Exploring Variation in Built Environment Predictors of Ridership by Transit Mode

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Study Context

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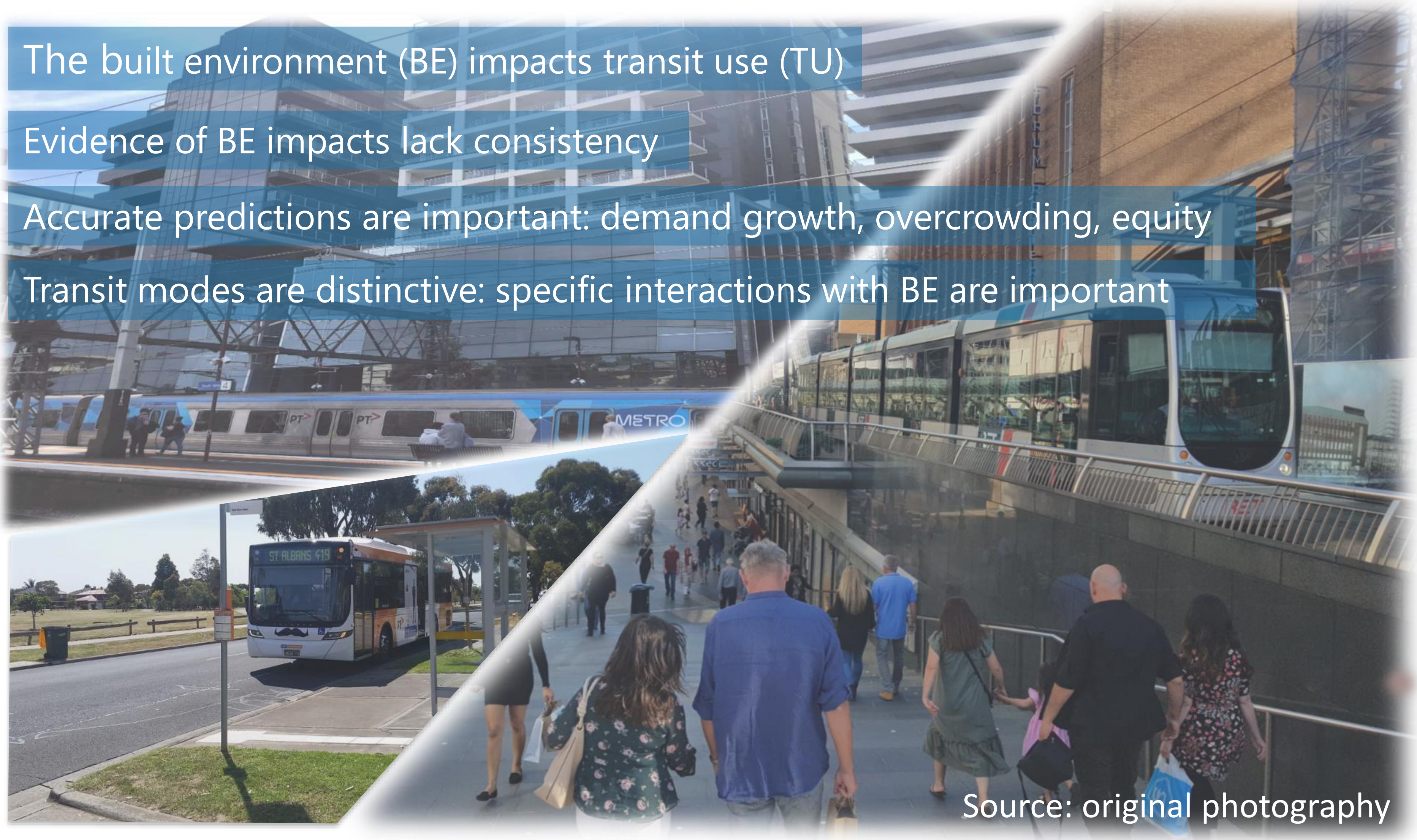
- The built environment (BE) impacts transit use (TU)
- Evidence of BE impacts lack consistency
- Accurate predictions are important: demand growth, overcrowding, equity
- Transit modes are distinctive: specific interactions with BE are important



Source: original photography

Study Aim and Approach

Aim	Identify the built environment attributes that significantly relate to ridership of different transit modes, while accounting for variability in the location characteristics of modes

Research Setting: Greater Metropolitan Melbourne

Sample: Co-located transit modes ('clusters') comprising:
- Bus and tram (n = 341)
- Bus and train (n = 141)

Method:
- Aggregate analysis of station-level ridership and built environment, sociodemographic and service level variables.
- Data reduction using factor analysis.
- Multivariate multiple linear regression accounts for inter-depence of co-located modes.

