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Flow Through Tensor: A Computational Graph Framework for Rewriting Transportation Planning Models with AI

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ASU Trans+AI Lab

Agenda

- Why a New Framework?
- Transportation Network Modeling
- Traffic System State Estimation
- Tensor Thinking for Transportation Planning
- Acknowledgements

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Why a New Framework?

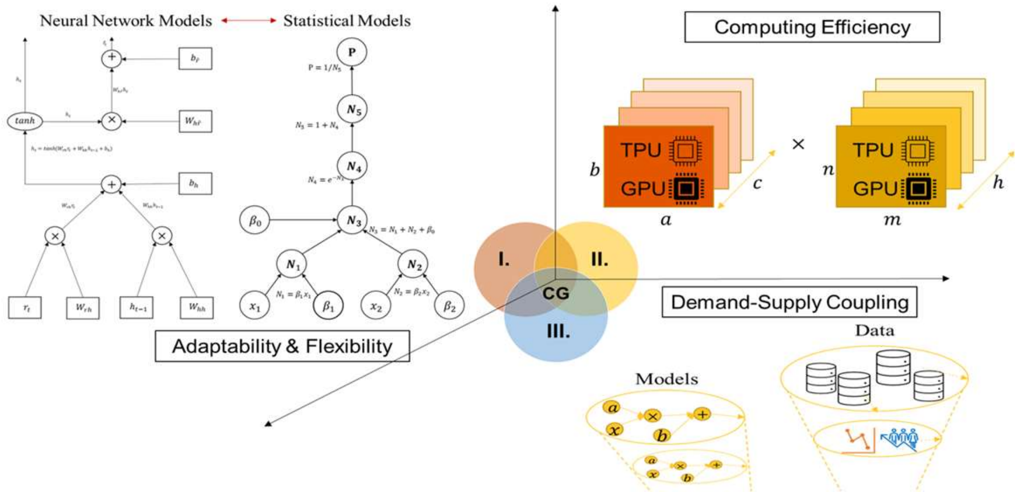
Why a New Framework?

1. **Data Explosion**

   Detectors, GPS, smartcards, connected vehicles, and large-scale surveys.

2. **Computing & Machine Learning Power**

   Modern GPUs, parallel computing, and AI techniques enable new modeling approaches.



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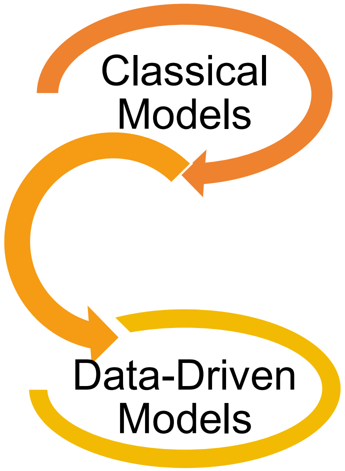
Why a New Framework?

3. New Models & Strategies

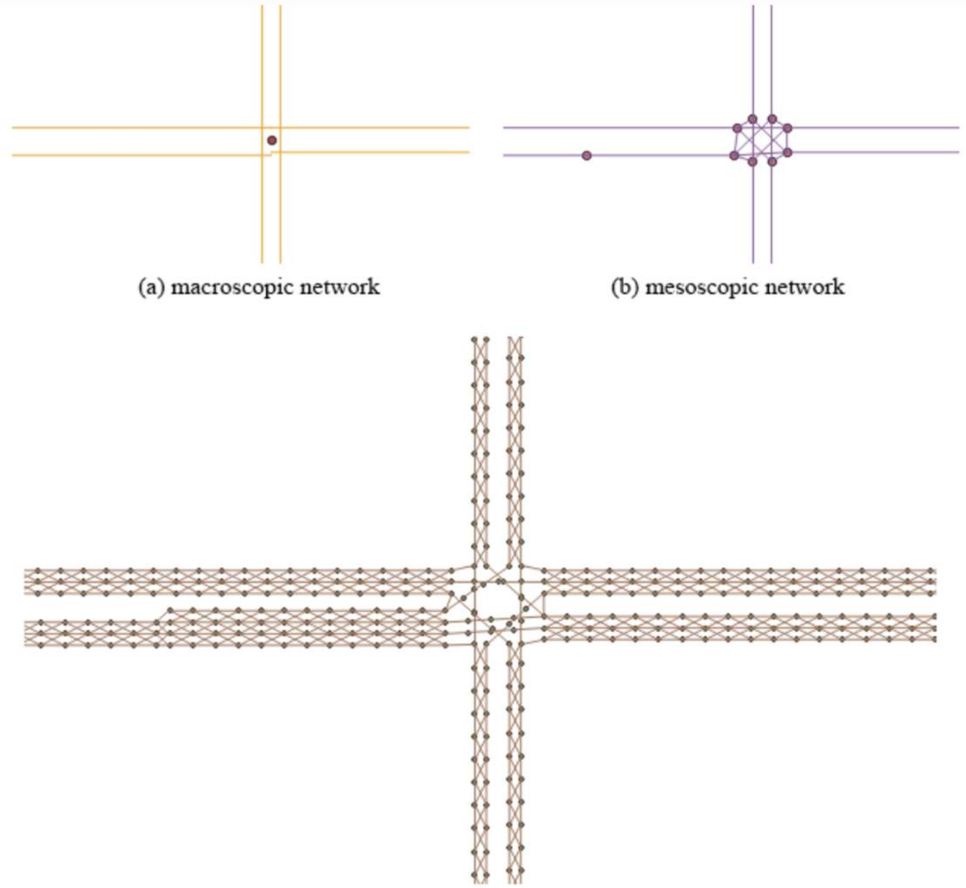
- Traditional analytical models vs. New data-driven frameworks.
- From simple trip-based methods → activity-based and tour-based → toward graph- and tensor-based extensions.



