Destination Choice Accessibility & 4S Models

Peter Davidson
TransPosition

Question

Answer

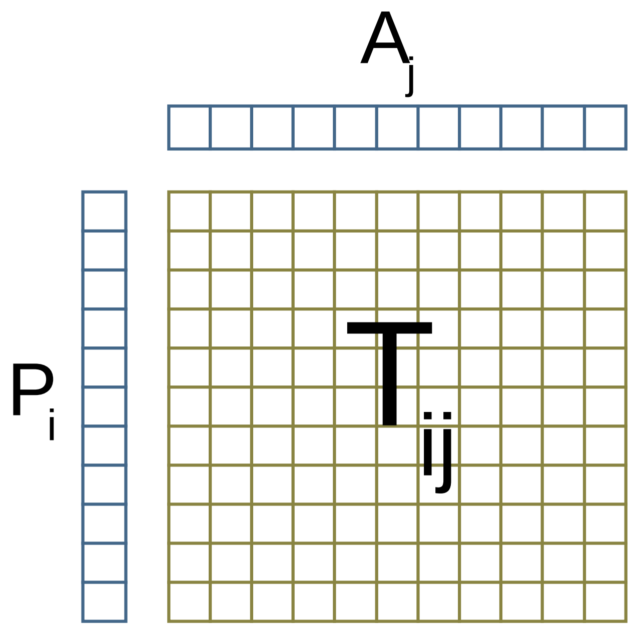
- **Transport is a derived demand**
- Usually we travel not for its own sake, but because there are benefits from being somewhere else
- BUT our models focus (almost) entirely on cost – the benefit of travel is ignored or hidden

- Destination choice – used here as a general term for modelling how people choose their destination
- Not just a discrete-choice based logit model
- Encompass traditional trip distribution models as well as newer approaches

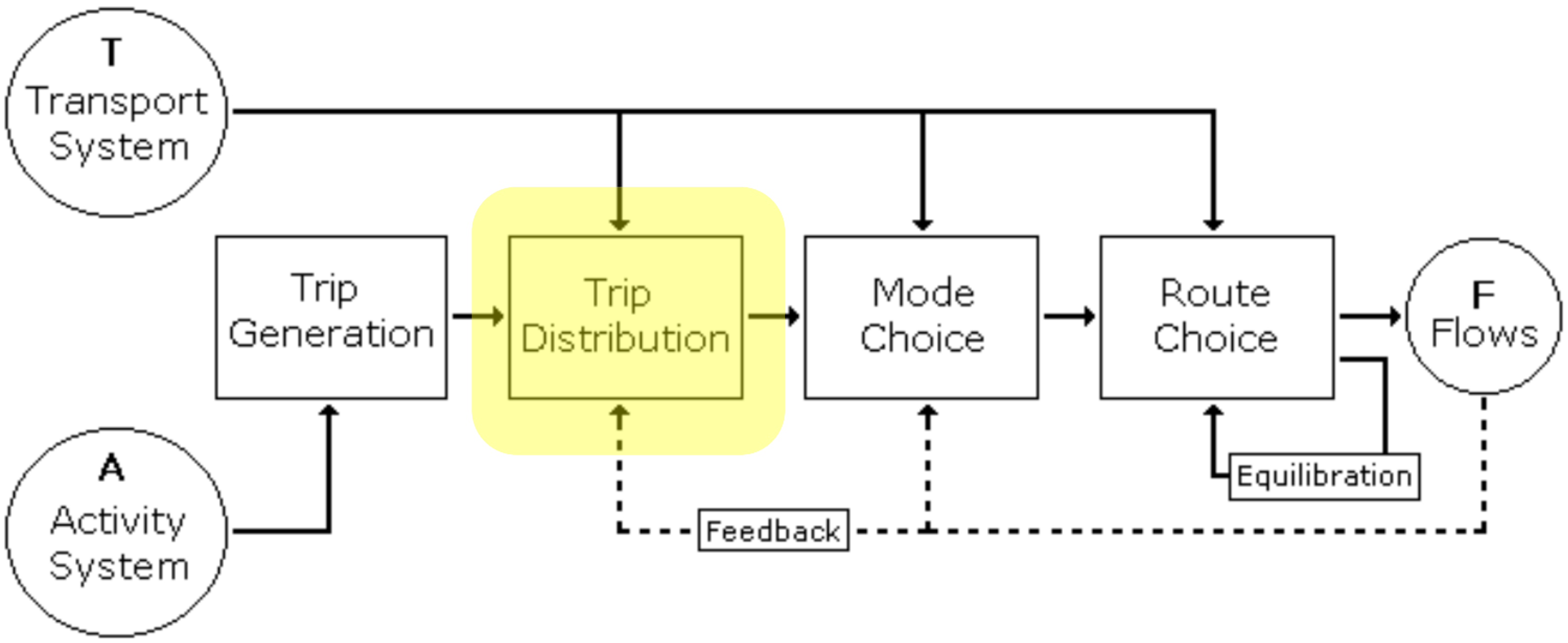
Traditional approaches

Trip distribution

- Conventionally understood as trip distribution not destination choice
- Convert from a vector of origin and destination demand to a matrix of flows



Four step model



Classic distribution model

- $$T_{ij} = P_i \frac{A_j f(C_{ij})}{\sum_k A_k f(C_{ik})}$$
- Gravity model has $f(C_{ij}) = C_{ij}^{-n}$
- Can also use negative exponential, gamma or discontinuous function
- Note: Need the full set of costs (C_{ij}) – the skim matrix (distance, time or generalised cost)

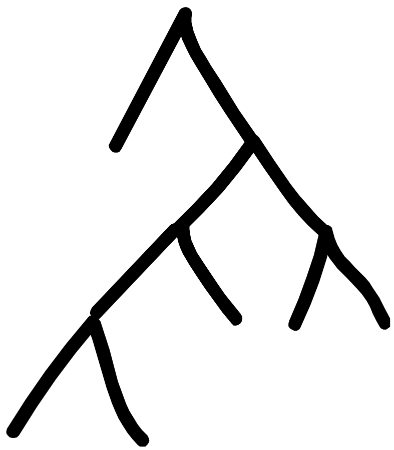
- Discrete choice analysis and random utility models (RUM) were developed by Daniel McFadden in 1974 (*Conditional Logit Analysis of Qualitative Choice Behavior*)
- He was awarded the Nobel memorial prize in economics in 2000 for this work –only transport modeller to receive a Nobel prize!