Developing an unbiased sampling strategy

Problem: Modes serve different functions and are competitive in different urban environments.

- The BE characteristics of station access/egress and transfer catchments in Melbourne differ by mode (Table below).
- This causes bias in the sample

	Ref	Tram	Train	Bus
Walk radius of catchment (m)		600	800	400
Employment density (employees/ km²)	2	7,400	2,450	898
Population density (persons/ km²)	3	4,980	3,020	2,450
Retail density (retail employees/ km²)	4	480	199	94.4
Attraction-generation balance	5	0.15	0.10	0.08
Pedestrian Connectivity (Intersection density)	7	115	89.7	13.4
Distance to CDB		6.26	16.9	22.9
Local accessibility (destination score)	9	1.40	1.42	1.54

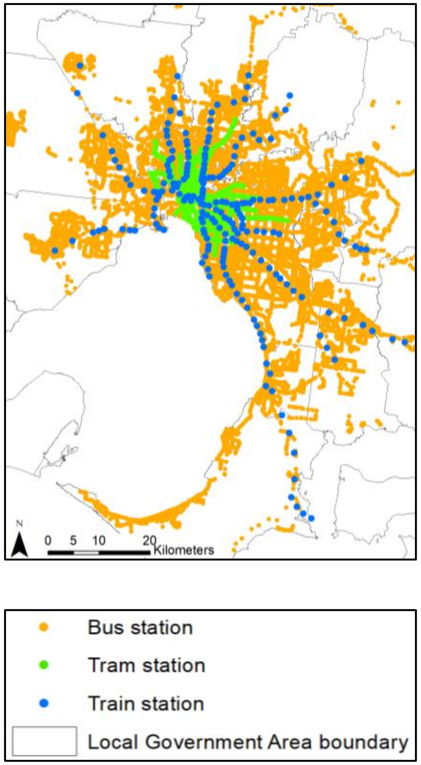
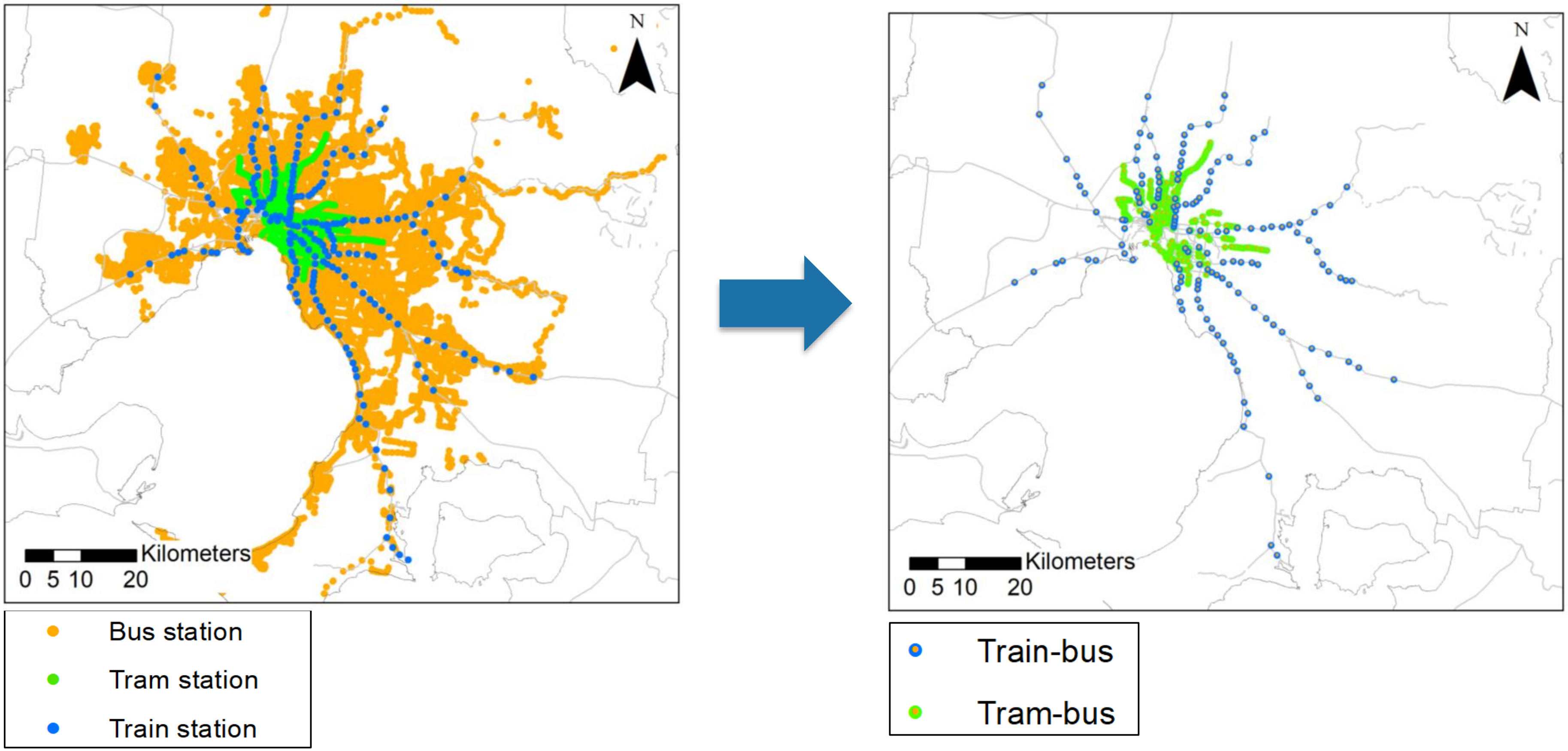