Why a New Framework?

4. Integration Challenge

- Macro vs. Meso vs. Micro levels.
- Existing models don't link across levels → need a new framework.
- Scalable, data-driven systems are required to unify models and leverage diverse data effectively.



Multi-resolution network representation

Source: ASU Trans+AI Lab

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Flow-through tensors: A unified computational graph architecture for multi-layer transportation network optimization

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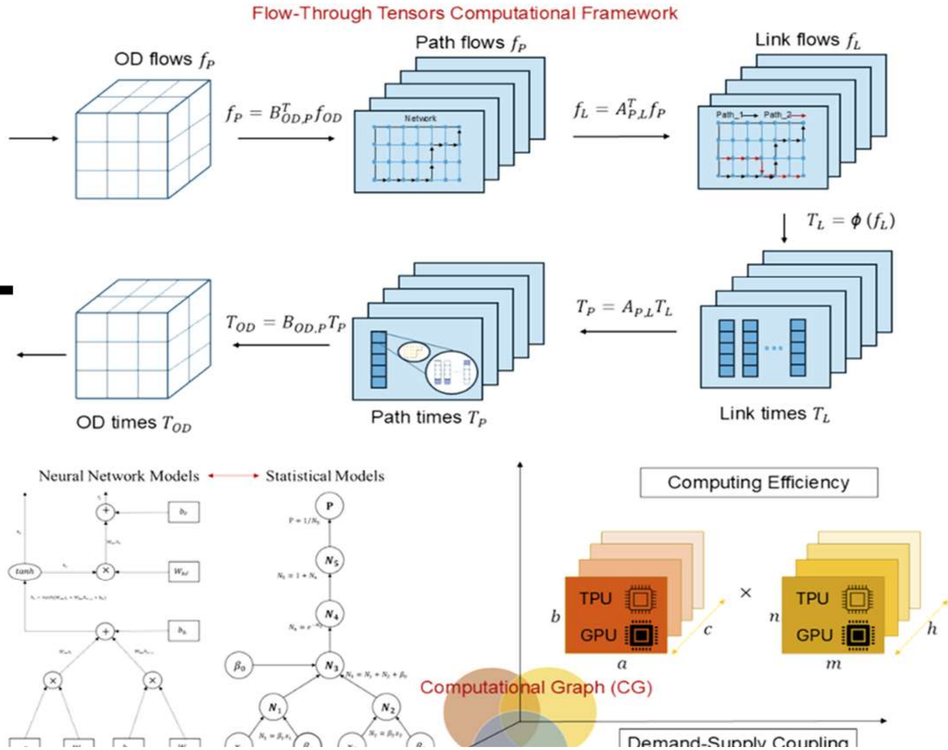
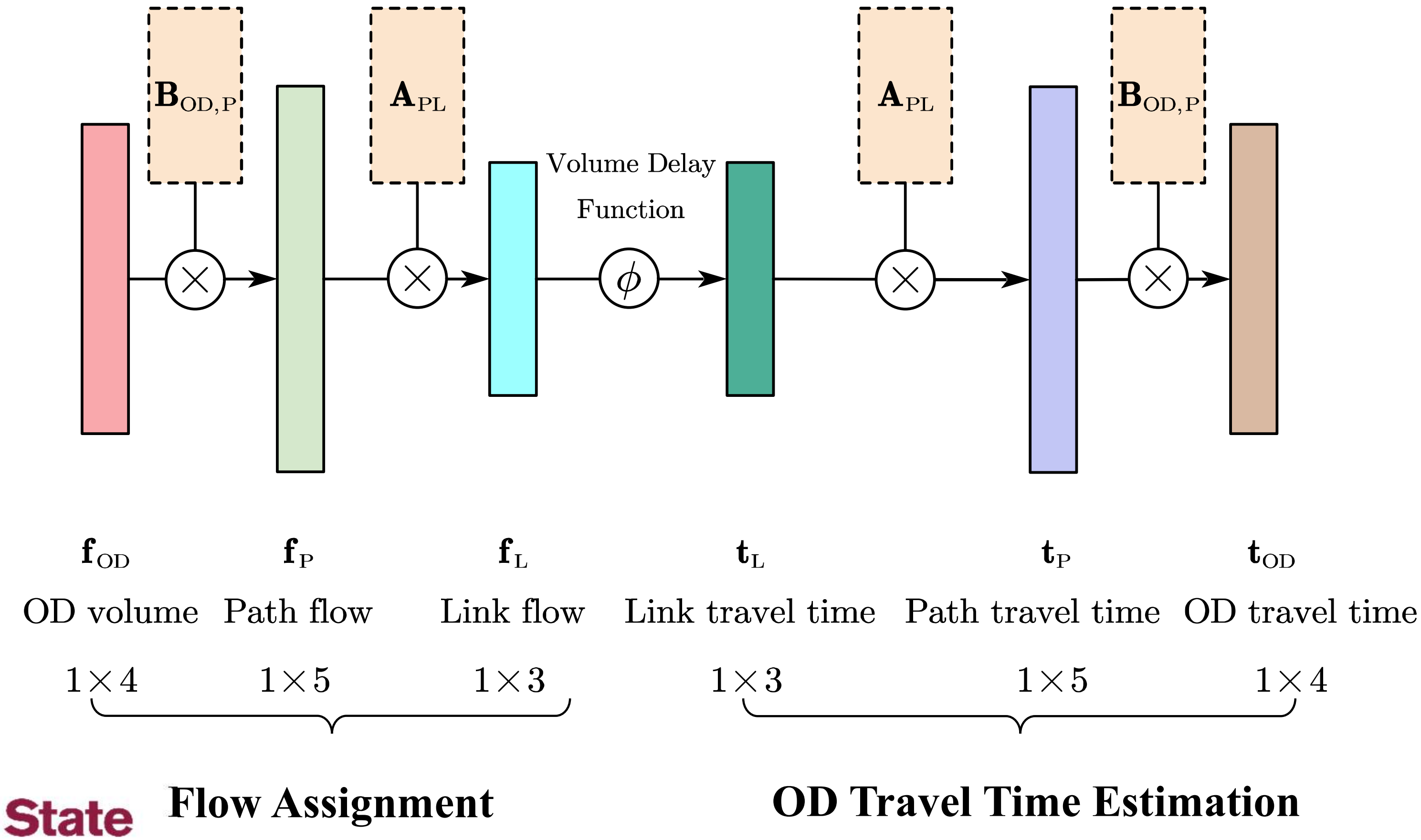


Flow-Through-Tensor (FTT) framework, a data-driven, end-to-end optimization architecture designed for complex transportation systems.

Scan for full paper

