UNIVERSITY OF LEEDS
Institute for Transport Studies

Assessing the viability of demand-responsive transport as a feeder in urban outskirts

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Background: The Challenge of Sustainable Mobility in Urban Peripheries

Urban sprawl and car dependence

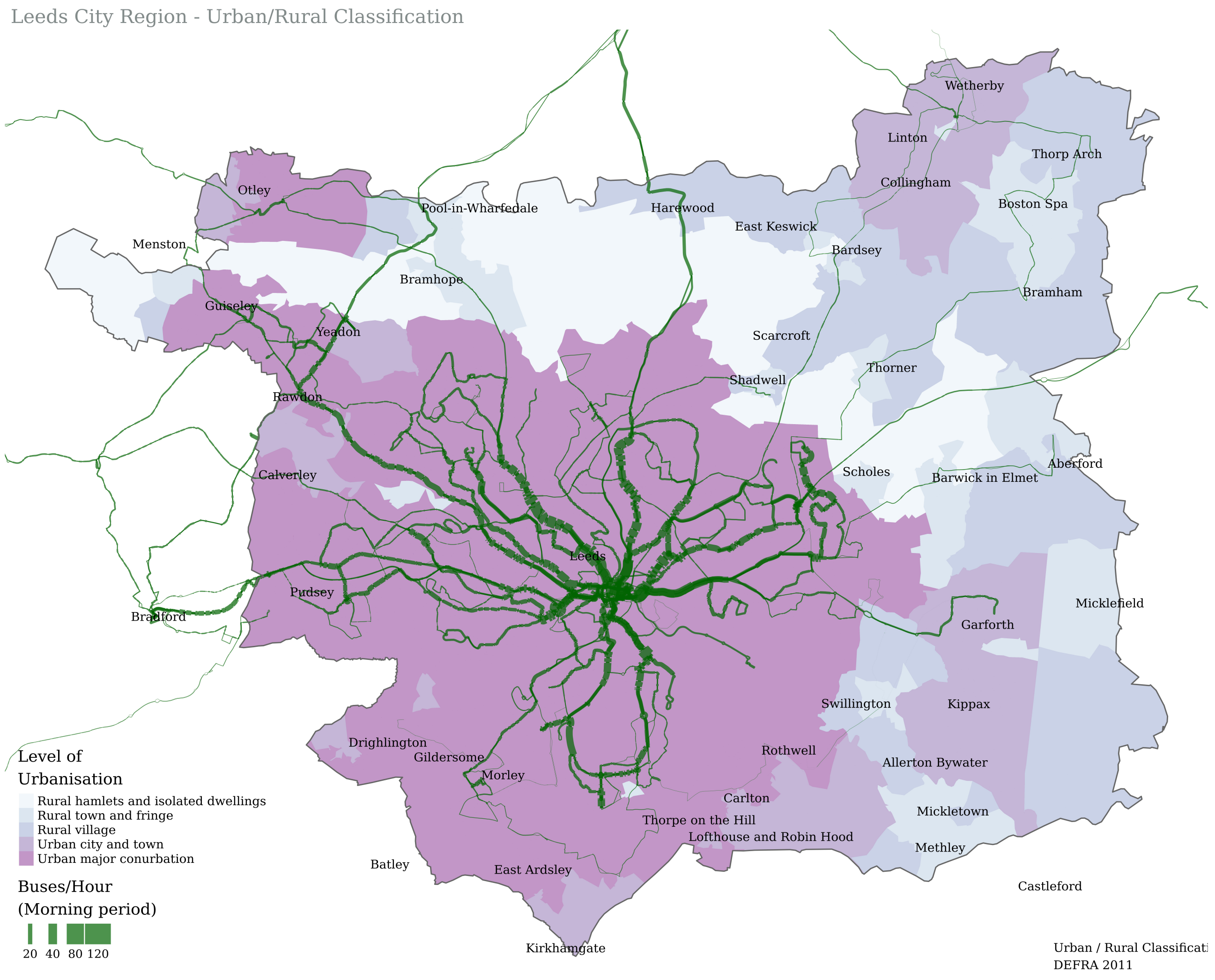
- Outward growth of cities → low-density, car-oriented development
- Limited access to public transport in these areas → high reliance on private vehicles

Implications for sustainability

- Increased greenhouse gas emissions and congestion
- Inequitable access to low-carbon transport options

Strategic need for alternatives

- WYCA net-zero target by 2038
- High target bus mode share increase



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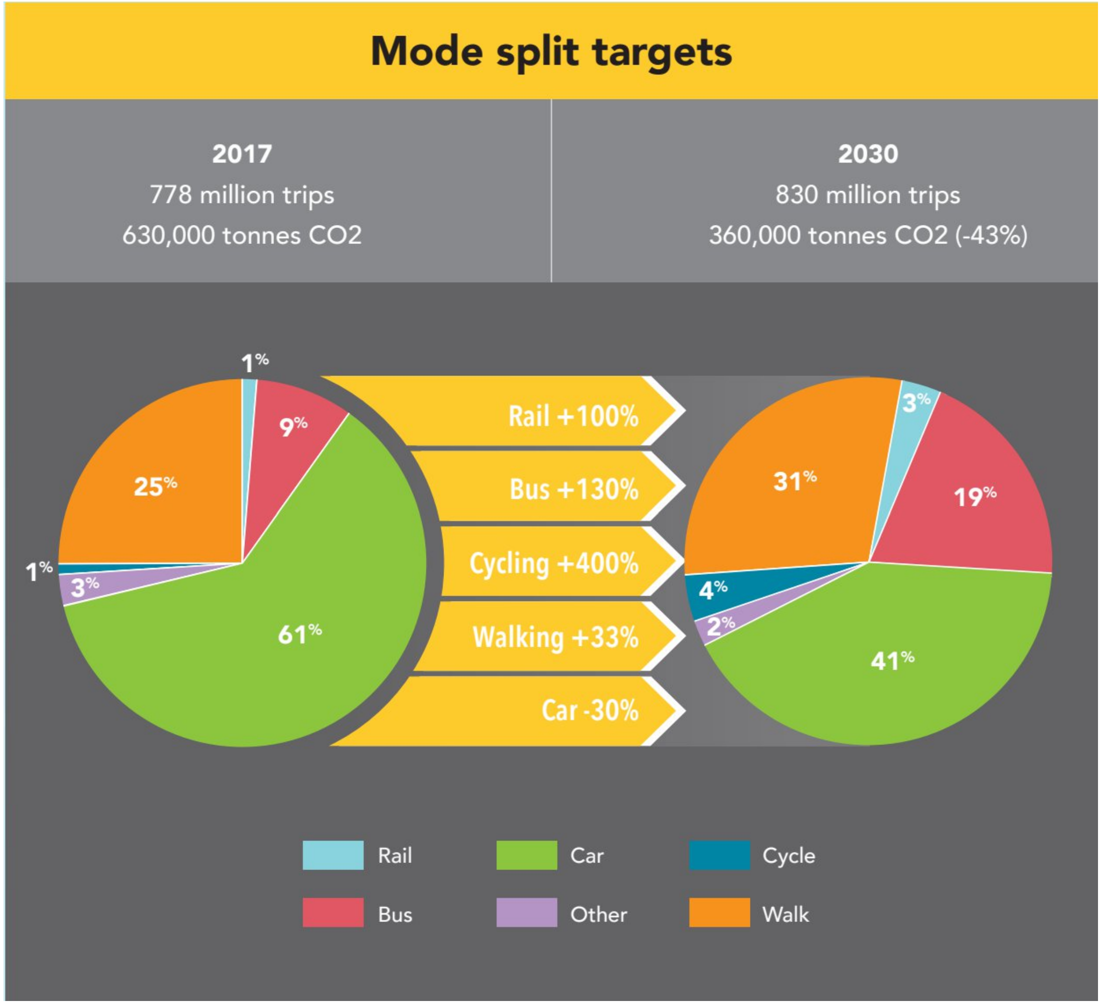


Source: Connecting Leeds Transport Strategy (https://www.leeds.gov.uk/parking-roads-and-travel/connecting-leeds-and-transforming-travel/transport-policy)

Background: The Role—and Limitations—of DRT

What is DRT?

