ASSESSING AND MINIMIZING PEDESTIRANS' EXPOSURE TO TRAFFIC NOISE WITH SPATIAL ANALYSIS AND WEB GIS

–

5.3.2020

Joose Helle

Introduction

- Active transport modes have become increasingly popular in cities
  - Promoted as healthy and harmless modes of transport
  - Positive but also negative health effects
  - Physical activity vs. exposure to pollution
  - Especially pedestrians and cyclists are exposed to their surroundings (light, noise, smell, visuals etc.)
- Vehicular traffic causes air and noise pollution
  - Pollution, among other things, affects walkability

- Pollution is one of the major problems in cities
  - Affects health, wellbeing, happiness of citizens
- Air pollution and its effects are widely studied
  - Relatively easy to measure, many known health effects
- However, also noise is gaining increasing attention
  - Invisible and often ignored pollutant
  - Health effects are likely but hard to distinguish
  - Increasing amount of data & interest
  - Policies and legislation on acceptable noise levels

- Noise data and noise exposure assessments are required by national and EU legislation
    - Measured and modelled datasets of noise pollution enable exposure analysis
    - Citizens' exposure to noise pollution?
    - Typically a static approach: e.g. number of people exposed to +60 dB noise based on where they live

- Dynamic exposure to pollutants
  - Probably covers a considerable share of the total daily exposure to pollutants
  - Pedestrians are exposed to noise in space and time
  - Integrated to studies on mobility, health and cities
  - GIS, as a technical framework, enables assessments of dynamic exposure

AIMS OF THE STUDY

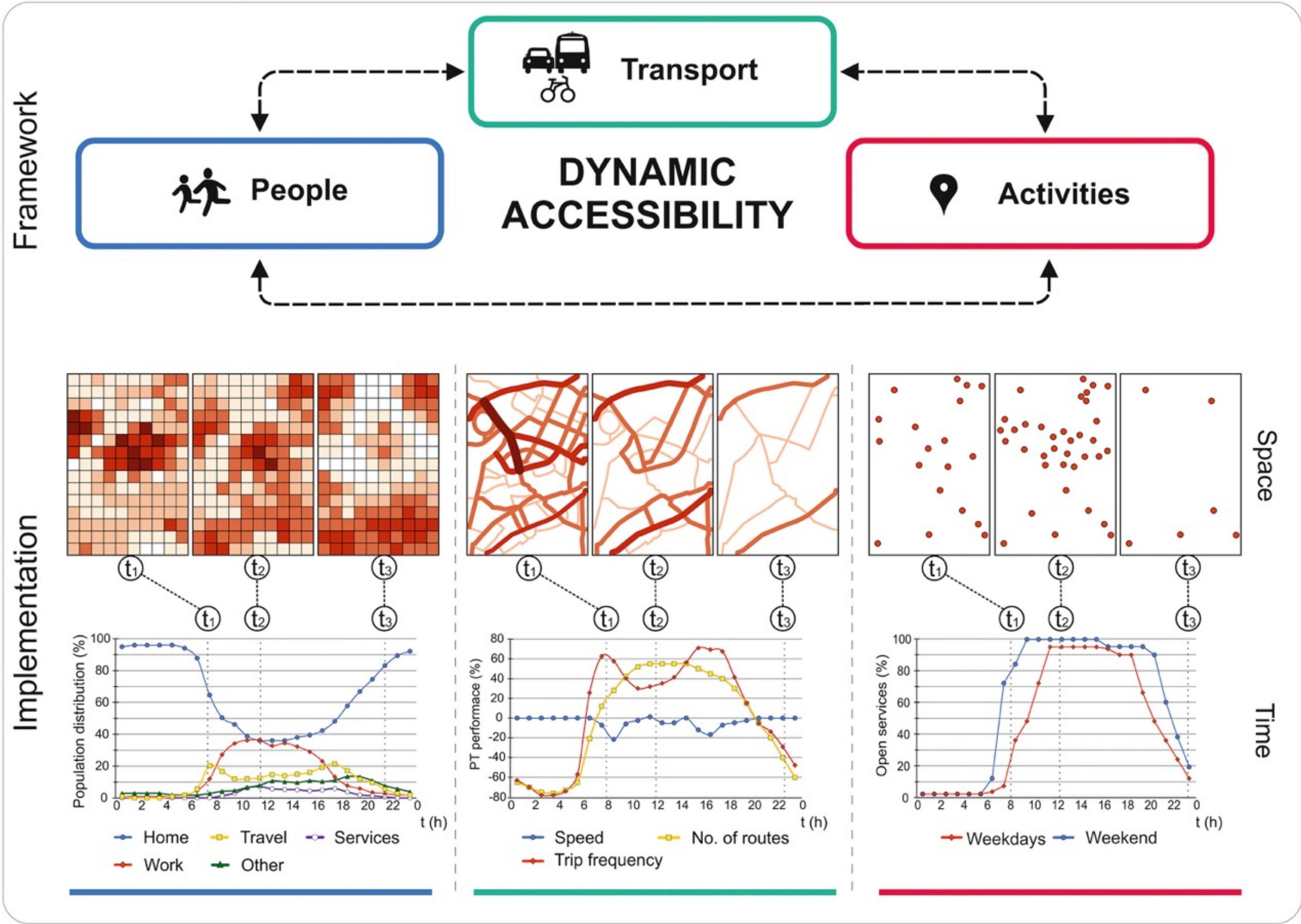
1. Develop a “quiet path” routing method that optimizes pedestrian–friendly walking routes by estimating and minimizing exposure to traffic noise
2. Explore spatial patterns in pedestrians’ exposure to traffic noise on typical local walks
   - Show spatial differences in exposure to noise on typical/average walks
   - Case study in Helsinki

3. Assess achievable reductions in exposure to traffic noise by choosing quiet paths
    - Performance of the quiet path routing application
4. Create a web-based route planner application based on the quiet path routing method
    - Mobile-friendly route planner web map application
    - Modular design to support also other exposures

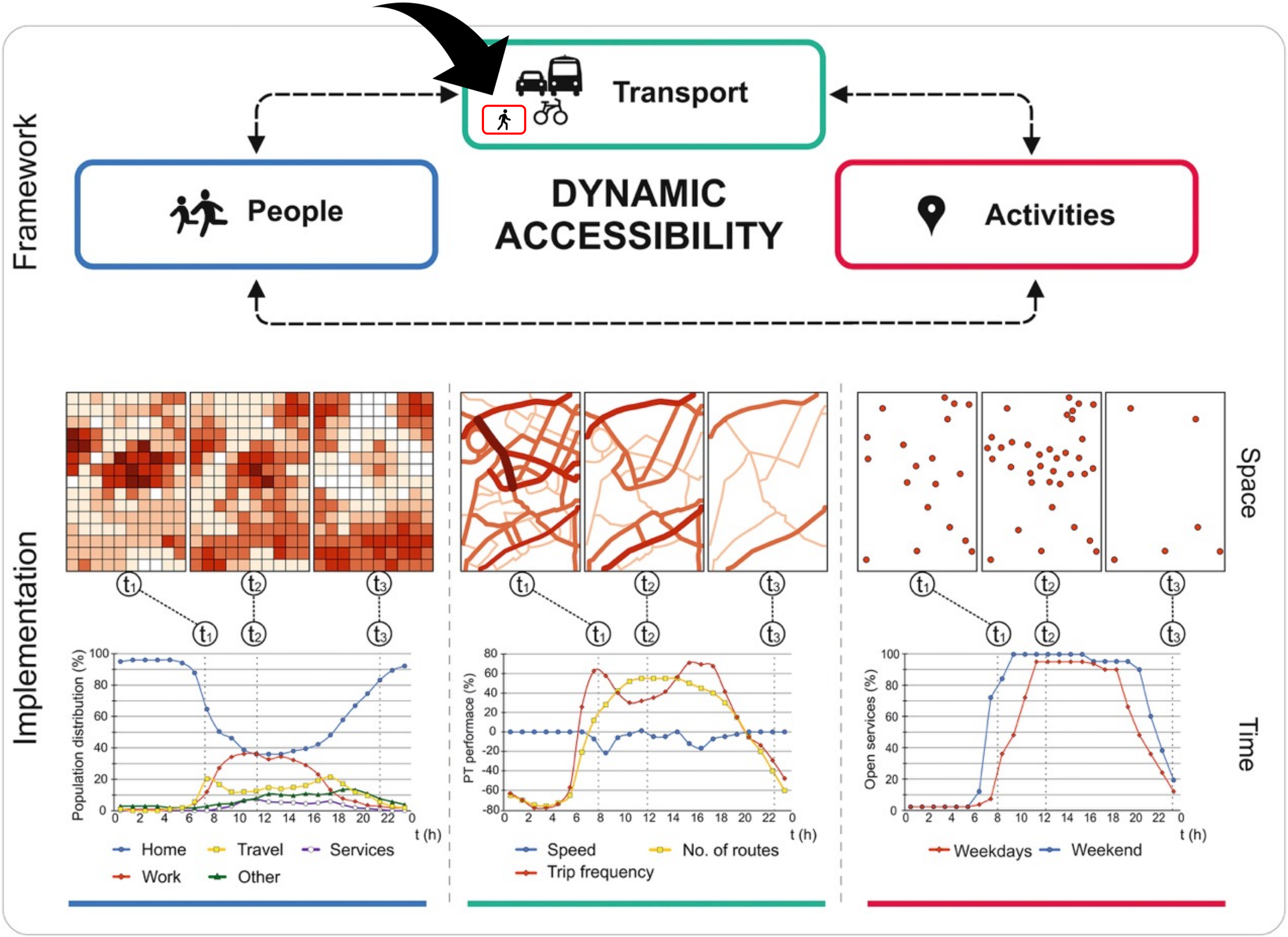
Background

- Accessibility, walkability
- Traffic noise and health
- Dynamic exposure
- Street network graphs
- Environmental impedance
- Web GIS

European Union
European Regional
Development Fund

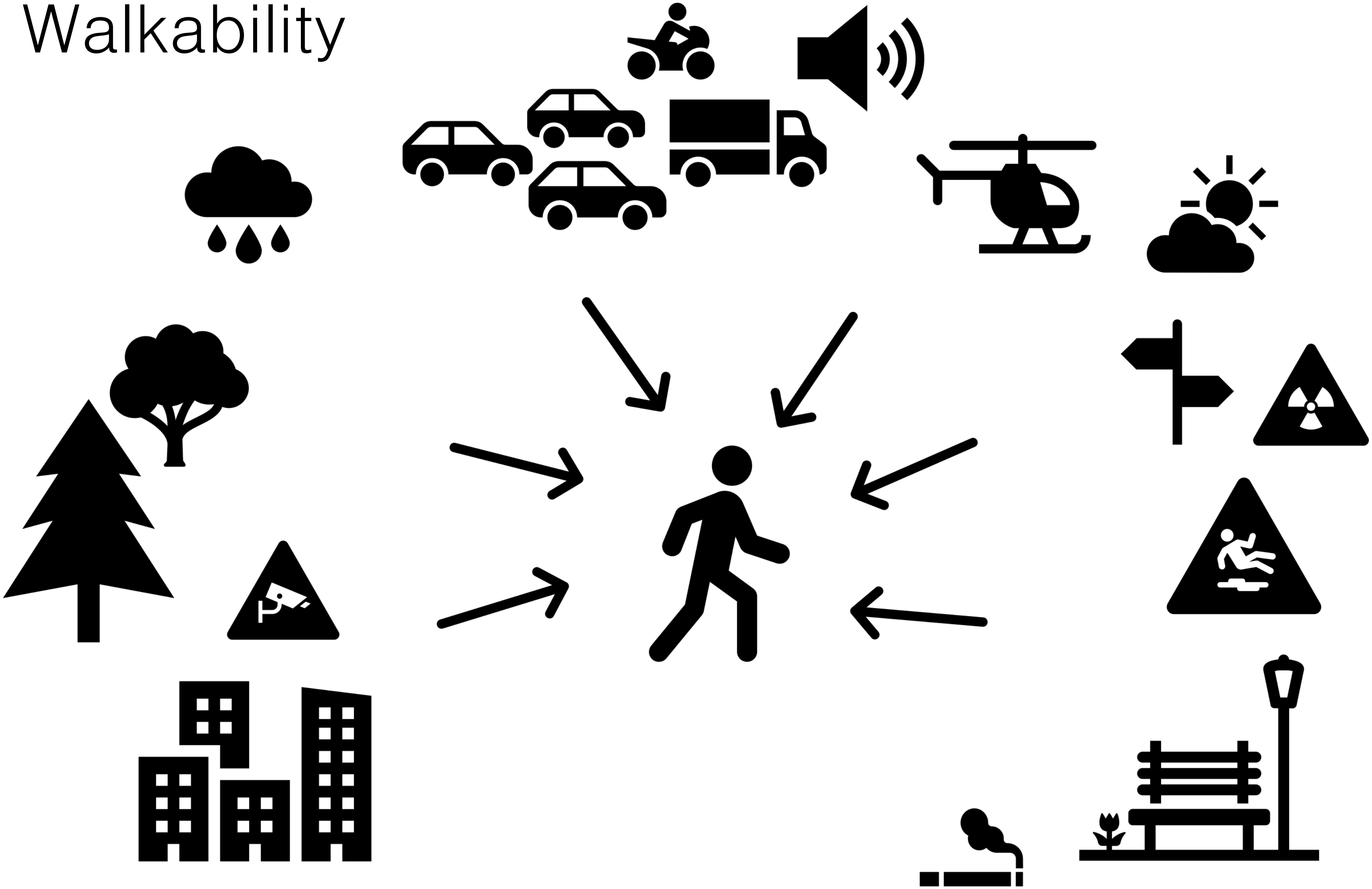


Järv, O., Tenkanen, H., Salonen, M., Ahas, R., & Toivonen, T. (2018).



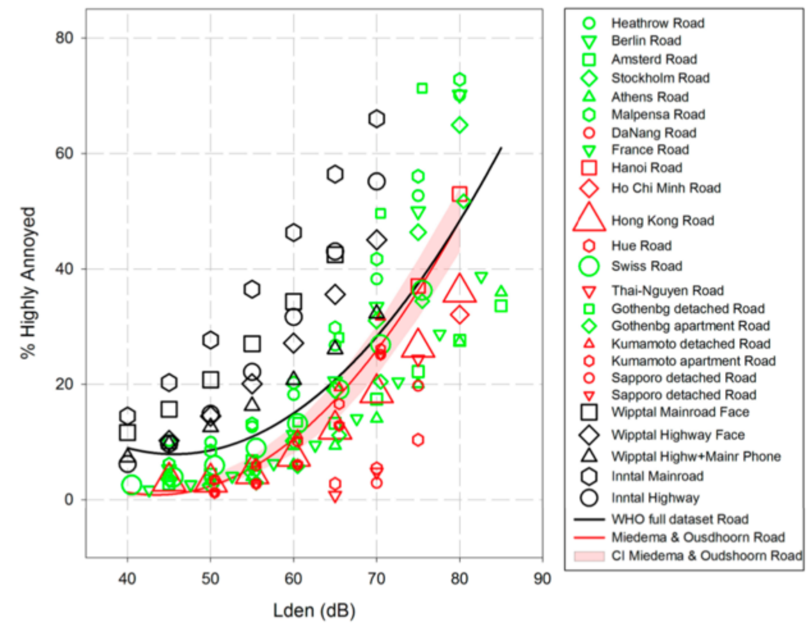
Järv, O., Tenkanen, H., Salonen, M., Ahas, R., & Toivonen, T. (2018).

