Urban Strategy:
Digital Twins for liveable and resilient cities

Applications in Ambient Air Quality

Leonard Oirbans | CONCAWE 2024

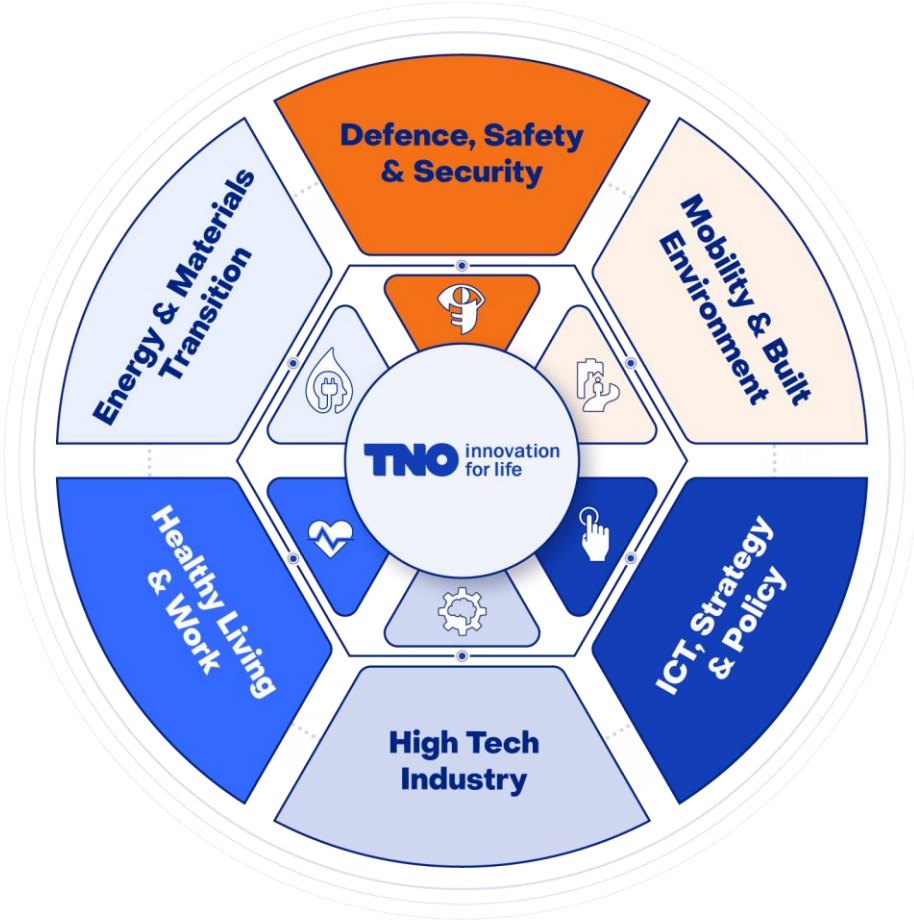
Digital Twins for liveable and resilient cities

- **About TNO**
- **Urban Challenges**
- **Urban Strategy**
- **Air quality simulation in Urban Strategy**
- **Examples of use cases**
  Integral urban planning city of Amsterdam
  Real time air quality in the Amsterdam region
  NO2 emission reduction strategies in Germany
  Zero emission strategy for busses in Singapore

About TNO

TNO: Innovation for life

- Netherlands largest, independent Research & Technology Organisation (RTO)
- 4.000+ employees
- Founded by law in 1932
- TNO's mission is to create impactful innovations for the sustainable wellbeing and prosperity of society.



Urban Challenges

Urbanisation and densification
Aging population
Scarcity of space
Decarbonisation
Mobility
Reliable & affordable Energy
Accessibility
Air pollution
Noise
Resilient infrastructure
Inclusion & equity
Electrification
Housing

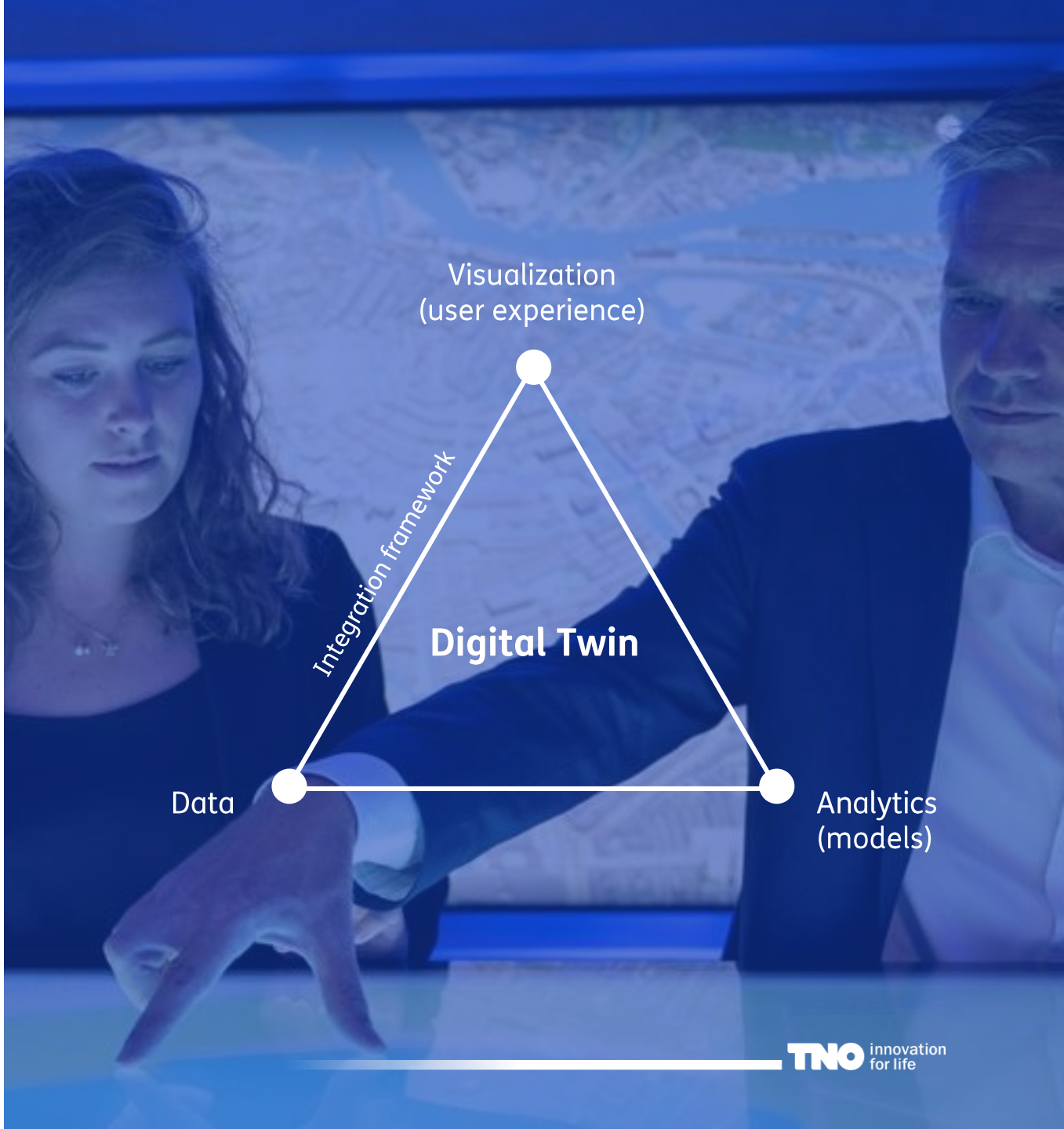
Cities are increasingly complex systems

- Simultaneous transitions in multiple domains, which are increasingly intertwined.
- Requiring a balanced and integral approach to form future proof policies.

