Improving Transit Connections via Transfer Optimization and On-Demand Services

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UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

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Transfer Time Optimization in Transit Scheduling and Coordination in Operational Control

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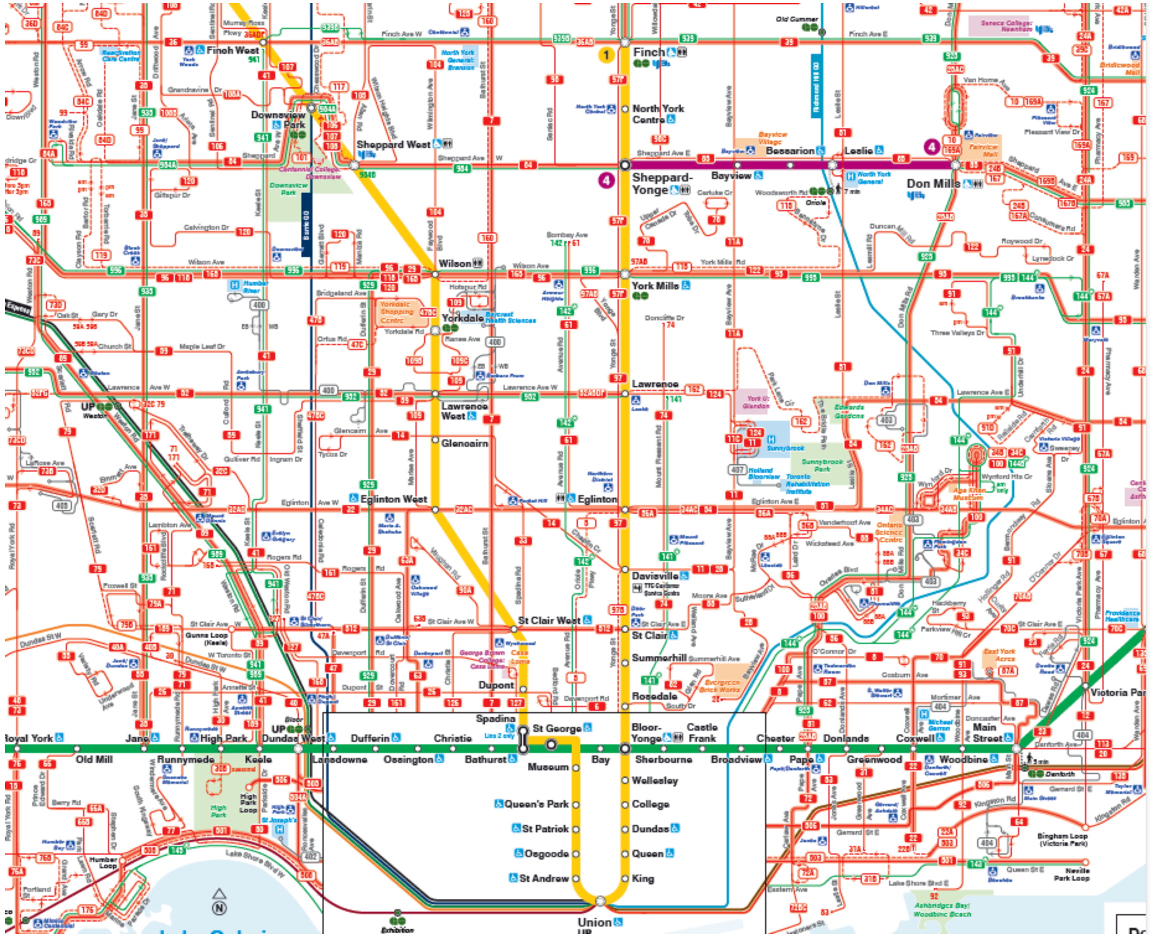
Outline

- Rationale for transfer coordination and challenges
- Transfer-optimized timetables: deterministic and stochastic approaches
- Next step: real-time connection protection

Transfers: Strategic Element of Transit Networks

- Connectivity
- High number of daily transfers
- Disutility of transferring
- Transfer synchronization both at the planning and operation stages



