CAREC

Central Asia Regional Economic Cooperation Program

21st Transport Sector Coordinating Committee Meeting

22–23 April 2024 • Almaty, Kazakhstan

21-е заседание Координационного комитета по транспортному сектору

22–23 апреля 2024 года • Алматы, Казахстан

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Big Data, Artificial Intelligence and Digitalization

Dr. S. Travis Waller
Managing Director
Mobility Thinking Pty Ltd

Evolution of Transport Modeling to Support Planning

Emergence of Big Data / Pervasive Data

- Alternatives to traditional sources
- Potential for exponential acceleration, also challenges (format, substance)

Advanced Statistical and Machine Learning AI Tools

- Potential to automated traditionally labour-intensive tasks
- New skillsets and specialists required but need to understand planning

Increased Need for Openness, Equity and Sustainability

- Drives new quantification and broader metrics (EJ, Equity, Resilience)
- We must free up our time to expand what we can do (eliminate repetitive)

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D I S R U P T I O N

To Look Forward, Let’s First Quickly Glance Back

- What has formed the noted view?
- During my relocation to Germany in 2022
  - I reflected on my relocation from Austin(Texas) to Sydney(Australia) in 2011
- I was working on 4 topics prior to 2011 that are still ongoing today
- The **exact 2011 slides** and some outcomes are briefly shown

Past and ongoing clients/sponsors including:

NVIDIA, Asian Development Bank, U.S. National Science Foundation, Australia Research Council, U.S. Federal Highway Administration, U.S. DOT, TfNSW, Mitsubishi Heavy Industries, Advisian, GoGet Carshare in addition to many other government agencies, software companies, infrastructure firms, advisory firms, banks, insurance companies, startups, etc.

1. Electric Vehicles

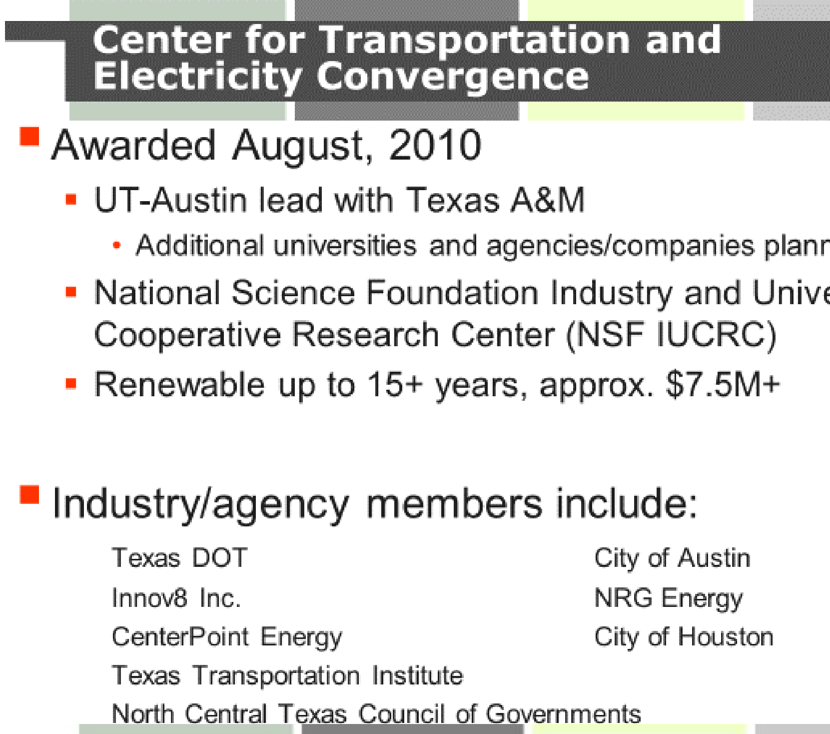
Very early research in the area of

- Studying the future behavior of travelers with the emerging reality of electric vehicles
- The work requires a blending of topics spanning **human behavior, technology,** and **emerging data**

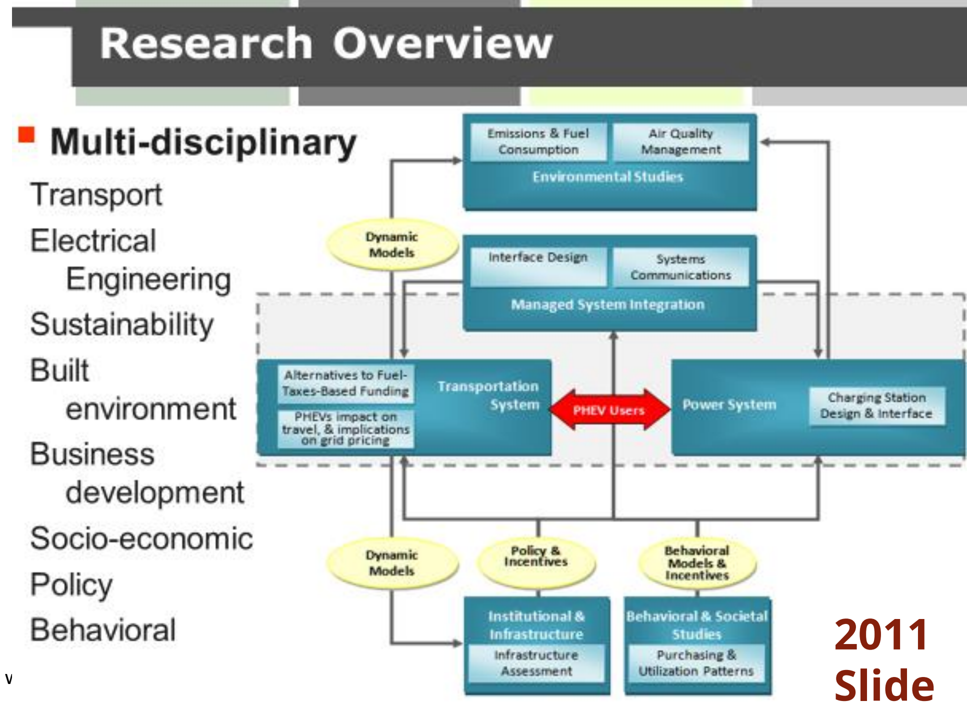
Our work began on this topic in 2007

- Collaborative with Dr. Mladen Kezunovic (Global Expert on Power Systems, NAE Member)

The established NSF Center was pioneering in the EV domain and our work on the topic has continued through today



2011 Slide



2011 Slide

2. Environmental Justice Across Protected Groups

We provided the first quantification of EJ for Transport Network Modelling and Planning in the literature (2008)

With my former PhD student, Dr. Jen Duthie (now head of Innovation for Cintra, one of the largest private developer of transport infrastructure globally)

Requires **new forms of data** and synthesis that include **social values**

The study won the U.S. Transportation Research Board Fred Burggraf Award

TRB is a division of the US National Academy of Science, Engineering and Medicine

