

Protocol for aggregation of built environment indicators to measure associations with transit ridership for Melbourne

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Summary:

This protocol presents a static database of indicators designed to quantify the built environment at Melbourne's transit stops and stations. The data is fused from over twenty sources. Sources, assumptions and aggregations procedures are set out to ensure traceability of the indicators.

The database presented in this paper is practice-ready and openly available, constituting a valuable input to understanding built environment impacts on transit ridership.

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Version	Date	Log of changes
1	6-10-2019	First uploaded
1.2	31-12-2019	1 - Bus patronage data updated 2 - Addition of indicator: 'Access to Employment'
V2	10-02-2020	1 – Renamed indicator 'land use mix' to 'jobs-housing balance' 2 – Removed indicator: pedestrian count (kept intersection density) 3 - Removed indicator: proportion 'rural' 4 - Added details of six clusters

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1. Study Area

The study area is defined as the Melbourne Greater Capital City Statistical Area (GCCSA), as set out by the Australian Statistical Geography Standard [1].

Transit that serves the Melbourne GCCSA is defined as the Melbourne Metropolitan Network [2]

2. Sample procedures

A census of Melbourne's train, tram and bus stop (point data) was used as the point of departure for the construction of a sample for this database. Table 1 summarises the number of points for each mode. Shapefiles pertaining to these points were downloaded from data.vic [3].

Table 1 - Summary of point data pertaining to train, tram and bus stop facilities for Melbourne

Mode	Total	Type	Eligible
Bus	18,151	Stops	18,151
Tram	1,675	Stops	1,675
	211*	Polygons	
Train	222	Stops	220

2.1 Tram – sampling unit

Although the dataset for Melbourne's tram network comprises 1,675 stops, patronage for these stops is collected only at the level of clustered stops. This convention gives rise to the terminology of tram 'polygons'. The use of tram polygons and stops was considered for use as the sampling unit. Both options entailed a trade-off in terms of data accuracy.

- Using the centroid of the polygons would provide an inaccurate reflection of the land use of the component stops
- Using the stops would require assumptions about even distribution of patronage associated with the polygon.

Due to the interest of this paper in examining land use, it was decided to assume uniform distribution of polygon patronage across the tram stop points each comprised.

2.2 Site clustering

It was assumed that stop pairs and co-located stops have the same trip generation and attraction value. A method was sought for clustering these proximate stops based on spatial proximity. The method chosen was to cluster tram stops that overlapped each other within a radius of 25 metres, and bus stops that overlapped within a radius of 50 metres.

The geographic-weighted centroid of each cluster of stops was defined and used to associate each cluster with the road network. Clusters varied in membership (number of composite stops). The largest clusters comprised 15 and 6 stops for bus and tram respectively. The mean cluster membership was 1.8 in both cases, signifying a sound pairing of bi-directional stops.

2.3 Missing data

Some point data were not able to be matched to patronage or GTFS data. The spatial geometry of other sites was incomplete or erroneous. Finally, some sites did not contain entries for data pertaining to certain indicators. These sites were removed from the sample.

Figure 1 summarises the reduction of PTV point data to a final set of sampling units.