Discrete choice analysis

- Utility is that which is maximised when making choices between alternatives
- Only differences in utility matter
- The scale of utility is arbitrary
- Random utility models (RUM) allow for utility described by random variables

Logit model

- Put all randomness in single error term $\tilde{\varepsilon}$ which is identically and independently distributed (iid) for all alternatives
- $\widetilde{U} = \sum \beta_k x_k + \tilde{\varepsilon} = \boldsymbol{\beta}' \boldsymbol{x} + \tilde{\varepsilon}$
- This gives $P_i = \frac{e^{\boldsymbol{\beta}' \boldsymbol{x}_i}}{\sum_j e^{\boldsymbol{\beta}' \boldsymbol{x}_j}}$
- Multinomial logit (MNL)
- Simpler form for binomial logit
- Note: Does not allow taste variations



Discrete destination choice

- Need to include some measure of size in the utility function
- $\widehat{U}_{ij} = \ln A_j + \theta C_{ij} + f(\text{market, origin}) + \hat{\varepsilon}$
- For the first time we see a term that corresponds to attraction utility: $\ln A_j$
- Not defined with A=0, so just set p=0
- C_{ij} can be log-sum from a mode choice
- Questions on the right hierarchy

Summary of existing models

- Gravity model distributes demand – justified by entropy considerations, but no utility
- Discrete destination choice is similar but recasts $T_{ij} \propto A_j$ as utility, giving $U_j = \ln(A_j)$. No other form would work.
- Both of these models have fractions, with a denominator that normalises probability to 1
- $P_i = \dfrac{e^{\boldsymbol{\beta}' \boldsymbol{x}_i}}{\sum_j e^{\boldsymbol{\beta}' \boldsymbol{x}_j}}$
- This requires the enumeration of ALL alternatives

TransPosition

Problem with full enumeration

- We need a full matrix of costs (skim)
- This needs to be done for each mode, time period, market segment
- THE fundamental limiting factor
- Matrix grows with zones^2 so we cannot have many zones
- Every new market segment and mode increases run time by a constant
- But most effort is wasted finding routes for travel that no-one will do

- Problem – metropolitan areas are growing larger and merging (SEQ), travel is becoming more complex (AV), people are becoming more different
- How can we build large, detailed, behaviourally sensitive models?
- We must eliminate fully enumerated matrices
- HOW?

A new idea

Explicit destination utility

- What if we could freely define utility?
- $\widetilde{U}_{ij} = \tilde{f}(S_j, Q_j) - \widetilde{\boldsymbol{\beta}}\boldsymbol{x}$
- Destination/attraction utility is random variable based on size and quality
- Allow for taste variations– e.g. variations in value of time, mode preference, toll choice
- This would be great → remove the need for separate mode or toll choice models

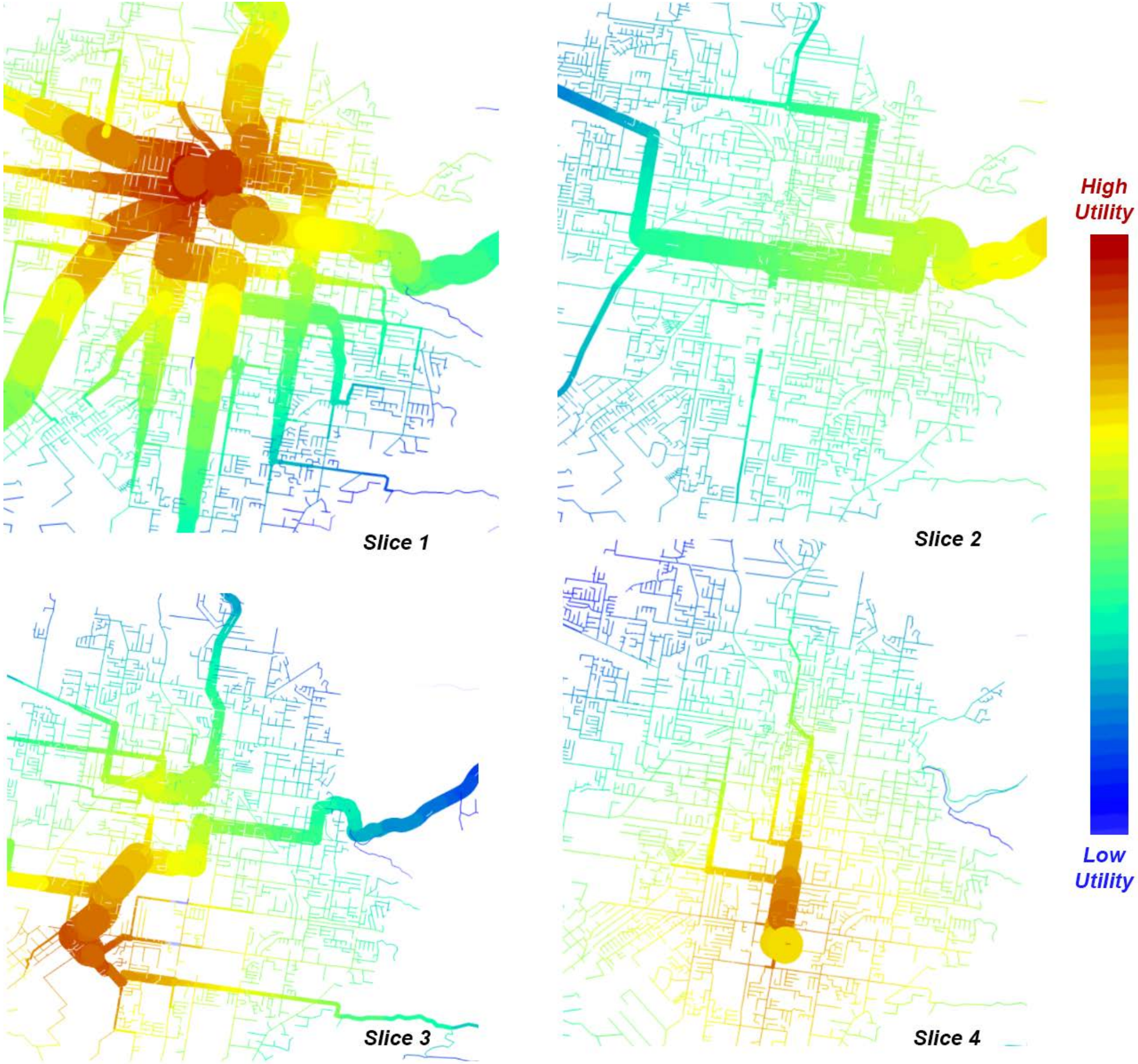
How can we do it?

- The key answer is not to try to deal with the whole distribution at once – use Monte Carlo sampling to solve the problem in slices
- In each slice, draw a single value for each random variable.
- For attraction utilities this means a single utility value for each attraction.
- For costs it means a single value of time, mode weights, walking speed etc

Maximum utility paths

- Classic skim - build paths of minimum cost from one origin to all destinations
- Maximum utility path – build paths from all destinations to their corresponding origins
- This is inherently localised – every destination has a catchment (possibly empty) for which it is best alternative
- Dijkstra's algorithm ensures highest utility options considered first

Slice utility plot



TransPosition

Equilibrium and convergence

- Monte Carlo process requires us to take many samples and integrate the results
- Equilibrium and convergence requires us to consider congestion and use updates skims
- BUT if we update the utility function throughout the Monte Carlo sampling we can kill two birds with one stone – use many slices to maximise sampling *and* convergence
- Can also consider other convergent factors – doubly-constrained, parking supply, PT crowding etc – in a **single loop**!

