Optimized Design of Low Emission Zones in SUMO: A Dual Focus on Emissions Reduction and Travel Time Improvement

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for Advanced Network Engineering and Digital Services

MASMOVIL

APUESTA POR EL TALENTO JOVEN UNIVERSITARIO

ABOUT US…

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- Prof. Dr. Alvaro Paricio-García
- Al. Pablo Mangano-Redondo.

Universidad de Alcalá www.uah.es

- Included in best 500 world-wide universities.
- 12th university in Spain.
- 5 QS stars.
- 22.000 students (2024), 10,48% foreign.
- Programs: 48 Bachelor, 57 Máster, 29 Doctorate

Catedra MANEDS: catedramaneds.web.uah.es

- Created in 2023.
- Working in Transport since 2018.
- Supported by MasMovil-Orange, biggest Telecom Operator in Spain (Thanks for it!)
- Research in Applied AI + Simulation + Optimization:
  - Transport
    - Urban transport
    - Pedestrian flows and emergency situations
  - IoT and networks:
    - Asset Management and Optimization.
    - Intelligent Conversational Agents
    - Process Discovery & Optimization

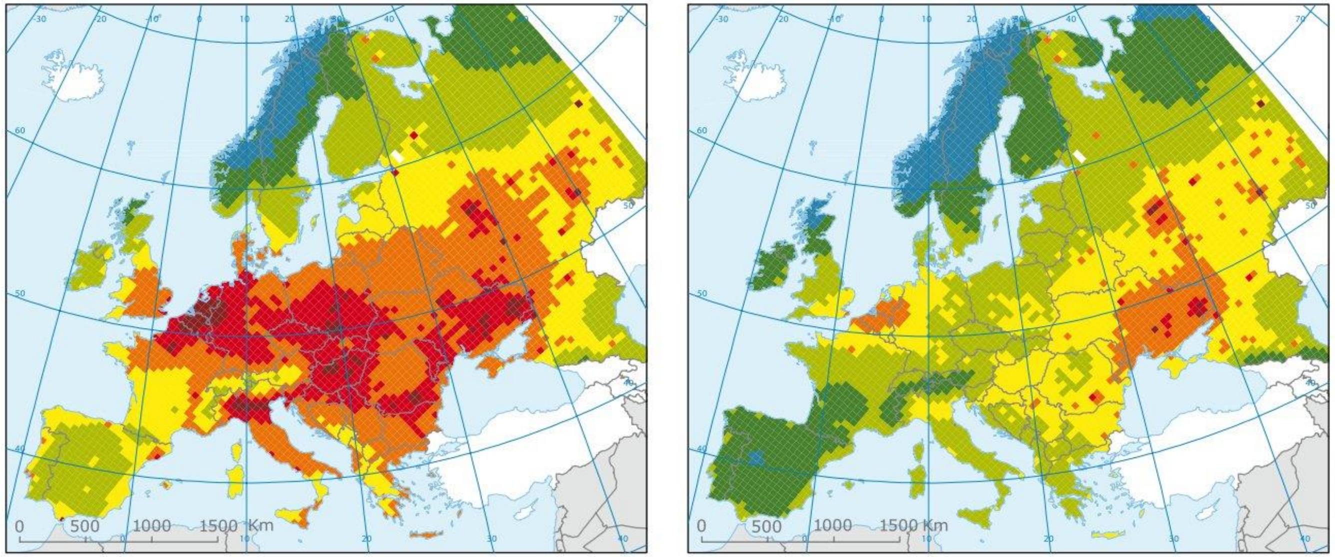
LOW EMISSIONS ZONES (LEZ)

AKA:

- Environment Zones,
- Umweltzonen (Germany),
- Zonas de Bajas Emisiones (Spain)
- Milieuzones (Netherlands),
- ZCR, Zone à Circulation Restreinte (France)
- Lage-emissiezone (Belgium)
- Clean Air Zones (England)
- Miljøzone (Denmark),
- Miljözon (Sweden),
- Lavutslippssone (Norway),
- Alacsony Kibocsátási Övezet (Hungary),
- ZTL ambiente (Italy).

- Mandatory deployment in the EU for urban environments.
- Two main implementation ways:
  - Eliminating the traffic.
  - Removing internal combustión engines (petrol, diesel, gas).
- Effect of emissions over the human health:

Loss of statistical life expectancy (months) that can be attributed to anthropogenic contributions to $PM_{2.5}$ for the emission levels in 2000 (left), and projected emission levels of the Thematic Strategy on Air Pollution for 2020 (right)



Loss in statistical life expectancy that can be attributed to man-made emissions of $PM_{2.5}$ for the emission levels in the year 2000 (left), and projected emission levels of the Thematic Strategy for 2020 (right)

Months 0–1 1–2 2–4 4–6 6–9 9–12 12–36 Outside report coverage

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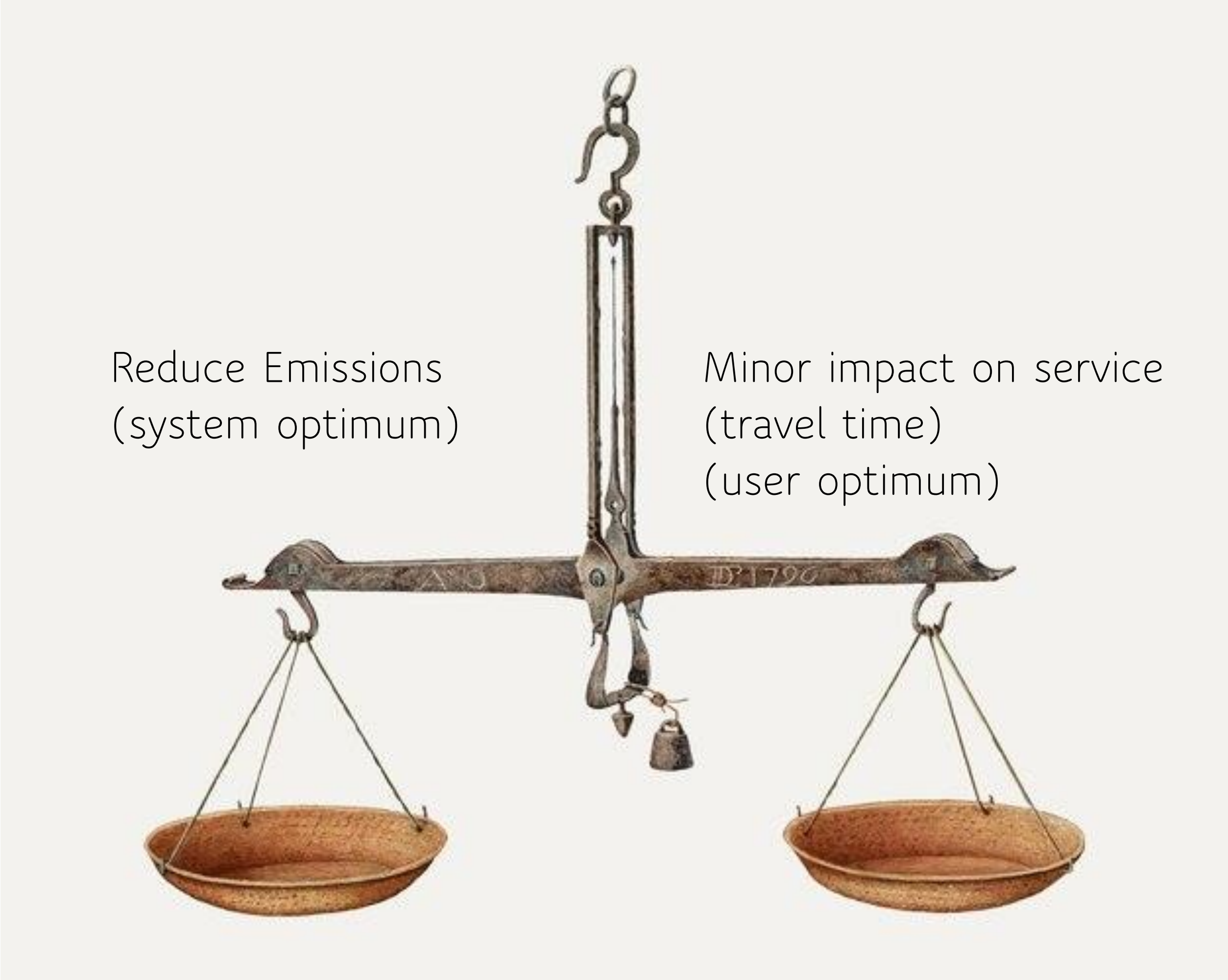
Low Emission Zones: Balancing emissions and travel time



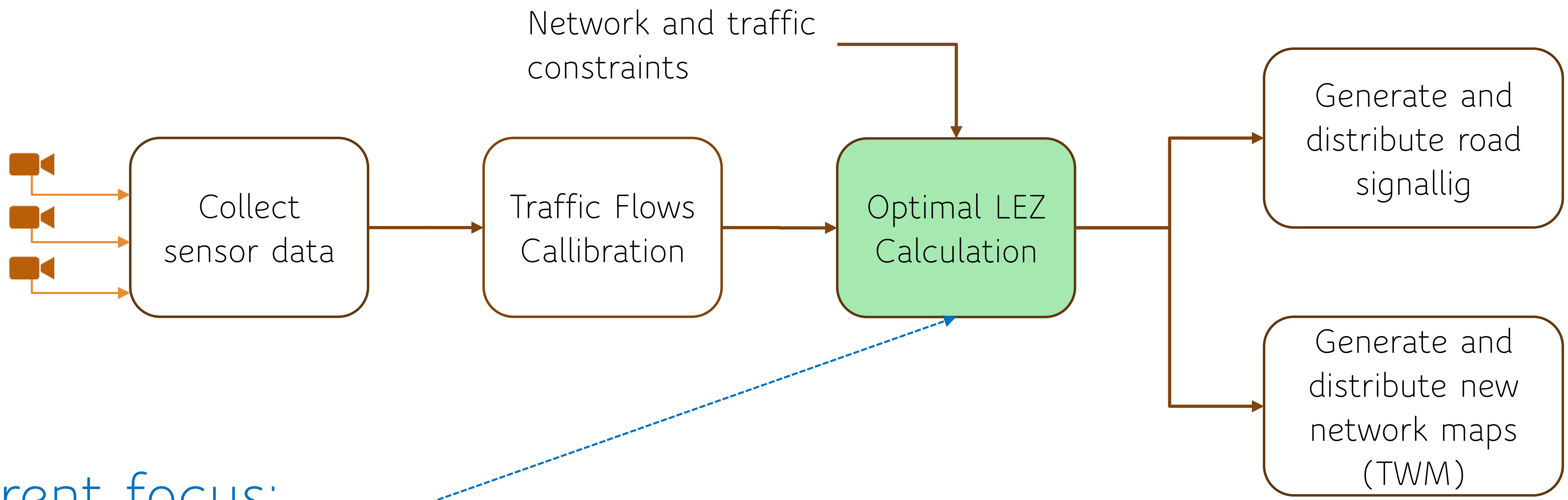
- How to reduce emissions, fulfilling the required objectives, at the minimum user cost?