Transfer Synchronization Steps

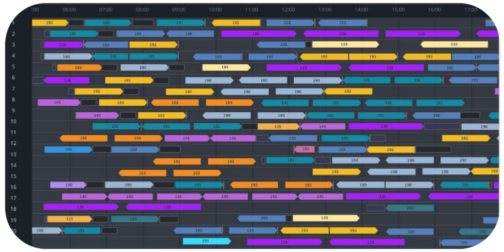
Operation Management

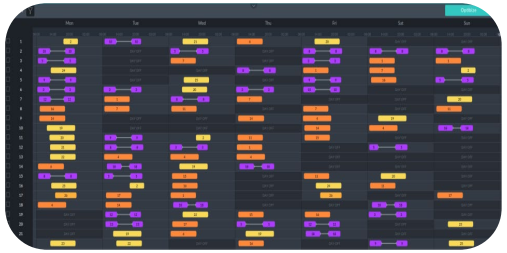
↕

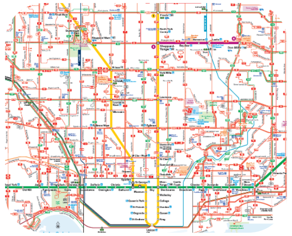
Tactical Planning

↕

Strategic planning







https://globalnews.ca/news/1776275/go-transit-and-ttc-to-make-fare-integration-announcement/, https://www.optibus.com/
https://www.theglobeandmail.com/canada/toronto/article-ttc-wants-to-spend-42-billion-to-improve-subway-buy-new-buses-and/

What Are the Main Challenges?

- Inherent stochasticity (unpredictable and predictable):
  - Recurrent and non-recurrent sources of variability
  - Essential need for proactive treatment of the stochastic characteristics of the system
- Data:
  - Historical and real-time: detailed demand data and operation data
  - For planning, monitoring, control and evaluation
- Model's Complexity:
  - Hard to formulate details → Long computational time

Previous and Ongoing Work

Deterministic Model

- ✓ Formulated new transfer synchronization process
- ✓ Considered transferring and through passengers separately in our model
- ✓ Considered capacity limitation for successful transfers
- ✓ Developed a new solution method to solve the model efficiently

Stochastic Model

- ✓ Formulated stochastic transfer synchronization process: two-stage stochastic modeling
- ➢ Considering joint distributions of travel time, dwell time, and demand uncertainty
- ➢ Developing a solution method to solve the model efficiently

Brief Explanations about Our Model Formulations (Deterministic)

- Objective

$$\min \sum_{n\in N_s}\sum_{l\in TP}\sum_{l'\in TP}\sum_{p\in P_l}\sum_{q\in P^+_{l'}} Twait^n_{lpl'q}\, td^n_{lpl'}\, c_{tw} +$$

Transferring waiting time

$$\sum_{l\in L}\sum_{n\in N_l}\sum_{q\in P^+_{l'}} EST^n_{l'q}\, ivd^n_{l'q}\, c_{tw} +$$

Extra service time-I

$$\sum_{l\in L}\sum_{n\in N_l}\sum_{q\in P^+_{l'}} PTB^n_{l'q}\, td^n_{lpl'}\, c_{tw} +$$

Extra service time-II

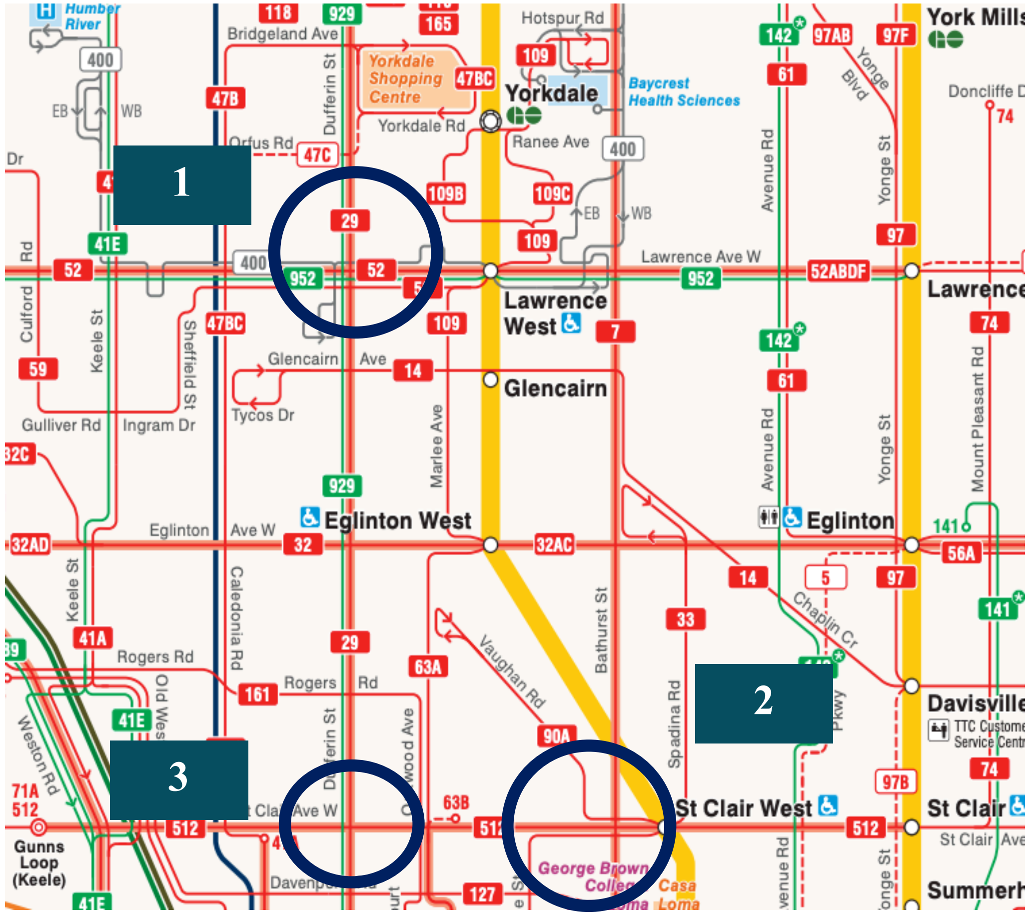
$$\sum_{l\in L}\sum_{n\in N_l}\sum_{q\in P^+_{l'}} flp^n_{l'q}\, c_{tw} +$$