While the work was mathematical in nature, it was also highly practical for usage

Used by one of the largest planning organization in the US

Kicked off a stream of activity through present day

Environmental Justice, Emissions, Sustainability and Uncertainty

- Quantifiable engineering tools for properly accounting for
  - Environmental justice considerations
  - Optimizing network improvements for emission reduction
  - Sustainable planning accounting for uncertainty
- Sponsors

  North Central Texas Council of Governments (Dallas MPO)

  Southwestern University Transportation Center

  National Science Foundation

  FHWA

2011 Slide

Definitions difficult. One EJ variation is: ***Avoid disproportionality and maintain/improve access for protected groups***

EJ-UE-DNDP

$$\min_{g\in\{0,1\}} Z(v^*(g),g) \quad (1)$$

$$s.t. \sum_{l\in I} g_l = \theta \quad (2)$$ ← total # of improvements

$$v^*(g) = \arg\min_v \sum_{l\in L} \int_{x=0}^{v_l} t_l(x)dx \quad (3)$$

$$s.t.\ v = Ah \quad (4)$$

$$d = Bh \quad (5)$$

$$v \geq 0 \quad (6)$$

$$t_l(v_l, g_l) = t_l(0) \times \left(1 + \alpha\left(\frac{v_l}{u_l + g_l\gamma}\right)^\beta\right), \quad \forall l \in I \quad (7)$$

$$t_l(v_l) = t_l(0) \times \left(1 + \alpha\left(\frac{v_l}{u_l}\right)^\beta\right), \quad \forall l \in L \setminus I \quad (8)$$

$d = d^{P_1} + d^{P_2} + \ldots + d^{P_n} + d^{up}$

$g_l = \begin{cases} 1 \text{ if } l \text{ is improved} \\ 0 \text{ o.w.} \end{cases}$

γ = potential capacity increase

2011 Slide

3. Study of Disease Spreading in Transport Networks

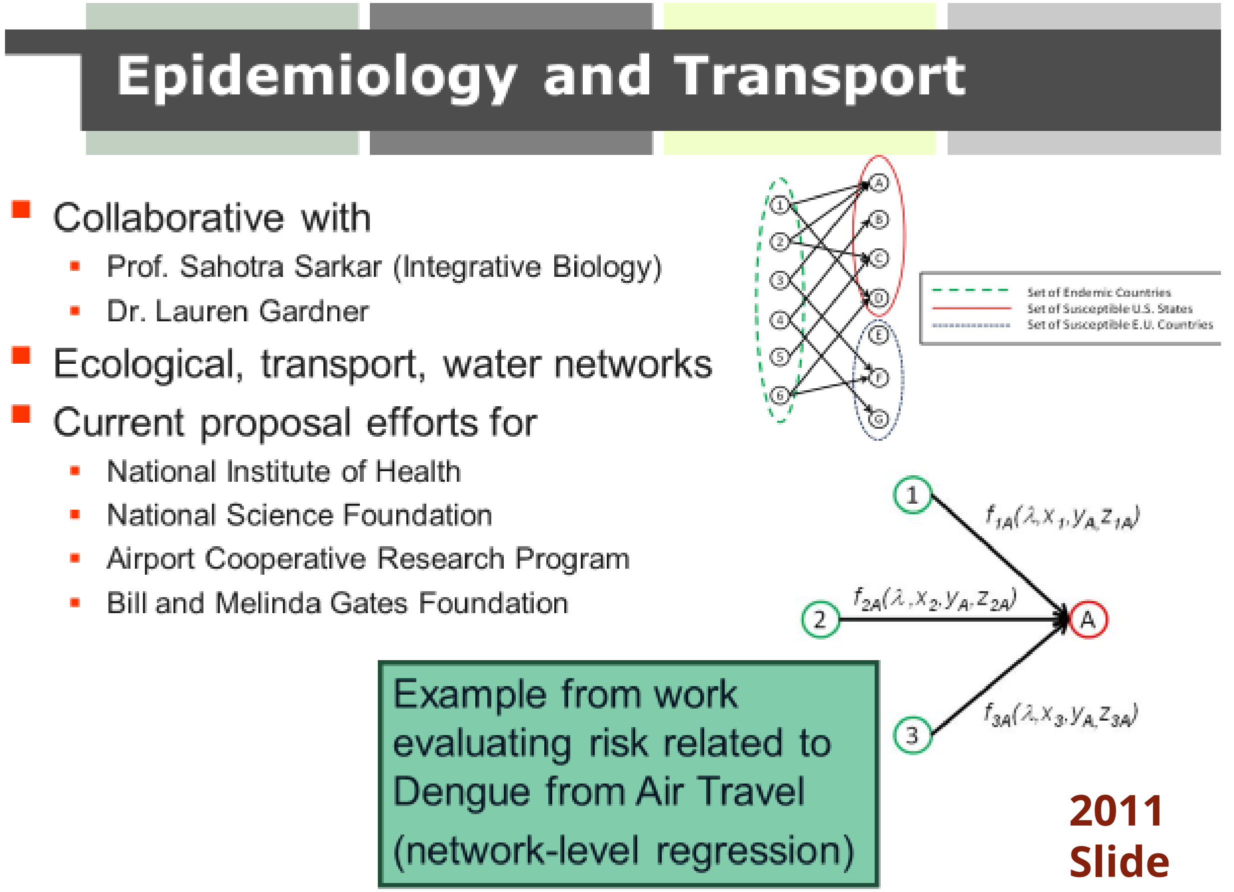
We began studying the spread of disease through transport networks very early (2005 onward)

Especially with **novel emerging big-data**

PhD (2011) thesis topic of Dr. Lauren Gardner (my former PhD student at UT Austin and mentored colleague at rCITI, UNSW 2011-2019).

Dr. Gardner would go on to create the well-known COVID19 Dashboard after her relocation to Johns Hopkins University in 2019 (and to be named to the list of TIME's 100 most influential people in the world of 2020).

