Geospatial Data Science, Spring 2022

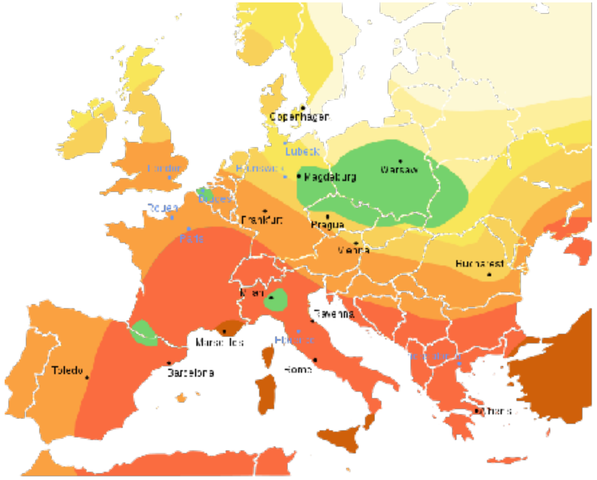
Lecture 14: Geospatial epidemiology and sustainable mobility

Instructor: Michael Szell
May 12, 2022

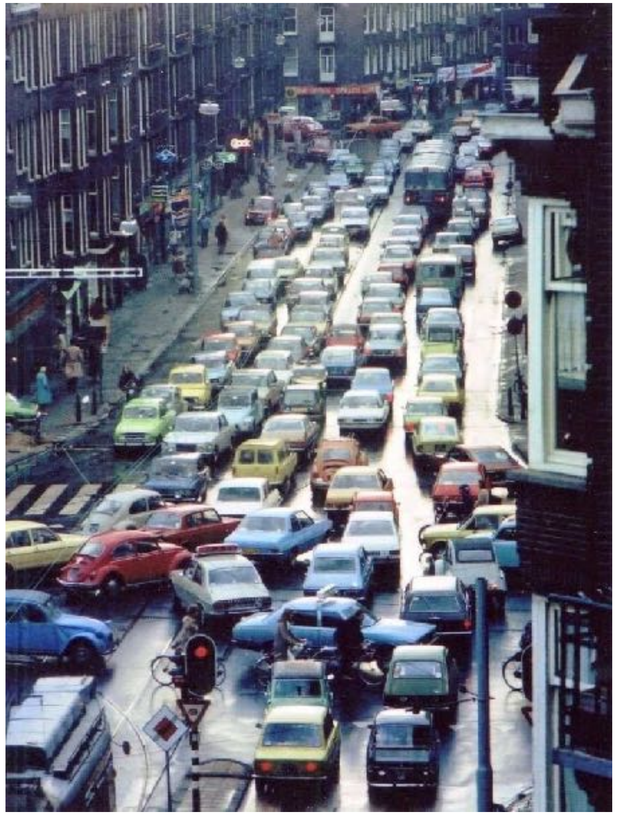
IT UNIVERSITY OF COPENHAGEN

Today you will learn about epidemiology and sustainable mobility

Geospatial epidemiology

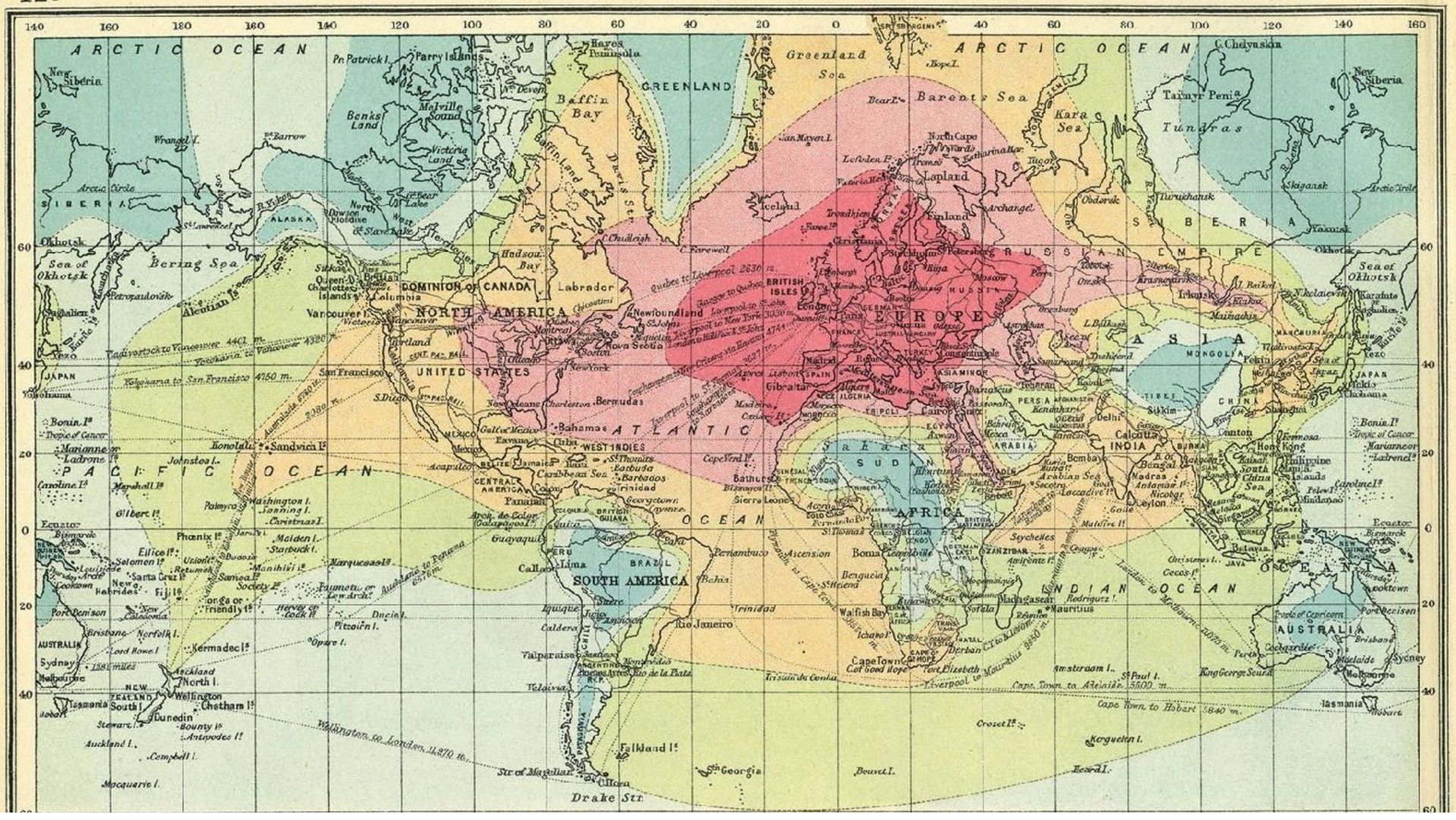


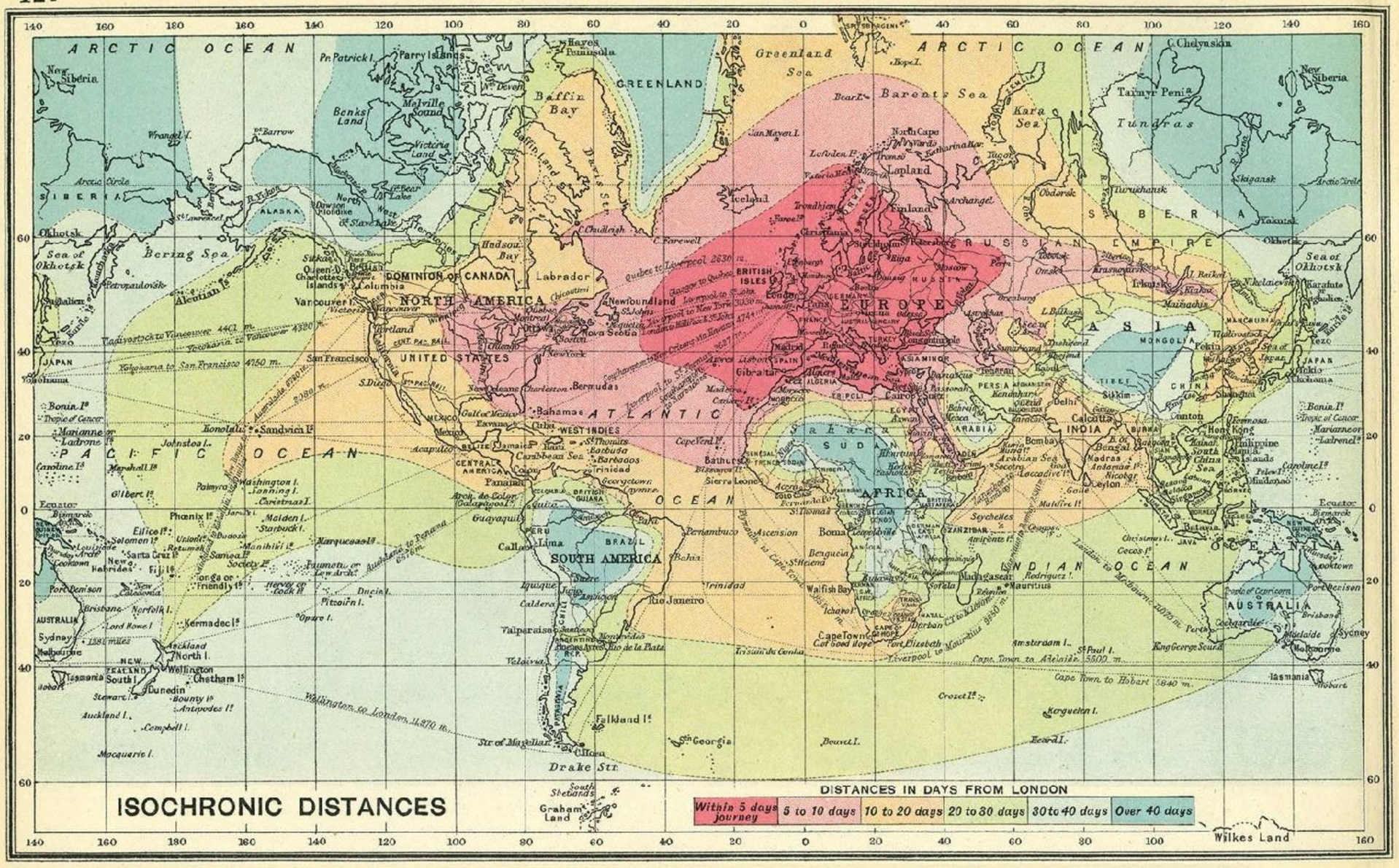
Sustainable mobility



Course Evaluation +
Exam questions

Geospatial epidemiology

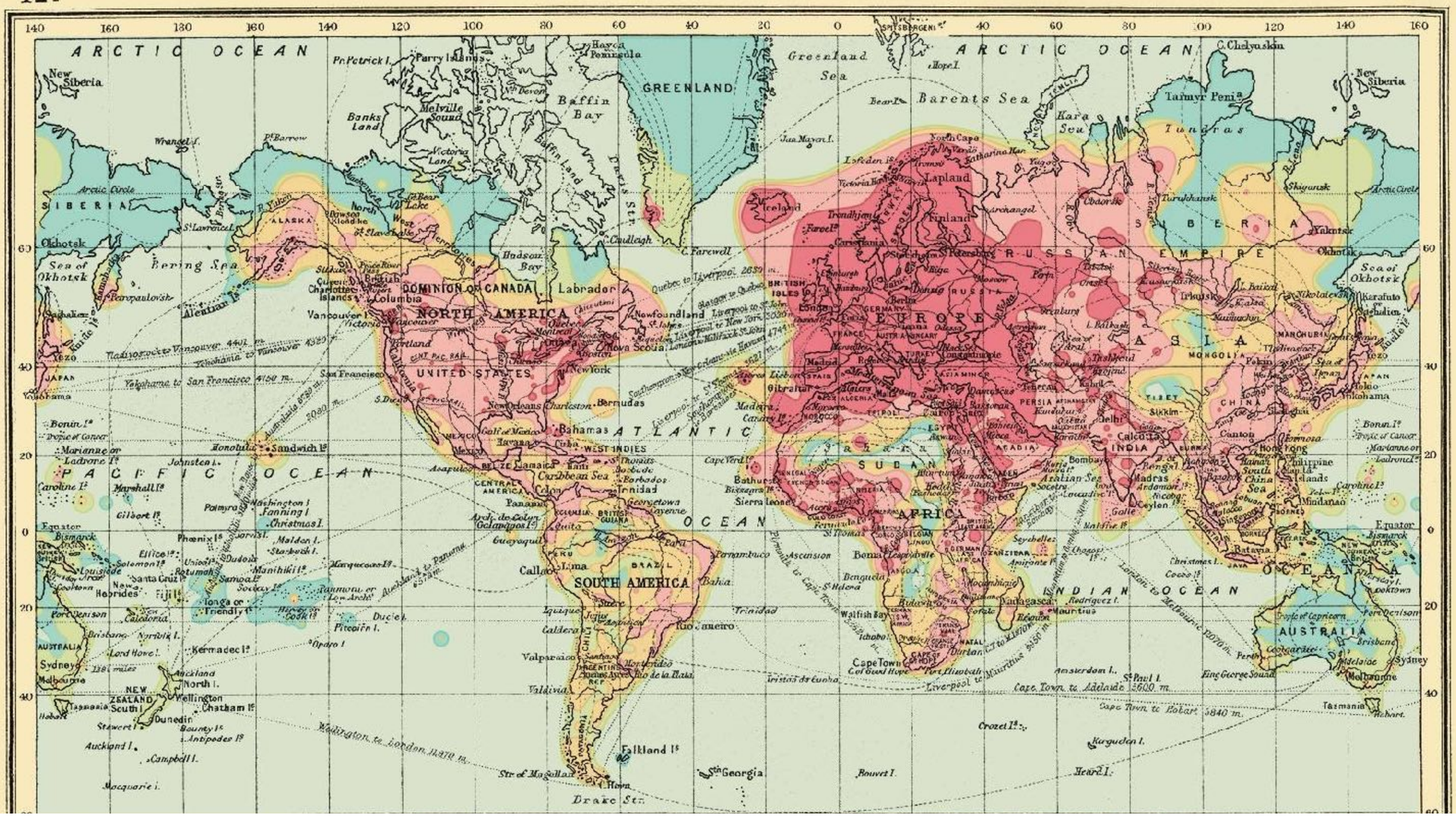

ARCTIC OCEAN
GREENLAND
Baffin Bay
Greenland Sea
Barents Sea
Kara Sea
Tundras
SIBERIA
RUSSIAN EMPIRE
Lapland
Iceland
Finland
Archangel
Moscow
Petersburg
Riga
Warsaw
Odessa
Kiev
Vienna
Budapest
Constantinople
Smyrna
Damascus
Tehran
Samarkand
Tashkend
Kabul
Delhi
Calcutta
Bombay
Madras
Ceylon
Nicobar
Andaman I.
Sikkim
Tibet
Mongolia
Pekin
Canton
Hong Kong
Shanghai
Nagasaki
Yokohama
Tokio
Formosa
Philippine Islands
Singapore
Batavia
Java
Borneo
Sumatra
Cocos I.
Christmas I.
Seychelles
Madagascar
Mauritius
Rodriguez I.
Amsterdam I.
St Paul I.
Kerguelen I.
Crozet I.
Heard I.
Bouvet I.
Tristan da Cunha
Cape Town
Cape of Good Hope
Port Elizabeth
Durban
Walfish Bay
Mozambique
Zanzibar
Aden
Arabian Sea
Bombay
Calcutta
Madras
Colombo
Bengal
Bay of Bengal
Persian Gulf
Red Sea
Suez
Cairo
Alexandria
Aden
Mecca
Medina
Jerusalem
Damascus
Beirut
Aleppo
Smyrna
Constantinople
Odessa
Sebastopol
Kiev
Moscow
Petersburg
Riga
Warsaw
Vienna
Budapest
Prague
Berlin
Hamburg
Frankfurt
Munich
Stuttgart
Cologne
Paris
London
Edinburgh
Dublin
Glasgow
Liverpool
Manchester
Birmingham
Cardiff
Bristol
Southampton
Portsmouth
Plymouth
Brest
Le Havre
Cherbourg
Boulogne
Calais
Dieppe
Rouen
Nantes
Bordeaux
Marseilles
Lyon
Geneva
Milan
Venice
Rome
Naples
Palermo
Messina
Malta
Gibraltar
Tangier
Algiers
Tripoli
Tunis
Cairo
Alexandria
Khartum
Suez
Madrid
Lisbon
Porto
Seville
Cadiz
Barcelona
Valencia
Zaragoza
Bilbao
Santander
Coruña
Vigo
Ceuta
Tangier
Fez
Marrakesh
Rabat
Casablanca
Algiers
Oran
Tunis
Tripoli
Benghazi
Cape Verde Is.
Dakar
Bathurst
Freetown
Sierra Leone
Monrovia
Accra
Lagos
Fernando Po
Libreville
Loanda
Benguela
Walfish Bay
Cape Town
Port Elizabeth
Durban
Lourenço Marques
Zanzibar
Mombasa
Aden
Massaua
Khartum
Suez
Cairo
Alexandria
Tripoli
Tunis
Algiers
Oran
Tangier
Ceuta
Fez
Marrakesh
Rabat
Casablanca
Madrid
Lisbon
Porto
Seville
Cadiz
Barcelona
Valencia
Zaragoza
Bilbao
Santander
Coruña
Vigo



1914

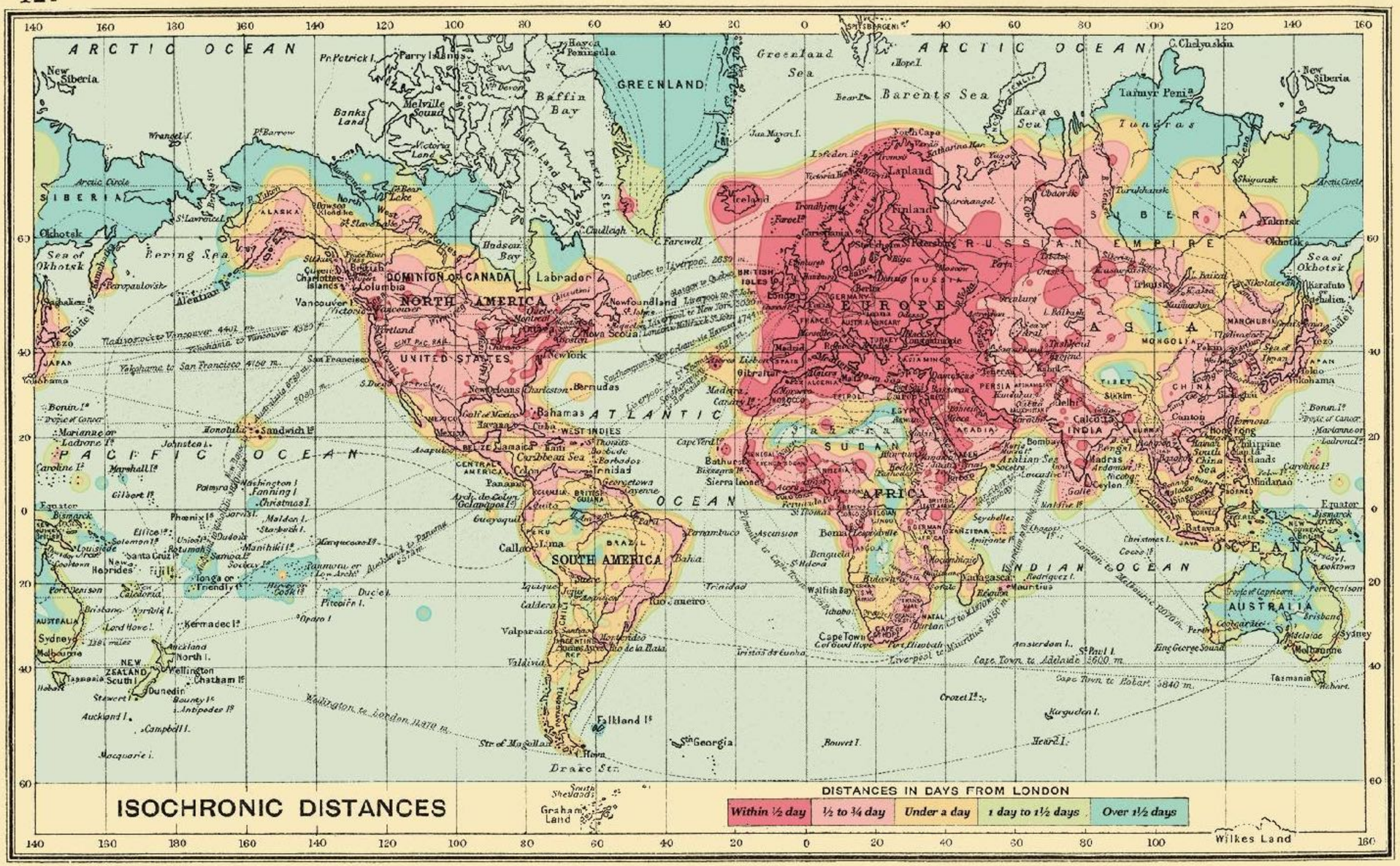
John George Bartholomew

12B



John George Bartholomew

12B



2016

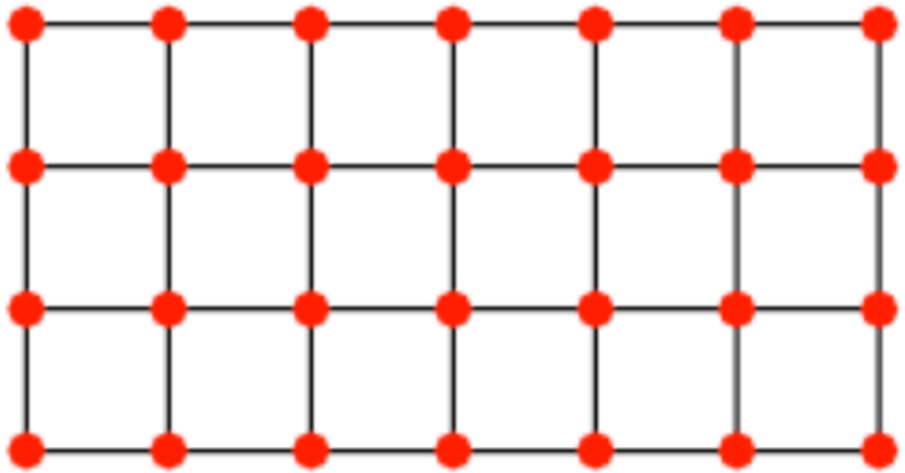
Rome2rio

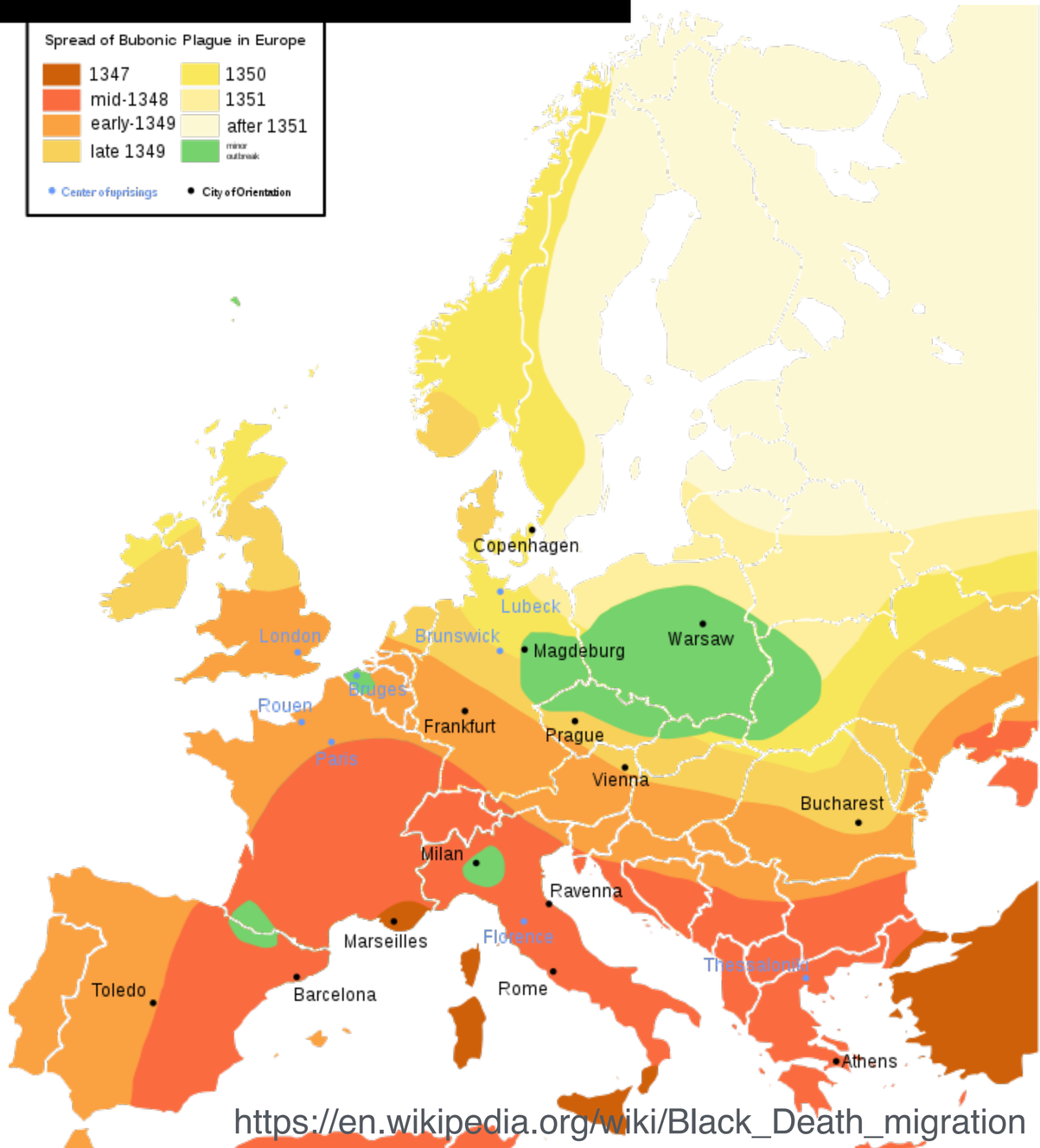
John George Bartholomew

Isochronic distances became "patchy". What happened?