Figure: Distribution of transit stops by mode in Greater Metropolitan Melbourne

Methodology

Developing an unbiased sampling strategy



Figures: (left) Distribution of transit stops by mode in Greater Metropolitan Melbourne and (right) location of sample sites for co-located train and bus (n = 147) and co-located tram and bus (n = 361 before excluding 20 sites in the free tram fare zone).

Variable aggregation

Travel behaviour:
Annual average (weekday) ridership (measured as station entries)

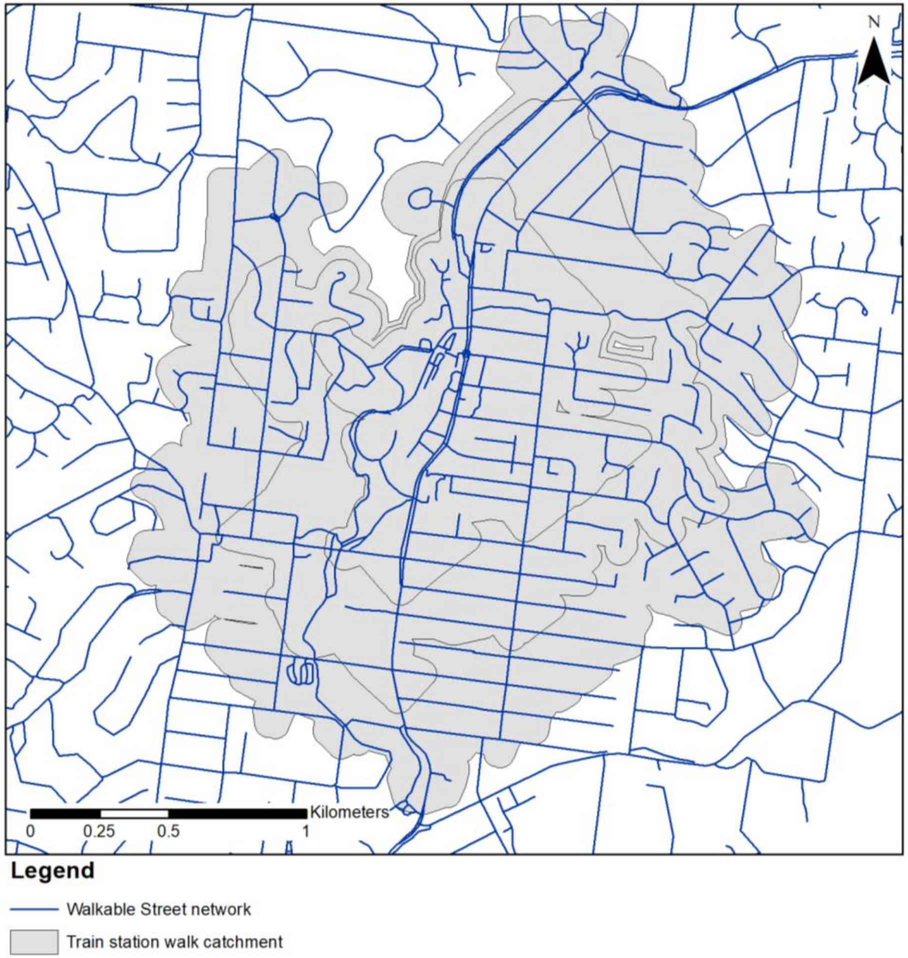
Built environment:

- Employment density
- Population density
- Commercial density
- Retail worker density
- Attraction-generation balance
- Land use diversity
- Housing diversity
- Intersections
- Cycle path length
- Destination score
- Destination count
- Distance to CBD
- Distance to Activity Centers
- Count of Activity Centers
- Proportion urban land
- Access to employment

Other variables:

- Bicycle facilities
- Car parking
- Level of service (departures/hour)
- Proportion full time employed
- Household income
- Household size
- Proportion born overseas
- Proportion tertiary educated

Figure: Walkable train station catchments (unit of analysis)



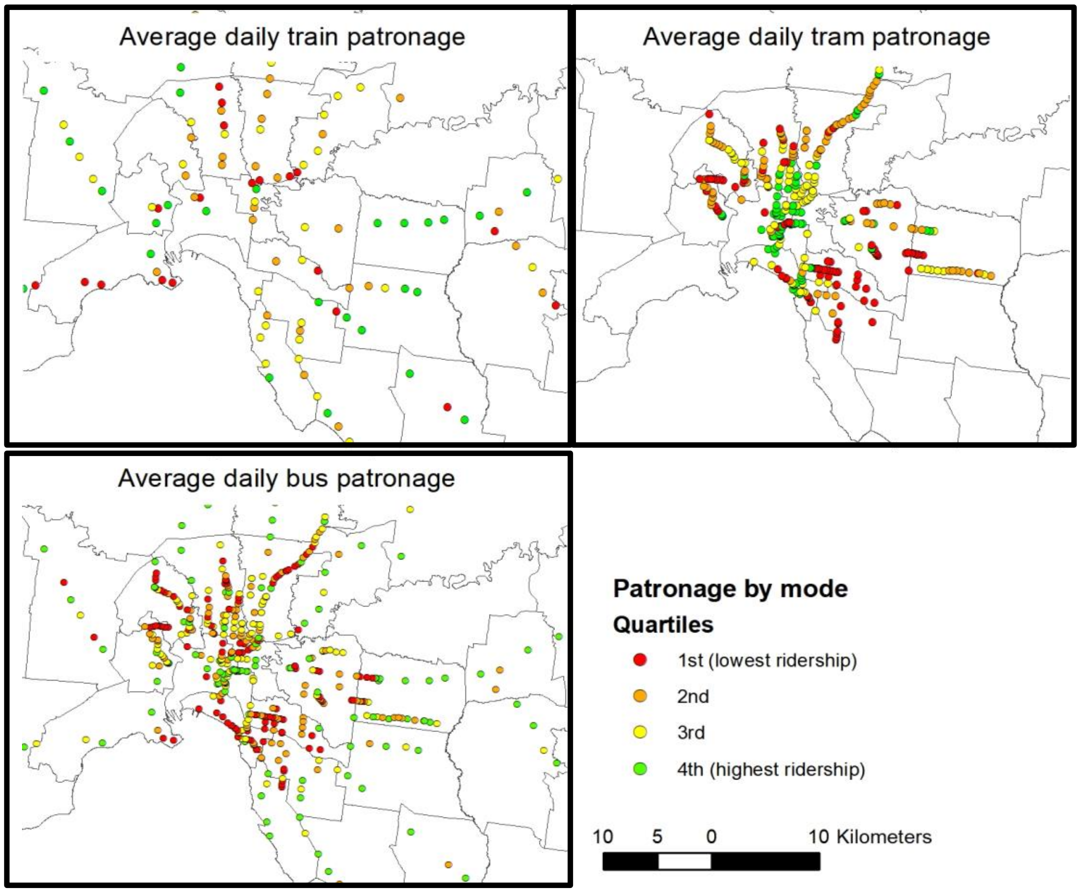
Descriptive Results: Built environment

	Ref	Tram-Bus[1]	Train-bus
Sample size (Clusters)		341	147
Centroid walkable buffer distance (m)		600	800
Built Environment Variables			
Employment density	2	2,770	1,120
Population density	3	4,270	2,690
Retail worker density	4	257	122
Attraction – generation balance	5	0.109	0.09
Housing diversity	6	7.5	6.8
Intersection density	7	107	86.4
Cycle path length (km)	8	0.19	0.18
Destination count	9	51.0	49.6
Distance to CBD (km)		8	18
Explanatory Variables			
Level of service (tram/train daily departures)	10	56.3	111
Level of service (bus daily departures)	10	39.6	67.1
Proportion full time employed	11	0.58	0.57

1 - Excludes tram-bus sites within Melbourne's free [fare] tram zone

Descriptive Results: Ridership

Figure: Distribution of patronage (average daily touch-ons) by quartiles for sample, by mode



Average ridership

	Tram-bus	Train-bus
Bus	85	456
Tram	358	
Train		2,500