Urban Strategy

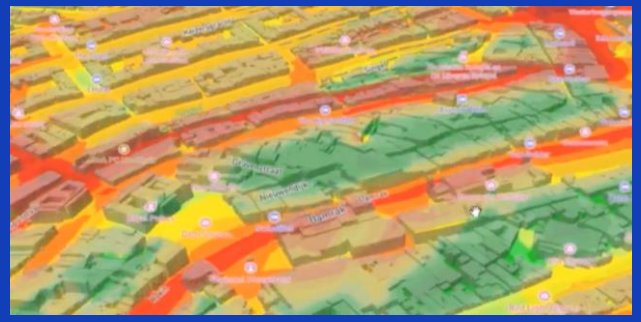
Making complexity manageable

- Unique multi-modal Digital Twin approach for interactive and integral urban planning.
- Integrating data, visualization and analytics to construct realistic digital replicas of the real world.
- Utilizing high performance computing, resulting in very large scaling potential.
- Interactively explore the solution space to accelerate resolving societal challenges.



Walter Lohman, Hans Cornelissen, Jeroen Borst, Ralph Klerkx, Yashar Araghi, Erwin Walraven, Building digital twins of cities using the Inter Model Broker framework, Future Generation Computer Systems, Volume 148, 2023, Pages 501-513, ISSN 0167-739X, https://doi.org/10.1016/j.future.2023.06.024.

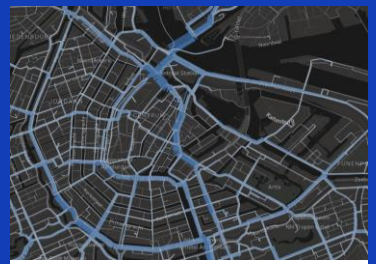
Urban Strategy



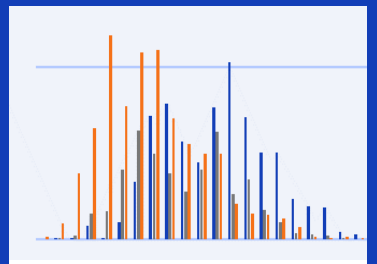
Urban Strategy simulation modules

Mobility
Demand

Multi-mode
network allocation

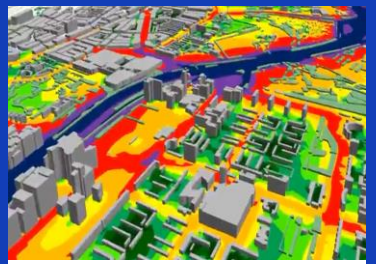


Active transport
Cycling & Walking

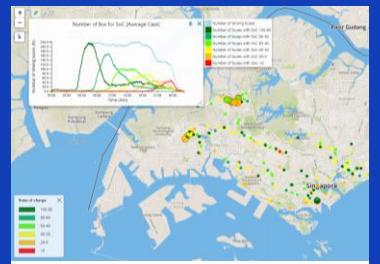


Distribution
of accessibility

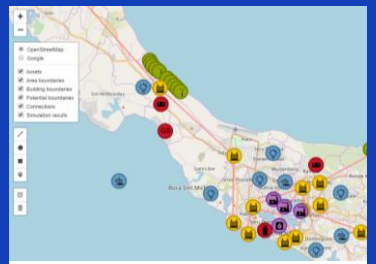
Air quality
Road & Industry



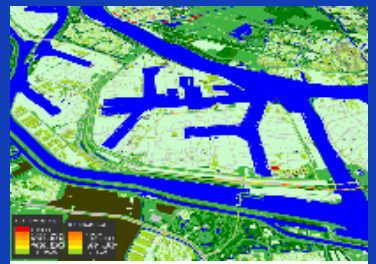
Noise
Road, Rail, Industry



Electric fleet
simulation



EV – power grid
Interaction



Greenhouse gas
emissions

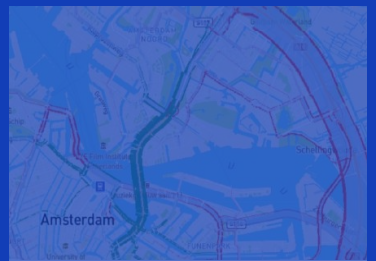
Infrastructure
Resilience

Spatial
impacts

Equity indicators

Urban Strategy simulation modules

Mobility
Demand



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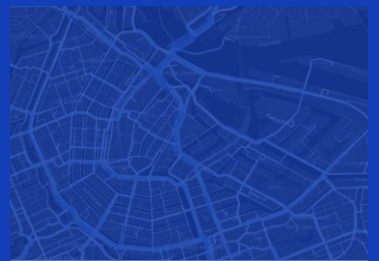

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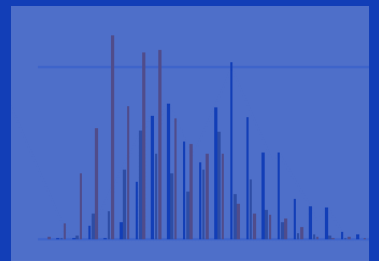
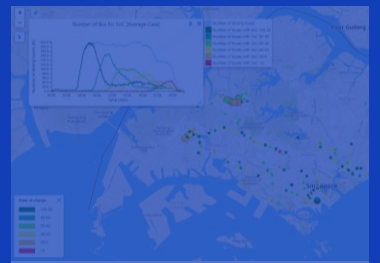


Distribution
of accessibility

Air quality
Road & Industry

Noise
Road, Rail, Industry



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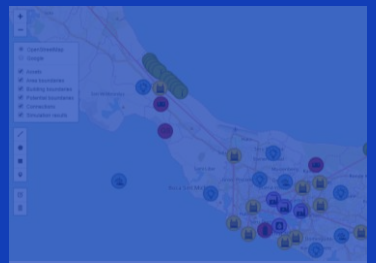

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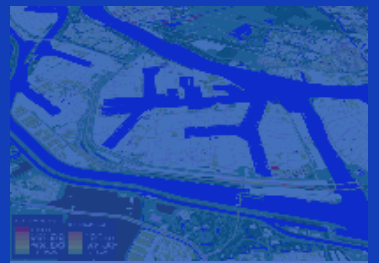
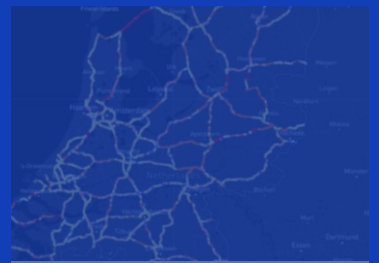