Penalty of missing the first connecting

$$\sum_{l\in L}\sum_{n\in N_l}\sum_{q\in P^+_{l'}} slp^n_{l'q}\, c_{tw}$$

Penalty of missing the second connecting

A Case Study: Input



THE NETWORK FEATURES(Nexus):

- Transfer stops
- Lines
- Lines' stop sequence
- Lines' headways
- Transfer pair directions
- Travel time between the stops of each line

DEMAND AND TIME DATA(Nexus):

- Transferring passengers
- In-vehicle passengers
- Alighting passengers
- Boarding passengers
- Scheduled dwell time
- Walking time for transferring

A Case Study: Synchronized timetables (Draft Results)

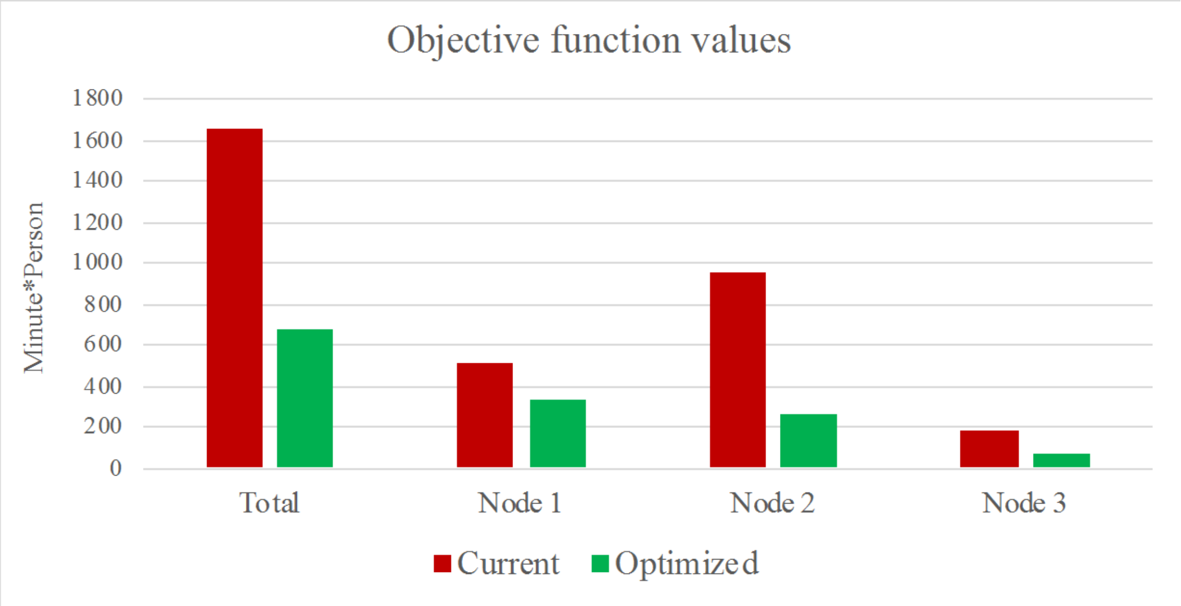
- Vehicle departure times from terminals
- Scheduled arrival and departure times of vehicles at transfer nodes