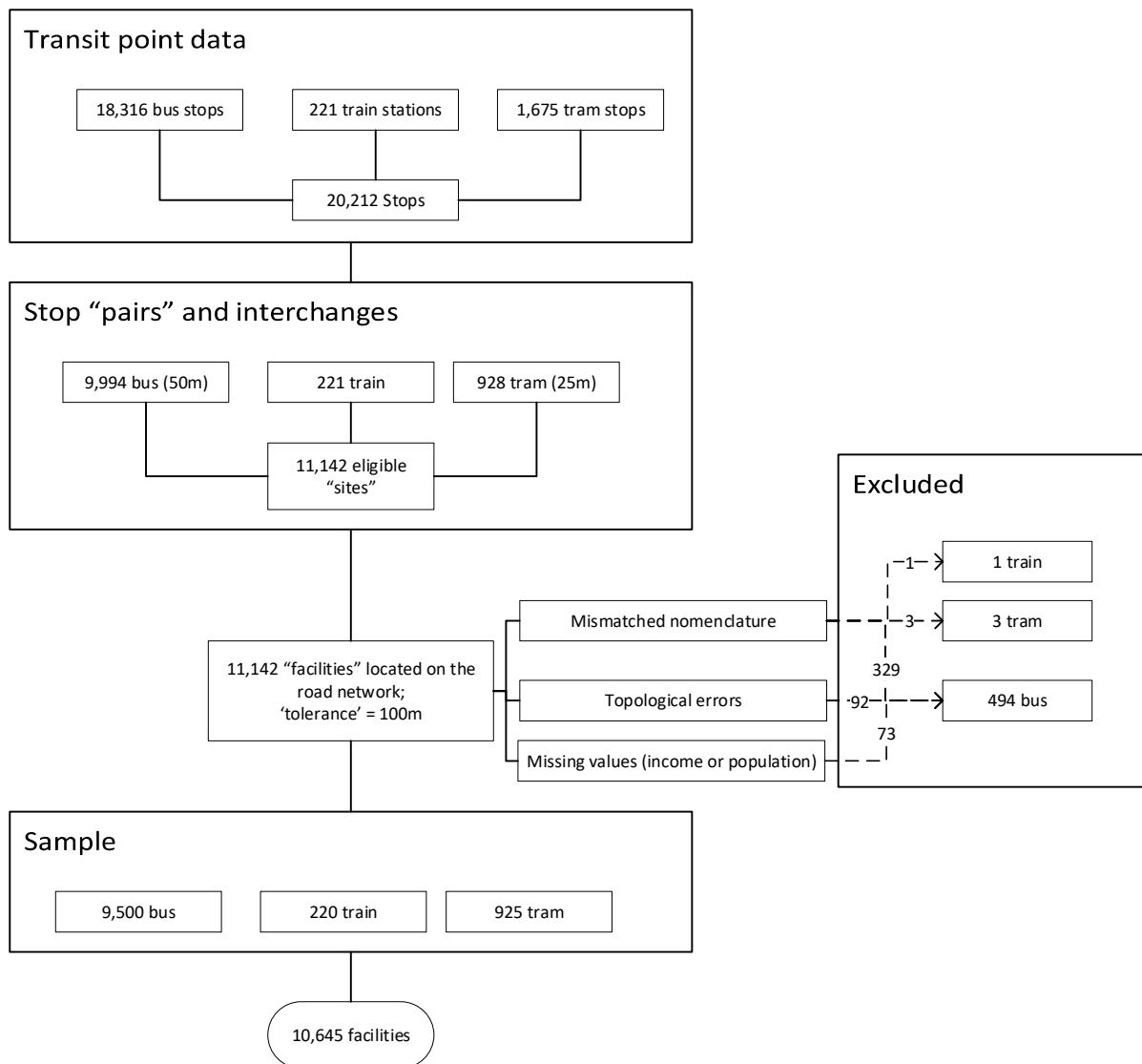


Figure 1- Steps in the creation of a sample of eligible transit sites for the Melbourne Metropolitan transit network

3. Unit of analysis

Transit-oriented development principles recognise the existence of zones of uses around a transit facility [4]. The measures developed for application to predicting transit ridership use a simplified zoning convention, of facility, transfer zone and access-egress catchment. Assumptions pertaining to each are shown below.

Unit	Spatial definition	Indicators
Facility (F)	Property of the transit facility itself	Ridership Level of service Distance to CBD Distance to nearest activity centre
Transfer zone (T)	160m euclidian buffer	Overlapping level of service Intersecting bicycle path length Car parking Bicycle parking
Access-egress catchment (C)	Mode-dependent, see below	Remaining indicators
Network (R)	Region serviced by transit network	Access to employment

3.1 Construction of the walkable access-egress catchment (C)

Three service areas were generated for each site, to facilitate sensitivity testing of the most meaningful walk catchment distance for each mode. Table 2 summarises the ‘breaks’ used to generate service areas, along a ‘cleaned’ (highways and freeways removed [5]p) network dataset built from the VicMap road centrelines shapefile [6]. The ArcGis Network Analyst tool was used to generate the buffers [7], using the following settings:

- Detailed polygon
- Trim at 50 metres
- Overlapping facilities
- Disks
- Away from facilities
- Ignore invalid locations
- Breaks (m):

Bus	400, 600, 800
Tram	400, 600, 800
Train	800, 1200 ,1600

3.2 Object identifier

Each facility corresponded to three service area ‘buffers’. The site ontology flow diagram in Appendix 1 demonstrates the process of mapping stop IDs to sites (clusters), facilities and walk catchments.

- Facility IDs were used for ‘stop-level’ indicators (‘S’)
- Object IDs of the Walk Catchment were used for ‘polygon-level’ indicators (‘P’)

The level of aggregation of each indicator (stop-level or polygon-level) is listed in the respective tables for variable construction

4. Variables: Data sources and aggregation procedures

4.1 Aggregation Software

- ArcMap [7]
- RStudio [8, 9]
- Microsoft Excel

4.2 Outcome variable: Patronage

	Indicator	Source	Aggregation formula	Unit	Level
1	Transit ridership	Tram, train: [10] Bus: [11]	$b_j = \frac{\sum b_i}{n_j}$ <p>b – touch-ons i,- stop i in cluster j n – number of stops in cluster j</p>	Annual ave normal weekday daily boardings	F

P – polygon (ID: Mode_Walk_CatchmentID); F - Facility (ID: FacilityID_Mode)

One-step indicators (Excel) Facility ID :

Patronage (bus, train): Sumif StopID linked to FacilityID

Patronage (tram): Lookup Stop ID polygon membership, assign average touch on rate to component Stops. Sumif Stop ID linked to Facility ID

4.3 Built environment variables

4.3.1 Density

Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
2A	Total employment	WPP W01 (SA2) [12]	$\sum(M_Tot_Tot + F_Tot_Tot) * A_p$	workers	✓	✓		C
2B	Employment density	WPP W01 (SA2) [12]	$\frac{\sum(M_Tot_Tot + F_Tot_Tot) * A_p}{\sum A}$	workers/ km ²	✓	✓		C
3A	Total Population	GCP G01 (SA1) [13]	$\sum(P_Tot_Tot) * A_p$		✓	✓		C
3B	Population density	GCP G01 (SA1) [13]	$\frac{\sum(P_Tot_Tot) * A_p}{\sum A}$	residents/ km ²	✓	✓		C
4	Dwelling Density	GCP G30 [14]	$\frac{\sum(Total_dwellings) * A_p}{\sum A}$	dwelling/ km ²	✓	✓		C
5	Activity Density		$\frac{1 + 3}{\sum A}$	Jobs and residents/ km ²	✓	✓		C
6	Commercial Density	Planning Zones (shapefiles) [15]	$\frac{A_{comm.}}{A}$		✓	✓		C
7	Retail employment density	WPP W09 (SA2) [12]	$\frac{\sum(RetT_Tot_P) * A_p}{\sum A}$	Retail workers/ km ²	✓	✓		C

C – Catchment (ID: Mode_Walk_CatchmentID); T – transfer zone (ID: FacilityID_Mode); F - Facility (ID: FacilityID_Mode)