Zhou, X. (Simon), Kim, T., Ameli, M., Zhu, H. (Bety), Honma, Y., & Pendyala, R. M. (2025). Flow-through tensors: A unified computational graph architecture for multi-layer transportation network optimization. Artificial Intelligence for Transportation, 1, 100006. https://doi.org/10.1016/j.ait.2025.100006

Preview of Tensor-Based Representation of Flows



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Transportation Network Modeling

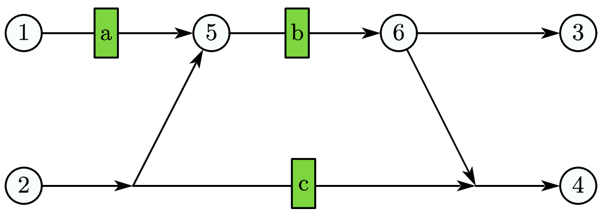
Transportation Network Modeling: FTT and Traffic Assignment

Mapping Matrices and Vectors

Matrix $\mathrm{A_{PL}} = \{\mathrm{a_{pl}}\}$

Vector $\mathrm{f_P} = (\cdots, f_p, \cdots)^{\mathrm{T}}$

Entry $\mathrm{a_{pl}}$ – value of path p and link l



OD pairs: (1,3), (1,4), (2,3), (2,4)