Walkability



Traffic noise and health

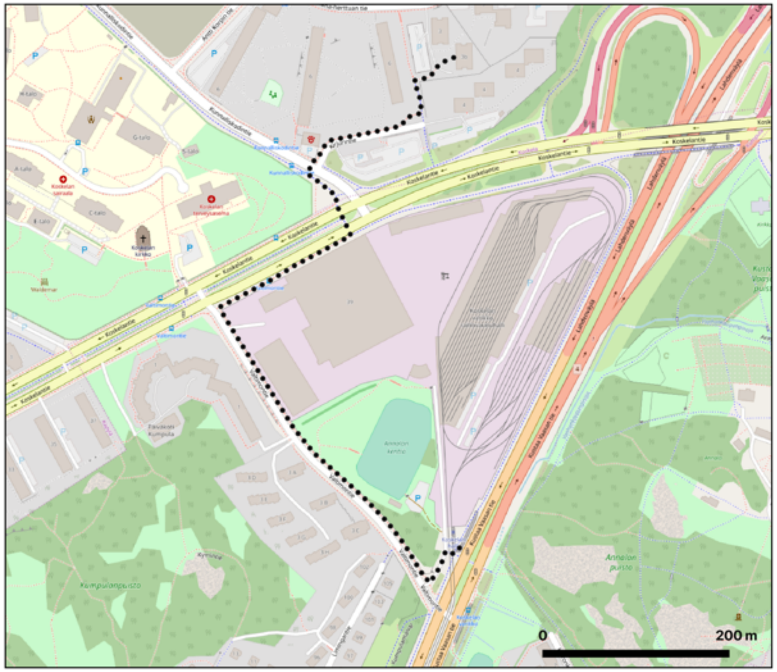
- Noise exposure -> response
  1. Sound pressure level
  2. Loudness
  3. Annoyance
- Potential health effects
  - Stress, respiratory infections
  - Cardiovascular disease
- However…
  - Only limited evidence
  - Overlapping short-term and long-term effects

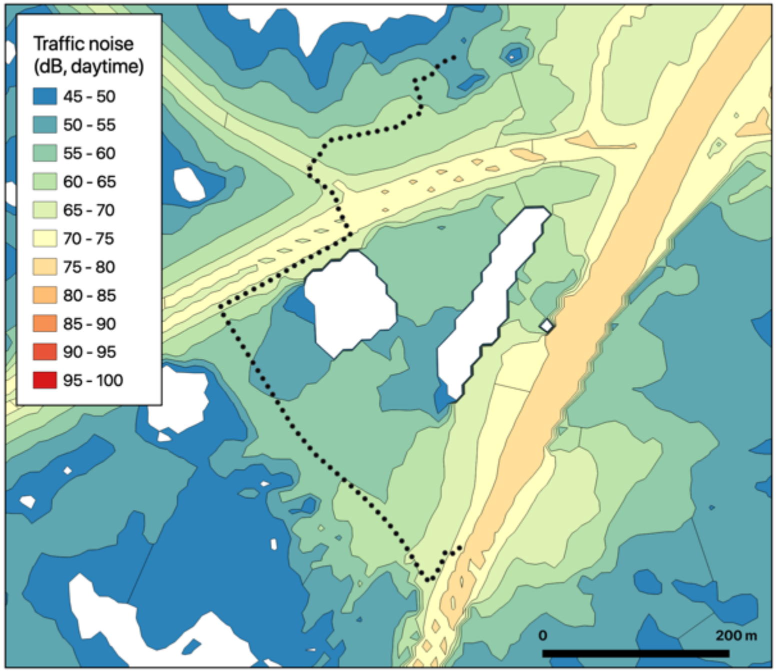


Guski et al., (2017)

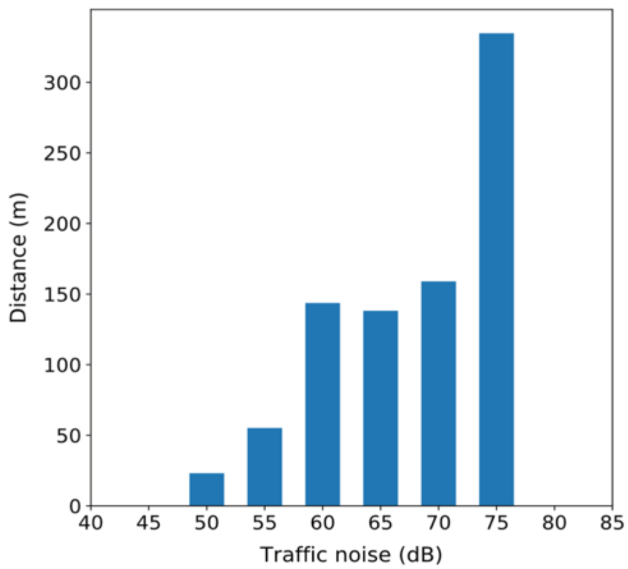
Dynamic exposure to pollutants

- ”journey–time exposure”
- Measured as distance or duration to certain levels or concentrations of a pollutant
  - For air pollution, the total amount of inhaled particles can be estimated
  - For noise pollution, e.g. the duration of exposure to high noise levels
- Various methods for assessing
  - GPS–tracking and measurement instruments for pollutants
  - Modelled data on mobility and pollutants

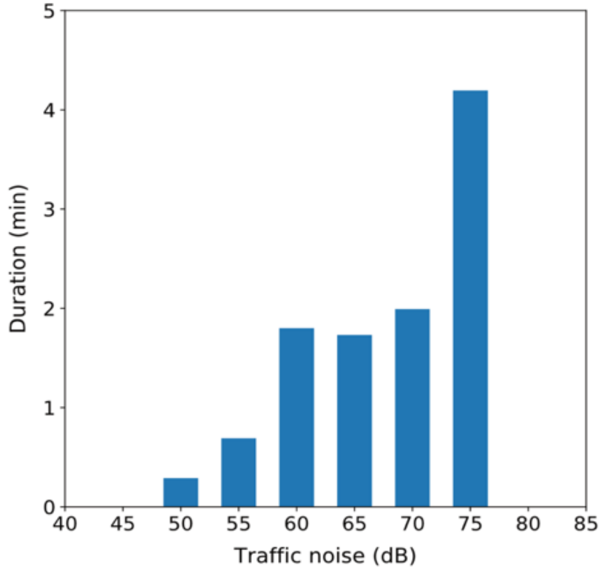




Traffic noise
(dB, daytime)
45 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 75
75 - 80
80 - 85
85 - 90
90 - 95
95 - 100
0
200 m



Distance (m)
Traffic noise (dB)



Duration (min)
Traffic noise (dB)

Research Article

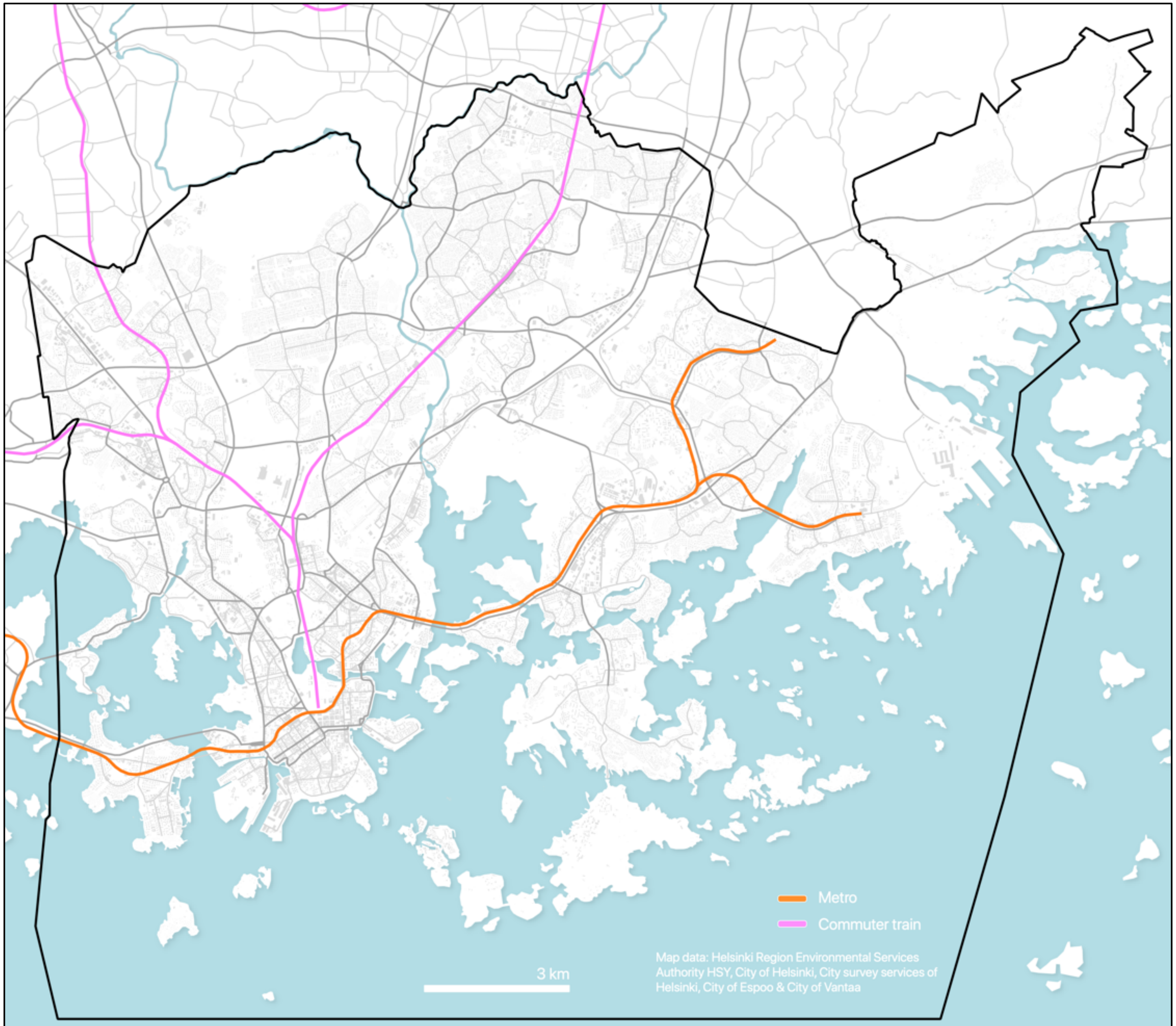
A Least-Cost Approach to Personal Exposure Reduction