4.3.2 Diversity

Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
8	Jobs-housing balance	GCP G01 'Total_P' (SA1) [13]; WPP W09 'Retail trade Total Persons' (SA2)[16]	$1 - \frac{[ABS(Total_P - RetT_{Tot_P})]}{Total_P + RetT_{Tot_P}}$ [17]		✓	✓	✓	C
9	Land use entropy	Planning Zones (shapefiles) [18]	Modified ¹ Shannon Entropy Index with 7 land use types: Residential, Industrial, commercial, civic, growth area, recreation, other ; (Appendix 3)		✓	✓	✓	C
10	Housing diversity	GCP G38 (SA1) (25) [19]	Count of number of eight housing types present [20] 1. Separate house 2. Semi- detached (1 storey) 3. Semi-detached (2+ storey) 4. Flat or apartment (1-2 storey block) 5. Flat or apartment (3 storey block) 6. Flat or apartment (4+ storey block) 7. Flat or apartment attached to a house 8. Other		✓	✓	✓	C

C – Catchment (ID: Mode_Walk_CatchmentID); T – transfer zone (ID: FacilityID_Mode); F - Facility (ID: FacilityID_Mode)

¹ – Shannon's entropy index [21] has been adopted to measure the “disorder” of land uses [17, 22], however the natural logarithm is used instead of log₁₀ as used in Shannon's original formulation.

4.3.3 Transit-friendly Design

Indicator			Source	Aggregation formula	Unit	Arc	R	Excel	Level
11	Pedestrian connectivity	Intersection density	VicMap Transport Road Centrelines [23]	$\frac{\text{Intersection count}}{\text{Buffer area (in sq.m)}}$		✓	✓		C
12	Cycle connectivity		VicMap Transport PBN [24]	$\sum \text{Length}_{\text{intersecting paths}}$ (direct intersection with a 160m offset from the facility centroid)	km	✓	✓		T
13	Destination score		PSMA Features of Interest [25] ² , OSM POI [26]	Count of the number of eight destination categories, adapted from: [27] 1. Community, culture and leisure 2. Convenience 3. Early years 4. Education 5. Food 6. Health and Social Services 7. Sport 8. Public Transport		✓	✓	✓	C ^{3,4}
14	Destination count			Count of the number of features of interest		✓	✓		C ^{3,4}
15	Bicycle parking cage (‘Parkiteer’)		Bicycle Network Victoria [28]	Dummy variable: 1 = presence of at least 1 bicycle cage (‘Parkiteer’), 0 otherwise		✓		✓	T

C – Catchment (ID: Mode_Walk_CatchmentID); T – transfer zone (ID: FacilityID_Mode); F - Facility (ID: FacilityID_Mode)

2 – The Aurin data portal was used to access PSMA data[29].

3 – Duplicate stops were removed as telebus was considered out of scope.

4 – Public transport stops that intersected the polygon with a tolerance of 100m (equal to the facility-finding tolerance) were included.

4.3.4 Regional Accessibility

Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
16	CBD distance	Crow-fly distance to CBD [30]	$NearDist$ of site centroid from CBD Activity Centre point	km	✓			F
17	Activity Centre distance	Neardist	$NearDist$ of closest existing Activity Centre	km	✓			F
18	Activity Centre Count	Number within catchment	Plan Melbourne, existing Major Activity Centre	km	✓	✓		C
19	% zone classified “urban” ⁶	Planning Zones (shapefiles) [18];	$\frac{A_{urban} * A_{pi}}{\Sigma A}$ [31]		✓	✓		C
20	Access to Employment	[12, 32]	Sum of jobs (employed persons) accessible within 30 minutes from stop using transit or walking ⁵	Persons	✓	✓	✓	R

C – Catchment (ID: Mode_Walk_CatchmentID); *T* – transfer zone (ID: FacilityID_Mode); *F* – Facility (ID: FacilityID_Mode)

5 - The ArcGIS network analyst feature was used to identify the spatial extent of coverage provided by Melbourne’s transit network for a 30-minute peak period on a normal weekday, using the GTFS timetable from 19 March 2018 [7]. The proportional overlap of SA2 shapefiles containing the number of working persons was used to approximate the number of jobs accessible.

6 – Appendix 3: Classification of urban/rural zones

4.4 Other Independent variables

4.4.1 Demand Management

Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
21	Free tram zone	PTV Network Maps [2]	Dummy variable, “1” if any points in the sample site (cluster) fall within the free tram zone, “0” if no		✓		✓	F
22	Parking	PTV polygon shapefile [33]	$\Sigma A_{car\ parks\ intersecting}$	m^2	✓		✓	T

C – Catchment (ID: Mode_Walk_CatchmentID); *T* – transfer zone (ID: FacilityID_Mode); *F* - Facility (ID: FacilityID_Mode)

1 – Duplicate stops were removed as telebus was considered out of scope.

4.4.2 Network Accessibility

Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
23	Average Frequency	GTFS 1Mar2018 [32, 34]	$\frac{\sum_{6-19} N_{arr}}{13}$ (1)	Arrivals/hour	✓	✓	✓	F
24	Frequency of overlapping bus	GTFS 19 Mar 2018 [32, 34]	Daily arrivals (N_{arr}) for mode of interest between 0600 – 1900 minus arrivals of stops at centroid if same type ^{3,7} Sum for intersecting transit stops, by type:		✓	✓	✓	T
25	Frequency of overlapping tram				✓	✓	✓	T

Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
26	Frequency of overlapping train		$\frac{\sum_{6-19} N_{arr}}{13} - LOS_i$		✓	✓	✓	T
27	Frequency of overlapping transit		Daily departures for all modes between 600 – 19000 minus arrivals of stops at centroid Sum for intersecting transit stops, by type: $\frac{\sum_{6-19} N_{arr}}{13} - LOS_i$		✓	✓	✓	T

C – Catchment (ID: Mode_Walk_CatchmentID); T – transfer zone (ID: FacilityID_Mode); F – Facility (ID: FacilityID_Mode)

3 - Duplicate stops were removed as telebus was considered out of scope.