Source: www.freepik.es

Should LEZs dynamically adapt to current traffic demand?

- Should the LEZ be **always ON**? When should it be active?
- What would be the right LEZ coverage? Adapted to the demand?
- How can it be operated?

Dynamic LEZ Design



Current focus:

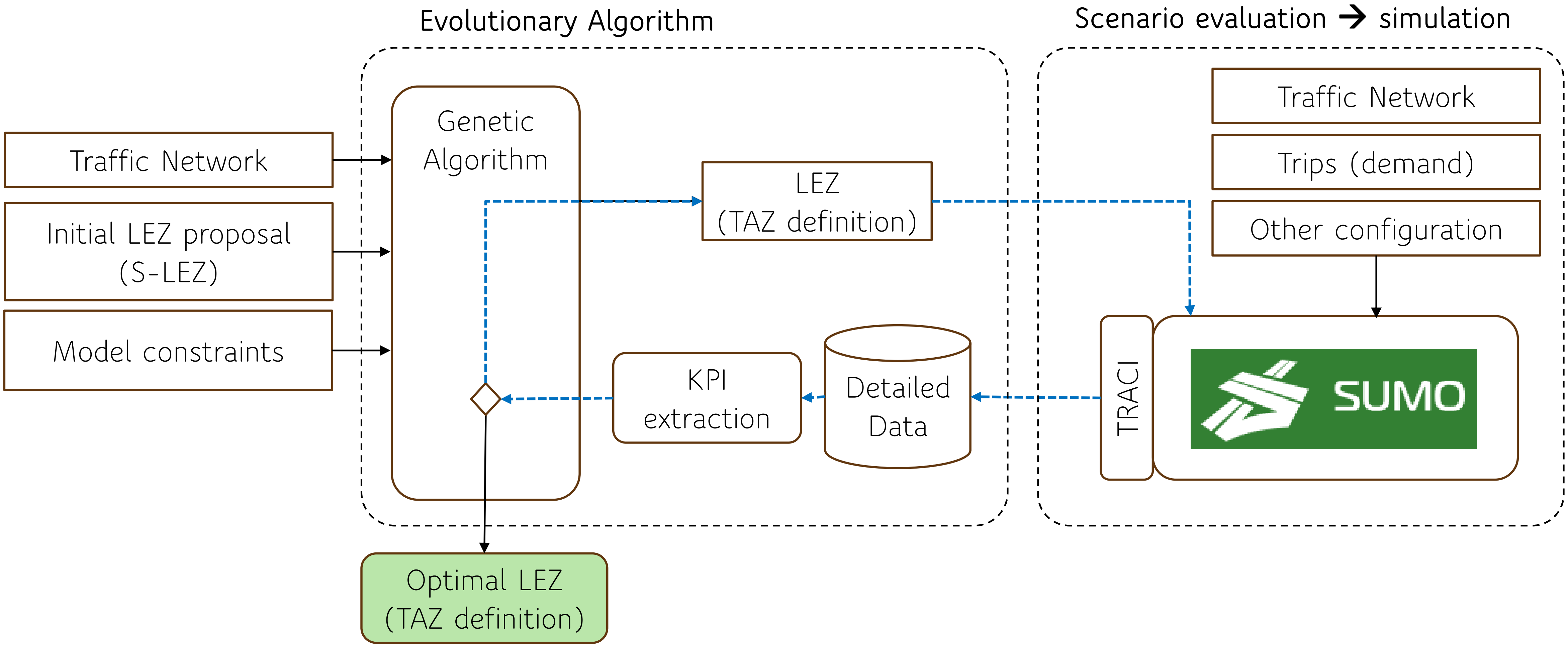
“Optimized Design of Low Emission Zones in SUMO: A Dual Focus on Emissions Reduction and Travel Time Improvement”

Optimal LEZ problem statement

- Problem statement:
  - Given a traffic **network**
  - Given a traffic **demand** (**traffic flows** between TAZs or individual trip sets),
  - Given a set of **emission standards and safety thresholds**
  - Given a set of **vehicle types**
  - And given a set of **regulatory constraints** and **urban policies**

- The objective: obtain the minimum set of edges conforming a LEZ, so that:
  1. The emissions generated for the considered traffic period are **under the acceptable threshold**
  2. **Most polluting edges** are selected with priority
  3. The **travel times** for the demand suffer a **minimum impact** when compared to the same travel time without considering any LEZ.
  4. The LEZ edges cover a **continuum área**: all the edges must be connected.
  5. The **constraints are fulfilled**
  6. The **traffic policies are fulfilled**

Optimal LEZ Designer



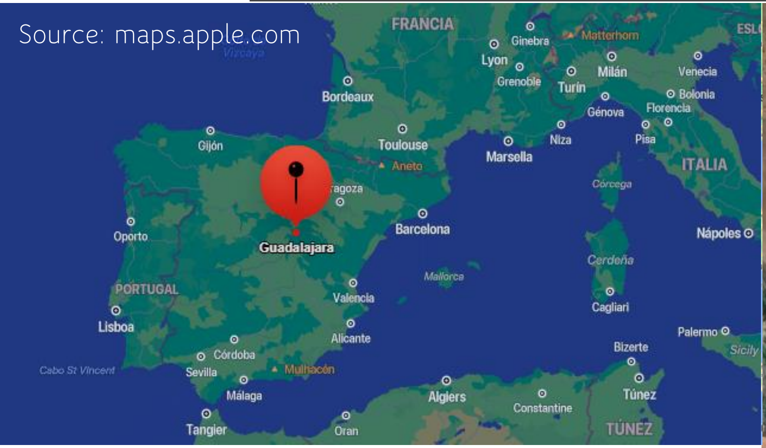
Evolutionary Algorithm Detailed Model

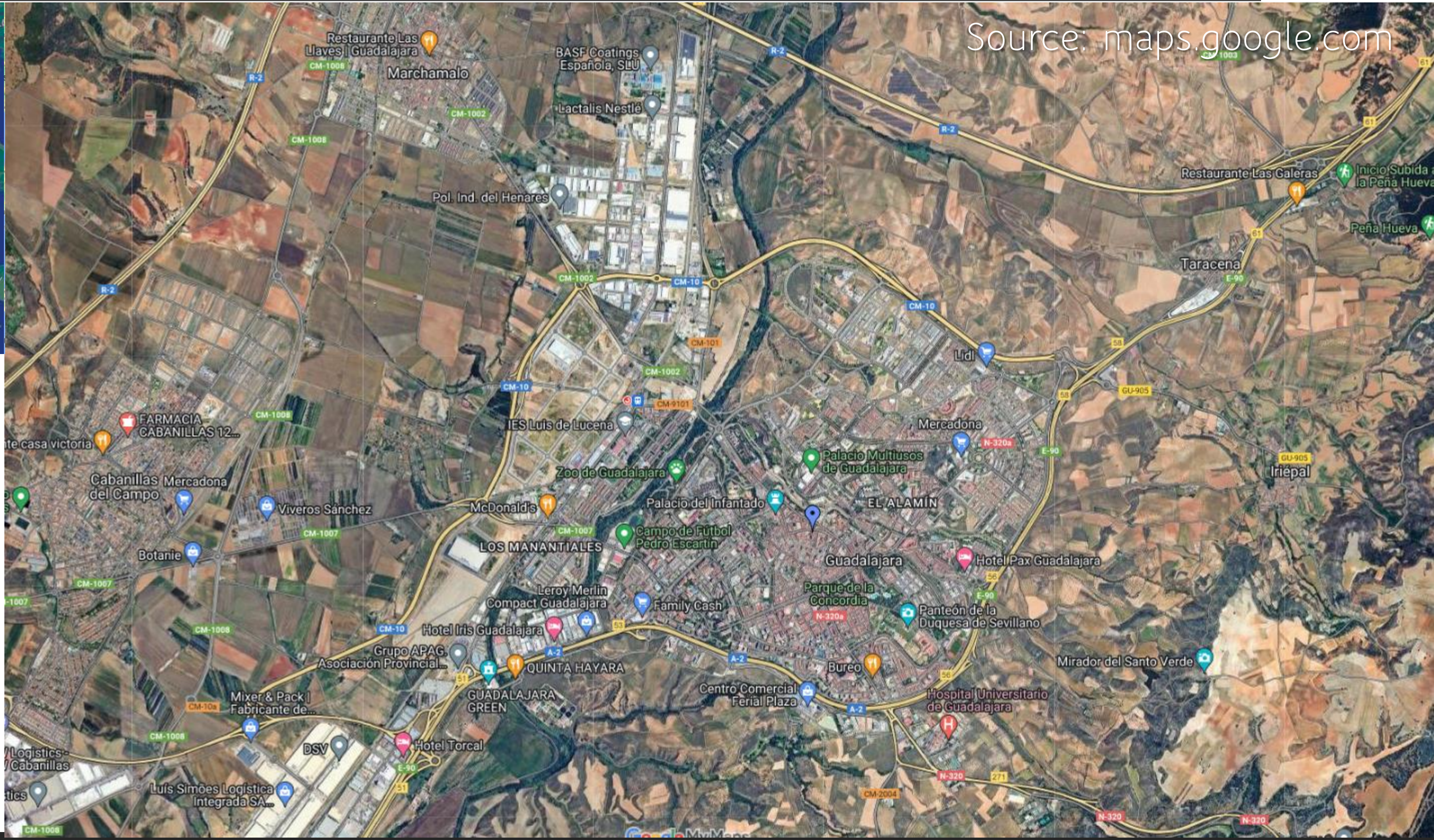
- Genes of the chromosome represent "**edge membership**":
  - Binary values for genes: {0,1} → {edge outside, edge inside}
  - The chromosome has K genes: $K = (E - J) - H - L)$
    - E = number of edges in the network
    - J = number of edges in the excluded regions (see constraints)
    - H = number of edges with highest emissions in the area (always present).
    - L = edges that "legally" must be included in the LEZ (historical, pedestrian, etc).
- Fitness function:
  - Comparing current values to those obtained in the standard official LEZ.
  - Weighted (w_i) combination of emissions ratio (ER) and waiting times ratio (WTR).