- Flexible, on-demand transport that pools passengers and adapts routes
- Can (theoretically) reduce VKT through pooling and increase PT ridership when used as a feeder service

Current challenges with DRT rollout

- Many services fail due to poor integration or unrealistic service expectations (East Leeds FlexiBus)
- Tension between *commercial viability and public value*
- Risk of *increased* VKT or reduced PT ridership in dense areas

Vision led approach

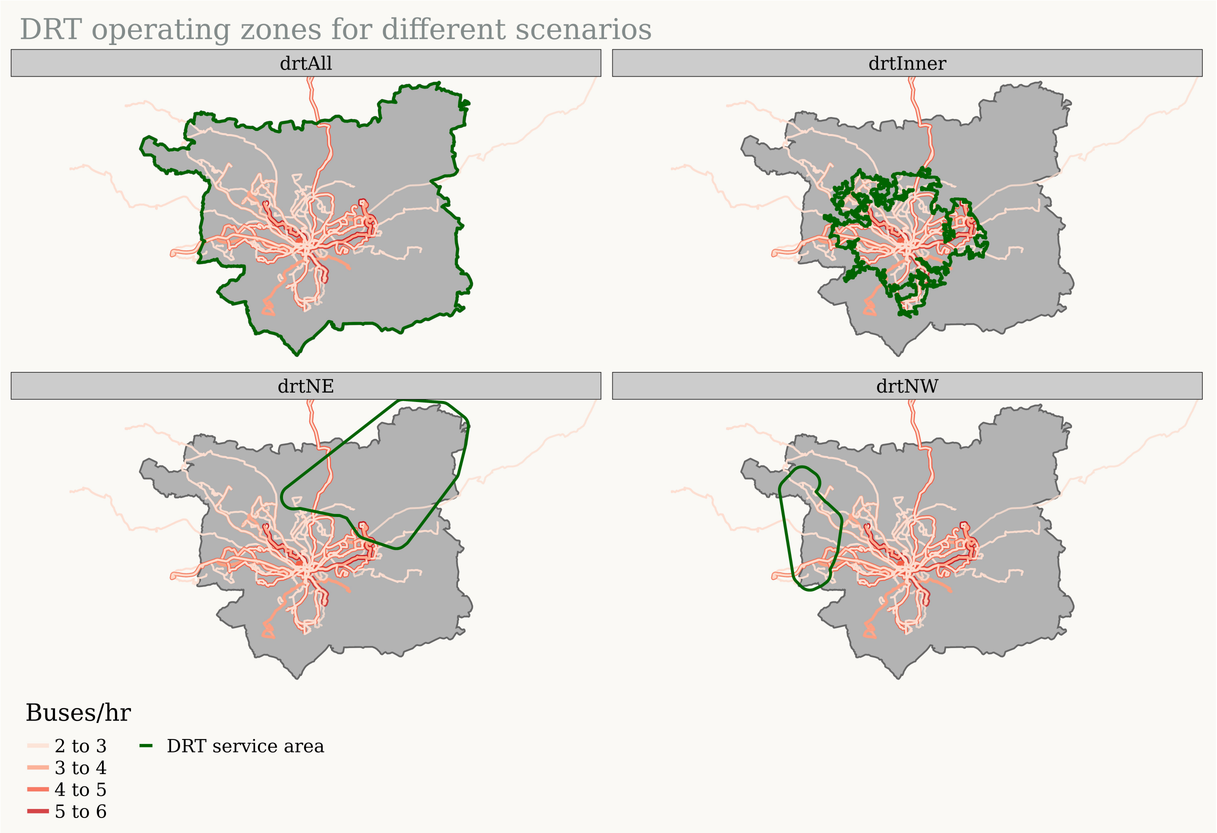
- *What is desired future? how can DRT contribute to it?*
- DRT as a public transport feeder:
  - Serves peripheral areas underserved by fixed-route PT
  - Is part of the larger PT system (a franchised system with **cross-subsidisation** of routes) -> emphasis more on environmental impact than farebox revenue

Contrast service logics

Operator-oriented DRT	Feeder-oriented DRT
Maximises ridership / cost recovery	Designed to integrate with PT
Operates in dense urban core	Constrained to urban periphery
Risks replacing PT and active travel	Should induce desired mode shift

Research Questions

- How does **service area design** (operator vs feeder) affect mode share and DRT uptake?
- What impact do **feeder-oriented zones** have on pooling and network-wide VKT?
- What is the trade-off between **environmental considerations** (e.g., reducing VKT) and service quality (e.g., increasing fleet size to improve waiting and travel times)?



Scenario	Type	Delineation Approach	Perspective	Population	Trips
drtAll	Operates everywhere	None	Operator	354,618	1,045,550
drtInner	Inner city	Built up inner core (inspired by Bischoff et al. 2018)	Operator	221,443	747,670
drtNE	North East zone	Clustering	Environmental	32,935	53,921
drtNW	North West zone	Clustering	Environmental	37,990	86,712

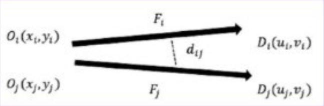
J. Bischoff, M. Maciejewski, K. Nagel, City-wide shared taxis: A simulation study in berlin, in: 2017 IEEE 20th international conference on intelligent transportation systems (ITSC), IEEE, 2017, pp. 275–280. doi:10.1109/ITSC.2017.8317926.

Simulation Framework

Methods

Scenario data: DRT operating zones

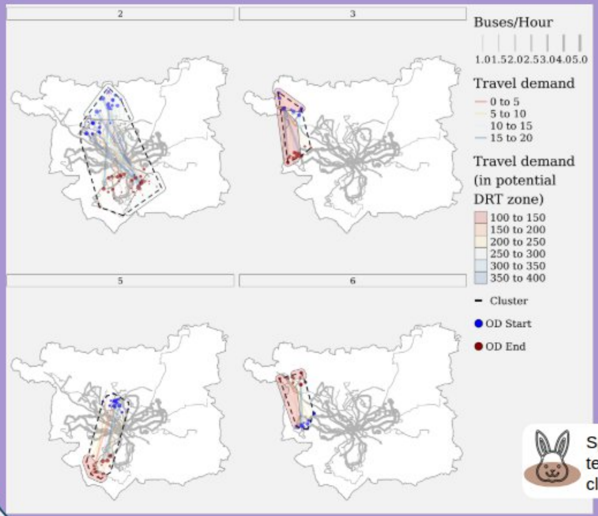
A) Clustering of flow data using DBScan



$$FDS_{ij} = \sqrt{\frac{\alpha\left[(x_i-x_j)^2+(y_i-y_j)^2\right] + \beta\left[(u_i-u_j)^2+(v_i-v_j)^2\right]}{L_i L_j}}$$

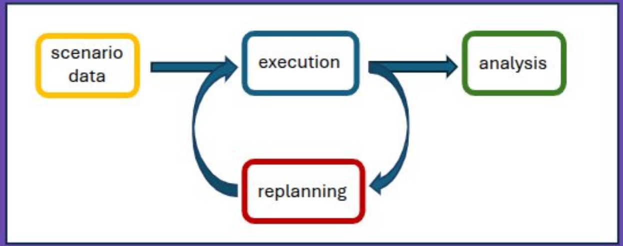
Source: Tao and Thill (2016)

B) Clusters to DRT zones



Spatio-temporal clustering

Agent-based framework (MATSim)



Source: Horni et al. (2016) - adapted for Discrete Mode Choice extension

Scenario data: Activity based model

Pipeline for generating activity-based travel demand data for any region in England

Replanning: Discrete mode choice

- Agents choose modes probabilistically, based on Discreate Mode Choice extension (Horl et al. 2018; Horl et al. 2019).
- MNL from Tsoleridis et al. (2022), but no utility for DRT

Utility of DRT

How to calculate utility of trips with DRT feeder leg?

- Utility of DRT = Utility of Bus
- Utility of feeder DRT
  - feederDRT extension (Chouaki and Horl 2024)
  - Utility of trip with DRT and PT = Utility PT leg + Utility DRT leg

DRT fare

- same as bus, with hopper fare to encourage use as feeder

DRT fare structure

Analysis: Scenarios

Scenario	Type	Note	Delineation approach	Perspective
Drt	City-wide	Operates everywhere	NA	Operator
DrtInner	Zone-based	Inner City	Inspired by Bischoff et. al. 2018)	Operator
DrtNE	Zone-based	Northeast Zone	Clustering	Environment
DrtNW	Zone-based	Northwest Zone	Clustering	Environment

A. Horni, K. Axhausen, K. Nagel, The multi-agent transport simulation MATSim, Ubiquity Press, 2016
J. Bischoff, M. Maciejewski, K. Nagel, City-wide shared taxis: A simulation study in berlin, in: 2017 IEEE 20th international conference on intelligent transportation systems (ITSC), IEEE, 2017, pp. 275–280. doi:10.1109/ITSC.2017.8317926.
R. Tao, J.-C. Thill, A density-based spatial flow cluster detection method, International Conference on GIScience Short Paper Proceedings
S. Hörl, M. Balac, K. W. Axhausen, A first look at bridging discrete choice modeling and agent-based microsimulation in matsim, Procedia computer science 130 (2018)
S. Hörl, M. Balać, K. W. Axhausen, Pairing discrete mode choice models and agent-based transport simulation with matsim, in: 2019 TRB annual meeting online, Transportation Research Board, 2019
T. Chouaki, S. Hörl, The feederdrt extension: simulation of intermodal on-demand services acting as feeders for public transit, in: Proceedings of the 12th symposium of the European Association for Research in Transportation (hEART), MATSim User Meeting, Aalto, Finland, 2024.