Gemma Davies
Lancaster Environment Centre
Lancaster University

Duncan Whyatt
Lancaster Environment Centre
Lancaster University

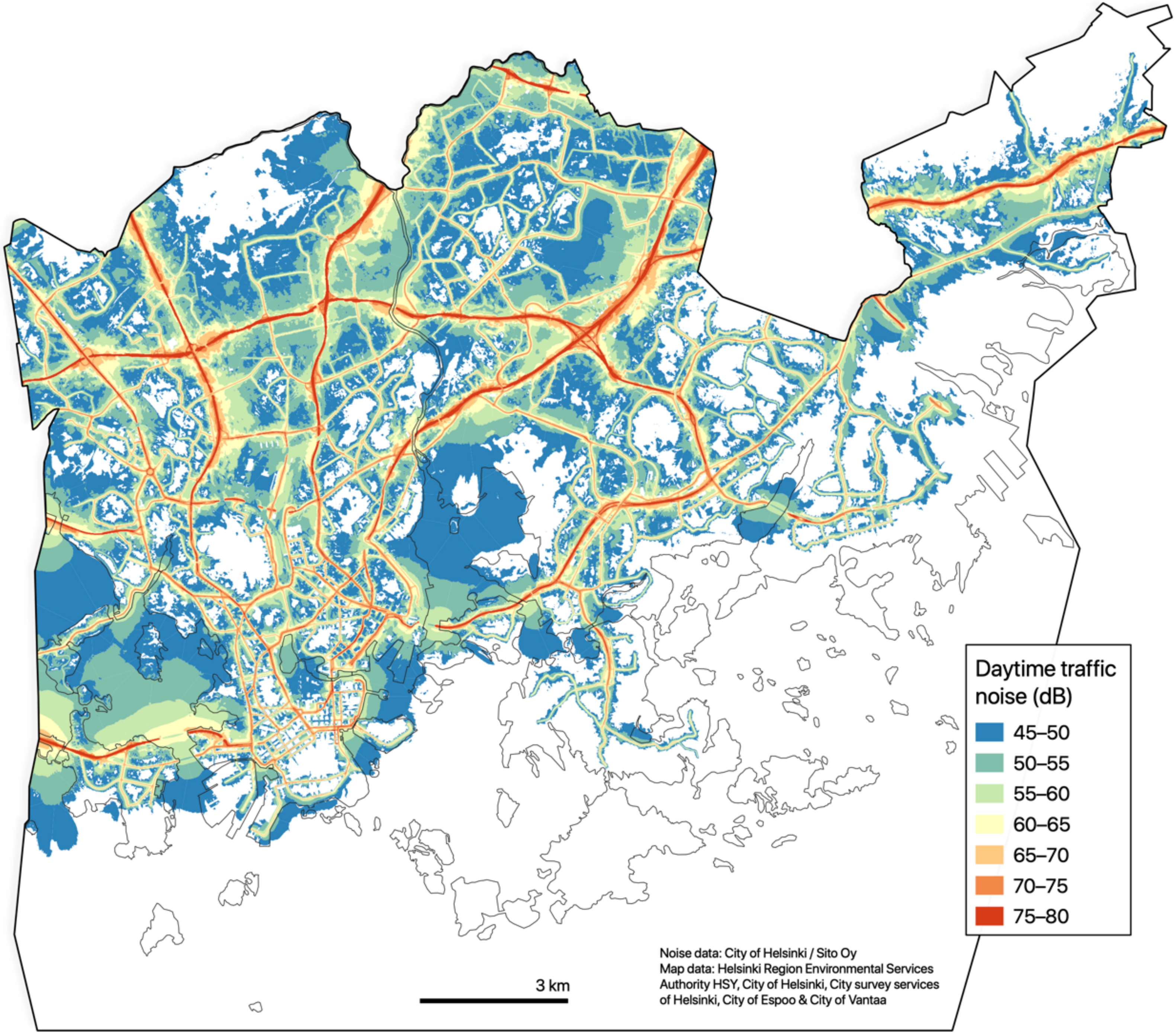
Abstract

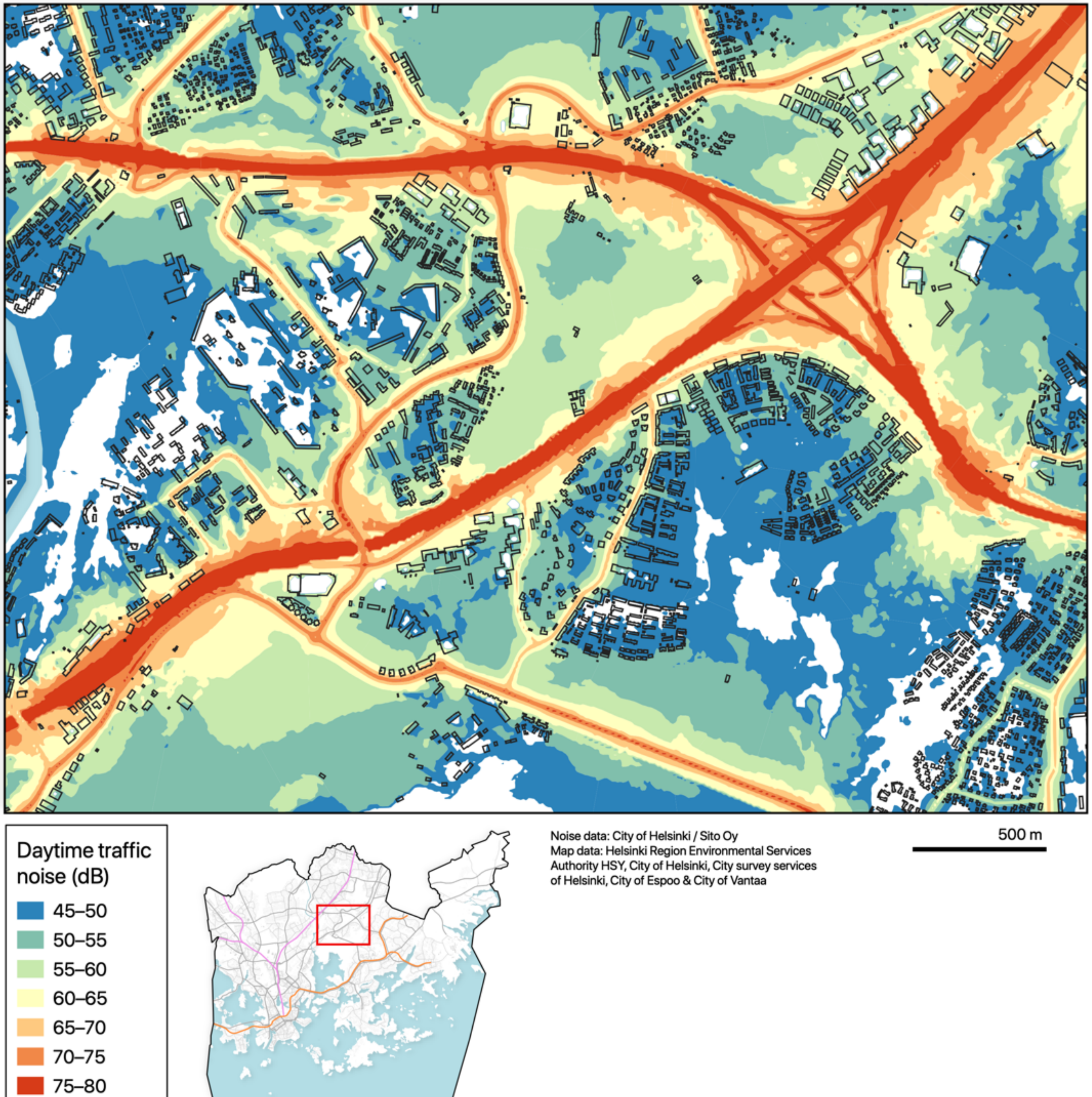
Concerns over the potential negative health effects from exposure to air pollution have led to interest in assessing personal exposure and finding ways to reduce it. As journey-time exposure accounts for a disproportionately high amount of an individual's total exposure, this article assesses the potential to apply least-cost techniques within a GIS in order to identify paths of lower journey-time exposure. The methodology adopted uses pollution surfaces for PM_{10} and CO generated by the

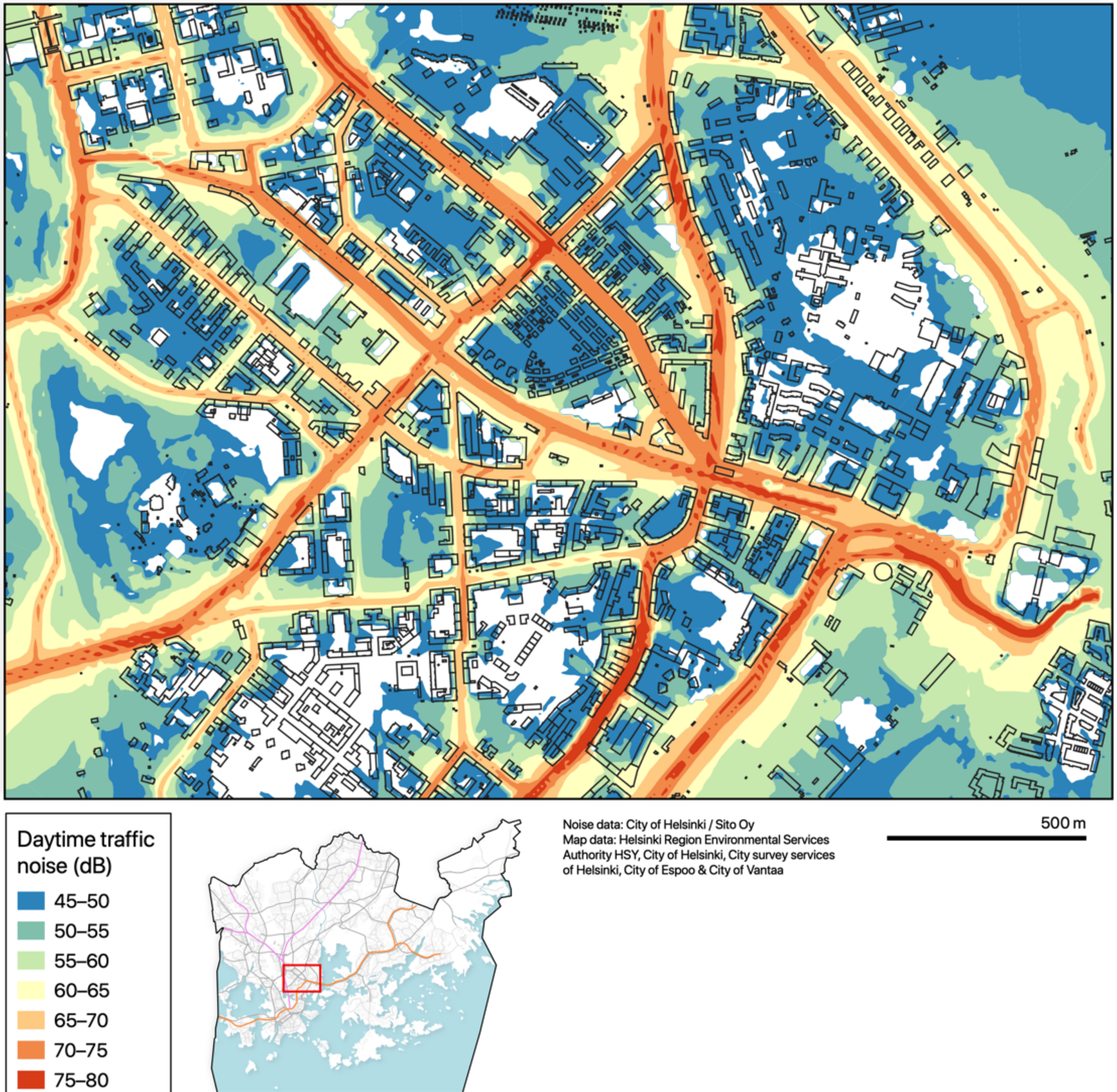

Metro
Commuter train
3 km
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa

Data

- City of Helsinki: strategic noise mapping, 2017
  - Joint-Nordic traffic noise estimation model
  - L_{Aeq} = typical daytime traffic noise level (dB)
  - High spatial precision
  - Open data
- OpenStreetMap (OSM)
  - Downloaded from OSM with OSMnx
  - Query for walkable streets by OSM tags
  - Facilitates adopting the methods in other areas

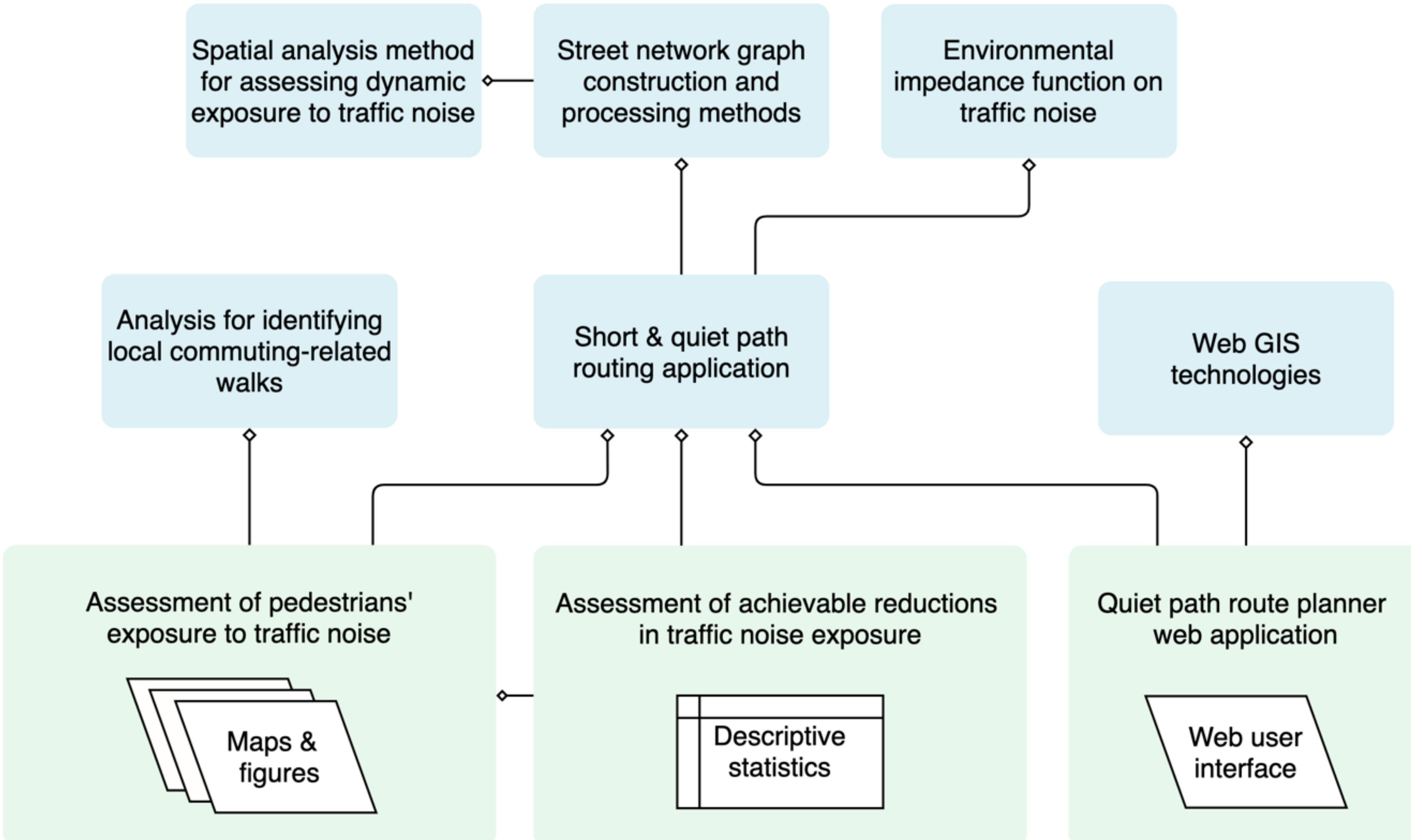

Daytime traffic noise (dB)
45–50
50–55
55–60
60–65
65–70
70–75
75–80
3 km
Noise data: City of Helsinki / Sito Oy
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa


Daytime traffic noise (dB)
45–50
50–55
55–60
60–65
65–70
70–75
75–80
Noise data: City of Helsinki / Sito Oy
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa
500 m



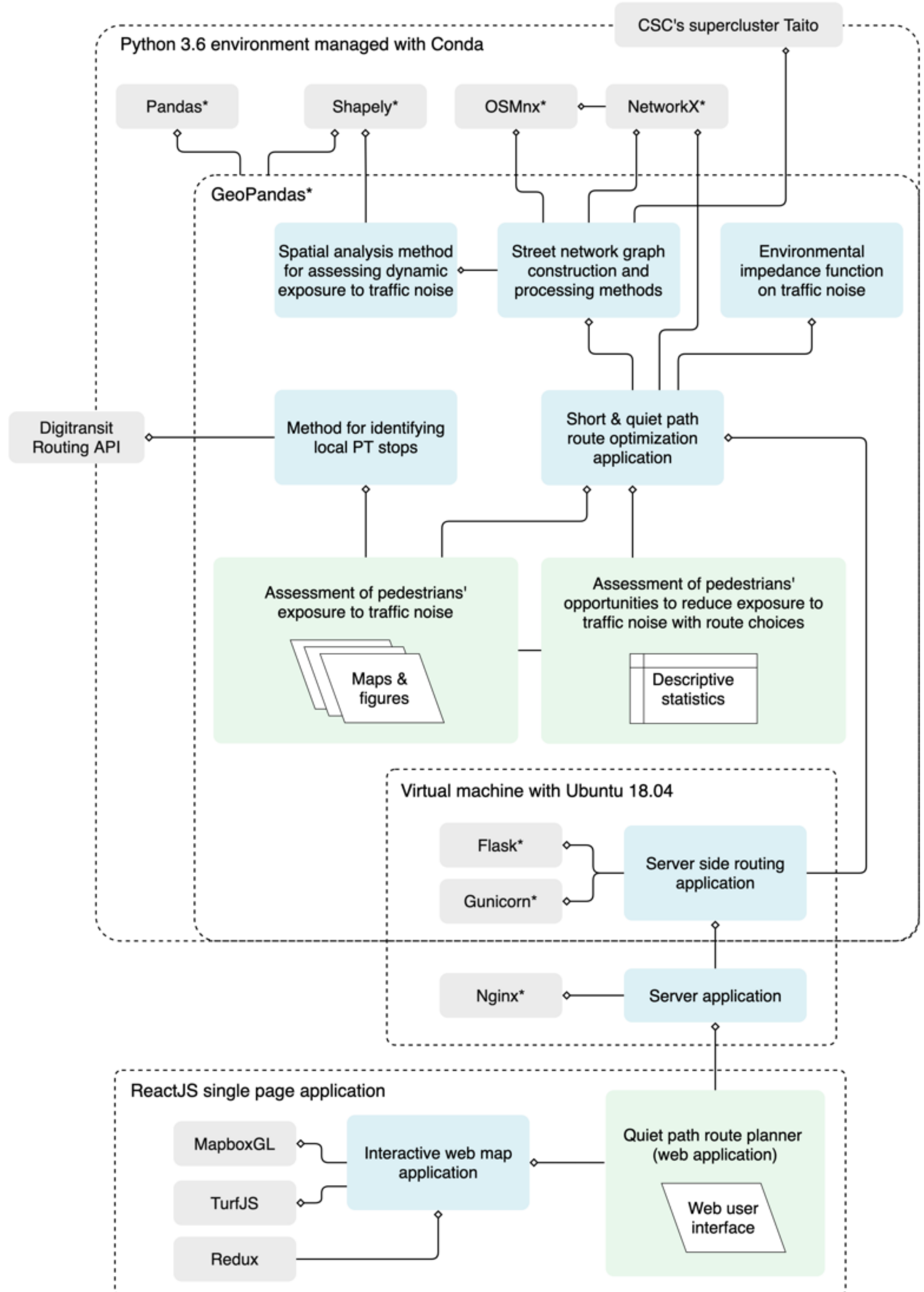
Noise data: City of Helsinki / Sito Oy
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa

- YKR Commutes (OD)
  - Census based, provided by Statistics Finland / Finnish Environmental Institute (Syke)
  - ODs aggregated to 250m grid
- Digitransit Routing API
  - Used to plan PT itineraries for commutes
  - Walks of the planned itineraries (routes) were used in the exposure analysis


