Multi-modal User Equilibrium And System Optimum In Urban Transport Systems Including Shared Mobility Services

Khadidja KADEM[1], Mostafa AMELI[1], Mahdi ZARGAYOUNA[1] and Latifa OUKHELLOU[1]

[1] Université Gustave Eiffel, COSYS, GRETTIA, Paris, France

December 6, 2023.

Multi-modal Network Modeling

- Integration of Shared Mobility Services (SMSs) with public transport has created a complex multi-modal system.
  - Commuters choose the mode and route to reduce their own travel expenses: User Equilibrium (UE) principle (Wardrop ,1952).
  - System owners and service providers satisfy the demand requirements while minimizing overall costs: System Optimum (SO).
- **Goal:** Comprehensive analytical model for urban transportation systems.
  - Understanding the impacts of SMSs on user behavior and traffic state.
  - Encompassing personal means of transport, public transport, SMSs, and intermodality.

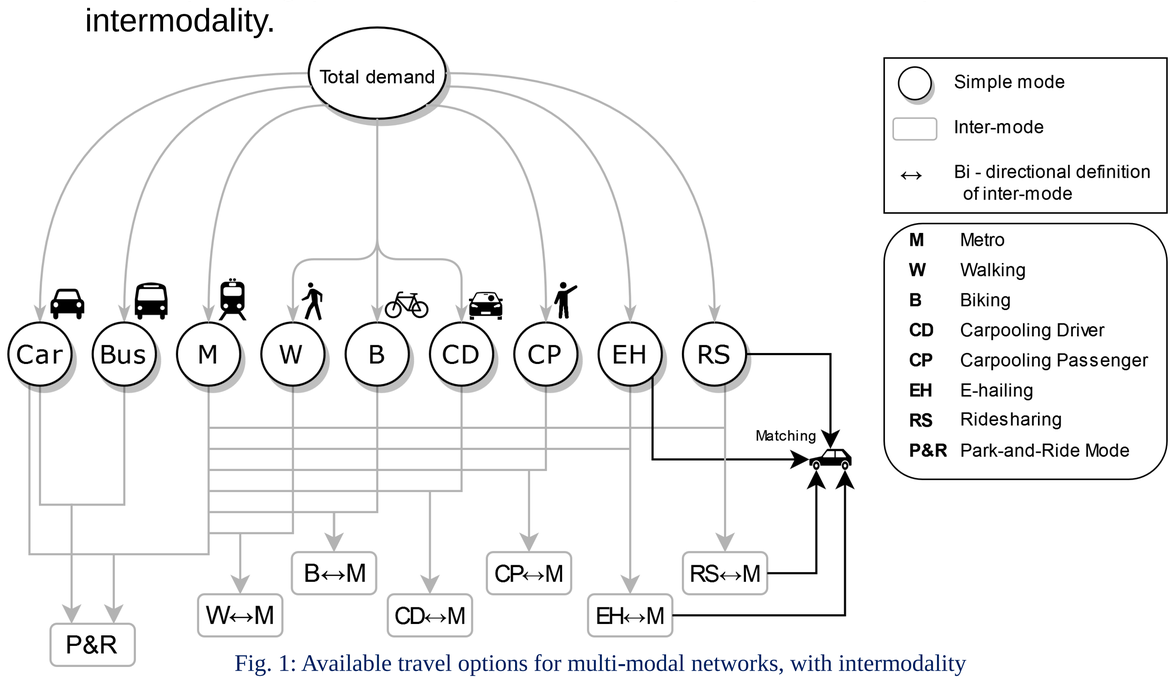
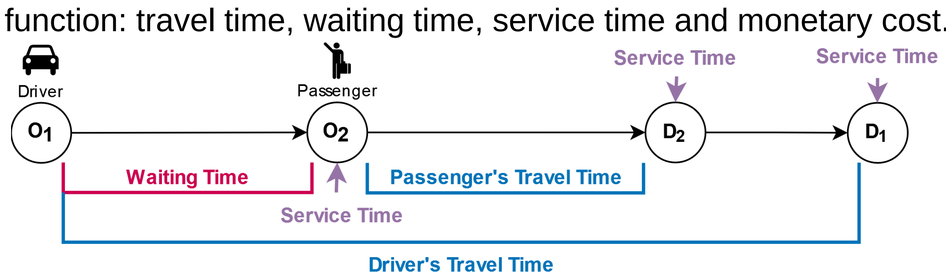


Fig. 1: Available travel options for multi-modal networks, with intermodality

- Intermodality: any combination of travel options to accomplish one trip.
- Trips are shared between any feasible Origin-Destination pairs.
- Ridesharing service handles First-In-First-Out and Last-In-First-Out situations.