Ridership covariance[2]

- Tram-bus: (weak): 0.29
- Train-bus: (strong): 0.66

2 – Covariance testing was performed on the natural logarithm of ridership, as this was the outcome variable analysed

Results: Tram-bus sample

Rank and direction of significant predictors of transit use

Tram Ridership (R^2 = 0.46)	Bus Ridership (R^2 = 0.44)
1. Level of service (+)	1. Level of service (+)
2. Access to employment (+)	2. Proportion tertiary educated (+)
3. Population density (ln) (+)	3. Population density (ln) (+)
4. Proportion overseas born (-)	4. Proportion full time employed (-)
5. Commercial density (+)	5. Commercial density (+)
6. Land use diversity (+)	6. Overlapping train level of service (+)

Key findings

- Tram and bus share two built environment variables (population and commercial density. The remaining predictors differed.
- The condition of joint significance of variables in the MMLR model and the weak covariance between bus and tram suggests the results of this regression unrepresentative of tram predictors in the network.

Results: Tram-bus sample

Rank and direction of significant predictors of transit use

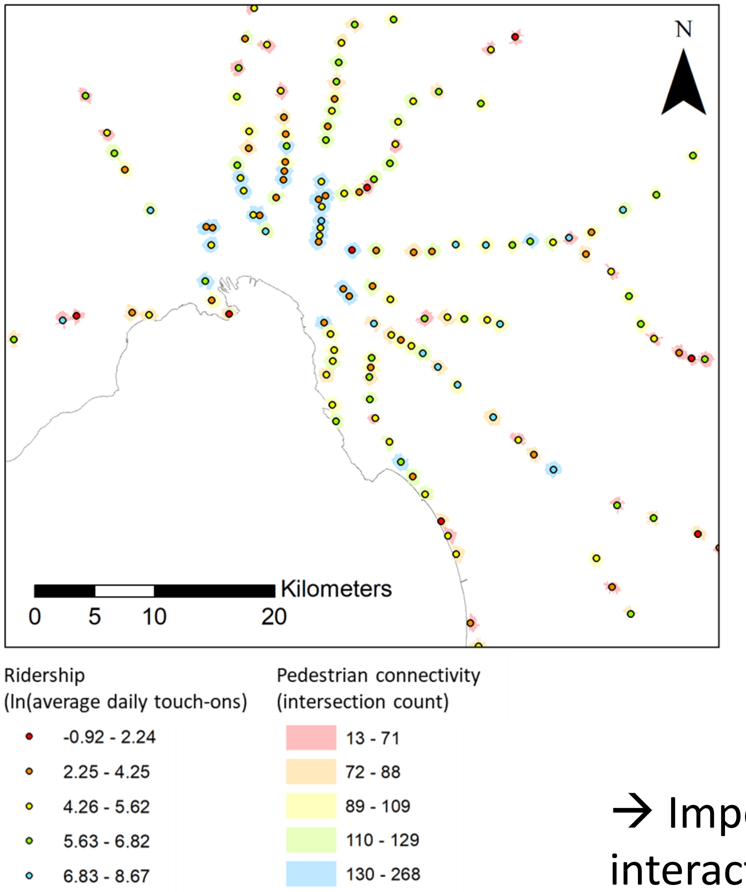
Train Ridership (R^2 = 0.62)	Bus Ridership (R^2 = 0.59)
1. Overlapping bus level of service (+)	1. Level of service (+)
2. Bicycle facilities (+)	2. Count of Activity Centers (+)
3. Level of service (+)	3. Land use balance (+)
4. Access to employment (+)	4. Distance to Activity Centers (+)
5. Population density (ln) (+)	5. Pedestrian connectivity (-)
6. Car parking (+)	6. Bicycle facilities (+)
	7. Overlapping train level of service (+)