RESULTS

OVERALL MODE SHIFT

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SHIFT FROM ALL MODES TO DRT (STANDALONE AND FEEDER)

Which modes are DRT trips coming from?

For each mode, we show: Number of Trips shifted to DRT (% of mode total that shifted to DRT)

		Car		Public Transport		Bike		Walk		Taxi		Total	
	Service Area	Standalone	Feeder	Standalone	Feeder	Standalone	Feeder	Standalone	Feeder	Standalone	Feeder	Standalone	Feeder
100	drtAll	918 (0.2)	26 (0)	2030 (2.1)	52 (0)	24 (1.3)	0 (0)	435 (0.2)	12 (0)	890 (3.9)	1 (0)	4297 (0.4)	91 (0)
	drtInner	665 (0.2)	52 (0)	2318 (2.4)	255 (0.3)	37 (2)	1 (0)	857 (0.3)	21 (0)	998 (4.3)	46 (0.2)	4875 (0.5)	375 (0)
	drtNE	68 (0)	188 (0)	97 (0.1)	550 (0.6)	29 (1.6)	2 (0.1)	99 (0)	20 (0)	66 (0.3)	140 (0.6)	359 (0)	900 (0.1)
	drtNW	120 (0)	125 (0)	162 (0.2)	610 (0.6)	18 (1)	5 (0.3)	185 (0.1)	44 (0)	97 (0.4)	138 (0.6)	582 (0.1)	922 (0.1)
200	drtAll	1816 (0.4)	28 (0)	3960 (4)	89 (0.1)	60 (3.2)	0 (0)	873 (0.3)	16 (0)	1748 (7.6)	6 (0)	8457 (0.8)	139 (0)
	drtInner	1328 (0.3)	103 (0)	4338 (4.4)	487 (0.5)	82 (4.4)	1 (0)	1595 (0.6)	46 (0)	1829 (7.9)	96 (0.4)	9172 (0.9)	733 (0.1)
	drtNE	69 (0)	191 (0)	97 (0.1)	564 (0.6)	27 (1.4)	2 (0.1)	99 (0)	20 (0)	69 (0.3)	144 (0.6)	361 (0)	921 (0.1)
	drtNW	122 (0)	128 (0)	162 (0.2)	610 (0.6)	18 (1)	5 (0.3)	188 (0.1)	45 (0)	97 (0.4)	139 (0.6)	587 (0.1)	927 (0.1)
500	drtAll	3915 (0.9)	77 (0)	9093 (9.3)	217 (0.2)	149 (8)	0 (0)	2039 (0.8)	53 (0)	3904 (16.9)	21 (0.1)	19100 (1.8)	368 (0)
	drtInner	2694 (0.6)	185 (0)	9128 (9.3)	920 (0.9)	170 (9.1)	3 (0.2)	3733 (1.5)	103 (0)	3678 (15.9)	179 (0.8)	19403 (1.9)	1390 (0.1)
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1000	drtAll	6467 (1.5)	124 (0)	16163 (16.5)	381 (0.4)	298 (16)	1 (0)	3865 (1.5)	86 (0)	6844 (29.6)	37 (0.2)	33637 (3.2)	629 (0.1)
	drtInner	3729 (0.9)	263 (0.1)	12944 (13.2)	1328 (1.4)	253 (13.6)	7 (0.4)	5701 (2.2)	150 (0.1)	5275 (22.8)	247 (1.1)	27902 (2.7)	1995 (0.2)
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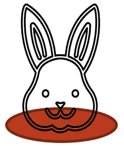

DRT fleet sizing and demand saturation

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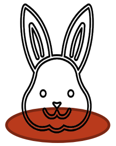

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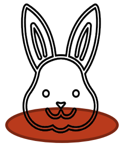

DRT fleet sizing and demand saturation

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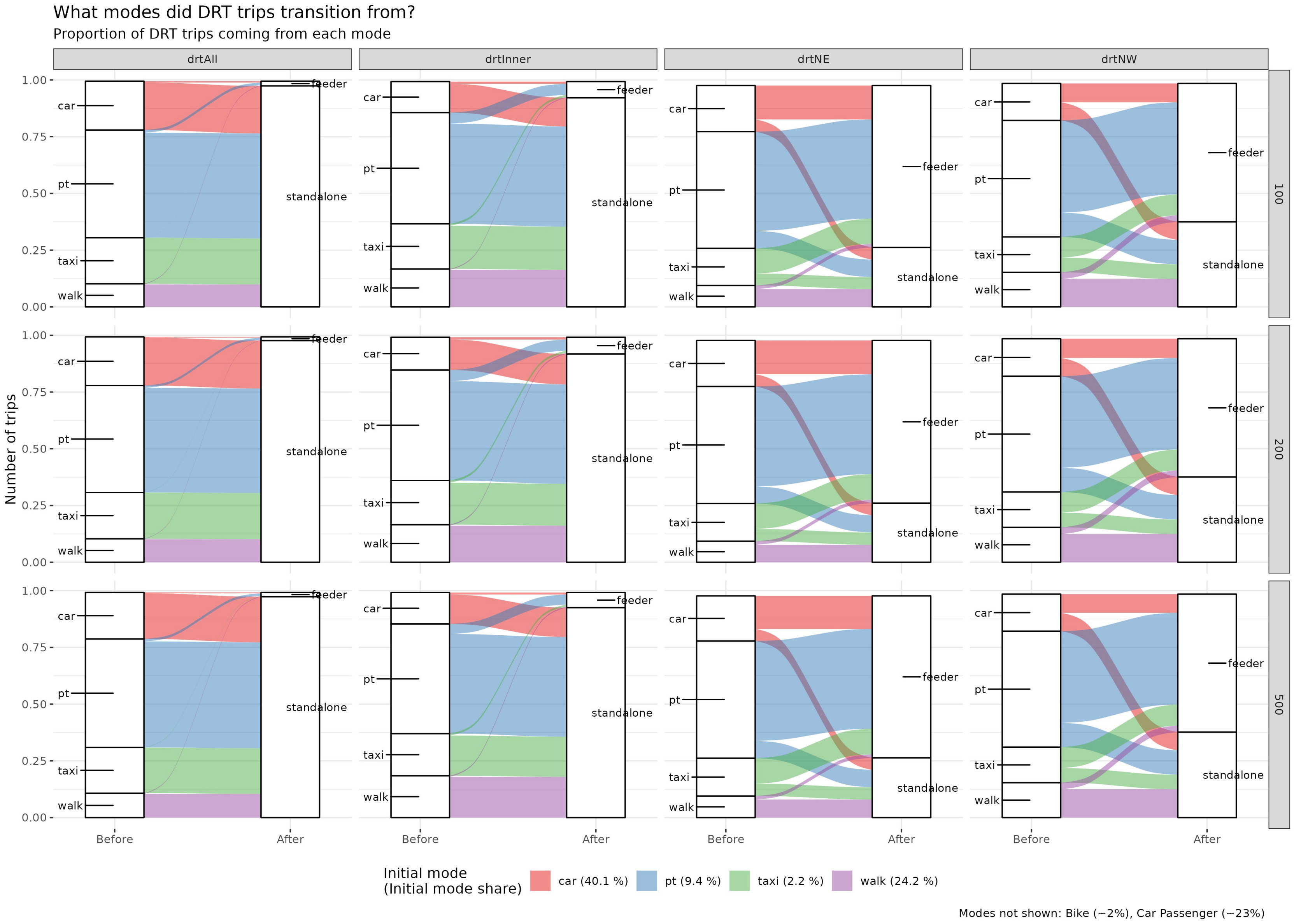


RESULTS

DRT INTEGRATION WITH PUBLIC TRANSPORT (FEEDER DRT USAGE)

FEEDER DRT USAGE

FEEDER VS STANDALONE

Table 5: DRT feeder statistics
Distinguishing between standalone and feeder DRT trips