Benefits

- Hugely more efficient than traditional skim – never build paths without using them
- Because taste variations are allowed, we can use a single multi-modal network and build multi-modal paths
- This eliminates the need for mode choice model
- Can immediately assign demand to found paths – eliminate assignment model

Simplified model construction

- Because we do not need to enumerate all options we can eliminate matrices
- Once matrices are gone, there is no need to use zones
- No zones → no centroid connectors
- High efficiency → no need to simplify network → no need to choose links
- No centroid connectors and use of full network eliminates most network coding effort

Attraction utility and accessibility

- Explicit inclusion of attraction utility gives us a new accessibility measure – net utility
- Flexibility of utility formulation means that we can make use of better data as it becomes available
- No zones means that we can include single premises in choice model – build on “big data”

The 4S Model

Structure

Segmented:
- Comprehensive breakdown of travel markets (20 private + 40 CV segments)
- Behavioural parameters vary by market segment

Stochastic:
- Monte Carlo methods to draw values from probability distributions
- Random variable parameters
- Number of slices can be varied

EXPLICIT RANDOM UTILITY

4S

SIMULTANEOUS

Slice:
- Takes slices of the travel market
  - across model area
  - through probability distributions
- Very efficient – detailed networks, large models

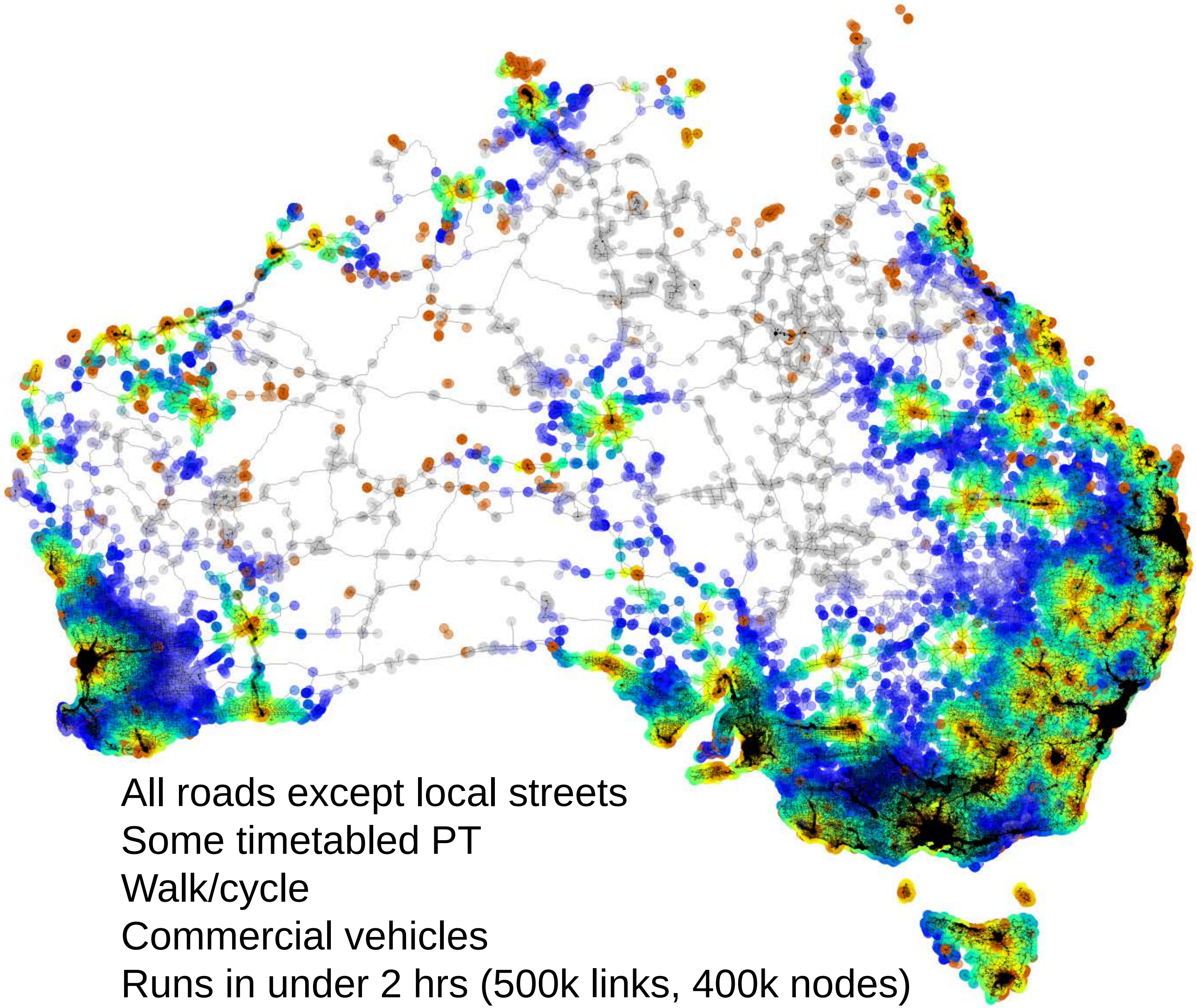
Simulation:
- Uses state-machine with very flexible transition rules
- Simulates all aspects of travel choice
- Complex public transport
- Multimodal freight
- Easily extended

TransPosition

Key features of 4S model

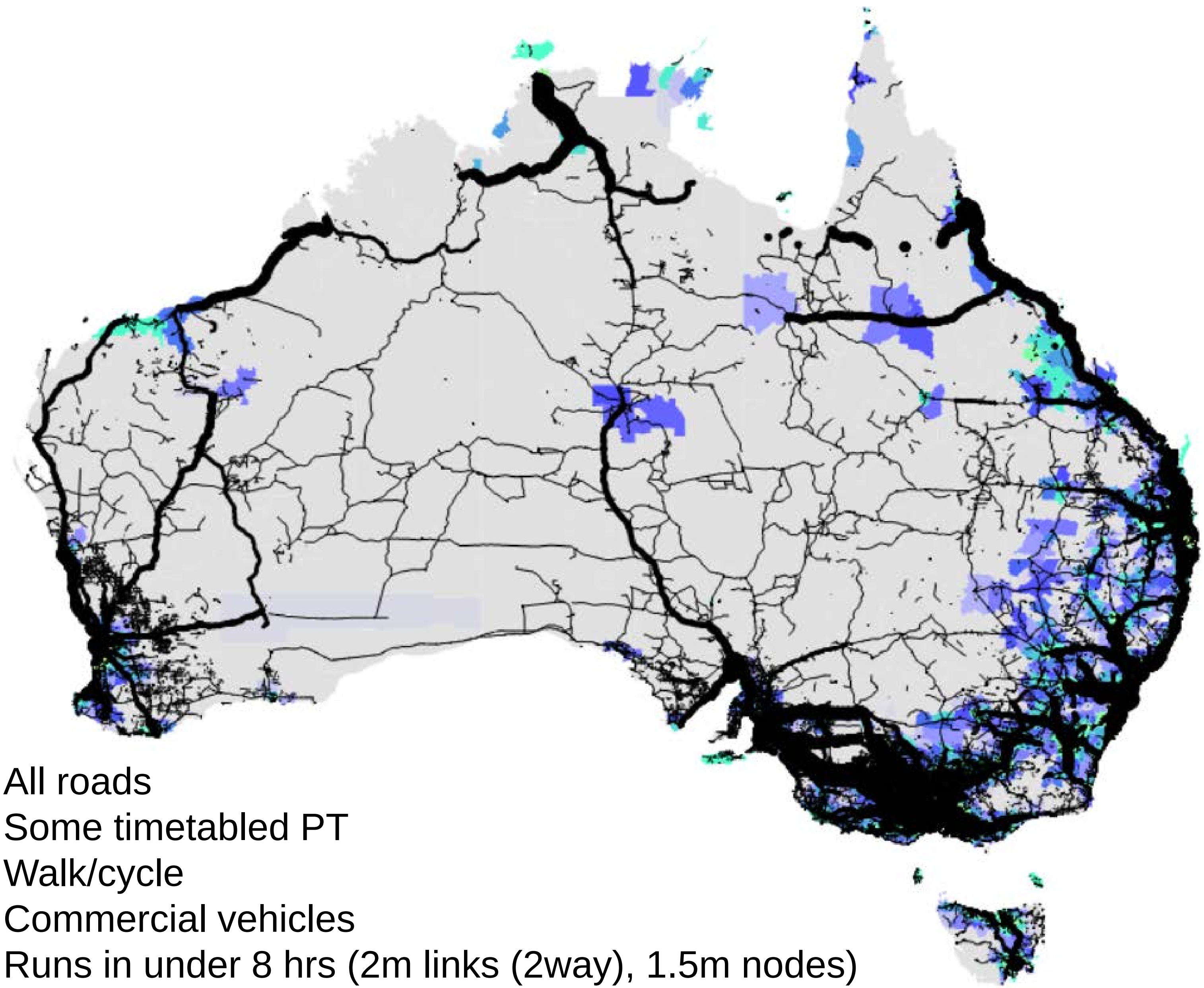
- No matrices, no skims, no zones, no centroid connectors
  - All travel is from node to node
  - Models constructed with MUCH less manual effort
- Include all roads, all paths, timetabled transit
- Population and employment from multiple sources
- Multimodal with all modes assigned
- Continuous time and simultaneous choice
- Easily include any demand based effects and capacity constraints (not just roads and transit)
- Much more detailed outputs (volumes by purpose)