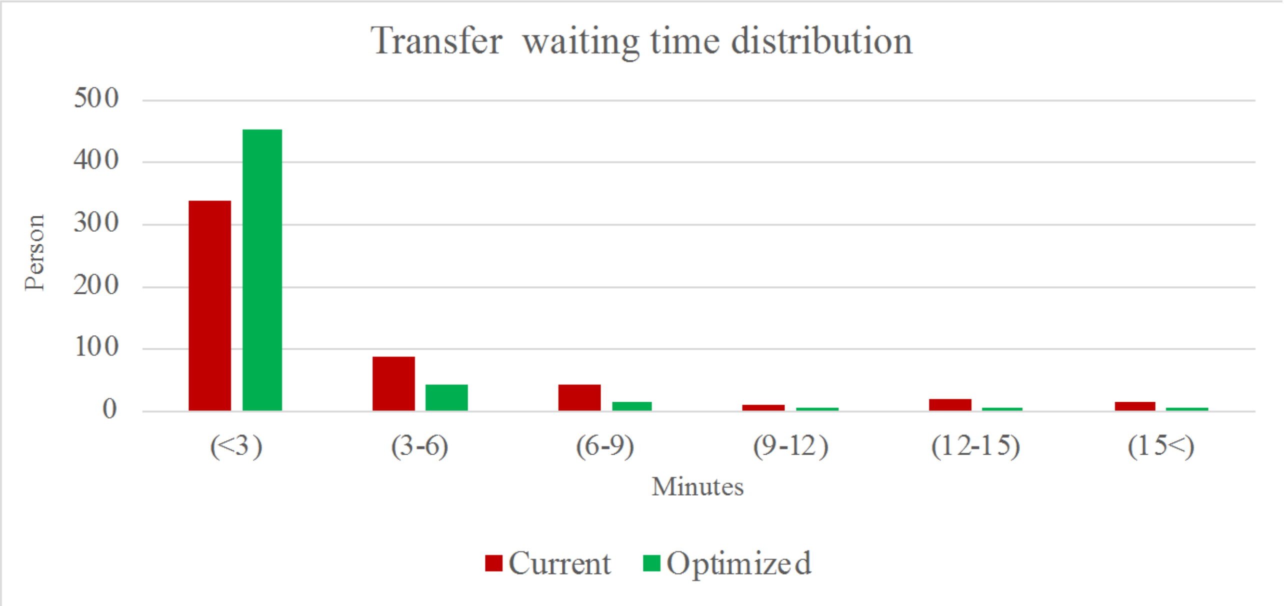
Headway(m)	3	11	8
Node 1	Line 1	Line 2	Line 3
Arrival	8:00:00 AM		
Departure	8:00:30 AM		
Arrival	8:03:00 AM	8:03:30 AM	
Departure	8:03:30 AM	8:04:00 AM	
Arrival	8:06:00 AM		8:06:30 AM
Departure	8:06:30 AM		8:07:00 AM
Arrival	8:09:00 AM		
Departure	8:09:30 AM		
Arrival	8:12:00 AM		
Departure	8:12:30 AM		
Arrival	8:15:00 AM	8:14:00 AM	8:14:30 AM
Departure	8:15:30 AM	8:15:00 AM	8:15:30 AM
Arrival	8:18:00 AM		
Departure	8:18:30 AM		

Optimized

Headway(m)	3	11	8
Node 1	Line 1	Line 2	Line 3
Arrival	8:01:00 AM		
Departure	8:01:30 AM		
Arrival	8:03:00 AM		
Departure	8:04:00 AM		
Arrival	8:06:30 AM	8:05:30 AM	8:06:30 AM
Departure	8:07:00 AM	8:07:00 AM	8:07:00 AM
Arrival	8:09:30 AM		
Departure	8:10:30 AM		
Arrival	8:12:30 AM		
Departure	8:13:30 AM		
Arrival	8:15:00 AM	8:15:30 AM	8:15:30 AM
Departure	8:16:00 AM	8:17:00 AM	8:16:30 AM
Arrival	8:18:00 AM		
Departure	8:18:30 AM		

Evaluation: Optimization Results Compared to Current Condition

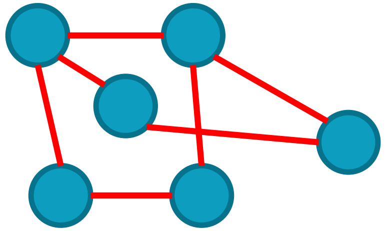




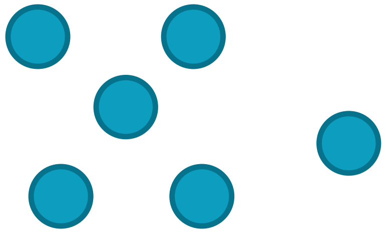
50% gap, takes around 30 minutes

Solution Method Overview

Using Lagrangian relaxation approach

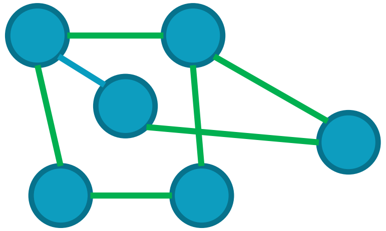


Disconnect the nodes from each other



Solve each node individually in parallel

Apply another heuristic algorithm to make the results feasible



Transfer Synchronization Modelling Phases

Deterministic

- Input: historical demand and operation data (fixed)
- Model: mixed integer programming
- Output: fixed timetables