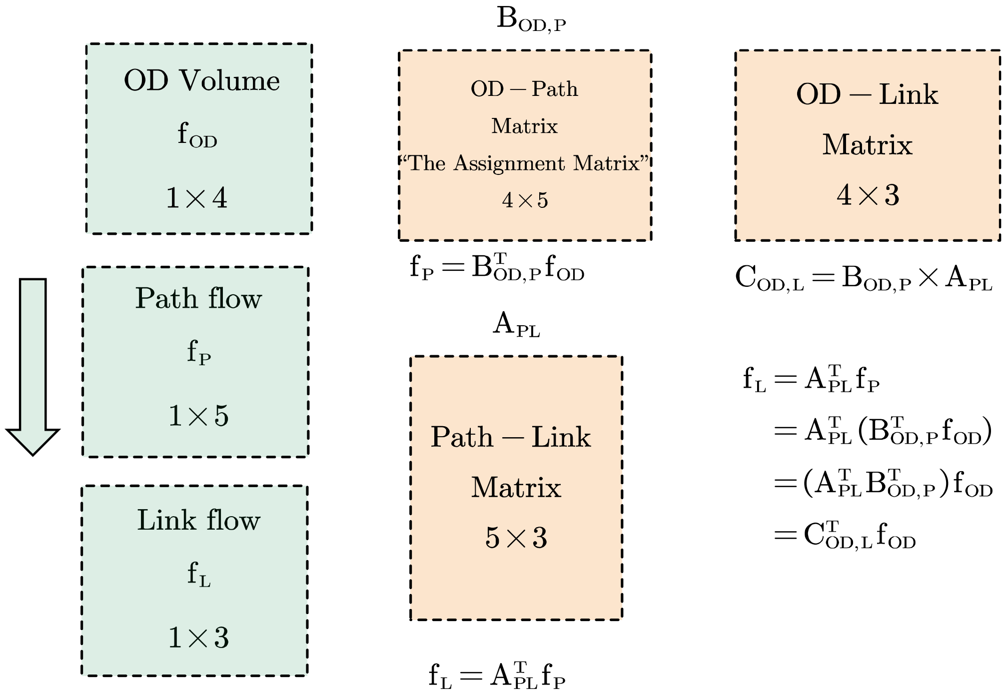
Links: a, b, c (other links are ignored)

Paths:

Path	OD	Traversed Nodes
P_1	(1,3)	1-5-6-3
P_2	(1,4)	1-5-6-4
P_3	(2,3)	2-5-6-3
P_4	(2,4)	2-5-6-4
P_5	(2,4)	2-4

Traffic Assignment

This example demonstrates how to integrate origin-destination (OD) matrices, path flows, and link flows using tensors to complete the traffic assignment task.



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Transportation Network Modeling: FTT and Route Choice

Route Choice

CG representation of choice model

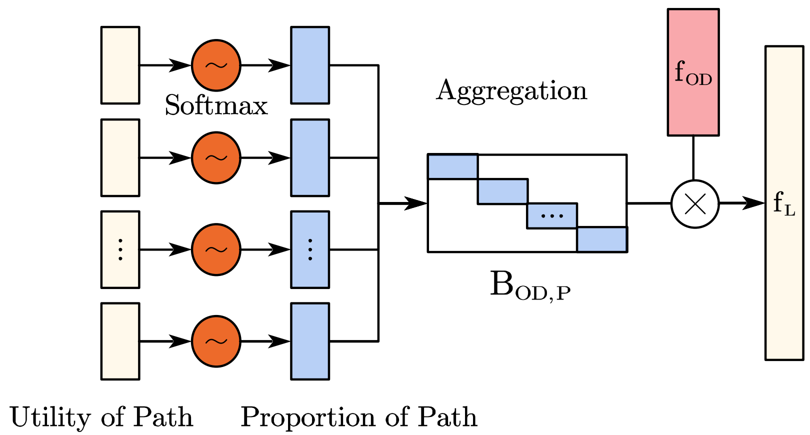
Calculate OD-path choice probability based on the Logit model

$$a_{od,p} = \frac{e^{\frac{1}{\mu} v_{od,p}(\beta, t_p)}}{\sum_{p' \in P_{od}} e^{\frac{1}{\mu} v_{od,p'}(\beta, t_{p'})}}$$

$v_{od,p}(\beta, t_p)$ the utility that a traveler of OD pair w will choose path p.