7 - Three bus facilities comprised elongated catchments that exceeded the ‘transfer zone of 160m radius’ (FacilityID_mode: 5359-bus, 5725-bus, 7317-bus). Overlapping bus frequency was assumed to be zero for these three cases.

4.4.3 Demography

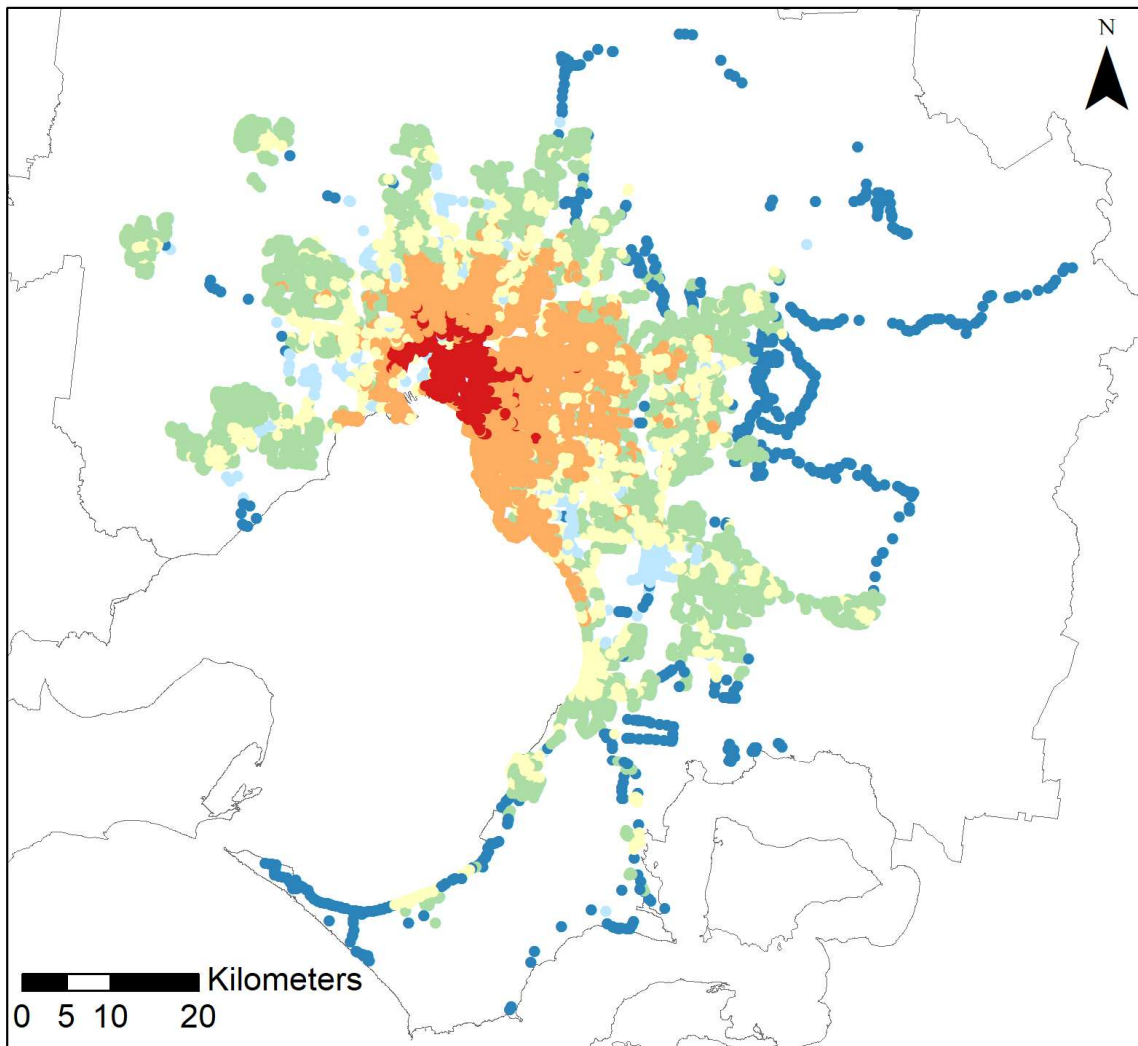
Indicator		Source	Aggregation formula	Unit	Arc	R	Excel	Level
28	Proportion full time employed ⁸	G43B (SA1) [35]	$\frac{\sum (P_Emp_FullT_Tot_i) * A_{Pi}}{\sum (P_Tot_LF_Tot_i) * A_{Pi}}$		✓	✓	✓	C
29	Mean household size ⁸	G01 SA1 [13]; G39 SA1 [14]	$\sum \frac{P_Tot_Tot * A_{Pi}}{Total_{dwellings} * A_{Pi}}$	Persons/dwelling	✓	✓	✓	C
30	Median Person income	G17 [36]	$\sum AVE(Income \text{ from } 14 \text{ declared income brackets})_i * w_i$	\$/week	✓	✓	✓	C
32	% foreign born	P_ Elsewhere Tot (G09H, SA1) [37], G01	P_ Elsewhere Tot/P_ Tot Tot (from G01)		✓	✓		C
32	% tertiary educated	G46B SA1 [38]	$\frac{P_{BachDegTotal} + P_{GradDipandGradCertTotal} + P_{PGradDegTotal}}{Persons_{Total}}$ 7		✓	✓		C

C – Catchment (ID: Mode_Walk_CatchmentID); T – transfer zone (ID: FacilityID_Mode); F - Facility (ID: FacilityID_Mode)

7 - Using total persons 15+

8 – Proportion full time employed and Mean household size have been found to contain extreme outliers in the Melbourne dataset. This can be addressed by censoring the data for each mode/catchment combination at the 95% value.