$$fitnessValue = w_E \cdot ER + w_W \cdot WTR \begin{cases} ER = \dfrac{\sum_{i \notin C} emissions_i}{\sum_{\forall i} emissions_i} \\[2ex] WTR = \dfrac{\sum_{i \notin C} waitingTime_i}{\sum_{\forall i} waitingTime_i} \end{cases}$$

- Genetic Algorithm, Python implementation using numPY.

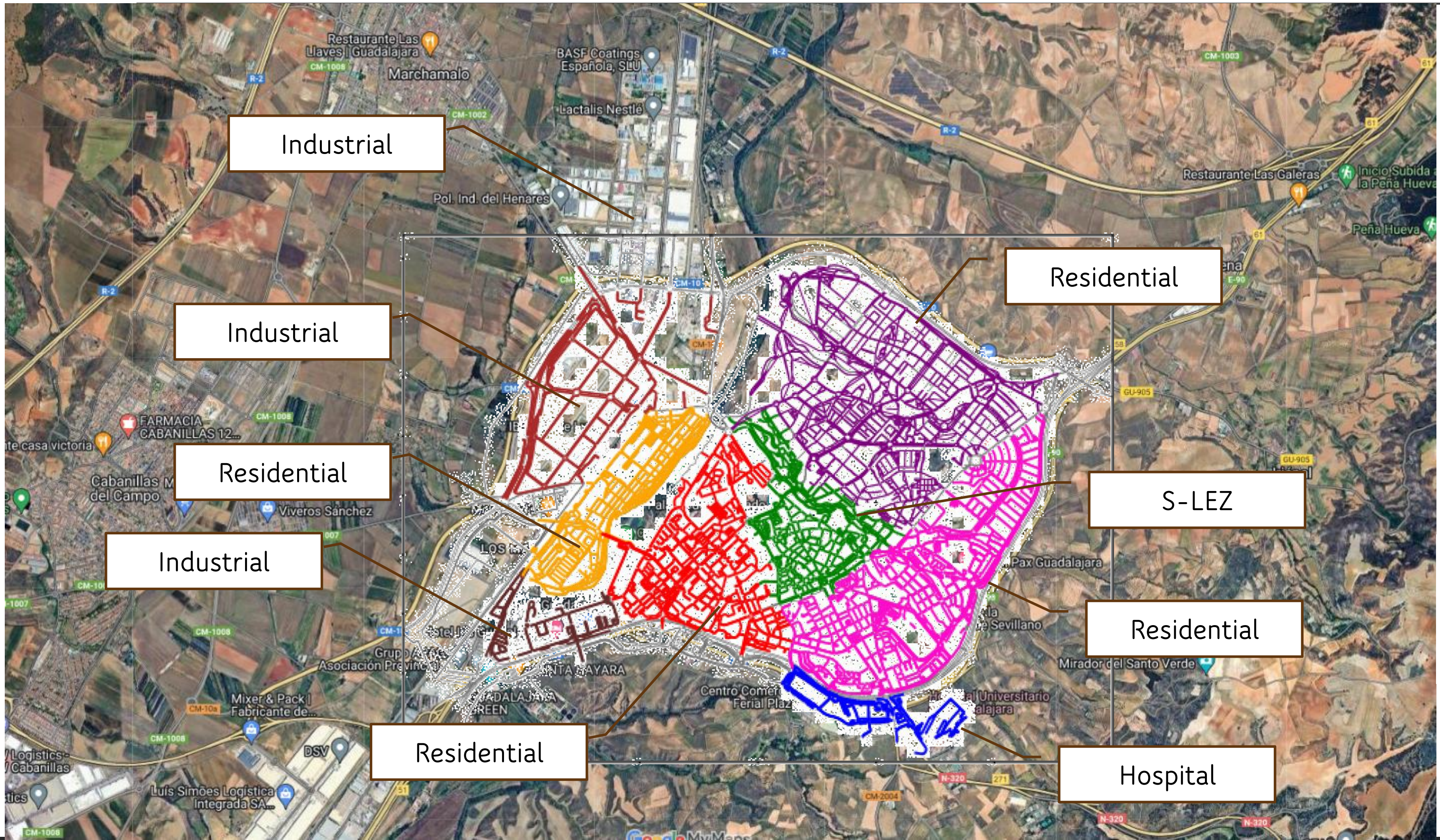
Experimental scenario: Guadalajara (Spain)





- Head of province.
- 50km from Madrid in the way to Barcelona.
- 90K population.
- 235,51 km^2.
- Growing fastly as an important logistics center due to the strategic position.
- In Jan-2024 created its first LEZ.

Guadalajara (Spain) utility model (TAZ)



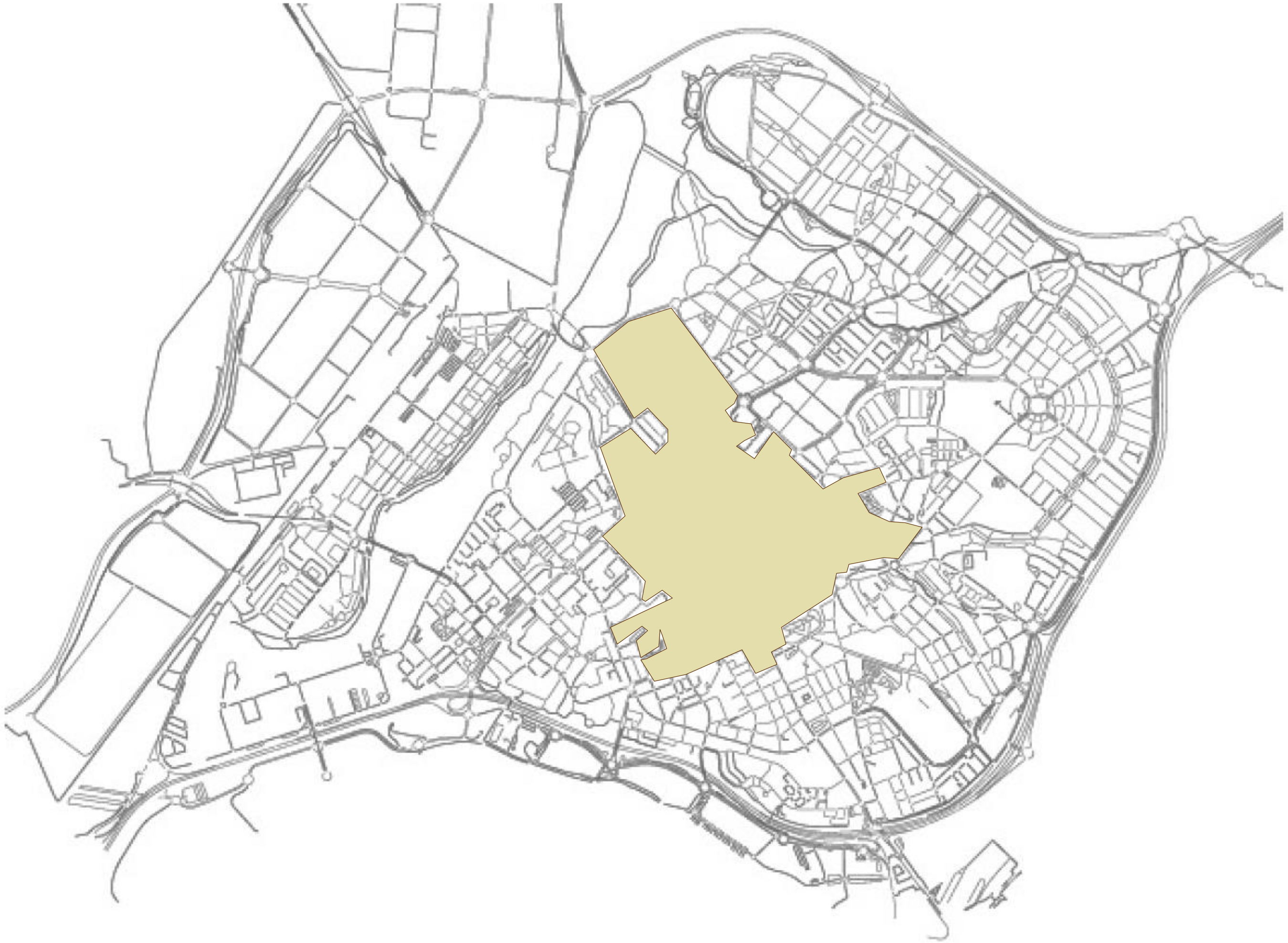
TAZ	Edges
LEZ	2101
Ejercito	1241
Balconcillo	218
Henares	286
CComercial	468
Manantiales	831
Sanroque	1678
Aguasvivas	2207

Brown: *Balconcillo*
Red: *Ejercito*
Yellow: *Manantiales*
Maroon: *Henares*
Blue: *Hospital*
Pink: *Sanroque*
Green: *LEZ*
Purple: *Aguasvivas*

Maps from OpenStreetMaps

Guadalajara's Standard LEZ (S-LEZ)

- Defined in 2023 → active in 01/04/2024
- Fixed Coverage: 718.000 m2
- 80 detection cameras, fiber-connected
- Emissions reduction objective: 14%
- Traffic allowed to:
  - Resident population + restricted guests
  - Workers and businesses.
  - Taxis and service vehicles.
  - School-related traffic



Guadalajara experimental constraints

- ✓ Topological connectivity of the edges → cannot create LEZ unconnected isles.
- ✓ Topological anchoring → LEZ must include historical area (pedestrian)
- ✓ Topological bounding → LEZ cannot expand out of certain áreas (highways, industrial areas).
- ✓ Volume bounding → LEZ cannot exceed a máximum of 10% of the whole network.
- ✓ Emissions bounding → LEZ must reduce emissions by 14%.