In the past, epidemics spread via spatial "waves"

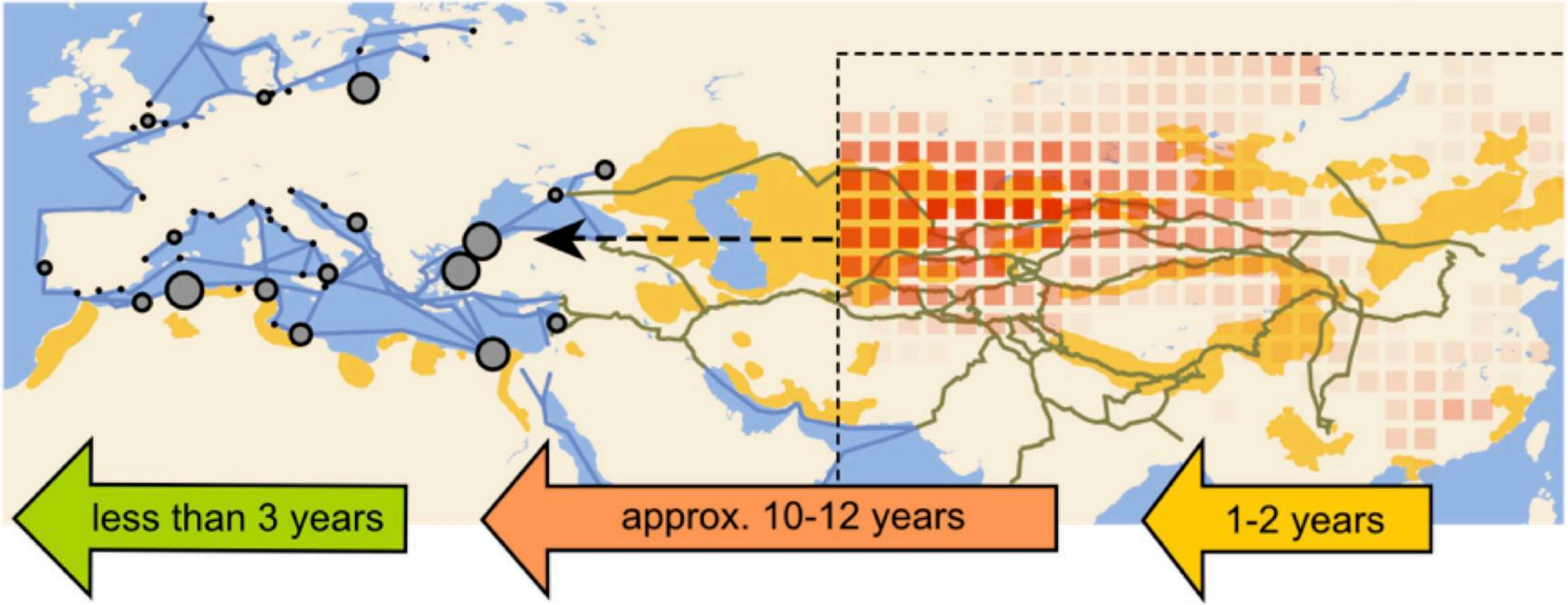
75-200 Mio, 1331 to 1353





https://en.wikipedia.org/wiki/Black_Death_migration

In the past, epidemics spread via spatial "waves"

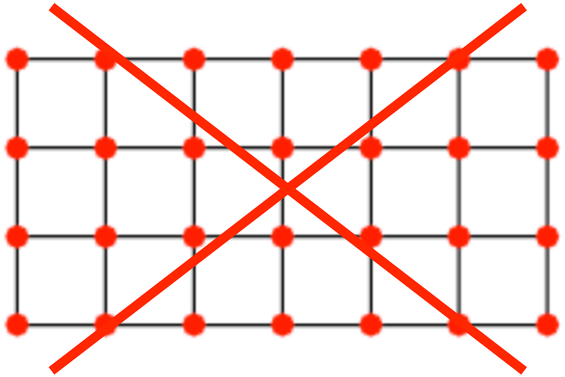


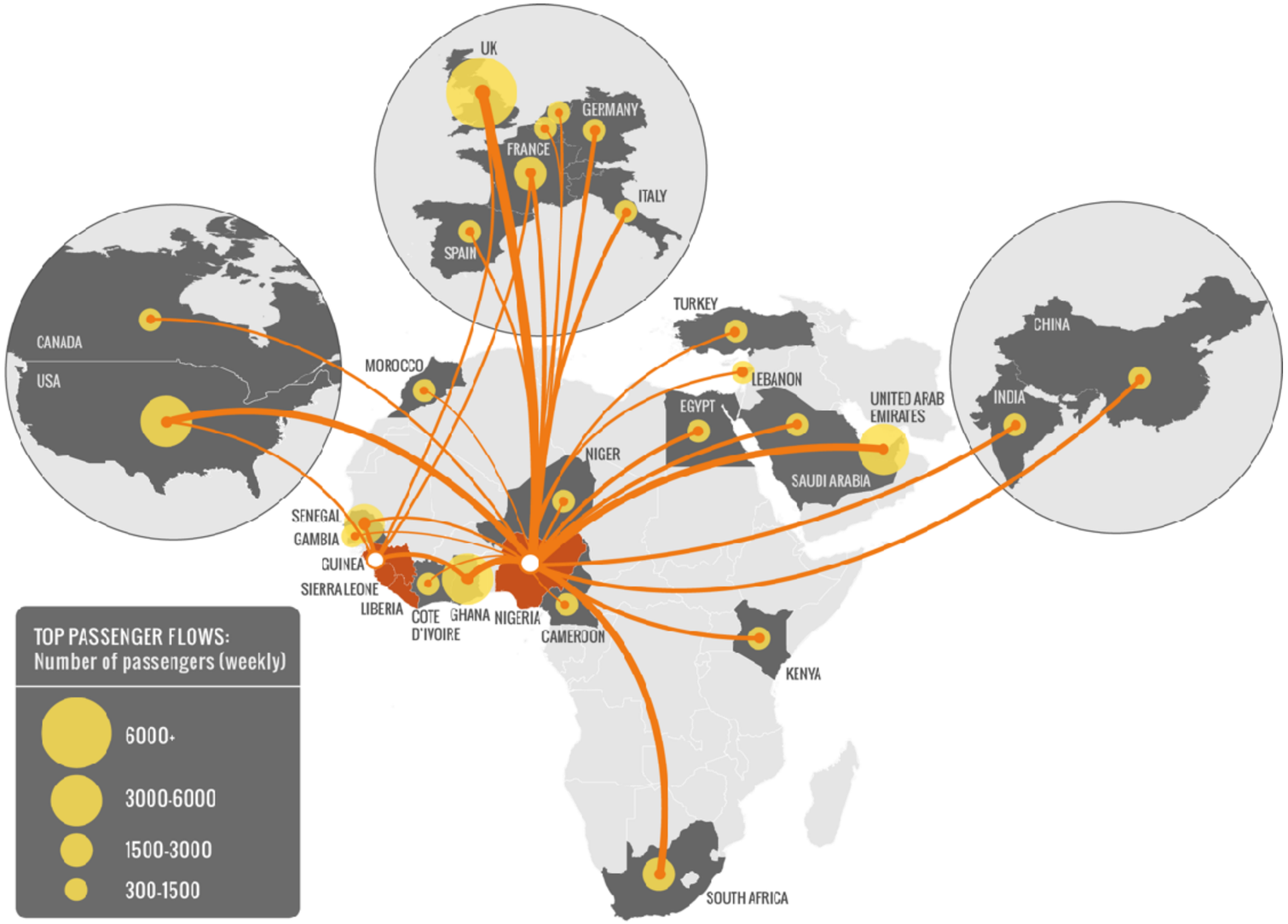
A new Asian plague pulse arrives in the harbors of Europe, and from there spreads into the mainland

Plague travels overland from western Central Asia to Europe, likely over the existing network of land traderoutes

Fleas find alternative hosts after a climate-induced rodent population boom and crash (red squares), and come into contact with humans.

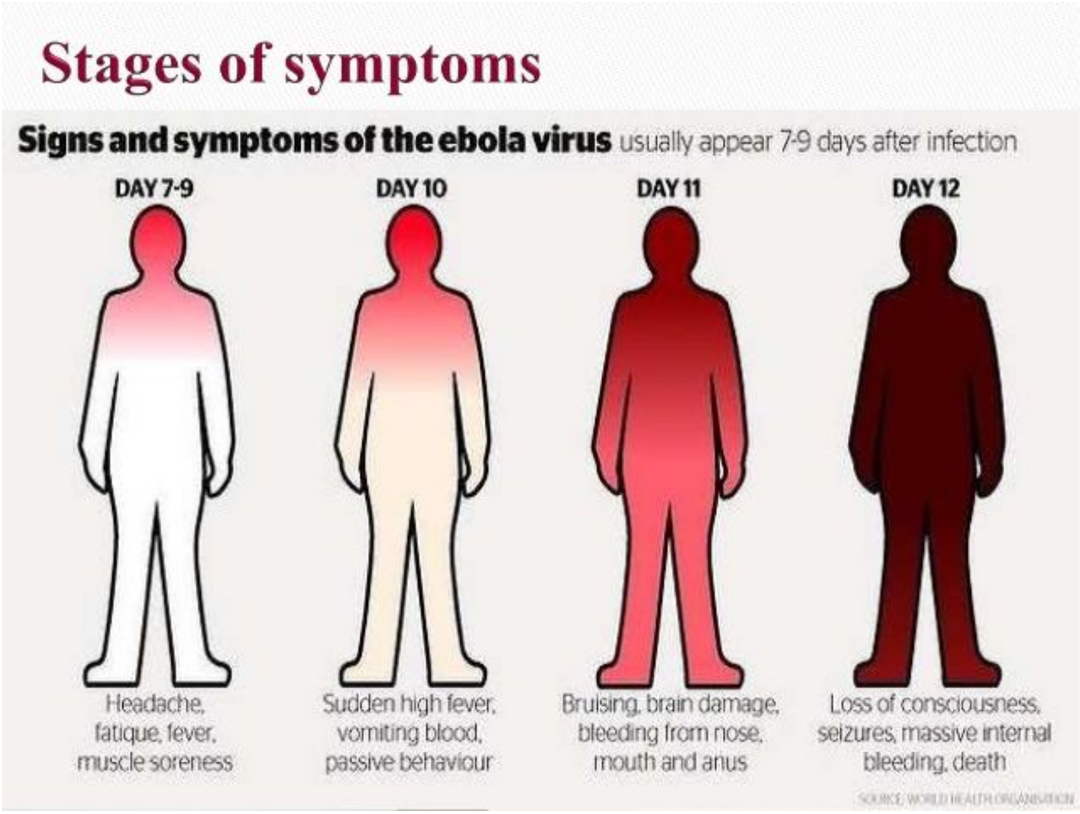
In the present, epidemics spread via spatial "hops"

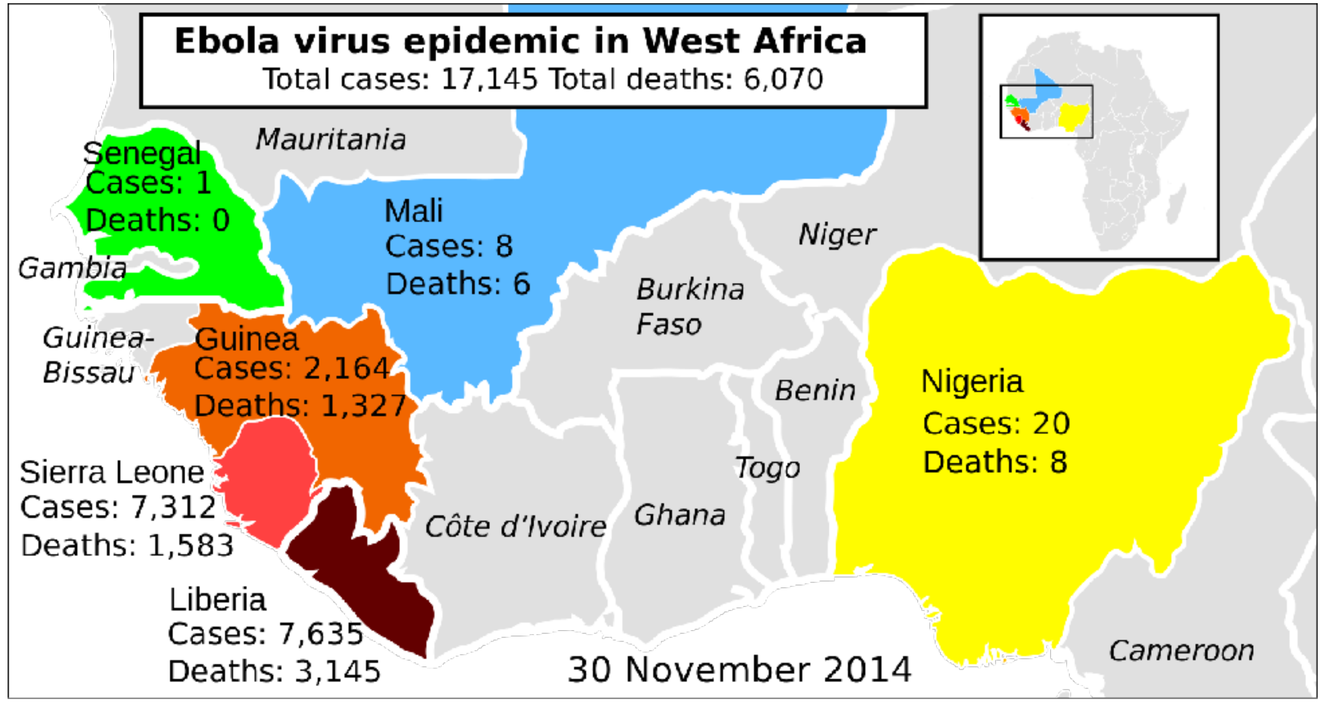




http://currents.plos.org/outbreaks/article/assessing-the-international-spreading-risk-associated-with-the-2014-west-african-ebola-outbreak/

In the present, epidemics spread via spatial "hops"



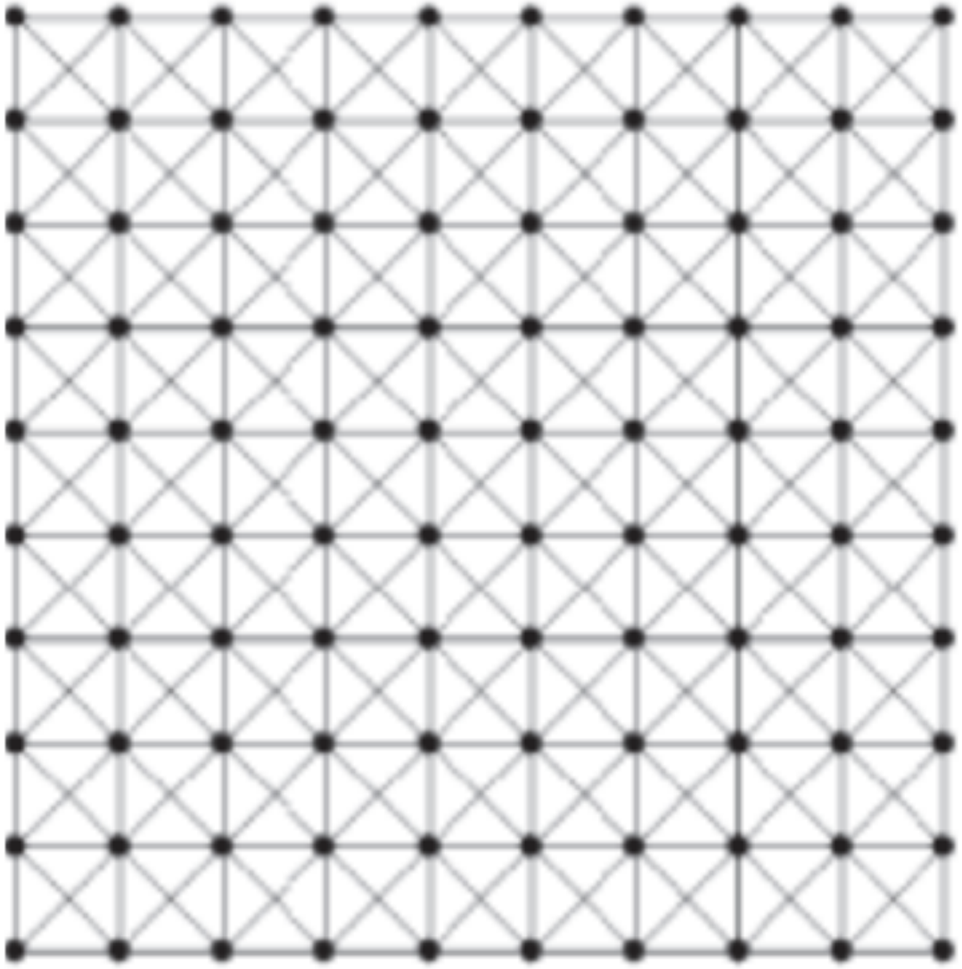


Over 50% fatality rate

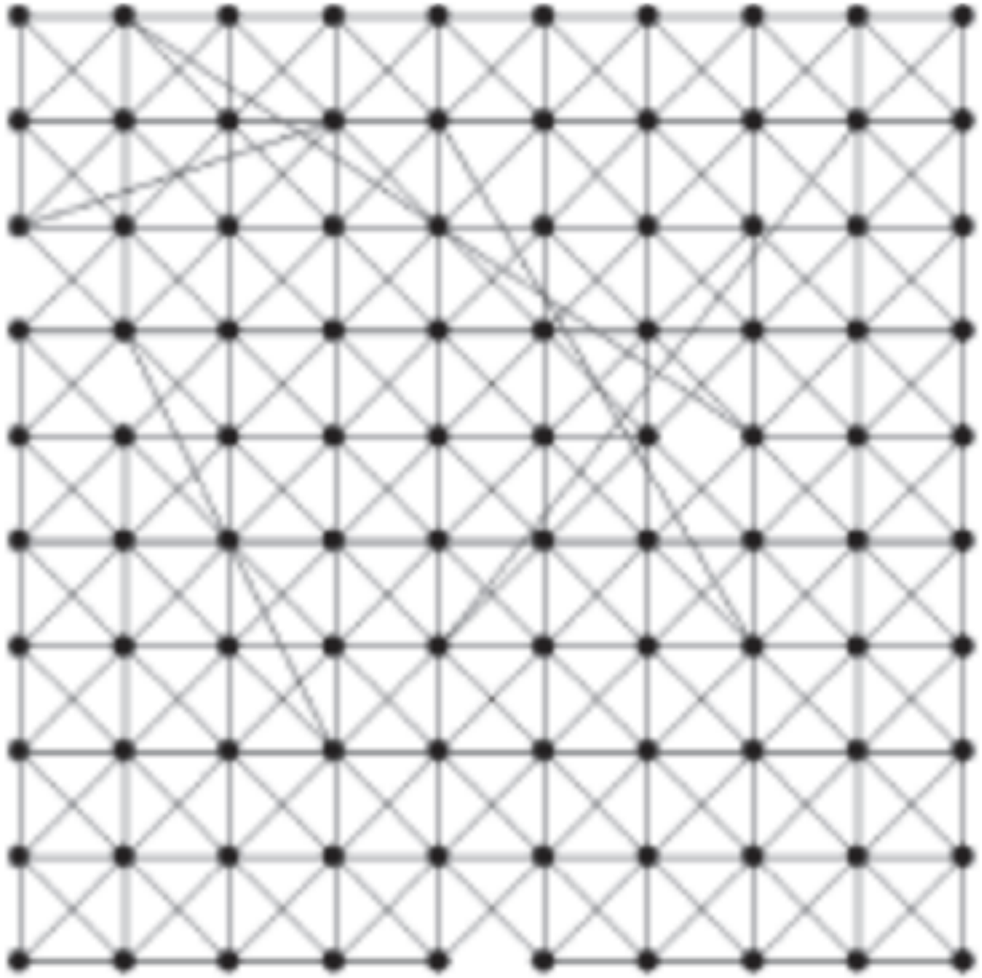
No treatment

https://en.wikipedia.org/wiki/West_African_Ebola_virus_epidemic

The grid has turned into a small world network



Regular network ϕ=0



Small-world network ϕ=0.01

Diseases spread through the airline network

https://flightstorome.moovellab.com/#roadsinthesky

You can study mobility=human movements at different scales

Individual

Single-scale

- Pedestrian movements
- Air transport
- Sea networks

Multi-scale

- Intra/Inter-urban mobility
- Epidemic spreading

Virtual scale

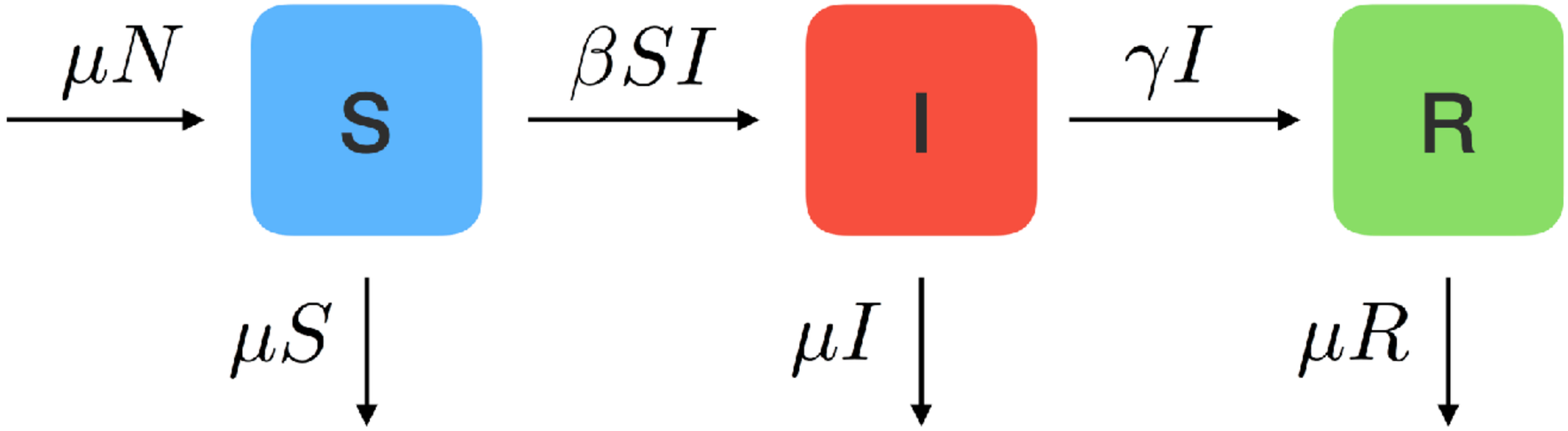
Population / Aggregate

- Migration
- Spatial Interaction

We can study spread dynamics on the airline network

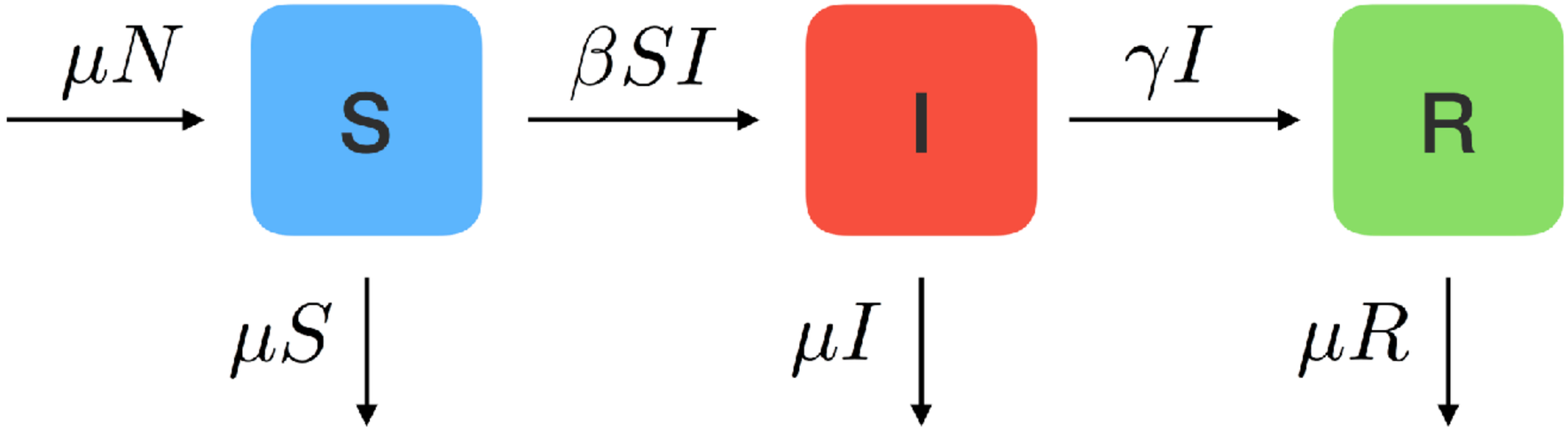
https://www.youtube.com/watch?v=ECJ2DdPhMxI

Compartment models simplify epidemiological dynamics



https://sineadmorris.github.io/project/the-sir-model/

Compartment models simplify epidemiological dynamics

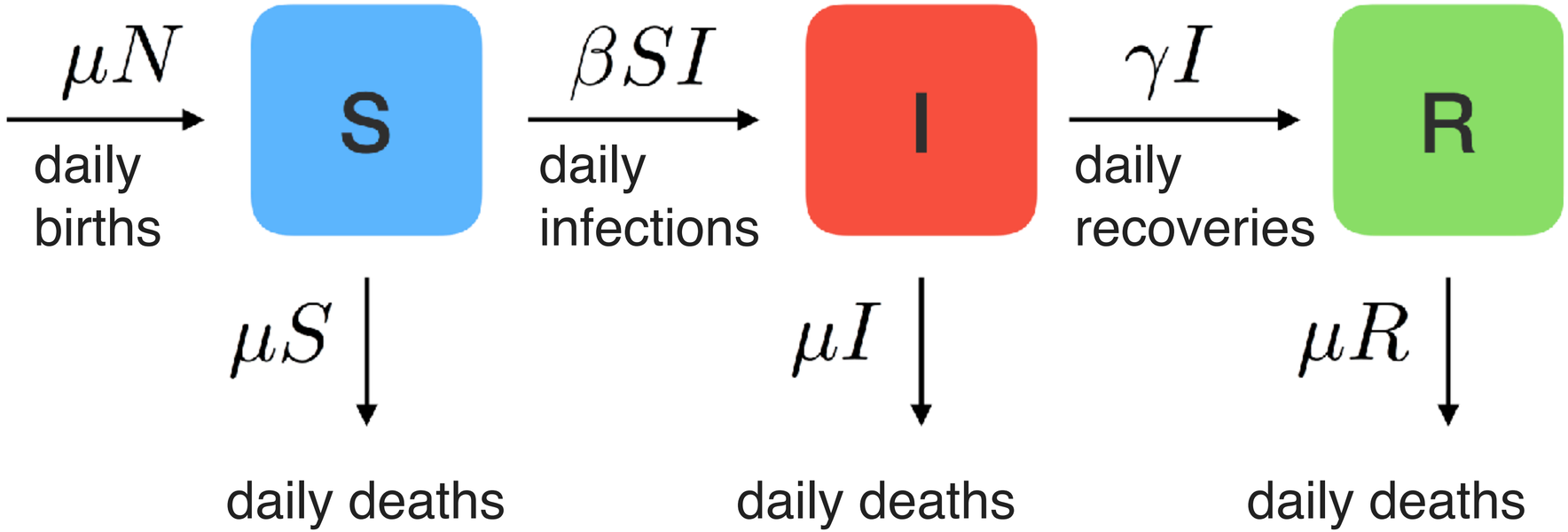


Compartment models are mathematical models of infectious diseases using differential equations. The population is divided into compartments, every individual in the same compartment has the same characteristics.

The simplest one is SIR (Susceptible, Infected, Recovered)

https://sineadmorris.github.io/project/the-sir-model/

Compartment models simplify epidemiological dynamics



$$\frac{dS}{dt} = \mu N - \beta SI - \mu S$$
$$\frac{dI}{dt} = \beta SI - \gamma I - \mu I$$
$$\frac{dR}{dt} = \gamma I - \mu R.$$

Compartment models simplify epidemiological dynamics

Because dynamics of epidemics are much faster than the vital dynamics (birth and death), we can omit those.

$$\frac{dS}{dt} = -\frac{\beta IS}{N}$$

$$\frac{dI}{dt} = \frac{\beta IS}{N} - \gamma I$$

$$\frac{dR}{dt} = \gamma I.$$

Compartment model on the airline network

$$\partial_t S_n = -\alpha I_n S_n / N_n,$$
$$\partial_t I_n = \alpha I_n S_n / N_n - \beta I_n \quad n = 1, \ldots, M$$

Same equations, but for n nodes in the air traffic network.

Compartment model on the airline network

$$\partial_t S_n = -\alpha I_n S_n / N_n,$$
$$\partial_t I_n = \alpha I_n S_n / N_n - \beta I_n \quad n = 1, \ldots, M$$

Same equations, but for n nodes in the air traffic network.