5. Cluster identities



Cluster membership

- Urban Core (n = 811)
- Inner Urban (n = 3,354)
- Mixed Use Suburban (n = 2,016)
- Residential Suburban (n = 3,570)
- Industrial (n = 242)
- Fringe Residential (n = 636)

 Melbourne greater capital city statistical area boundary

See also 'S4_Cluster centroids' at https://github.com/Laura-k-a/BE-TU_Melb_Clusters

6. File index

The following inputs to indicator derivation are located on github at https://github.com/Laura-ka/BE-TU_Melb_Clusters

Document	Description
Stop_Data_Only	<ul style="list-style-type: none">• Index of Stops clustered at each 'Facility' by mode• Patronage for stops• Tram polygon:stop patronage estimation
BETU.Melbourne.Database.10Feb2020	<ul style="list-style-type: none">• Aggregated database containing 32 independent variables, 1 outcome variable for 10,645• 3 x entries for each sites corresponding to 3 'catchment' buffer• Includes list of sites removed
RScripts	Scripts used to aggregate data to each facility/catchment
Aggregated spreadsheets	For each variable, aggregated data exported from either: <ul style="list-style-type: none">• Arc (attribute tables), or• R (csv files)

7. References

1. Australian Bureau of Statistics, *Main Structure and Greater Capital City Statistical Areas, July 2016* in *Australian Statistical Geography Standard (ASGS)*, C.G.o. Australia, Editor. 2016.
2. Public Transport Victoria. *Network Maps*. 2019 Available from: www.ptv.vic.gov.au.
3. Public Transport Victoria, *Public Transport Points in Public Transport: A collection of PTV datasets*, S.G.o. Victoria, Editor. 2018.
4. Monzón, A., S. Hernández, and F. Di Ciommo, *Efficient Urban Interchanges: The City-HUB Model*. Transportation Research Procedia, 2016. **14**(C): p. 1124-1133.
5. Mavoa, S., et al., *Area-Level Disparities of Public Open Space: A Geographic Information Systems Analysis in Metropolitan Melbourne*. Urban Policy and Research, 2015. **33**(3): p. 1-18.
6. Department of Environment Land Water and Planning. *Road Network - Vicmap Transport 2018 18/1/18*; Available from: <https://www.data.vic.gov.au/data/dataset/road-network-vicmap-transport>.
7. ESRI, *ArcMap*, in *ArcGIS Desktop*, E.S.R.I. (ESRI), Editor. 2019: New York Street Redlands, CA, USA.
8. RStudio Team, *RStudio: Integrated Development for R*. 2016, RStudio, Inc.,: Boston MA.
9. Wickham, H., et al., *dplyr: A Grammar of Data Manipulation*, in *R package version 0.7.6*. 2018.
10. Department of Transport, *Data Request Metropolitan Patronage - Stop Level (2018)*, State of Victoria, Editor. 2019.
11. Department of Transport, *Data Correction: Metropolitan Bus Patronage - Updated Stop Level (2018)*, State of Victoria, Editor. 2019.
12. 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.
13. 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.
14. Australian Bureau of Statistics, *Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G32: Dwelling Structure*, in *2016 Census of Population and Housing*. 2017: Canberra.
15. Department of Environment Land Water & Planning, *FOI - Point - Vicmap Features of Interest*, T.S.o. Victoria, Editor. 2018.
16. 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.
17. Cervero, R., *Built environment and mode choice: toward a normative framework*. Transportation Research Part D, 2002. **7**(2002): p. 265 - 284.
18. Department of Environment Land Water & Planning, *Planning scheme zones - Vicmap Planning*, S.o. Victoria, Editor. 2018.
19. Australian Bureau of Statistics, *Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G38: Dwelling Structure by Household Composition and Family*