Spatial analysis method for assessing dynamic exposure to traffic noise
Street network graph construction and processing methods
Environmental impedance function on traffic noise
Analysis for identifying local commuting-related walks
Short & quiet path routing application
Web GIS technologies
Assessment of pedestrians' exposure to traffic noise
Maps & figures
Assessment of achievable reductions in traffic noise exposure
Descriptive statistics
Quiet path route planner web application
Web user interface

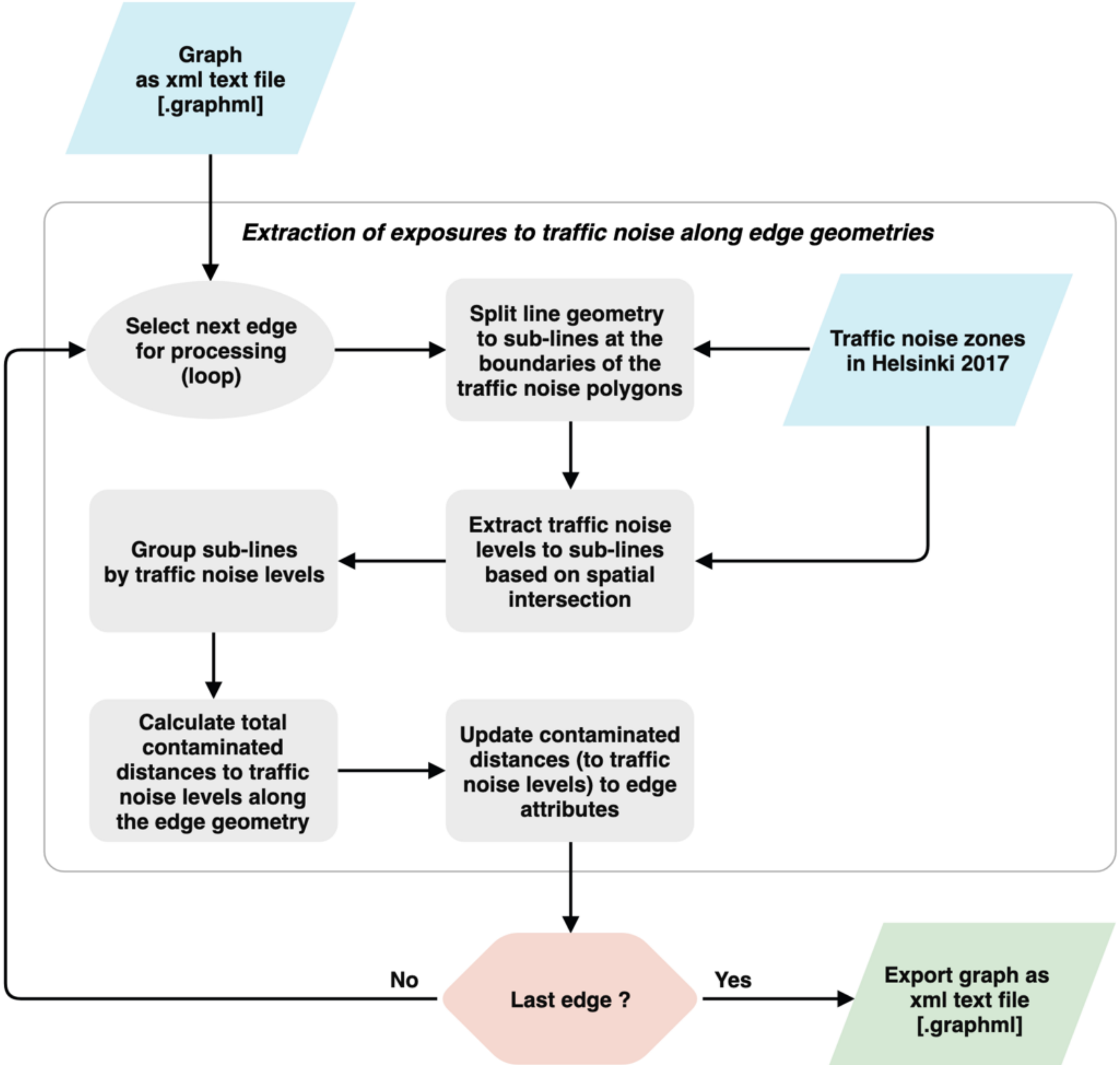
Technical framework

- Python 3.6
- Open source libraries
- Modularity
- Published as open source (in GitHub)



Street network graph construction

- OSM street data download and conversion to an undirected NetworkX graph (with OSMnx)
- Spatial join of traffic noise data to street segments
  - -> noise-aware walkable street network graph
  - Contaminated distances with different noise levels
  - E.g. 15m edge can have contaminated distances:
    10m of 55dB, 3m of 60dB and of 2m 65dB
  - Lossless vector-based spatial join was expensive operation


Graph
as xml text file
[.graphml]
Extraction of exposures to traffic noise along edge geometries
Select next edge for processing (loop)
Split line geometry to sub-lines at the boundaries of the traffic noise polygons
Traffic noise zones in Helsinki 2017
Group sub-lines by traffic noise levels
Extract traffic noise levels to sub-lines based on spatial intersection
Calculate total contaminated distances to traffic noise levels along the edge geometry
Update contaminated distances (to traffic noise levels) to edge attributes
No
Last edge ?
Yes
Export graph as xml text file [.graphml]

Quiet path routing application

- Three functions
  1. Calculates the shortest path
  2. Calculates alternative quiet paths
  3. Assesses and compares dynamic exposure to noise on the paths
- Python implementation
  - Composed from several custom and external modules
  - Utilizes igraph graph library (/NetworkX)

Quiet path routing method

- Graph-based least cost path analysis
  - Dijkstra's algorithm
  - Finding the least cost path between two nodes in a connected graph by a numerical cost attribute
- Noise exposure -based edge costs by environmental impedance function
  - Cost should be based on dynamic exposure to different traffic noise levels on the edge

Adjusted, noise–based edge costs

$$C_e = d_e + C_{en}$$

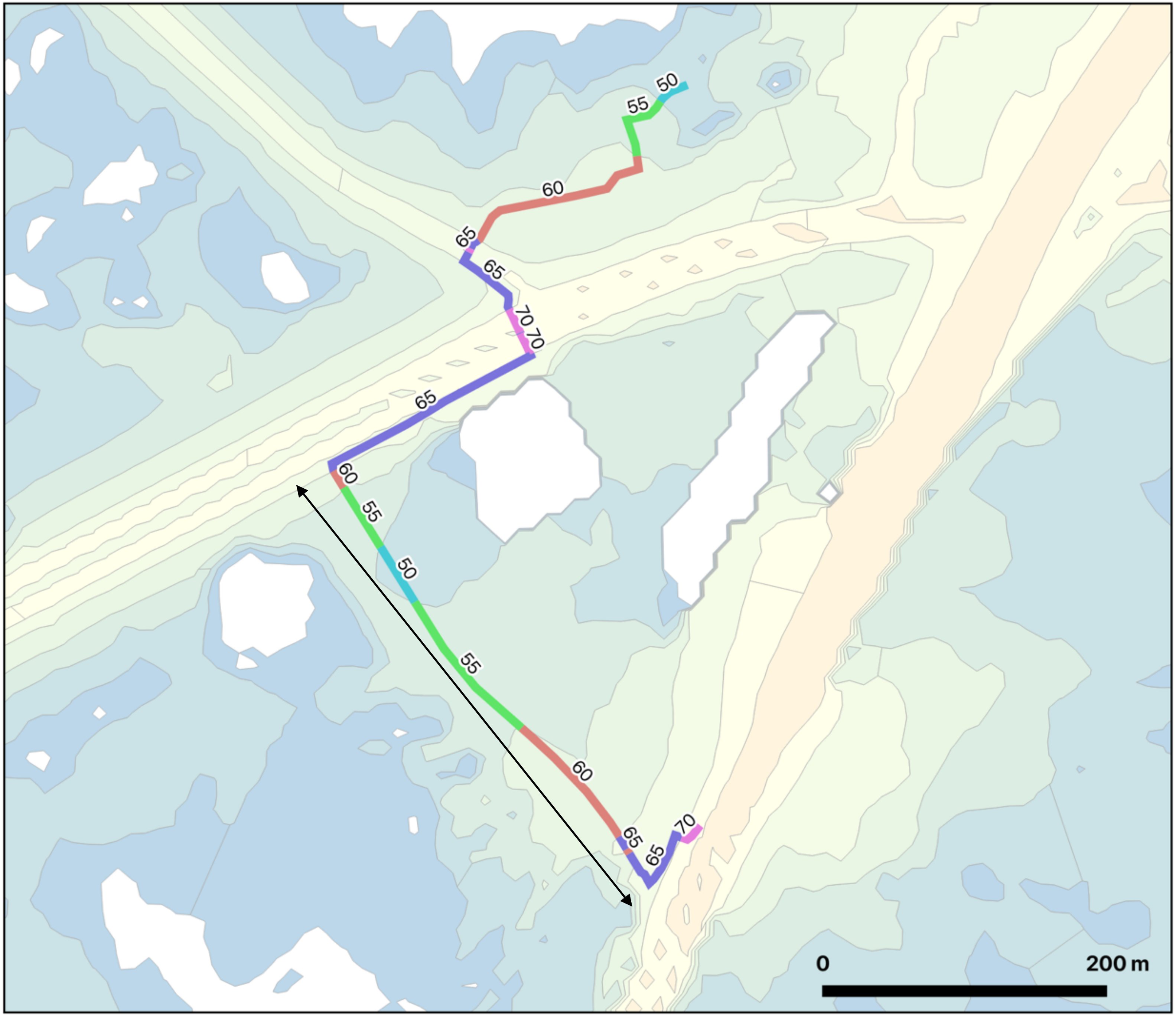
C_e = total cost of the edge
d_e = base cost of the edge (length)
C_{en} = noise cost of the edge

$$C_{en} = \sum_{i=dB_{min}}^{dB_{max}} d_{dB_i} \times a_{dB_i} \times s$$

d = distance

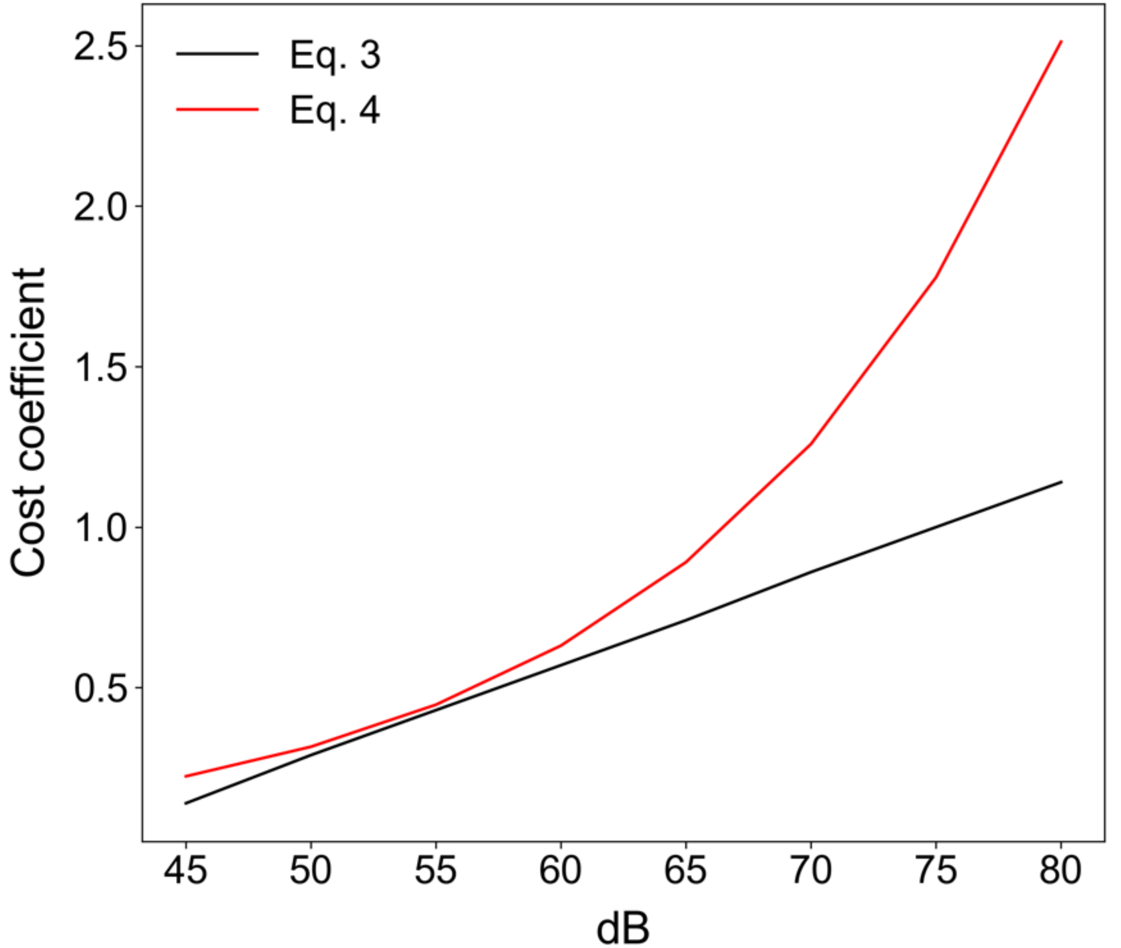
a_{dB_i} = noise cost coefficient (dB-specific)
s = sensitivity

$$a_{dB_i} = 10^{\frac{0.3 * dB_i}{10}}$$



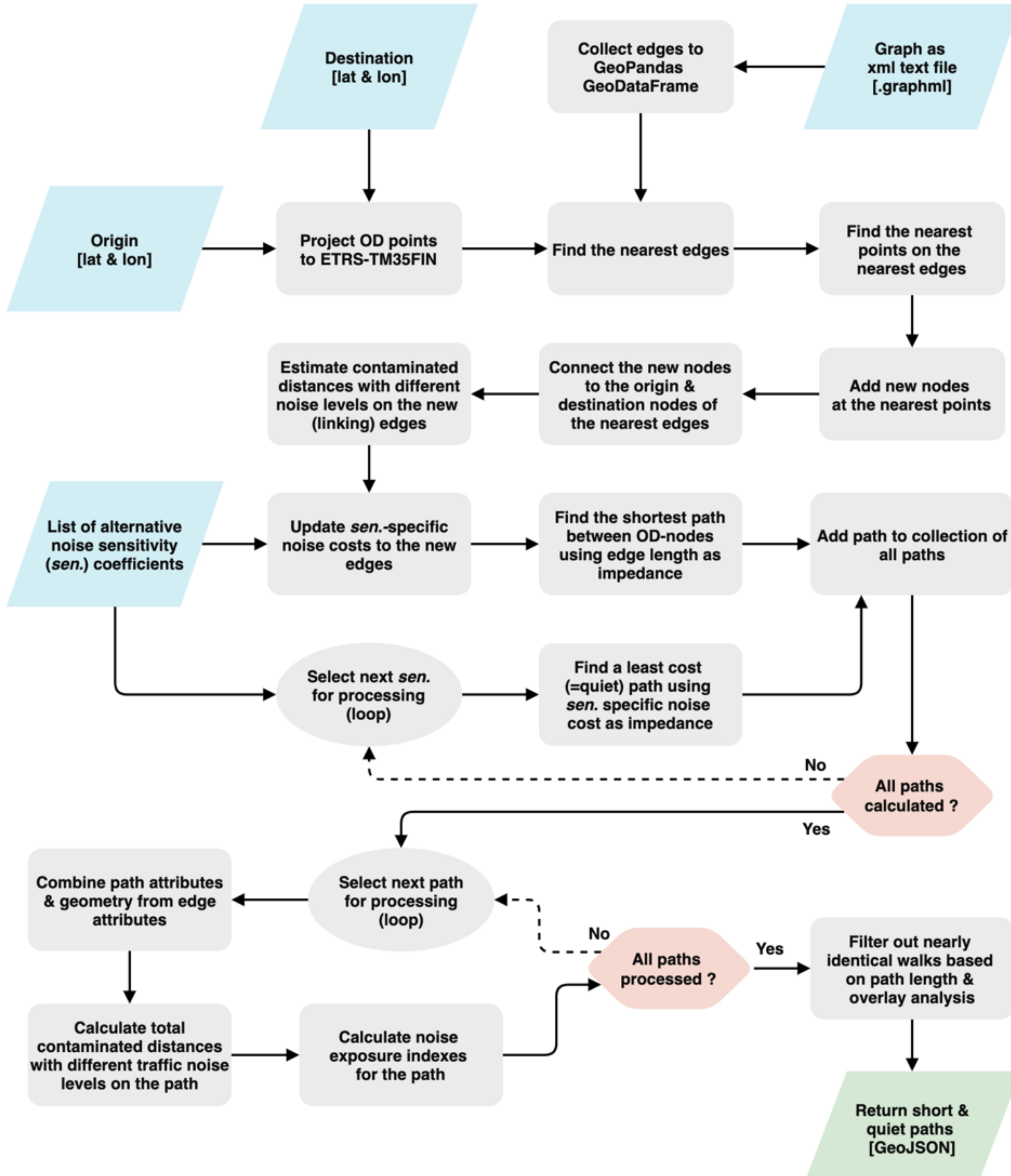
50
55
60
65
65
70
70
65
60
55
50
55
60
65
65
70
0
200 m