Australia wide model



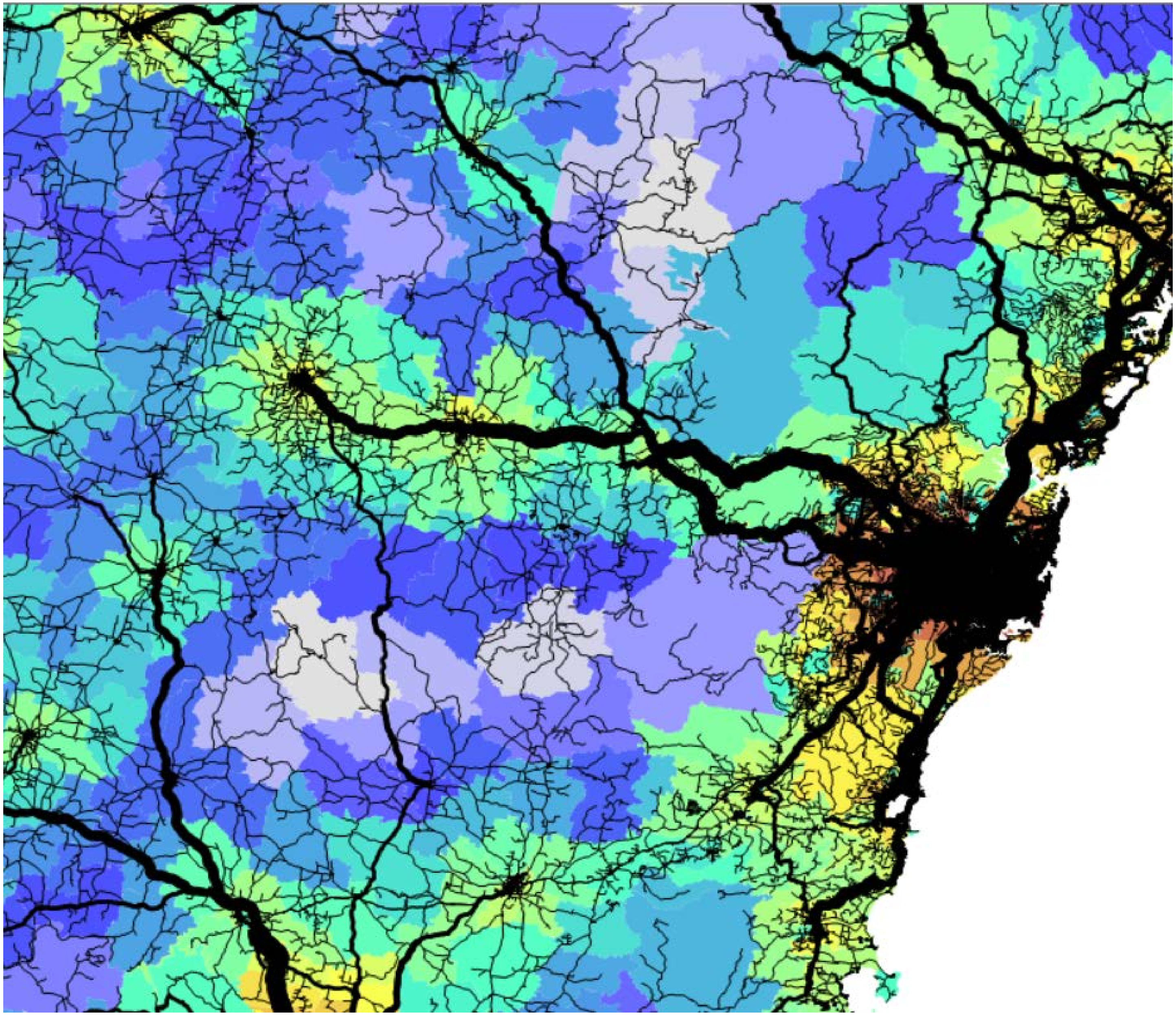
All roads except local streets
Some timetabled PT
Walk/cycle
Commercial vehicles
Runs in under 2 hrs (500k links, 400k nodes)