Problem Formulation

- Mixed-Integer Quadratic Program non-convex formulation, with fixed demand and time-independent setting.
- Simultaneous mode and path choice, and passengers-driver matching handled by Gurobi Solver.
- Cost function: travel time, waiting time, service time and monetary cost.



- User equilibrium by Beckmann Formulation

$$\min Z_{UE} = \sum_{n \in N} \sum_{a \in A_n} \int_0^{x_a} \alpha \cdot t_{a,n}(\omega) d\omega + \sum_{a \in A} \sum_{m \in \psi} \left[\alpha\left(WT_{m,a} + ST_{m,a}\right) + C_{m,a}\right] \cdot x_{a,m}$$

- System optimum calculation
- Price of Anarchy analysis in multi-modal systems with SMSs and intermodality.
- Constraints to ensure the system's coherence :
  - Demand satisfaction and flow conservation for each mode.
  - Fleet management for the ridesharing service.
  - Matching passenger and driver paths for shared mobility services.
  - Parking capacity for Park-and-Ride mode.
  - Commuters' state transition at transfer points for intermodality.

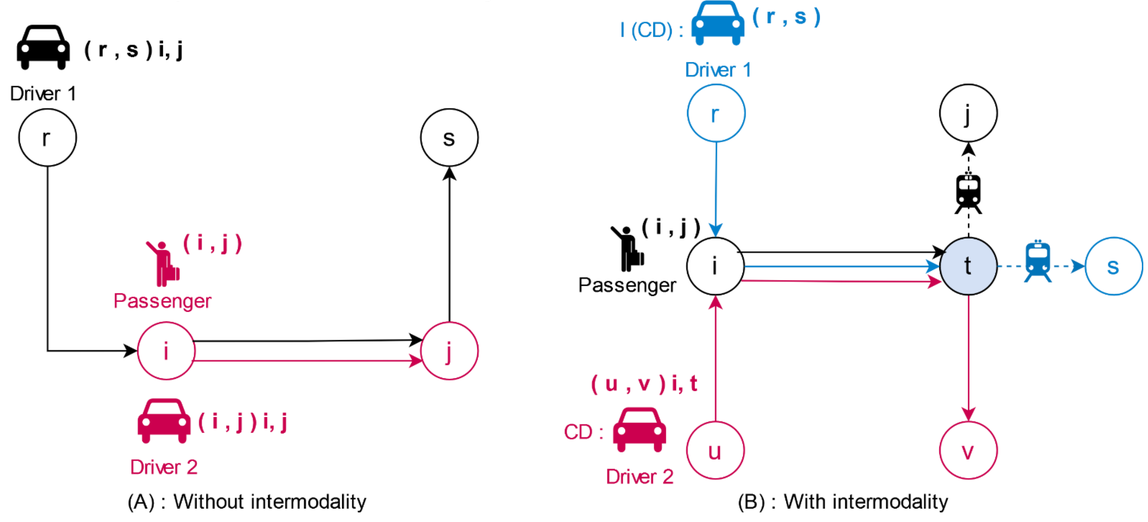


Fig. 2: Passenger-Driver matching for shared mobility services

Numerical Results

Analytical Test Case:

- 4 Nodes, 2 transfer nodes.
- 12 Origin-Destination pairs.
- 100 demand by OD pair.
- Solving Time: 12s.