Also, there are network flow dynamics:

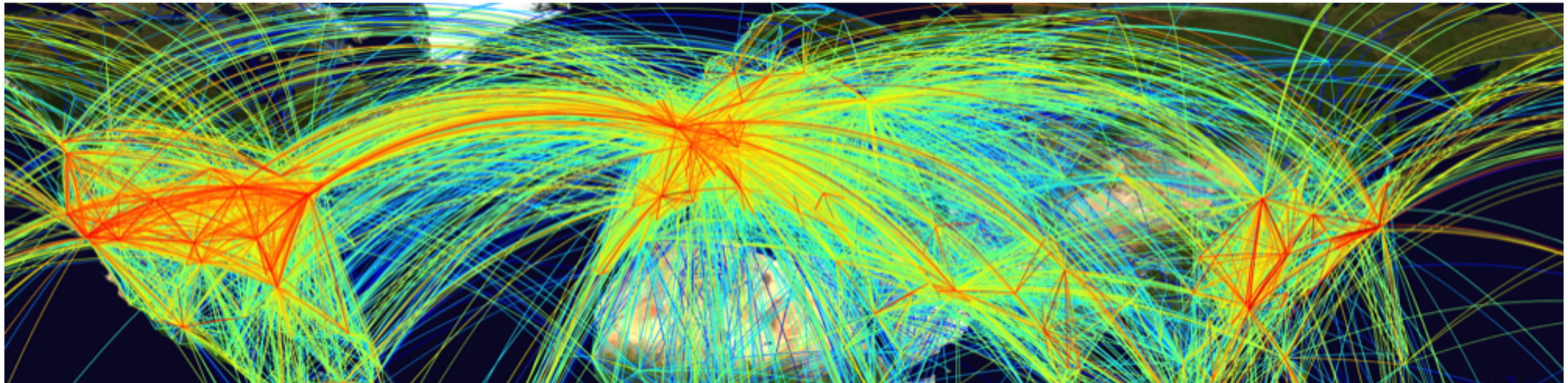
$$\partial_t U_n = \sum_{m \neq n} w_{nm} U_m - w_{mn} U_n$$

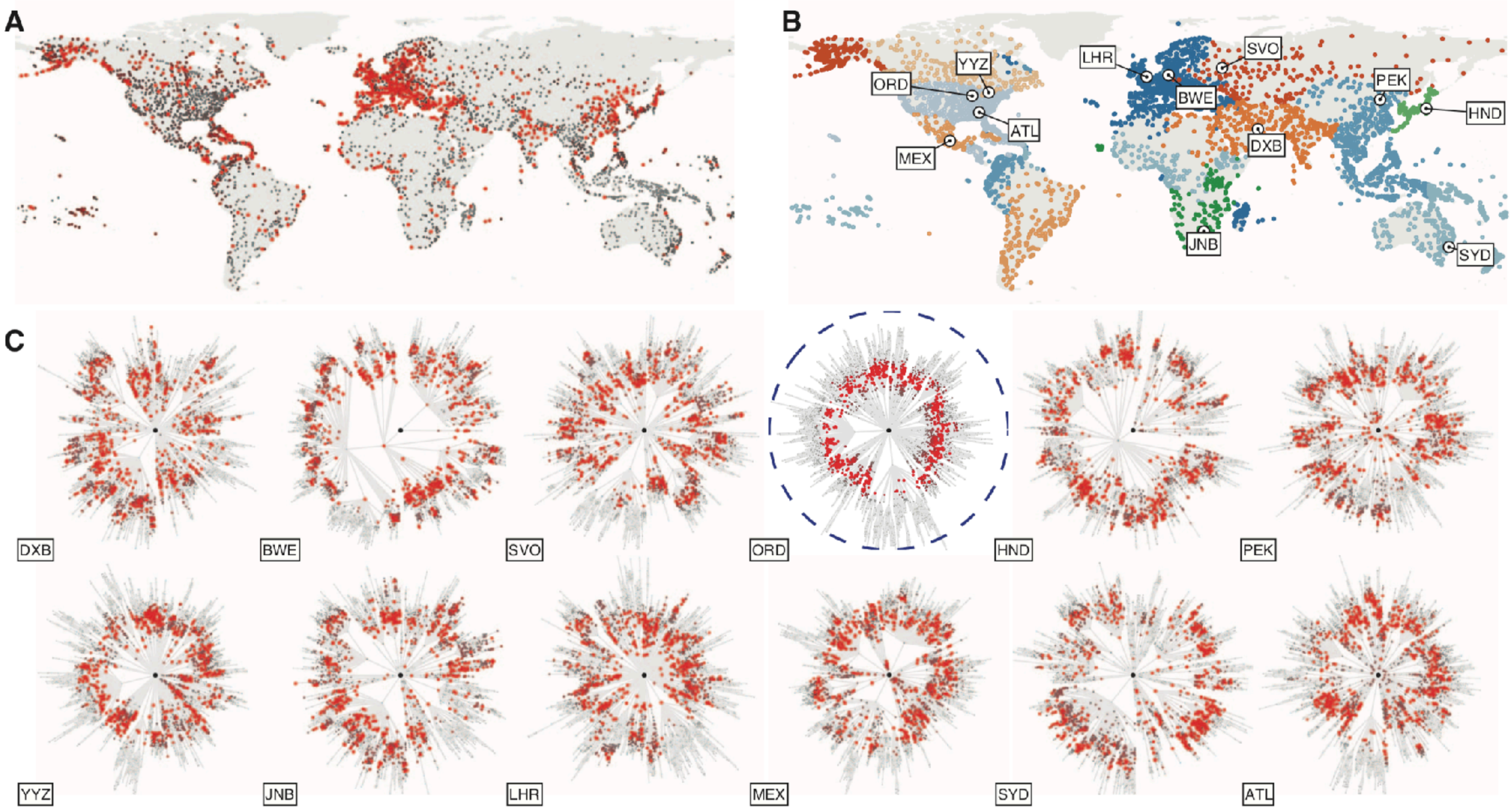
Where U stands for S,I, or R

w_{nm} is the flow from place n to m

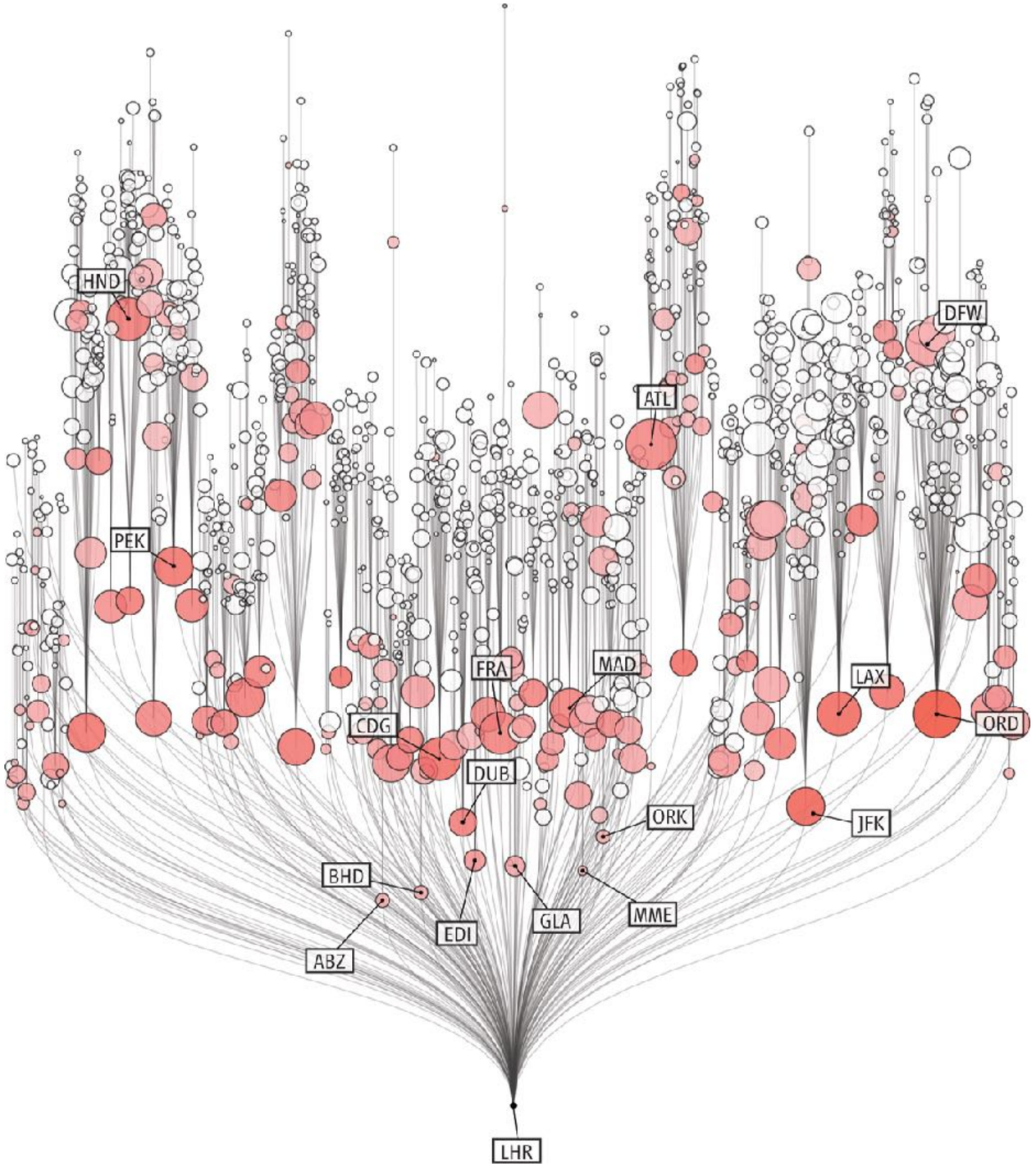
4069 airports, 25,453 direct connections

Flow: 9,000,000 passengers per day





https://rocs.hu-berlin.de/viz/sgb/



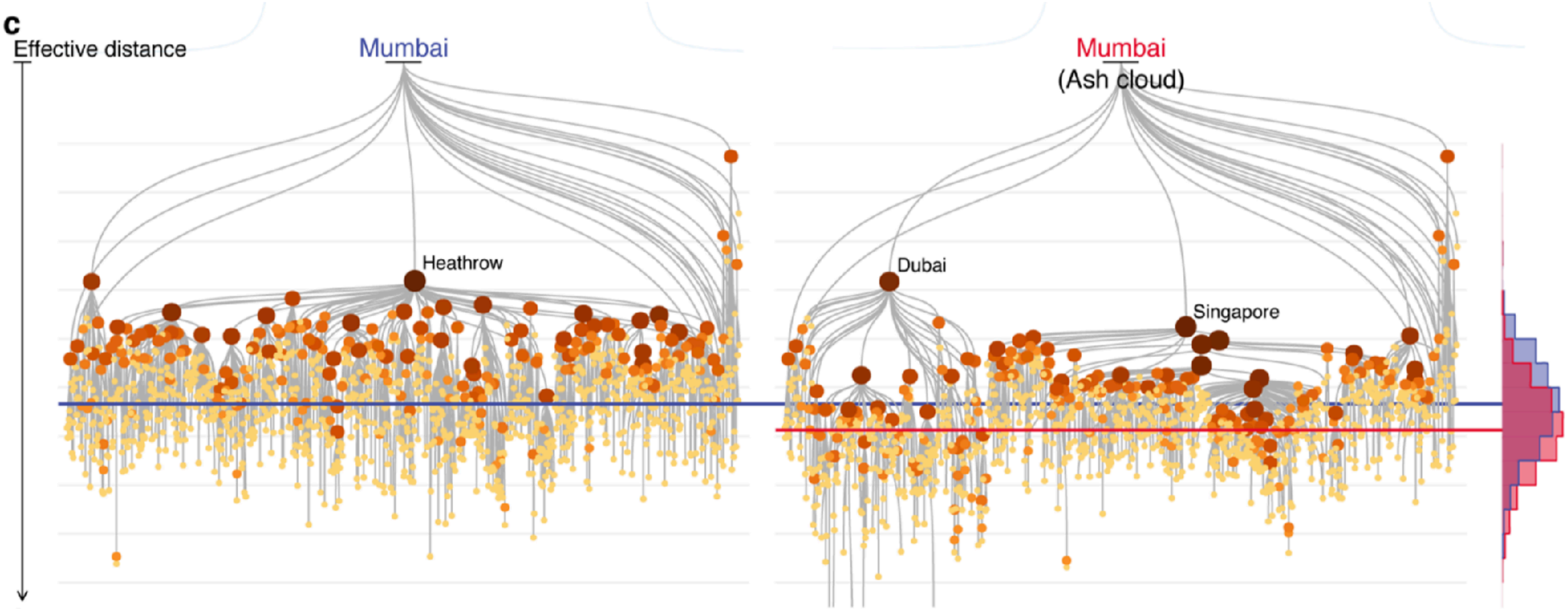
Node size: traffic
Node color: degree
Node y-position: distance

These shortest paths
are not anymore about
geographic distance!

http://science.sciencemag.org/content/342/6164/1330.full

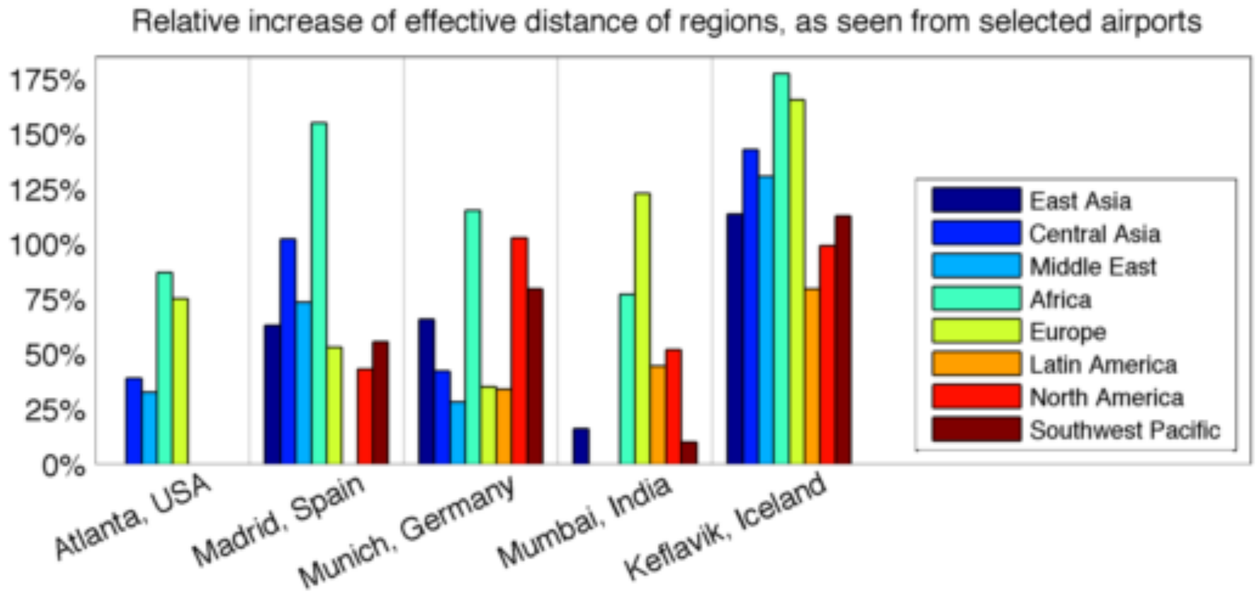
Application to Eyafjallajökull

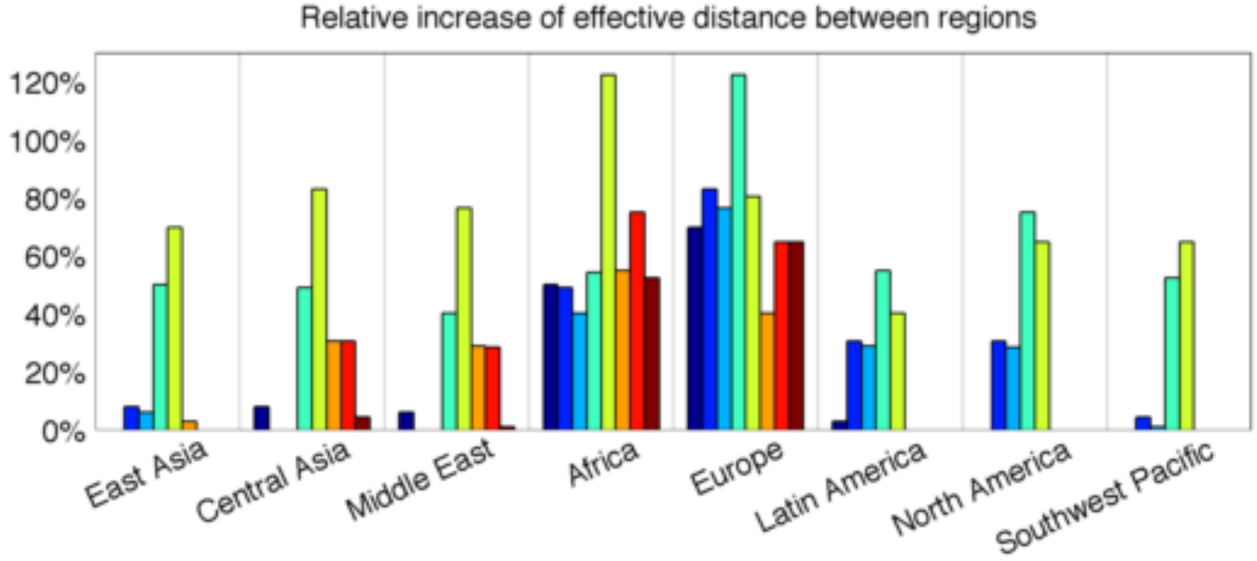
When the volcano broke out, 27 European airports closed (nodes removed), changing dramatically the shortest path trees worldwide



https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0069829

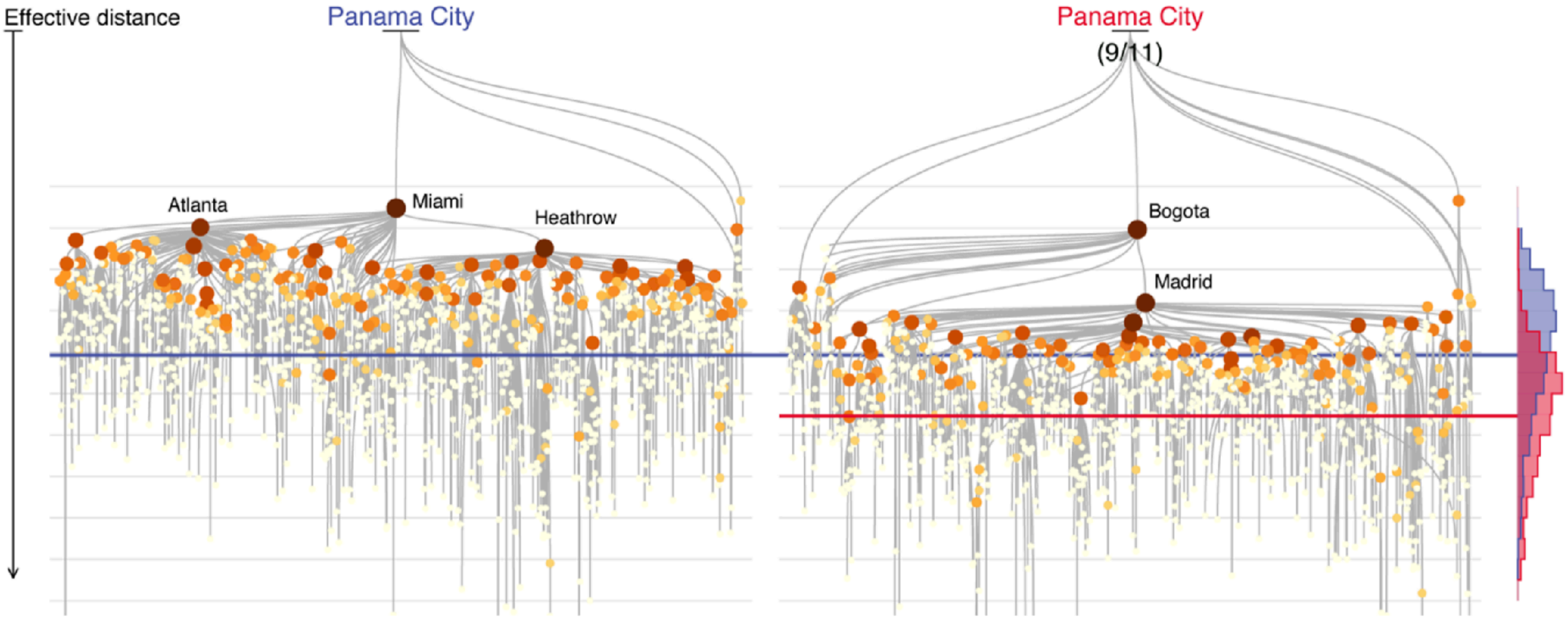
Application to Eyafjallajökull





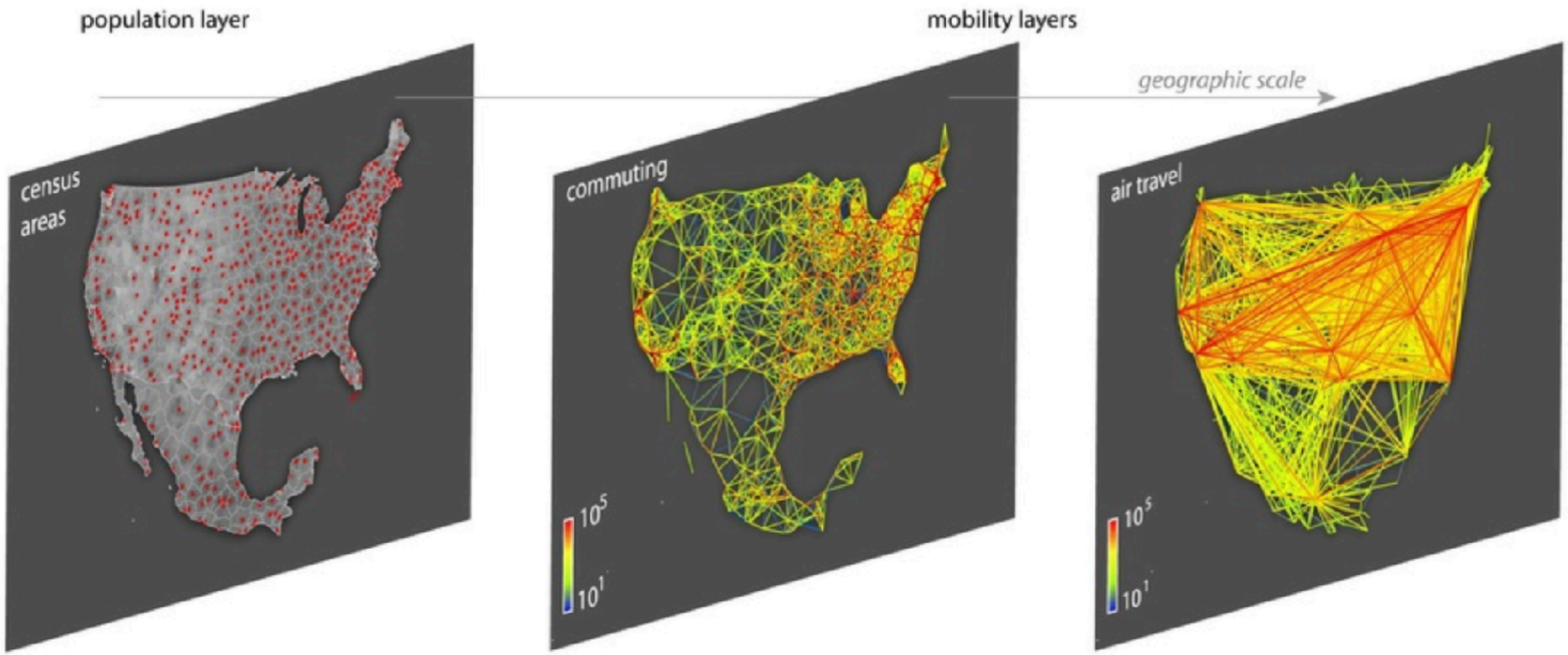
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0069829

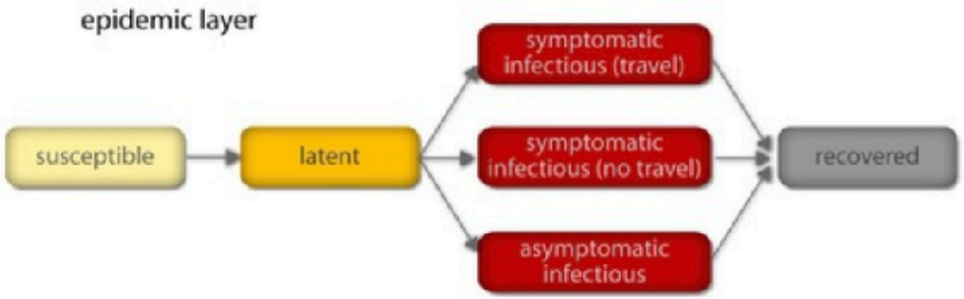
Application to 9/11



https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0069829

GLEAM (Global Epidemic and Mobility Model)





Parameter	Value	Description
β	from R_0	transmission probability
ε^{-1}	1.9 [1.1-2.5] d	average latency period
μ^{-1}	3 [3-5] d	average infectious period
p_t	50%	probability of traveling for infectious individuals
p_a	33%	probability of being asymptomatic
r_β	50%	relative infectiousness of asymptomatic infectious individuals

http://www.gleamviz.org

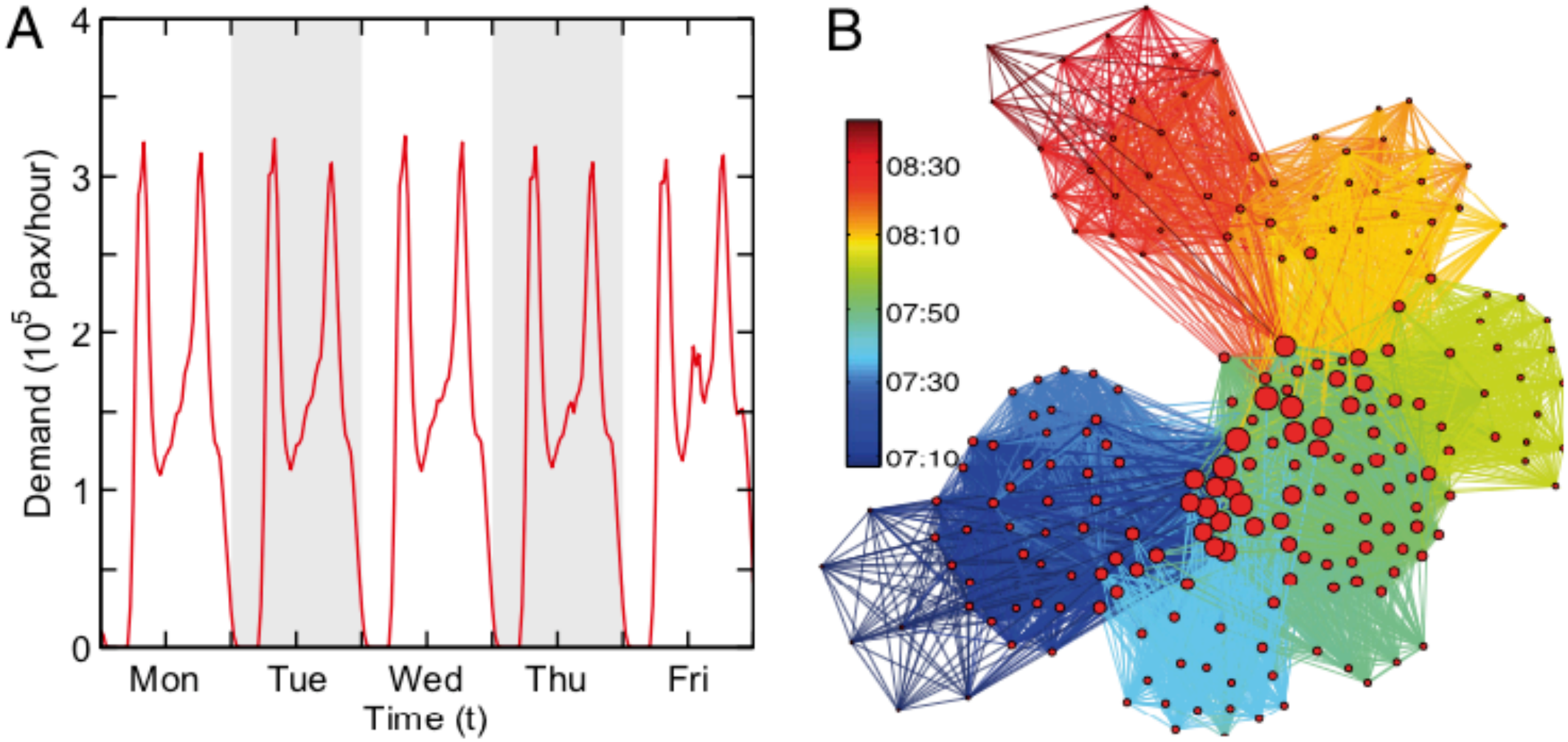
Urban mixing

How do people come together in cities?

Social mixing means that people of different social classes come together in their daily lives.

What is the effect of our daily activities and mixing on the spread of diseases?

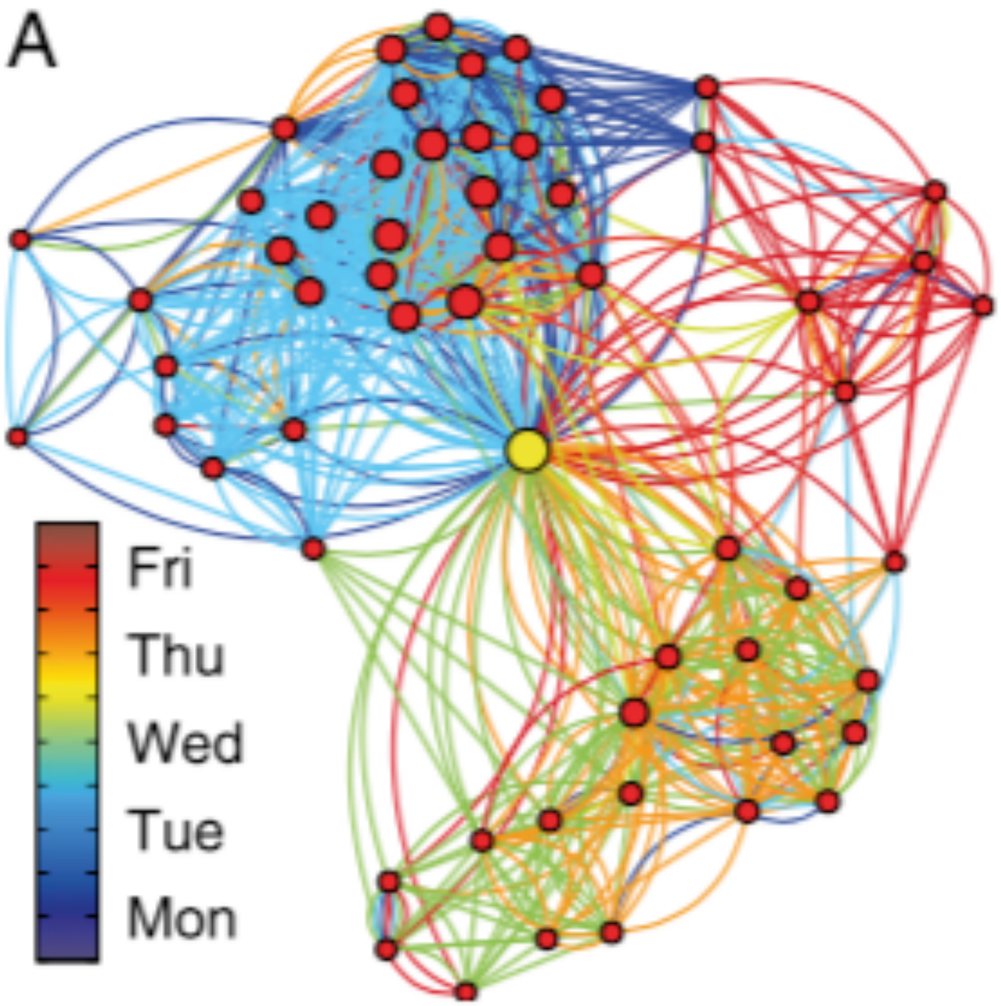
Our daily daily encounters define a city-wide contact network