Fleet size	Scenario	Distance travelled (km)		No. of trips		PT connections	
		Alone	Feeder (%)	Alone	Feeder (%)	Avg feeder trips per bus route served	Avg feeder trips per bus route served (top 5)
100	drtAll	123474	70 (0%)	47975	1164 (2%)	2	4
	drtInner	90451	302 (0%)	26296	2370 (8%)	4	13
	drtNE	6750	5470 (45%)	377	966 (72%)	41	131
	drtNW	7905	1026 (11%)	590	967 (62%)	24	95
200	drtAll	237545	190 (0%)	49341	1201 (2%)	2	7
	drtInner	168218	626 (0%)	27465	2403 (8%)	8	23
	drtNE	6803	5686 (46%)	376	971 (72%)	42	133
	drtNW	7970	1024 (11%)	594	968 (62%)	24	96
500	drtAll	523342	490 (0%)	52619	1236 (2%)	4	17
	drtInner	345325	1352 (0%)	30149	2450 (8%)	14	43
	drtNE	6957	5957 (46%)	379	968 (72%)	42	133
	drtNW	7967	1020 (11%)	595	965 (62%)	24	96
1000	drtAll	876792	798 (0%)	57150	1332 (2%)	6	27
	drtInner	488106	2051 (0%)	32317	2517 (7%)	19	59
	drtNE	7209	6150 (46%)	383	966 (72%)	42	133
	drtNW	7947	1015 (11%)	593	964 (62%)	24	95

FEEDER DRT USAGE

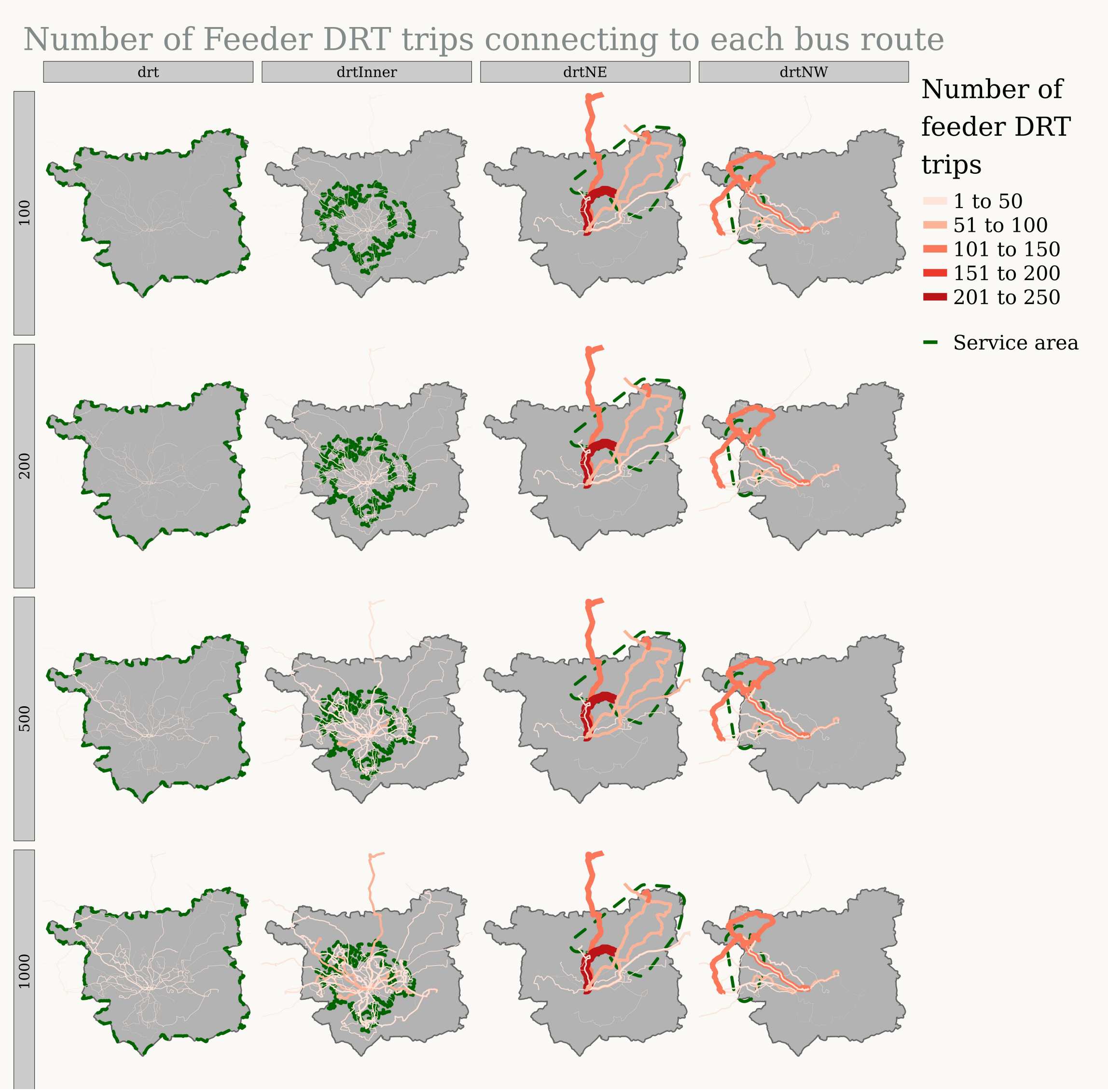
FEEDER VS STANDALONE

Table 5: DRT feeder statistics
Distinguishing between standalone and feeder DRT trips

Fleet size	Scenario	Distance travelled (km)		No. of trips		PT connections	
		Alone	Feeder (%)	Alone	Feeder (%)	Avg feeder trips per bus route served	Avg feeder trips per bus route served (top 5)
100	drtAll	123474	70 (0%)	47975	1164 (2%)	2	4
	drtInner	90451	302 (0%)	26296	2370 (8%)	4	13
	drtNE	6750	5470 (45%)	377	966 (72%)	41	131
	drtNW	7905	1026 (11%)	590	967 (62%)	24	95
200	drtAll	237545	190 (0%)	49341	1201 (2%)	2	7
	drtInner	168218	626 (0%)	27465	2403 (8%)	8	23
	drtNE	6803	5686 (46%)	376	971 (72%)	42	133
	drtNW	7970	1024 (11%)	594	968 (62%)	24	96
500	drtAll	523342	490 (0%)	52619	1236 (2%)	4	17
	drtInner	345325	1352 (0%)	30149	2450 (8%)	14	43
	drtNE	6957	5957 (46%)	379	968 (72%)	42	133
	drtNW	7967	1020 (11%)	595	965 (62%)	24	96
1000	drtAll	876792	798 (0%)	57150	1332 (2%)	6	27
	drtInner	488106	2051 (0%)	32317	2517 (7%)	19	59
	drtNE	7209	6150 (46%)	383	966 (72%)	42	133
	drtNW	7947	1015 (11%)	593	964 (62%)	24	95

FEEDER DRT USAGE

FEEDER POOLING EFFECTIVENESS: NUMBER OF FEEDER TRIPS PER UNIQUE BUS ROUTE



- Zone-based DRT services
  - lead to feeder trips being concentrated to a smaller number of bus routes
  - Could improve ridership on those routes.
  - Positive feedback loops?
- City-wide DRT service
  - feeds bus routes all over the city.
  - May not increase ridership sufficiently on any routes to warrant improved headway

RESULTS

OPERATIONAL EFFICIENCY OF DRT

OVERALL DRT USAGE

VEHICLE OCCUPANCY

Table 6: Vehicle and passenger distance travelled

Fleet size	Scenario	Passenger			Vehicle			
		Km travelled	Avg distance per trip	Avg distance per vehicle	Km travelled	Avg distance per trip	Avg distance per vehicle	pkm / vkm
100	drtAll	123544	24.3	1235	78631	19.7	786	1.57
	drtInner	90755	15.5	908	64765	13.4	648	1.40
	drtNE	12221	9.5	122	12946	11.6	129	0.94
	drtNW	8929	5.3	89	9014	6.1	90	0.99
200	drtAll	237735	23.8	1189	149112	19.1	746	1.59
	drtInner	168844	15.3	844	119039	13.1	595	1.42
	drtNE	12488	9.5	62	12447	10.9	62	1.00
	drtNW	8993	5.3	45	8251	5.6	41	1.09
500	drtAll	523831	23.1	1048	328035	18.9	656	1.60
	drtInner	346679	15.1	693	238650	12.6	477	1.45
	drtNE	12914	9.8	26	12108	10.6	24	1.07
	drtNW	8986	5.5	18	7603	5.1	15	1.18
1000	drtAll	877589	22.2	878	561330	17.6	561	1.56
	drtInner	490158	14.9	490	332907	12.0	333	1.47
	drtNE	13360	9.7	13	12056	10.1	12	1.11
	drtNW	8963	5.5	9	7234	4.8	7	1.24

RESULTS

OVERALL VKM

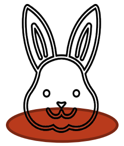
OVERALL VKM

CHANGE IN VKM OF DIFFERENT MODES

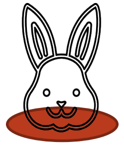
Table 7: VKM change per mode
Values are in Thousands of KM

	Scenario	DRT	Car	Taxi	Total
100	drtAll	79	-216 (-3%)	-88 (-48%)	-226 (-4%)
	drtInner	65	-74 (-1%)	-55 (-30%)	-64 (-1%)
	drtNE|NW	22	-16 (-0%)	-11 (-6%)	-5 (-0%)
200	drtAll	149	-213 (-3%)	-88 (-47%)	-152 (-2%)
	drtInner	119	-70 (-1%)	-54 (-29%)	-6 (-0%)
	drtNE|NW	21	-16 (-0%)	-11 (-6%)	-6 (-0%)
500	drtAll	328	-205 (-3%)	-86 (-47%)	36 (1%)
	drtInner	239	-65 (-1%)	-53 (-29%)	121 (2%)
	drtNE|NW	20	-16 (-0%)	-11 (-6%)	-7 (-0%)
1000	drtAll	561	-195 (-3%)	-85 (-46%)	281 (4%)
	drtInner	333	-61 (-1%)	-52 (-28%)	220 (3%)
	drtNE|NW	19	-16 (-0%)	-11 (-6%)	-7 (-0%)

How to read: Each value shows the actual VKT change in thousands of km (with percent change in brackets). The DRT column reports total DRT vehicle kilometres travelled (not net change).