Traffic Demand

- A synthetic demand is used, for Mid-Sized traffic (M).
- Scaled by *k-factor*, into a T-Shirt model.

Demand size"M": TAZ flows (aprox. 1k.veh/h)

	Ejercito	Balconcillo	Henares	CComercial	Manantiales	Sanroque	Aguasvivas
Ejercito	67	67	67	67	67	67	67
Balconcillo	67	67	67	67	67	67	67
Henares	67	67	67	67	67	67	67
Hospital	67	67	67	67	67	67	67
Manantiales	67	67	67	67	67	67	67
Sanroque	67	67	67	67	67	67	67
Aguasvivas	67	67	67	67	67	67	67

Simulation time = 1h.

Scaling later using T-Shirt sizing:

Size	Factor
XS	$\frac{1}{3}$ of M
S	$\frac{1}{2}$ of M
M	1 (Base Size)
L	2 times M
XL	3 times M

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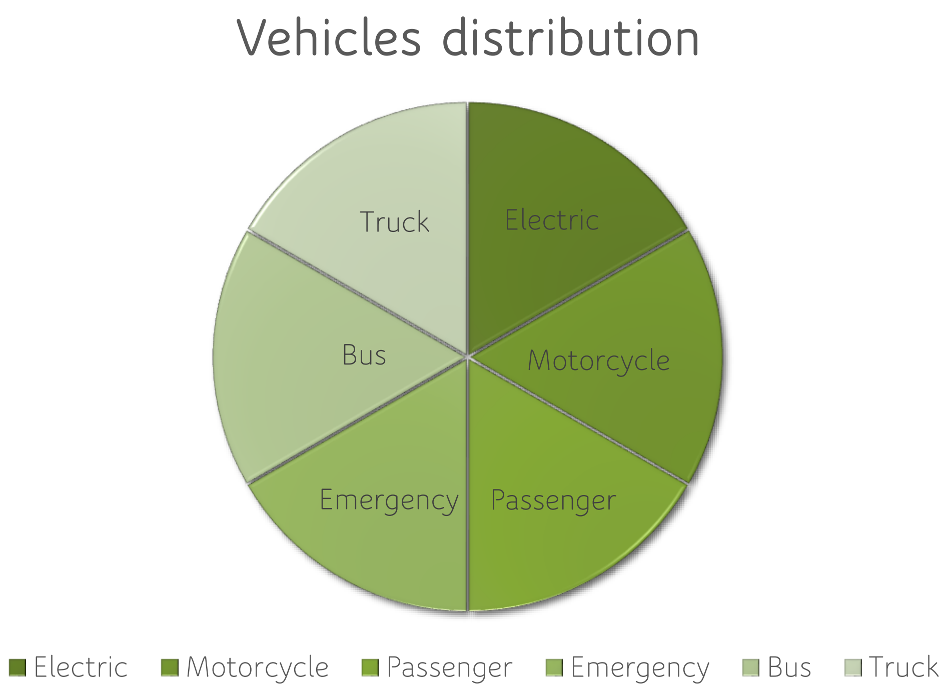
Emissions Model

- HBEFA v3.1 emission model.
- SUMO provides CO2, CO, HC, Nox, PMx and fuel consumption metrics
- It is a generic model for any pollutant. Here we focus on CO2 as an example.



Example Configurations

Kia Soul EV 2020

The values are provided by courtesy of Jim Div based on his own calibration.

```
<vType id="soulEV65" minGap="2.50" maxSpeed="29.06" color="white" accel="1.0" decel="1.0" sigma="0.0" emissionClass="Energy/unknown">
    <param key="has.battery.device" value="true"/>
    <param key="airDragCoefficient" value="0.35"/>       <!-- https://www.evspecifications.com/en/model/e94fa0 -->
    <param key="constantPowerIntake" value="100"/>       <!-- observed summer levels -->
    <param key="frontSurfaceArea" value="2.6"/>          <!-- computed (ht-clearance) * width -->
    <param key="rotatingMass" value="40"/>               <!-- guesstimate, inspired by PHEMLight5 PC_BEV -->
    <param key="maximumBatteryCapacity" value="64000"/>
    <param key="maximumPower" value="150000"/>           <!-- website as above -->
    <param key="propulsionEfficiency" value=".98"/>      <!-- guesstimate value providing closest match to observed -->
    <param key="radialDragCoefficient" value="0.1"/>     <!-- as above -->
    <param key="recuperationEfficiency" value=".96"/>    <!-- as above -->
    <param key="rollDragCoefficient" value="0.01"/>      <!-- as above -->
    <param key="stoppingThreshold" value="0.1"/>         <!-- as above -->
    <param key="vehicleMass" value="1830"/>              <!-- 1682kg curb wt + average 2 passengers / bags -->
</vType>
```