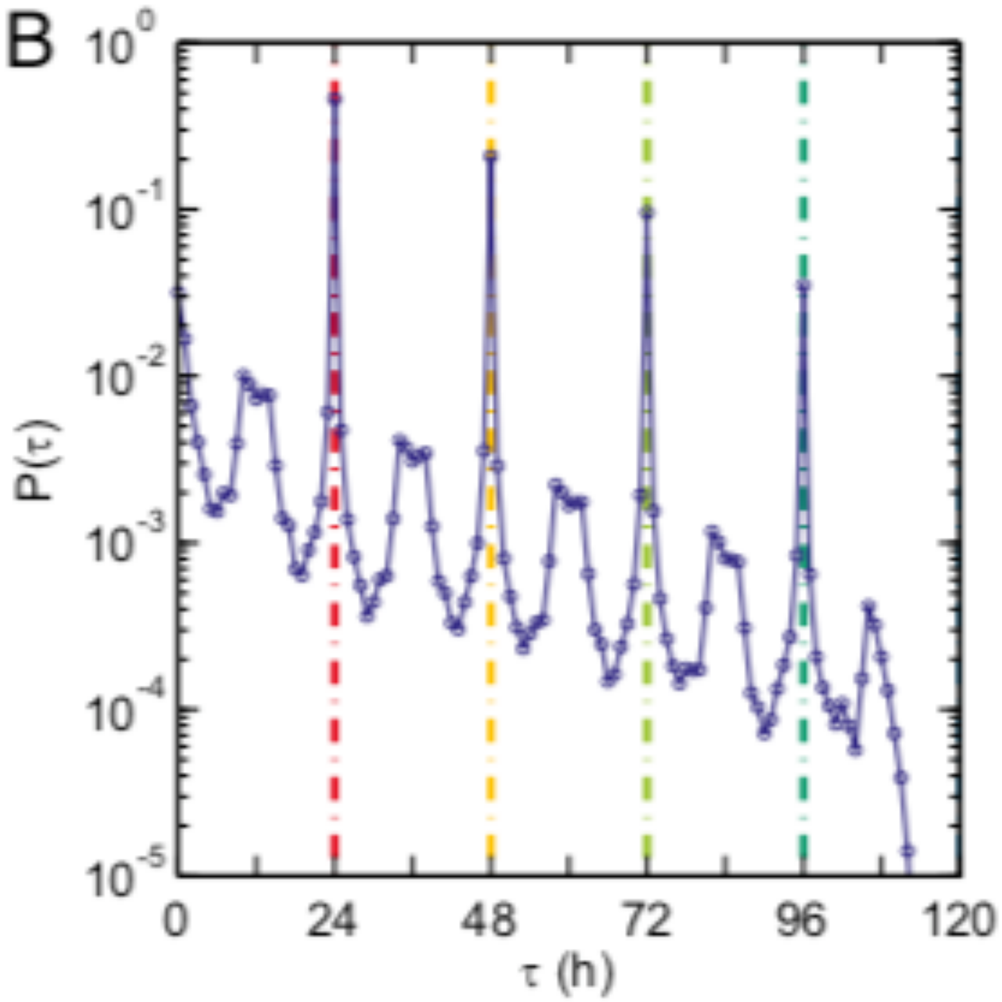


Encounter network on one bus line in Singapore (214 nodes)

https://www.pnas.org/doi/abs/10.1073/pnas.1306440110

There are many "familiar strangers"



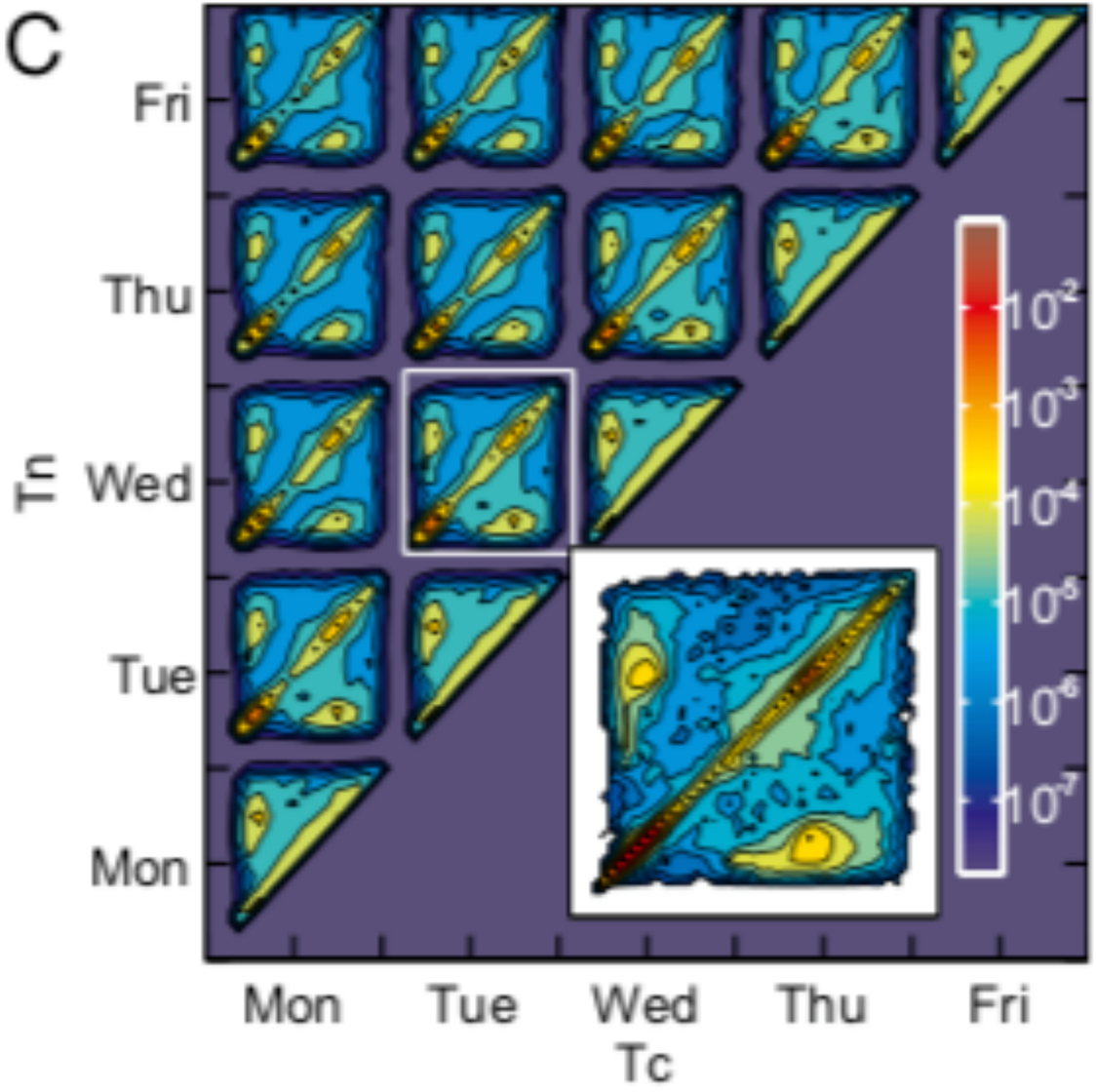


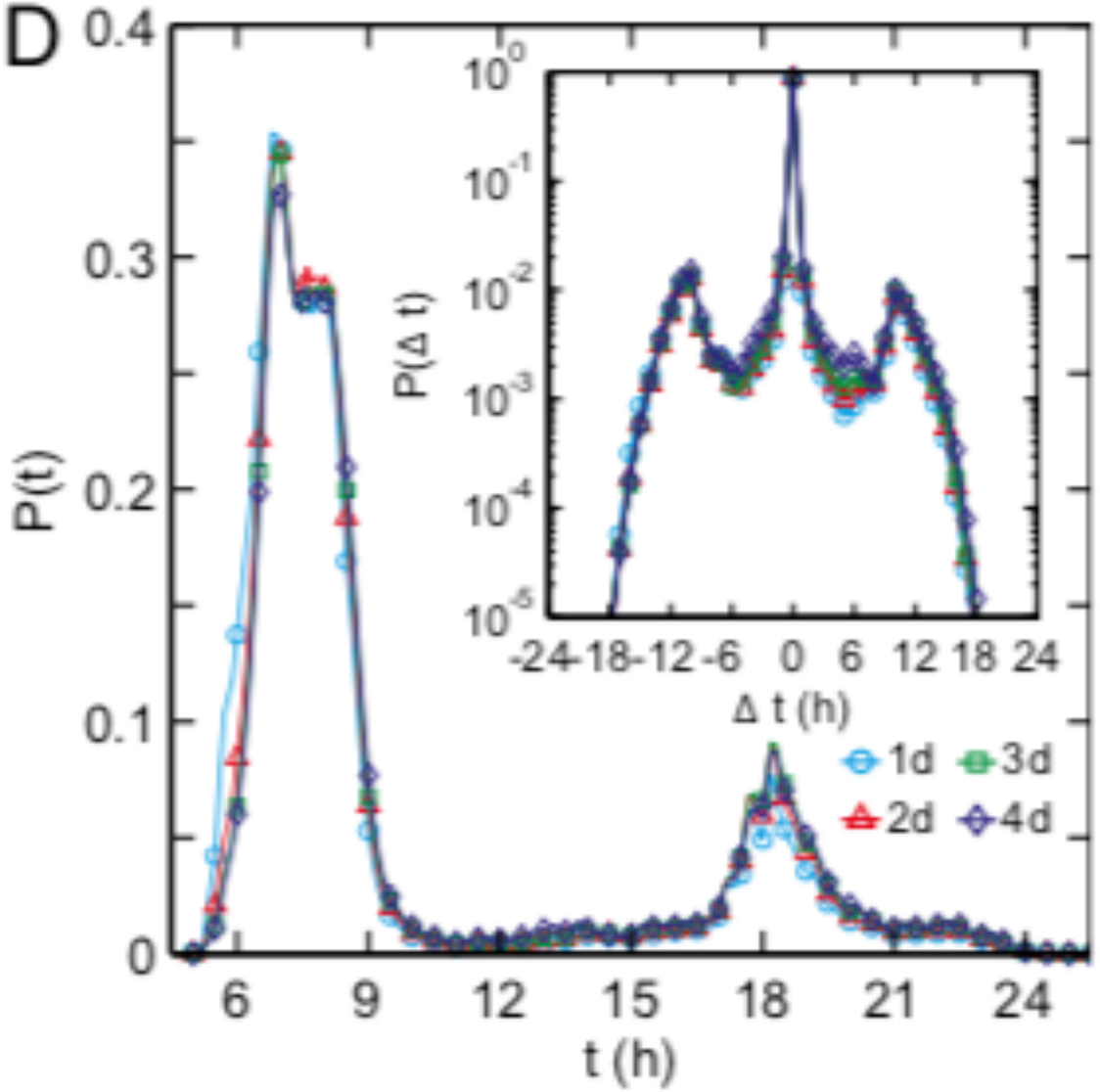
Many neighbors are connected too!

Contacts are likely to happen after 24 hours

https://www.pnas.org/doi/abs/10.1073/pnas.1306440110

Patterns are the same every day



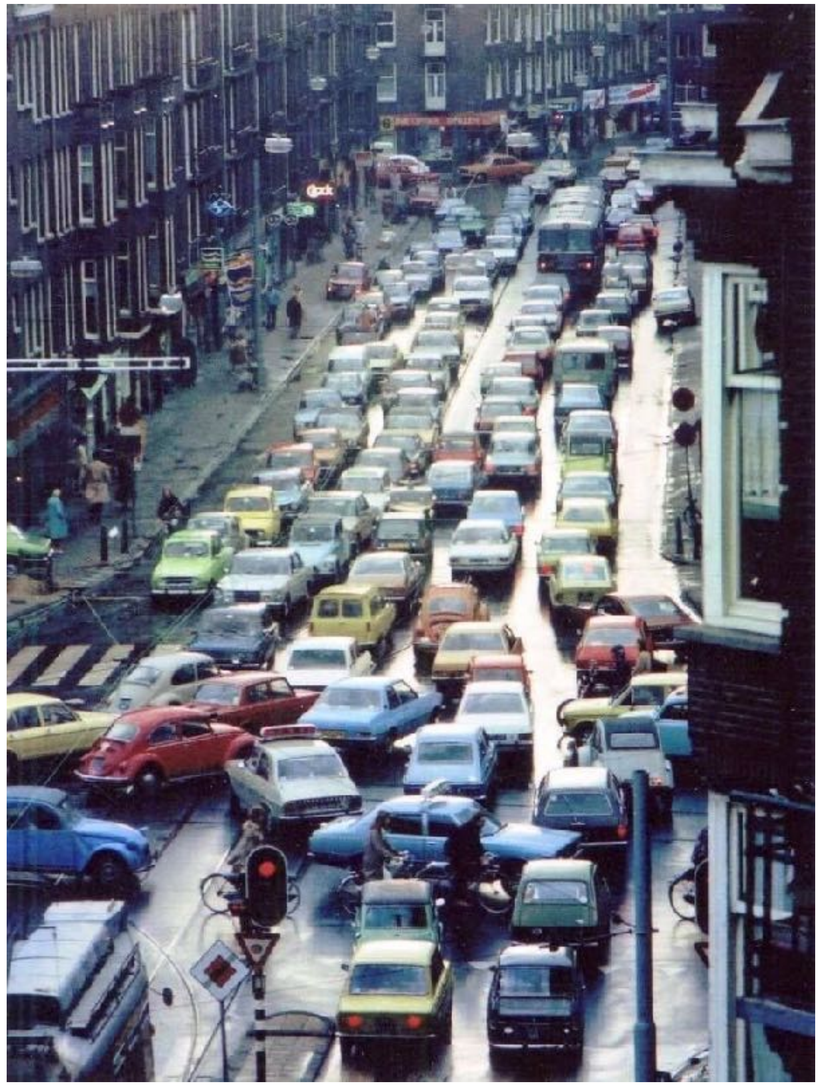


https://www.pnas.org/doi/abs/10.1073/pnas.1306440110

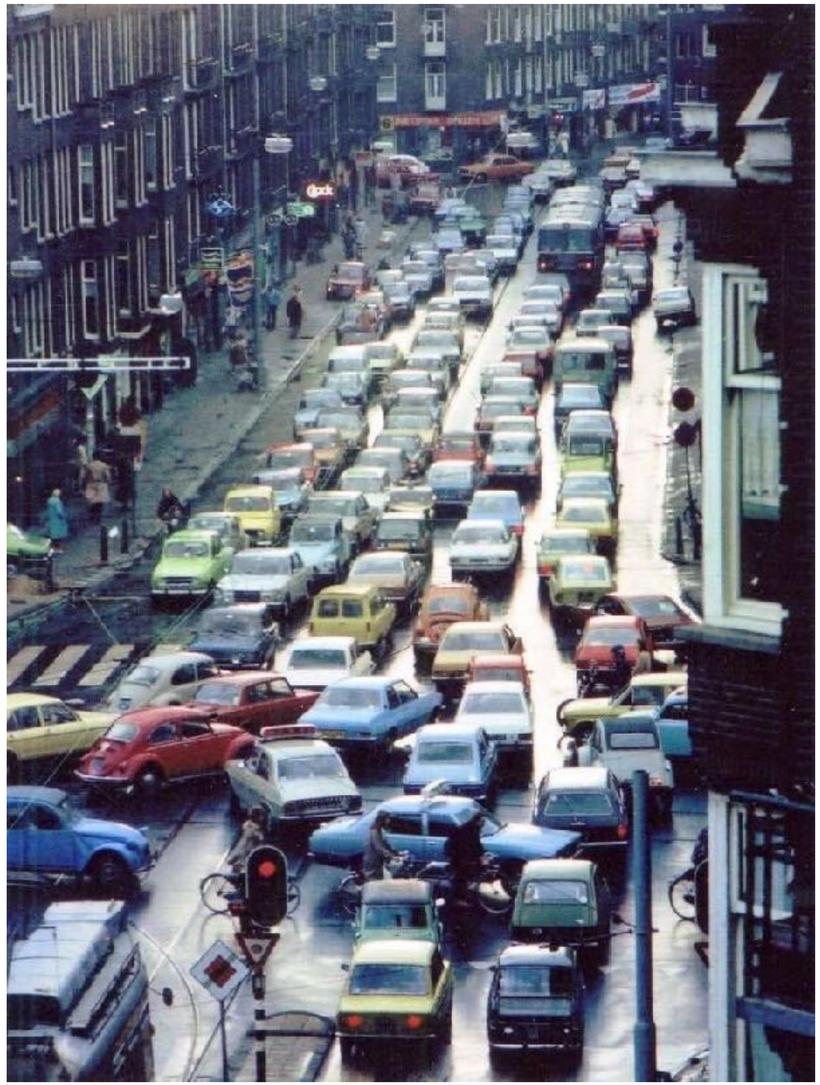
Course evaluation

Sustainable mobility

Which city is this?



Amsterdam



1978

Today

Amsterdam

1920

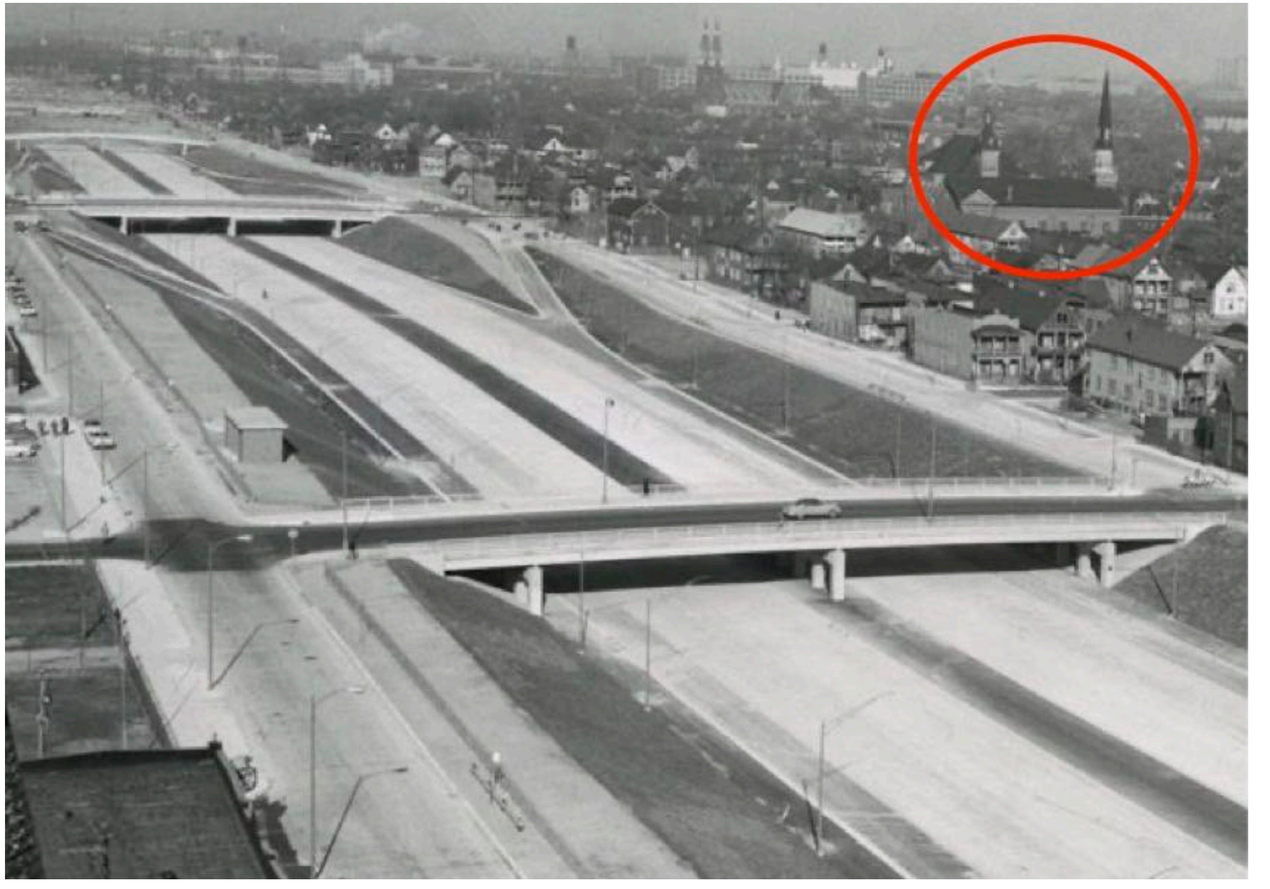
1978

2015

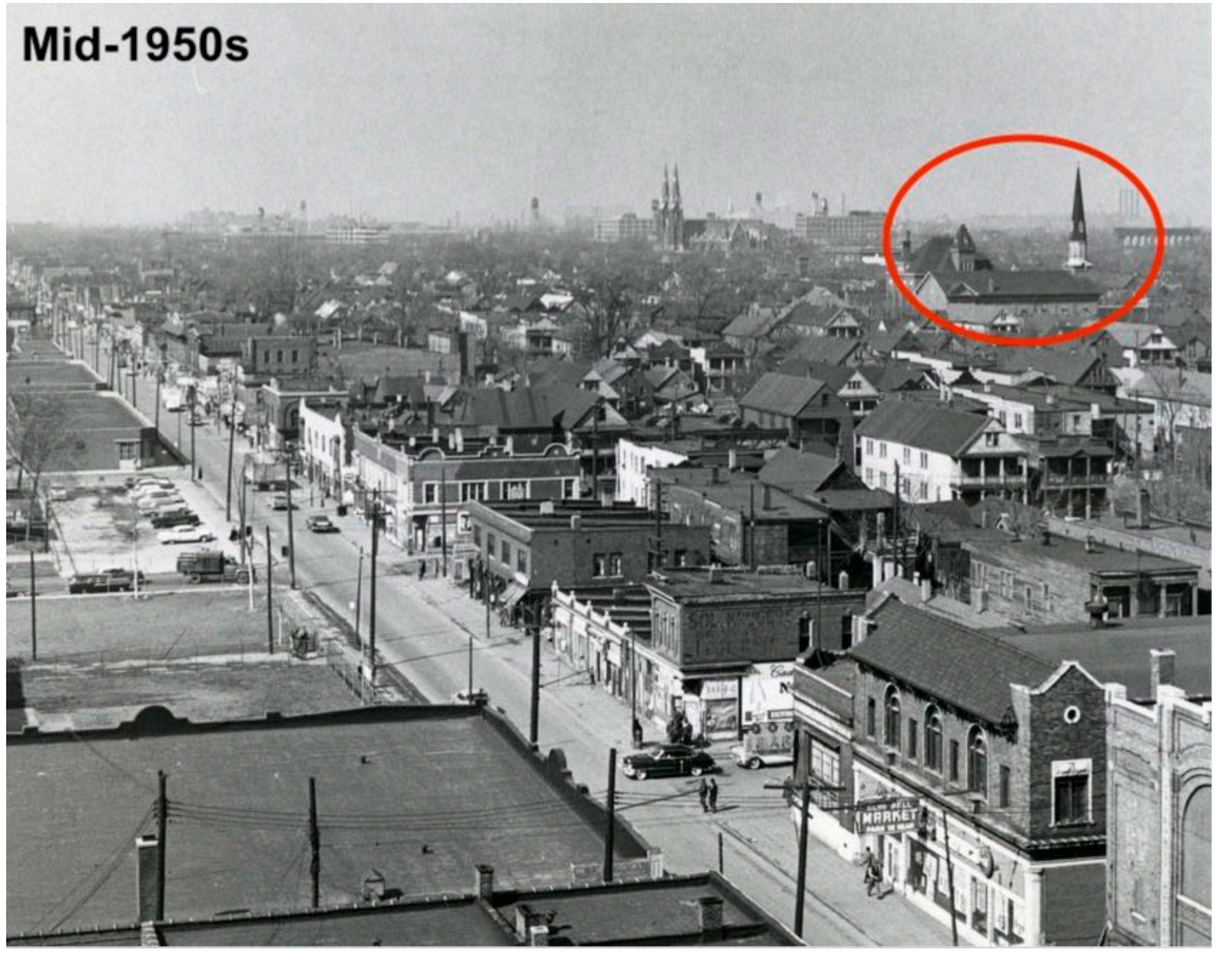
https://www.fastcompany.com/3052699/these-historical-photos-show-how-amsterdam-turned-itself-into-a-bike-riders-paradise

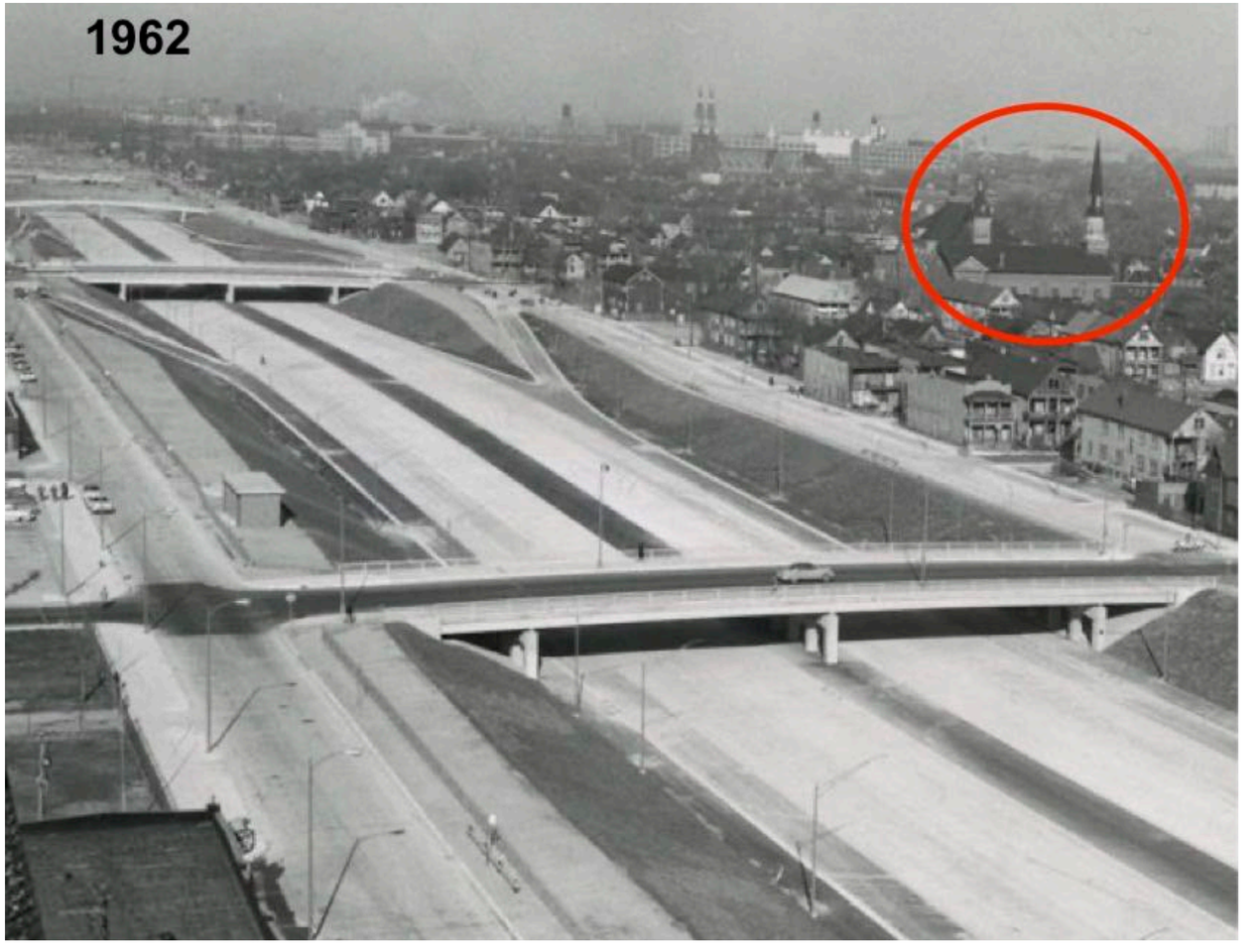
MARKET

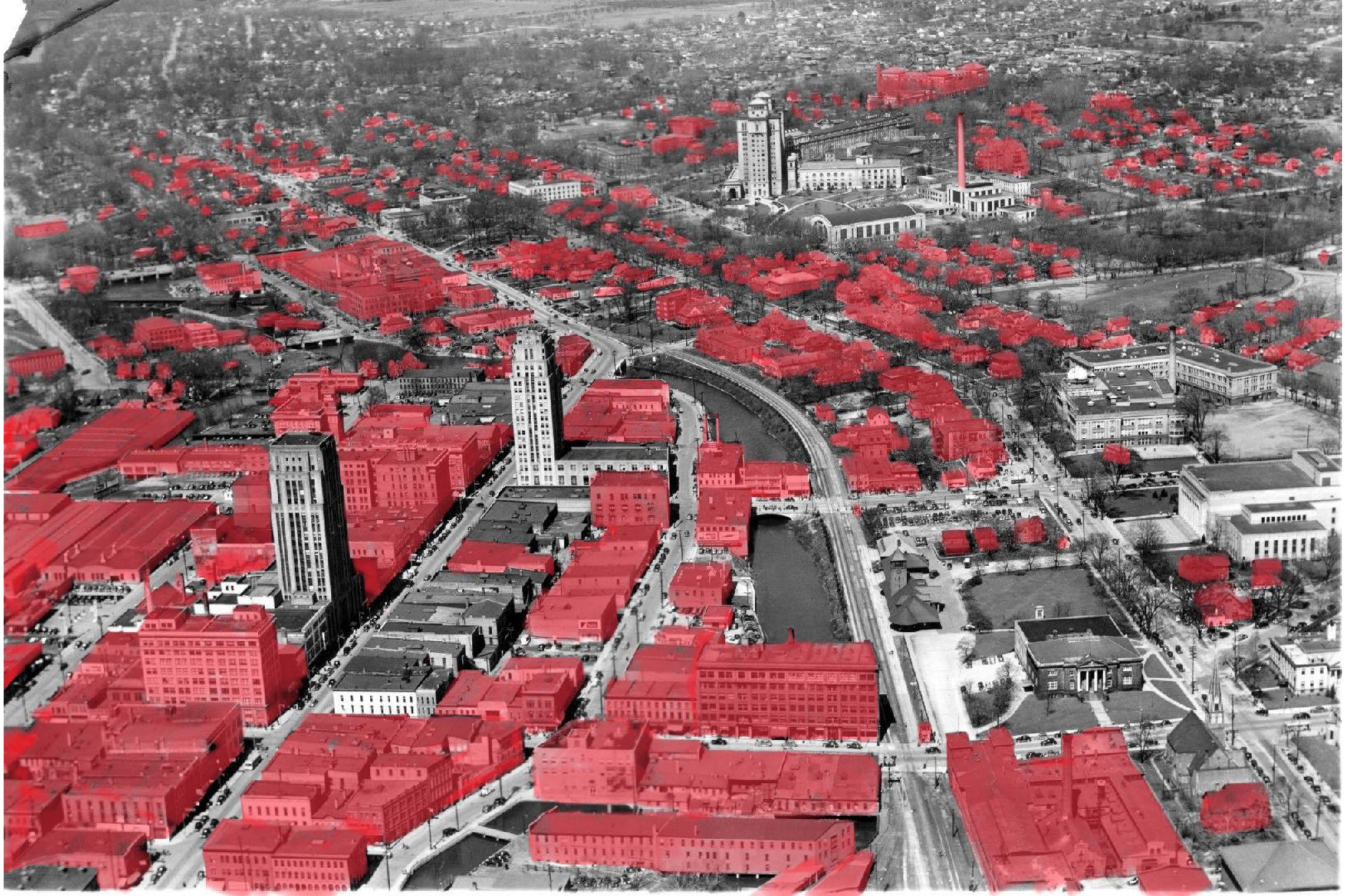
MARKET



Detroit







Battle Creek, MI

Battle Creek, MI

Groningen

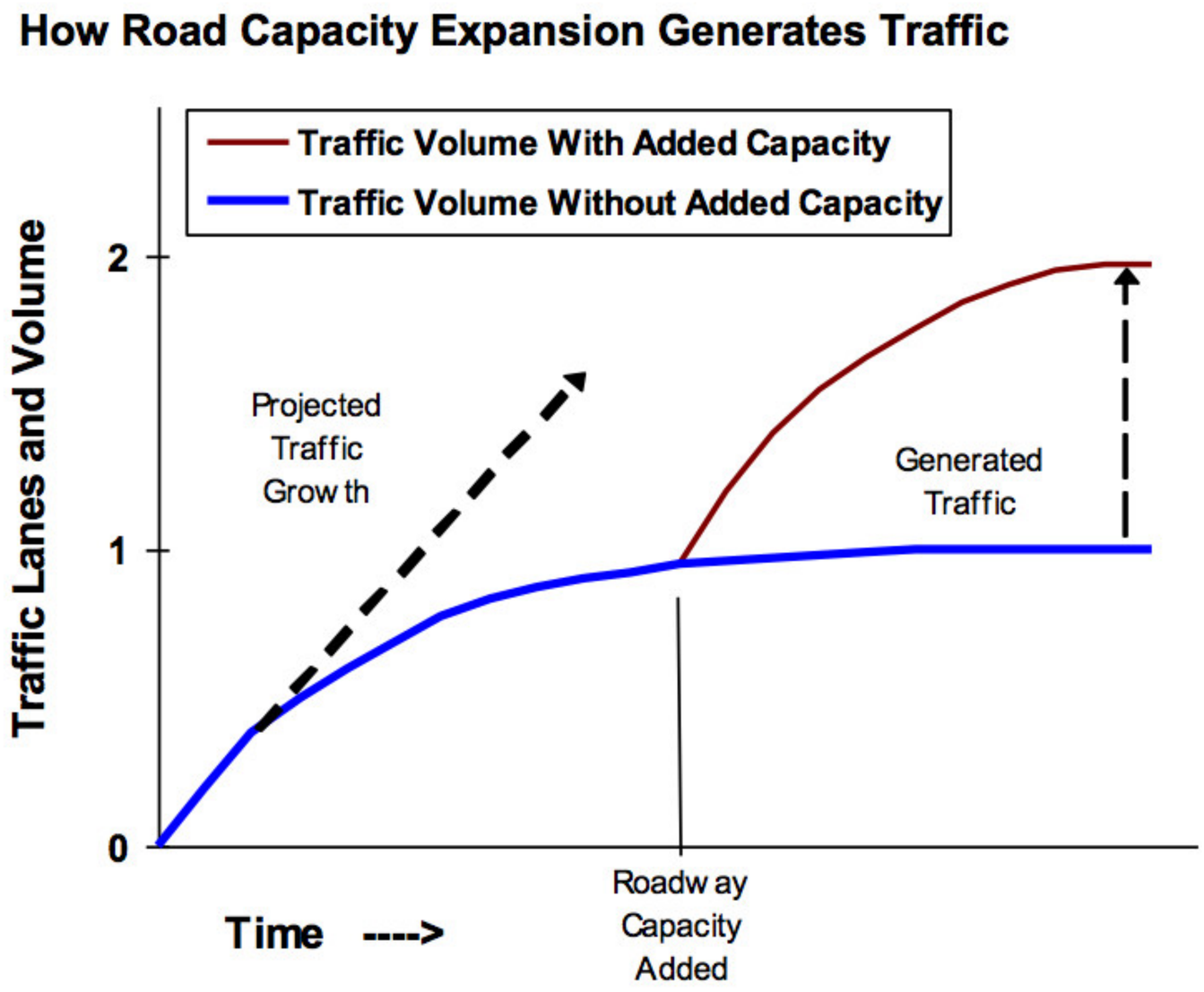
Cities can change radically within a few decades