DRT fleet rebalancing



DRT utility calculation vs actual performance

Discussion – Trade-offs And Intermodal Potential

Overview of results

- We took a vision-led approach, integrating DRT fares with PT.
  - This reflects a public service mindset rather than a market-driven one, and supports system-wide outcomes like increased PT ridership.
- Operator-oriented DRT boosts efficiency
  - Higher pooling rates, lower rejections
  - But replaces PT/walk trips → net VKT increase
- Feeder-oriented DRT supports environmental goals
  - Encourages PT use, preserves walking and cycling
- Feeder DRT enables intermodal feedback loops
  - Increased PT access → higher ridership → potential service improvements
- Policy context matters
  - Without parking charges, tolls, or differentiated fares, DRT may not induce desired mode shift

Key modelling limitations

- Simplified mode choice (DRT = bus utility)
- Static fleet assumptions (could change throughout day)
- Limited representation of wait times and rejections

Future directions

Modelling improvements

- Custom mode choice models
- Improved *DRT utility integration with actual user experience (See G. Kagho thesis, Chapter 3)*
- Account for car parking time and cost

Conceptual innovations

- Dynamic fleet sizing and service areas
  - Fleet size can change temporally based on demand
  - ***Service areas based on spatiotemporal clustering*** *(Yao et al. 2018)*

G. Kagho, Planning for the future of transport with agent-based modelling: The role of on-demand mobility services, Ph.D. thesis, ETH Zurich (2023).
Yao, X., Zhu, D., Gao, Y., Wu, L., Zhang, P., Liu, Y., 2018. A stepwise spatio-temporal flow clustering method for discovering mobility trends. Ieee Access 6, 44666–44675.

THANK YOU :)

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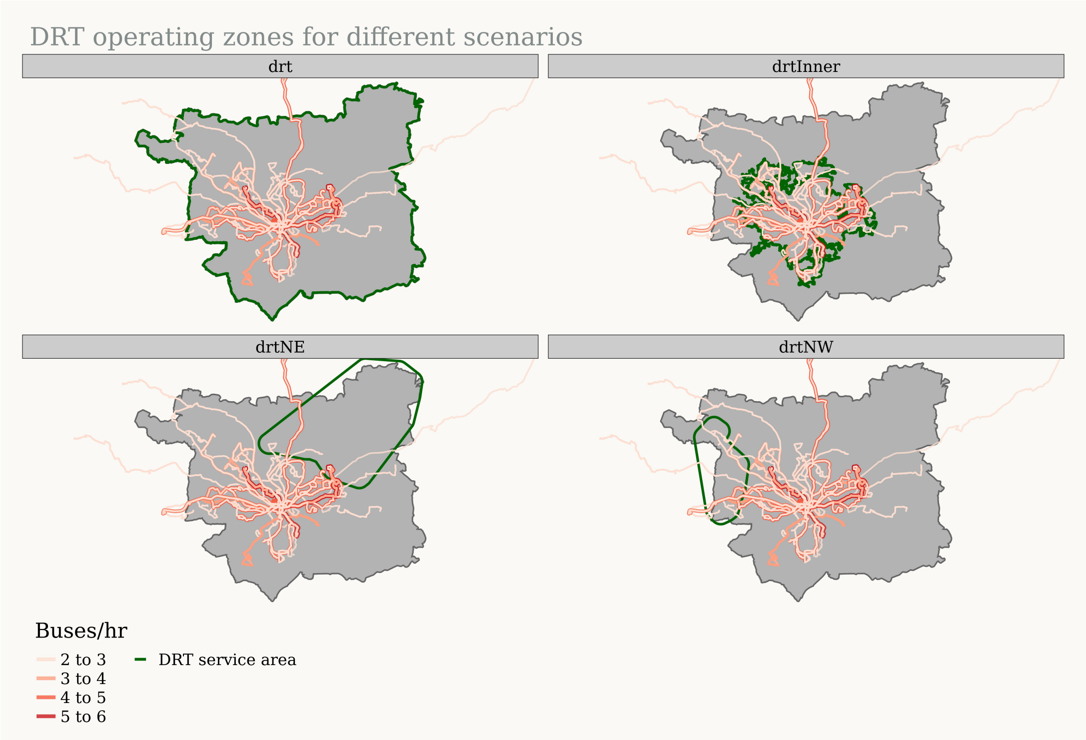
https://github.com/Hussein-Mahfouz/matsim-drt

Research Questions

- How does the delineation of a DRT **service area**, designed with a feeder service in mind, affect mode share and DRT usage compared to a service area designed from an operator perspective to maximise cost recovery?

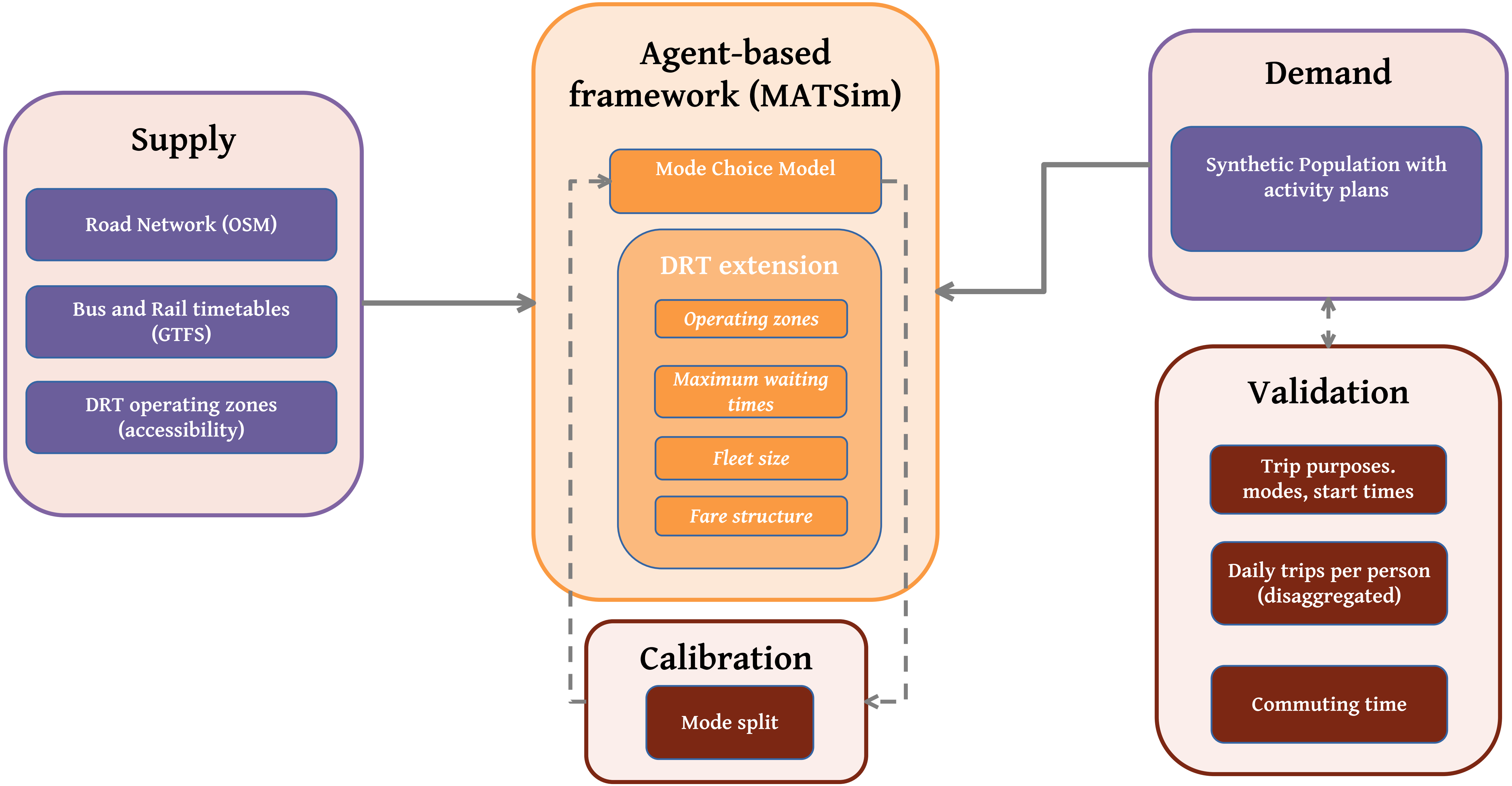
- What impact do service areas designed for **DRT as a feeder mode** have on pooling efficiency and the reduction of overall VKT in the network?