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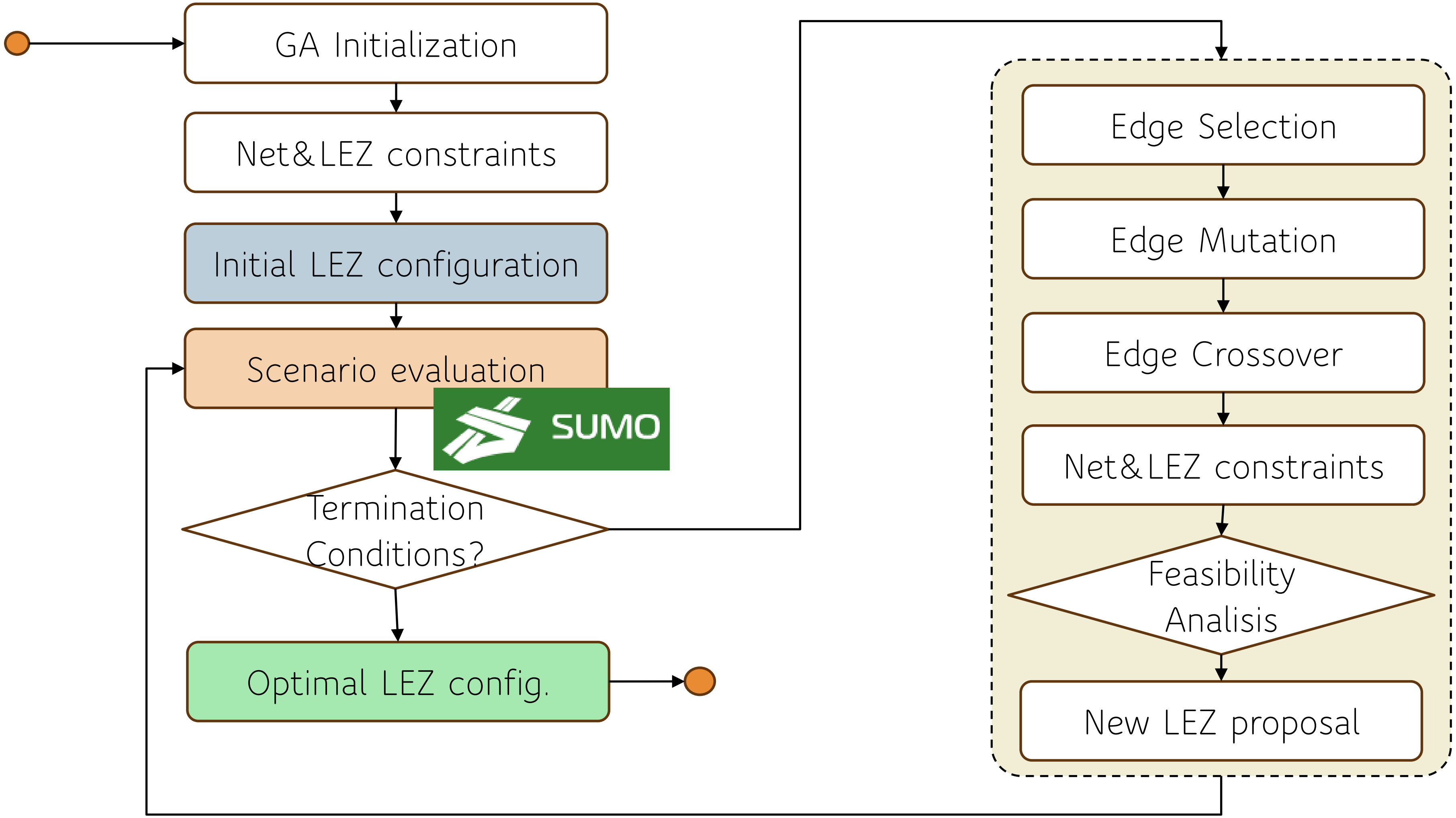
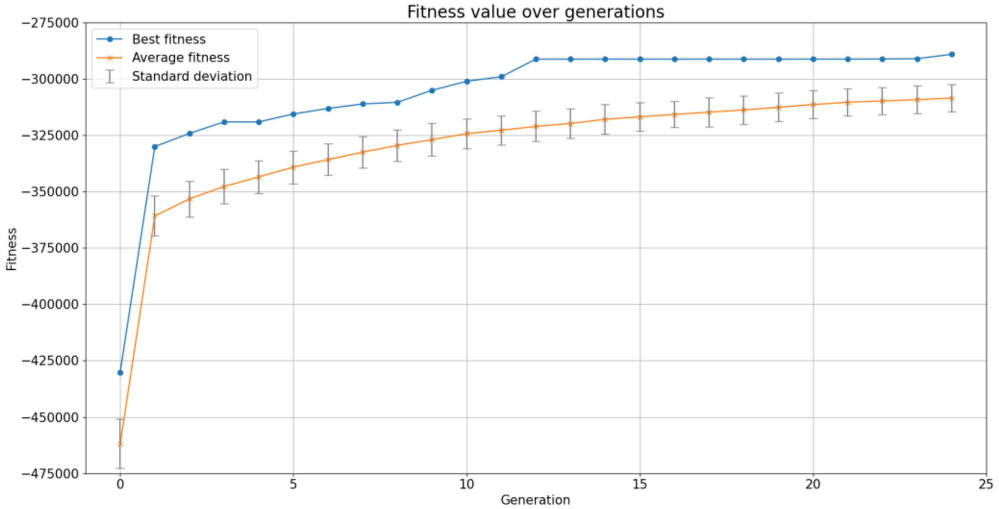
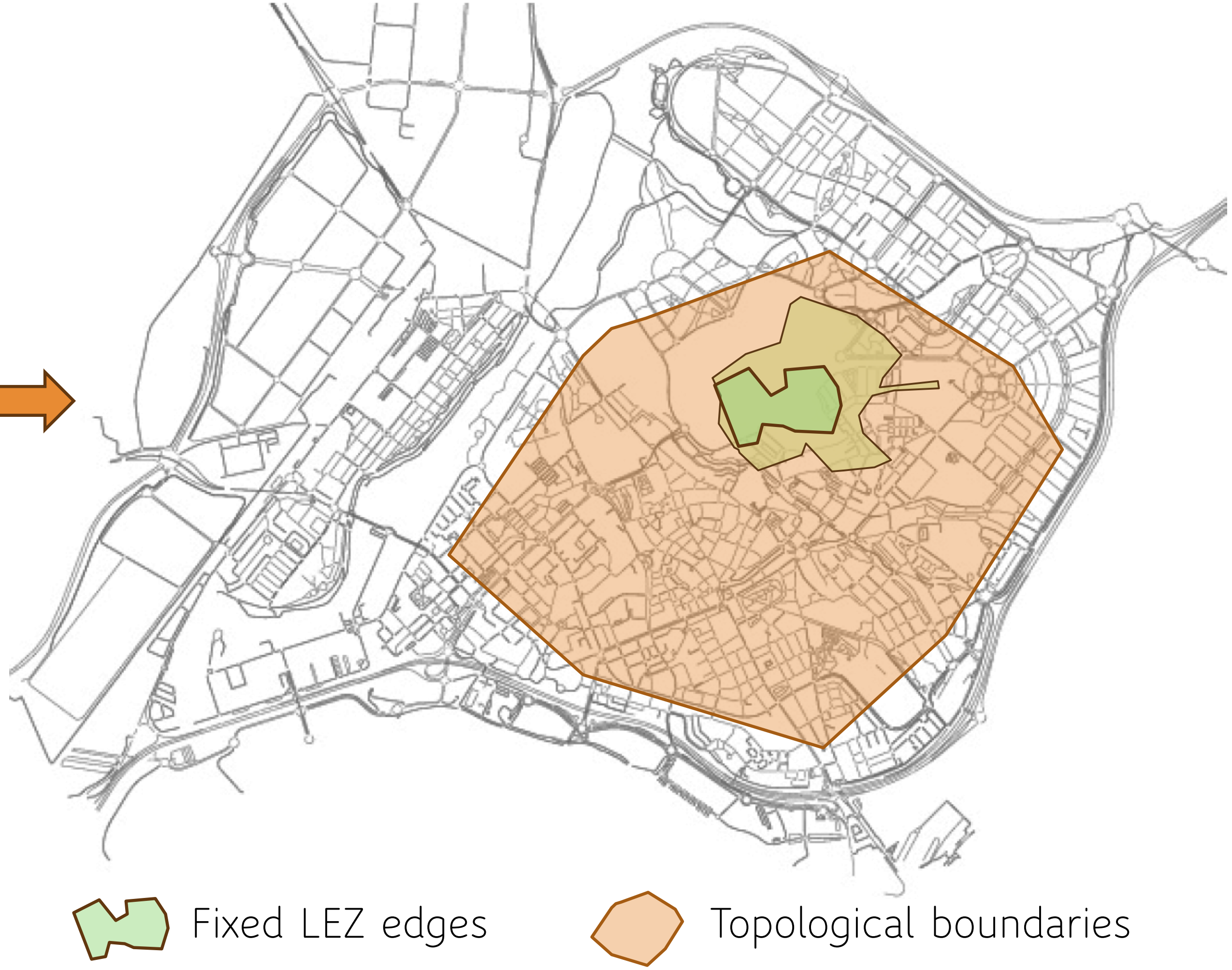
Evolutionary algorithm



Calculating the O-LEZ for the M-demand

- Evolutionary algorithm details:
  - Population size: 500
  - Max. Number of generations: 25
  - Tournament selection: 3
  - Mutation rate: 0.01 (1%)
  - Crossover: 0.8 (80%)

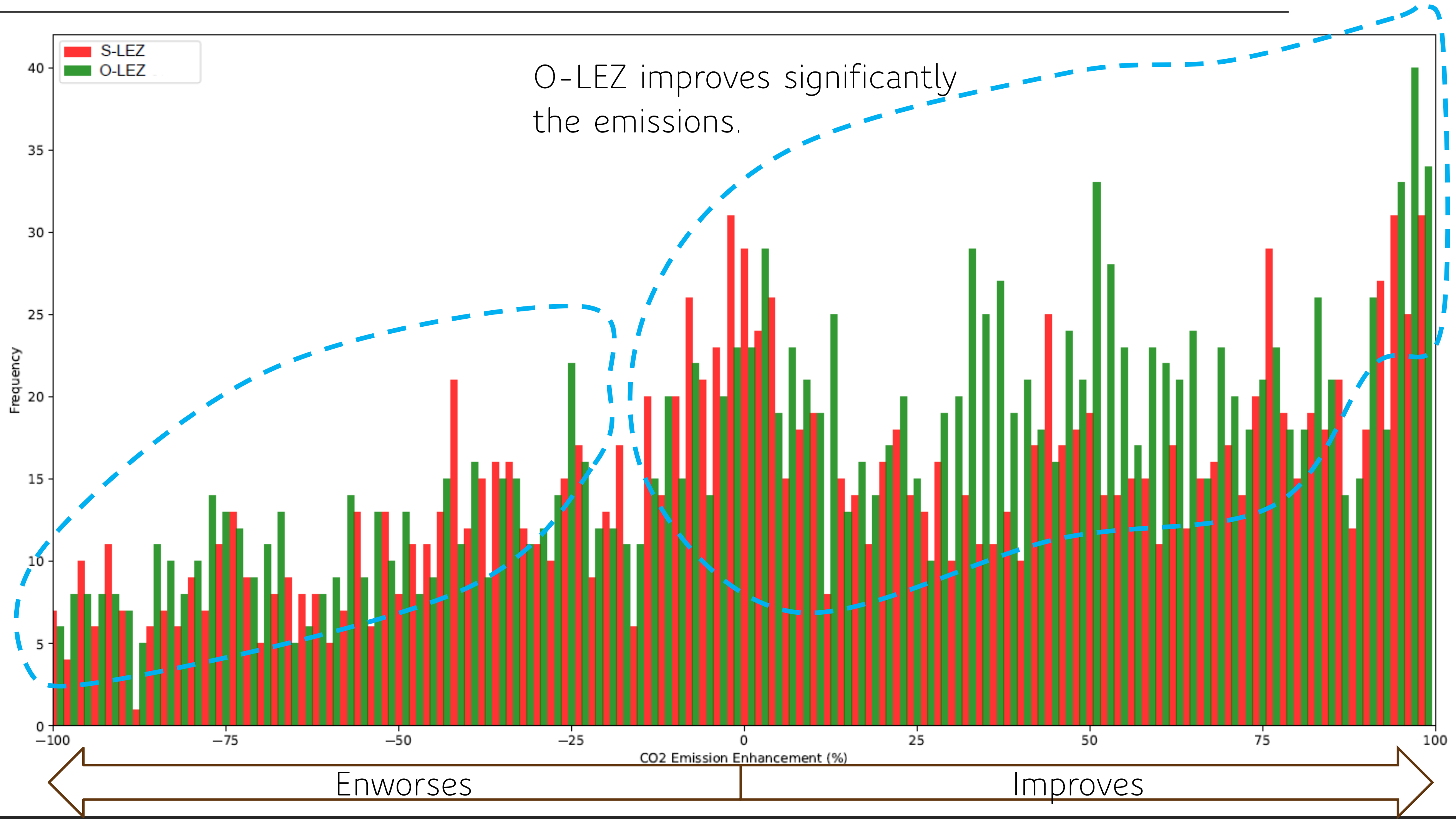




The Standard LEZ (S-LEZ) vs. the Optimized O-LEZ (M-demand)