Detailed Australia model

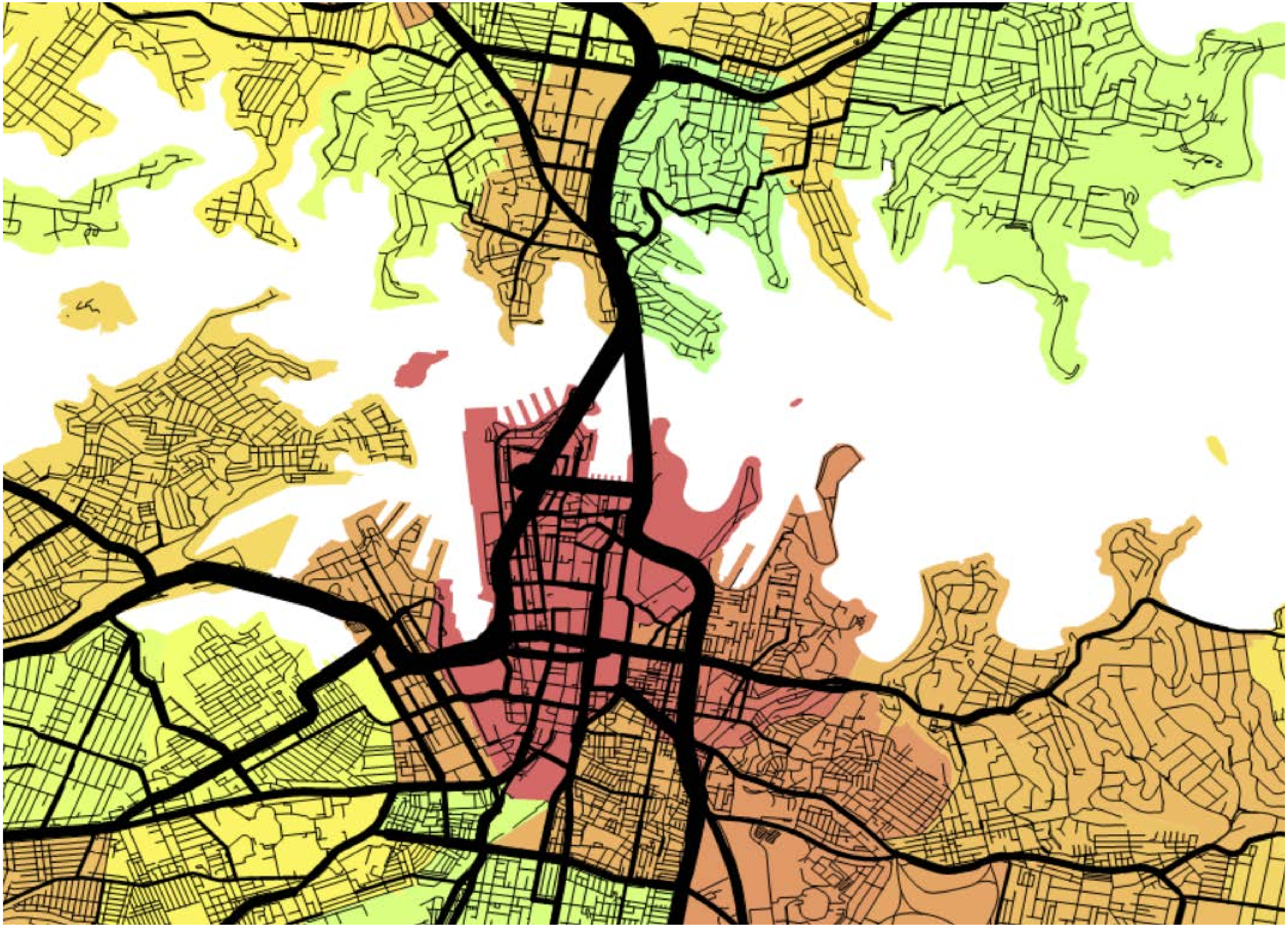


All roads
Some timetabled PT
Walk/cycle
Commercial vehicles
Runs in under 8 hrs (2m links (2way), 1.5m nodes)