Greenhouse gas
emissions



Infrastructure
Resilience

Spatial
impacts

Equity indicators

Air Pollutant Emissions

Emissions from traffic

- Carbon dioxide (CO_2)
  ➔ Greenhous gas ➔ Global Warming
- Nitrogen oxides (NO_x)
  ➔ Nitrogen deposition (Natura 2000)
- Nitrogen dioxide (NO_2)
  ➔ NO_x ➔ NO_2 ➔ Health impact
- Particulate matter (PM_{10} and $PM_{2.5}$)
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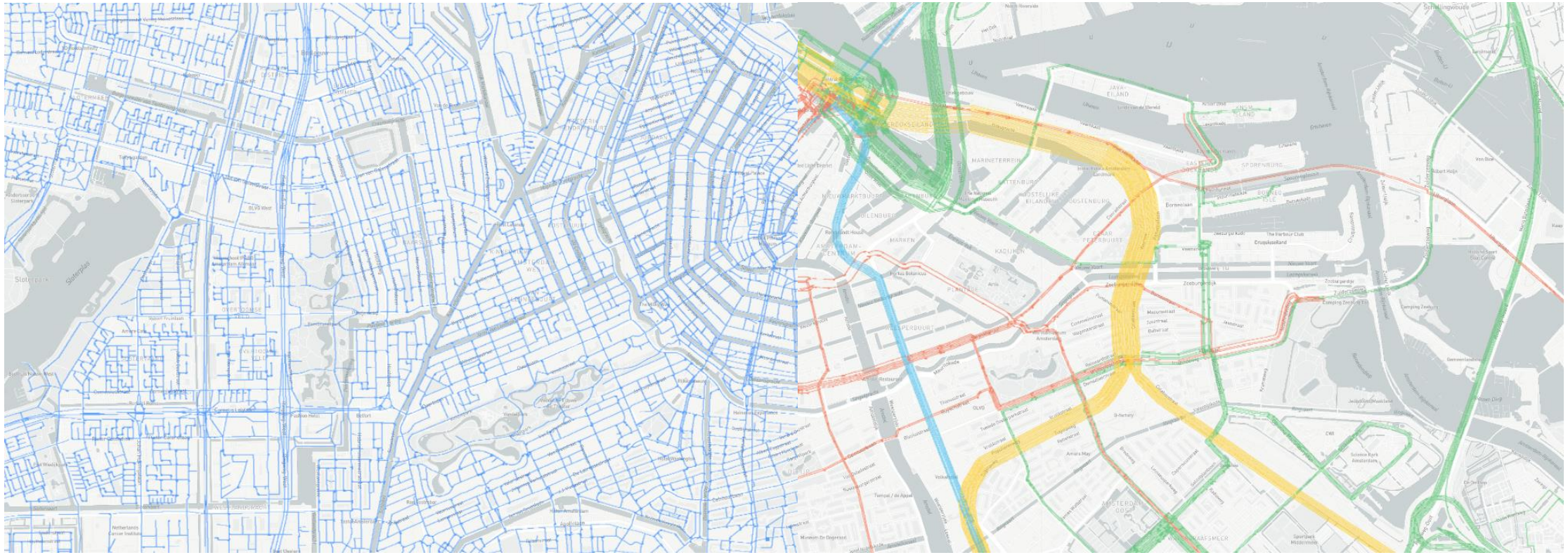
Air Quality

Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects

Spatial plan
Location of houses, jobs, amenities, ...

Air Quality

Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects



Transportation network

Speed and capacity on roads, cycle paths, public transport options, ...

Air Quality

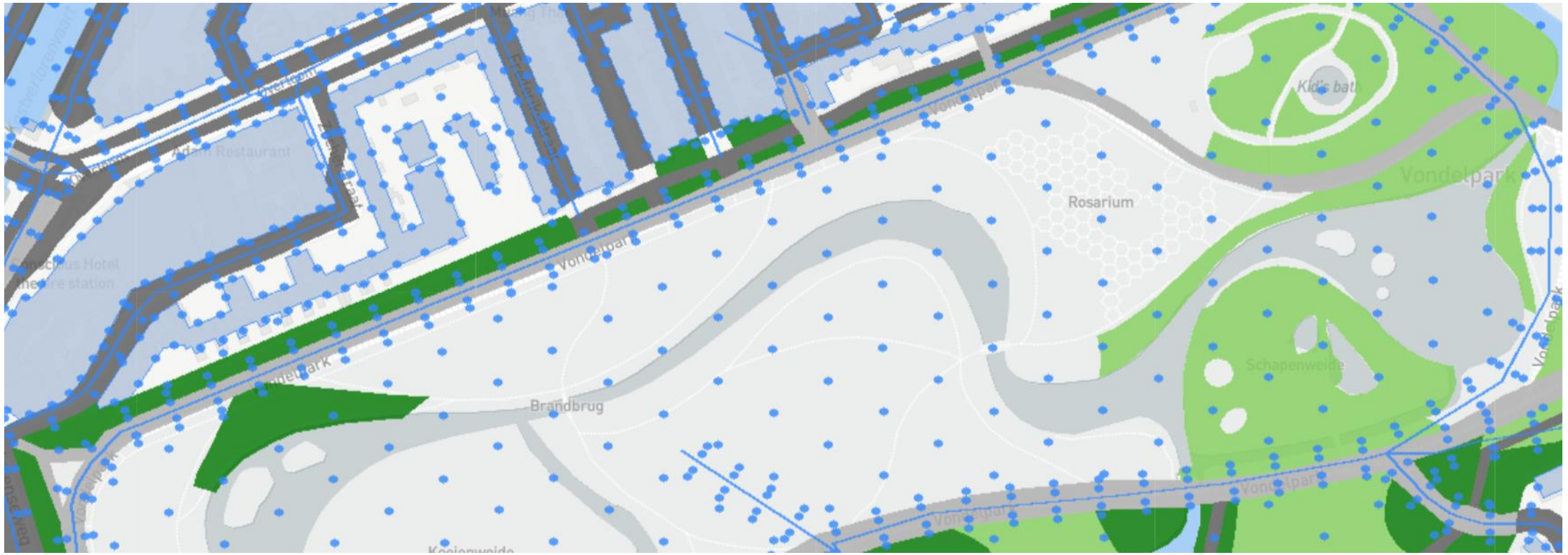
Transportation demand → **Traffic flow** → Emissions → Concentrations → Exposure → Health impact effects

Traffic characteristics

Fleet composition, street type, congestion levels, ...

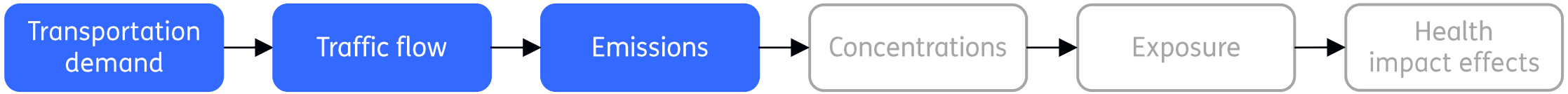
Air Quality

Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects



Calculation points: ‘receptors’

Air Quality


Transportation demand
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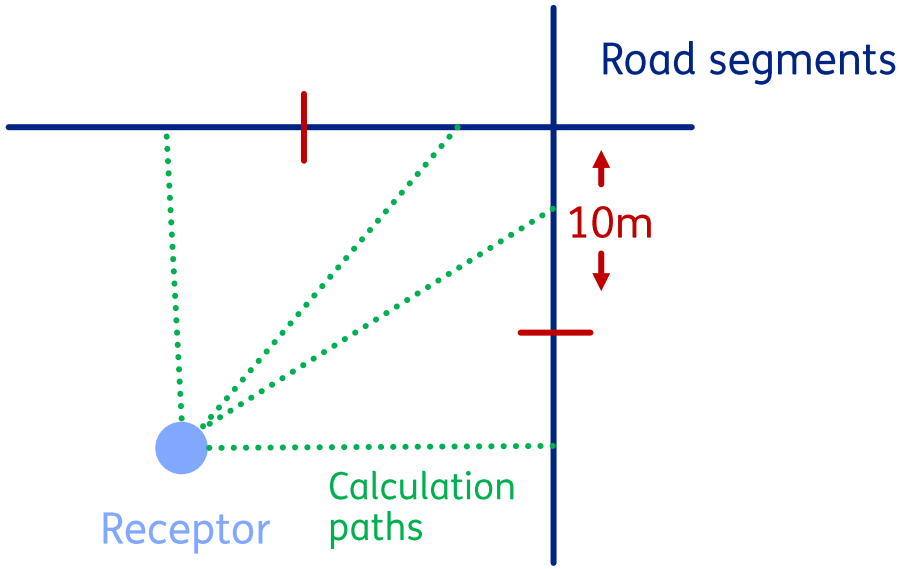
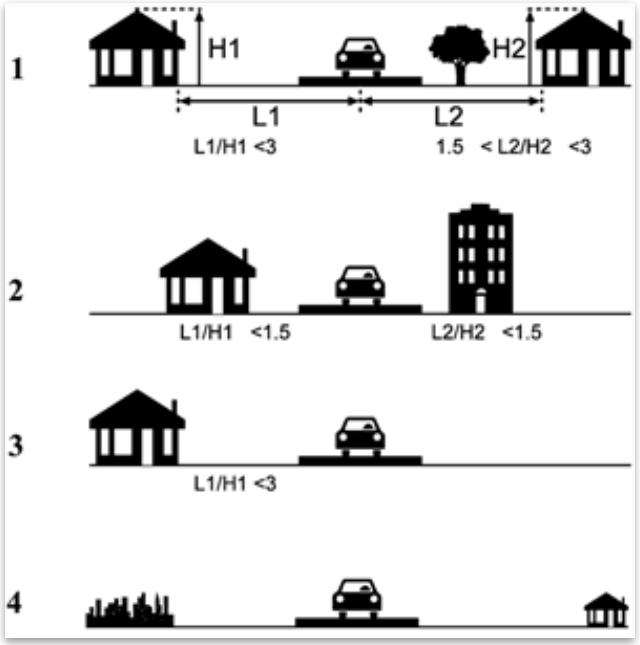