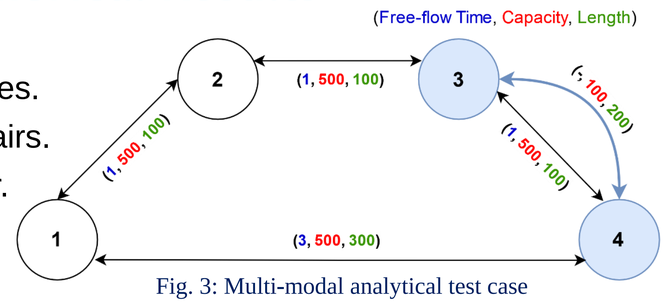


Fig. 3: Multi-modal analytical test case

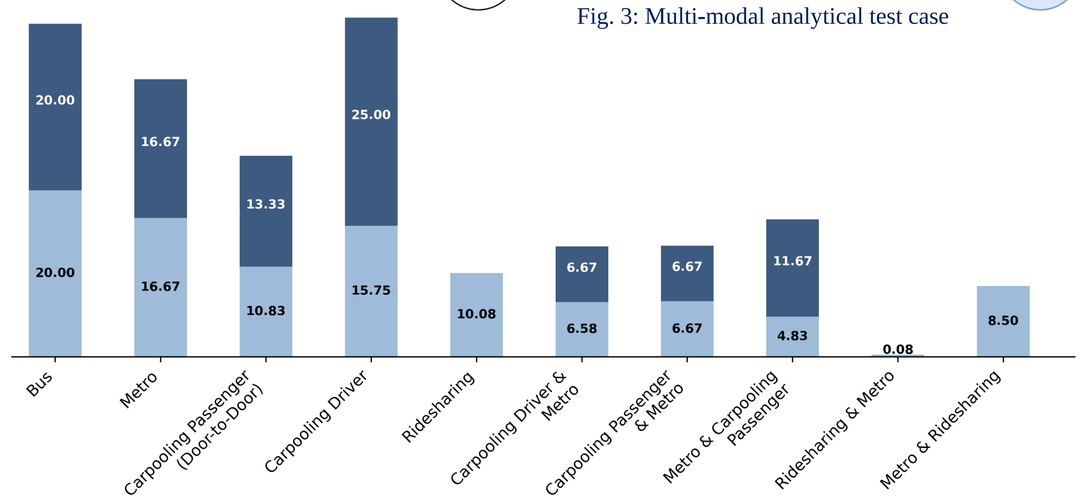


Fig. 4: Modes usage in the analytical test case, with UE and SO

Sioux Falls Network:

- 24 Nodes, 4 transfer nodes.
- 17 Metro stations ↔
- 14 Bus stops ←x→
- 30 Origin-Destination pairs.
- Value of Time : 20 $/h
- Fleet Size : 3500 vehicles
- Solving Time: 61s