β the pre-carlibrated parameter vector that represents the traveler preference.

t_p the travel time of path p, a function of f_l with the consideration of the congestion effect.

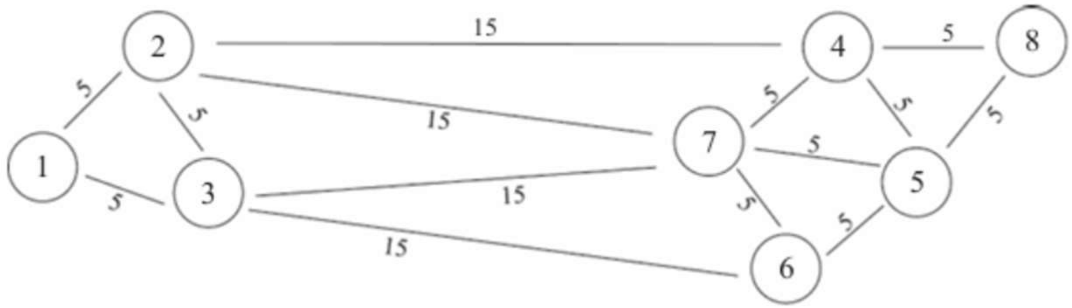


Source: ASU Trans+AI Lab

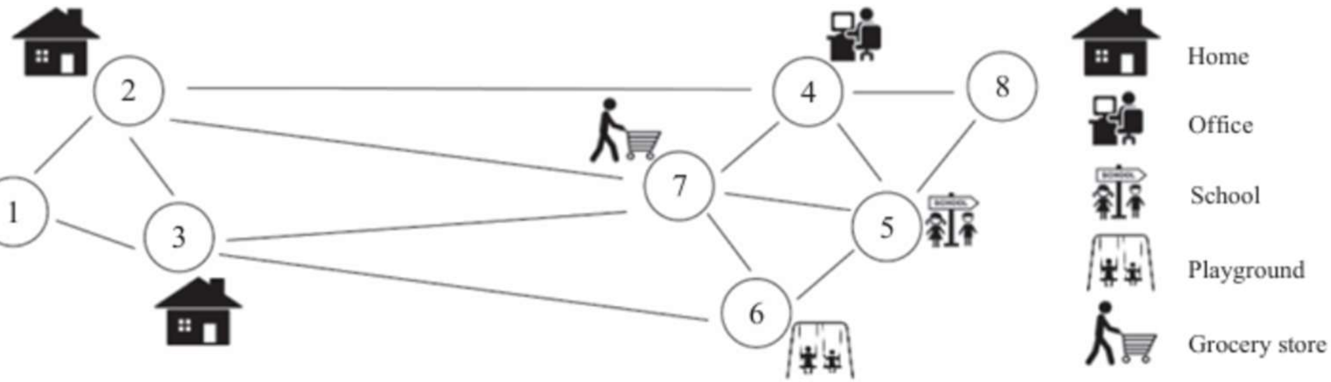
Integrated into FTT

- The logit model is a widely used choice model for travelers' behavior. In existing research, it is often embedded within optimization models.
- FTT also supports the embedding of the logit model.