- What is the trade-off between **environmental considerations** (e.g., reducing VKT) and service quality (e.g., increasing fleet size to improve waiting and travel times) in DRT deployments on the urban periphery?



Scenario	Population	Trips						
		Car	Car (Passenger)	PT	Taxi	Walk	Bicycle	Total
drtAll	354,618	419,175 (40.1%)	250,526 (24%)	98,101 (9.4%)	23,111 (2.2%)	252,779 (24.2%)	1,858 (0.2%)	1,045,550
drtInner	221,443	288,125 (38.5%)	183,404 (24.5%)	71,028 (9.5%)	16,479 (2.2%)	187,488 (25.1%)	1,346 (0.2%)	747,670
drtNE	32,935	28,647 (53.1%)	11,633 (21.6%)	5,005 (9.3%)	1,433 (2.7%)	7,068 (13.1%)	135 (0.3%)	53,921
drtNW	37,990	35,548 (41%)	19,780 (22.8%)	7,548 (8.7%)	1,644 (1.9%)	22,074 (25.5%)	118 (0.1%)	86,712

Context: Simulation Framework



Context: Transport Supply (DRT)

Flow Clustering

What is it?

- Trying to detect spatial patterns using spatial proximity measures
- Methods
  - Identify **IF** there are clusters: Ripley's K, L function, G
  - Identify **WHERE** the clusters are: DBSCAN, HDBSCAN, OPTICS

Why use it

- Identifying concentrated demand clusters could help address one of the main reasons for high DRT failure rates - unnecessarily flexible 'many-to-many' services – by constraining the service to clusters of high demand that is not satisfied by PT

Method used

- Tao and Thill (2016)

Supply

Road Network (OSM)

Bus and Rail timetables (GTFS)

DRT operating zones

Tao, R., & Thill, J.-C. (2016). A density-based spatial flow cluster detection method. International Conference on GIScience Short Paper Proceedings, 1. https://doi.org/10.21433/B3118MF4R9RW

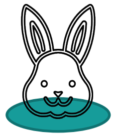
Context: Transport Supply (DRT)

Supply

Road Network (OSM)

Bus and Rail timetables (GTFS)

DRT operating zones



Spatiotemporal clustering

Context: Transport Supply (DRT **Configuration**)

Table 2: Summary of DRT input parameters

Input variable	Symbol	Value	Note
maxWaitTime	—	10 min	Maximum time a passenger waits for pickup before request rejection
maxTravelTimeAlpha	α_{travel}	1.5	Multiplier for direct ride time to calculate allowable total travel time
maxTravelTimeBeta	β_{travel}	5 min	Fixed buffer added to direct ride time for total travel time
maxDetourAlpha	α_{detour}	∞ (default)	Proportion of direct ride time allowed as detour
maxDetourBeta	β_{detour}	∞ (default)	Fixed time added to detour allowance
minimumAllowedDetour	t_{min}	0 min (default)	Lower limit on detour time
maxAbsoluteDetour	t_{absMax}	∞ (default)	Upper limit on total detour time
Stop duration	—	15 s	Time allocated for vehicle stops during pick-up/drop-off
Rebalancing interval	—	30 min	Interval for redistributing idle vehicles in the network
Repositioning grid size	—	500 m $\times$ 500 m	Resolution of the grid used for vehicle repositioning

Context: Transport Demand (AcBM)

github.com/Urban-Analytics-Technology-Platform/acbm/tree/62-documentation-for-repo?tab=readme-ov-file

README Code of conduct License

acbm

CI passing

A package to create activity-based models (for transport demand modelling)

Step 1: Prepare Data Inputs

You need to populate the data/external directory with the required datasets. A guide on where to find / generate each dataset can be found in the [data/external/README.md]

Step 2: Setup your config.toml file

You need to create a config file in the config directory. The config file is a toml file that contains the parameters for the pipeline. A guide on how to set up the config file can be found in the [config/README.md]

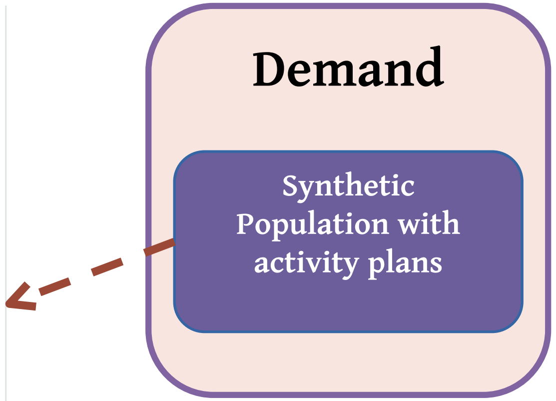
Step 3: Run the pipeline

The scripts are listed in order of execution in the scripts/run_pipeline.sh bash file

You can run the pipeline by executing the following command in the terminal from the base directory:

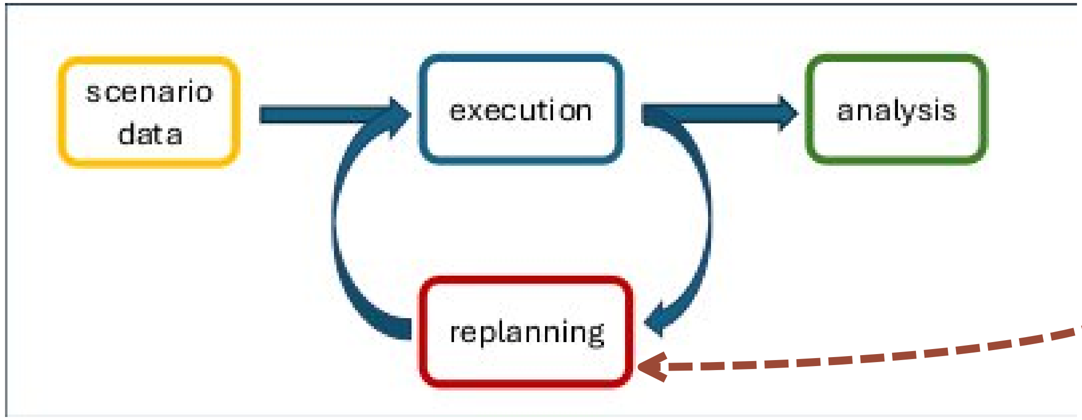
```
bash ./scripts/run_pipeline.sh config/<your_config_file>.toml
```

where your config file is the file you created in Step 2.



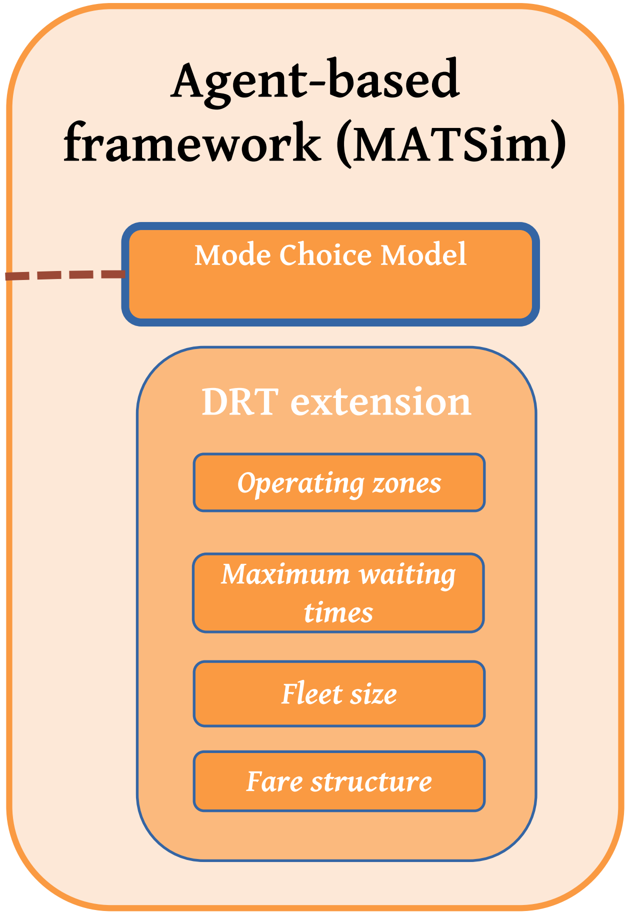
- ✓ Command line tool (uses a config file)
- ✓ Example notebooks
- ✓ Wiki
- ✓ Open issues :)