Stochastic

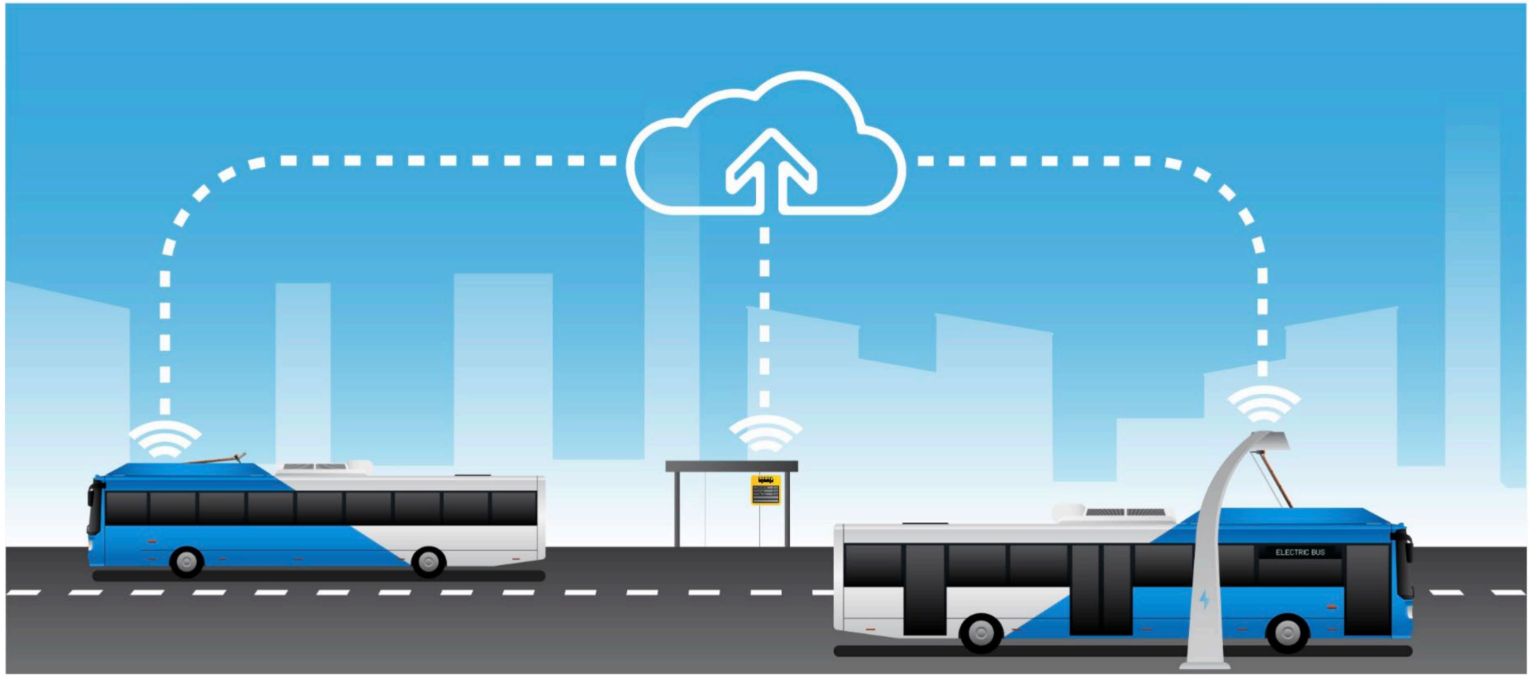
- Input: historical demand and operation data (distribution/scenarios)
- Model: stochastic two-stage mixed integer programming
- Output: combination of fixed and option-based timetables

Real-Time

- Input: historical and real-time demand and operation data
- Approach: reinforcement learning or deep learning
- Output: combination of fixed and adaptive/flexible timetables

Connected Buses and Passengers

- Bus ↔ Bus. (B2B)
- Bus ↔ Infrastructure (B2I)
- Passenger ↔ Bus (P2B)
- Passenger ↔ Infrastructure (P2I)



https://www.wsp.com/en-SA/insights/connected-automated-vehicles-and-public-transportation

Our Proposed Approach

Data preparation and analysis

Historical data

Real Time data: Vehicle-based and Passenger/Driver based

Detection and prediction

Develop analytics for detection and prediction of transfer problems

Strategy selection and Optimization

1. Identify candidate strategies and select appropriate strategy
2. Develop optimization model for adaptive real-time control of selected strategy

Demand Responsive Transit: Review of Research Literature and Practice

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Outline

- Background and Research Objective
- State of Art and Practice: Summary
- Future Directions

What is Demand Responsive Transit ?