Initiated activity to better understand disciplinary impacts and interactions of mobility



2011 Slide

4. Automated/Autonomous Vehicles

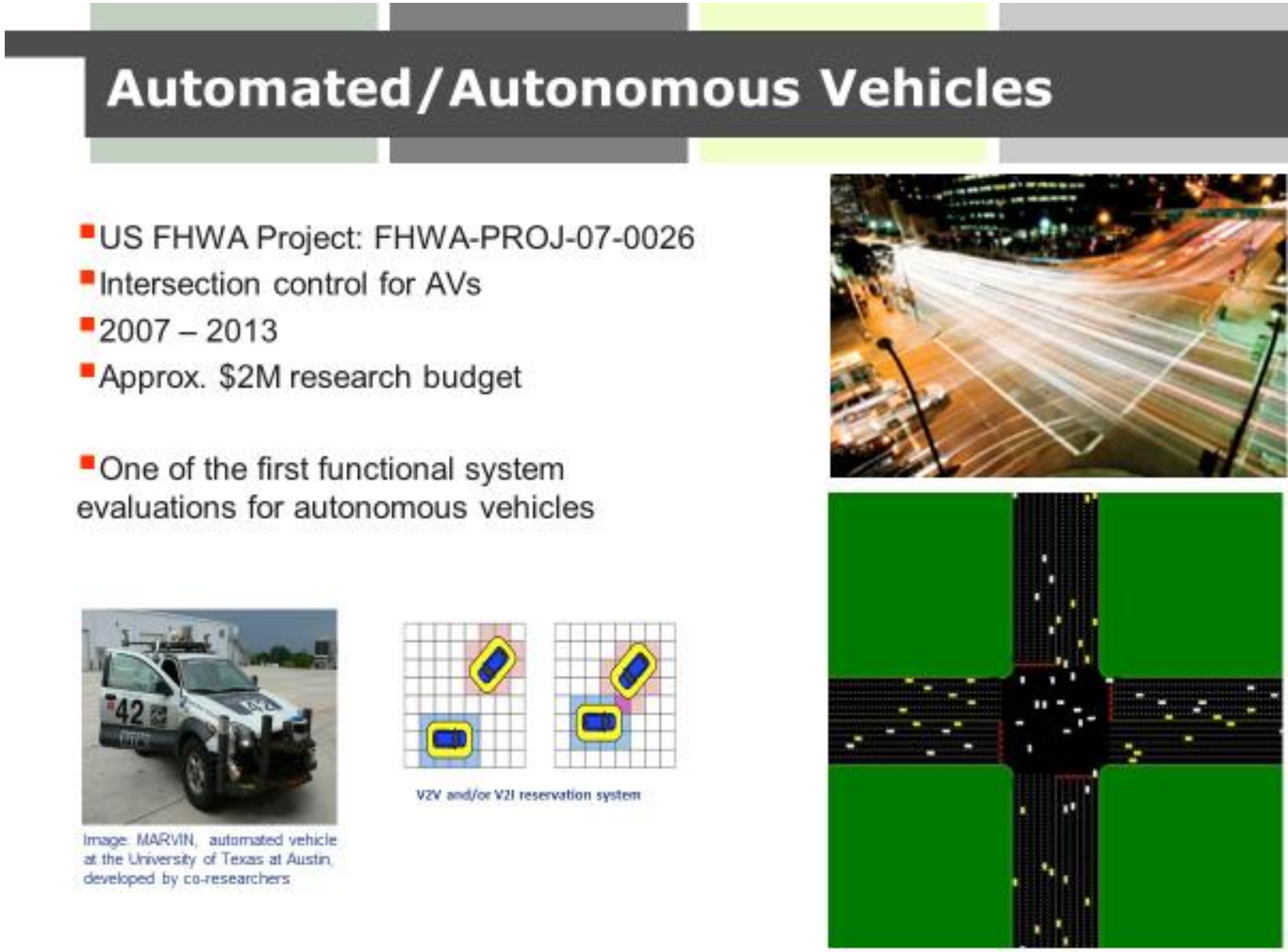
Beginning from work in 2006, jointly conducted first large (over $1.8m) project globally to study

- How AVs would function in a transport system
- Computationally complex with travel behavior changes (**machine learning, early AI work**)

This project was collaborative work with Computer Science Professor Peter Stone

- Co-founder of Cogitai, Inc. and now Executive Director of Sony AI America

Began long series of activities spanning many studies and projects including for government agencies, advisories, banks, insurance firms, etc.



2011 Slide

The Present and Future: Evolution and Progress

From these emerging topics (all starting before 2010):

1. Electric Vehicles (leading onto broader e-mobility)
2. Environmental Justice Including Impact Across Protected Groups
3. Pandemics in Transport Networks
4. Automated/Autonomous Vehicles

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D I S R U P T I O N

For the topics of today we need to leverage lessons learned including new methodologies on

- **Emerging novel big-data**
- **Machine Learning (Applied AI)**
  - **While including travel network behavior**

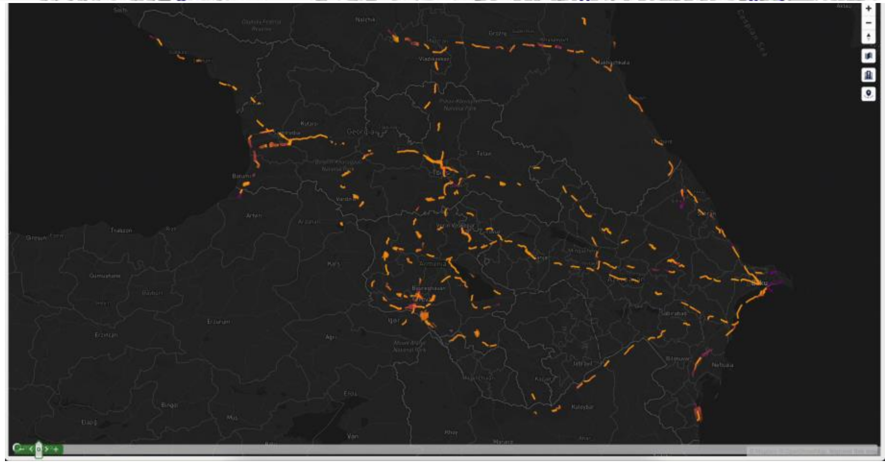
All of this while incorporating more capacity to quantify social values

Impact on Transportation Planning

Covered by earlier talk

In short, opportunities include

- To cut the time and cost dramatically
- Standardize across regions
- Increase transparency and engagement
- Incorporate novel metrics
  - Equity
  - Sustainability
  - Environmental impact/justice
  - Resilience
  - Etc.



Critical Note:

In doing all of this, we must not lose the capacity to appropriately model "what-if" scenarios.

If we lose this, we lose our purpose in the planning process.

To plan is not simply to analyse. It is not just data analytics.