Road segments
10m
Receptor
Calculation paths

Air Quality

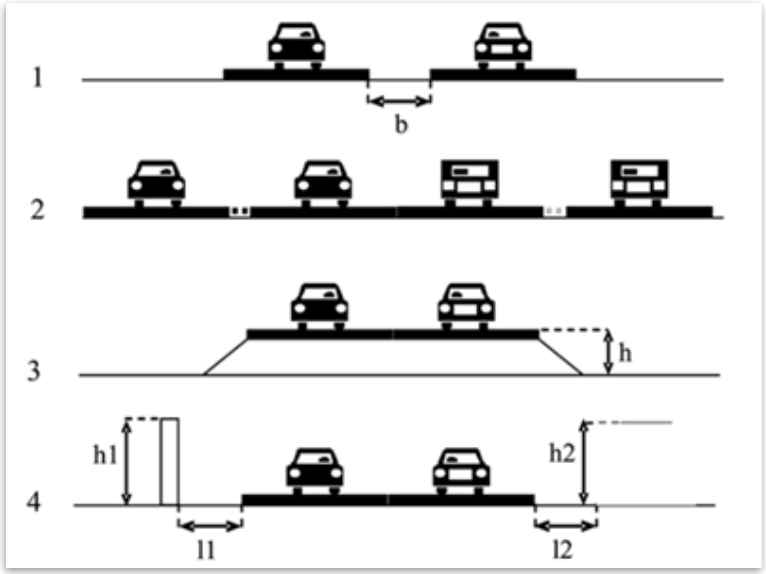
Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects

Standard calculation method

- SRM1 ‘CAR’ for urban roads (speed < 70 km/h)



- SRM2 ‘Gaussian plume’ for rural roads and highways (speed ≥ 70km/h)



Air Quality: SRM1 'CAR'

Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects

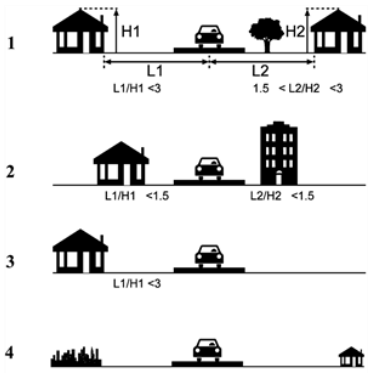
$$C = C_{road} + C_{background}$$

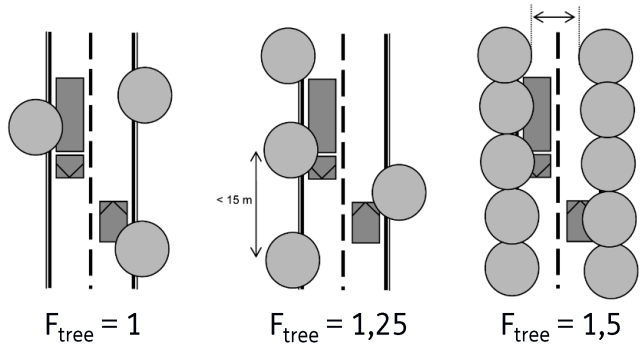
$$C_{road} = E \cdot \Theta \cdot F_{tree} \cdot F_{region}$$

$$\Theta = a \cdot S^2 + b \cdot S + c$$

$$E = N \cdot \left(\left(1 - (f_M + fZ) \right) \cdot E_L + fM \cdot E_M + fH \cdot E_H \right) \cdot \frac{1000}{24 \cdot 3600}$$

Parameter	wegtype			
	4	1	2	3
a	$3{,}1 \cdot 10^{-4}$	$3{,}25 \cdot 10^{-4}$	$4{,}88 \cdot 10^{-4}$	$5{,}00 \cdot 10^{-4}$
b	$-1{,}82 \cdot 10^{-2}$	$-2{,}05 \cdot 10^{-2}$	$-3{,}08 \cdot 10^{-2}$	$-3{,}16 \cdot 10^{-2}$
c	0,33	0,39	0,59	0,57





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N: number of vehicles [24hour^{-1}]
f_M : fraction mid duty vehicles
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Air Quality: SRM1 'CAR'

Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects

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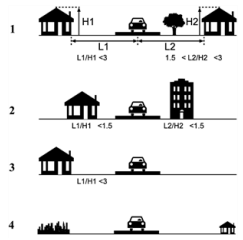

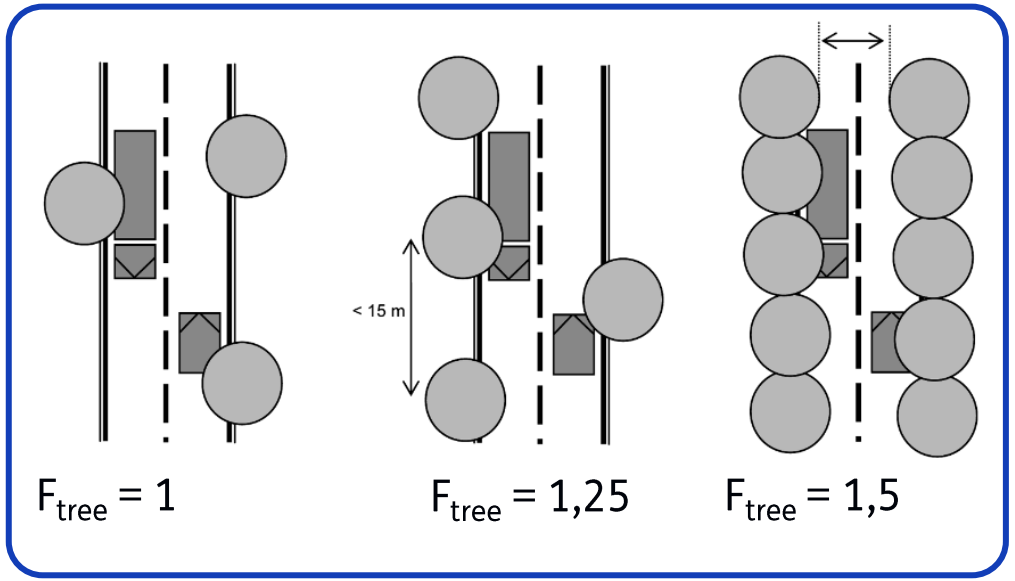

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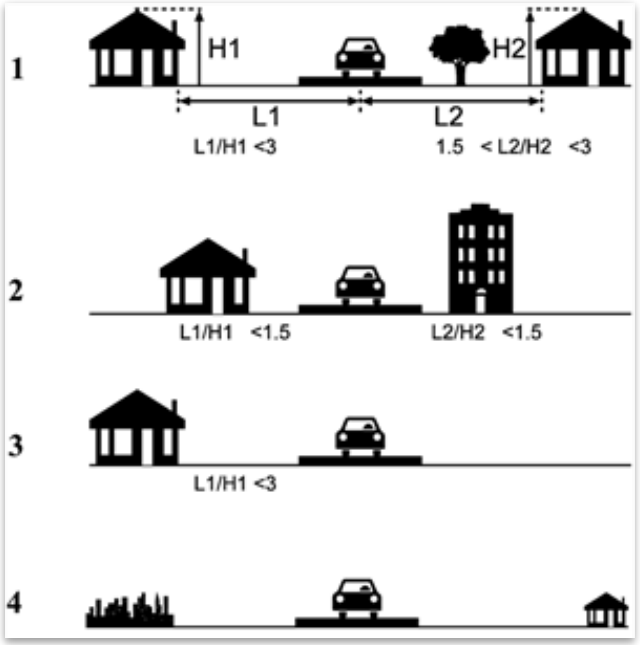
Air Quality