NSW

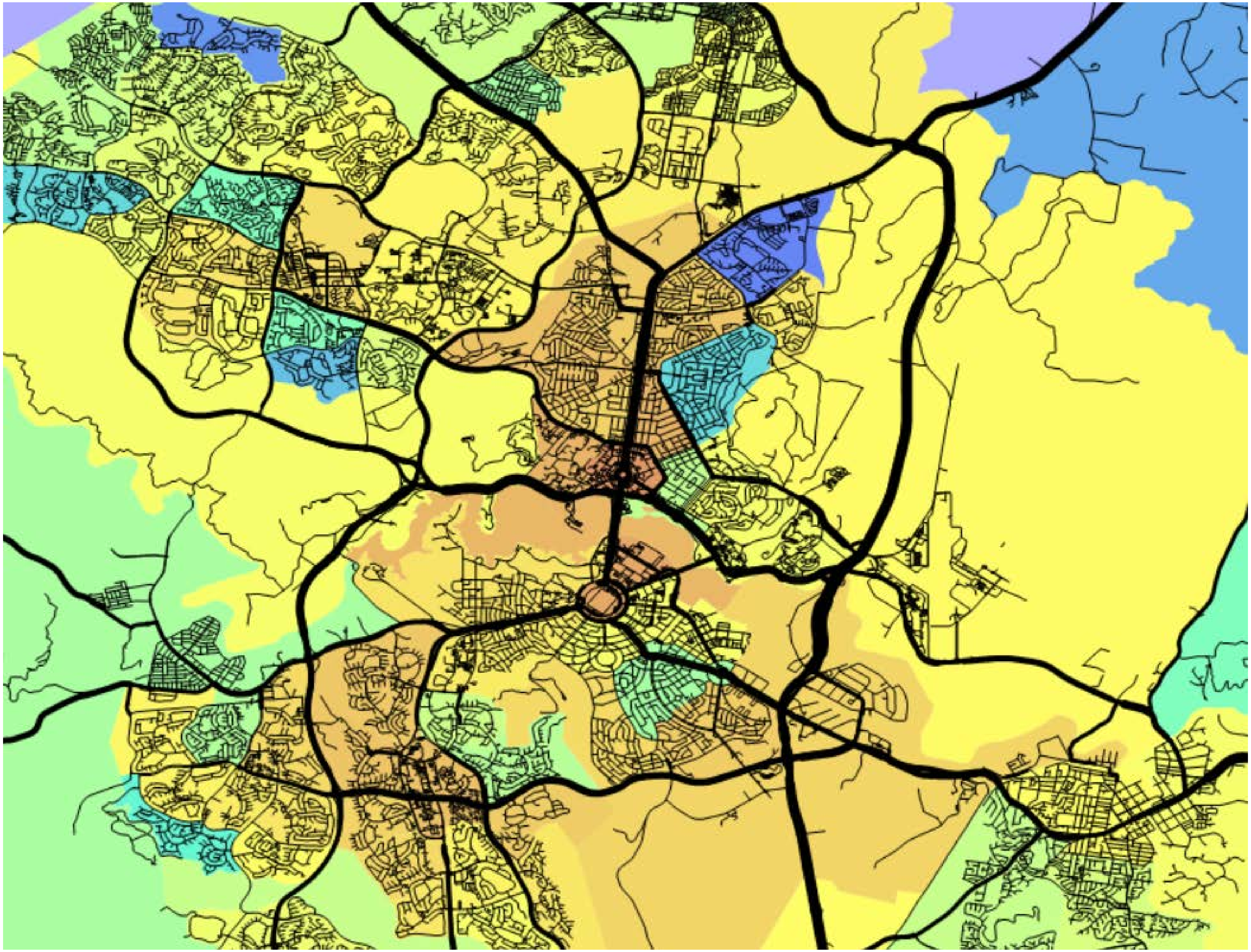


Central Sydney

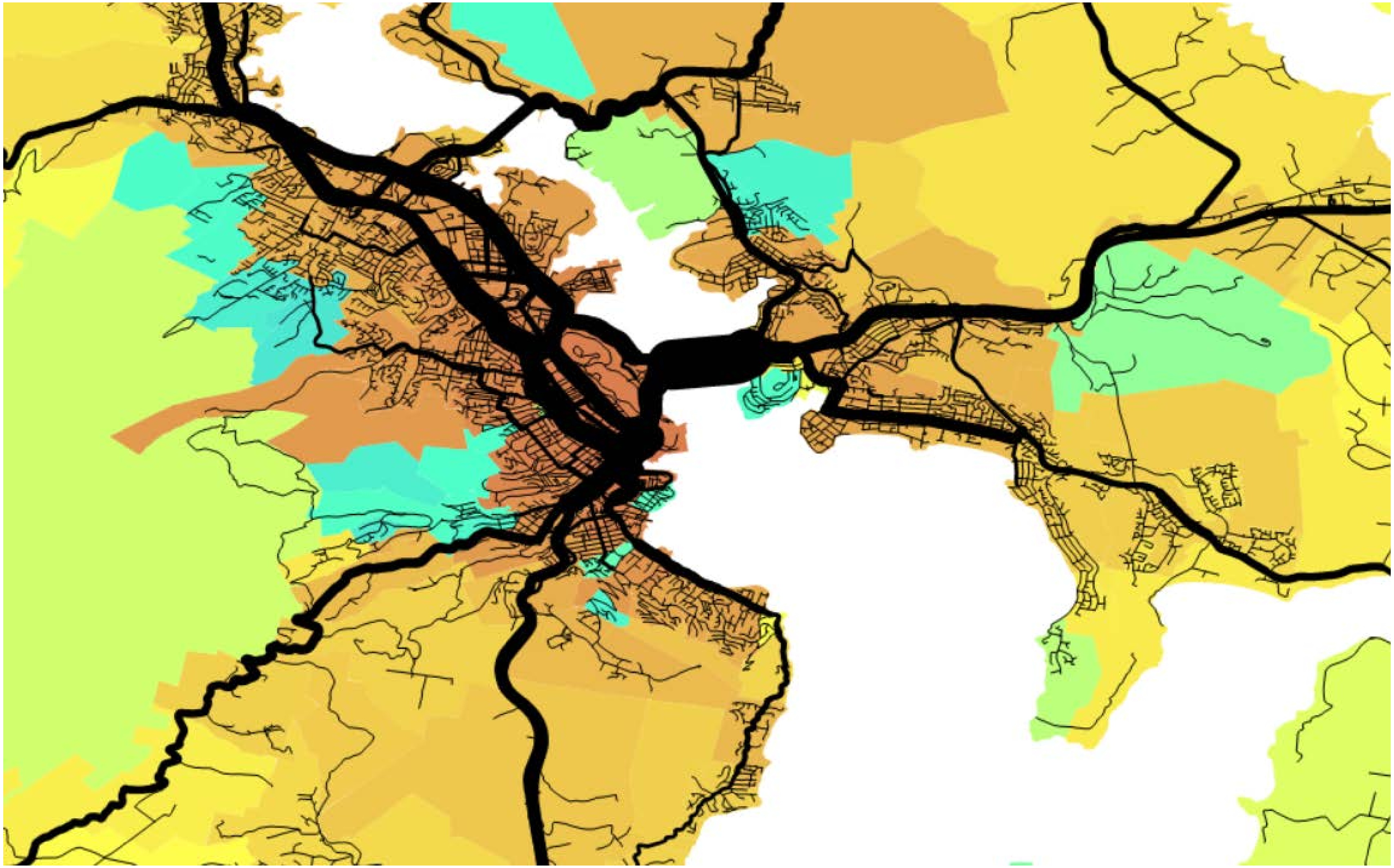


TransPosition

ACT

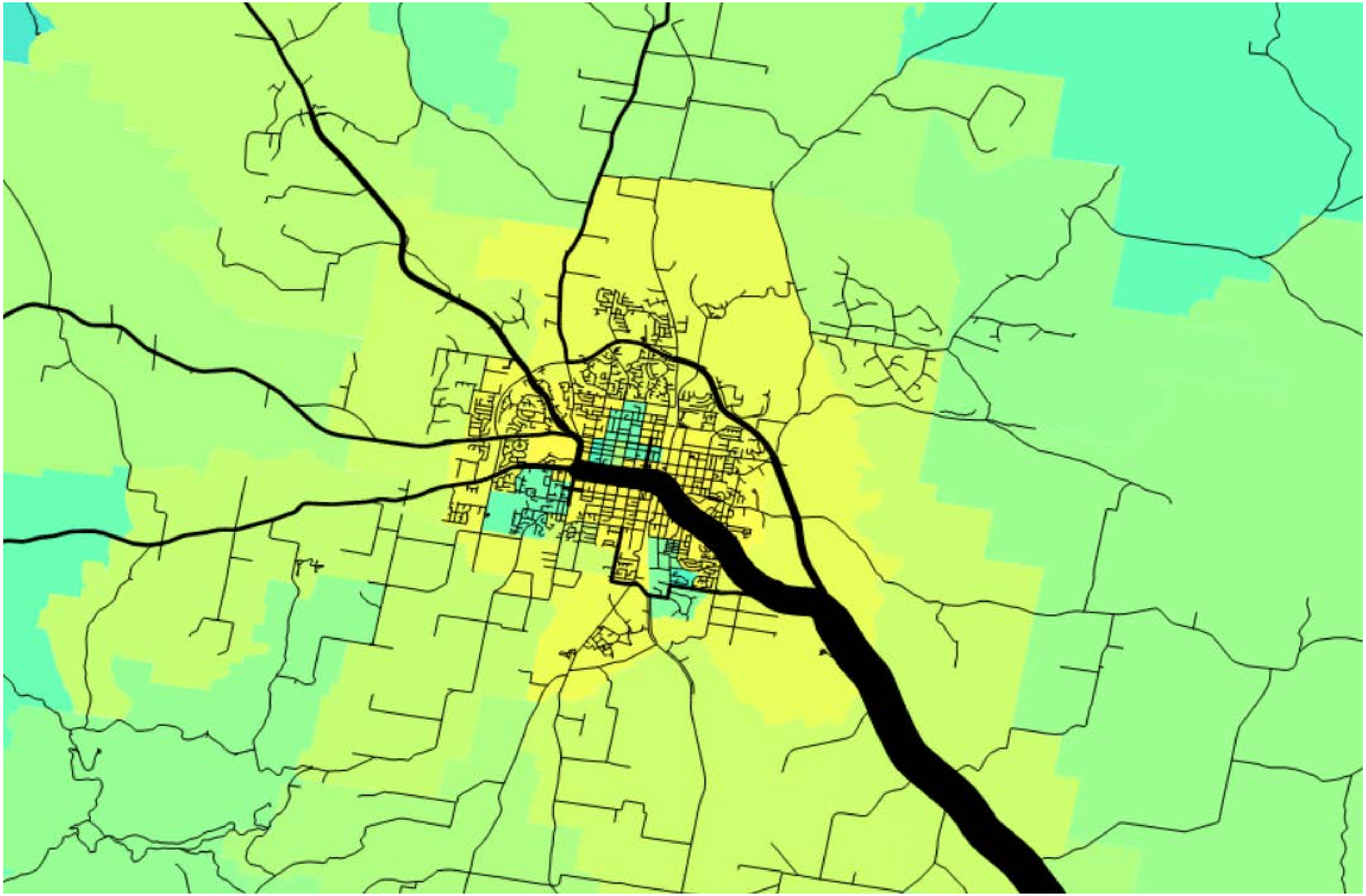


Hobart

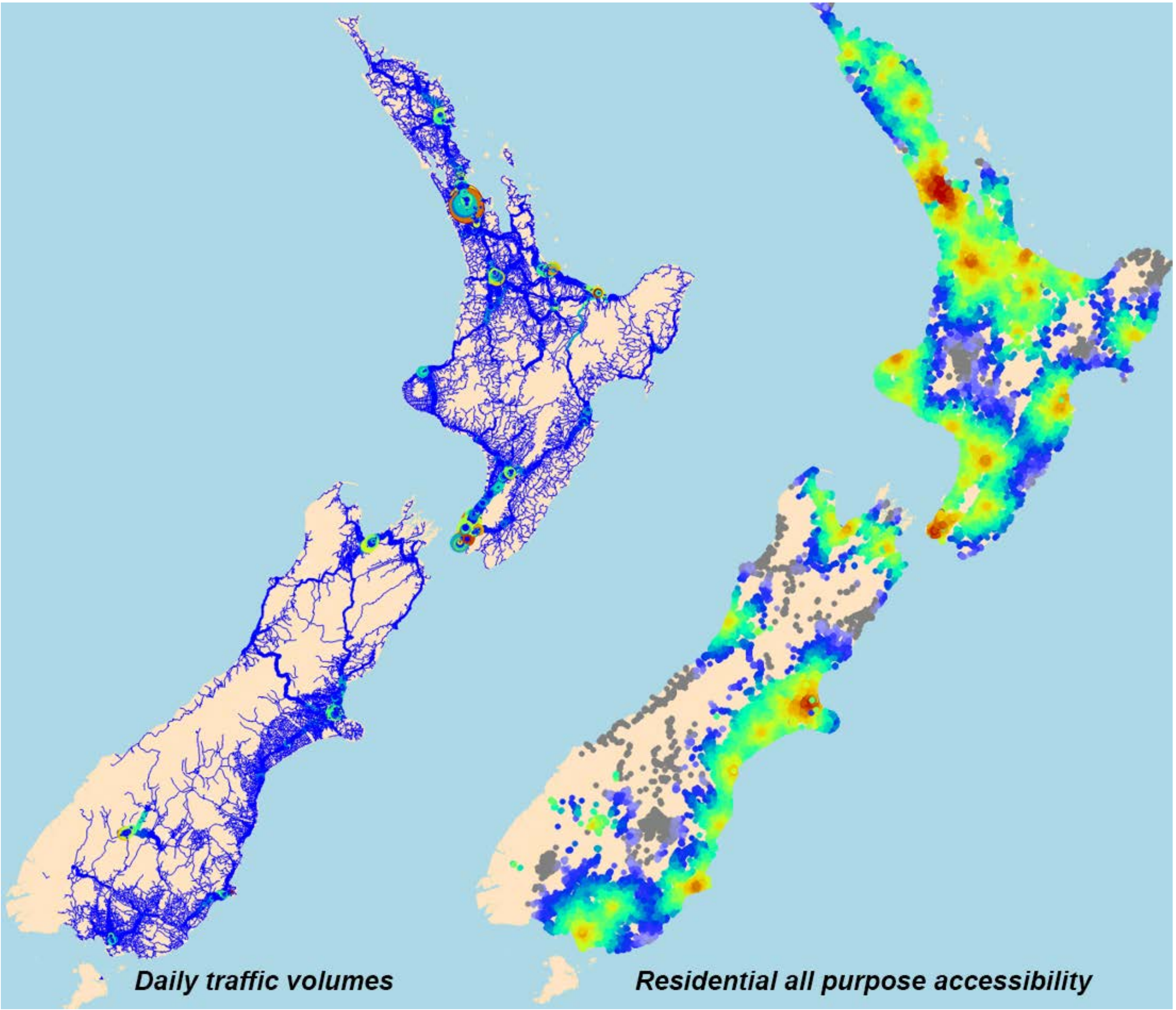