We would like to acknowledge collaboration with NVIDIA

Safety and Technology

- Technology changes travel behavior
  - Critical implications for planning

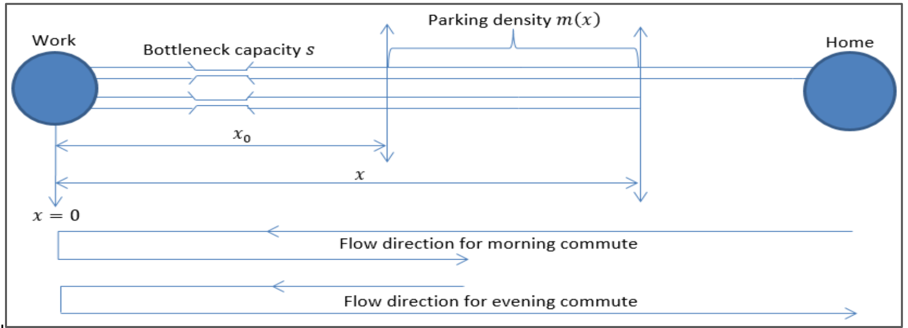
- We need to understand the safety impact of emerging technology to **plan better**
  - AVs, e-mobility, micromobility

- Also, using the new tools to **estimate safety in real-time**

N Virdi;H Grzybowska;ST Waller;V Dixit (2019) **'A safety assessment of mixed fleets with Connected and Autonomous Vehicles using the Surrogate Safety Assessment Module'**, Accident Analysis and Prevention, Vol 131, pp. 95-111.

E Qiu; N Virdi; H Grzybowska; ST Waller (2022) **'Recalibration of the BPR function for the strategic modelling of connected and autonomous vehicles',** Transportmetrica B: transport dynamics 10 (1), pp. 779-800.

X Zhang; E Robson; ST Waller (2020) **' An integrated transport and economic equilibrium model for autonomous transportation systems considering parking behavior '** Computer-Aided Civil and Infrastructure Engineering, vol 36(7), pp 902-921.



Road Vehicle Carbon and Emission Modelling (Ongoing Work)

With the new data and methods, metrics can be more readily calculated

Example: Road vehicle carbon

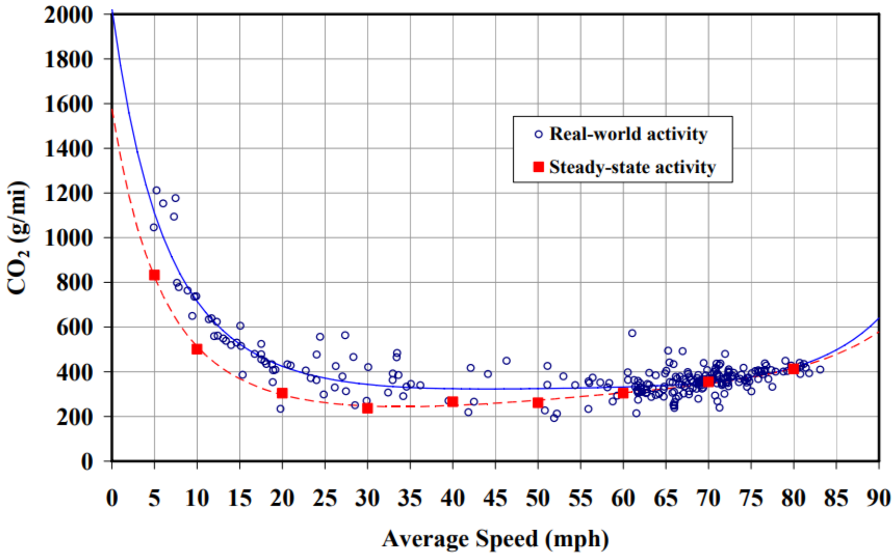
3 Methods examined including:

Method #1:

Utilizing the fitted fourth-order polynomial equation (Barth equation).

Where y is CO2 emissions in g/mi, and x is the average trip speed in mph.

Barth, M., & Boriboonsomsin, K. (2008). Real-world carbon dioxide impacts of traffic congestion. Transportation research record, 2058(1), 163-171.



$$\ln(y) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4$$

Table 1. Derived line-fit parameters for Eqn. (1).

	Real-World
N	241
R^2	0.668
b_0	7.613534994965560
b_1	- 0.138565467462594
b_2	0.003915102063854
b_3	- 0.000049451361017
b_4	0.000000238630156

Comparison to the International Energy Agency (IEA) Report for CO_2 emissions

London:

- IEA: UK road transport emissions are 114 million tonnes per year
  - 312k tonnes per day, nationally
- Using a common peak-hour factor of 10 (i.e., two 3-hour peak periods, 4 off-peak)
  - **31k** tonnes per peak hour, nationally
- The Automated London *city model* reports **2.9k** tonnes for a specific 8-9am case
  - Approximately 9.3% of UK road carbon per peak hour

Auckland:

- IEA: New Zealand road transport emissions are 14.3 million tonnes per year
  - **3.9k** tonnes per peak hour
- The automated Auckland city model reports **778** tonnes for a specific 8-9 am case
  - Approximately 19.85% of New Zealand's road carbon per peak hour

Methods 2 and 3 for road carbon estimation

Method 2: Similar to Barth approach though volume-capacity ratios referenced.

Tsanakas, N., Ekström, J., & Olstam, J. (2017). Reduction of errors when estimating emissions based on static traffic model outputs. Transportation research procedia, 22, 440-449.

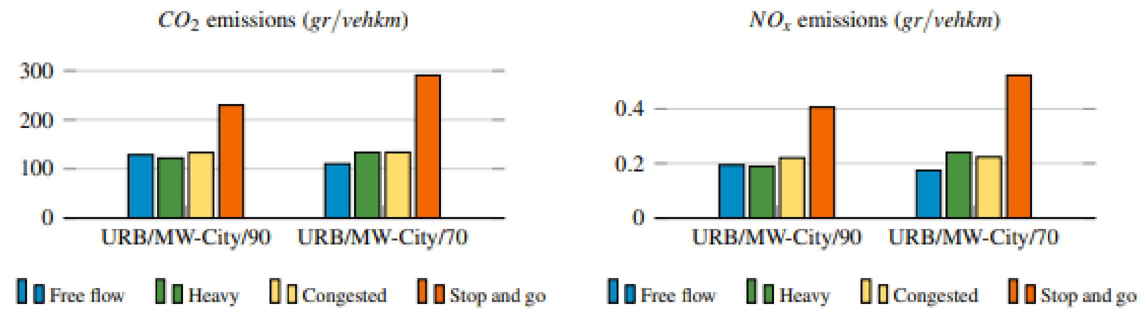


Figure 1. HBEFA emission factors; (a) CO_2 (b) NO_x.

Table 1. Volume/Capacity ratio thresholds.