Key findings

- Bus ridership is predicted by five BE variables, and train by four; one of which (bicycle facilities) is common to both.
- The strongest predictor of bus ridership in the was its own service frequency. Train ridership was also most strongly predicted by overlapping bus LOS, while its own frequency was the third strongest predictor.

Probing unexpected results for co-located bus: pedestrian connectivity

Pedestrian connectivity and bus ridership at Co-located train-bus stops



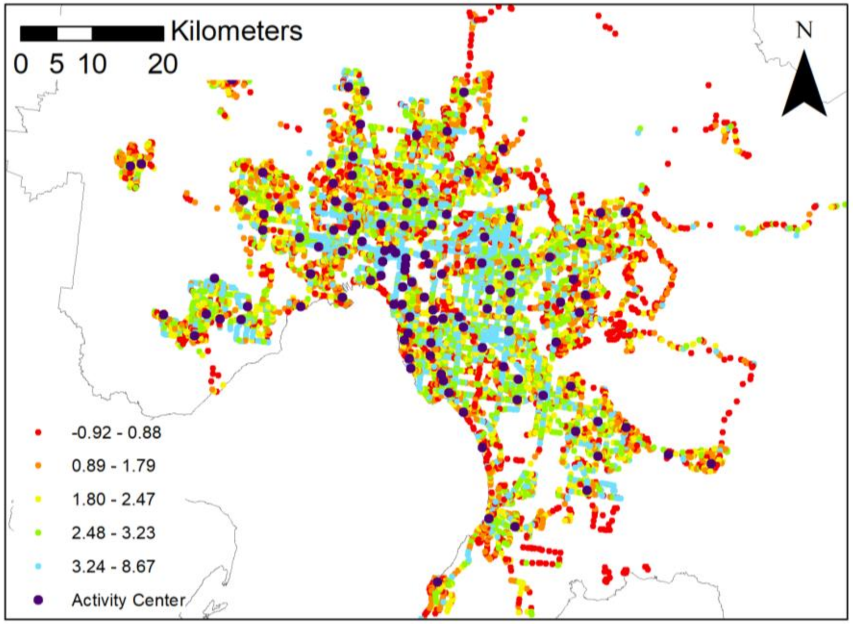
- Research suggests increasing crossing opportunities for pedestrians in transit catchments is associated with increasing transit use (Boulange 2017)
- Figure (inset) illustrates a lack of association between high ridership and high connectivity sites.
- Train stations are less well connected to the street network (Batty 2013).
- Because of its significant association with train ridership at train-bus sites it is included in MMLR.
- After accounting for interaction between modes, a negative relationship is identified for bus ridership and pedestrian connectivity.

→ Important to account for the function of modes, including interaction with other modes, when estimating demand

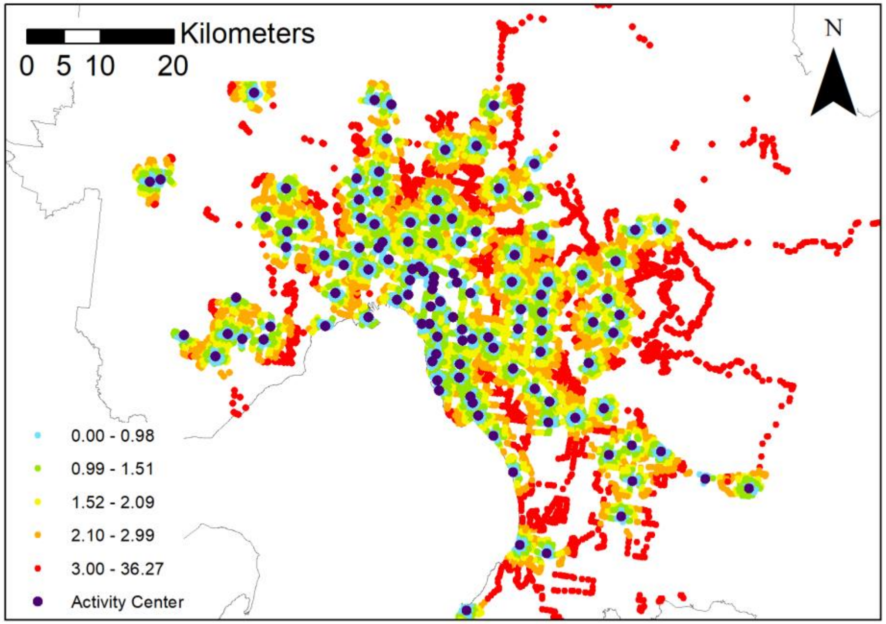
Probing unexpected results for co-located bus: Activity Center distance