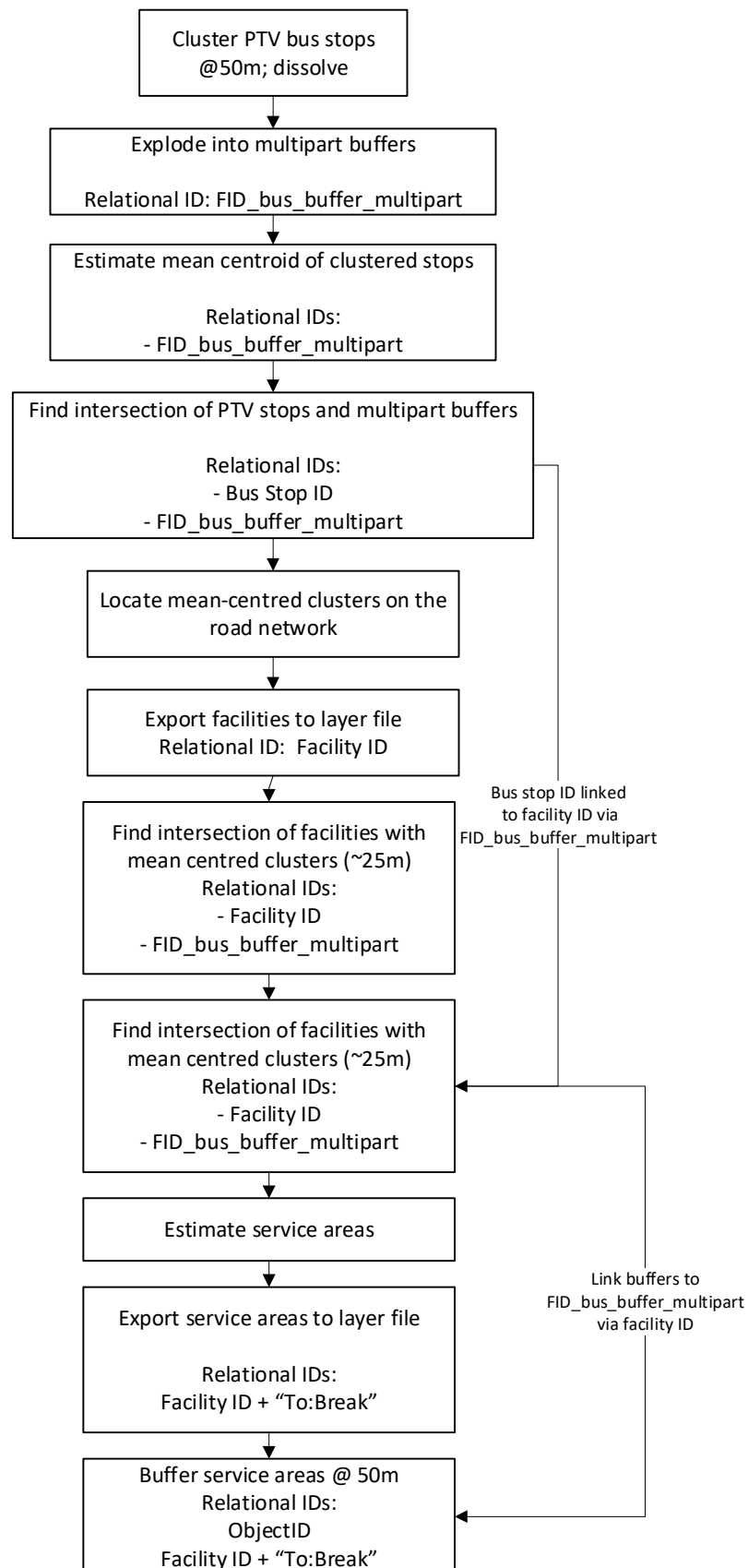
- Composition*, in *2016 Census of Population and Housing*, Commonwealth Government of Australia, Editor. 2017: Canberra.
20. Boulange, C., et al., *Examining associations between urban design attributes and transport mode choice for walking, cycling, public transport and private motor vehicles*. Journal of Transport & Health, 2017.
 21. Shannon, C.E., *A mathematical theory of communication*. Bell System Technical Journal, 1948. **27**: p. 379 - 423, 623 - 656.
 22. Mavoa, S., et al., *Identifying appropriate land-use mix measures for use in a national walkability index*. Journal of Transport and Land Use, 2018. **11**(1): p. 681-700.
 23. Department of Environment Land Water & Planning, *Road Network - Vicmap Transport*, S.G.o. Victoria, Editor. 2018.
 24. VicRoads, *Principal Bicycle Network*, S.G.o. Victoria, Editor. 2017.
 25. 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.
 26. GeoFabrik downloads, *GIS OSM pois free 1: Australia*, Open Street Map, Editor. 2019.
 27. Badland, H., et al., *Identifying, creating, and testing urban planning measures for transport walking: Findings from the Australian national liveability study*. J. Transp. Health, 2017. **5**: p. 151-162.
 28. Bicycle Network Victoria. *Parkiteer Locations*. 2019 Available from: <https://www.bicyclenetwork.com.au/our-services/parkiteer/locations/>.
 29. AURIN. *AURIN Portal*. 2019 Available from: <https://portal.aurin.org.au>.
 30. State Government of Victoria, *Activity Centres Overview*, in *Plan Melbourne*, L. Department of Environment, Wate and Planning,, Editor. 2017.
 31. Greenwald, M.J. and M.G. Boarnet, *Built environment as determinant of walking behavior: Analyzing nonwork pedestrian travel in Portland, Oregon*, in *Transportation Research Record*. 2001. p. 33-42.
 32. Public Transport Victoria, *1 March 2018*, in *PTV GTFS*. 2018, OpenMobilityData.
 33. Public Transport Victoria, *PTV Train Station Car Park*, S.G.o. Victoria, Editor. 2019: Victoria.
 34. Public Transport Victoria. *PTV Google Transit Feed Specification*. 2018 27 July 2018 Available from: <https://transitfeeds.com/p/ptv/497>.
 35. 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.
 36. Australian Bureau of Statistics, *Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G17 Total Personal Income (Weekly) by Age and Sex*, in *2016 Census of Population and Housing*, Commonwealth Government of Australia, Editor. 2017: Canberra.
 37. Australian Bureau of Statistics, *Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: G09H Table Country of Birth of Person by Age by Sex*, in *2016 Census of Population and Housing*, Commonwealth Government of Australia, Editor. 2017: Canberra.
 38. Australian Bureau of Statistics, *Victoria (STE) (Statistical Area Level 1) 2016 General Community Profile: Table G46B Non-School Qualification: Level of Education by Age by Sex*,

in *2016 Census of Population and Housing*, Commonwealth Government of Australia, Editor. 2017: Canberra.

39. Higgs, C., et al., *The Urban Liveability Index: developing a policy-relevant urban liveability composite measure and evaluating associations with transport mode choice*. International Journal of Health Geographics, 2019. **18**(1): p. 14.