TransPosition

Orange, NSW

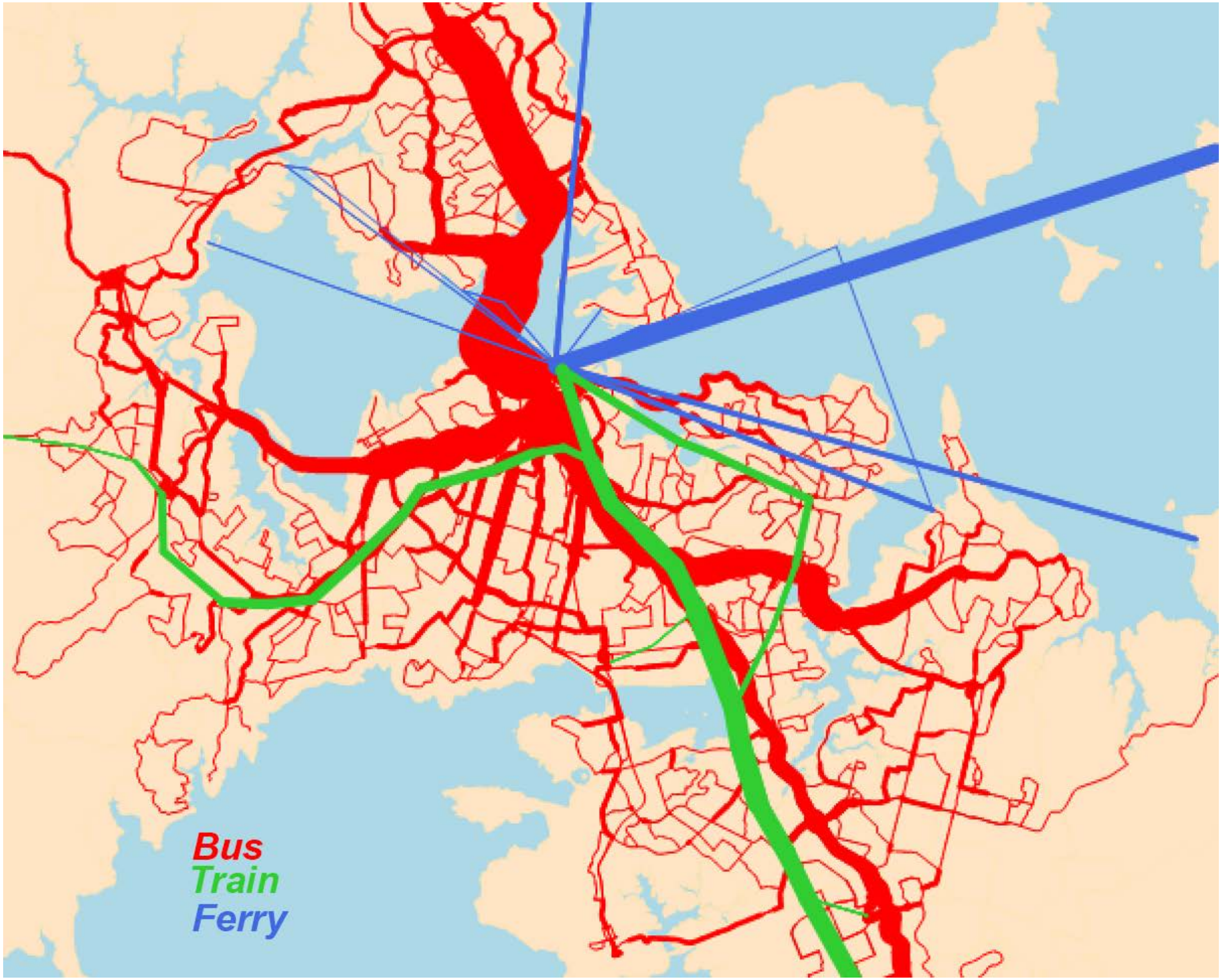


New Zealand



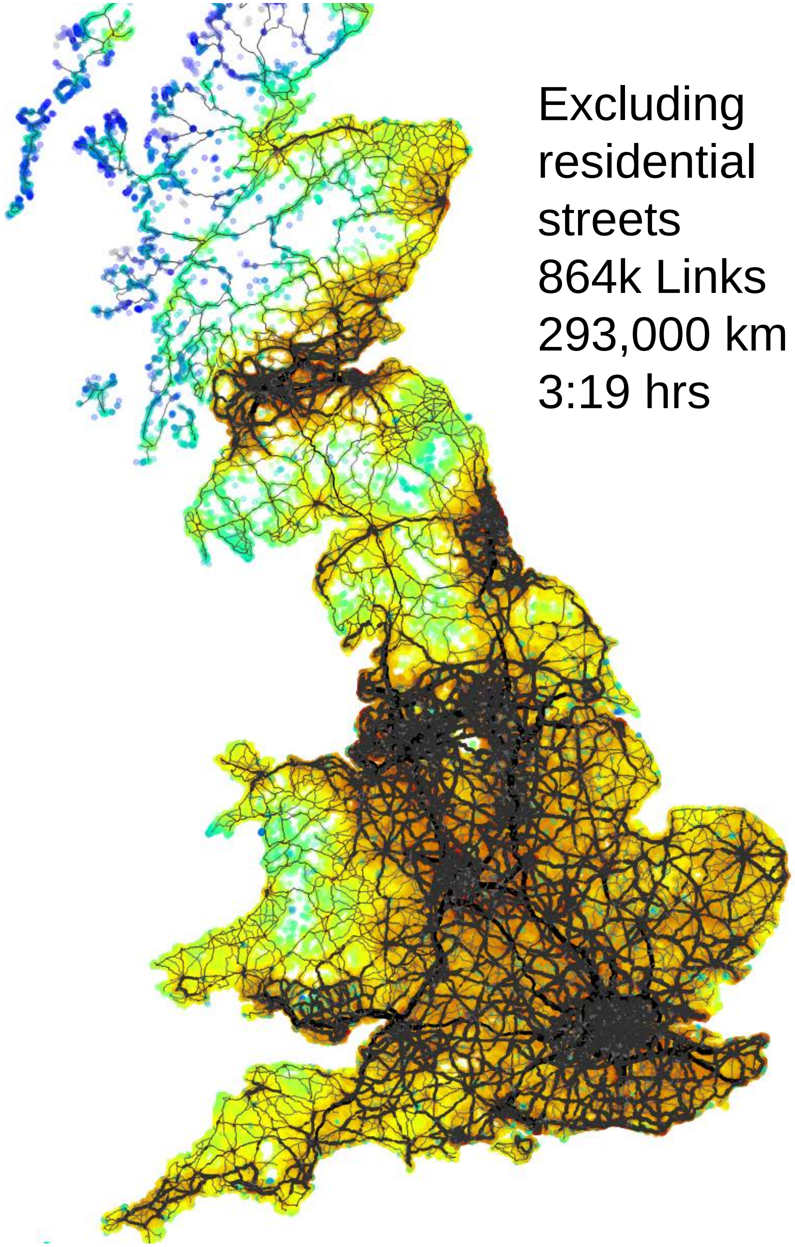
Daily traffic volumes
Residential all purpose accessibility