Speed limit (km/h)	Free flow	Heavy	Congested	Stop and go
90	V/C <0.65	0.65≤ V/C <0.85	0.85≤ V/C <1.35	V/C ≥1.35
70	V/C <0.39	0.39≤ V/C <0.84	0.84≤ V/C <1.35	V/C ≥1.35
<50	V/C <0.52	0.65≤ V/C <0.78	0.65≤ V/C <1.22	V/C ≥1.22

Method 3: uses a MOVES function (U.S. Environmental Protection Agency 2014) to model energy consumption alongside BPR to model link performance function:

BPR function:

$$t_{ij} = t_{ij}^0 \cdot \left(1 + \alpha \left(\frac{x_{ij}}{c_{ij}}\right)^\beta\right) \quad \forall (i,j) \in A \tag{1}$$

MOVES function:

$$\begin{cases} LTEC_{ij} = TEC_{ij} \cdot L_{ij} \\ TEC_{ij} = 9.9 \cdot S_{ij}^{-0.56} \end{cases} \quad \forall (i,j) \in A \tag{2}$$

where TEC_{ij} is the transport energy consumption rate per vehicle kilometre travelled on link (i,j), which is measured in kWh/km if the dimension of speed S_{ij} is km/h. By substituting the BPR function into Formula (2), the TEC_{ij} function becomes:

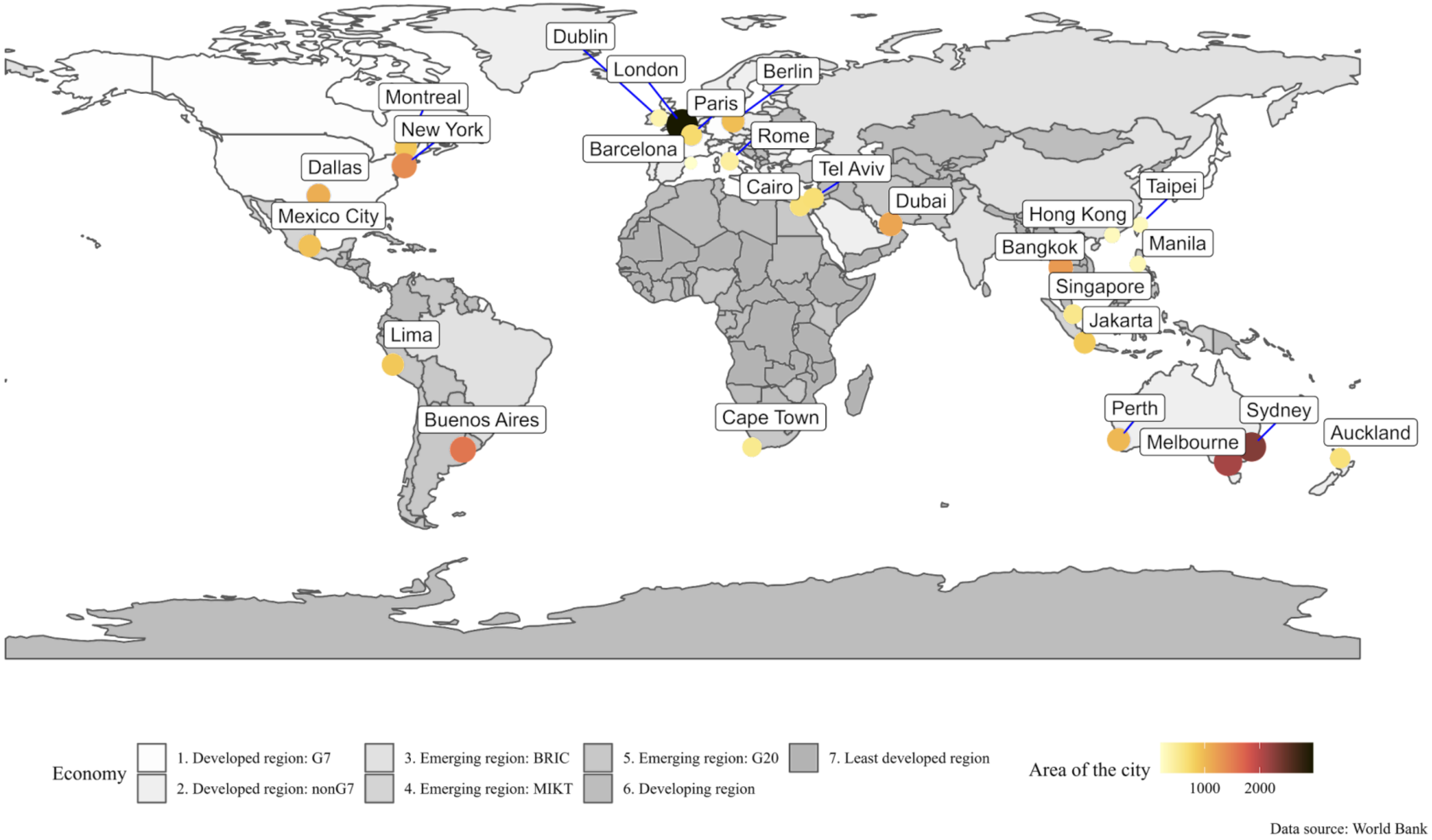
We employed this approach in this study:

Zhang, X., & Waller, S. T. (2019). Implications of link-based equity objectives on transportation network design problem. Transportation, 46(5), 1559-158