- Accessibility to trip attractors such as Melbourne's 'Activity Centers' should increase demand for travel (Stevens 2017).
- Bus ridership was significantly associated with distance *away* from Activity Centers.
- Sensitivity testing revealed this finding was unaffected by collinearity with the related measure, *Count of Activity Centers*. Statistical associations were consistent when either was removed from the model.

Quintiles: Distance to nearest Activity Center (km)



Ridership quintiles [ln(average daily touch-ons)]

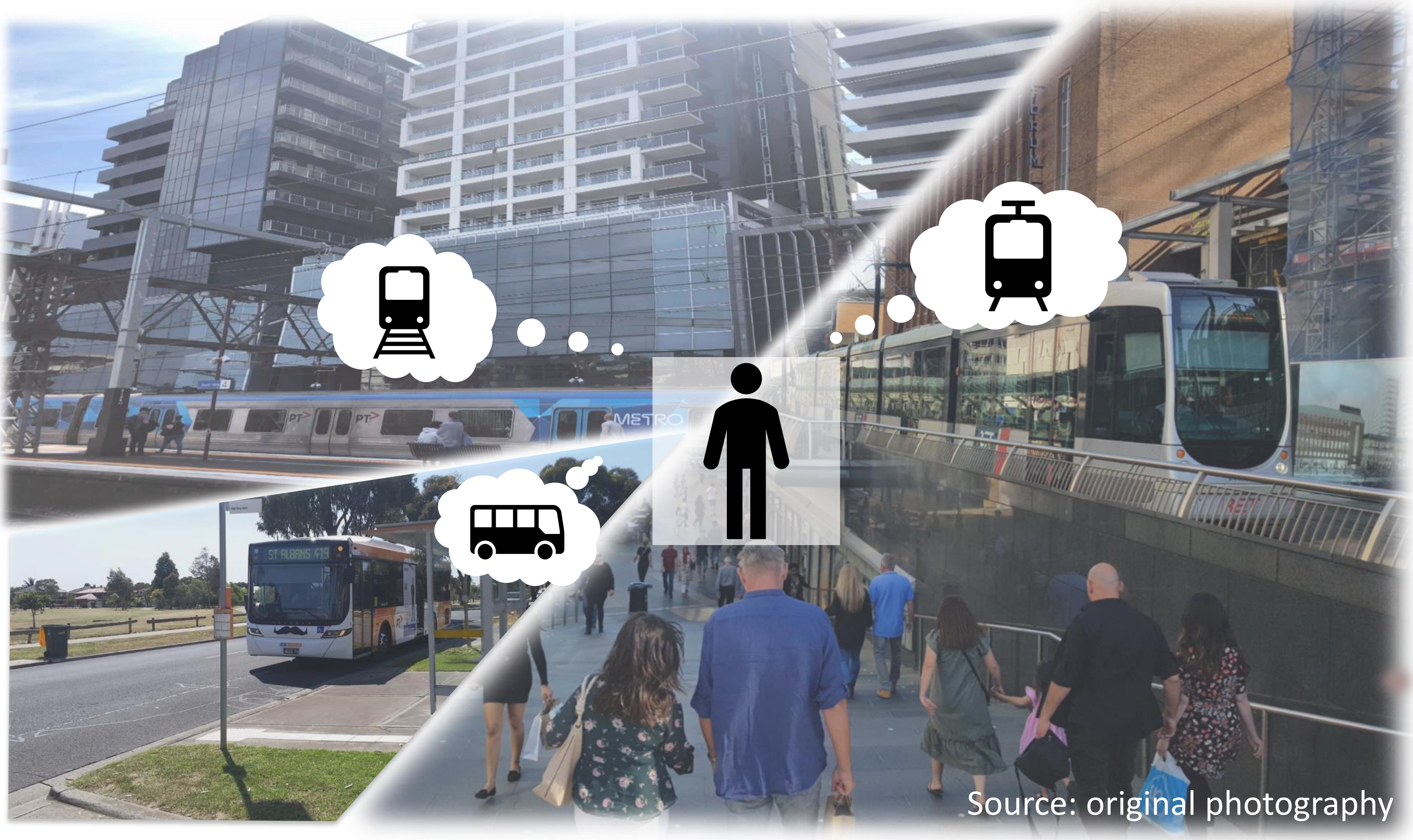


Conclusions

- Tram and bus share three of six BE predictors, while train and bus share only two, suggesting the BE predictors of demand differ by mode.
- Covariance between modes and statistical significance of overlapping transit services suggests interaction between modes is an important predictor of ridership.
- Pedestrian connectivity at train-bus sites was negatively associated with ridership. This suggests context and the function of modes is also important to consider.
- Differentiating ridership models by mode could improve accuracy.

- Sampling of co-located transit is not representative of the function of modes across the network. Future comparison between should adopt a sampling approach that is more representative of the network.
- Comparison between modes in different networks would be useful for testing the external validity of the finding that BE predictors differ by mode.
- Research that considers psychological factors mediated by BE are needed to understand why BE predictors for modes vary.

Discussion



Data sources

Transit stop points		Public Transport Victoria, Public Transport Points in Public Transport: A collection of PTV datasets, State of Victoria, Editor. 2018.
Total ridership (average weekday boardings)	1	Department of Transport, Data Request Metropolitan Patronage - Stop Level (2018), State of Victoria, Editor. 2019, & Department of Transport, Data Correction: Metropolitan Bus Patronage - Updated Stop Level. 2018.
Employment density	2	Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 2) 2016 Working Person Profile: Table W01 Labour Force Status by Age by Sex, in 2016 Census of Population and Housing. 2017: Canberra.
Population, Population density	3	Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G01: Selected Person Characteristics by Sex, in 2016 Census of Population and Housing, Commonwealth Government of Australia, Editor. 2017: Canberra.