Volinski (2019) defines general demand responsive transit (DRT) service as “*the chameleon of the public transportation world. The service can take many forms in different environments and can even change its form in the middle of its duty cycle.*”

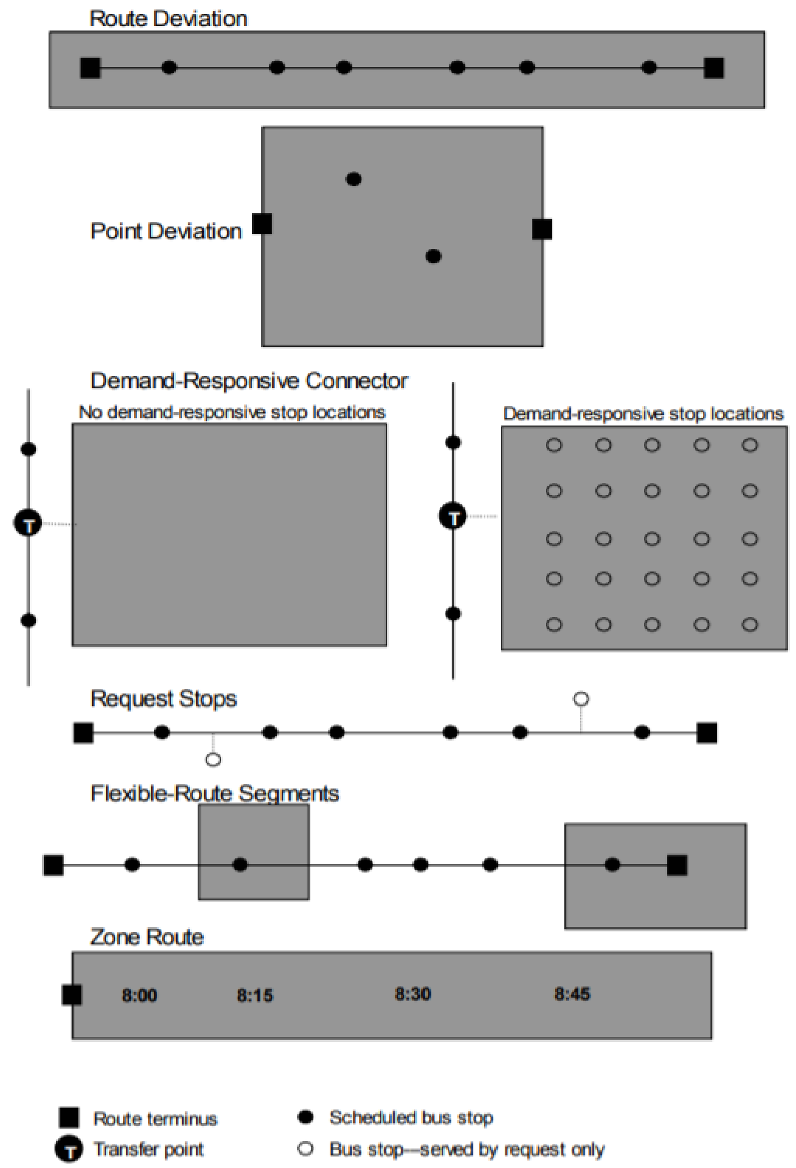


FIGURE 1 Flexible service types.

Volinski, Joel. 2019. Microtransit or General Public Demand-Response Transit Services: State of the Practice. Washington, D.C.: Transportation Research Board. https://doi.org/10.17226/25414.

Renewed Interest in DRT

- Appealing solution to different urban mobility problems as early as the 1970s
- Resistance from public and inefficient routing led to the discontinuation of many services
- Growing appreciation of flexibility, the acceptance of sharing rides, and technological advancements