Considered World Cities

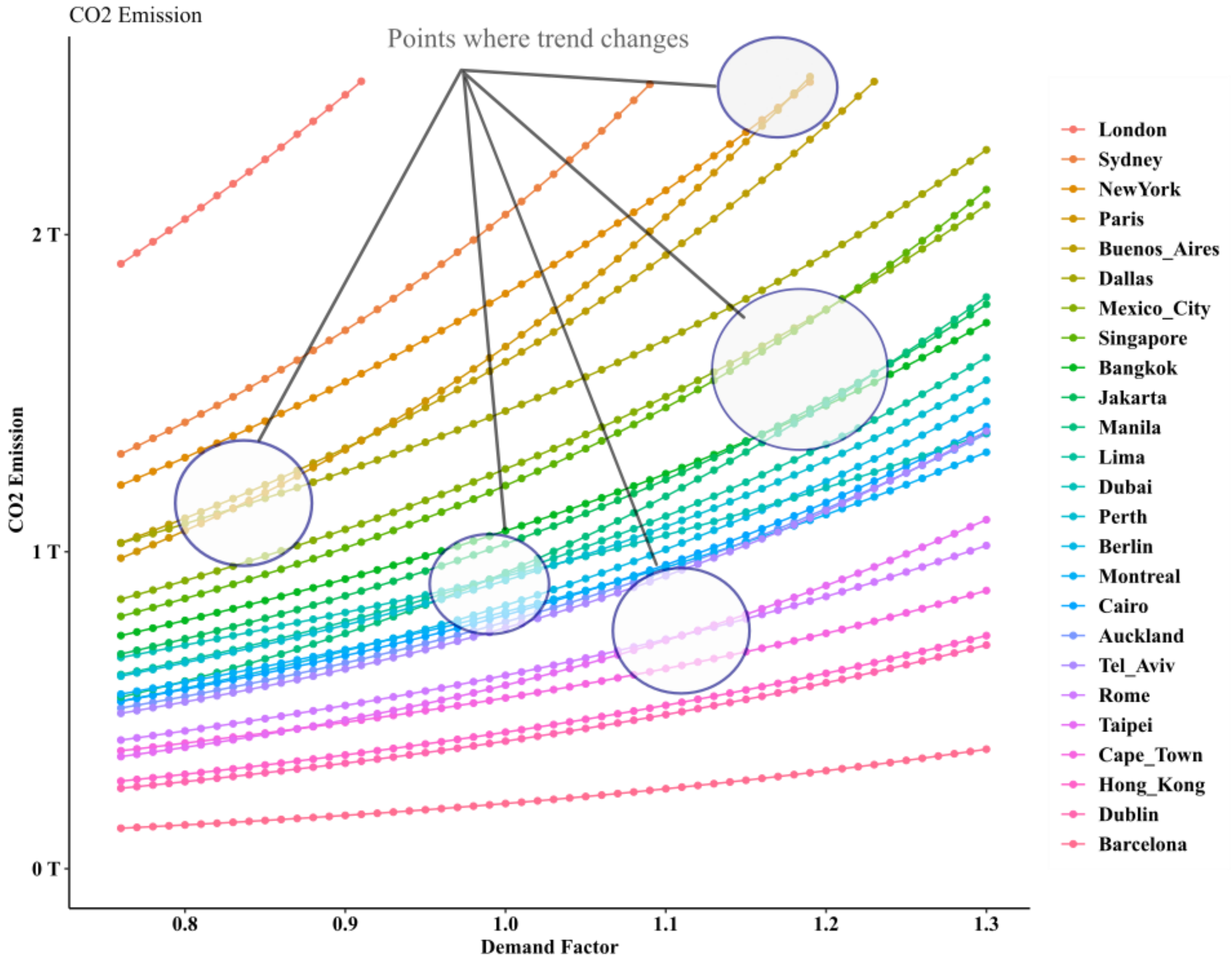
City	Region	[1] Economic Representation	[2]Area of city [km^2]
Auckland	Oceania	Developed : Non G7	645
Bangkok	Asia	Emerging : G20	1267
Barcelona	Europe	Developed : G7	201
Berlin	Europe	Developed : G7	954
Buenos Aires	South America	Emerging : G20	1571
Cairo	Africa	Emerging : G20	657
Cape Town	Africa	Emerging : G20	540
Dallas	North America	Developed :G7	1091
Dubai	Middle East	Developing	1159
Dublin	Europe	Developed :G7	360
Hong Kong *	Asia	Emerging : BRIC	281
Jakarta	South East Asia	Emerging : MIKT	860
Lima	South America	Emerging : G20	880
London	Europe	Developed : G7	2961
Manila	South East Asia	Emerging : G20	313
Melbourne	Australia	Developed : Non G7	2103
Mexico City	South America	Emerging : MIKT	931
Montreal	North America	Developed : G7	890
New York	North America	Developed : G7	1388
Paris	Europe	Developed : G7	717
Perth	Australia	Developed : Non G7	1008
Rome	Europe	Developed : G7	452
Singapore *	Asia	Developing	556
Sydney	Europe	Developed : Non G7	2305
Taipei	Asia	Developed : Non G7	273
Tel Aviv	Middle East	Developed : Non G7	681

[1] Data Source: World Bank [4]
[2] Area of the city considered in the study through GIS mapping
* Considered as developed economies based on the high GDP



Quantification of the Gradient of Road Traffic Carbon (Carbon Sensitivity)

- The approach embeds a (travel demand)-(network supply) equilibrium
- This facilitates examination across numerous demand scenarios
- As a result, the gradient of road traffic carbon can be quantified
    - This allows for a different lens on city to city comparison



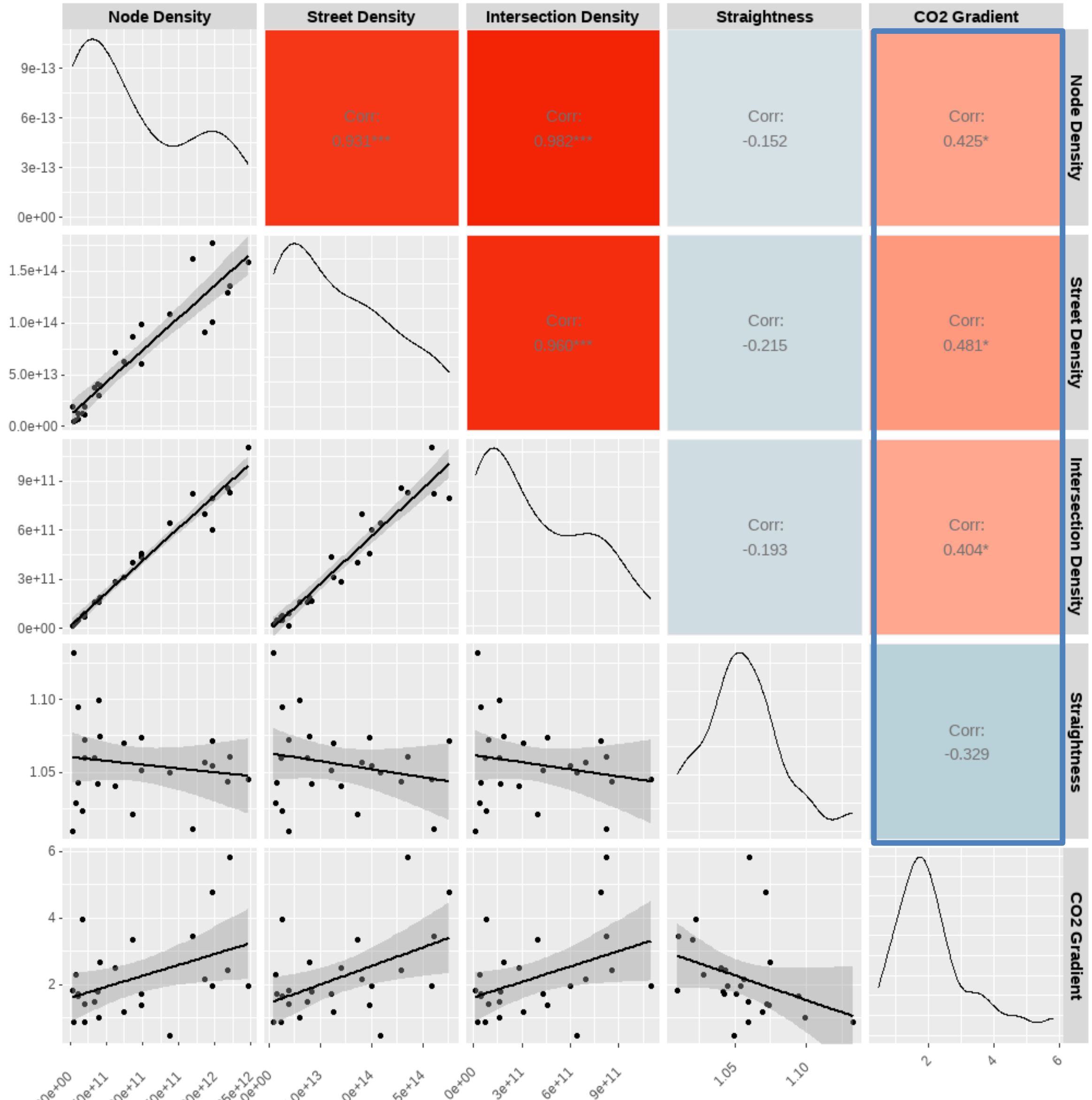
Do network parameters have any influence on gradient of emissions?

