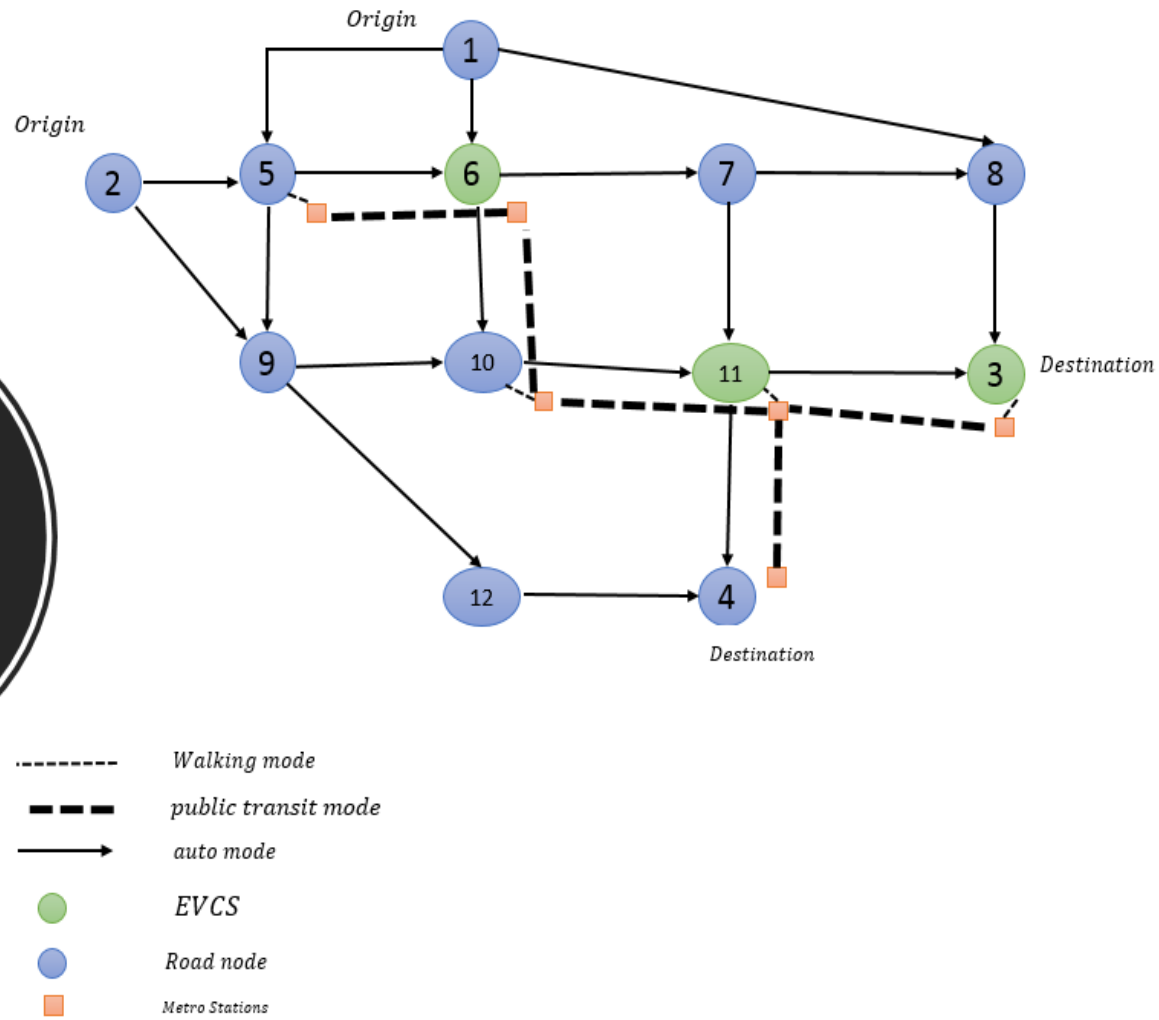