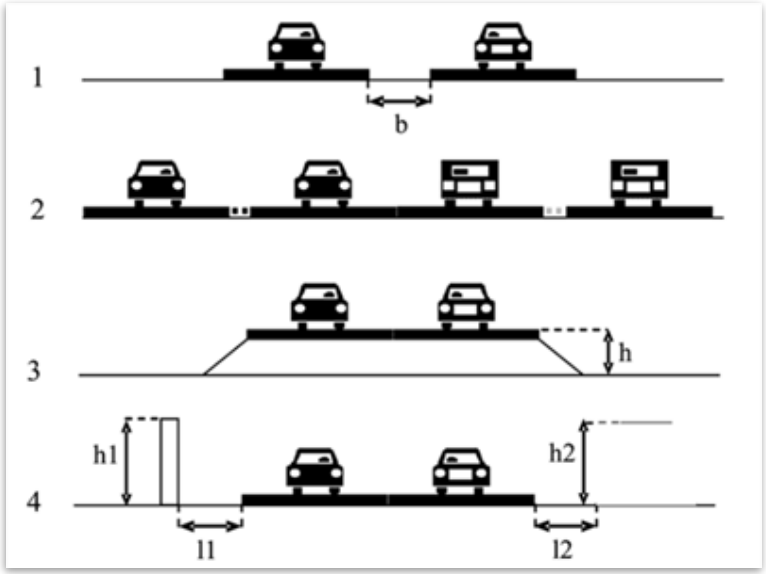
Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects

Standard calculation method

- SRM1 ‘CAR’ for urban roads (speed < 70 km/h)



- SRM2 ‘Gaussian plume’ for rural roads and highways (speed ≥ 70km/h)



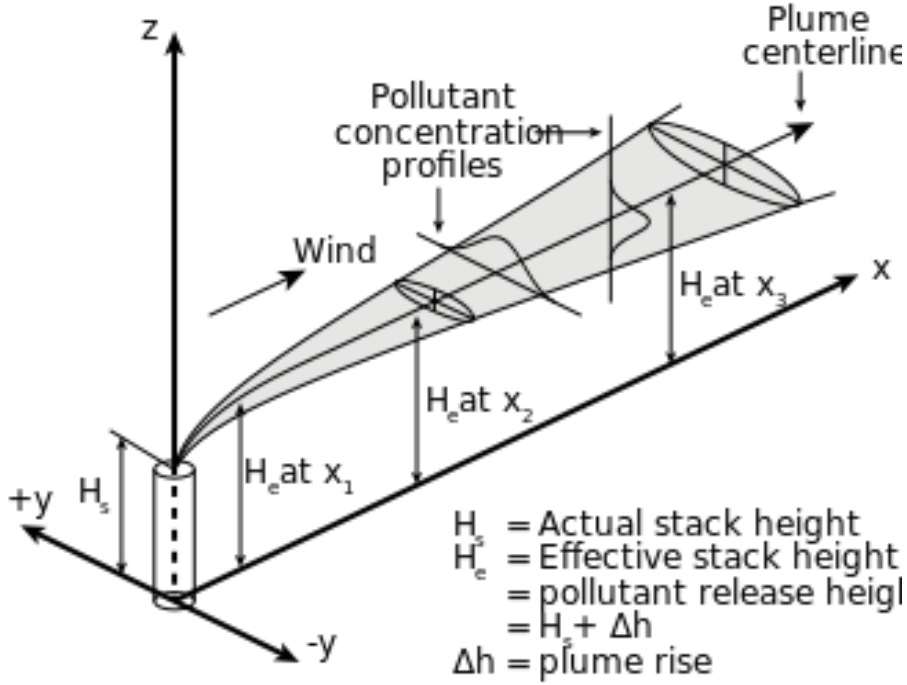
Air Quality: SRM2 'Gaussian plume'

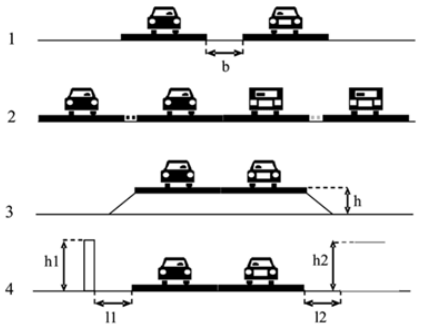
Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects

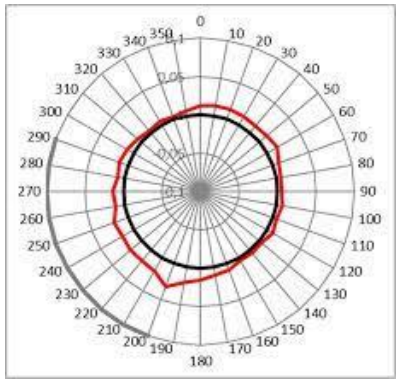
$$C = C_{road} + C_{background}$$

$$C_{road} = \sum_{n}^{12} \frac{E\, f_n d_r}{\sqrt{2\pi}\, \sigma_z\, C\, un\, \pi\, 12\, Sr} \exp[\frac{-z^2}{2\sigma_z^2}]$$

E : emission [µg/ms-1]
dr : length of road segment [m]
σ_z : vertical dispersion coefficent
z : height of the calulation point [m]
Sr : distance to road [m]
C : correction for surface rougness
un : windspeed in direction n [m/s]
fn : time fraction of wind direction
n=1 – 12 : number of wind directions







Air Quality

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SRM1 'CAR' speed < 70 km/h

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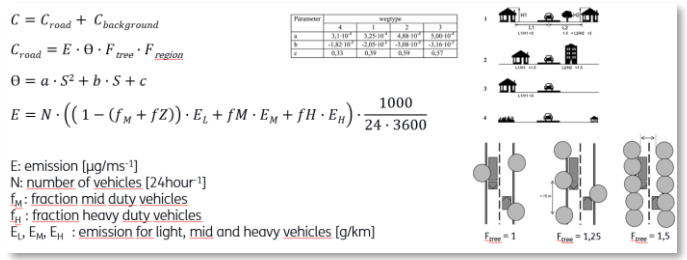

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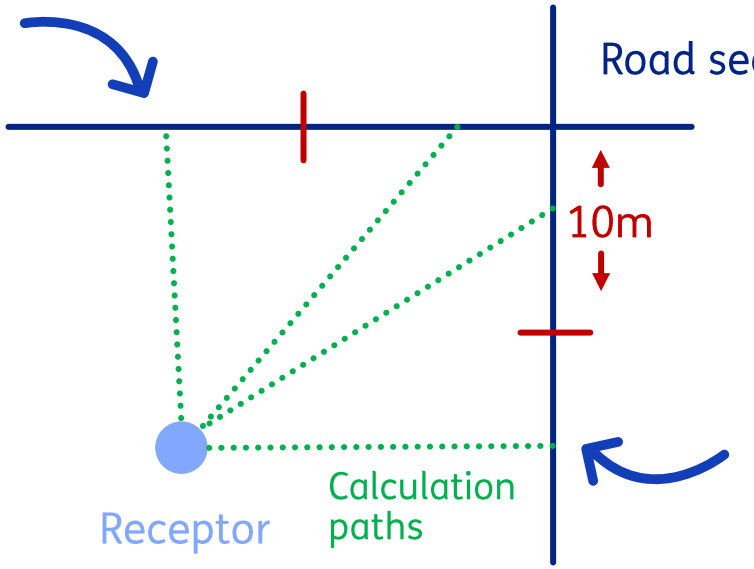