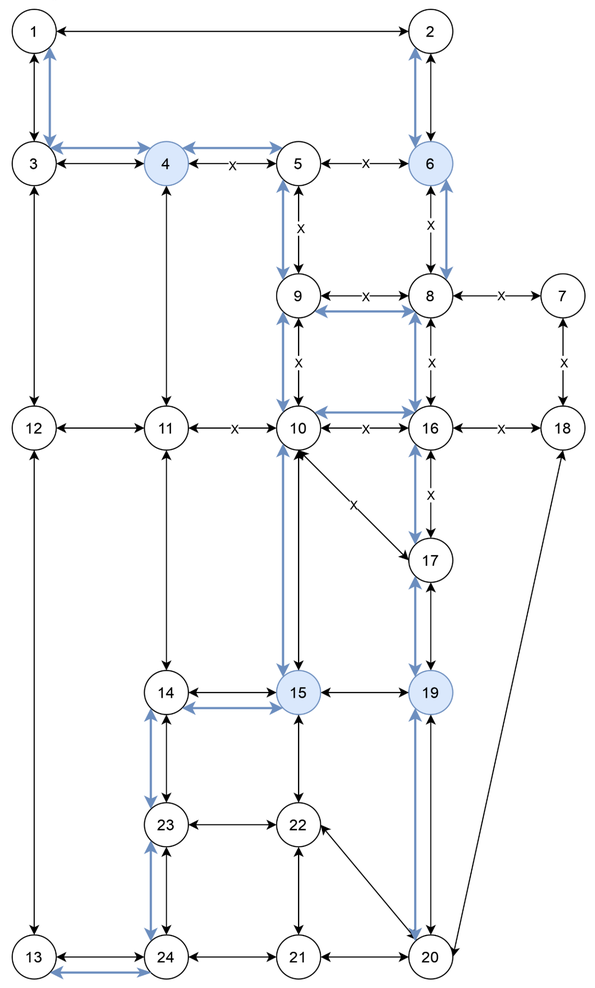


Fig. 5: Sioux Falls Network with PT infrastructure

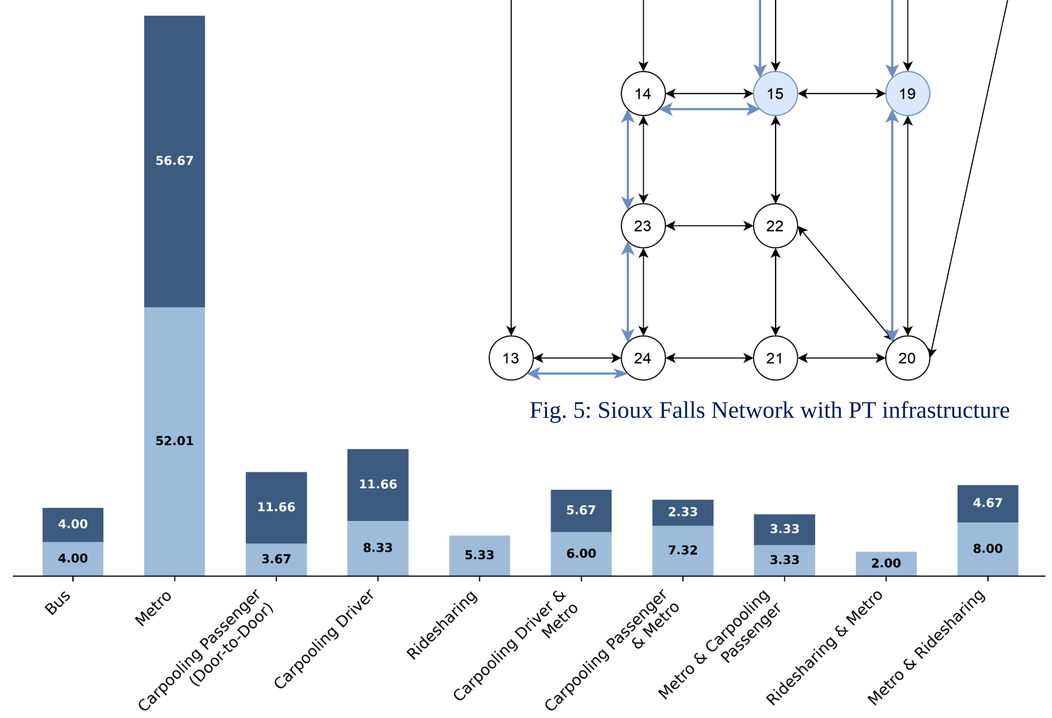


Fig.6: Modes usage in Sioux Falls network, with UE and SO

General Observations for both test cases :

- Public transport is preferred for its low costs.
- Carpooling used for long trips, ridesharing for short distance.
- Intermodality with SMSs is preferred over personal means of transport.
- Ridesharing used when carpooling is crowded.
- In SO, carpooling is preferred over ridesharing to reduce drivers costs.

Conclusion

- Comprehensive mathematical assignment model is formulated for multi-modal urban transportation networks.
- General framework for analyzing and optimizing commuters' behavior within multi-modal transportation networks.
- Future research: integrating personal preferences, service providers' objectives, and traffic dynamics in the model's formulation.

Contact : khadidja.kadem@univ-eiffel.fr

FRANCE 2030 — PROGRAMME DE RECHERCHE — DIGITALISATION et DECARBONATION des MOBILITES

LABORATOIRE GRETTIA TRANSPORTATION NETWORKS ENGINEERING AND ADVANCED COMPUTING LABORATORY