More than 25 different networks parameters were investigated

- Defining size, shape, capacity, and orientation of road networks in world cities

- **<u>Preliminary Analysis</u>**: 4 are found to have significant relation with gradient of emission

  (i) Street Density (per km)
  (ii) Node Density (per km)
  (iii) Intersection Density (per km)
  (iv) Straightness / Circuity



All the densities are estimated at per square kilometers of area

Duthie and Waller (2008) on Metrics for Environmental Justice

Similarly new metrics on equity and environmental justice can be calculated

Mandate: Respond to U.S. Presidential Order to use Environmental Justice in infrastructure planning

Agency needed a quantified method of incorporating novel concept for them

An early example of digitizing our emerging values into the formalized planning process

$$\min_{g \in \{0,1\}} Z\left(v^*(g), g\right) \qquad (1)$$

subject to

$$\sum_{l \in L \setminus I} g_l = \theta \qquad (2)$$

$$v^*(g) = \arg\min_{v} \sum_{l \in L} \int_{x=0}^{v_l} t_l(x)\,dx \qquad (3)$$

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$$t_l(v_l) = t_l(0) \times \left(1 + \alpha\left(\frac{v_l}{u_l}\right)^{\beta}\right) \qquad \forall l \in L \setminus I \qquad (8)$$

$$Z_1 = \frac{\sum_{ij} s_{ij}^{t} d_{ij} p_{ij} / e_{ij}^{f}}{\sum_{ij} d_{ij} p_{ij}}; \qquad Z_2 = \frac{\sum_{ij} s_{ij}^{f} d_{ij} / e_{ij}^{f}}{\sum_{ij} d_{ij}};$$

$$Z_3 = \left(\frac{\sum_{ij} s_{ij}^{f} d_{ij} p_{ij} / e_{ij}^{f}}{\sum_{ij} d_{ij} p_{ij}} - \frac{\sum_{ij} s_{ij}^{f} d_{ij} (1 - p_{ij}) / e_{ij}^{f}}{\sum_{ij} d_{ij} (1 - p_{ij})}\right)^2;$$

$$Z_4 = \left(\frac{\sum_{ij} \left(s_{ij}^{f} d_{ij} p_{ij} / e_{ij}^{f} - s_{ij}^{0} d_{ij} p_{ij} / e_{ij}^{0}\right)^2}{\sum_{ij} d_{ij} p_{ij}} - \frac{\sum_{ij} \left(s_{ij}^{f} d_{ij} (1 - p_{ij}) / e_{ij}^{f} - s_{ij}^{0} d_{ij} (1 - p_{ij}) / e_{ij}^{0}\right)^2}{\sum_{ij} d_{ij} (1 - p_{ij})}\right)^2;$$

$$Z_5 = \frac{\sum_{ij} s_{ij}^{f} d_{ij} p_{ij}}{\sum_{ij} d_{ij} p_{ij}}; \qquad Z_6 = \frac{\sum_{ij} s_{ij}^{f} d_{ij}}{\sum_{ij} d_{ij}};$$

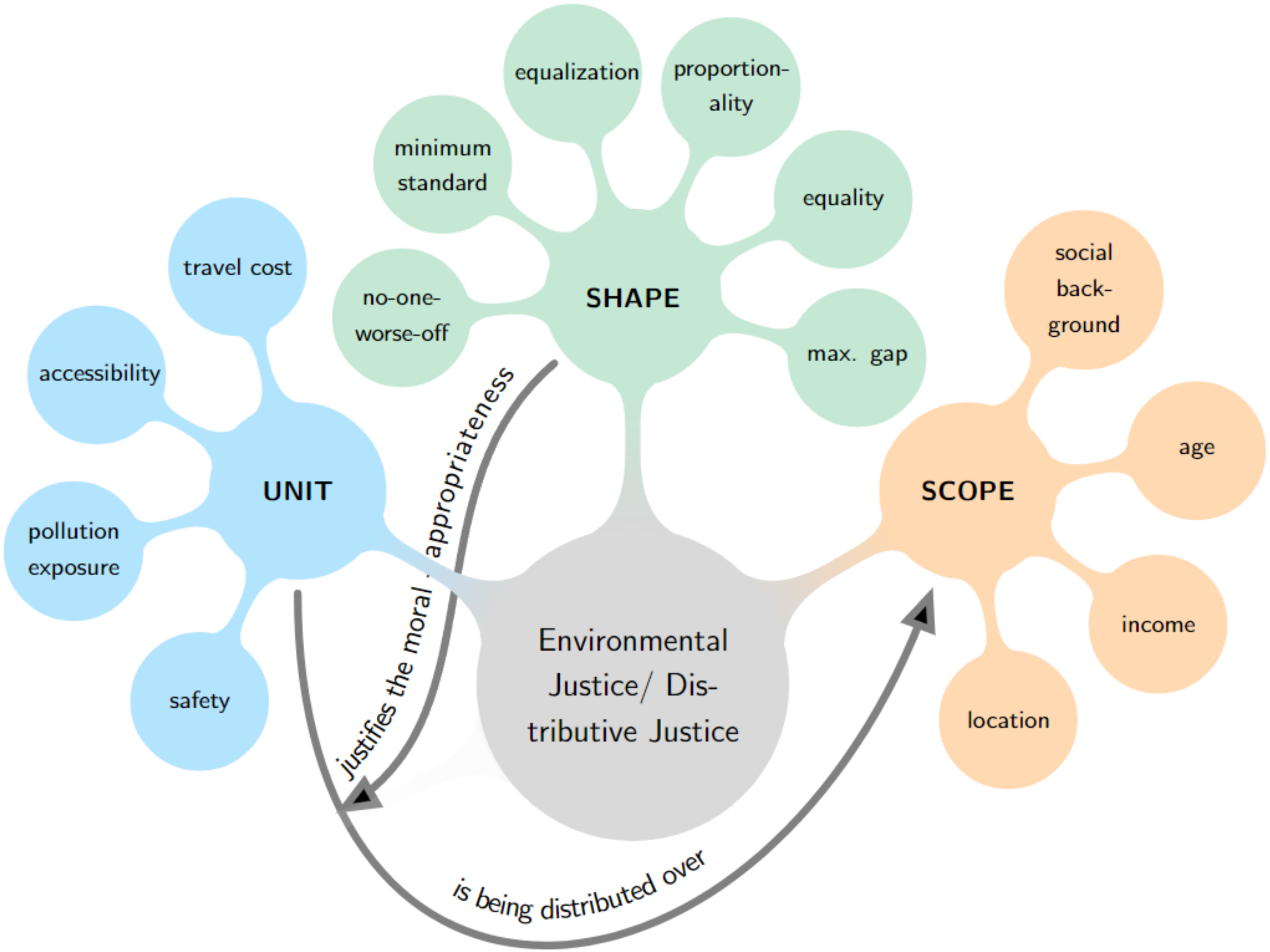
$$Z_7 = \left(\frac{\sum_{ij} s_{ij}^{f} d_{ij} p_{ij}}{\sum_{ij} d_{ij} p_{ij}} - \frac{\sum_{ij} s_{ij}^{f} d_{ij} (1 - p_{ij})}{\sum_{ij} d_{ij} (1 - p_{ij})}\right)^2;$$