SRM2 'Gaussian plume' speed ≥ 70km/h

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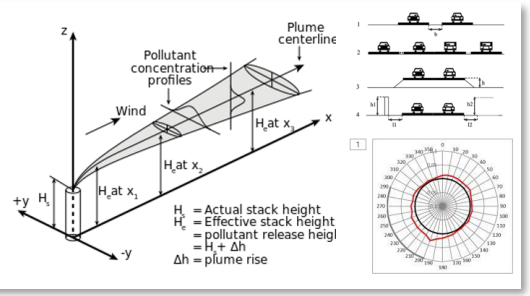

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Calculation points: ‘receptors’

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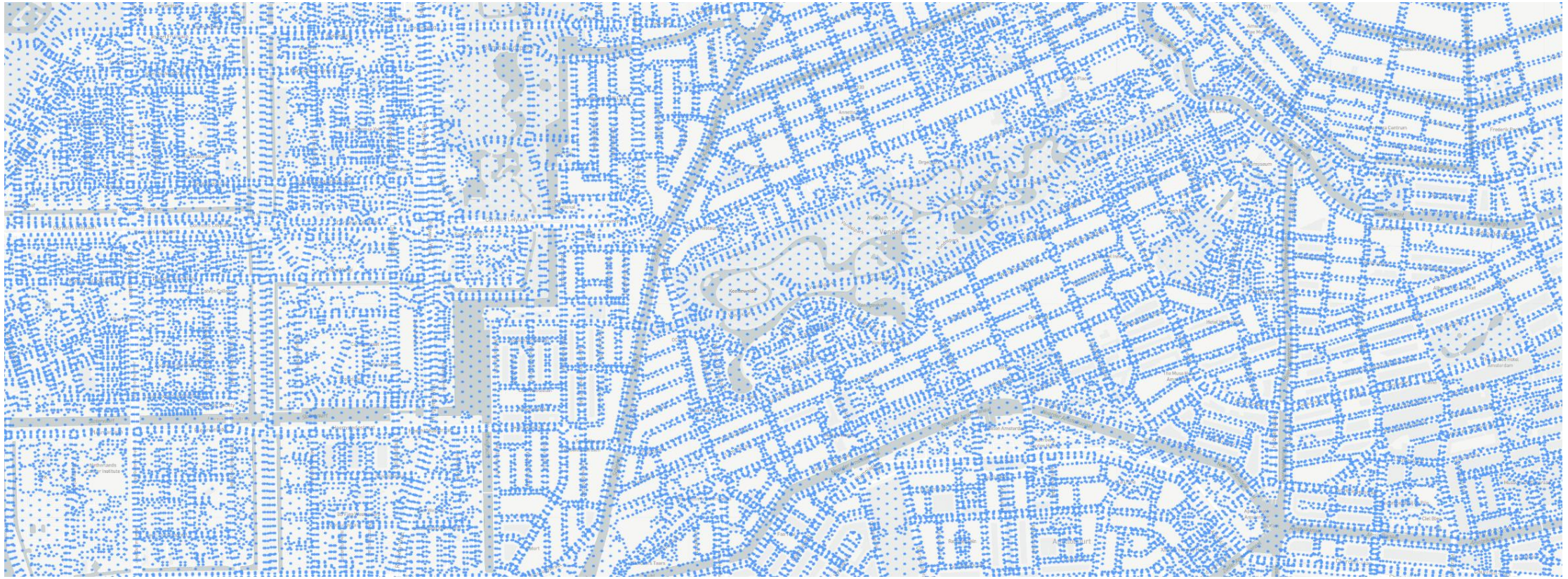

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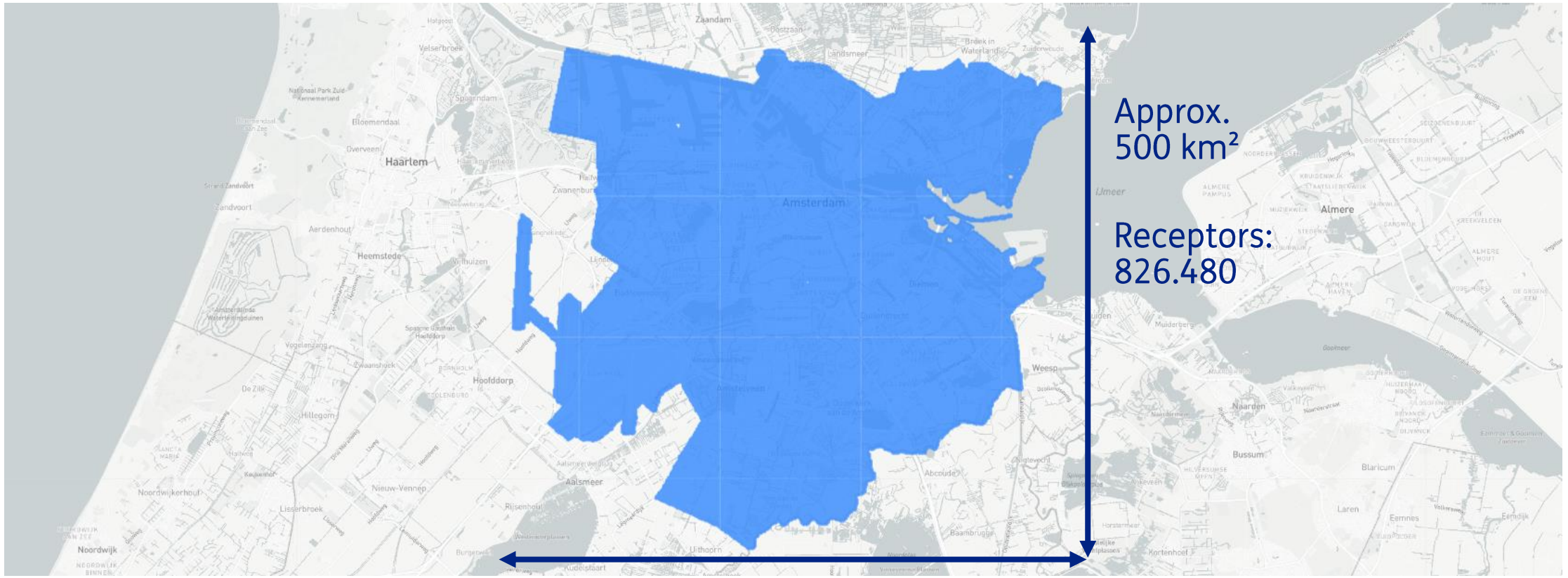