Noise cost coefficient (a_{dBi})



Quiet path routing

- Routing of many alternative quiet paths by gradually altering the noise sensitivity coefficient
    - E.g. 0.1, 0.15, 0.25, 0.5, 1, 1.5, 2, 4, 6, 10, 20 and 40
    - Calculating many alternative quiet paths increases the probability that some of them are good
    - Different pedestrians and situations require different paths
- Processing of paths
    - Collect edges & attributes by list of node ids
    - Remove identical paths by geometry


Destination
[lat & lon]
Collect edges to
GeoPandas
GeoDataFrame
Graph as
xml text file
[.graphml]
Origin
[lat & lon]
Project OD points
to ETRS-TM35FIN
Find the nearest edges
Find the nearest
points on the
nearest edges
Estimate contaminated
distances with different
noise levels on the new
(linking) edges
Connect the new nodes
to the origin &
destination nodes of
the nearest edges
Add new nodes
at the nearest points
List of alternative
noise sensitivity
(sen.) coefficients
Update sen.-specific
noise costs to the new
edges
Find the shortest path
between OD-nodes
using edge length as
impedance
Add path to collection of
all paths
Select next sen.
for processing
(loop)
Find a least cost
(=quiet) path using
sen. specific noise
cost as impedance
No
All paths
calculated ?
Yes
Combine path attributes
& geometry from edge
attributes
Select next path
for processing
(loop)
No
All paths
processed ?
Yes
Filter out nearly
identical walks based
on path length &
overlay analysis
Calculate total
contaminated distances
with different traffic noise
levels on the path
Calculate noise
exposure indexes
for the path
Return short &
quiet paths
[GeoJSON]

Noise exposure indexes

$$ED_{dB_i} = d_{dB_i}$$

$$ED_{+dB_i} = \sum_{i=+dB_i}^{dB_{max}} ED_{dB_i}$$

$$EI = \sum_{i=dB_{min}}^{dB_{max}} ED_{dB_i} \times a_{dB_i}$$

1. ED = Exposure to dB_i (m)
2. Exposure to dB_i or higher dB (m)
3. Noise exposure index (noise cost without base cost and sensitivity coeff.)

Noise exposure indexes

$$EI_n = \frac{EI}{EI_{max}} = \frac{EI}{a_{max} * d} = \frac{EI}{a_{75dB} * d}$$

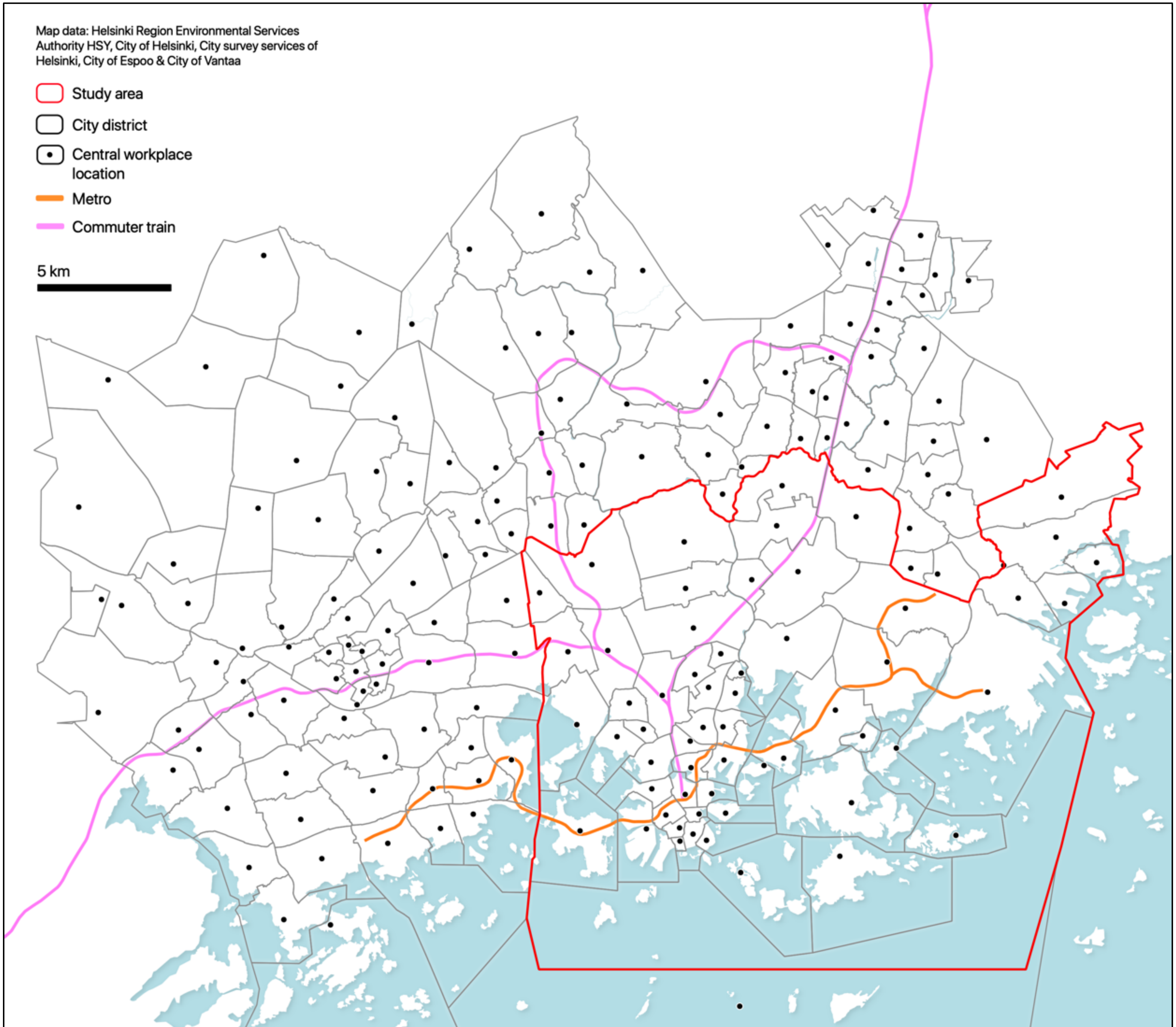
$$dB_{mean} = \frac{\sum_{i=dB_{min}}^{dB_{max}} ED_{dB_i} * dB_i}{d}$$

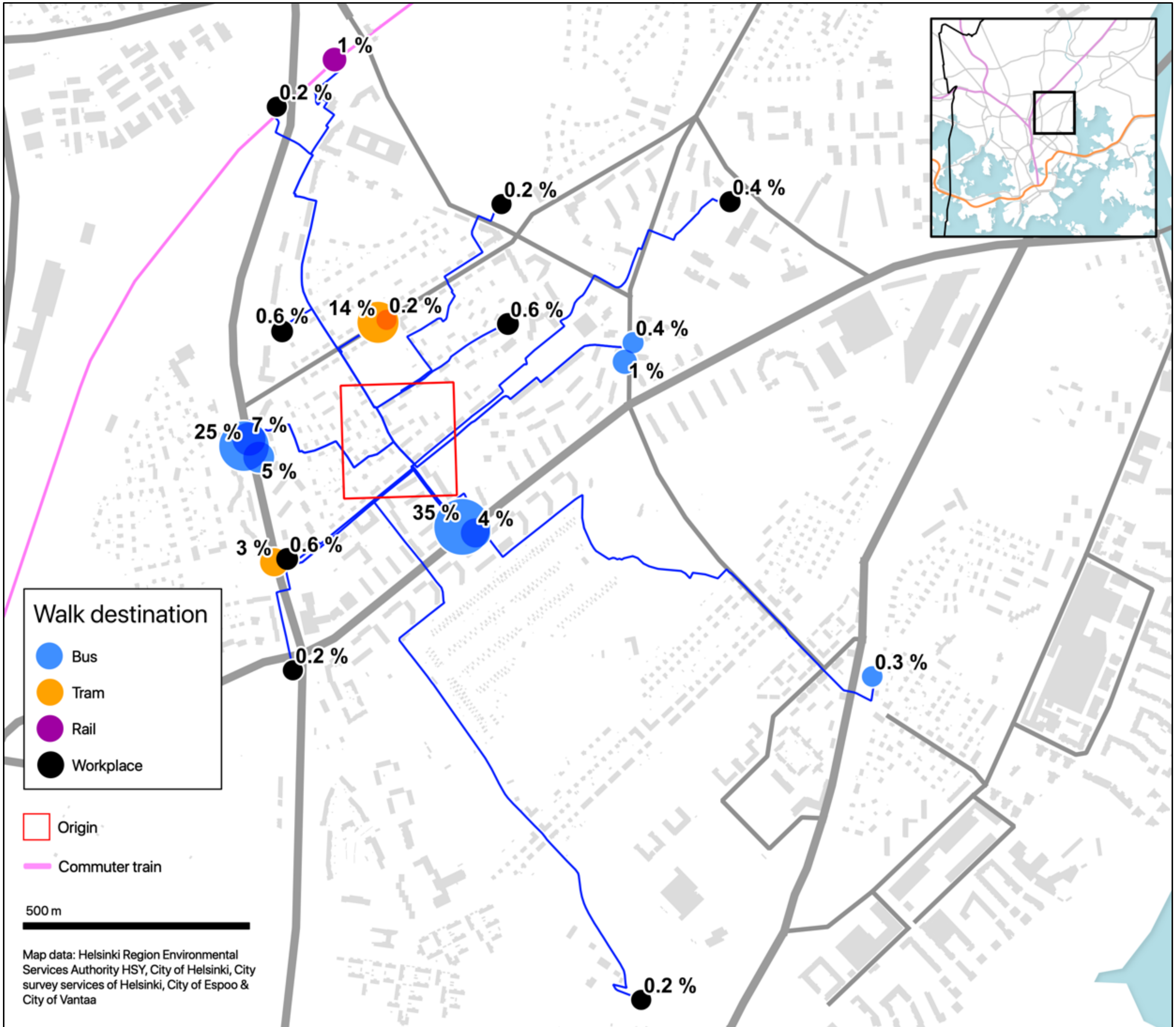
$$EI_{diff} = \frac{\Delta EI}{EI_s} * 100 = \frac{EI_q - EI_s}{EI_s} * 100$$

4. Distance normalized noise exposure index (0.0–1.0)
5. Mean dB
6. Difference in exposure index between a quiet and the shortest path (%)

Pedestrians' exposure to traffic noise

- YKR commutes OD data
    - ODs by 250m grid
- What if everyone used public transport?
    - Dynamic noise exposure on the local walks:
      walks from homes to PT stops
- Finding PT itineraries for all commutes from Helsinki
    - Digitransit Routing API (HSL/HRT)
    - Extraction of first walks of the itineraries (home–PT)


Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa
Study area
City district
Central workplace location
Metro
Commuter train
5 km


1 %
0.2 %
0.2 %
0.4 %
0.6 %
14 %
0.2 %
0.6 %
0.4 %
1 %
25 %
7 %
5 %
35 %
4 %
3 %
0.6 %
0.2 %
0.3 %
0.2 %
Walk destination
Bus
Tram
Rail
Workplace
Origin
Commuter train
500 m
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa

Pedestrians' exposure to traffic noise

- Dynamic noise exposure analysis of the walks with quiet path route planner
  - Re-route the walks with quiet path route planner
  - Save both shortest and quiet paths
  - Filter out the paths outside the extent of the noise data
  - Filter out the paths with significant difference in length to the reference paths (from Digitransit Routing API)

Spatial patterns in exposures to noise

- Aggregation of the paths
  - Calculation of utilization rates of the walks based on the total OD flows (in YKR commutes data)
  - Utilization rates are needed to calculate weighted averages of dynamic exposure to noise (aggregated, origin-level statistics)
- Calculating aggregated statistics by origin
  - dB_{mean}, ED_{+60dB} (m), ER_{+60dB} (%), EI_n etc.
  - Visualizing the statistics as choropleth maps

Assessment of achievable reductions in noise exposure

- Quiet paths vs. shortest paths
- Aggregate OD–level statistics of reductions in noise exposure indexes by different quiet paths
  - ER_{+60dB} (%), ER_{+65dB} (%), dB_{mean} etc.
  - Aggregate effect of the quiet paths by length difference thresholds 100 m, 200 m and 300 m
  - e.g. What is the expected reduction in exposure to traffic noise by taking a quiet path no more than 100 m longer than the shortest path?