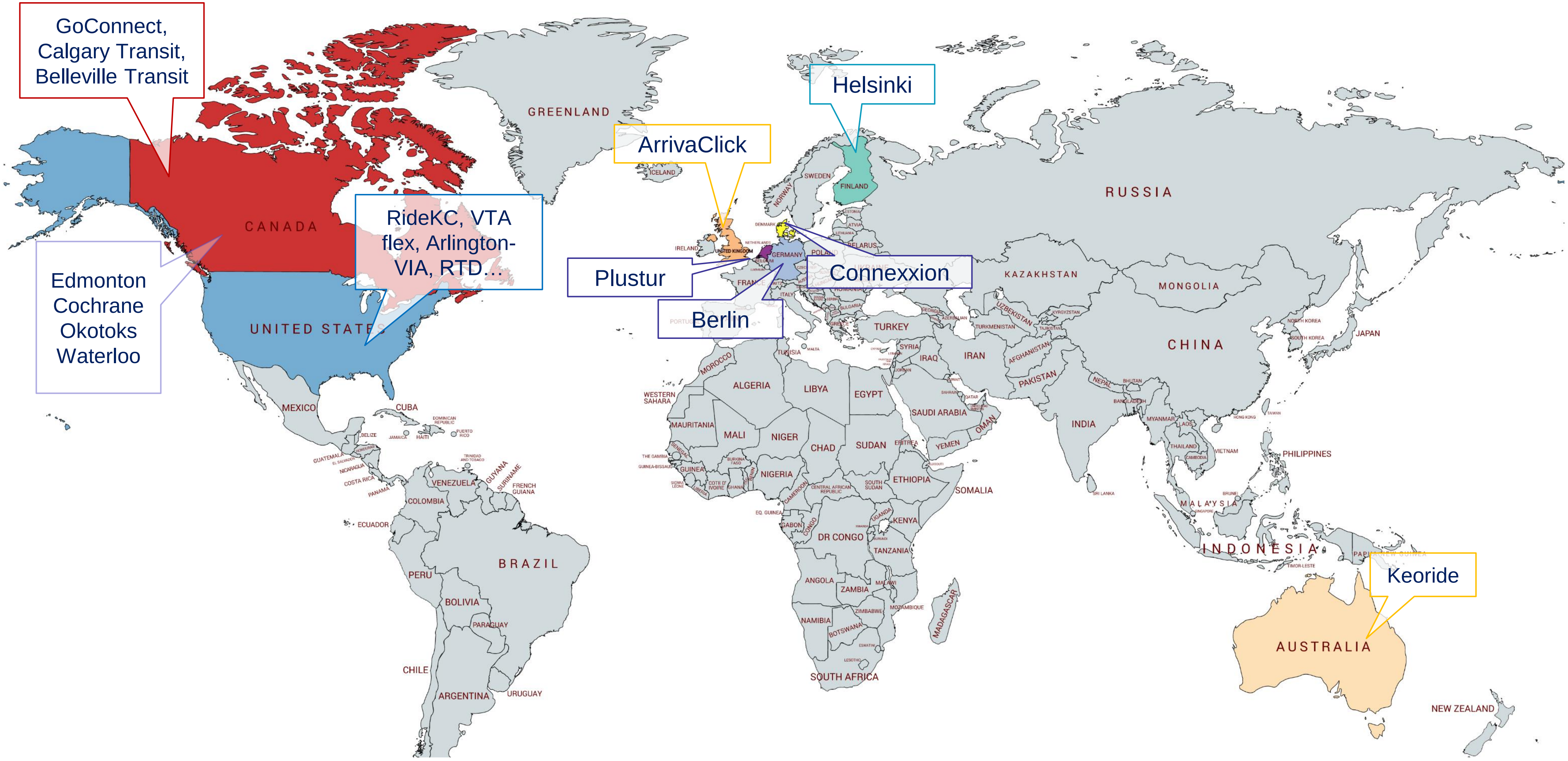
Research Objective

Study the state of art and practice on service planning, management, and operation of DRT

Develop service guidelines and standards for DRT operation

Develop a modelling framework for planning and managing DRT operations

Real-World Examples



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Scope of DRT Planning and Management

- **Service Planning and Operations**
  - What?
    - Service Design
    - Service Capacity
  - Where?
    - Service Area
    - User Characteristics
  - When?
    - Service Span
    - Planning Horizon
  - How?
    - Dispatching Policies
    - Technology Platform
    - Financing and Partnership