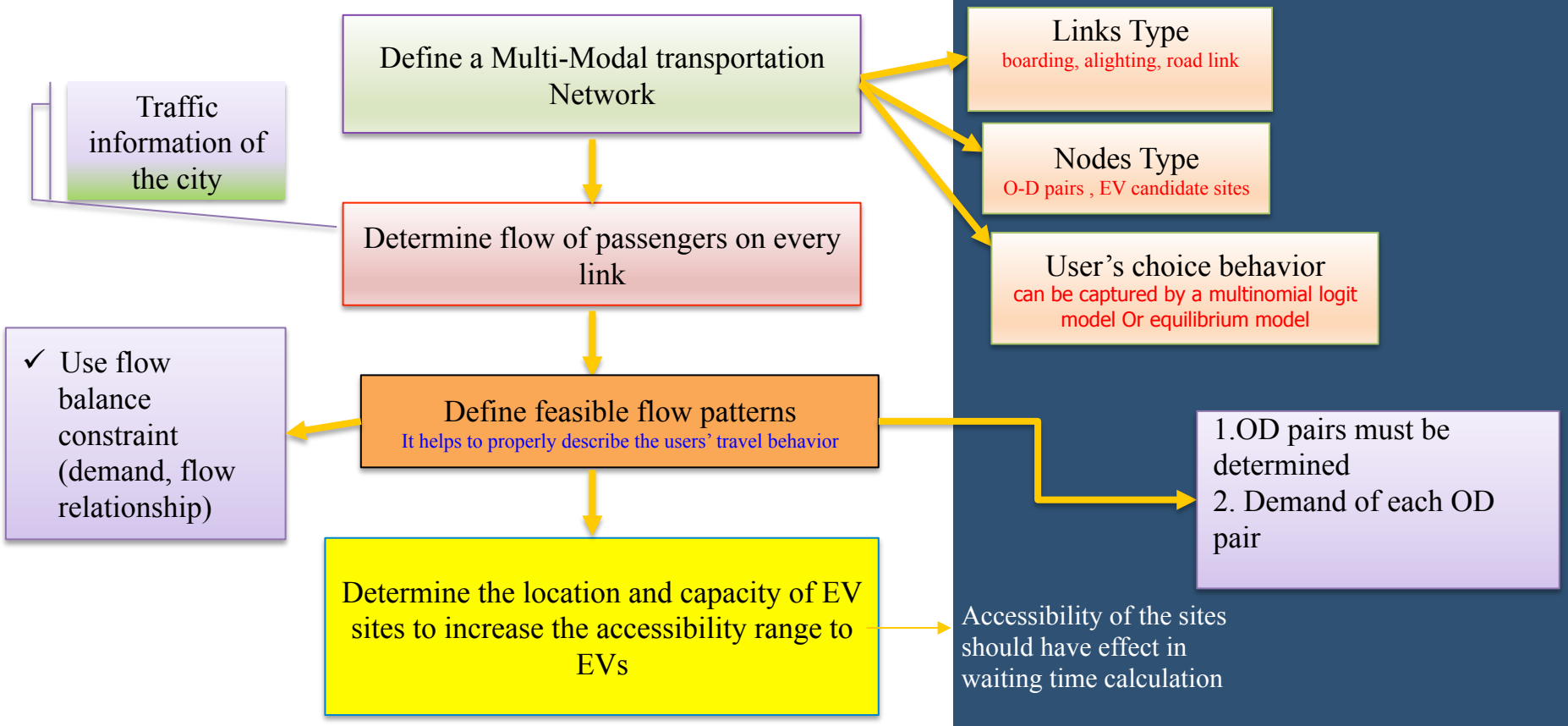