Context: Mode Choice Model



- **Replanning**
  - Use DCM model to calculate utility of fulfilling plan with all feasible chain combinations
  - E.g. : {walk - pt - pt - walk} , {car, car}, {bicycle, bicycle}, {bicycle, pt, pt, bicycle} etc
  - For specified % of people, select chain based on utility
- **Execution**
  - utility changes at each iteration due to network conditions

$$\mathbb{P}(j) = \frac{\exp(U_j)}{\sum_i \exp(U_i)}$$



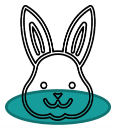
Hörl, S., Balac, M., & Axhausen, K. W. (2018). A first look at bridging discrete choice modeling and agent-based microsimulation in MATSim. *Procedia computer science*, *130*, 900-907.
Hörl, S., Balać, M., & Axhausen, K. W. (2019). Pairing discrete mode choice models and agent-based transport simulation with MATSim. In *2019 TRB annual meeting online* (pp. 19-02409). Transportation Research Board.

Context: Mode Choice Model

- **Mode choice model**
  - from *Tsoleridis* et. al (2022)
  - Modes available:
    - Car, Bus, Rail, Walk, Cycle, Taxi
    - no DRT
    - Bus and rail are different services

- **Utility of DRT**
  - DRT mode choice parameters taken from PT
    - Justification: I am modeling DRT as an extension to the PT service, not as a competing mode
  - Alternatives: Hybrid (Rath et. al 2023); From Taxi (Basu et al. 2018); Bespoke MNL with DRT included

- **Utility of feeder DRT**
  - Utility PT leg + Utility DRT leg



How to calculate utility of trips with DRT feeder leg?

- **DRT and PT fare integration**
  - Fare for feeder is lower than fare for standalone DRT trip
  - If DRT only -> fare = fare(DRT)
  - If DRT + PT -> fare = fare(PT) i.e. hopper fare – NOT fare(PT) + fare(DRT)

Basu, R, A. Araldo, A. P. Akkinepally, B. H. Nahmias Biran, K. Basak, R. Seshadri, N. Deshmukh, N. Kumar, C. L. Azevedo, M. Ben-Akiva, Automated mobility-on-demand vs. mass transit: a multi-modal activity-driven agent-based simulation approach, Transportation Research Record 2672 (8) (2018)
Räth, Y. M. , M. Balac, S. Hörl, K. W. Axhausen, Assessing service characteristics of an automated transit on-demand service, Journal of Urban Mobility 3 (2023)
Tsoleridis, Panagiotis, Charisma F. Choudhury, and Stephane Hess. "Deriving transport appraisal values from emerging revealed preference data." Transportation Research Part A: Policy and Practice 165 (2022)

Context: Mode Choice Model

$$U_{\text{car}} = \beta_{\text{time, car}} \cdot \frac{(\text{TravelTime})^{\lambda_{\text{car}}} - 1}{\lambda_{\text{car}}} + \beta_{\text{cost, car}} \cdot \ln(\text{TravelCost}) + \beta_{\text{commute, car}} \cdot \mathbb{1}(\text{Commute}) + \beta_{\text{am, car}} \cdot \mathbb{1}(\text{AM Peak}) + \beta_{\text{pm, car}} \cdot \mathbb{1}(\text{PM Peak})$$

$$U_{\text{rail}} = \text{ASC}_{\text{rail}} + \beta_{\text{IVT, rail}} \cdot \text{IVT} + \left(\beta_{\text{OVT, rail}} \cdot \left(\frac{\text{Income}}{\text{RefIncome}}\right)^{\epsilon_{\text{rail}}}\right) \cdot \frac{(\text{OVT})^{\lambda^{\text{OVT}}_{\text{rail}}} - 1}{\lambda^{\text{OVT}}_{\text{rail}}} + \beta_{\text{cost, rail}} \cdot \ln(\text{TravelCost}) + \beta_{\text{peak, rail}} \cdot \mathbb{1}(\text{AM or PM}) + \beta_{\text{incomeNR, rail}} \cdot \mathbb{1}(\text{Income Not Reported})$$

$$U_{\text{bike}} = \text{ASC}_{\text{bike}} + \beta_{\text{time, bike}} \cdot \frac{(\text{TravelTime})^{\lambda_{\text{bike}}} - 1}{\lambda_{\text{bike}}} + \beta_{\text{male, bike}} \cdot \mathbb{1}(\text{Male}) + \beta_{\text{income10-20k, bike}} \cdot \mathbb{1}(\text{Income 10–20k}) + \beta_{\text{income75-100k, bike}} \cdot \mathbb{1}(\text{Income 75–100k}) + \beta_{\text{incomeNR, bike}} \cdot \mathbb{1}(\text{Income Not Reported}) + \beta_{\text{weekend, bike}} \cdot \mathbb{1}(\text{Weekend}) + \beta_{\text{student, bike}} \cdot \mathbb{1}(\text{Student}) + \beta_{\text{unemployed, bike}} \cdot \mathbb{1}(\text{Unemployed})$$

$$U_{\text{bus}} = \text{ASC}_{\text{bus}} + \beta_{\text{IVT, bus}} \cdot \frac{(\text{IVT})^{\lambda_{\text{bus}}} - 1}{\lambda_{\text{bus}}} + \left(\beta_{\text{OVT, bus}} \cdot \left(\frac{\text{Income}}{\text{RefIncome}}\right)^{\epsilon_{\text{bus}}}\right) \cdot \frac{(\text{OVT})^{\lambda^{\text{OVT}}_{\text{bus}}} - 1}{\lambda^{\text{OVT}}_{\text{bus}}} + \beta_{\text{cost, bus}} \cdot \ln(\text{TravelCost}) + \beta_{\text{peak, bus}} \cdot \mathbb{1}(\text{AM or PM}) + \beta_{\text{weekend, bus}} \cdot \mathbb{1}(\text{Weekend}) + \beta_{\text{income, bus}} \cdot \mathbb{1}(\text{High Income}) + \beta_{\text{unemployed, bus}} \cdot \mathbb{1}(\text{Unemployed})$$

$$U_{\text{taxi}} = \text{ASC}_{\text{taxi}} + \beta_{\text{time, taxi}} \cdot \frac{(\text{TravelTime})^{\lambda_{\text{taxi}}} - 1}{\lambda_{\text{taxi}}} + \beta_{\text{cost, taxi}} \cdot \ln(\text{TravelCost}) + \beta_{\text{male, taxi}} \cdot \mathbb{1}(\text{Male}) + \beta_{\text{age18-24, taxi}} \cdot \mathbb{1}(\text{Age 18–24}) + \beta_{\text{age25-29, taxi}} \cdot \mathbb{1}(\text{Age 25–29}) + \beta_{\text{lowEdu, taxi}} \cdot \mathbb{1}(\text{Low Education}) + \beta_{\text{income40-50k, taxi}} \cdot \mathbb{1}(\text{Income 40–50k}) + \beta_{\text{am, taxi}} \cdot \mathbb{1}(\text{AM Peak}) + \beta_{\text{pm, taxi}} \cdot \mathbb{1}(\text{PM Peak})$$

$$U_{\text{walk}} = \text{ASC}_{\text{walk}} + \beta_{\text{time, walk}} \cdot \frac{(\text{TravelTime})^{\lambda_{\text{walk}}} - 1}{\lambda_{\text{walk}}} + \beta_{\text{age18-29, walk}} \cdot \mathbb{1}(\text{Age 18–29}) + \beta_{\text{lowEdu, walk}} \cdot \mathbb{1}(\text{Low Education}) + \beta_{\text{weekend, walk}} \cdot \mathbb{1}(\text{Weekend}) + \beta_{\text{student, walk}} \cdot \mathbb{1}(\text{Student})$$