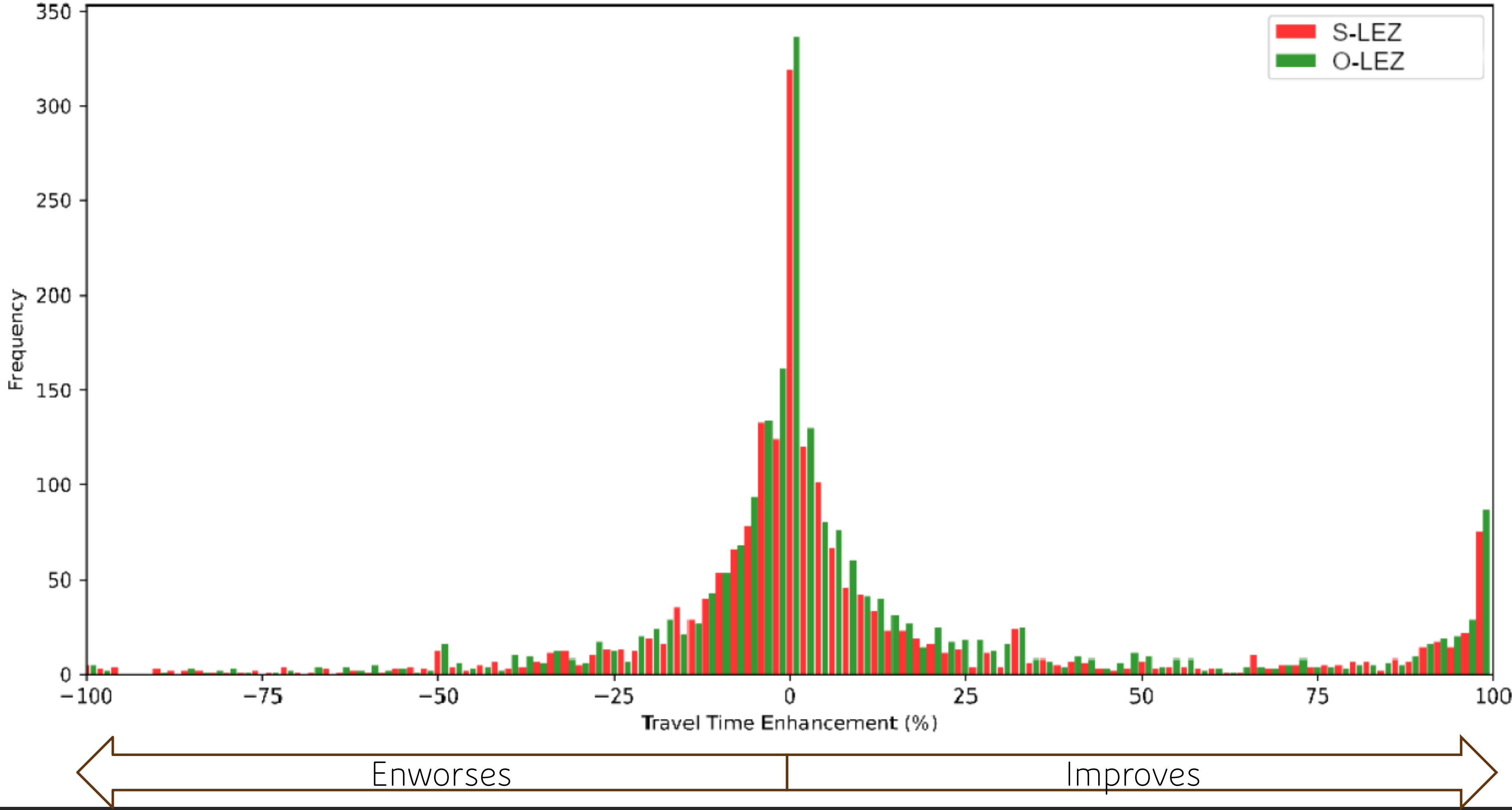
Relative emissions improvement (S-LEZ vs. O-LEZ)

- Comparison of emissions impact when applying different LEZs.
  - Paired stats: comparing individual behavior.

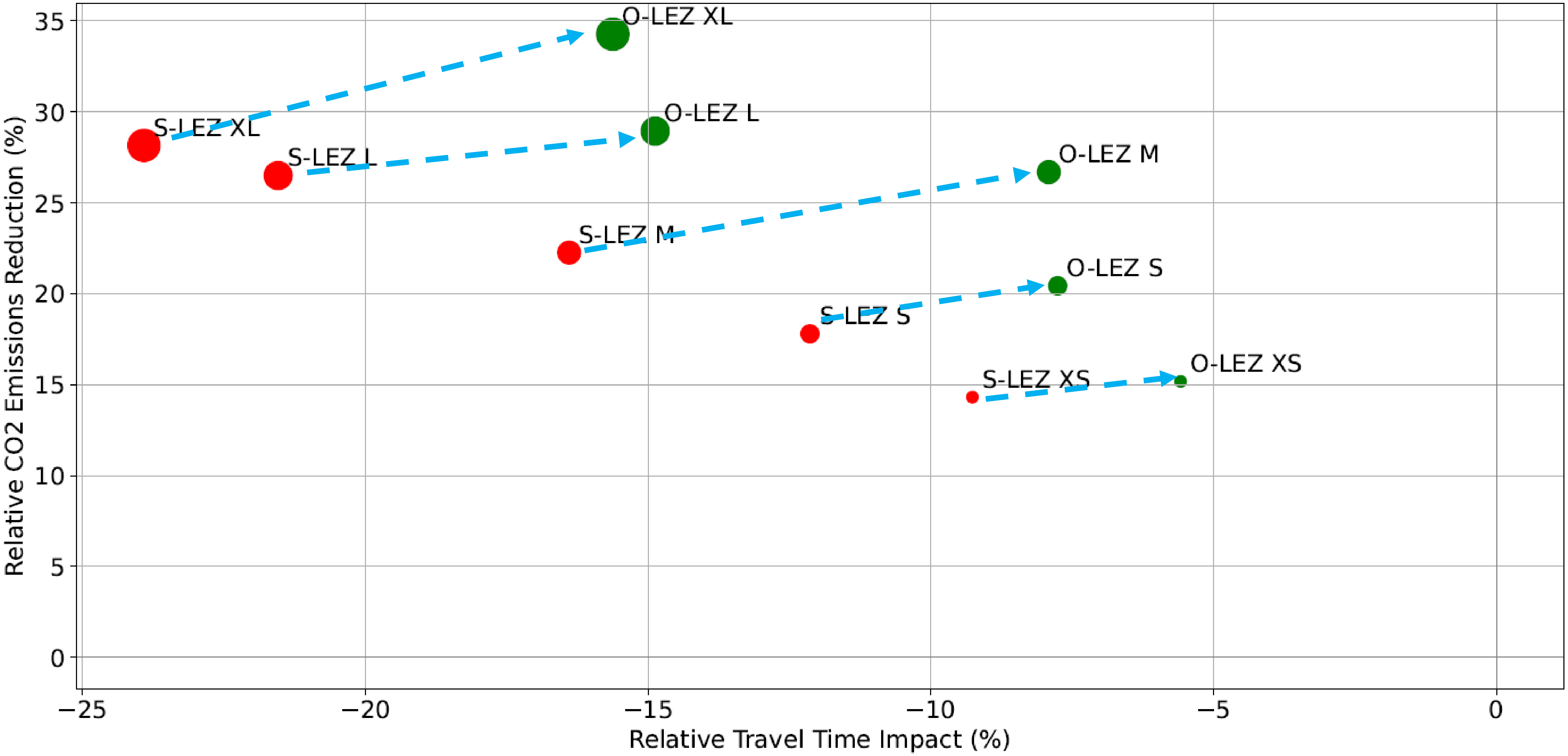


Relative travel time improvement (S-LEZ vs. O-LEZ)

- Leptokurtic distribution.
- The optimized LEZ improves the travel time, as we wanted.



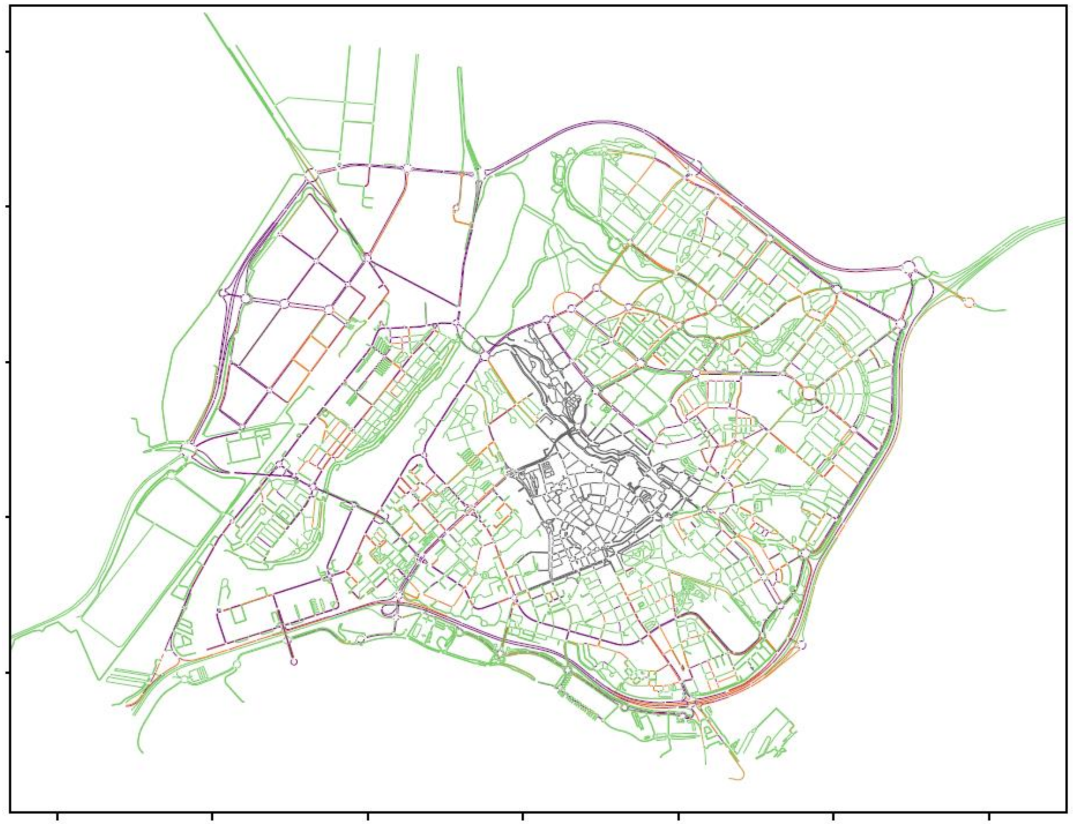
Relative Improvement in Emissions and Travel Time for different Demand Sizes.