Transportation Network Modeling: FTT and Tour-Based Modeling



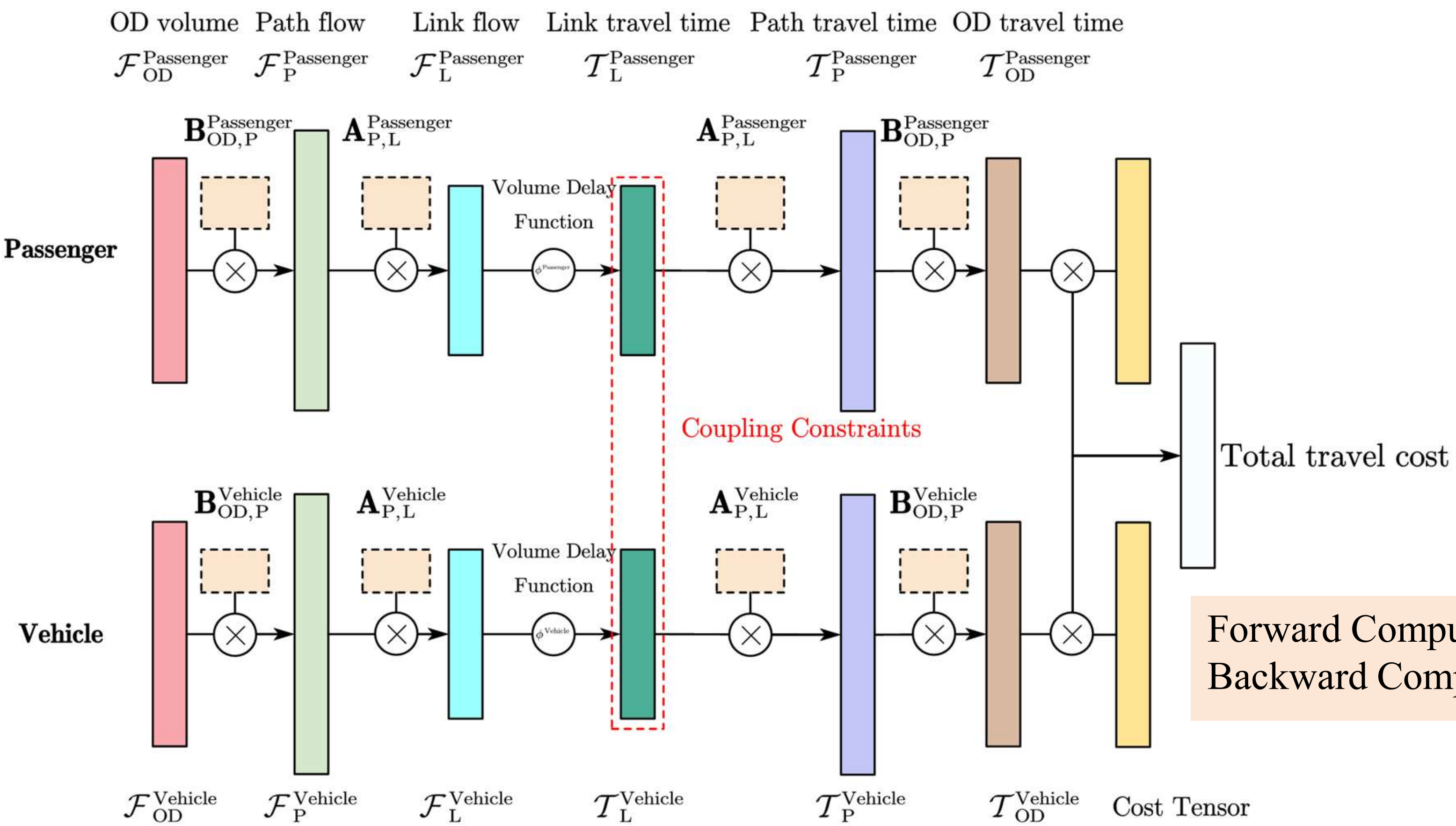
(a) An eight-node transportation network



(b) The location of activities

Reference: Mahmoudi, M., Tong, L. (Carol), Garikapati, V. M., Pendyala, R. M., & Zhou, X. (2021). How many trip requests could we support? an activity-travel based vehicle scheduling approach. Transportation Research Part C: Emerging Technologies, 128, 103222.