Sharing of the methods

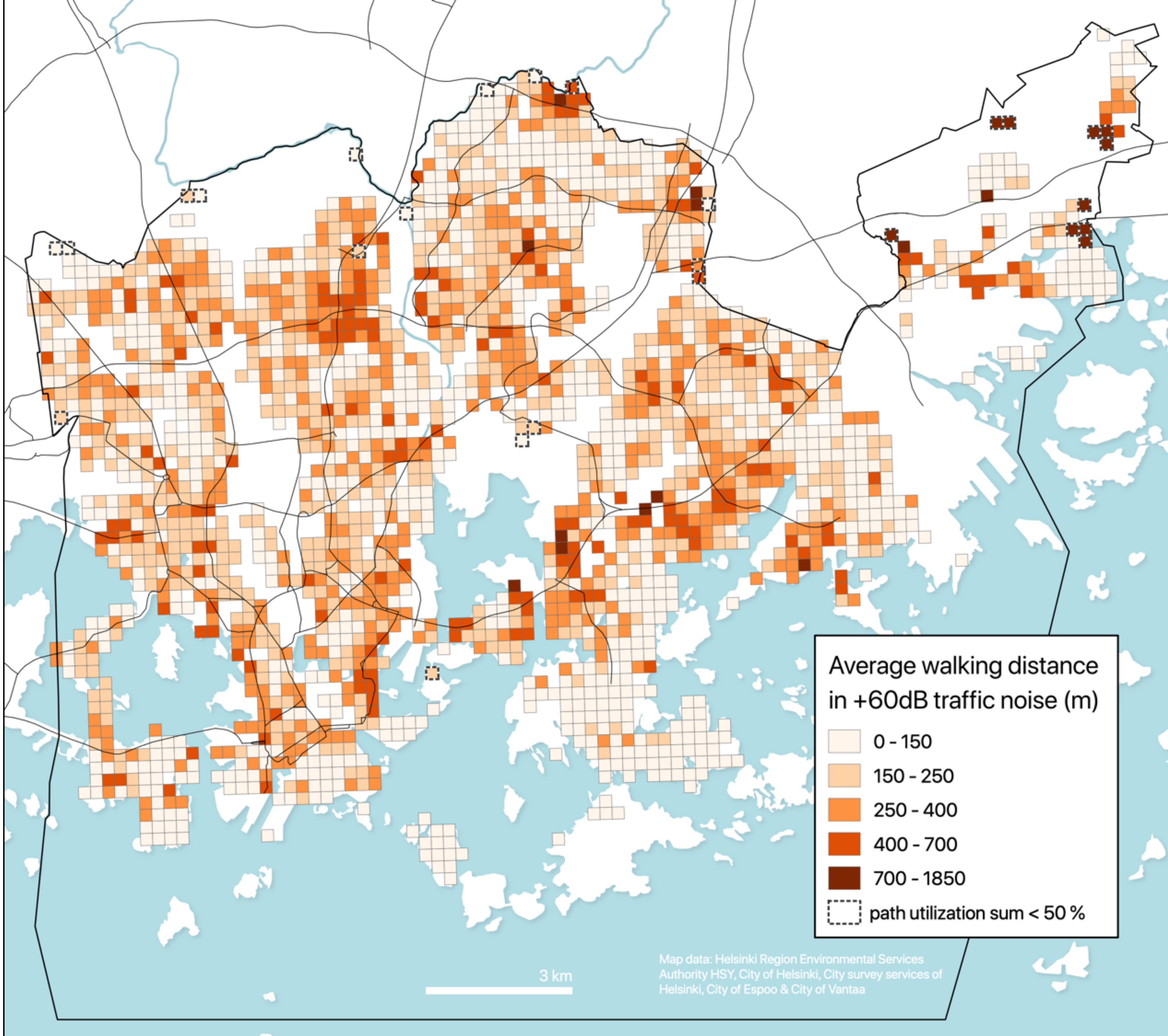
- Via GitHub
  - github.com/hellej/quiet-paths-msc/
- Latest version of the quiet path routing application is under DGL's GitHub
  - github.com/DigitalGeographyLab/hope-green-path-server
  - github.com/DigitalGeographyLab/hope-green-path-ui
  - Faster (NetworkX -> igraph)
  - Better documented and refactored code
  - Releases at the time of writing this: v1.3 & v1.2

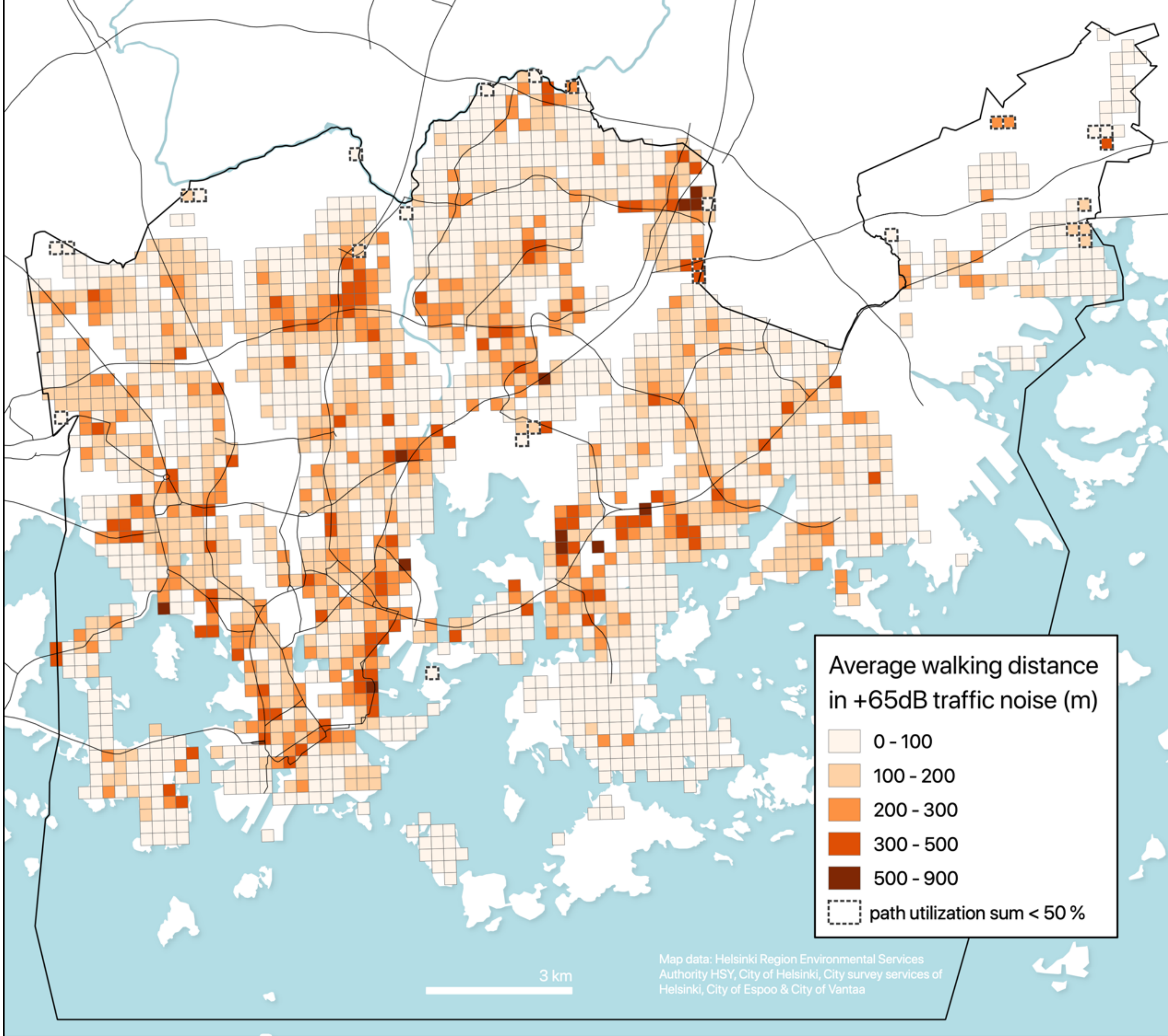
Results

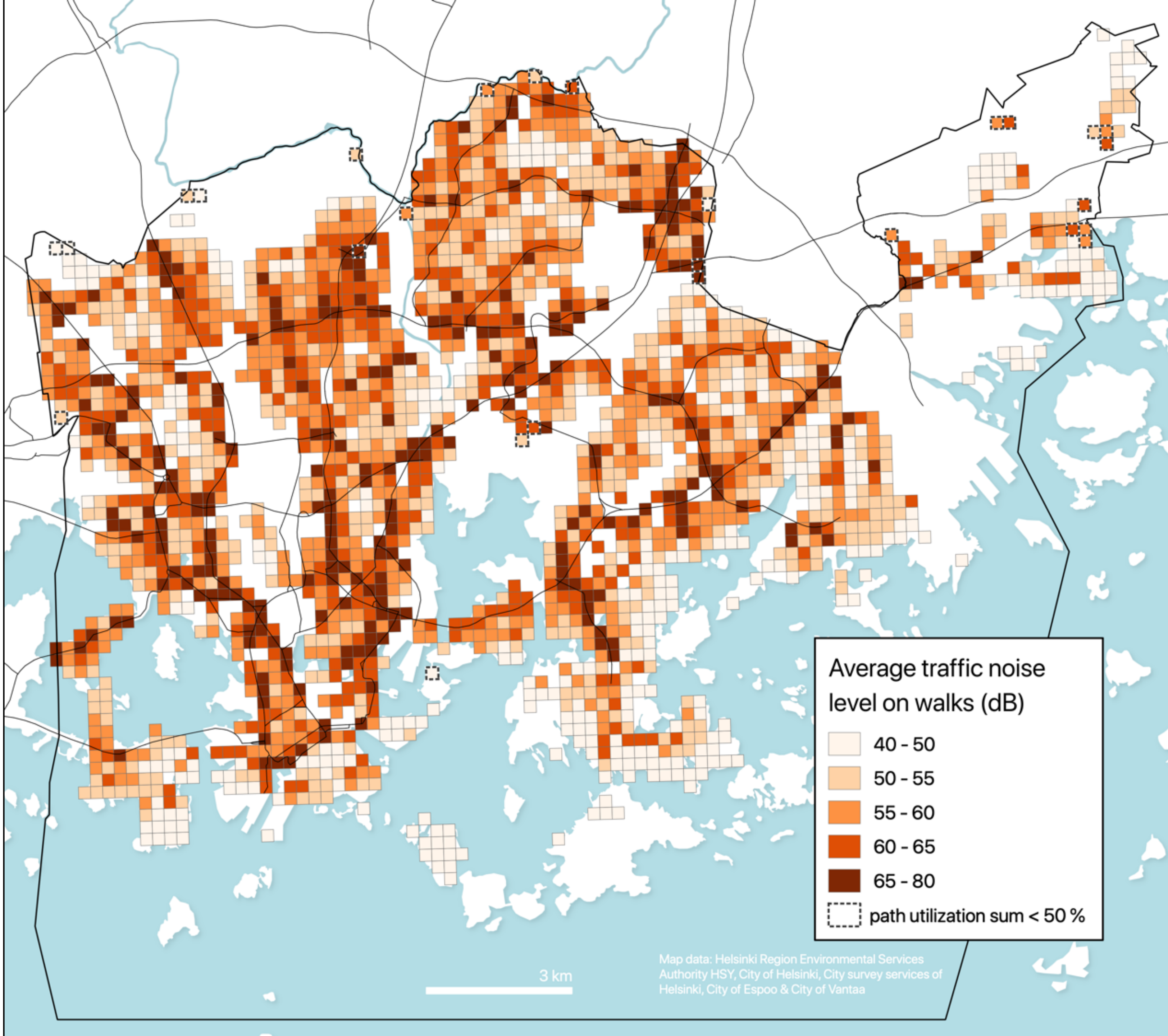
- Pedestrians' exposure to traffic noise on typical local walks
  - Descriptive statistics of all walks
  - Origin-level differences as choropleth maps
- Quiet path routing API
- Quiet path route planner (web application)
- Achievable reductions in noise exposure in Helsinki

Results

Variable	Mean	Median	SD	p10	p25	p75	p90
EI	100	74	93	15	35	135	221
EI_n	0.36	0.34	0.22	0.07	0.19	0.53	0.66
dB_{mean}	58	57	7	47	52	63	67
ED_{+60dB} (m)	210	142	215	13	64	293	497
ED_{+65dB} (m)	136	75	176	0	22	179	342
ED_{+70dB} (m)	53	8	101	0	0	64	150
ER_{+60dB} (%)	46	41	33	4	18	74	100
ER_{+65dB} (%)	30	21	30	0	5	47	79
ER_{+70dB} (%)	12	2	20	0	0	14	37

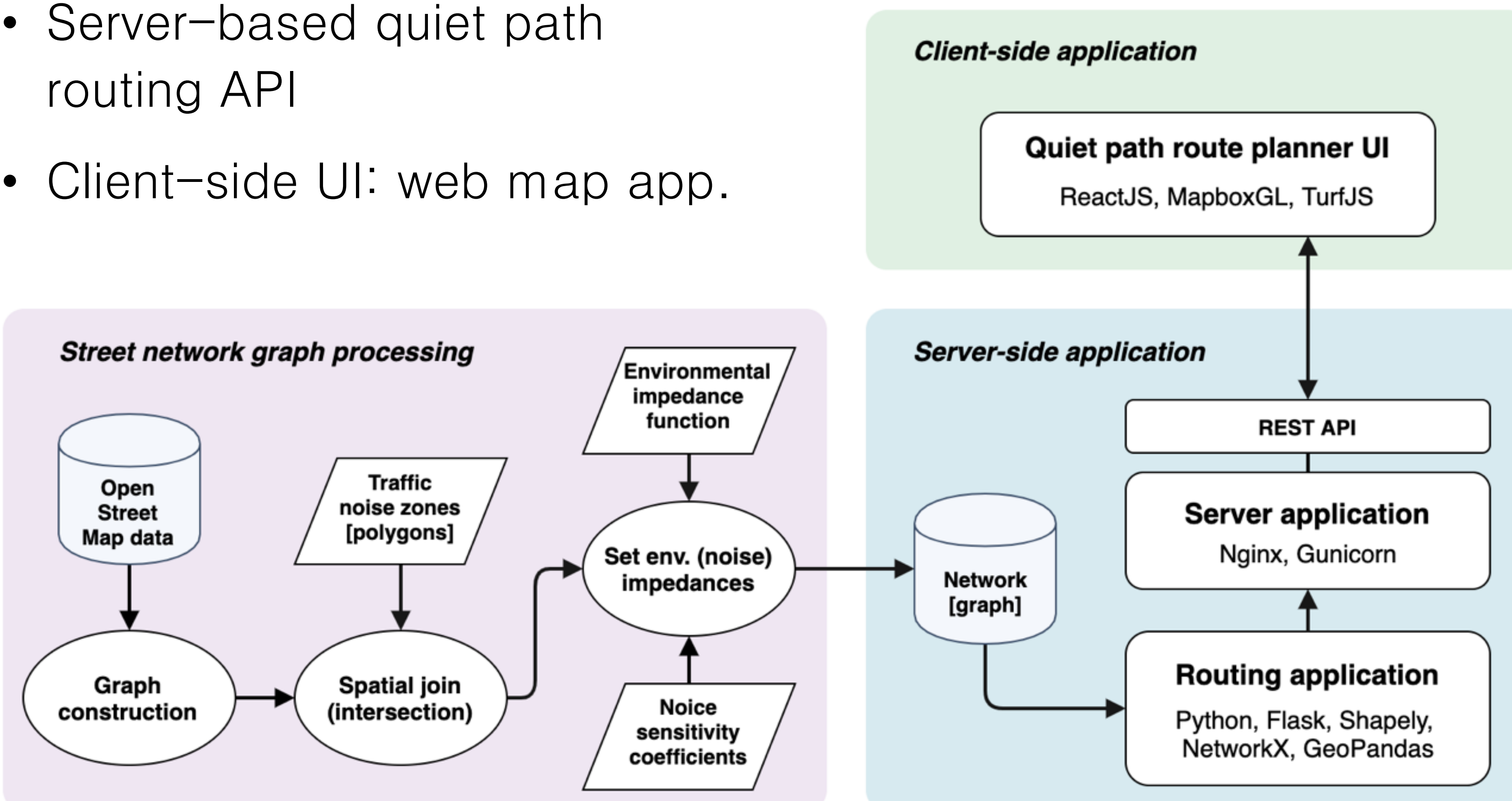

Average walking distance in +60dB traffic noise (m)
0 - 150
150 - 250
250 - 400
400 - 700
700 - 1850
path utilization sum < 50 %
3 km
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa