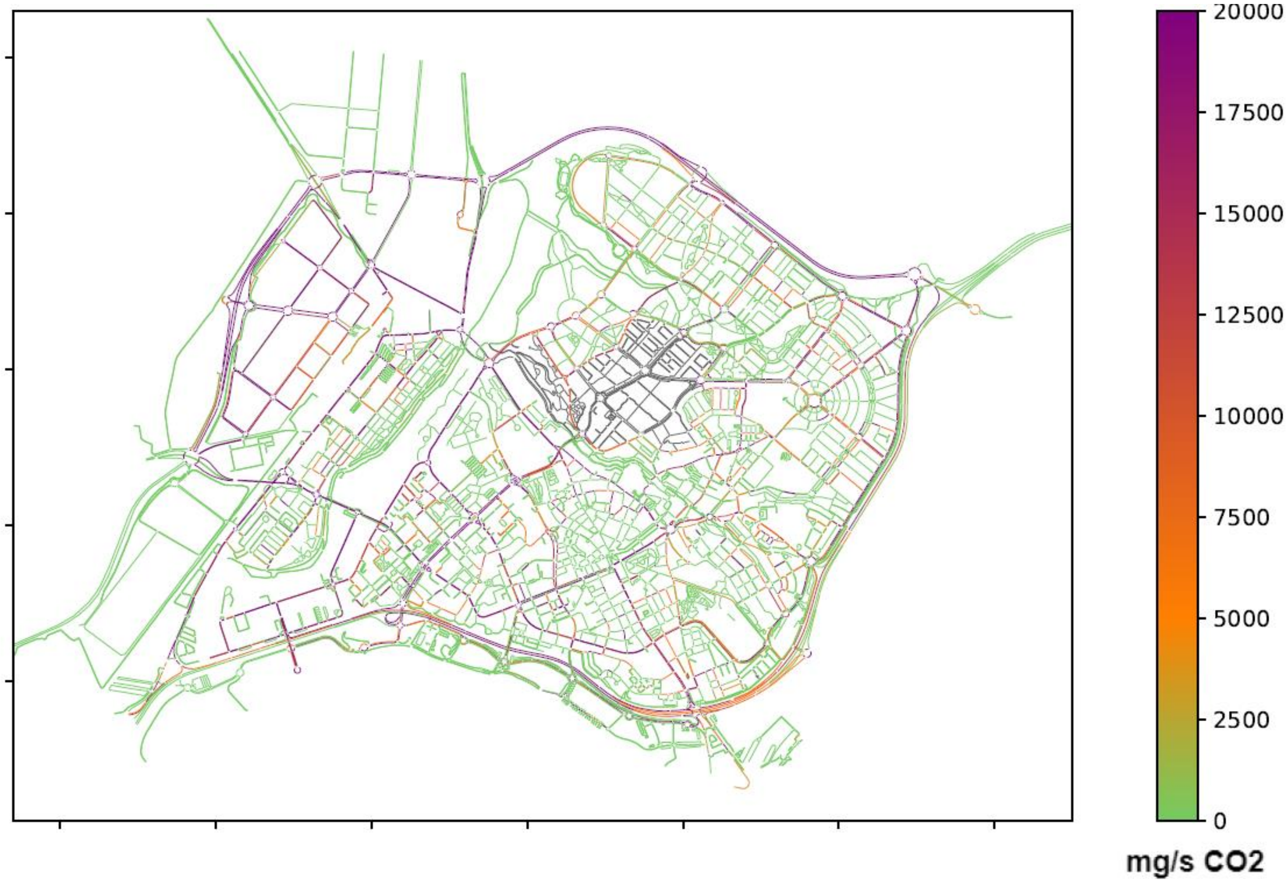
Relative Improvement in Emissions and Travel Time for different Demand Sizes.

Size	O-LEZ Travel Time (%)	S-LEZ Travel Time (%)	O-LEZ CO2 (%)	S-LEZ CO2 (%)
XS	- 5.58	- 9.26	15.18	14.31
S	- 7.76	- 12.14	20.43	17.79
M	- 7.91	- 16.40	26.68	22.26
L	- 14.87	- 21.54	28.94	26.49
XL	- 15.62	- 23.91	35.27	28.15

Comparing emissions (S-LEZ vs. O-LEZ)