Auckland public transport

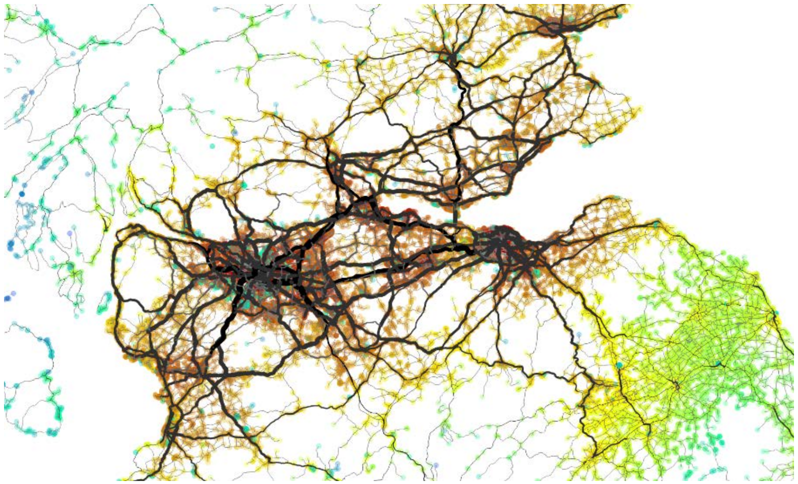


TransPosition

Great Britain

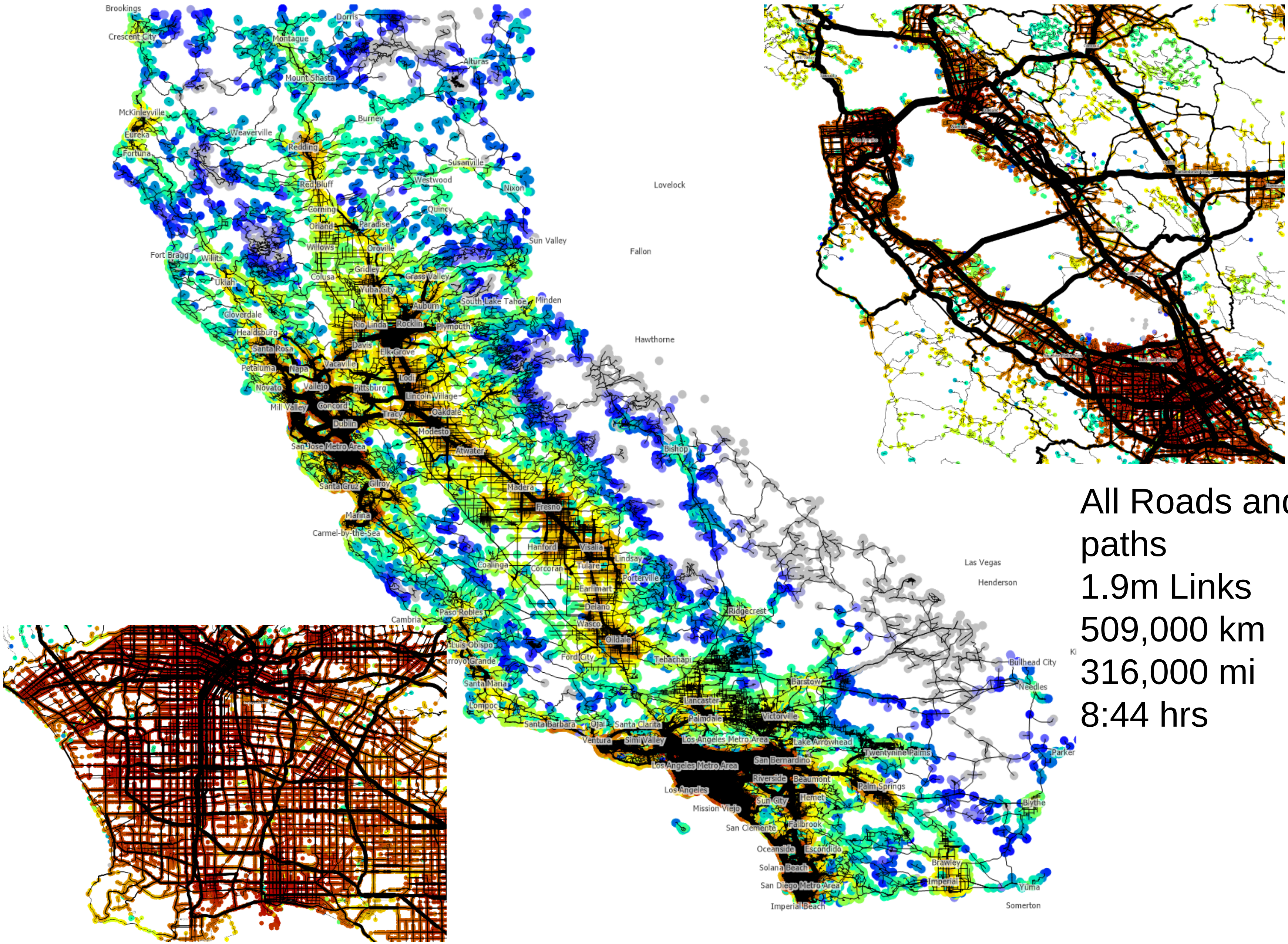


Excluding residential streets
864k Links
293,000 km
3:19 hrs



TransPosition

California



All Roads and paths
1.9m Links
509,000 km
316,000 mi
8:44 hrs

Physical theories

- Gravity model – Classical mechanics (Isaac Newton *Principia Mathematica* 1687)
- Entropy maximisation – Statistical mechanics (Ludwig Bolzmann *Lectures on Gas Theory* 1896)
- Discrete destination choice – Analytical probability (Pierre Simon de Laplace *Analytical theory of probability* 1812)
- 4S model – Monte Carlo analysis (Stanislaw Ulam *Heuristic Studies in Problems of Mathematical Physics on High Speed Computing Machines* 1953)

TransPosition