Building more roads to prevent congestion

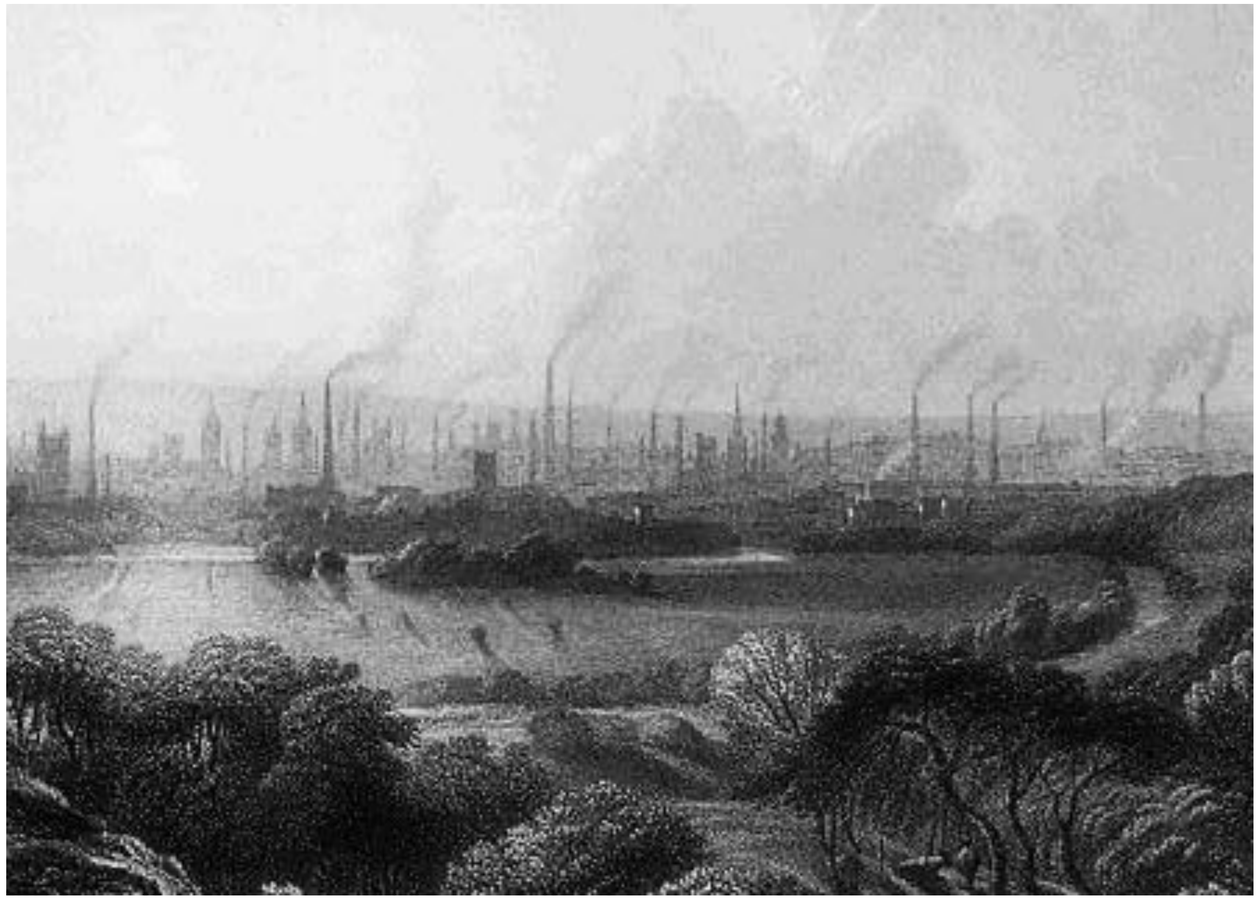
is like a fat man loosening his belt to prevent obesity

Lewis Mumford

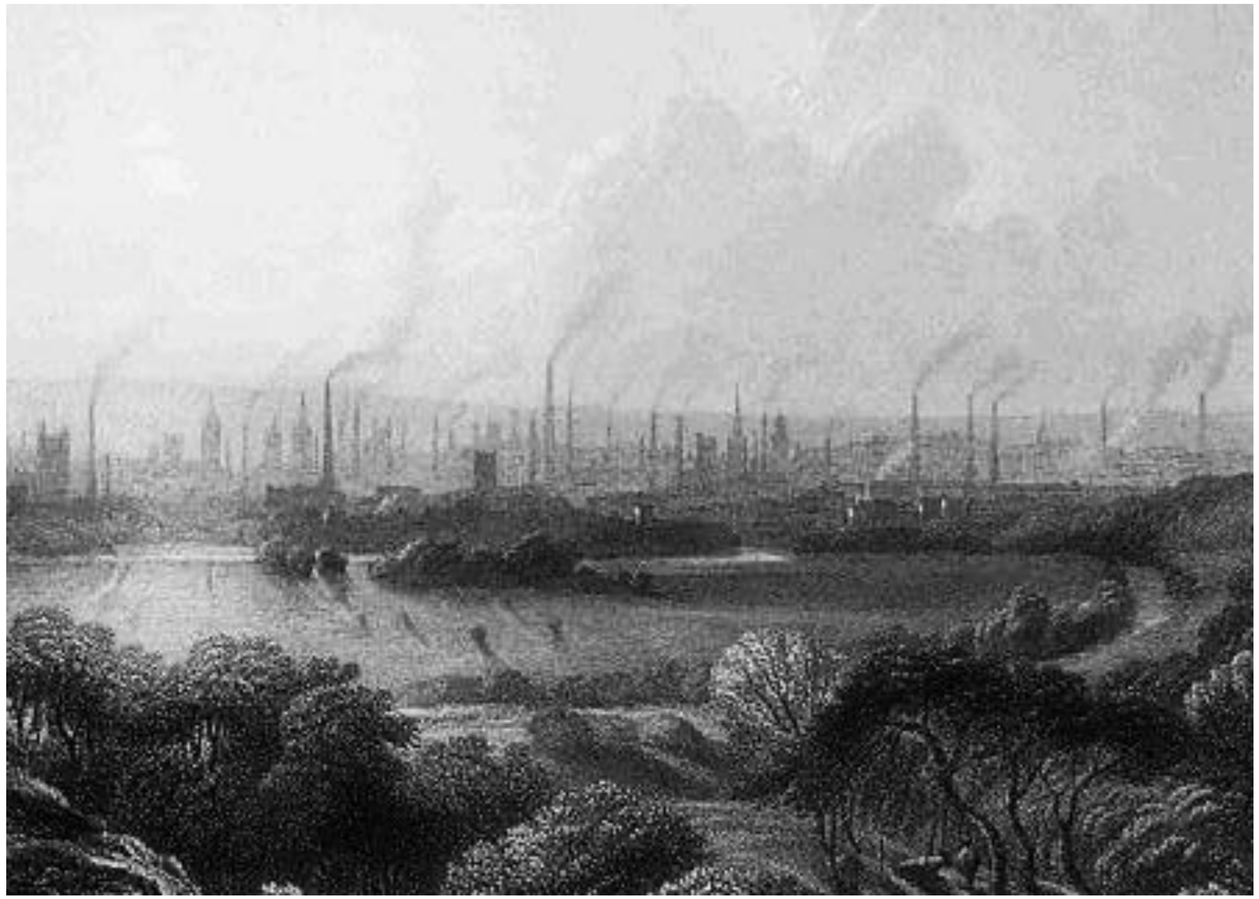
Induced demand: Building roads causes more traffic



Jevons paradox, Rebound effect (backfire)



Jevons paradox, Rebound effect (backfire)



Technological progress increases consumption

Jevons paradox, Rebound effect (backfire)

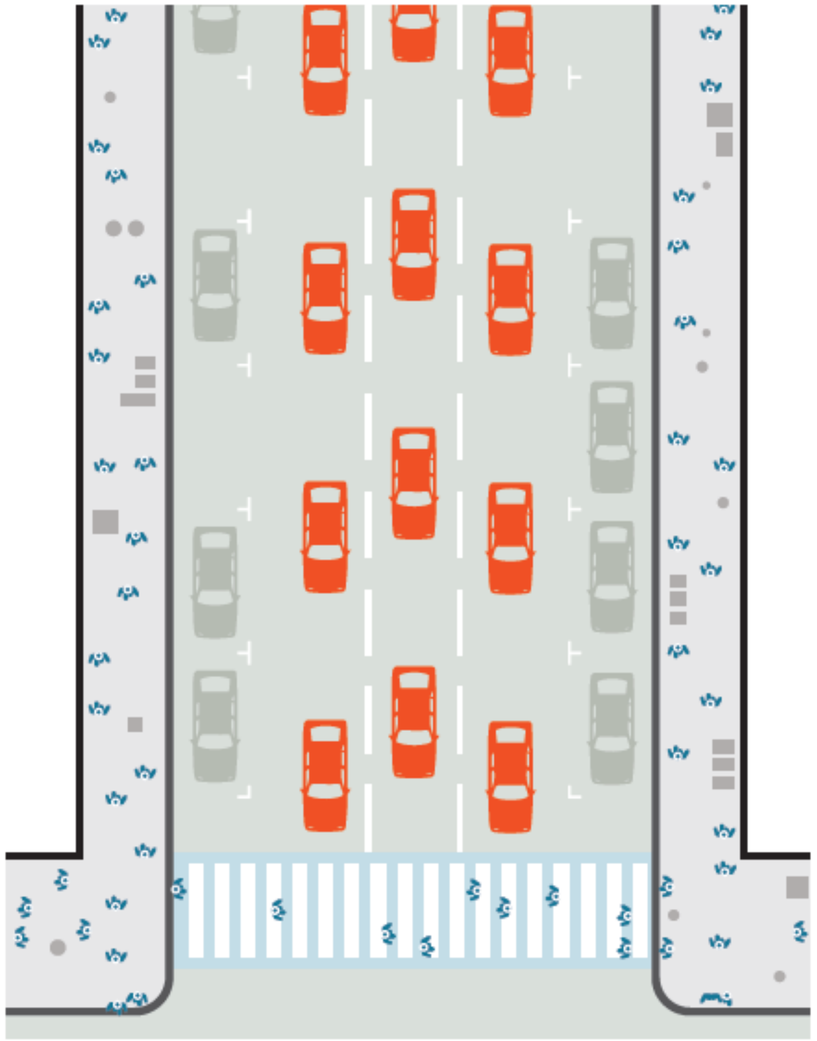
A decrease in cost or price will increase demand.
(Jevons: so much that the efficiency gains are exceeded)

When cars become more fuel efficient, people travel more.

When there are more lanes, people travel more.

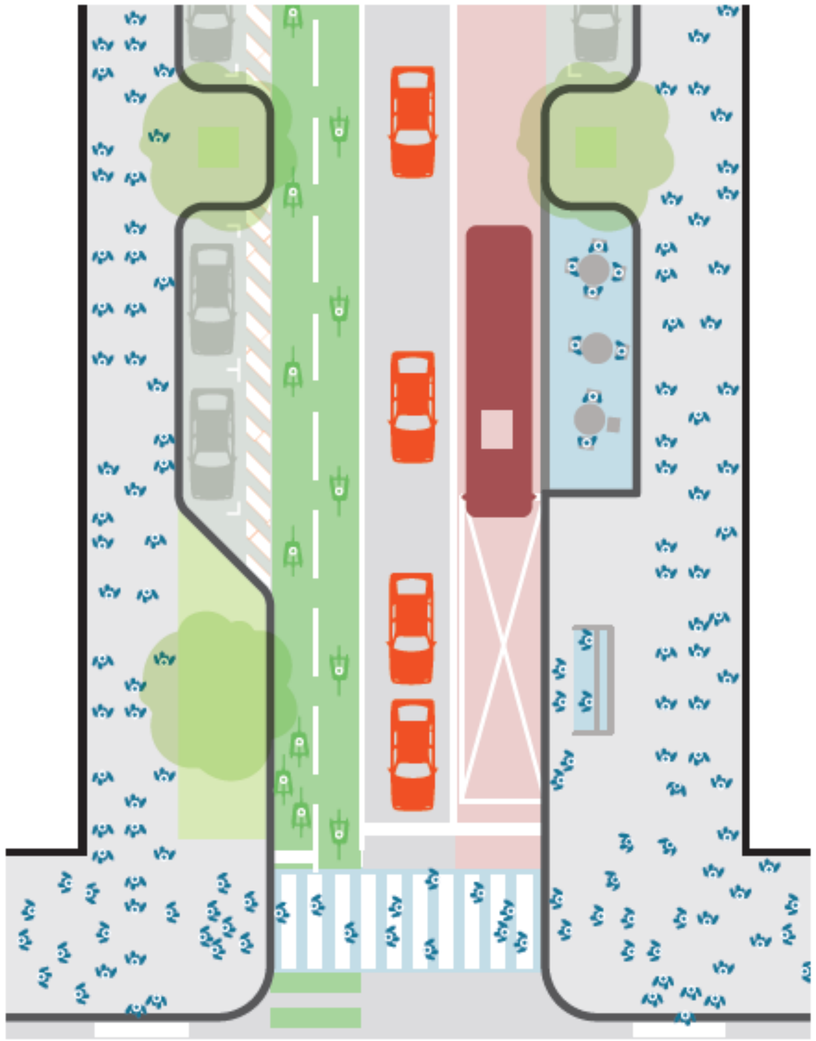
The opposite of induced demand is disappearing traffic

Car-Oriented Street



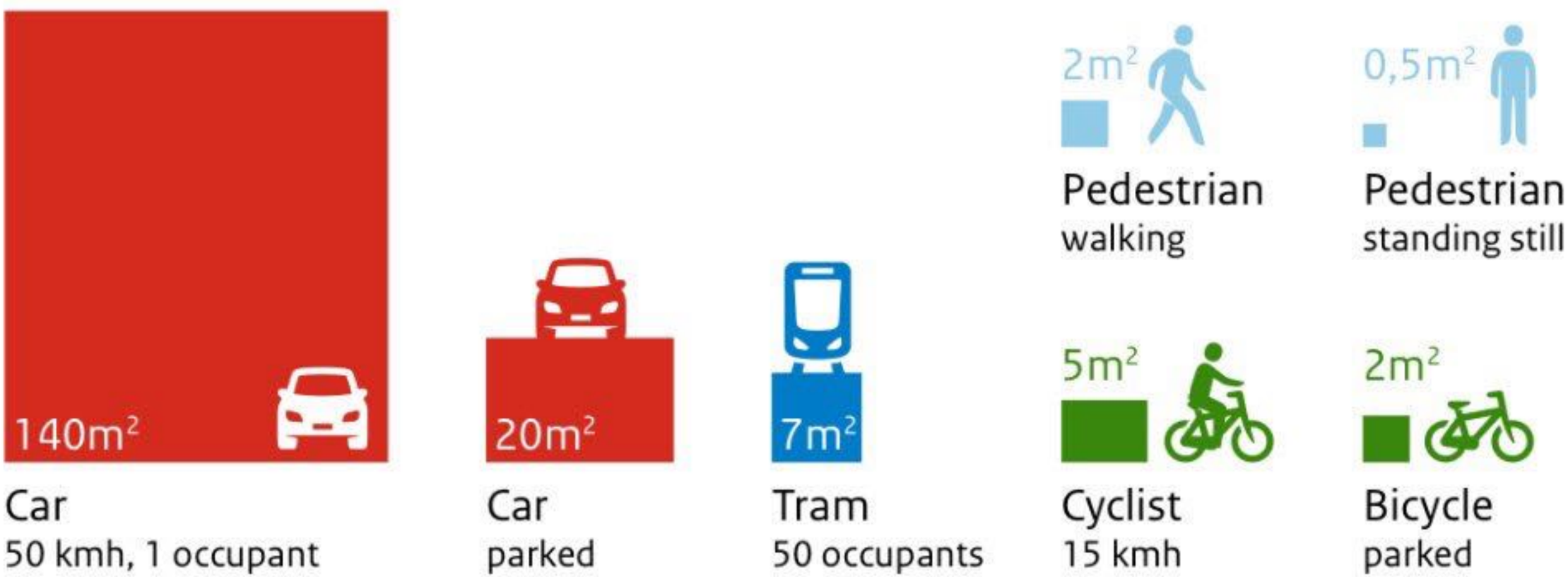
Road diet

Multimodal Street



https://www.icevirtuallibrary.com/doi/full/10.1680/muen.2002.151.1.13

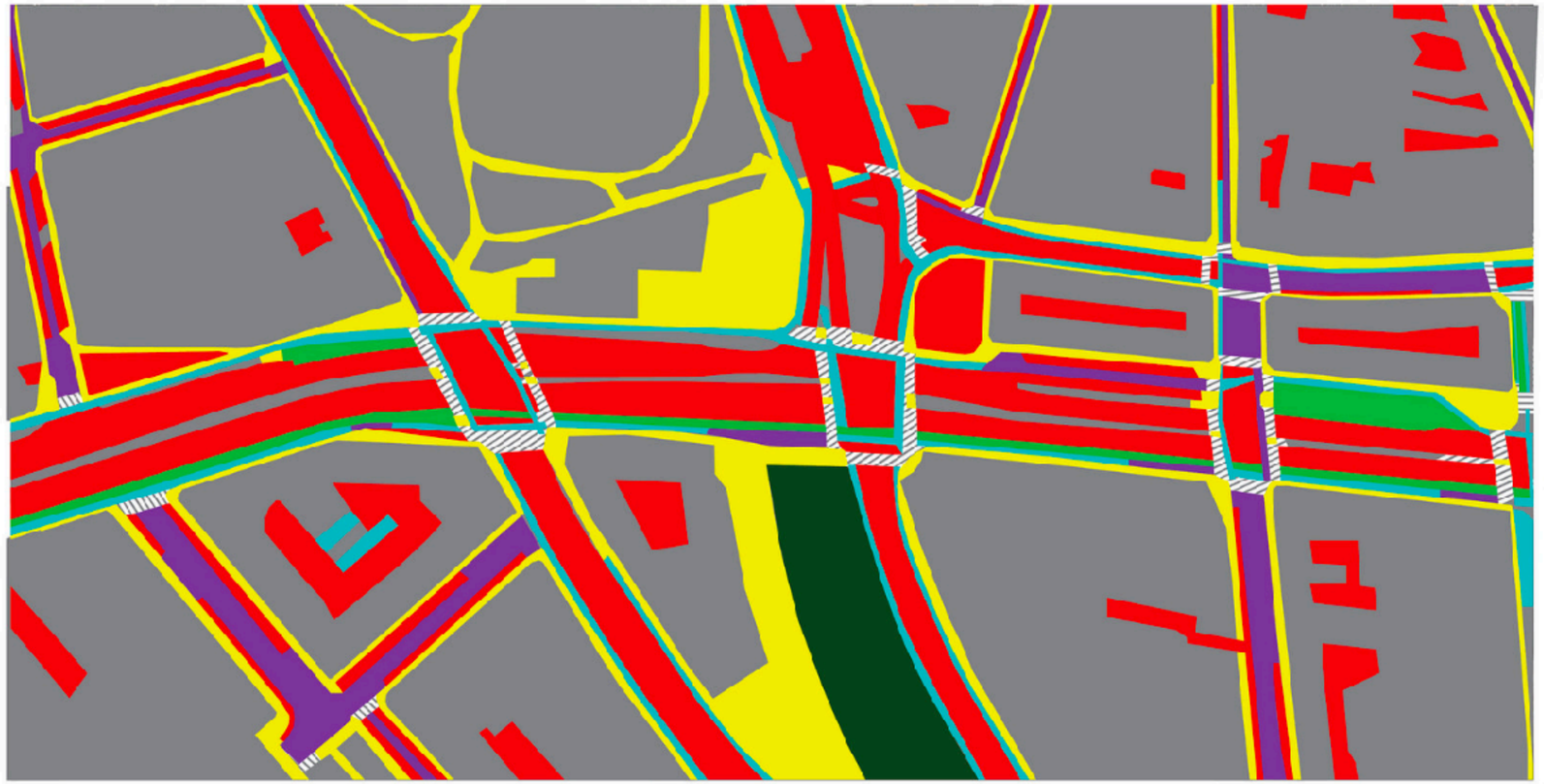
Spatial efficiency shows us what works and what doesn't



Harms and Kansen, Netherlands Institute for Transport Policy Analysis (2017)

Spatial efficiency shows us what works and what doesn't

Most space is for cars, but most people use bikes



Arrogance of Space - Copenhagen. A Section of Hans Christian Andersen Boulevard

Motorised Vehicles | Bikes | Pedestrians | Shared Space | Bus | Non Transport Space | Zebra Crossing | Trains

Modal Share for Copenhageners Commuting to Work/Education

Allocation of Transport Space in Copenhagen

COPENHAGENIZE Design Co. EU

Copenhagenize

Sustainability: Definition

What is the definition of "Sustainability"?

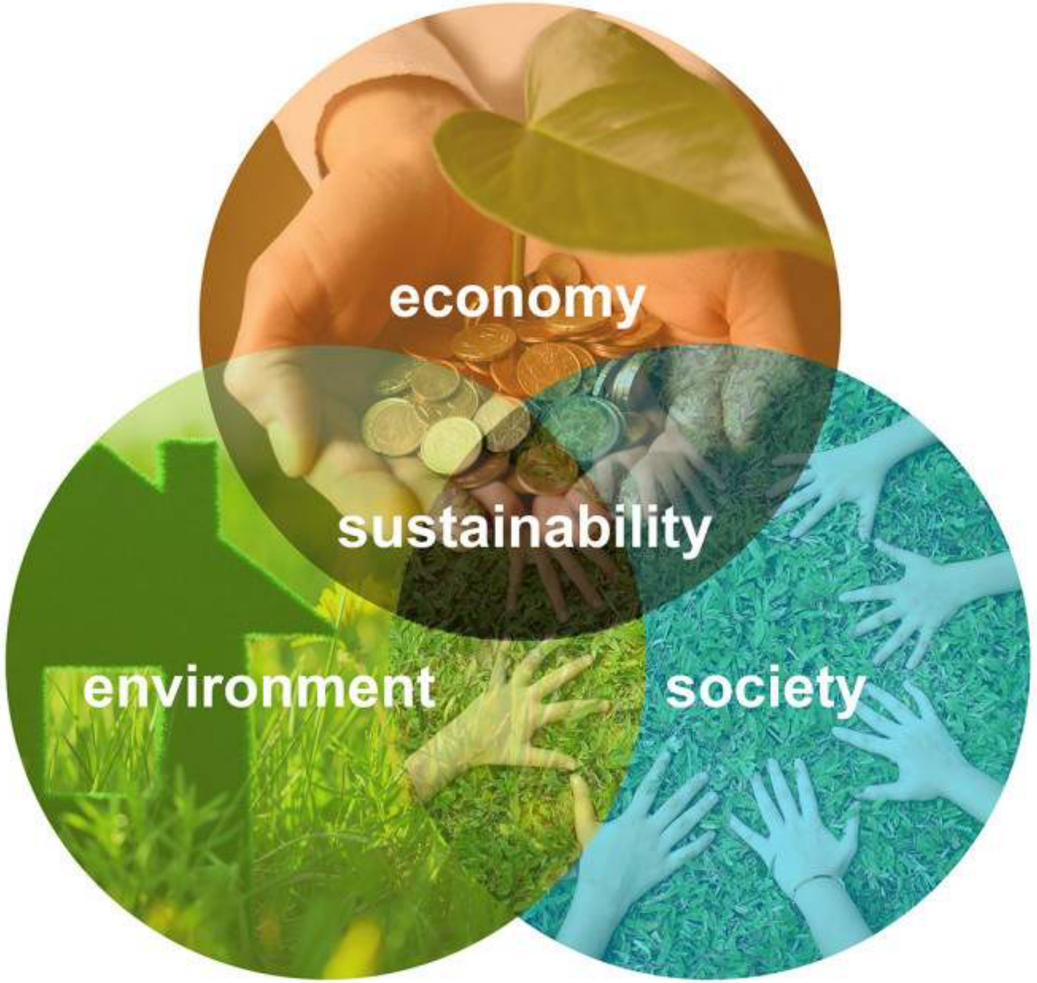
Sustainability: Definition

"*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*"

Brundtland Report, 1987

Brundtland, Gro Harlem, and Mansour Khalid. *Our common future*. UN, 1987

Sustainability: Definition



Replacement of cars with e-cars takes too long

Home 〉 News 〉 Obsessing over electric cars is impeding the race to net zero: More active travel is essential

Obsessing over electric cars is impeding the race to net zero: More active travel is essential

https://www.ox.ac.uk/news/2021-06-14-obsessing-over-electric-cars-impeding-race-net-zero-more-active-travel-essential

Brand et al, Trans Res D 93 (2021)

More active travel is also an *economic* "no-brainer"

Cost-benefit analysis in EU that accounts for

- Health
- Environment
- Travel / Congestion

shows:

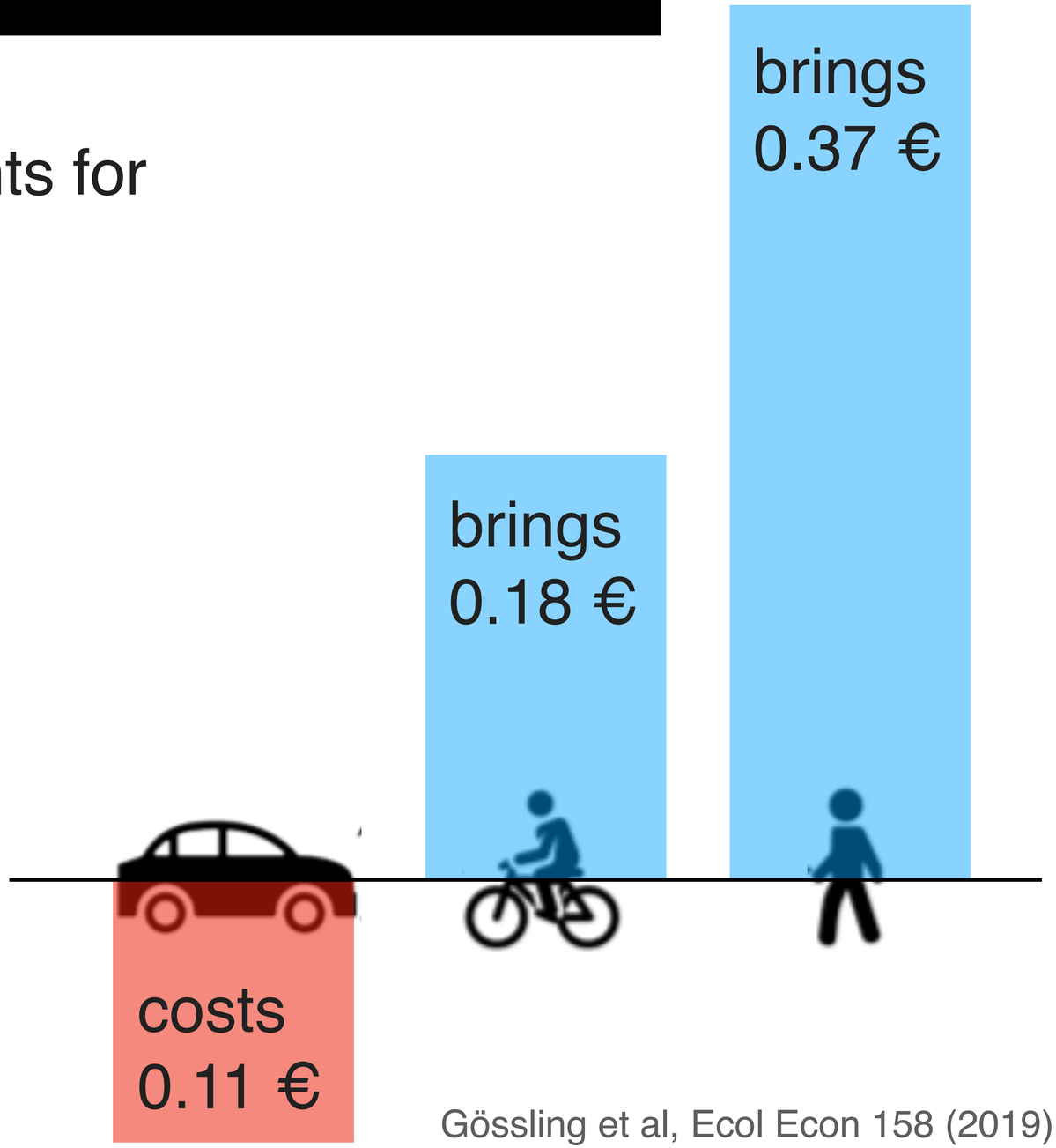
Gössling et al, Ecol Econ 158 (2019)

More active travel is also an *economic* "no-brainer"

Cost-benefit analysis in EU that accounts for

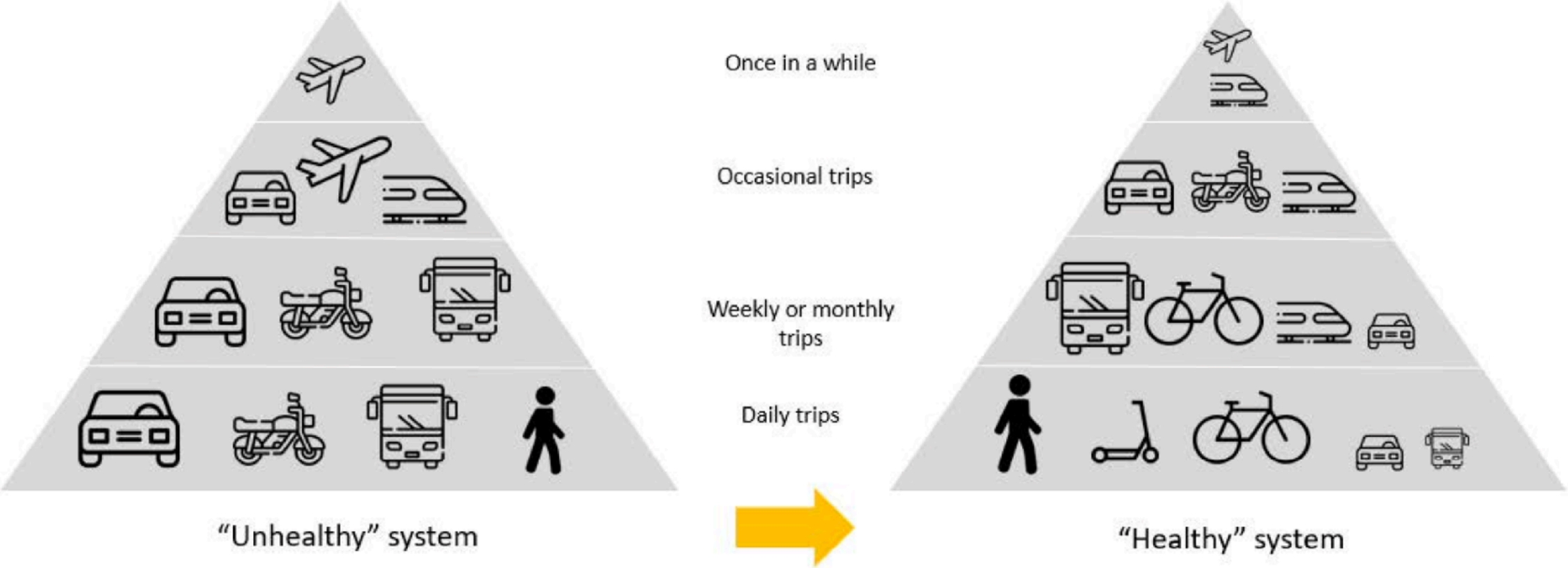
- Health
- Environment
- Travel / Congestion

shows: 1 km travelled by



Gössling et al, Ecol Econ 158 (2019)

We need to transition from unhealthy to healthy transport systems



https://www.oecd.org/environment/transport-strategies-for-net-zero-systems-by-design-0a20f779-en.htm

12 best tested ways to reduce car use in cities

City car use reduction strategies ranked

INTERVENTIONS	'STICK' ELEMENTS	'CARROT' ELEMENTS	EFFECTIVENESS
1. Congestion charge	Drivers pay to enter city centre	Revenues go to city's sustainable transport schemes	12-33% reduction in city-centre cars
2. Parking & traffic control	Remove parking spaces, alter traffic routes	Replace parking spaces with bike lanes and walkways, add car-free streets	11-19% drop in city-centre cars
3. Limited traffic zone	Exclude cars from part of the city (except residents)	Violation fines fund public transport	10-20% reduction in city-centre cars
4. Mobility service for commuters		Workers given free public transport pass, then private shuttles to workplace	37% drop in car commuters
5. Workplace parking charge	Drivers pay to park at work	Cash-out scheme for employees to use public transport; parking revenues fund public transport	8-25% reduction in car commuters
6. Workplace travel planning	Parking management and removal of spaces	Discounts for public transport; improved bike infrastructure; advice to help commuters use public transport/walk/cycle	3-18% drop in car use by commuters
7. University travel planning	Reduced parking on campus	Discounts for public transport; improved bike infrastructure; advice and promotion to students and staff of car alternatives	7-27% reduction in car use by university commuters
8. Mobility services for university		Free public transport pass and shuttle connections for students	24% drop in students commuting by car
9. Car sharing		Car sharing access integrated to work and neighbourhoods	12-15 private cars replaced by each shared car
10. School travel planning		Advice and events to help students and parents walk, cycle or carpool to school	5-11% reduction in car use for school trips
11. Personalised travel planning		Discounted public transport; advice to help city residents walk and cycle	6-12% drop in car use share among residents
12. App for sustainable mobility		Rewards for achieving targets for walking, cycling or using public transport	73% - proportion of app users declaring reduced car use

Source: Kuss and Nicholas, 2022, Case Studies on Transport Policy • Get the data • Created with Datawrapper

https://www.theguardian.com/environment/2022/apr/16/12-most-effective-ways-cars-cities-europe

12 best tested ways to reduce car use in cities

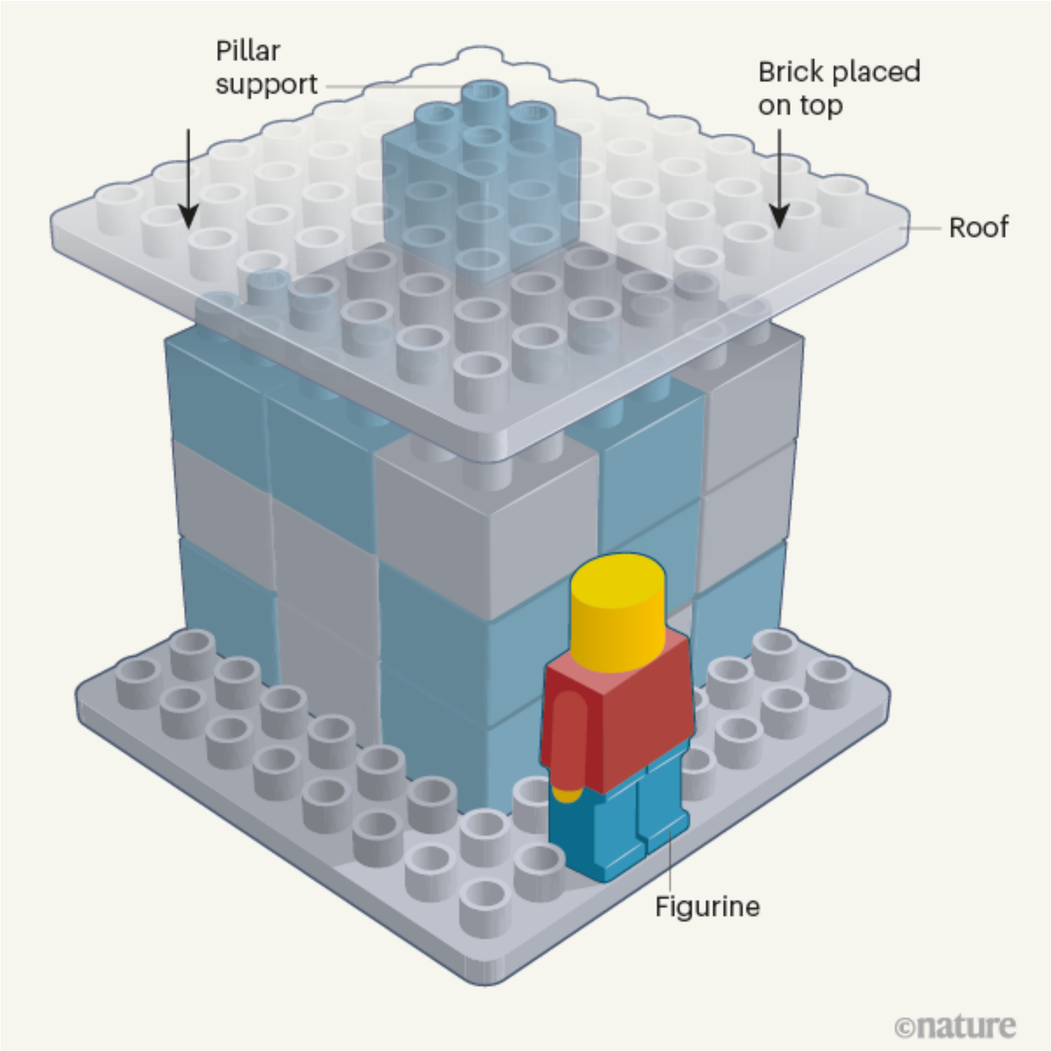
City car use reduction strategies ranked

INTERVENTIONS	'STICK' ELEMENTS	'CARROT' ELEMENTS	EFFECTIVENESS
1. Congestion charge	Drivers pay to enter city centre	Revenues go to city's sustainable transport schemes	12-33% reduction in city-centre cars
2. Parking & traffic control	Remove parking spaces, alter traffic routes	Replace parking spaces with bike lanes and walkways, add car-free streets	11-19% drop in city-centre cars
3. Limited traffic zone	Exclude cars from part of the city (except residents)	Violation fines fund public transport	10-20% reduction in city-centre cars
4. Mobility service for commuters		Workers given free public transport pass, then private shuttles to workplace	37% drop in car commuters
5. Workplace parking charge	Drivers pay to park at work	Cash-out scheme for employees to use public transport; parking revenues fund public transport	8-25% reduction in car commuters
6. Workplace travel planning	Parking management and removal of spaces	Discounts for public transport; improved bike infrastructure; advice to help commuters use public transport/walk/cycle	3-18% drop in car use by commuters
7. University travel planning	Reduced parking on campus	Discounts for public transport; improved bike infrastructure; advice and promotion to students and staff of car alternatives	7-27% reduction in car use by university commuters
8. Mobility services for university		Free public transport pass and shuttle connections for students	24% drop in students commuting by car
9. Car sharing		Car sharing access integrated to work and neighbourhoods	12-15 private cars replaced by each shared car
10. School travel planning		Advice and events to help students and parents walk, cycle or carpool to school	5-11% reduction in car use for school trips
11. Personalised travel planning		Discounted public transport; advice to help city residents walk and cycle	6-12% drop in car use share among residents
12. App for sustainable mobility		Rewards for achieving targets for walking, cycling or using public transport	73% - proportion of app users declaring reduced car use

Source: Kuss and Nicholas, 2022, Case Studies on Transport Policy • Get the data • Created with Datawrapper

Why is this so hard?

https://www.theguardian.com/environment/2022/apr/16/12-most-effective-ways-cars-cities-europe

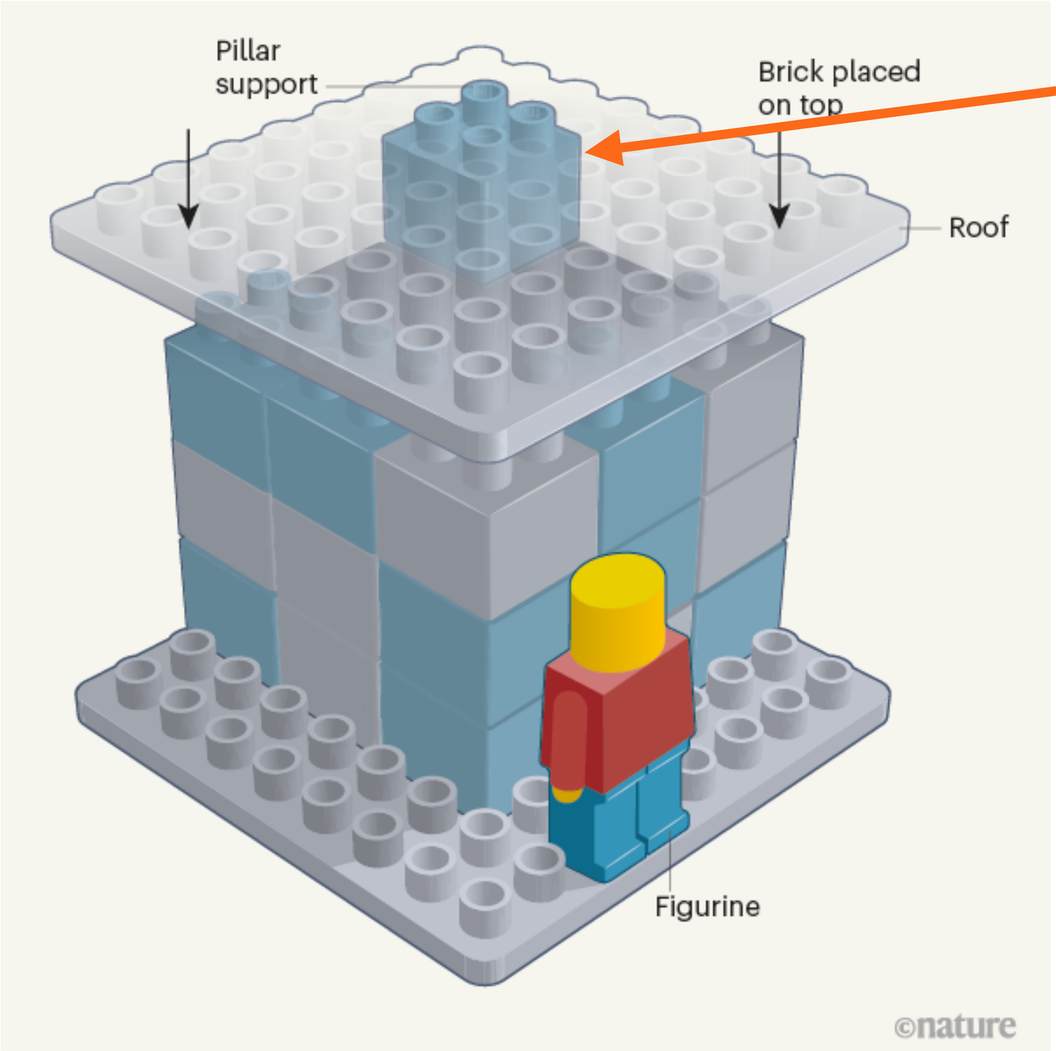


Any additional brick you use costs 10 cents.

How would you improve the roof's stability most efficiently?

https://www.nature.com/articles/d41586-021-00592-0

Adding is favored over subtracting in problem solving



Remove this one. Cost: 0

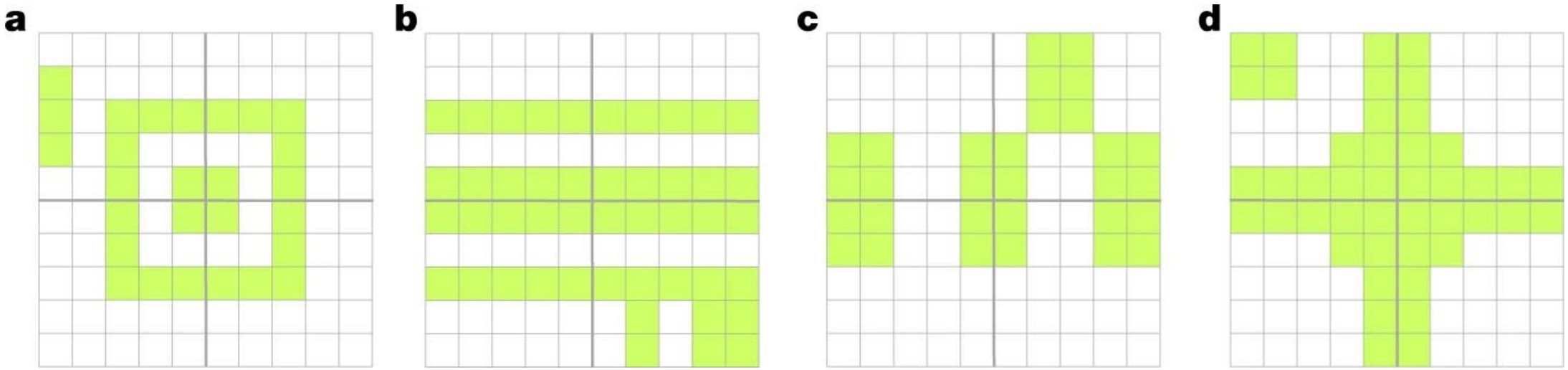
Any additional brick you use costs 10 cents.

How would you improve the roof's stability most efficiently?

https://www.nature.com/articles/d41586-021-00592-0

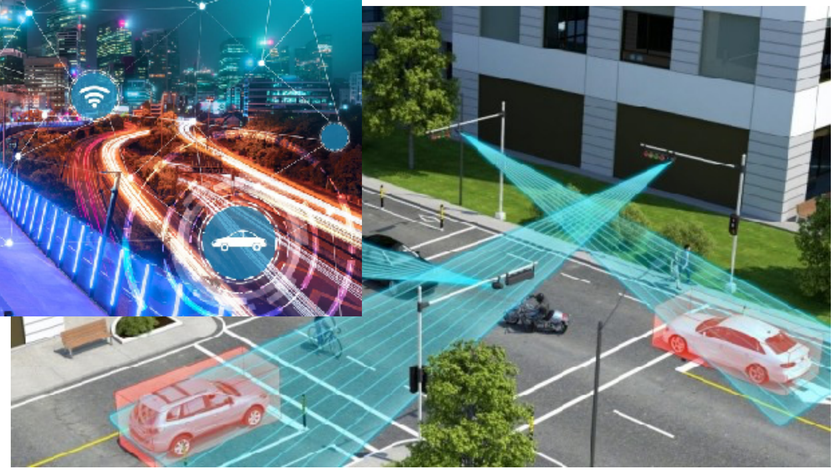
Adding is favored over subtracting in problem solving

Achieve symmetry

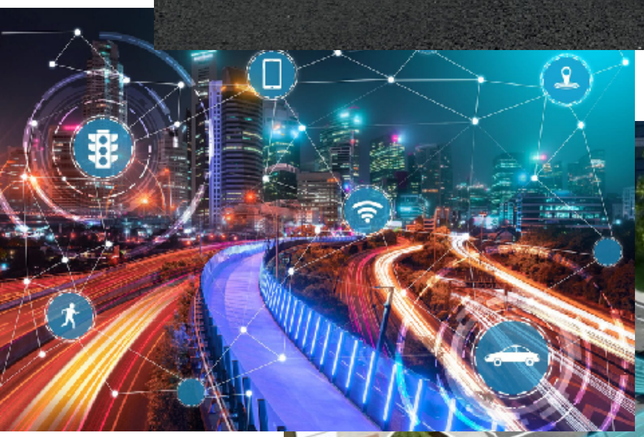


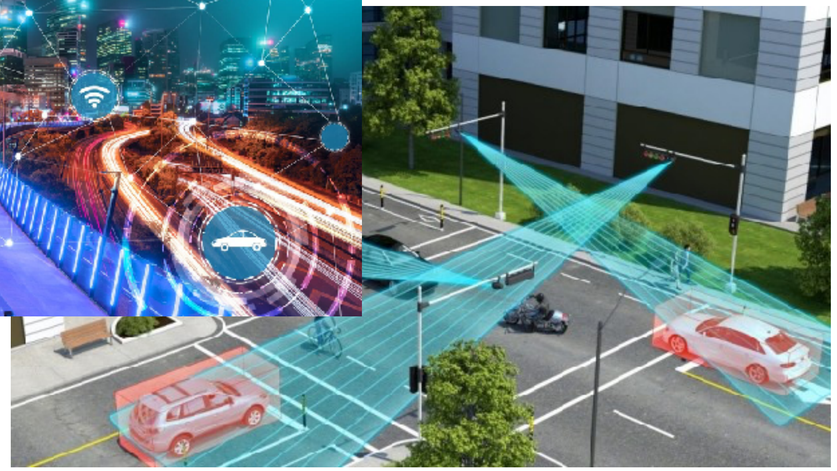
https://www.nature.com/articles/d41586-021-00592-0