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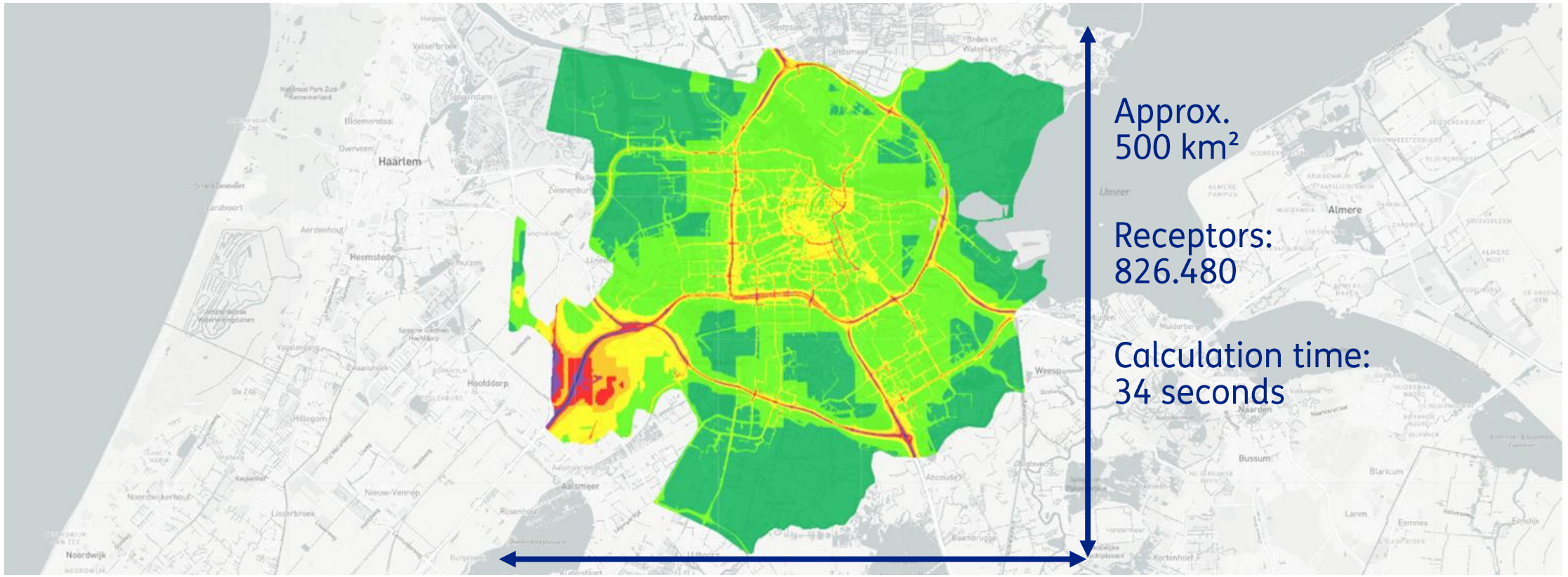
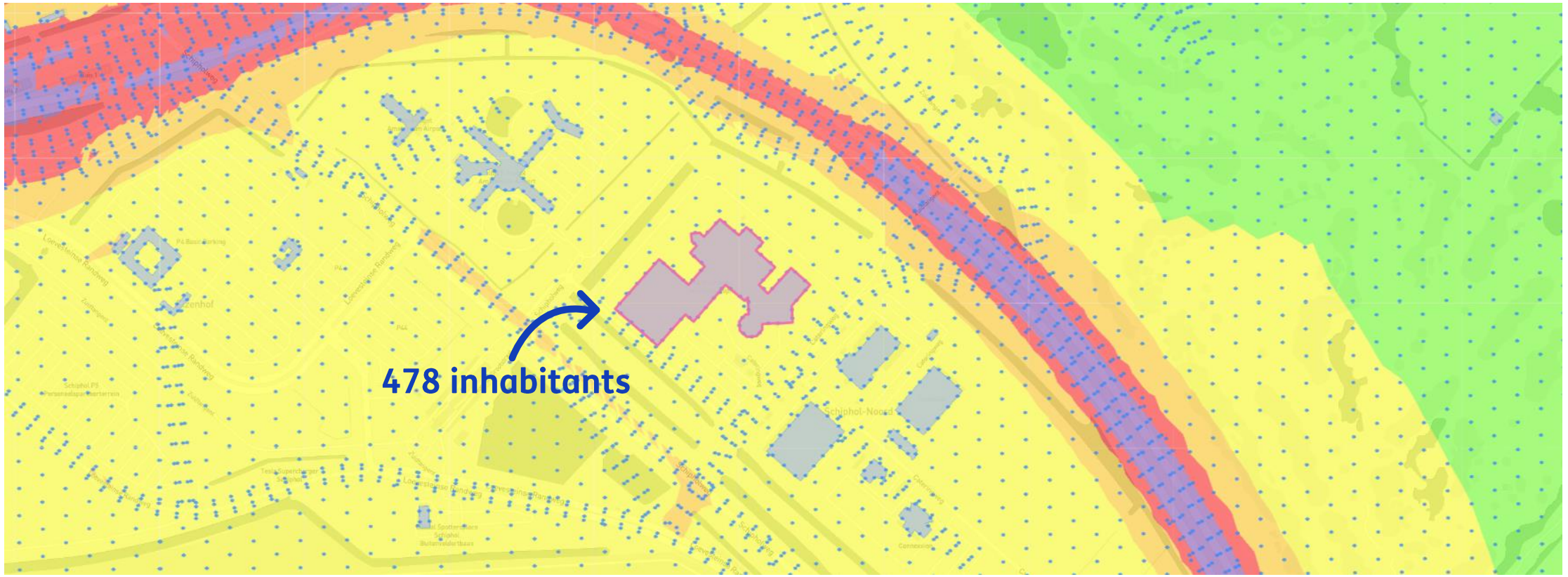


Air quality map: NO_2

Air Quality

Transportation demand → Traffic flow → Emissions → Concentrations → Exposure → Health impact effects



Air quality map: NO_2

Air Quality

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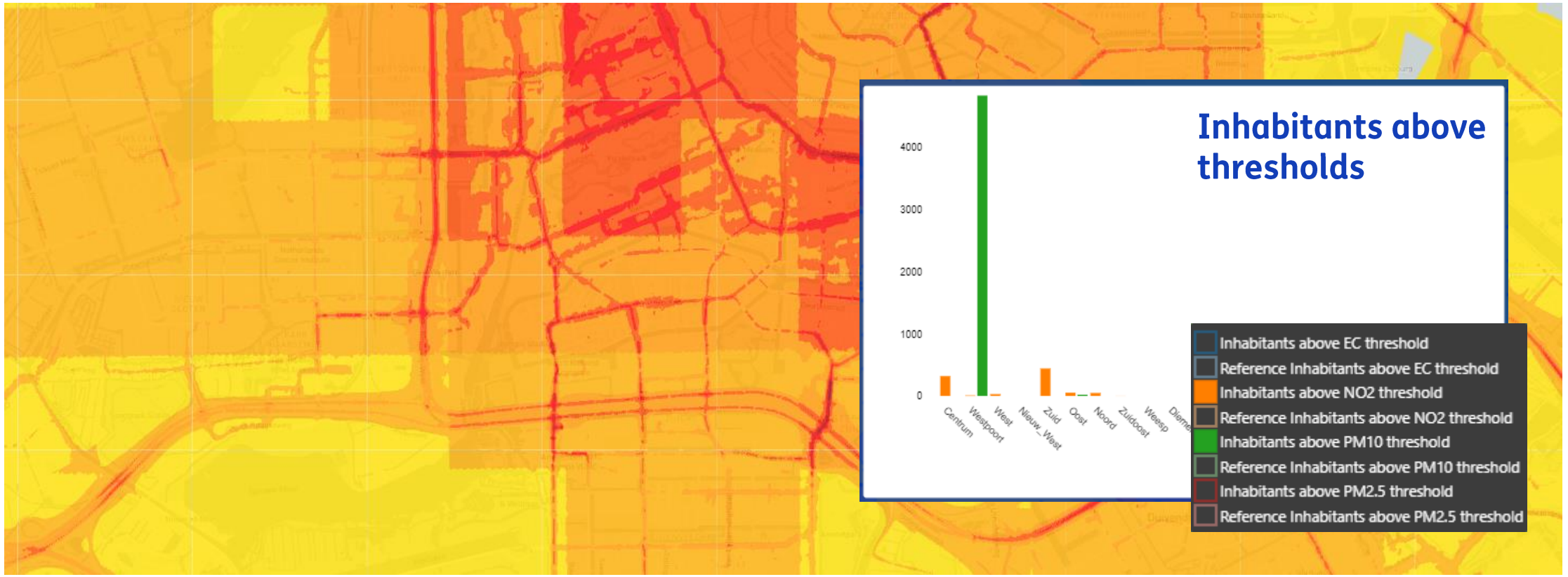