Multi-Modal Network

An example of multimodal transportation network.



Framework for designing a Multimodal Network



Data Sources

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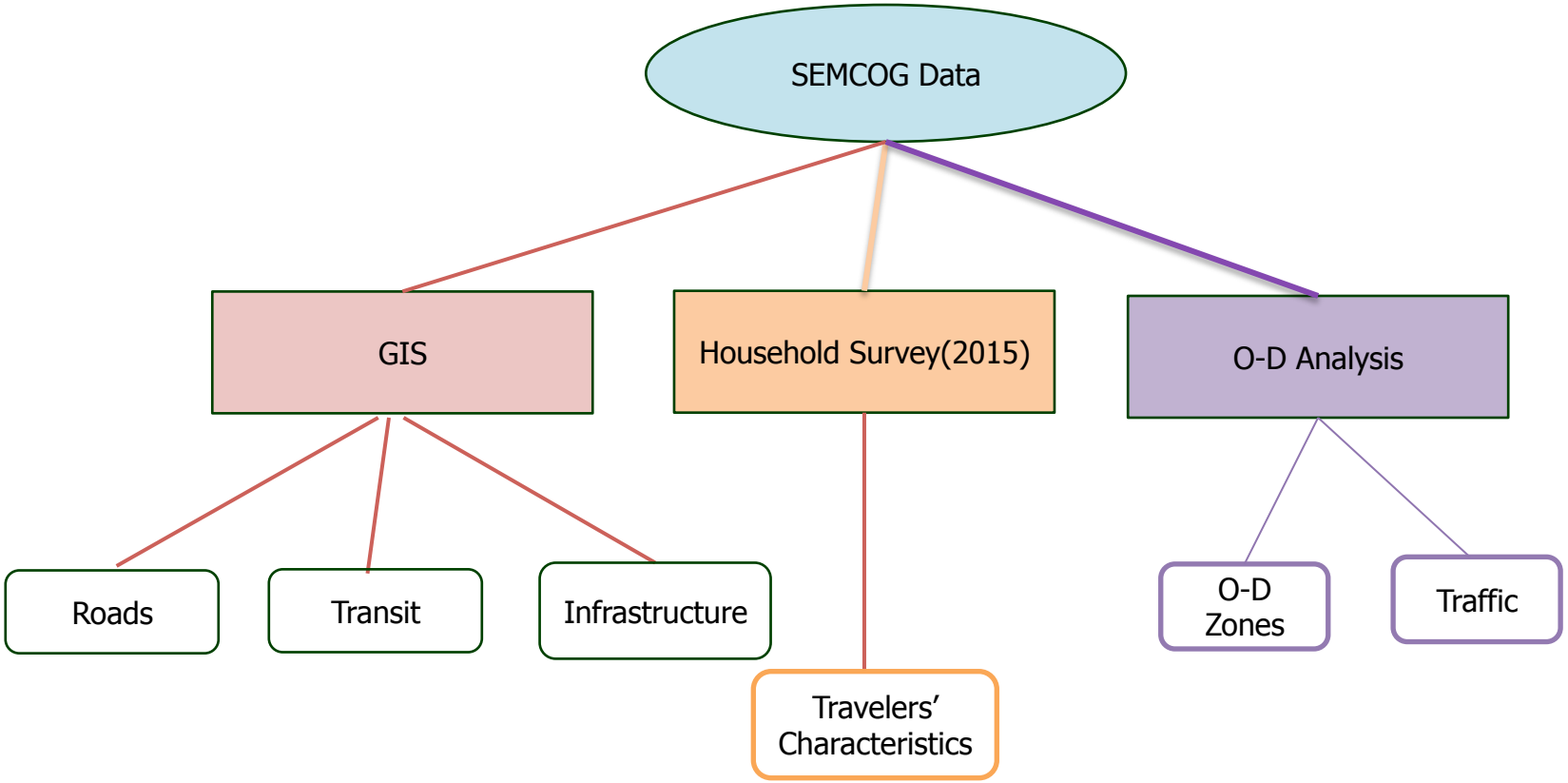
- SEMCOG supports coordinated, local planning with technical, data, and intergovernmental resources.
- SEMCOG's plans improve the quality of the region's environmental resources, make the transportation system safer and more efficient, revitalize communities, and encourage economic development.



Expected Outcomes

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- A modeling framework for planning agencies to design network for EV charging stations based on consideration of randomness in OD demand, walking range, arrival pattern, SOC, accessibility, multi-modal transportation.

- Interdisciplinary behavioral study on the drivers' willingness to walk and adoption of multi-modal transportation based on the quality, accessibility and proximity to EV charging station.

- Case study for a community with the guidance of a planning agency such as the SEMCOG. Documentation and reports on results of the study and details on the integration of the tool.

Thank You!