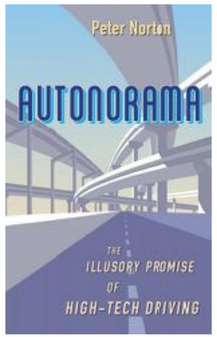
Flying cars



Flying cars



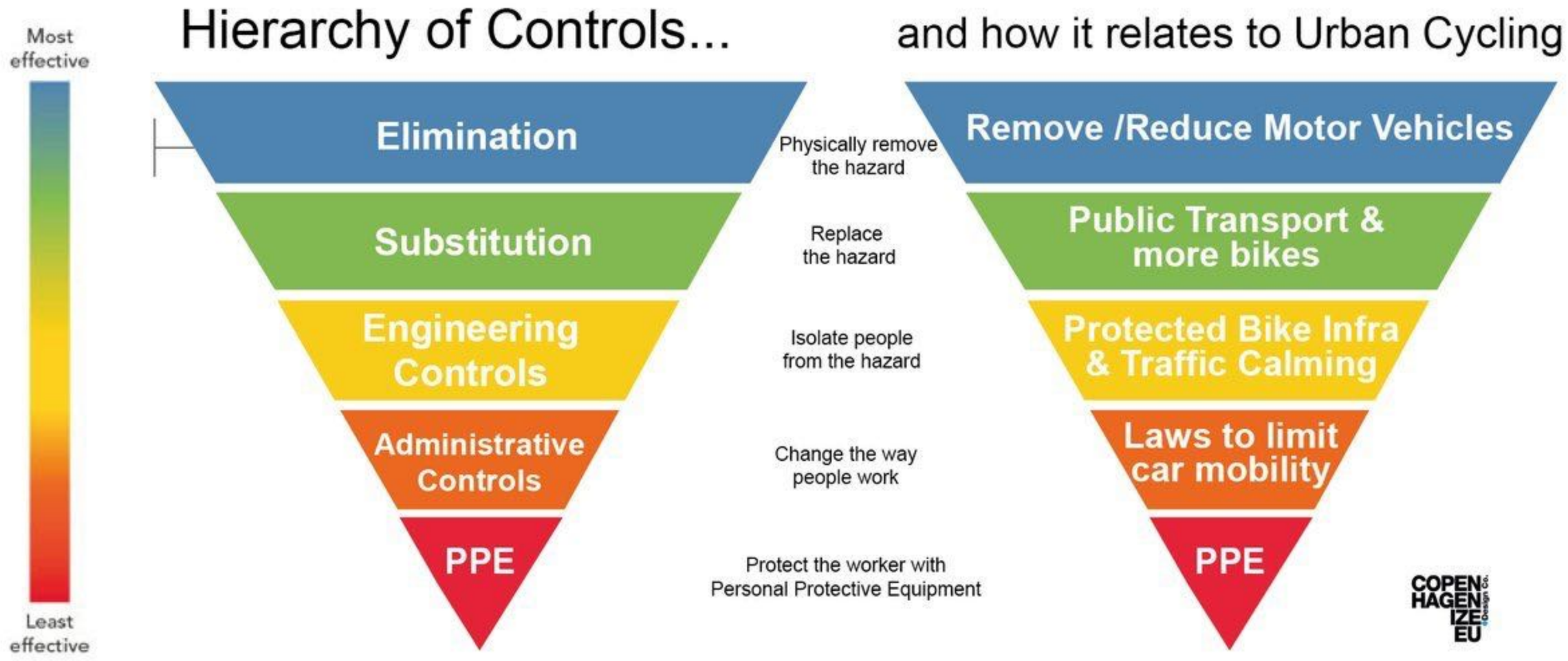




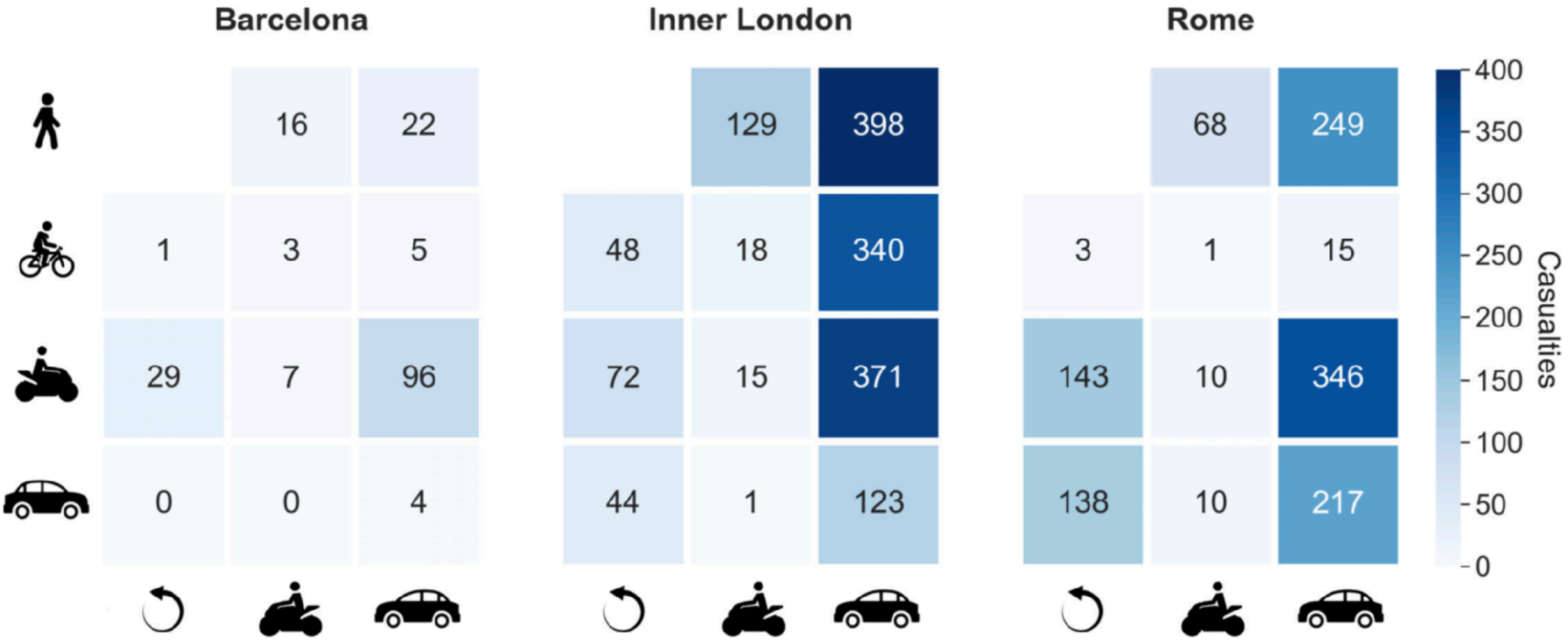
http://www.jan-kamensky.de/

Peter Norton: Autonorama

Eliminate the biggest hazards first

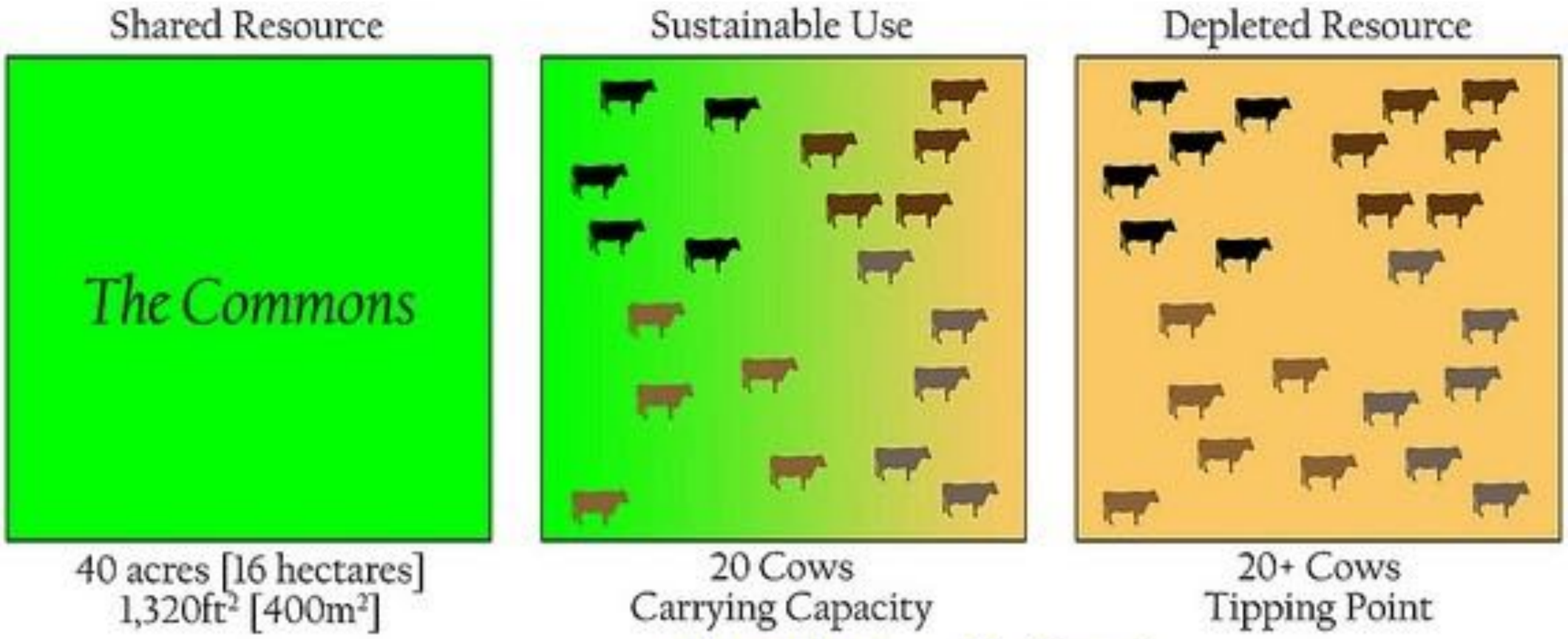


Eliminate the biggest hazards first

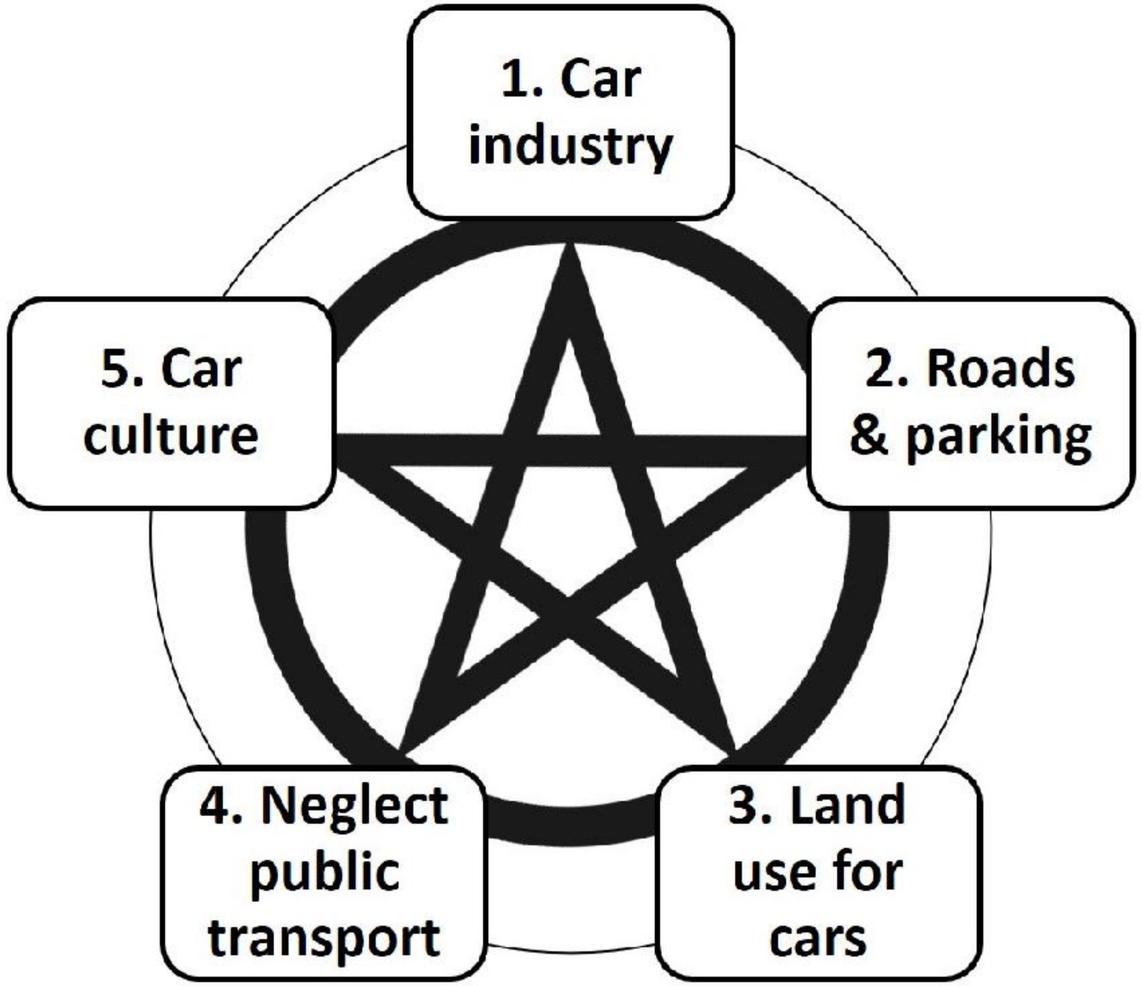


https://epjdatascience.springeropen.com/articles/10.1140/epjds/s13688-022-00339-5

Tragedy of the commons



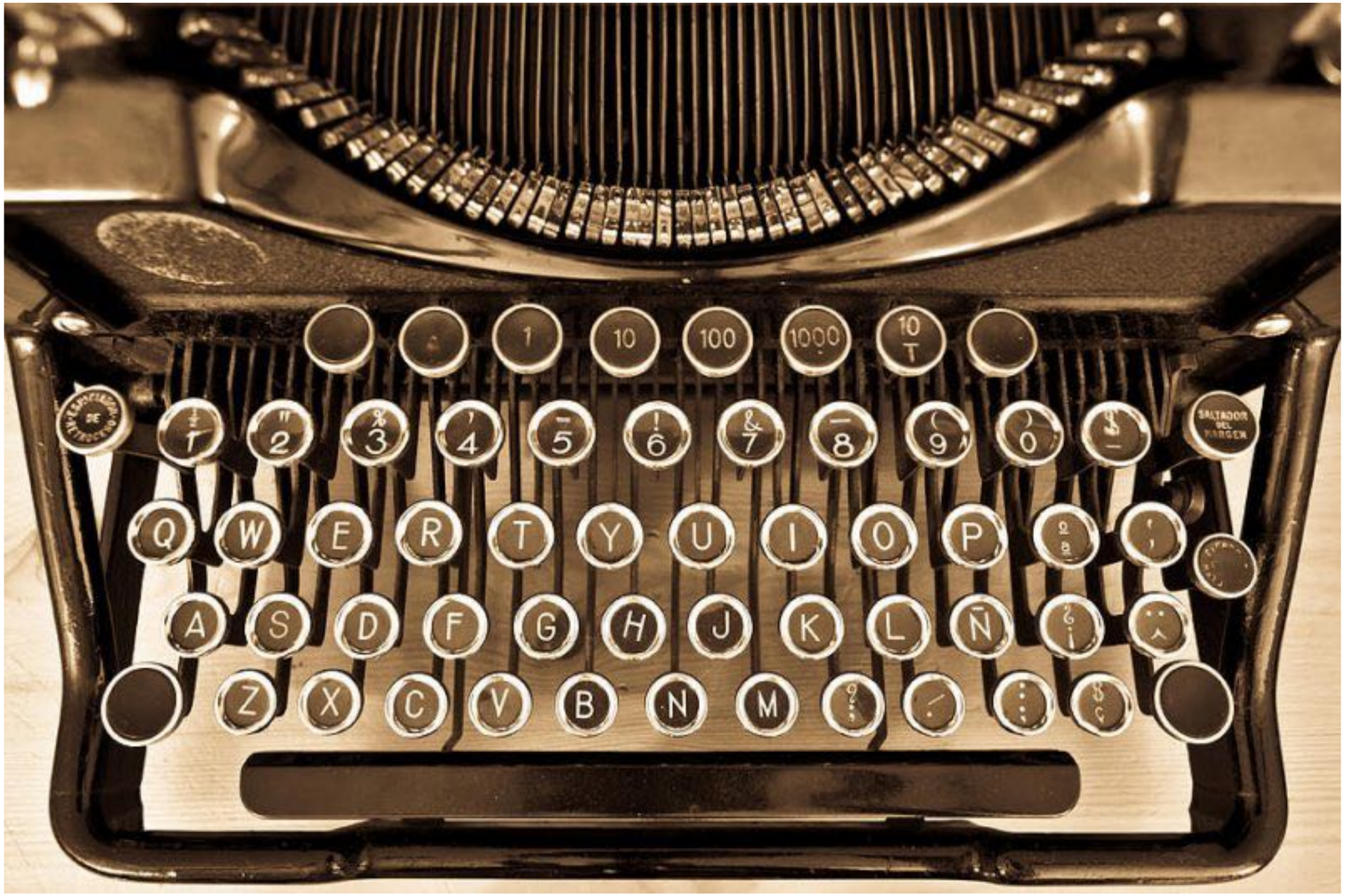
It is hard to avoid the tragedy of the commons in transport



https://www.sciencedirect.com/science/article/pii/S2214629620300633#tbl0003

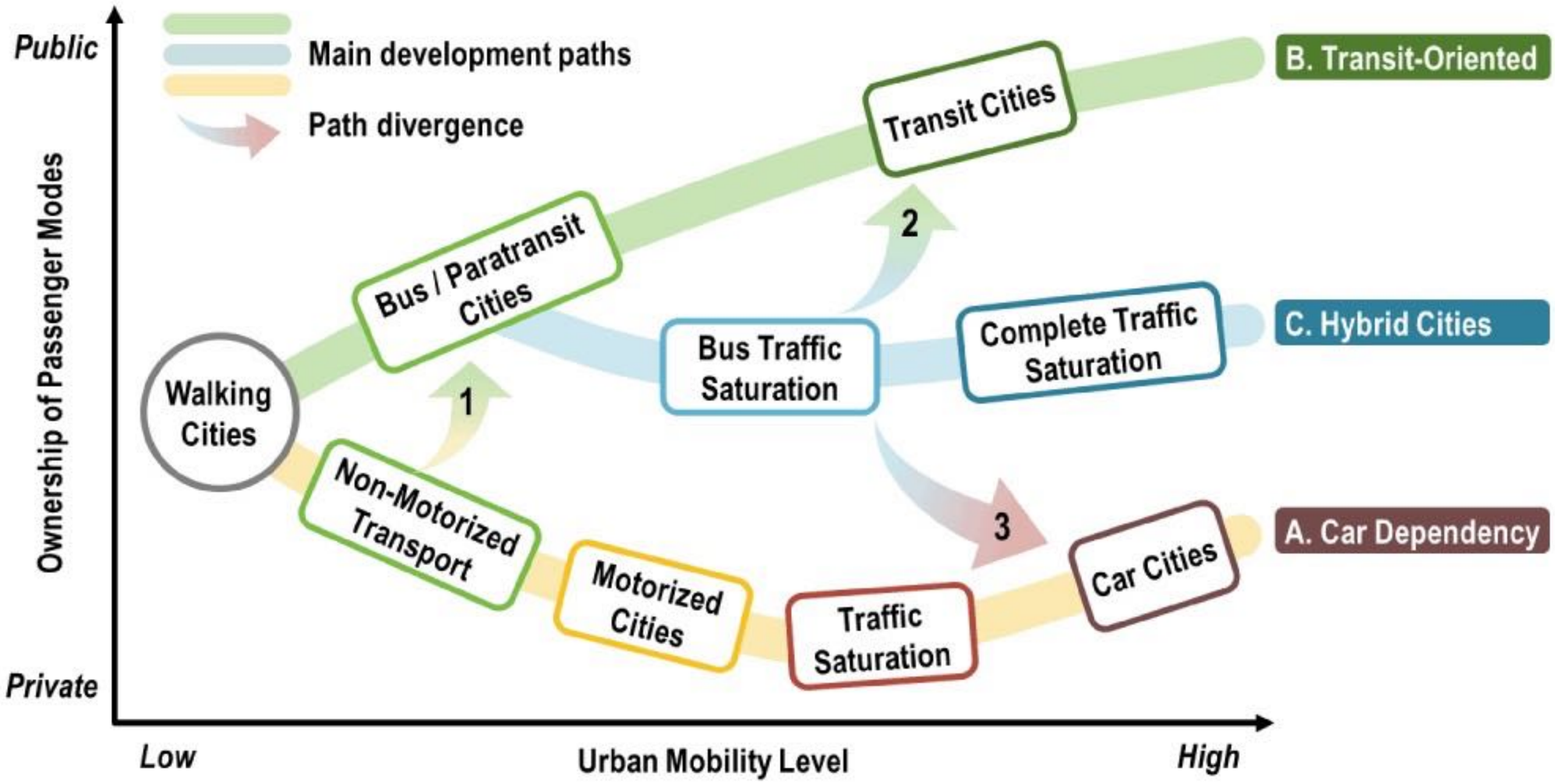
Mattioli et al, Energy Research & Social Science 66 (2020): 101486

Lock-in: The more we go into one direction, the harder it is to go back



Lock-in: The more we go into one direction, the harder it is to go back

Path-dependence

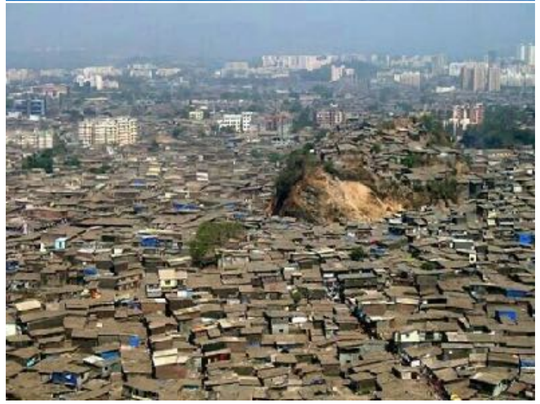


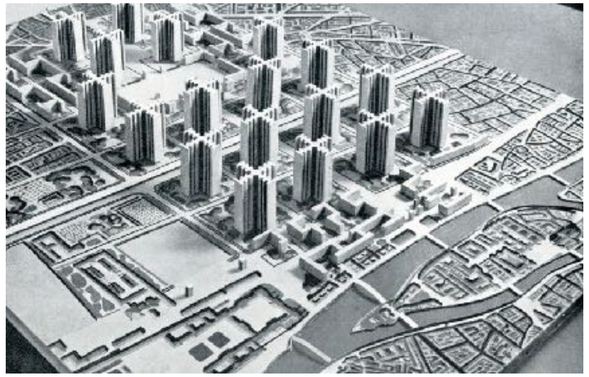
https://transportgeography.org/contents/chapter8/transportation-urban-form/urban-transport-development-paths/

How much are we in control?

Self-organized

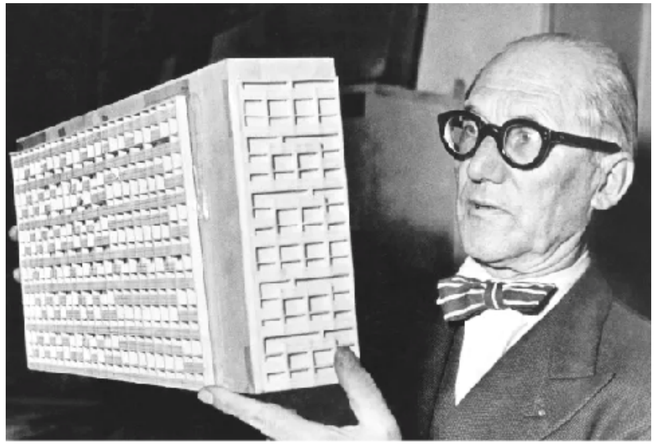
Planned





How much should we be in control?

Self-organized — Planned



Imposing plans often brings counterintuitive effects

But: Central planning can be important

We inherit the past. Retrofitting is a cheap way to make the best of it.

The best time to plant a tree was 20 years ago.
The second best time is now.

Post-growth

We cannot grow indefinitely

Let's improve human well-being, not grow GDP

Let's improve human well-being for all, not just for a minority

https://www.nature.com/articles/s41560-021-00884-9

Post-growth for streets: Optimize quality of life, not traffic flow

Post-growth

We cannot grow indefinitely

Let's improve human well-being, not grow GDP

Let's improve human well-being for all, not just for a minority

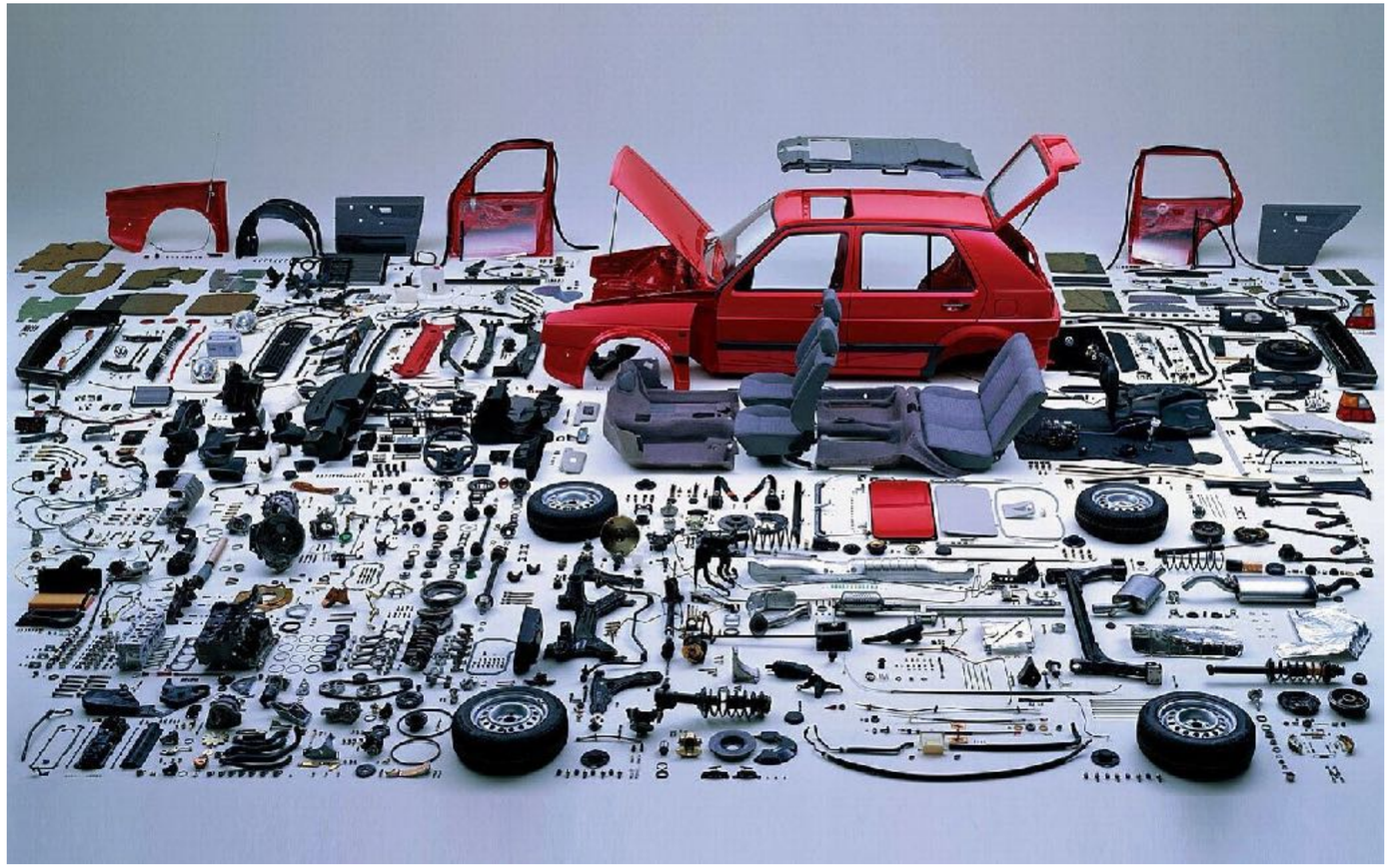
We need to understand complex systems

https://www.nature.com/articles/s41560-021-00884-9

20th century thinking followed a linear, compartmental approach

Compartmentalization: We can study a subsystem on its own

Linearization: Processes can be simplified as being linear

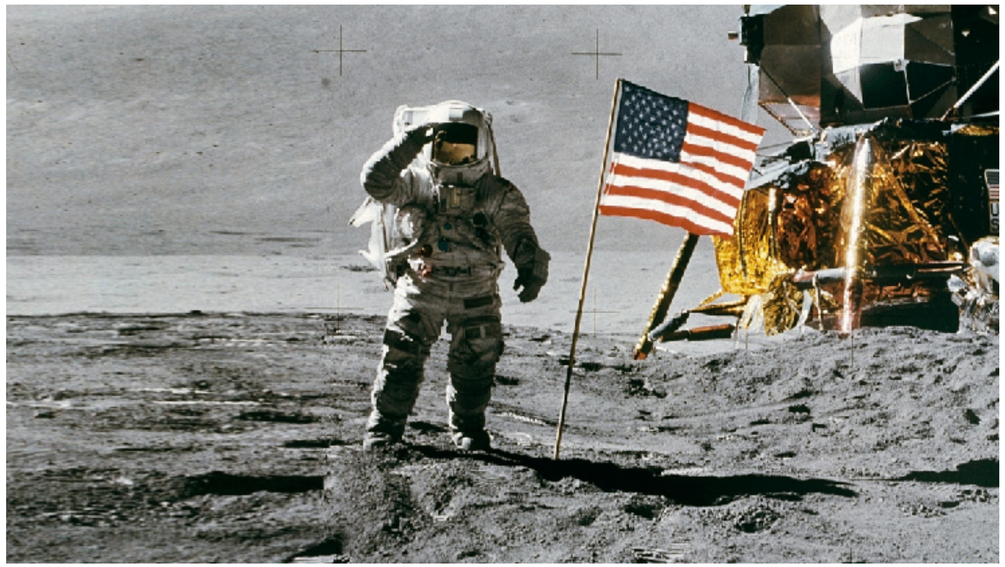


20th century thinking followed a linear, compartmental approach

Compartmentalization: We can study a subsystem on its own

Linearization: Processes can be simplified as being linear

Huge success for engineering

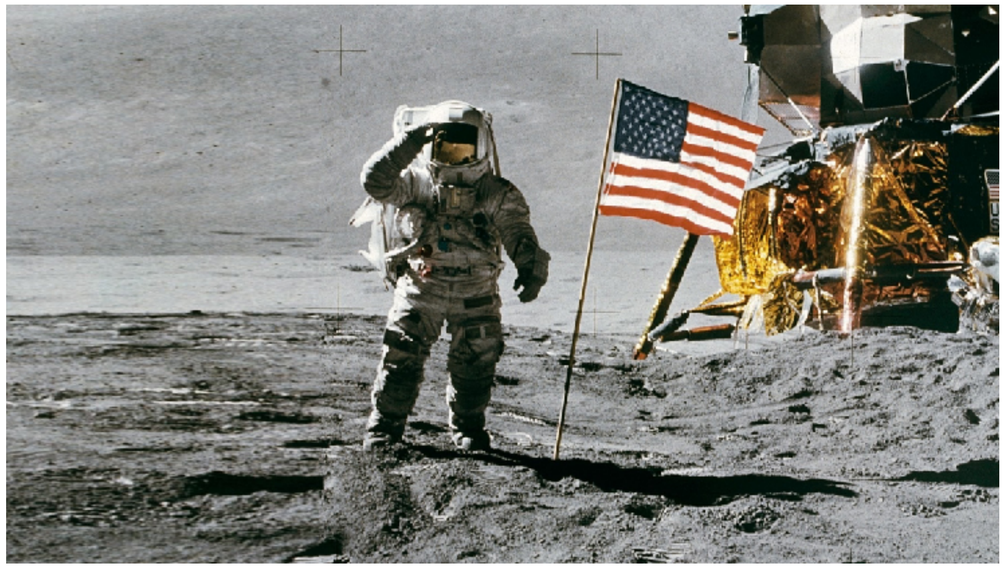


20th century thinking followed a linear, compartmental approach

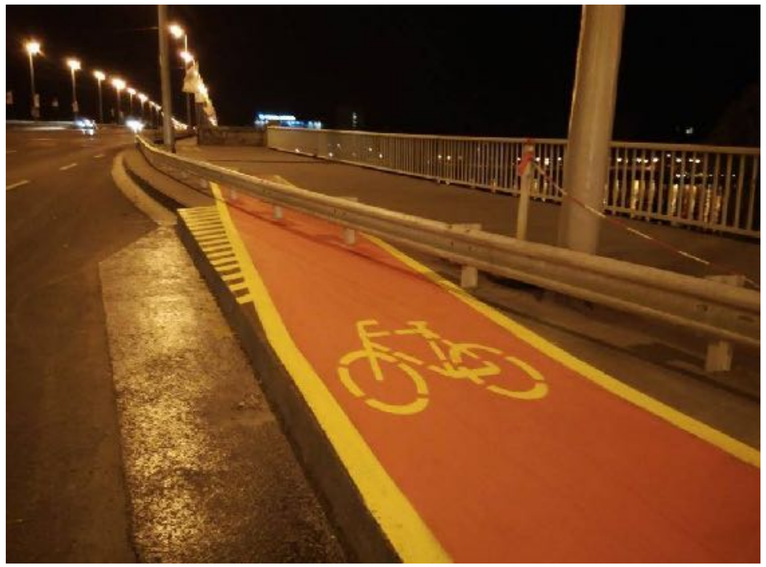
Compartmentalization: We can study a subsystem on its own

Linearization: Processes can be simplified as being linear

Huge success for engineering



Huge failure for complex systems, especially socio-technical systems



21st century thinking understands nonlinearity and complexity

Complexity: We cannot study a subsystem on its own

No Linearization: Most processes cannot be simplified as being linear

Complex systems have:

Many single units

Strong, nonlinear interactions

Emergence of collective behavior

$$\frac{d\theta_i}{dt} = \omega_i + \frac{K}{N}\sum_{j=1}^{N}\sin(\theta_j - \theta_i)$$

https://ncase.me/fireflies/

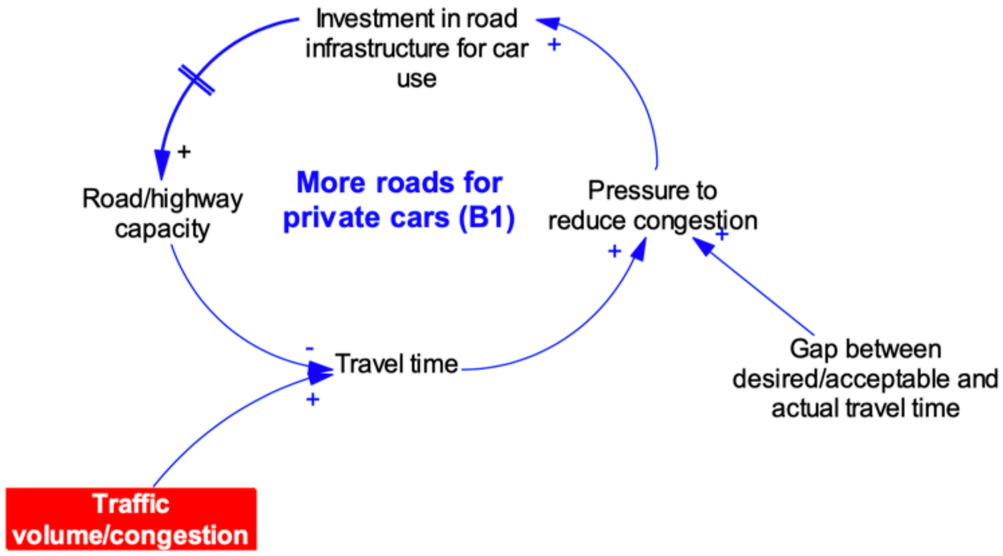
Complex networks are the backbones of complex systems