8. Appendices

Appendix 1: Site ontology



Appendix 2: Classification of points of interest into local access categories

Table 2 - Classification of PSMA Points of Interest [25] and Open Street Map Features of Interest [26] into local access categories

Local Access Classification	FEATSUBTYPE [25]	Fclass [26]	Transit stops [3]
Community, culture and leisure	Aquarium Art Gallery Bandstand Church Club House Community Centre Gardens Grandstand Hall Library Mosque Museum Neighbourhood Neighbourhood House Neighbourhood Safer Place Park Place Of Worship Playground Senior Citizens Synagogue Vihara (Buddhist)		
Convenience		Newsagent Convenience	
Early years	Child Care Maternal And Child Health Centres		
Education	Further Education Kindergarten Primary And Secondary School Primary School School Secondary School Special School Tafe College Tertiary Institution University		
Food		Supermarket Greengrocer	
Health and social services	Aged Care Community Health Centre Court Customer Service Centre Day Procedure Centre Dental Practice Disability Support General Hospital General Hospital (Emergency) Health Facility Hospital	Pharmacy Dentist	
Sport	Boating Club Cycling Track Golf Course Lifesaving Club Racecourse Sport Facility Sports Complex Swimming Pool Walking Track		
Public transport			Bus stop points Tram stop point Train station point

1 –Categories were taken from local access classifications used as an input to liveability for Melbourne [39]

Appendix 3: Classification of land use zones

Zone description	Category	Urban Rural
COMMONWEALTH LAND NOT CONTROLLED BY PLANNING SCHEME	Civic	
PUBLIC CONSERVATION AND RESOURCE ZONE		
PUBLIC USE ZONE - CEMETERY/CREMATORIUM		
PUBLIC USE ZONE - EDUCATION		Urban
PUBLIC USE ZONE - HEALTH AND COMMUNITY		
PUBLIC USE ZONE - LOCAL GOVERNMENT		
PUBLIC USE ZONE - OTHER PUBLIC USE		Urban
PUBLIC USE ZONE - SERVICE AND UTILITY		
PUBLIC USE ZONE - TRANSPORT		
ROAD ZONE - CATEGORY 1		
ROAD ZONE - CATEGORY 2		
RURAL CONSERVATION ZONE		
RURAL CONSERVATION ZONE - SCHEDULE 1		Rural
RURAL CONSERVATION ZONE - SCHEDULE 10		
RURAL CONSERVATION ZONE - SCHEDULE 11		
RURAL CONSERVATION ZONE - SCHEDULE 12		
RURAL CONSERVATION ZONE - SCHEDULE 13		
RURAL CONSERVATION ZONE - SCHEDULE 14		
RURAL CONSERVATION ZONE - SCHEDULE 15		
RURAL CONSERVATION ZONE - SCHEDULE 2		
RURAL CONSERVATION ZONE - SCHEDULE 3		
RURAL CONSERVATION ZONE - SCHEDULE 4		
RURAL CONSERVATION ZONE - SCHEDULE 5		
RURAL CONSERVATION ZONE - SCHEDULE 6		
RURAL CONSERVATION ZONE - SCHEDULE 7		
RURAL CONSERVATION ZONE - SCHEDULE 8		
RURAL CONSERVATION ZONE - SCHEDULE 9		
ACTIVITY CENTRE ZONE - SCHEDULE 1	Commercial	Urban
ACTIVITY CENTRE ZONE - SCHEDULE 2		
ACTIVITY CENTRE ZONE - SCHEDULE 3		
CAPITAL CITY ZONE - SCHEDULE 1		
CAPITAL CITY ZONE - SCHEDULE 2		
CAPITAL CITY ZONE - SCHEDULE 3		
CAPITAL CITY ZONE - SCHEDULE 4		
CAPITAL CITY ZONE - SCHEDULE 5		
CAPITAL CITY ZONE - SCHEDULE 6		
CAPITAL CITY ZONE - SCHEDULE 7		
COMMERCIAL 1 ZONE		
COMMERCIAL 2 ZONE		
INDUSTRIAL 1 ZONE		
INDUSTRIAL 2 ZONE		Urban
INDUSTRIAL 3 ZONE		
MIXED USE ZONE		
MIXED USE ZONE - SCHEDULE 1		

Zone description	Category	Urban Rural
MIXED USE ZONE - SCHEDULE 2		
MIXED USE ZONE - SCHEDULE 3		
RURAL ACTIVITY ZONE		
RURAL ACTIVITY ZONE - SCHEDULE 1		
RURAL ACTIVITY ZONE - SCHEDULE 2		
RURAL ACTIVITY ZONE - SCHEDULE 3		
TOWNSHIP ZONE		
TOWNSHIP ZONE - SCHEDULE 2		
URBAN GROWTH ZONE	Growth zone	Urban
URBAN GROWTH ZONE - SCHEDULE 1		
URBAN GROWTH ZONE - SCHEDULE 10		
URBAN GROWTH ZONE - SCHEDULE 11		
URBAN GROWTH ZONE - SCHEDULE 12		
URBAN GROWTH ZONE - SCHEDULE 13		
URBAN GROWTH ZONE - SCHEDULE 14		
URBAN GROWTH ZONE - SCHEDULE 15		
URBAN GROWTH ZONE - SCHEDULE 2		
URBAN GROWTH ZONE - SCHEDULE 3		
URBAN GROWTH ZONE - SCHEDULE 4		
URBAN GROWTH ZONE - SCHEDULE 5		
URBAN GROWTH ZONE - SCHEDULE 6		
URBAN GROWTH ZONE - SCHEDULE 7		
URBAN GROWTH ZONE - SCHEDULE 8		
URBAN GROWTH ZONE - SCHEDULE 9		
COMPREHENSIVE DEVELOPMENT ZONE - SCHEDULE 1	Industrial	Urban
COMPREHENSIVE DEVELOPMENT ZONE - SCHEDULE 2		
COMPREHENSIVE DEVELOPMENT ZONE - SCHEDULE 3		
COMPREHENSIVE DEVELOPMENT ZONE - SCHEDULE 4		
COMPREHENSIVE DEVELOPMENT ZONE - SCHEDULE 5		
COMPREHENSIVE DEVELOPMENT ZONE - SCHEDULE 6		
DOCKLANDS ZONE - SCHEDULE 1		
DOCKLANDS ZONE - SCHEDULE 2		
DOCKLANDS ZONE - SCHEDULE 3		
DOCKLANDS ZONE - SCHEDULE 4		
DOCKLANDS ZONE - SCHEDULE 5		
DOCKLANDS ZONE - SCHEDULE 6		
DOCKLANDS ZONE - SCHEDULE 7		
FARMING ZONE		
FARMING ZONE - SCHEDULE 1		
FARMING ZONE - SCHEDULE 2		
FARMING ZONE - SCHEDULE 3		
FARMING ZONE - SCHEDULE 4		
PORT ZONE		
PRIORITY DEVELOPMENT ZONE		
PRIORITY DEVELOPMENT ZONE - SCHEDULE 1		Urban