Transportation Network Modeling: FTT and Multimodal Coordination



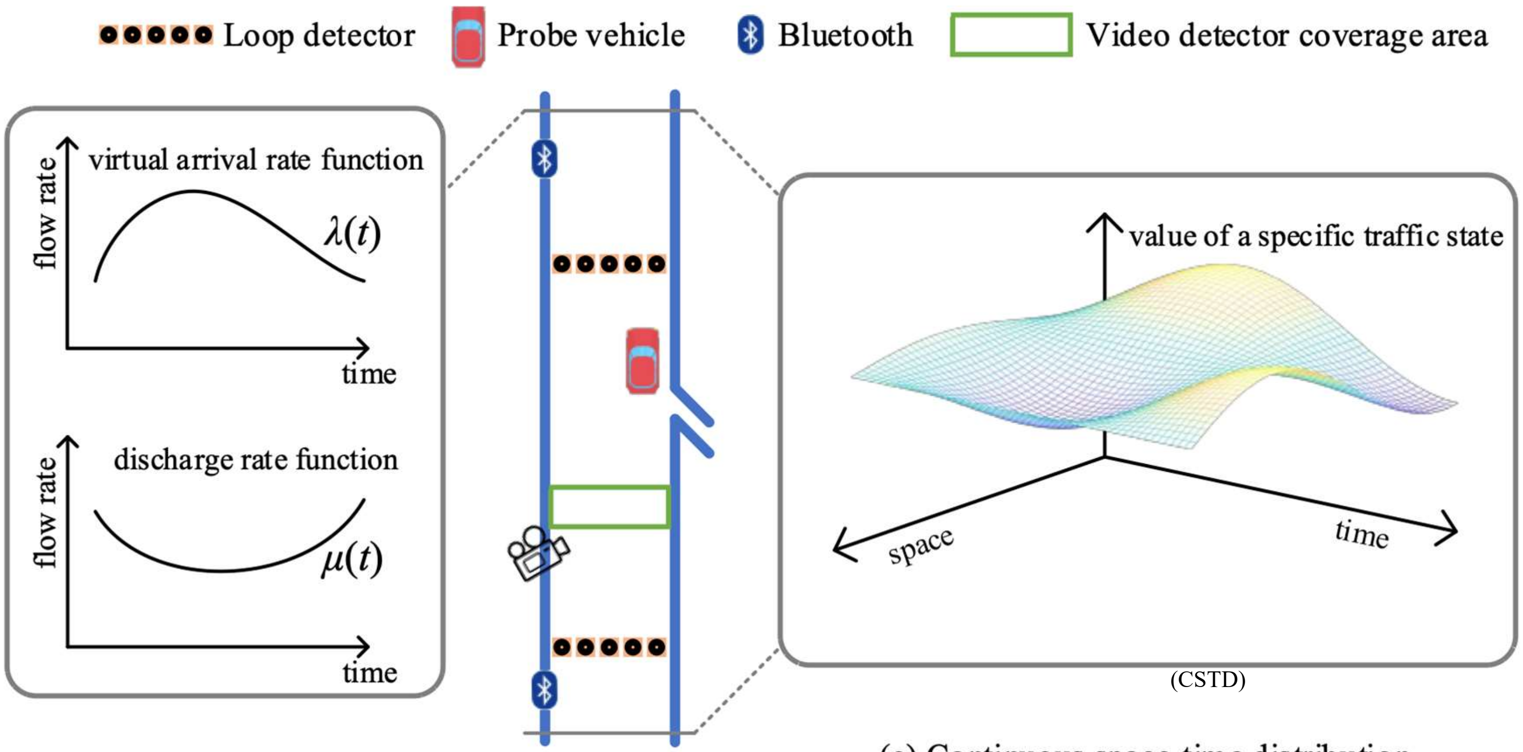
Forward Computation — Optimization Objective
Backward Computation — Decision Update

Source: ASU Trans+AI Lab

Traffic System State Estimation

Traffic System State Estimation

State Representation



(b) System-wide arrival and discharge rate functions

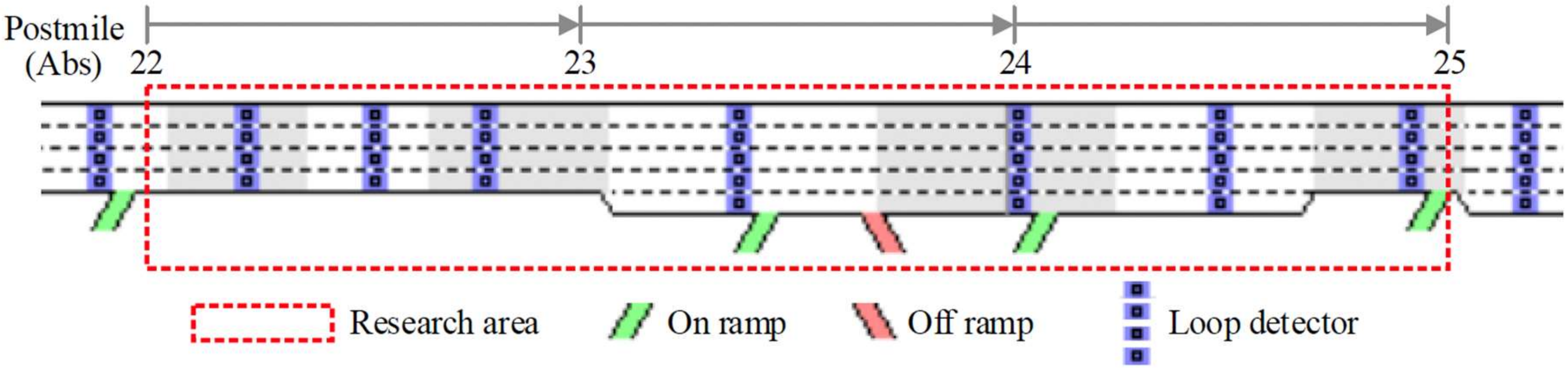
(a) Physical roads with traffic detectors

(c) Continuous space-time distribution function of each traffic state (e.g., flow, density, speed, net volume)