Many single units

Strong, nonlinear interactions

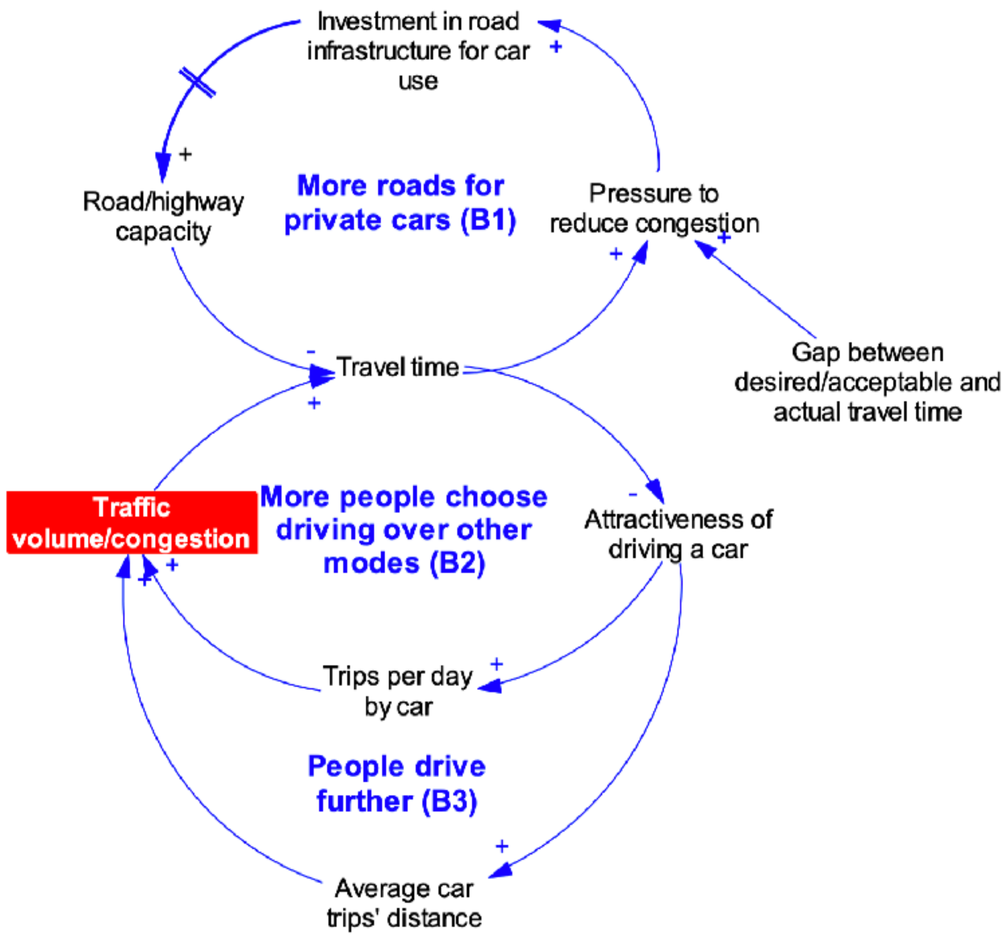
Emergence of collective behavior

Systems-thinking reveals feedback-loops & long-term dynamics

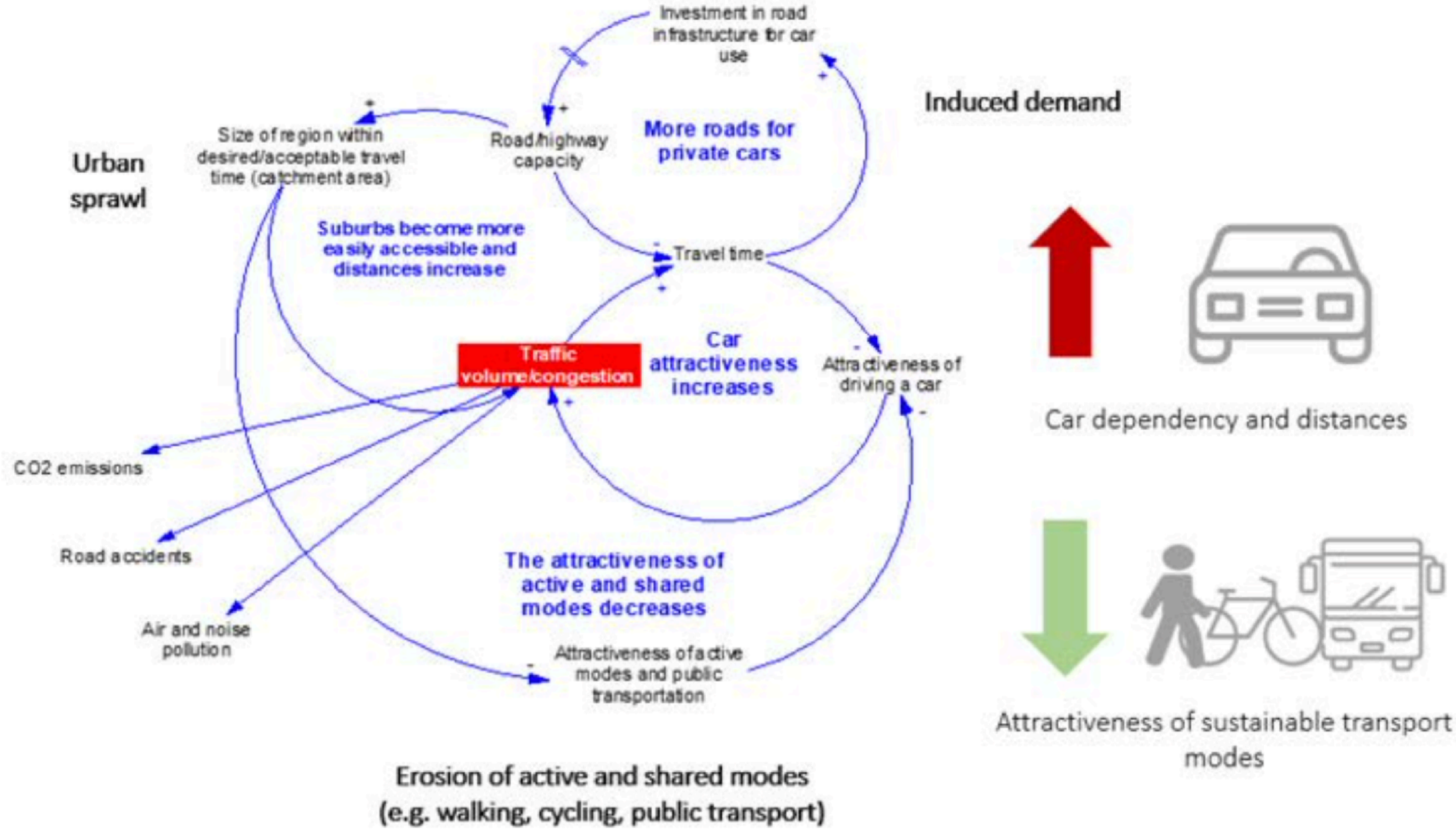


https://www.oecd.org/environment/transport-strategies-for-net-zero-systems-by-design-0a20f779-en.htm

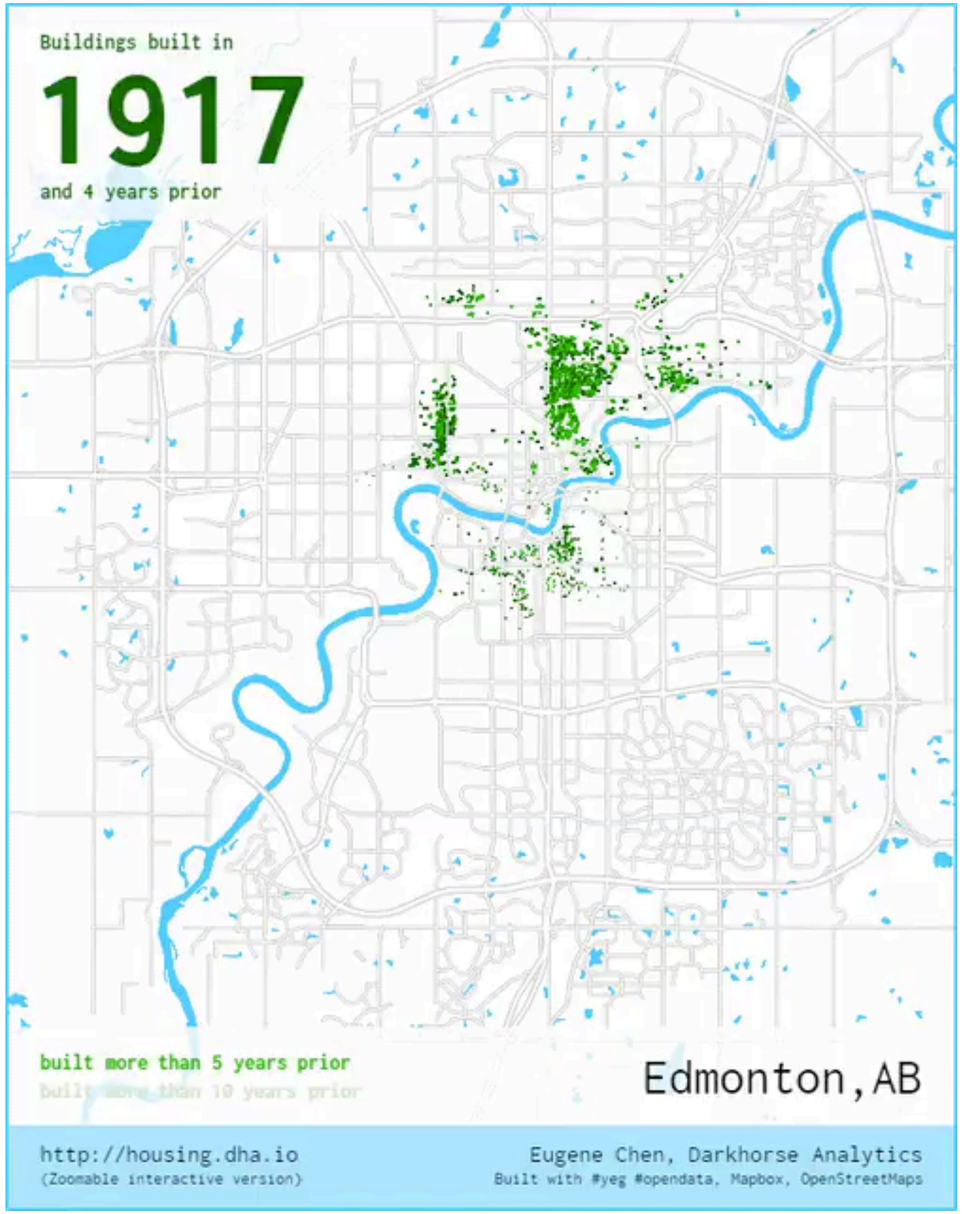
Systems-thinking reveals feedback-loops & long-term dynamics



Systems-thinking reveals feedback-loops & long-term dynamics



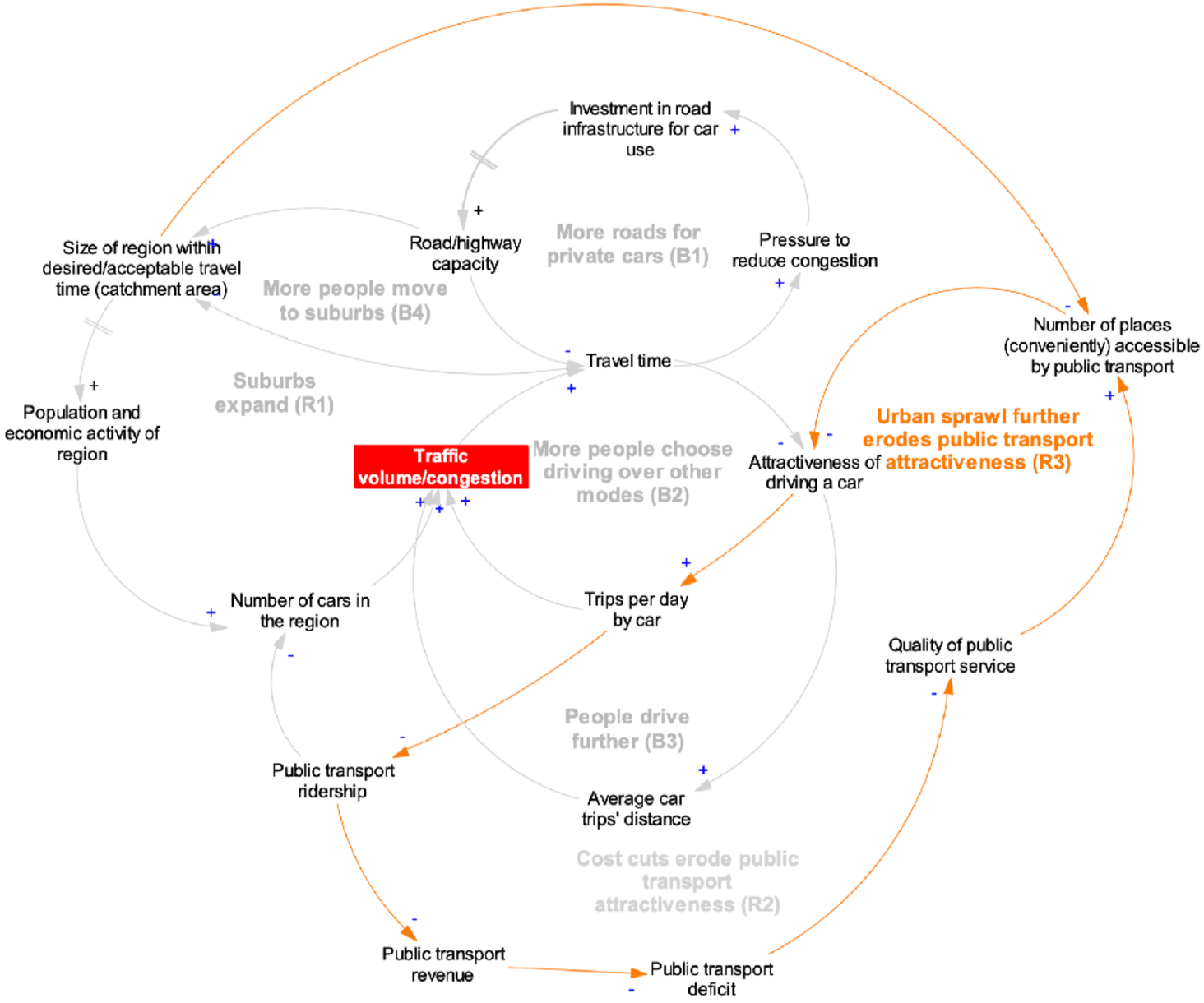
Systems-thinking reveals feedback-loops & long-term dynamics



Urban sprawl

http://housing.dha.io/

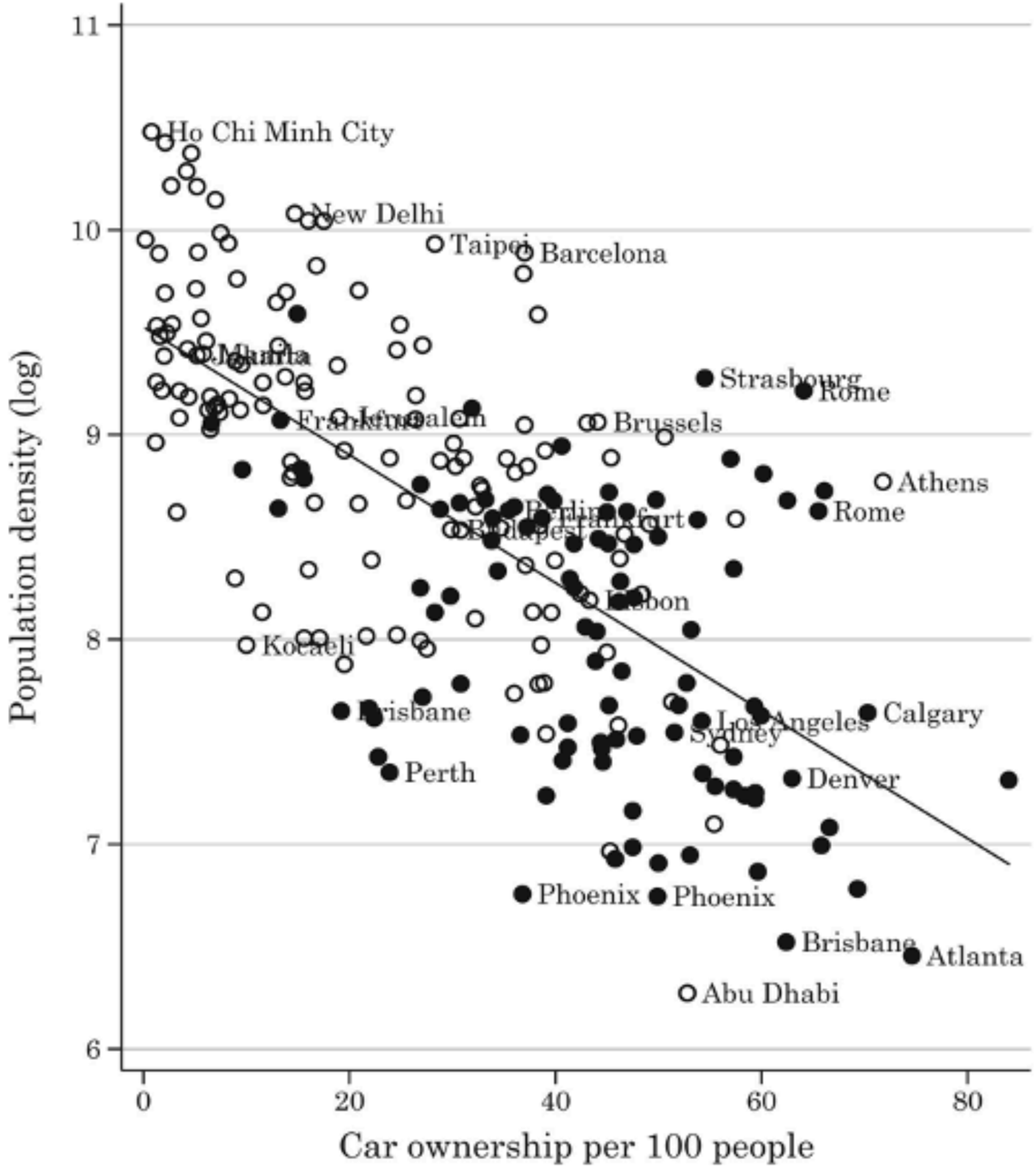
Systems-thinking reveals feedback-loops & long-term dynamics

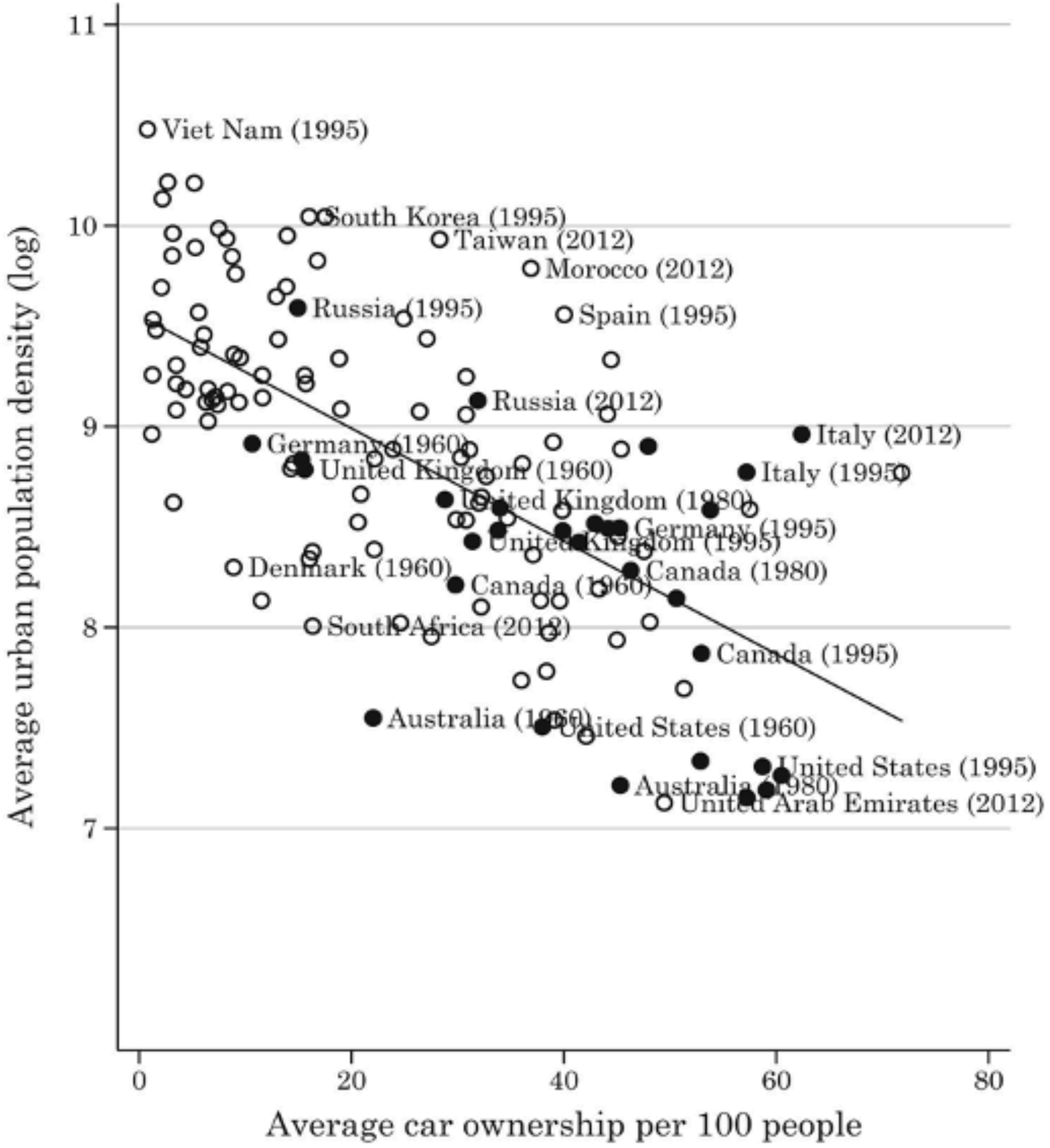


Urban sprawl

As the *size of the region accessible by road* increases, density decreases (not shown in figure) and the *number of places conveniently accessible by public transport* decrease.

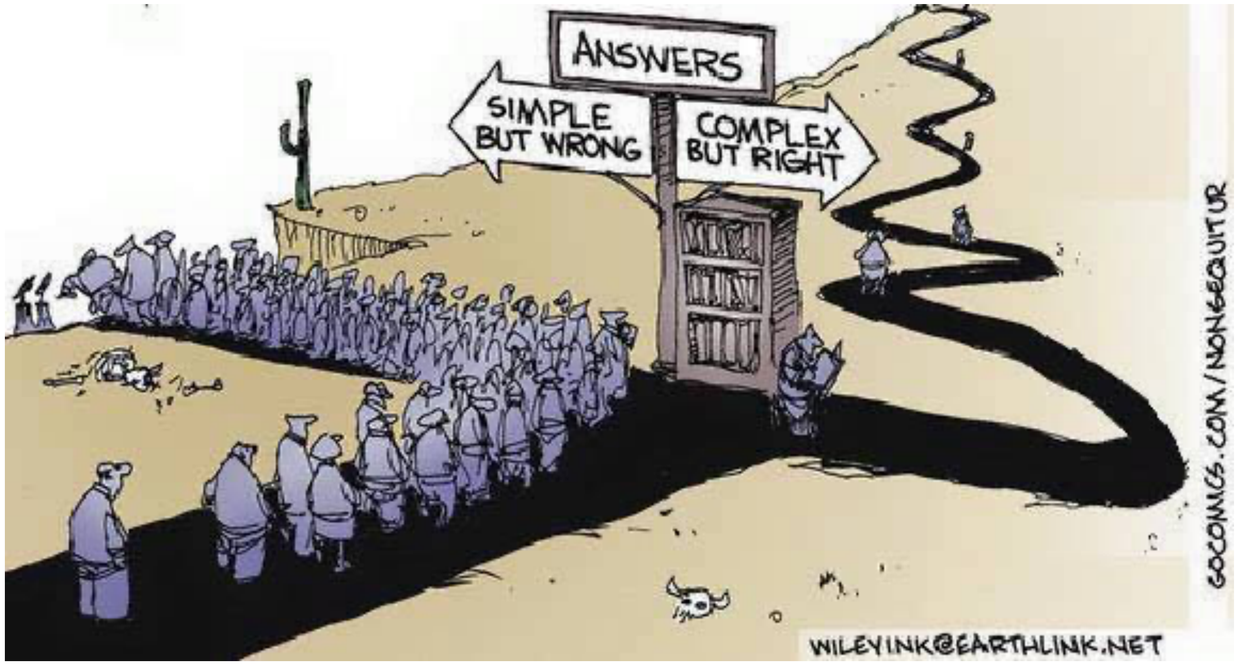
Thus, as the region expands, places may be less well served by public transport, reducing the attractiveness of public transport and increasing the attractiveness of its alternative: the car.

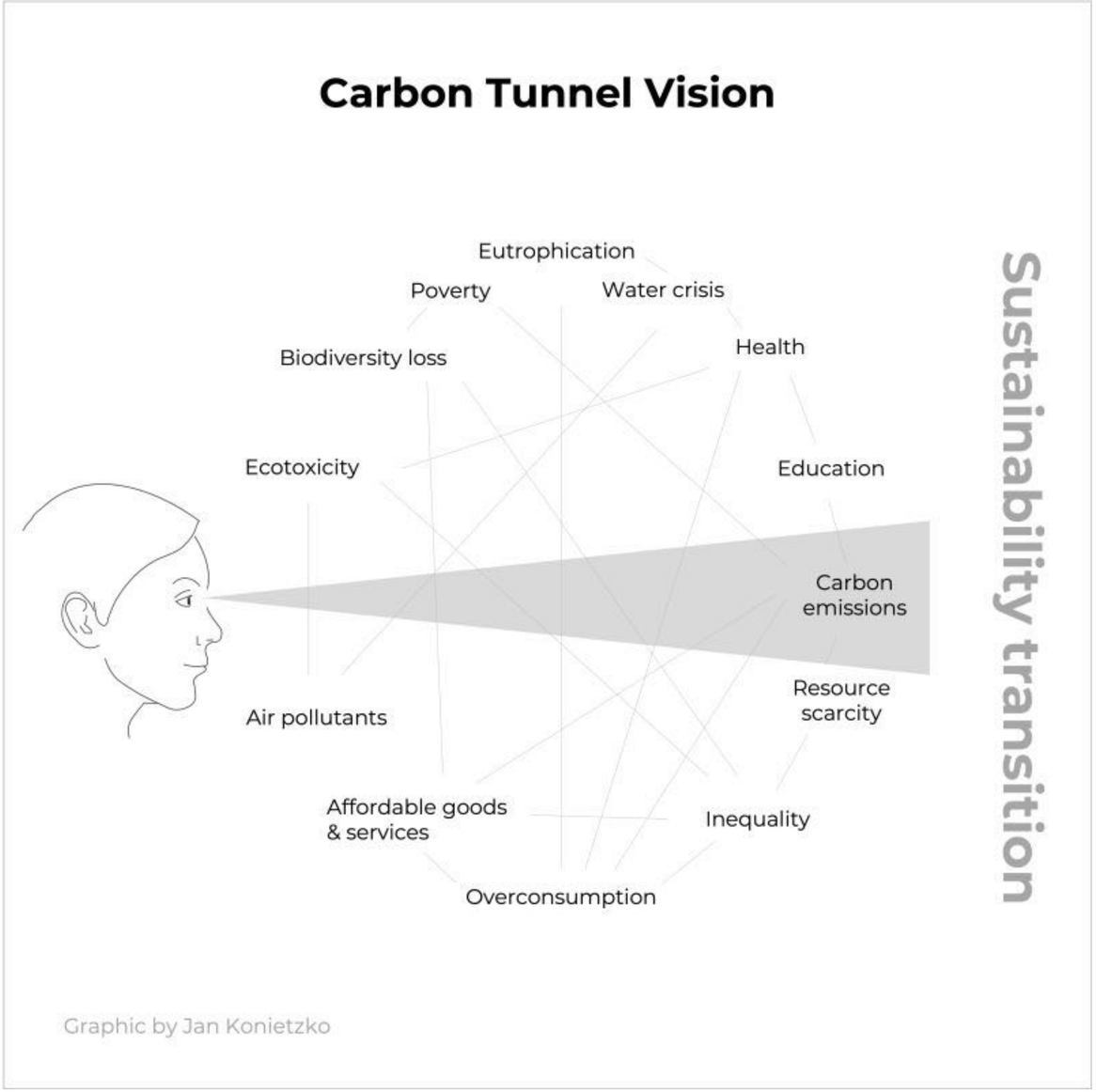




https://voxeu.org/article/cars-make-cities-less-compact?deliveryName=DM140584

We want easy answers, but reality is a complex system





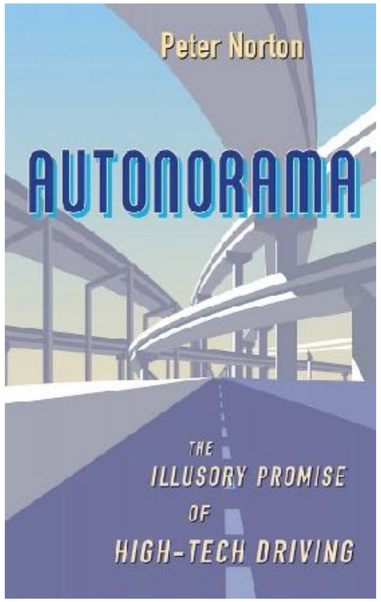
Take-home message: Induced demand

If you widen roads, you create more traffic

https://www.governing.com/now/why-the-concept-of-induced-demand-is-a-hard-sell

https://www.bloomberg.com/news/features/2021-09-28/why-widening-highways-doesn-t-bring-traffic-relief

Sources and further materials for today's class

http://science.sciencemag.org/content/342/6164/1330.full

https://www.oecd.org/environment/transport-strategies-for-net-zero-systems-by-design-0a20f779-en.htm