Air quality map: PM_{10}

Examples of use cases

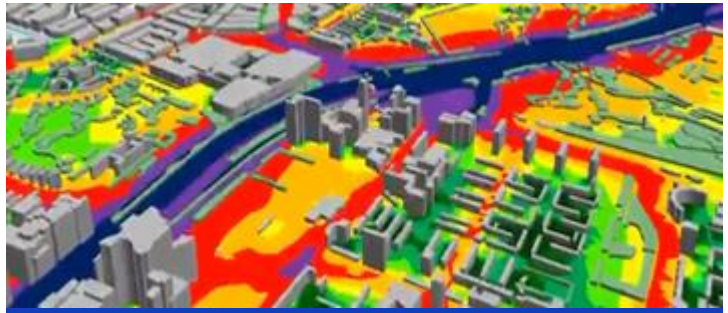
Digital Twin city of Amsterdam

Examples of use cases

Challenge

The city is growing within its limited boundaries. Newly built-up areas to be developed

This will lead to increasing pressure on the mobility system and the environment.



Approach

Jointly identify complex challenges and bottlenecks, using Urban Strategy to assess, monitor and evaluate system interventions.

Close the “learning cycle” and validate assumptions with the real-time data.

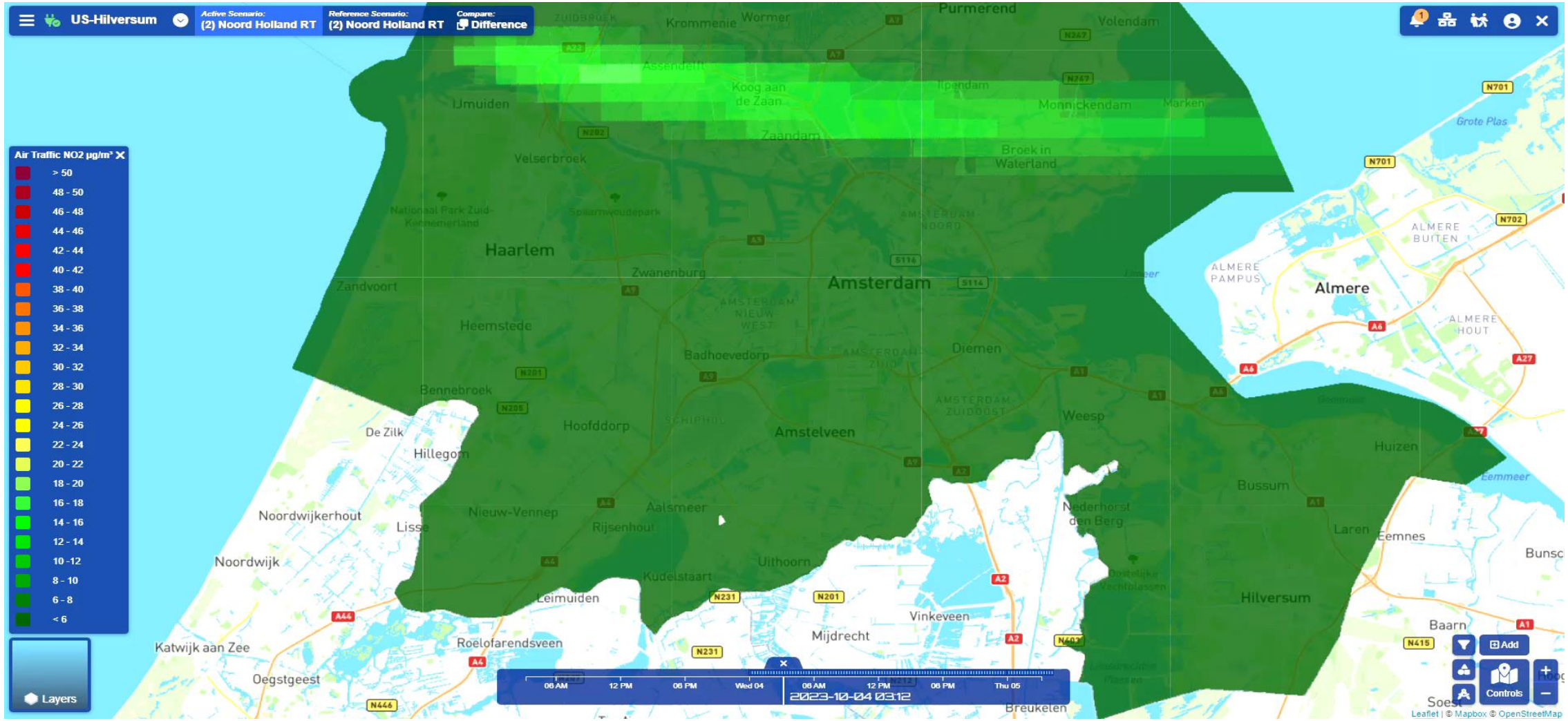
Results

Continuous support in challenge to redevelop parts of the city while maintaining accessibility.

Currently focused on the redevelopment of the business district: Amsterdam Zuidas

Integral urban planning city of Amsterdam

Examples of use cases



Real time air quality in the Amsterdam region

Examples of use cases

Challenge

In many German cities, the legal amounts of NO_2 set by the EU were exceeded. That leads local courts to act against those municipalities, increasing pressure on authorities to implement clean-air plans with quick results.

PTV GROUP
the mind of movement

TNO

Approach

City authorities in Hannover, Kiel, Heilbronn and Ludwigsburg suggest action plans.

Impact analysis study by PTV Group and TNO, sponsored by Volkswagen, with the use of Urban Strategy.

Results

The analysis found that a large impact could be attributed to the change of vehicle fleets, i.e. cleaner (or electric) engines.

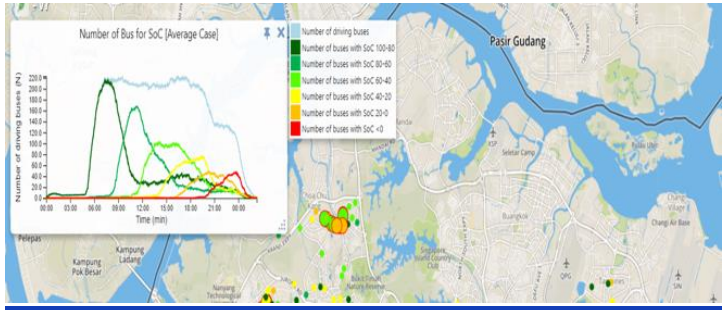
In all four cities positive impacts of fleet renewal were combined with planning and engineering measures in order to improve air quality quickly.

NO_2 emission reduction strategies in Germany
https://blog.ptvgroup.com/en/city-and-mobility/reducing-no2-car-emissions/

Examples of use cases

Land Transport Authority
We Keep Your World Moving

TNO



Challenge

Collaboration on assessment of concrete use-cases and (what-if) scenarios for bus electrification in Singapore.

Goal: Complete electrification in 2040 of Singapore's 6.000 buses

Approach

Assessment framework, development and application of e-Bus simulation model on different scenarios for E-Bus deployment strategies.

Taking into account charging strategies, routing, weather, and so on. Knowledge transfer to the Land Transport Authority (LTA).

Results

Assessment of use-cases (what-if) scenarios.

Tailored platform for LTA as a central instrument for informed decision making.

Zero emission strategy for busses in Singapore

Let’s improve our cities together

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