Zone description	Category	Urban Rural
PRIORITY DEVELOPMENT ZONE - SCHEDULE 2	Other	
SPECIAL USE ZONE - SCHEDULE 1		
SPECIAL USE ZONE - SCHEDULE 10		
SPECIAL USE ZONE - SCHEDULE 11		
SPECIAL USE ZONE - SCHEDULE 13		
SPECIAL USE ZONE - SCHEDULE 14		
SPECIAL USE ZONE - SCHEDULE 15		
SPECIAL USE ZONE - SCHEDULE 16		
SPECIAL USE ZONE - SCHEDULE 2		
SPECIAL USE ZONE - SCHEDULE 3		
SPECIAL USE ZONE - SCHEDULE 4		
SPECIAL USE ZONE - SCHEDULE 5		
SPECIAL USE ZONE - SCHEDULE 6		
SPECIAL USE ZONE - SCHEDULE 7		
SPECIAL USE ZONE - SCHEDULE 8		
SPECIAL USE ZONE - SCHEDULE 9		Urban
SPECIAL USE ZONE - SCHEDULE 12		
URBAN FLOODWAY ZONE		
GREEN WEDGE A ZONE	Recreation	Rural
GREEN WEDGE A ZONE - SCHEDULE 1		
GREEN WEDGE A ZONE - SCHEDULE 2		
GREEN WEDGE A ZONE - SCHEDULE 4		
GREEN WEDGE A ZONE - SCHEDULE 5		
GREEN WEDGE A ZONE - SCHEDULE 6		
GREEN WEDGE ZONE		
GREEN WEDGE ZONE - SCHEDULE 1		
GREEN WEDGE ZONE - SCHEDULE 2		
GREEN WEDGE ZONE - SCHEDULE 3		
GREEN WEDGE ZONE - SCHEDULE 4		
GREEN WEDGE ZONE - SCHEDULE 5		
GREEN WEDGE ZONE - SCHEDULE 6		
PUBLIC PARK AND RECREATION ZONE		
GENERAL RESIDENTIAL ZONE	Residential	Urban
GENERAL RESIDENTIAL ZONE - SCHEDULE 1		
GENERAL RESIDENTIAL ZONE - SCHEDULE 10		
GENERAL RESIDENTIAL ZONE - SCHEDULE 11		
GENERAL RESIDENTIAL ZONE - SCHEDULE 12		
GENERAL RESIDENTIAL ZONE - SCHEDULE 13		
GENERAL RESIDENTIAL ZONE - SCHEDULE 14		
GENERAL RESIDENTIAL ZONE - SCHEDULE 15		
GENERAL RESIDENTIAL ZONE - SCHEDULE 17		
GENERAL RESIDENTIAL ZONE - SCHEDULE 2		
GENERAL RESIDENTIAL ZONE - SCHEDULE 3		
GENERAL RESIDENTIAL ZONE - SCHEDULE 4		
GENERAL RESIDENTIAL ZONE - SCHEDULE 5		

Zone description	Category	Urban Rural
GENERAL RESIDENTIAL ZONE - SCHEDULE 6		
GENERAL RESIDENTIAL ZONE - SCHEDULE 7		
GENERAL RESIDENTIAL ZONE - SCHEDULE 8		
GENERAL RESIDENTIAL ZONE - SCHEDULE 9		
LOW DENSITY RESIDENTIAL ZONE		
LOW DENSITY RESIDENTIAL ZONE - SCHEDULE 1		
LOW DENSITY RESIDENTIAL ZONE - SCHEDULE 2		
LOW DENSITY RESIDENTIAL ZONE - SCHEDULE 3		
NEIGHBOURHOOD RESIDENTIAL ZONE		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 1		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 10		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 11		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 12		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 2		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 3		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 4		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 5		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 6		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 7		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 8		
NEIGHBOURHOOD RESIDENTIAL ZONE - SCHEDULE 9		
RESIDENTIAL GROWTH ZONE		
RESIDENTIAL GROWTH ZONE - SCHEDULE 1		
RESIDENTIAL GROWTH ZONE - SCHEDULE 2		
RESIDENTIAL GROWTH ZONE - SCHEDULE 3		
RESIDENTIAL GROWTH ZONE - SCHEDULE 4		
RESIDENTIAL GROWTH ZONE - SCHEDULE 5		
RURAL LIVING ZONE		Rural
RURAL LIVING ZONE - SCHEDULE 1		
RURAL LIVING ZONE - SCHEDULE 2		
RURAL LIVING ZONE - SCHEDULE 3		
RURAL LIVING ZONE - SCHEDULE 4		
RURAL LIVING ZONE - SCHEDULE 5		
RURAL LIVING ZONE - SCHEDULE 6		