Average walking distance in +65dB traffic noise (m)
0 - 100
100 - 200
200 - 300
300 - 500
500 - 900
path utilization sum < 50 %
3 km
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa


Average traffic noise level on walks (dB)
40 - 50
50 - 55
55 - 60
60 - 65
65 - 80
path utilization sum < 50 %
3 km
Map data: Helsinki Region Environmental Services Authority HSY, City of Helsinki, City survey services of Helsinki, City of Espoo & City of Vantaa

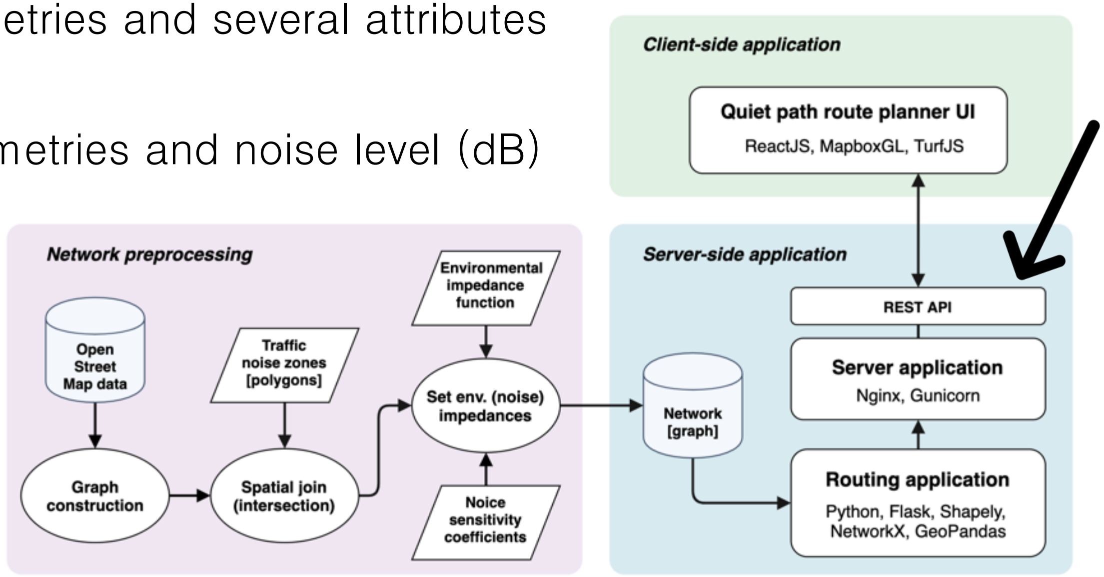
Web-based quiet path route planner

- Server-based quiet path routing API
- Client-side UI: web map app.



Quiet path routing API

- https://greenpaths.fi
  - https://greenpaths.fi/quietpaths/60.20495,24.96248/60.16754,24.9402
- Response (data)
  - 2 x GeoJSON (FeatureCollection)
  - path_FC: path geometries and several attributes on noise exposure
  - edge_FC: edge geometries and noise level (dB)

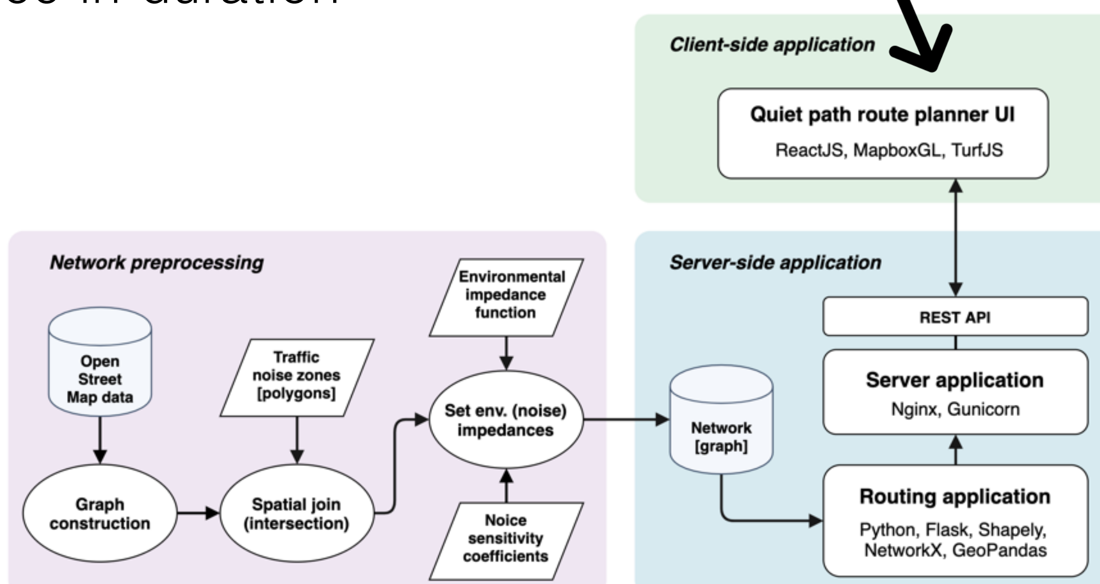


GeoJSON Schema (path_FC)

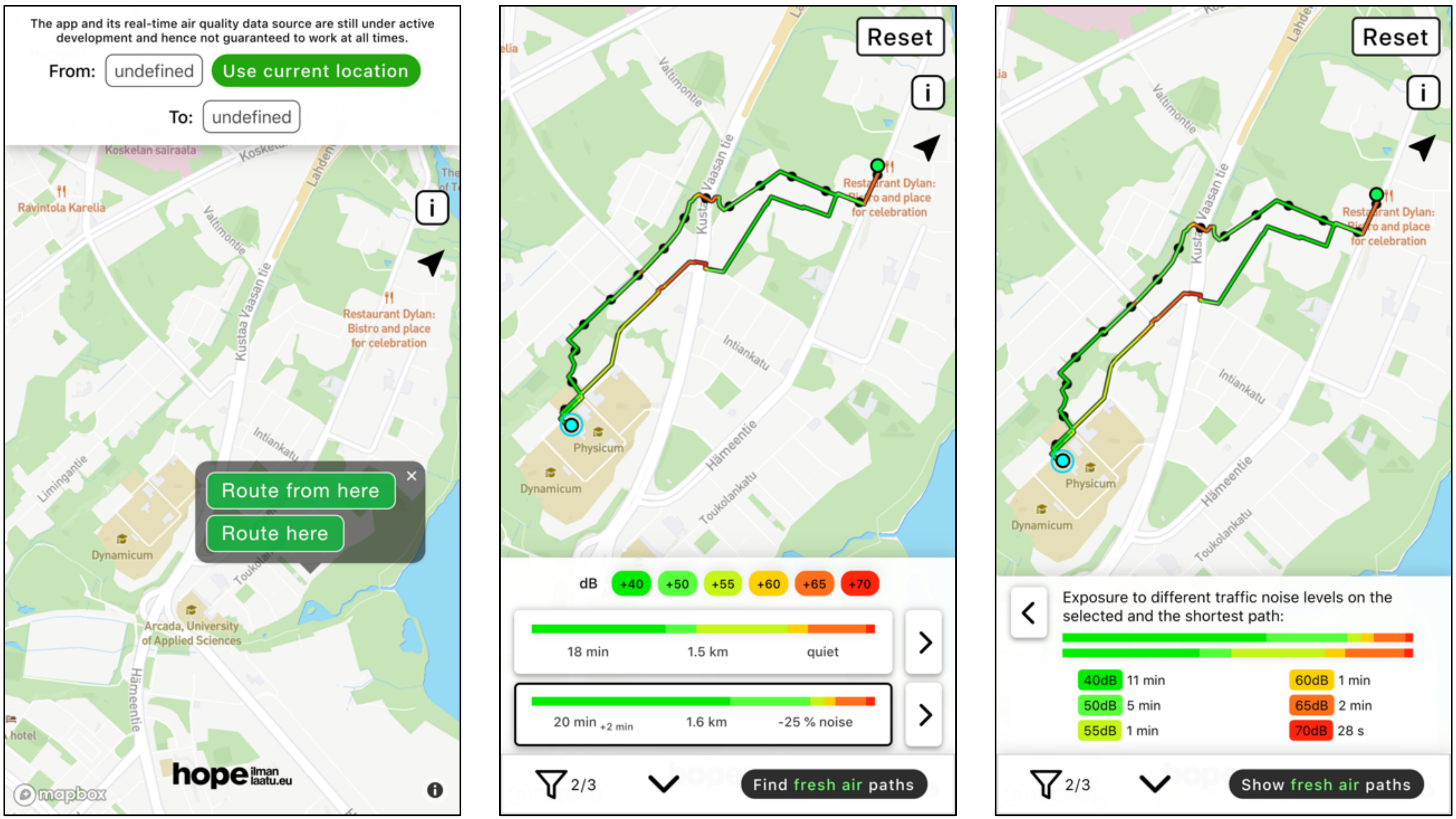

```
Path_FC {
  features: [ {
     geometry: { coordinates : [...], type: "LineString" },
     properties: {
       type:  “quiet” ,
       id: “q_3” ,
       length: 312.6,
       cost_coeff: 3,
       len_diff: 12,
       len_diff_rat: 1.3,
       mdB: 59,
       mdB_diff: -6.2,
       nei: 514.2,
       nei_norm: 0.31,
       nei_diff: -52.3,
       nei_diff_rat: -16.6,
       noises: { 45: 182.16, 50: 428.69, 55: 212.42, 60: 393.18,
                 65: 346.72, 70: 61.49, 75: 6.45 },
       noises_diff: { 40: 105, 45: 82.1, 50: 82.67, 55: 103.69, 60: 151.27,
                      65: -22.53, 70: -277.62, 75: -11.57 },
     type: “Feature” },
     {...}, {...}, ... ],
  type: "FeatureCollection"
}
```

Quiet path route planner UI

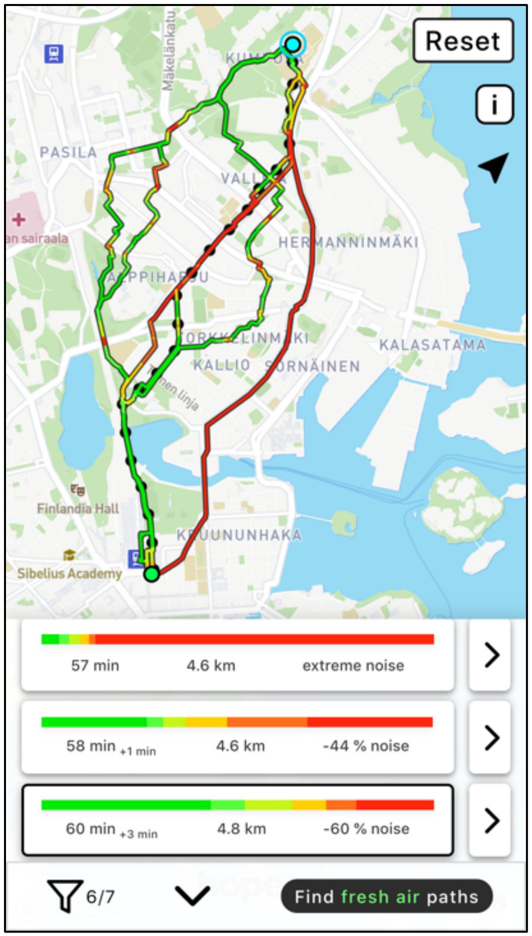
- https://green-paths.web.app/
- Finds alternative quiet paths for OD-pair
- Visualizes noise exposure and shows EI_{diff}
- Shows difference in duration