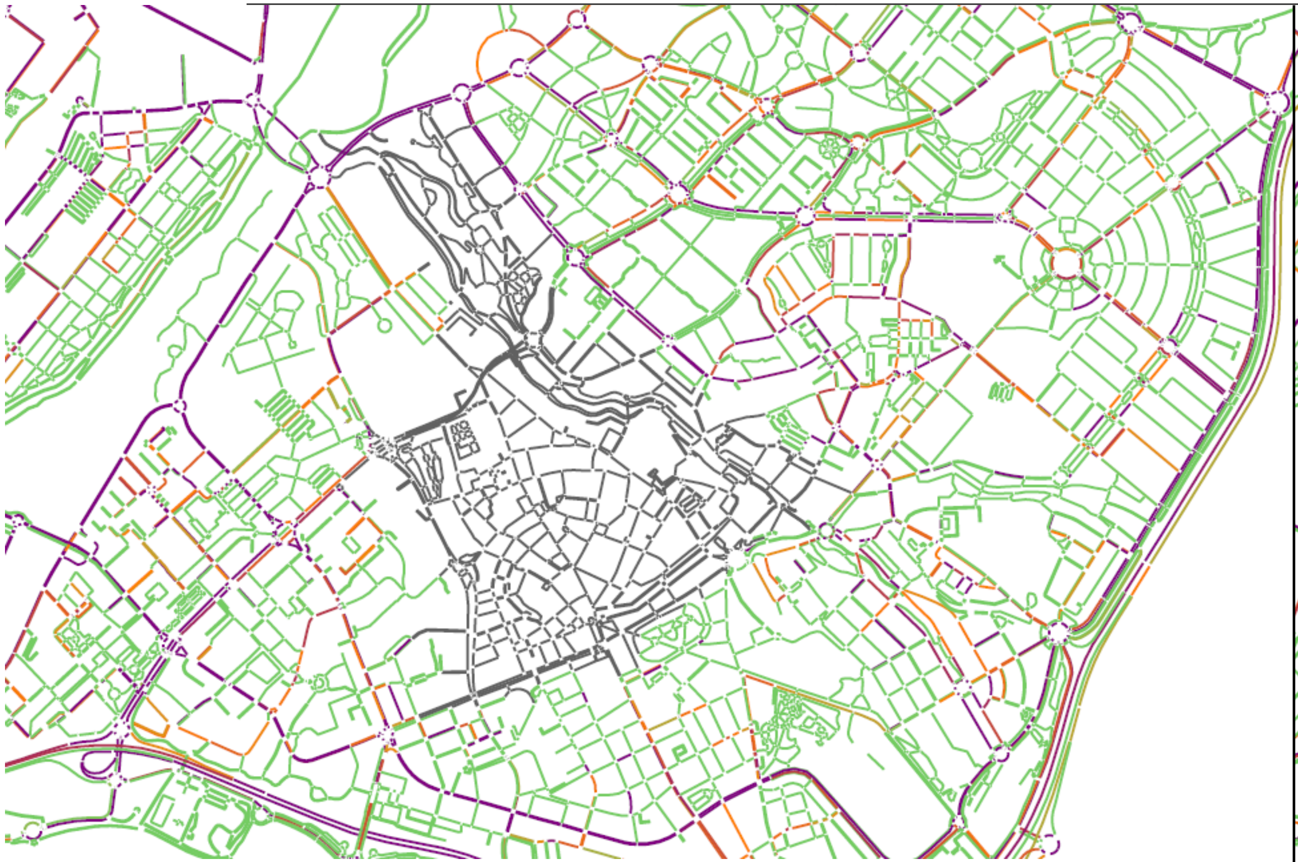


Standard LEZ

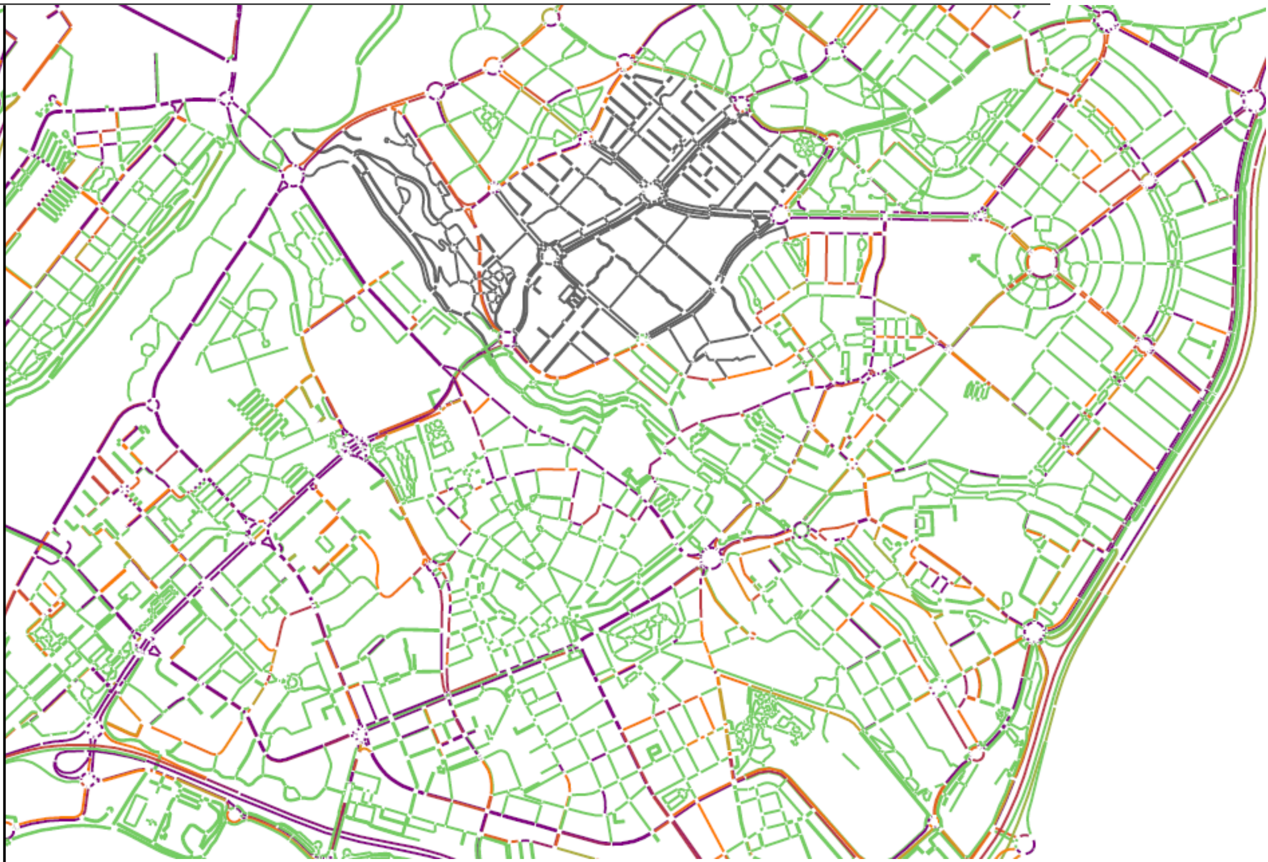


Optimized LEZ

Comparing emissions (S-LEZ vs. O-LEZ) Zoomed …

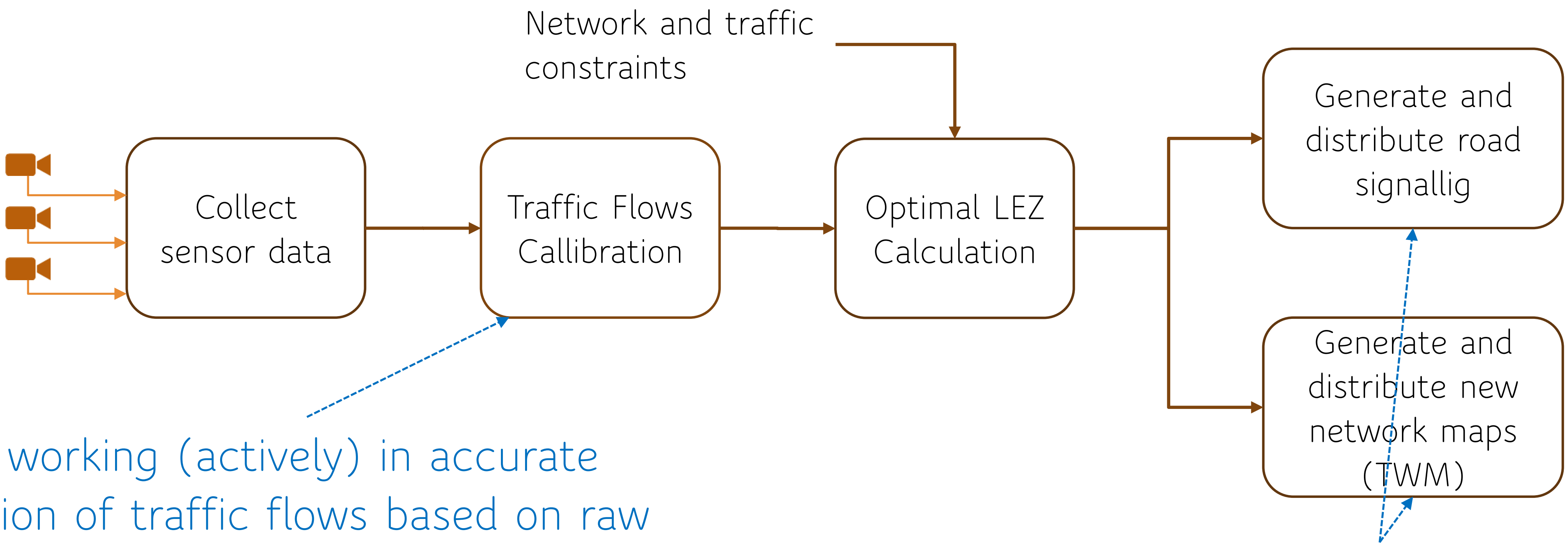


Standard LEZ



Optimized LEZ

Where are we now?



We are working (actively) in accurate estimation of traffic flows based on raw sensor measurement, using AI-based learning and SUMO as data-generator for training.

We are revisiting our TWM map generation platform for simulation and cloud-servicing

Future works

- Implement dynamic access policies for LEZs for different fleets.
- LEZ constraints based on graph databases.
- Implementation in multiple urban scenarios: bigger, more complex, more variations.
- Adapt LEZs flexibly to environmental conditions.
- Calibrate traffic flows to accurately reflect real-world scenarios.
- Implement dynamic traffic signaling for LEZ management.

THANK YOU!!!

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SUMO Advantages and challenges

- Advantages of using SUMO:
  - Traci is a great integration interface.
  - Rich configuration capaciblities (additional files).
  - Demand modelling and trip generation.
- SUMO Challenges:
  - TAZ access restrictions hard to manage.
  - SUMO wrapping for detectors creation and positioning.
  - Long microscopic simulations are hard to execute, but mesoscopic simulation requires extra features.

- We have many suggestions and ideas for SUMO ….

Our Previous Works in Traffic Simulation

- Differential Traffic Routing and Dynamic Management (Multimaps, TWM)
  - Paricio, A., y M. A. Lopez-Carmona. «Urban traffic routing using weighted multi-map strategies». *IEEE Access, IEEE* 7 (2019): 153086-101. https://doi.org/10.1109/ACCESS.2019.2947699.
  - Paricio, A., y M. A. Lopez-Carmona. «Application of traffic weighted multi-map optimization strategies to traffic assignment». *IEEE Access* 9 (2021): 28999-19. https://doi.org/10.1109/ACCESS.2021.3058508.
  - Paricio., A., y M. A. Lopez-Carmona. «Modeling Driving Experience in Smart Traffic Routing Scenarios: Application to Traffic Multi-Map Routing». *IEEE Access* 9 (2021): 90170-84. https://doi.org/10.1109/ACCESS.2021.3091322.

- Traffic Planning
  - Paricio-Garcia, Alvaro, y Miguel A. Lopez-Carmona. «Application of traffic weighted multi-maps based on disjoint routing areas for static traffic assignment». *Applied Sciences* 13, n.º 18 (2023). https://doi.org/10.3390/app131810071.
  - Paricio-Garcia, Alvaro, y Miguel A. Lopez-Carmona. «Impact of static urban traffic flow-based traffic weighted multi-maps routing strategies on pollutant emissions». *Systems* 12, n.º 3 (2024). https://doi.org/10.3390/systems12030089.

- Crossings, Intersections and roudabouts:
  - Cruz-Piris, Luis, Miguel A. Lopez-Carmona, y Ivan Marsa-Maestre. «Automated Optimization of Intersections Using a Genetic Algorithm». *IEEE Access* 7 (2019): 15452-68. https://doi.org/10.1109/ACCESS.2019.2895370.
  - Cruz-Piris, Luis, Ivan Marsa-Maestre, y Miguel A. Lopez-Carmona. «A Variable-Length Chromosome Genetic Algorithm to Solve a Road Traffic Coordination Multipath Problem». *IEEE Access* 7 (2019): 111968-81. https://doi.org/10.1109/ACCESS.2019.2935041.
  - Ibanez, Guillermo, Tobias Meuser, Miguel A. Lopez-Carmona, y Diego Lopez-Pajares. «Synchronous Roundabouts with Rotating Priority Sectors (SYROPS): High Capacity and Safety for Conventional and Autonomous Vehicles». *Electronics* 9, n.º 10 (octubre de 2020): 1726. https://doi.org/10.3390/electronics9101726.

Our Previous Works in Traffic Simulation

- Pedestrian Simulation and Management:

  - Lopez-Carmona, Miguel A., y Alvaro Paricio Garcia. «LED Wristbands for Cell-Based Crowd Evacuation: An Adaptive Exit-Choice Guidance System Architecture». *Sensors* 20, n.º 21 (2020). https://doi.org/10.3390/s20216038.
  - Lopez-Carmona, Miguel A., y Alvaro Paricio Garcia. «CellEVAC: An adaptive guidance system for crowd evacuation through behavioral optimization». *Safety Science, Elsevier BV, Amsterdam* 139 (julio de 2021): 105215. https://doi.org/10.1016/j.ssci.2021.105215.
  - Lopez-Carmona, Miguel A., y Alvaro Paricio Garcia. «Adaptive cell-based evacuation systems for leader-follower crowd evacuation». *Transportation Research Part C: Emerging Technologies* 140 (1 de julio de 2022): 103699. https://doi.org/10.1016/j.trc.2022.103699.
  - Lopez-Carmona, Miguel A., y Alvaro Paricio Garcia. «Linear and nonlinear Model Predictive Control (MPC) for regulating pedestrian flows with discrete speed instructions». *Physica A: Statistical Mechanics and its Applications* 625 (1 de septiembre de 2023): 128996. https://doi.org/10.1016/j.physa.2023.128996.
  - Lopez-Carmona, Miguel A., y Alvaro Paricio Garcia. «Multiple-Input-Single-Output prediction models of crowd dynamics for Model Predictive Control (MPC) of crowd evacuations». *Transportation Research Part C: Emerging Technologies* 154 (2023): 104268. https://doi.org/10.1016/j.trc.2023.104268.
  - Lopez-Carmona, Miguel A., y Alvaro Paricio-Garcia. «Crowd Evacuation Management with Optimal Time-Multiplexed Exit-Choice Recommendations through Simulation Optimization». *Advanced Theory and Simulations* n/a, n.º n/a (abril de 2024): 2400265. https://doi.org/10.1002/adts.202400265.