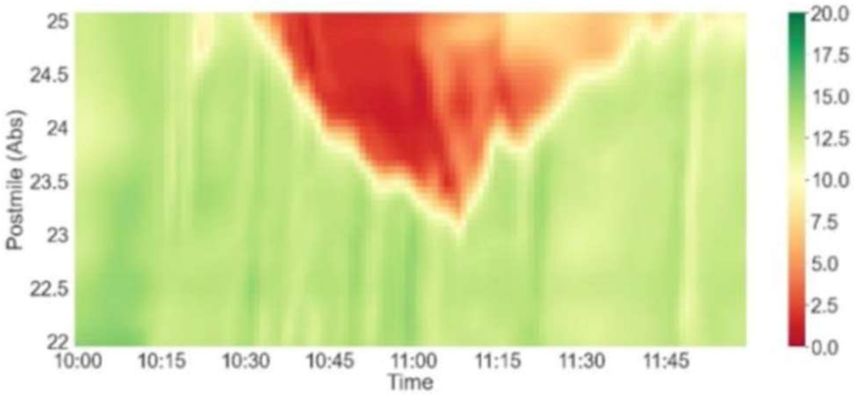
Construct Functions Based on Partial Observations and Traffic Flow Models

References: Lu, J., Li, C., Wu, X. B., & Zhou, X. S. (2023). Physics-informed neural networks for integrated traffic state and queue profile estimation: A differentiable programming approach on layered computational graphs. *Transportation Research Part C: Emerging Technologies*, *153*, 104224.

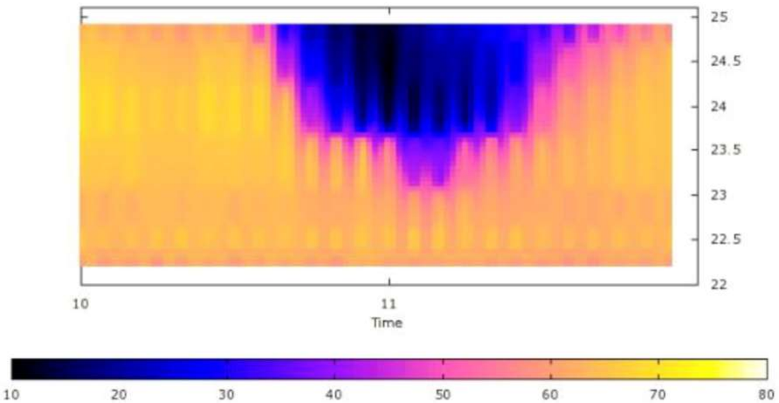
Traffic System State Estimation



Freeway I880-N in Alameda County, California (postmile 22 to 25). Loop detector data and GPS data



(a) Speed estimations of the proposed method



(b) Speed estimations from PeMS

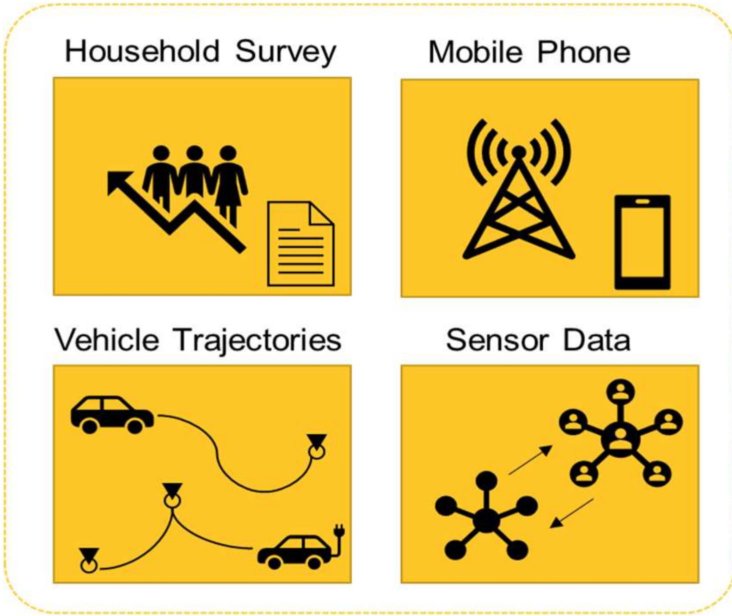
Source: ASU Trans+AI Lab

Tensor Thinking for Transportation Planning

Travel Modeling at a Crossroads

- Traditional: 4-Step models, ABM
- Data-driven: ML/AI methods
- Surveys vs. Big Data
- Rigid structure vs. flexibility, behavior vs. scalability

Urban Traffic Big Data Sources



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Thank You

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