Retail worker density	4	Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 2) 2016 Working Person Profile: Table W09 Industry of Employment by Sex, in 2016 Census of Population and Housing. 2017: Canberra
Attraction – generation balance	5	• Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G01: Selected Person Characteristics by Sex, in 2016 Census of Population and Housing, Commonwealth Government of Australia, Editor. 2017: Canberra. • Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 2) 2016 Working Person Profile: Table W09 Industry of Employment by Sex, in 2016 Census of Population and Housing. 2017: Canberra
Housing diversity	6	Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G38: Dwelling Structure by Household Composition and Family Composition, in 2016 Census of Population and Housing, Commonwealth Government of Australia, Editor. 2017: Canberra.
Intersections^ (600/800m)	7	State Government of Victoria, Vicmap Transport, Department of Environment Land Water and Planning, Editor. 2017, data.vic.gov.au.
Cycle path length (km)	8	VicRoads, Principal Bicycle Network, State of Victoria, Editor. 2017.
Destination count	9	• GeoFabrik downloads, GIS OSM pois free 1: Australia, Open Street Map, Editor. 2019. • PSMA Australia Limited, PSMA Australia Limited, PSMA Features of Interest (Polygon) (August 2018); accessed from AURIN on 1/3/2019, PSMA Australia Limited, Editor. 2018.
Level of service (average weekday departures/hour)	10	Public Transport Victoria. PTV Google Transit Feed Specification. 2018 27 July 2018; Available from: https://transitfeeds.com/p/ptv/497.
Proportion full time employed	11	Australian Bureau of Statistics, Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G43B: Dwelling Structure by Household Composition and Family Composition, in 2016 Census of Population and Housing. 2017: Canberra.

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The authors confirm contribution to the paper as follows: study conception and design: Laura Aston, Graham Currie, Md. Kamruzzaman, Alexa Delbosc and David Teller; data collection: Laura Aston and Nicholas Fournier; analysis and interpretation of results: Laura Aston and Md Kamruzzaman; draft manuscript preparation: Laura Aston. All authors reviewed the results and approved the final version of the manuscript.

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