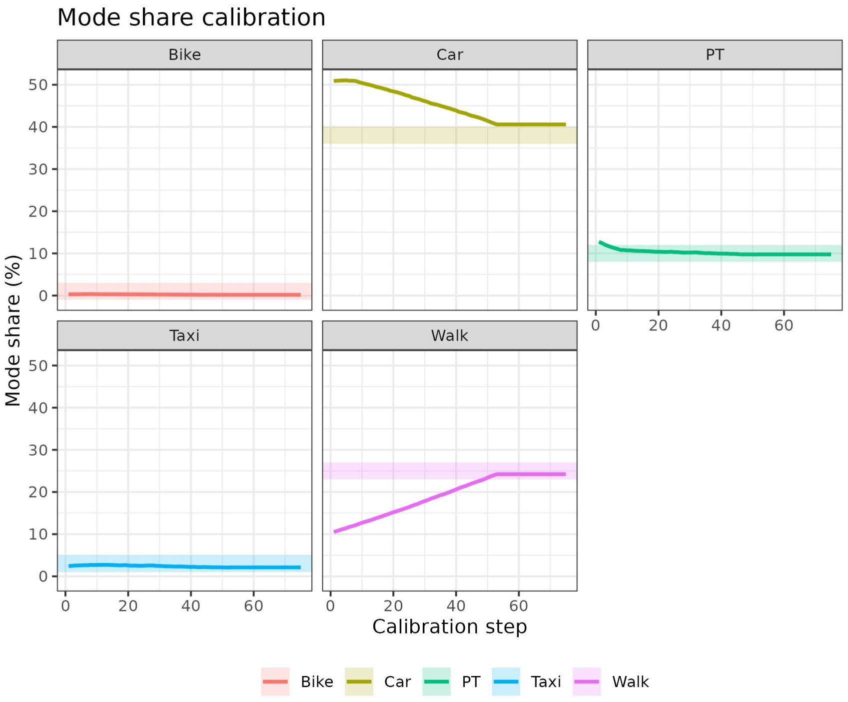
Tsoleridis, Panagiotis, Charisma F. Choudhury, and Stephane Hess. "Deriving transport appraisal values from emerging revealed preference data." Transportation Research Part A: Policy and Practice 165 (2022)

Context: Mode Choice Model

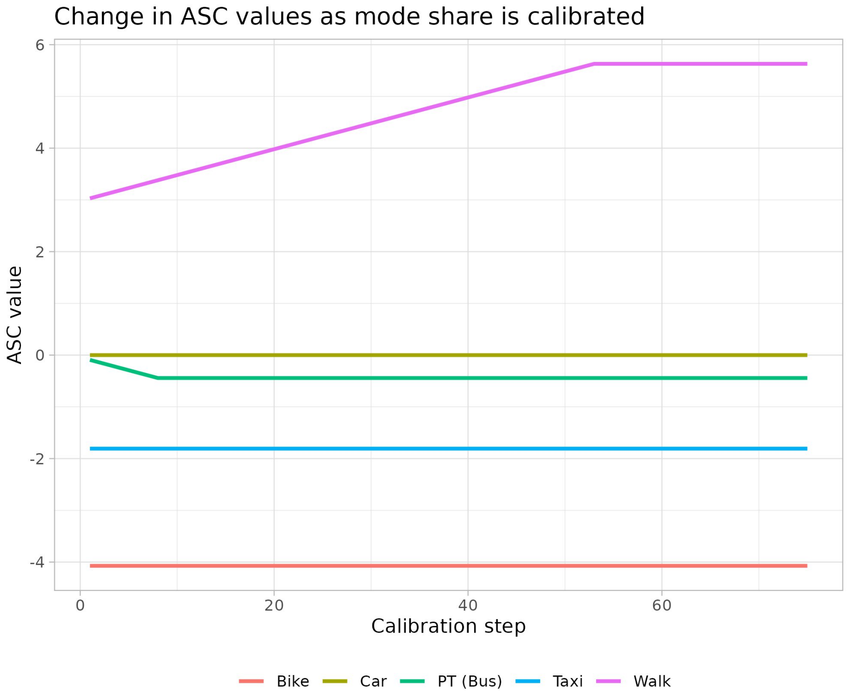
Parameter	Car	Bike	Walk	Taxi	Bus	Rail
alpha_u	0	-4.0728	3.0294	-1.8075	-0.0929	2.4421
betaCommuting	-0.1478	NA	NA	NA	NA	NA
betaAmPeak	-0.1637	NA	NA	-0.1709	NA	NA
betaPmPeak	0.1282	NA	NA	-0.1423	NA	NA
lambdaTravelTime	0.5424	0.5424	0.5424	0.5424	0.5424	0.5424
betaMale	NA	1.1047	NA	-0.6434	NA	NA
betaStudent	NA	1.1559	0.6964	NA	NA	NA
betaIncome10kto20k	NA	0.802	NA	NA	NA	NA
betaIncome75kto100k	NA	3.515	NA	NA	NA	NA
betaAge18to29	NA	NA	0.6964	NA	NA	NA
betaTravelTime_u_min	NA	NA	NA	-0.4525	NA	NA
betaAge18to24	NA	NA	NA	1.5014	NA	NA
betaAge25to29	NA	NA	NA	0.9324	NA	NA
betaIncome40kto50k	NA	NA	NA	-0.7975	NA	NA
betaInVehicleTime_u_min	NA	NA	NA	NA	-0.1281	-0.008
betaOutofVehicleTime_u_min	NA	NA	NA	NA	-1.1484	-1.7365
betaAmPmPeak	NA	NA	NA	NA	-0.0998	-0.0327
betaIncome50k	NA	NA	NA	NA	-1.1902	-1.1902
lambdaOutofVehicleTime	NA	NA	NA	NA	0.1452	0.1452

Tsoleridis, Panagiotis, Charisma F. Choudhury, and Stephane Hess. "Deriving transport appraisal values from emerging revealed preference data." Transportation Research Part A: Policy and Practice 165 (2022)

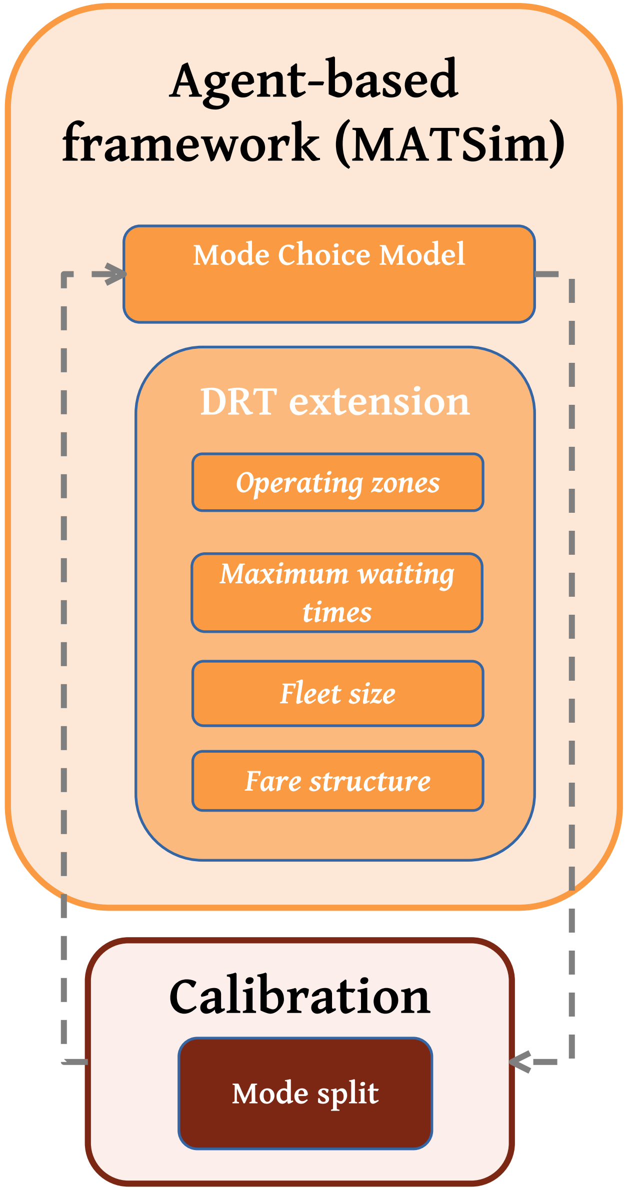
Context: Model Calibration



Mode share at each iterative calibration step. Each step represents a full simulation (with 70 iterations). Car passenger trips are excluded from the calibration as the mode choice model does not explicitly have utility equation for car passengers



ASC values at each calibration step. The ASC for car is fixed at 0. The ASC for rail is also fixed (2.44) because the reference mode shares for public transport (PT) are aggregated and not disaggregated into bus and rail. Therefore, calibration to the overall PT share is achieved by adjusting only the bus ASC



Same method as: M. Prédhumeau, E. Manley, Agent-based modelling of older adult needs for autonomous mobility-on-demand: a case study in Winnipeg, Canada, Transportation (2025) 1–32 doi:10.1007/s11116-025-10590-0.

OVERALL DRT USAGE

VEHICLE OCCUPANCY