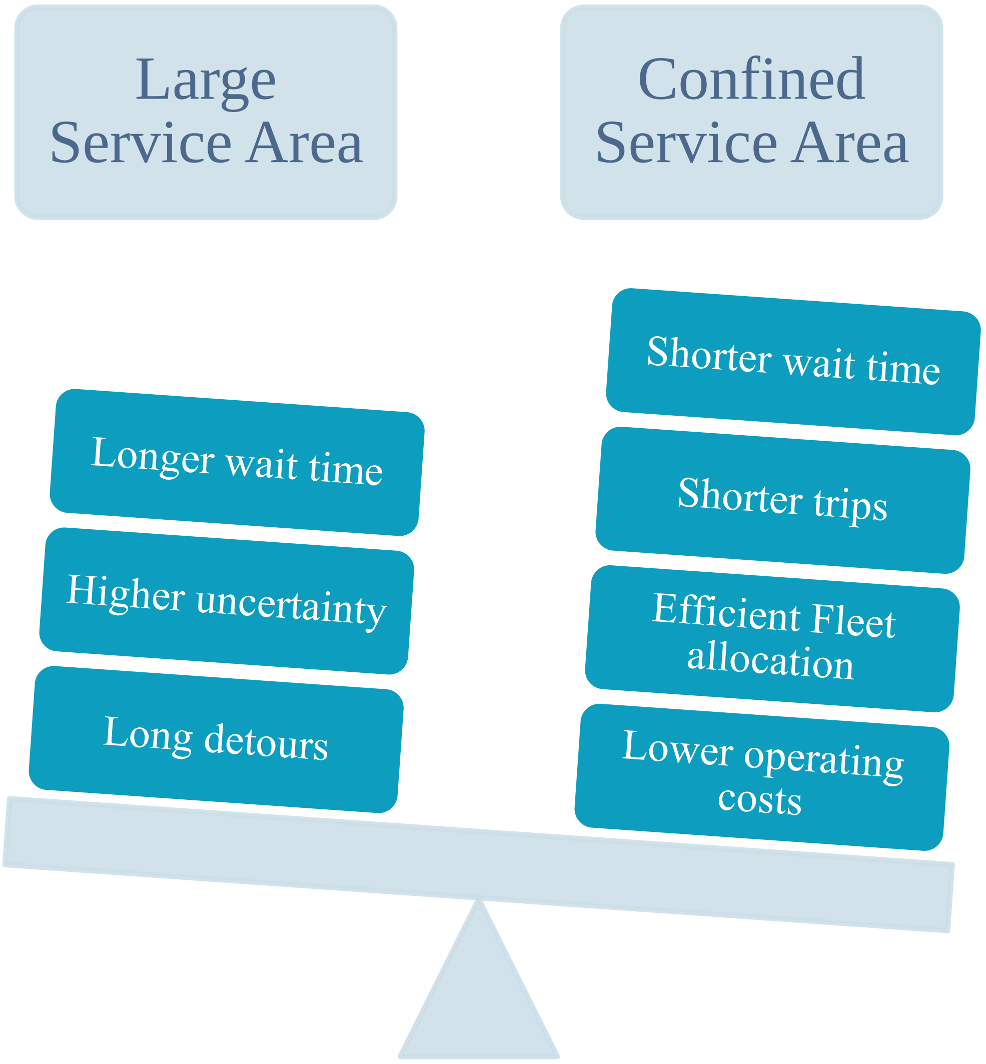
Flexible or Fixed Route?

- ✓ Agencies operate DRT in low demand area → A cost-effective solution in areas with lower population density and dispersed demand
- ✓ Agencies operate in areas of high deficiency → Address issues of socio-economic and jurisdictional equity
- ✓ Most agencies contracted with technology company → Benefits from the availability of technology in ridesharing and optimization software
- ✓ More than 50% of operators run DRConnector → Provides an efficient solution for the first and last mile trips

Critical Density and Service Area

There exists a threshold beyond which DRT is less effective than fixed-route service

- ✓ Arlington County: Fixed to DRT when ridership < **10 passengers/hour/vehicle**
- ✓ RTD (Denver): DRT to fixed route when ridership > **20 passengers/hour/vehicle**
- ✓ **Critical density is highly dependent on the service area**



Performance Metrics

Operating Cost

- High marginal cost
- Low fare-box recovery ratio of less than 10%

Productivity

- High productivity >> longer detours >> lower on-time performance

Calgary Transit

- Avg. Walk time to a virtual stop = 4mins

Arlington-VIA

- 36% reduction inVKT

ArrivaClick

- 50% mode shift from auto

FlexRide-RTD

- Avg. $21.84/trip

Dynamic Operations

Stochastic Models to estimate the fleet size

Vary by type of operation and objective

Real-time Vehicle Routing

Addresses stochasticity in demand and travel time, and incorporates operational constraints

Recent Developments in DRT

Operations using Autonomous vehicles

E.g. Endeavour in UK

Partnerships with TNCs

Innisfil, Ontario partnership with UberPool

Transactional Data Specifications

FlexDanmark, a technological platform

GTFS Flex

Ongoing extension of the existing GTFS

Response during Pandemic

Efficient service to move lower ridership

Conclusion

- The dynamic nature of DRT makes it hard to identify one agreed practice, but some practices are better than others
- Most agencies rely on experience and personal judgement
- Performance metrics should go beyond cost and ridership
- No conventional set of service guidelines to help agencies in planning for DRT services
- No rigorous planning tool that allows assessing different scenarios in hybrid transit network with fixed and demand-responsive transit

Next Steps

Service Guidelines/Standards

This includes developing a comprehensive and standardized set of performance measures

Demand responsive transit decision support toolkit

Integrated tool for planning on-demand transit with fixed-route transit, creating a unified framework for planning hybrid networks.

Thank you!
Q&A

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