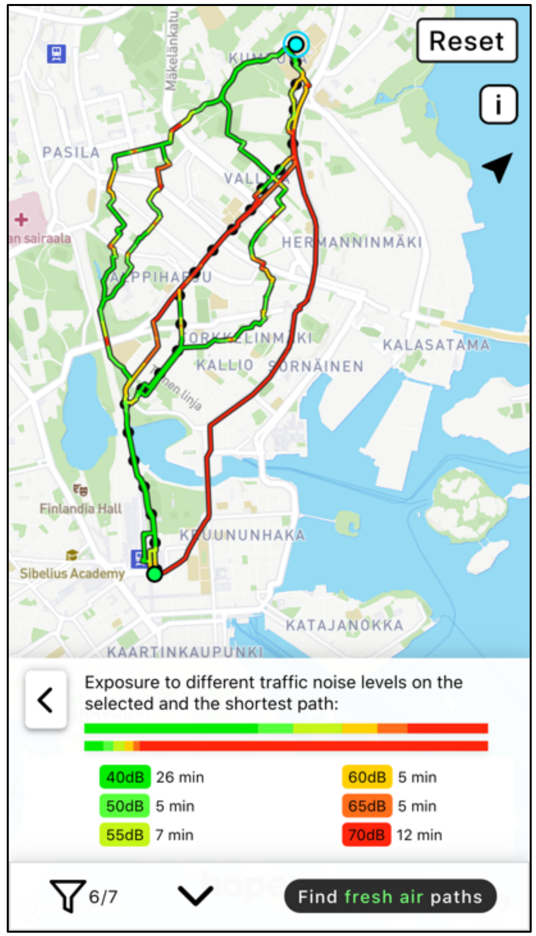


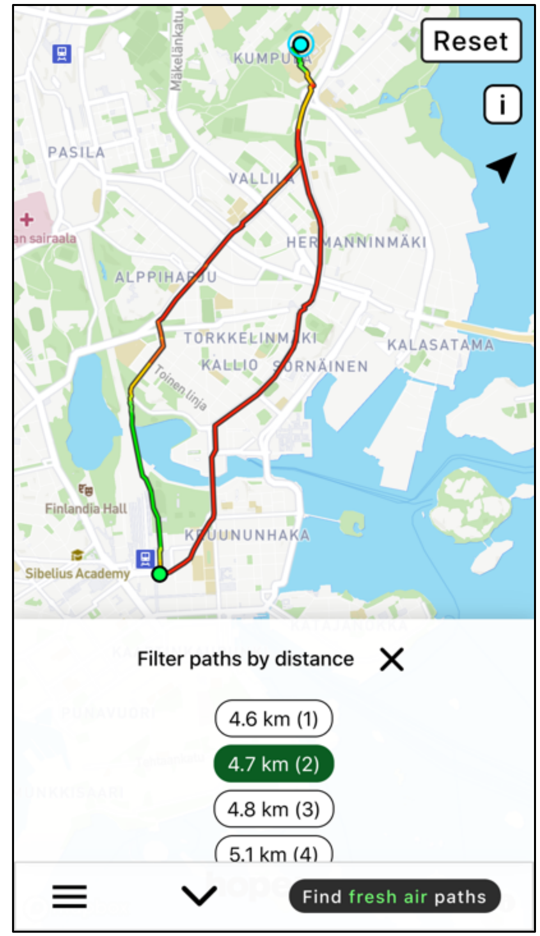
Quiet path route planner UI



Quiet path route planner UI





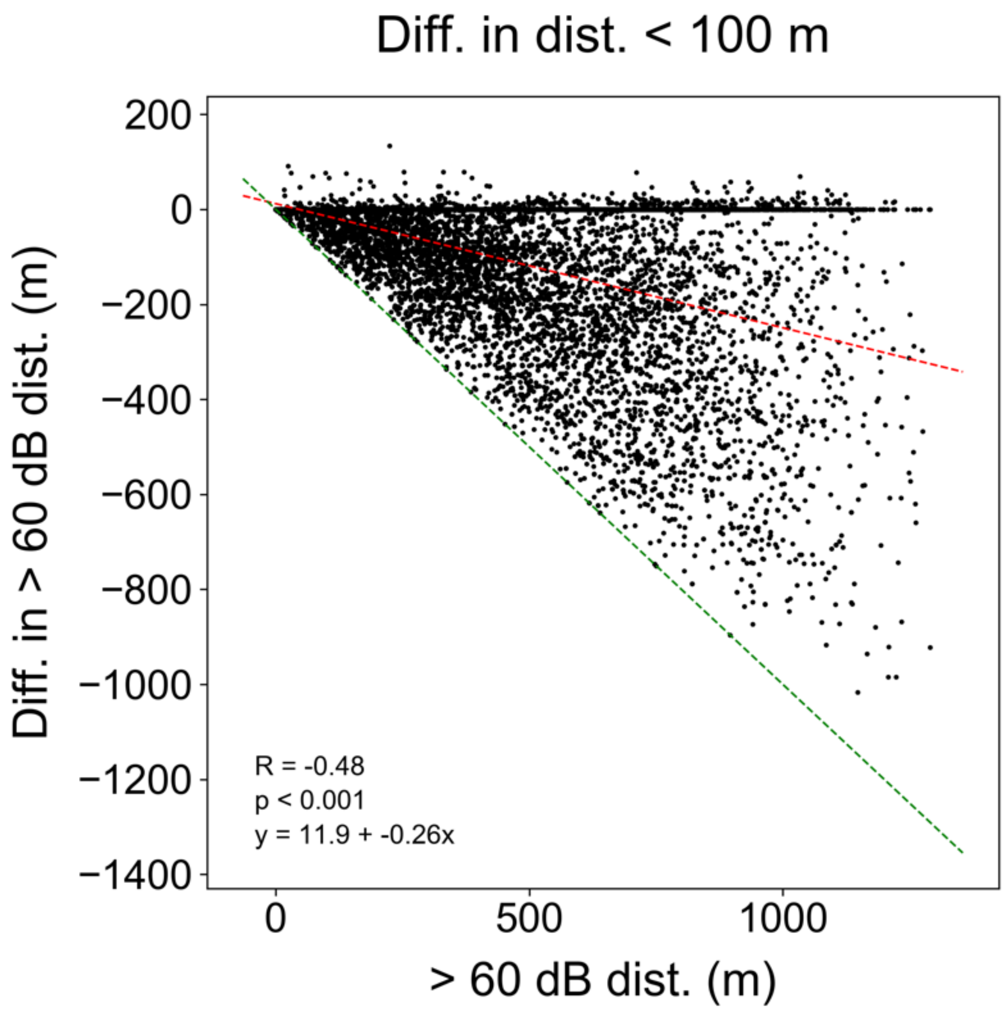


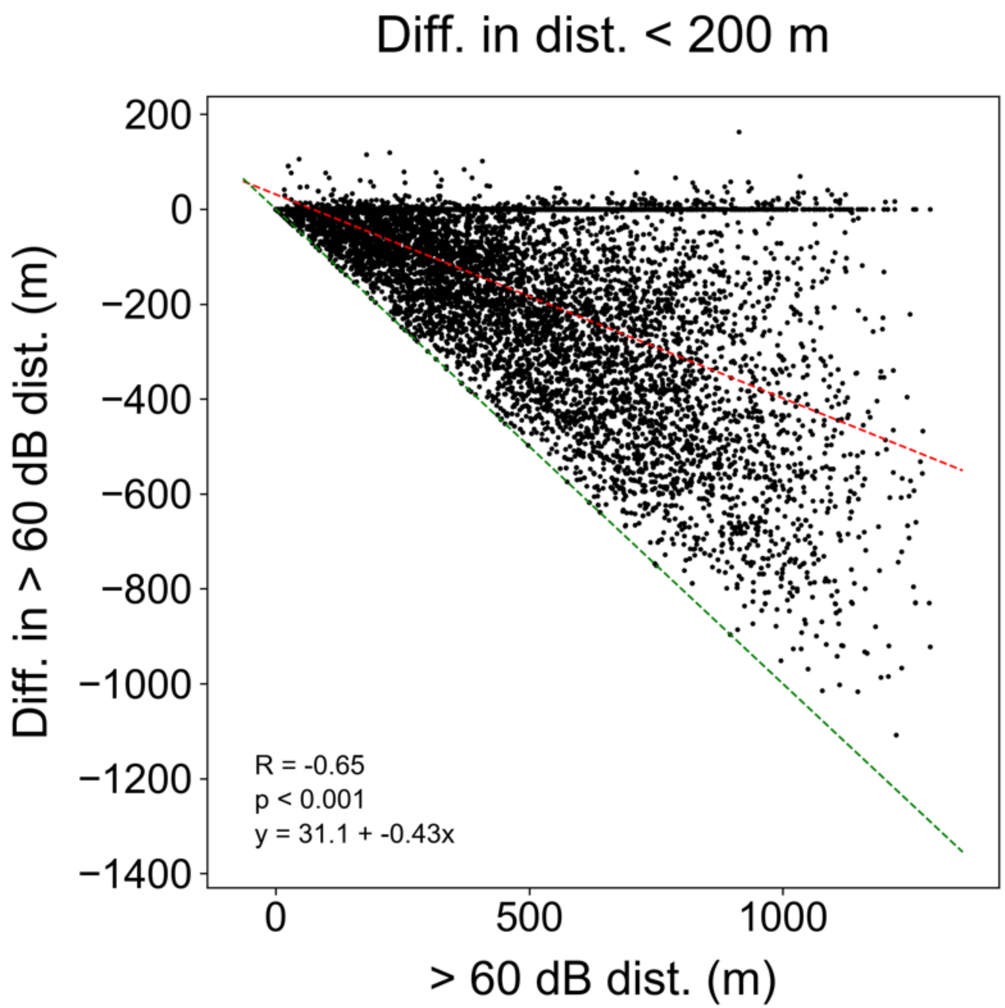
Achievable reductions in noise exposures

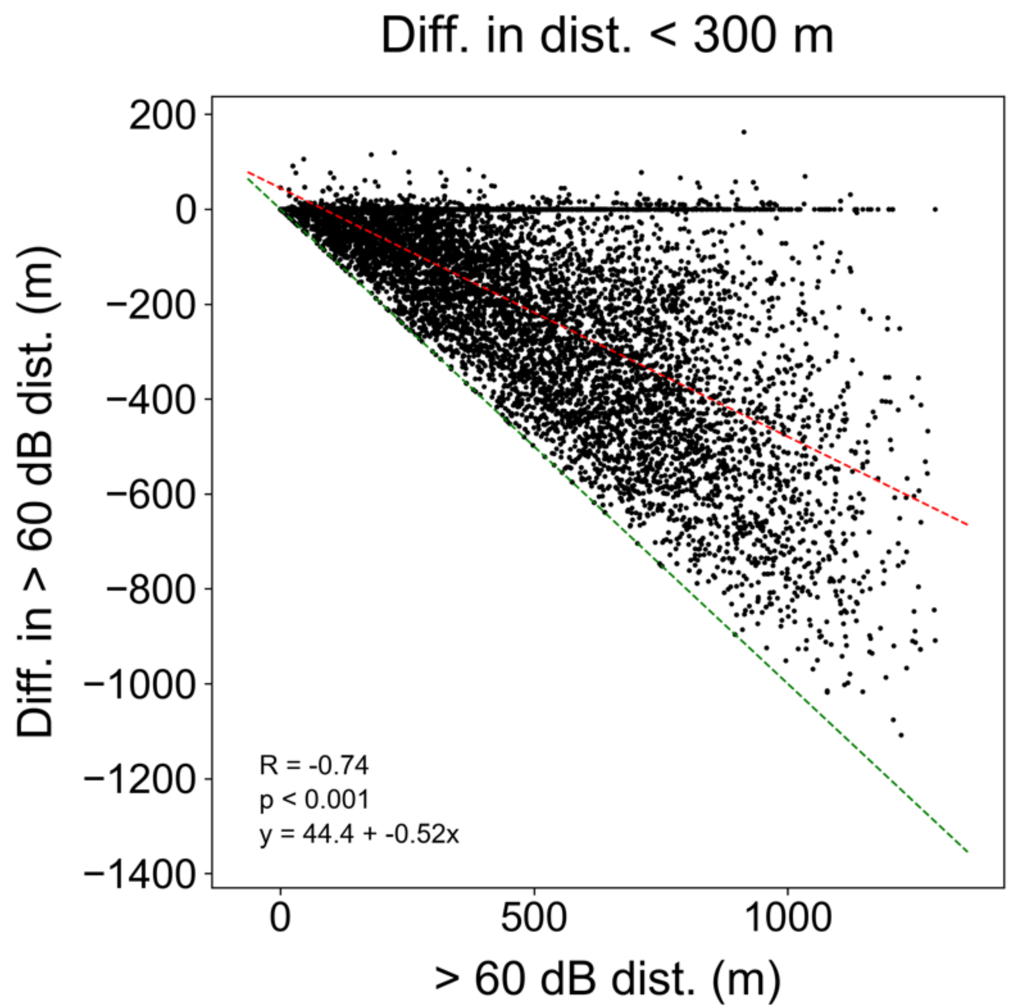
- Assessment of achievable reductions in exposure to noise (by quiet paths)
  - Compare reduction in exposure to addition in distance
  - ER_{+60dB} (%), ER_{+65dB} (%), dB_{mean} etc.
  - Aggregate effect of the quiet paths by length difference thresholds: 100 m, 200 m and 300 m
    (compared to the length of the respective shortest path)

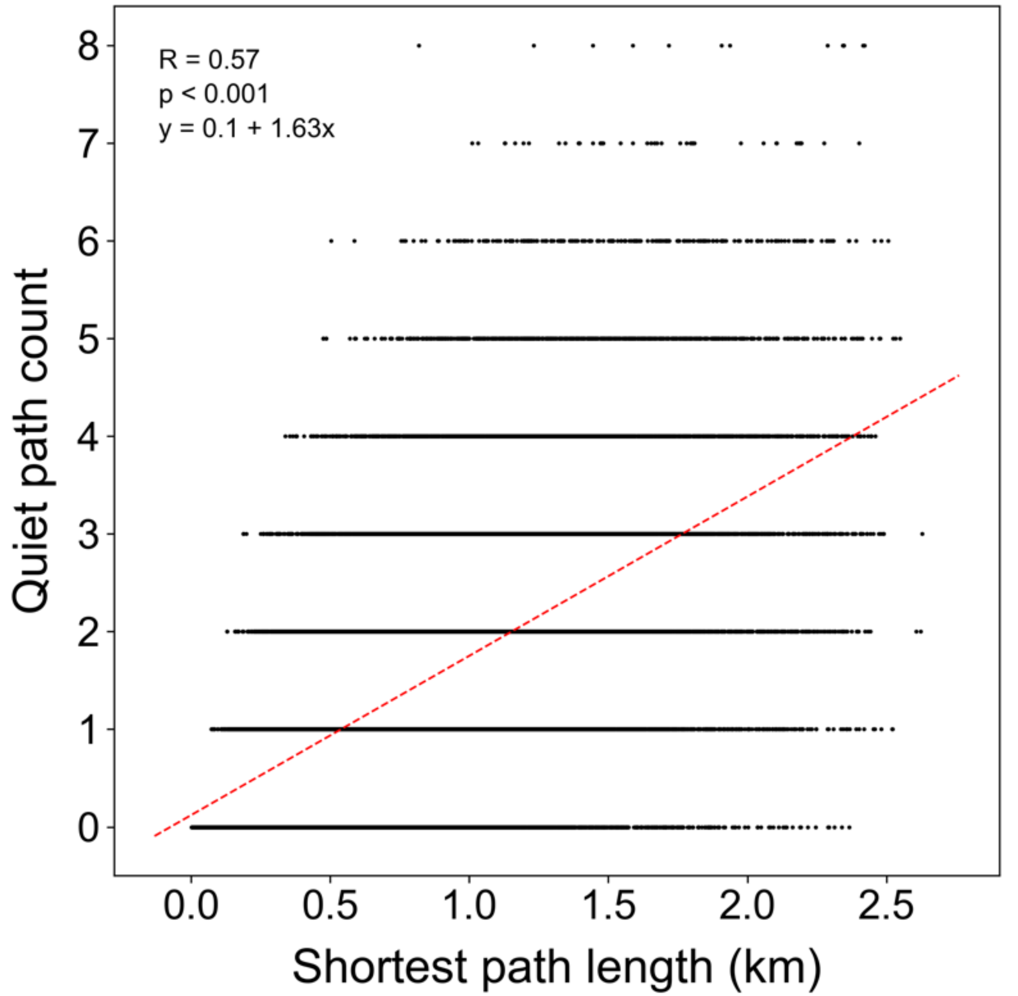
Achievable reductions in noise exposures

					Subset of paths by ER_{+65dB}		
Path length (m)	Quiet path length difference (m)				10–40 %	40–70 %	70–100 %
Range	Max	Mean	Median	SD	Difference (%) in ER_{+65dB} (mean, median, SD)		
300–600	< 100	18	0	28	-12, 0 (26)	-23, -0 (31)	-20, -0, (27)
300–600	< 200	44	12	58	-16, -0 (29)	-32, -26 (33)	-31, -28, (30)
300–600	< 300	65	21	83	-18, -0, (30)	-36, -36 (34)	-38, -41, (31)
700–1300	< 100	30	19	32	-21, 0 (29)	-32, -28 (31)	-30, -25, (29)
700–1300	< 200	75	67	63	-29, -20 (32)	-46, -49 (31)	-46, -51, (30)
700–1300	< 300	117	107	93	-32, -27, (33)	-53, -59 (29)	-55, -62, (27)


Diff. in dist. < 100 m
200
0
−200
−400
−600
−800
−1000
−1200
−1400
Diff. in > 60 dB dist. (m)
0
500
1000
> 60 dB dist. (m)
R = -0.48
p < 0.001
y = 11.9 + -0.26x


Diff. in dist. < 200 m
Diff. in > 60 dB dist. (m)
> 60 dB dist. (m)
200
0
−200
−400
−600
−800
−1000
−1200
−1400
0
500
1000
R = -0.65
p < 0.001
y = 31.1 + -0.43x


Diff. in dist. < 300 m
200
0
−200
−400
−600
−800
−1000
−1200
−1400
Diff. in > 60 dB dist. (m)
0
500
1000
> 60 dB dist. (m)
R = -0.74
p < 0.001
y = 44.4 + -0.52x


R = 0.57
p < 0.001
y = 0.1 + 1.63x
Quiet path count
Shortest path length (km)
0
1
2
3
4
5
6
7
8
0.0
0.5
1.0
1.5
2.0
2.5

Discussion and conclusions

- Technical assessment – quality of the shortest paths
  - Most of the paths were ok
- Significant, yet varying, reductions in traffic noise exposure can be achieved with quiet path routing
- Alternative quiet paths are needed for different situations and users
  - Desired trade-off between travel-time/noise exposure varies between levels of hurry and personal noise sensitivity

Discussion and conclusions

- Uncertainties in exposure–response relationships challenge the environmental impedance function
  - How much worse is exposure to 70 dB compared to 65 dB ?
- Exposure–based routing should be developed as a concept to consider multiple pollutants
- Publishing an online green path route planner can facilitate citizens to choose healthier paths