$$Z_8 = \left(\frac{\sum_{ij} \left(s_{ij}^{f} d_{ij} p_{ij} - s_{ij}^{0} d_{ij} p_{ij}\right)^2}{\sum_{ij} d_{ij} p_{ij}} - \frac{\sum_{ij} \left(s_{ij}^{f} d_{ij} (1 - p_{ij}) - s_{ij}^{0} d_{ij} (1 - p_{ij})\right)^2}{\sum_{ij} d_{ij} (1 - p_{ij})}\right)^2$$

TABLE 2 Range of Fitness and Number of Generations to Convergence

Objective Function	Z^{min}	Z^{max}	$n_{converge}$
Z_1	1.98	2.31	7
Z_2	1.99	2.23	6
Z_3	4.00×10^{-5}	8.52×10^{-4}	17
Z_4	0.44	206.08	29
Z_5	3.91	4.45	5
Z_6	3.98	4.51	5
Z_7	5.27×10^{-3}	8.90×10^{-3}	16
Z_8	8.06	2,480.51	12

Our Current Work in Germany, Australia and Hong Kong



Adopted Jafino (2021) Framework for Model Quantification

Developing methods to incorporate varying measures for equity and justice into automated transport modeling tools

Equity Measurement	Formulation
Rawl's Egalitarian (RE)	$RE = \max \sum_{i=1}^{k} Y_i$
Utilitarianism (U)	$U = \max \sum_{i=1}^{n} Y_i$
Gini index (GINI)	$GINI = \frac{1}{2n^2\bar{Y}} \sum_{i=1}^{n} \sum_{j=1}^{n} \lvert Y_i - Y_j \rvert$
Theil index (THEIL)	$THEIL = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{Y_i}{\bar{Y}} \log\log \frac{Y_i}{\bar{Y}} \right)$
Atkinson index (ATK)	$ATK = \begin{cases} 1 - \left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{Y_i}{\bar{Y}} \right)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}, \epsilon \neq 1 \\ 1 - \frac{1}{\bar{Y}} \left(\prod_{i=1}^{n} Y_i \right)^{\frac{1}{n}}, \epsilon = 1 \end{cases}$
Sadr's theory of Justice (SADR)	$SADR = \begin{cases} \max \sum_{i=1}^{n} Y_i; \\ s.t\ Y_i > m1 \times Y_j, \forall i,j \\ \sum_{i,j} \frac{Y_i - Y_j}{2n^2\bar{Y}} < m2 \end{cases}$
Relative mean deviation (RMED)	$RMED = \frac{1}{n} \sum_{i=1}^{n} \lvert \frac{Y_i}{\bar{Y}} - 1 \rvert$
Mean log deviation (LDEV)	$LDEV = \frac{1}{n} \sum_{i=1}^{n} \lvert \log\log Y_i - \log\log \bar{Y} \rvert$

Planning, Equity and Resilience

- Quantifying metrics is not sufficient
- We must plan, including for resilience
- Resilience planning absolutely requires hypothetical analysis
  - It is all about the potential future disrupted phase
- Ultimately, this requires a synthesis
  - New data
  - New methods
  - Traditional principles of transport planning

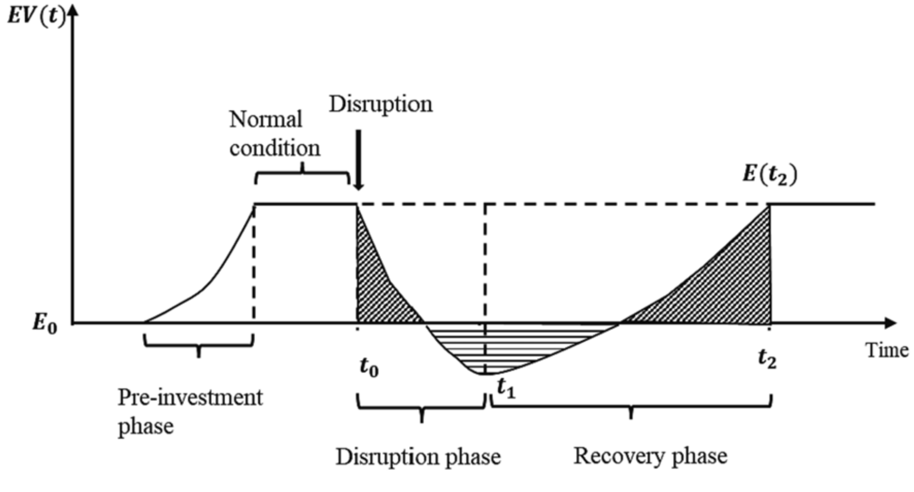
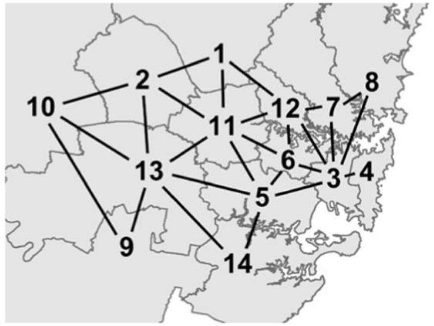


Fig. 1. Economic-based Network Resilience Measurement with a pre-investment project.

T Zhang, C Niu, D Nair, V Dixit, and ST Waller (2023) '**Equity analysis and improvement in transportation resilience optimisation at the pre-event stage**' Transportation Research Part D: Transport and Environment, Vol 122, pp 1-24.



Summary

Emerging big data and Machine Learning/Applied AI have dramatic potential

Significant developments have already been made

- Many more remain

But, we must appropriately integrate these emerging tools into the principles of our professional domain

We have a process though

- Use emerging tools to first quantify, measure, make metrics
- Modify the planning tools to employ these new metrics
- Automate as many repetitive steps as we can