Managing Urban Traffic and Air Quality: Simulation Techniques and Practical Applications

DS-RT 2024 Tutorial

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Motivation

Why Managing Urban Traffic and Air Quality Matters

- Traffic congestion and air pollution are critical urban challenges
- Cities are adopting Low Emission Zones (LEZs) to reduce pollution and improve air quality
- EU legislation, such as Directive 2008/50/EC, sets rigorous air quality standards for pollutants: NOx, PM10
- Simulations are essential tools for developing strategies that balance urban mobility and pollution reduction

The Role of Simulation Tools

Simulation Tools for Traffic and Air Quality

- Simulate traffic to optimize flow and reduce congestion.
- Model air quality impacts to ensure regulatory compliance.
- Combined simulations optimize urban traffic management and air quality.

What Traffic Simulations Can Solve

- How to reduce peak-hour congestion while maintaining air quality?
- Which traffic strategies lower emissions?
- What's the impact of LEZ on traffic and air quality?
- Will increasing the number of electric vehicles depollute the city center?
- Can preventing diesel vehicles from entering the city center reduce pollution?

Open-Source Tools for Solving the Challenges

We'll use these free tools to explore solutions for urban traffic and air quality.

- SUMO: github.com/eclipse-sumo/sumo
- GRAL: github.com/GralDispersionModel/GRAL
- SUMO2GRAL: github.com/seniel98/SUMO2GRAL

- Dotnet SDK: dotnet.microsoft.com/download/
- Python: python.org/download/

Outline

4 stages

- Building Traffic Networks
- Creating Traffic Demand
- Traffic Simulation
- Air Quality Analysis

Outline

Stage 1

Building Traffic Networks

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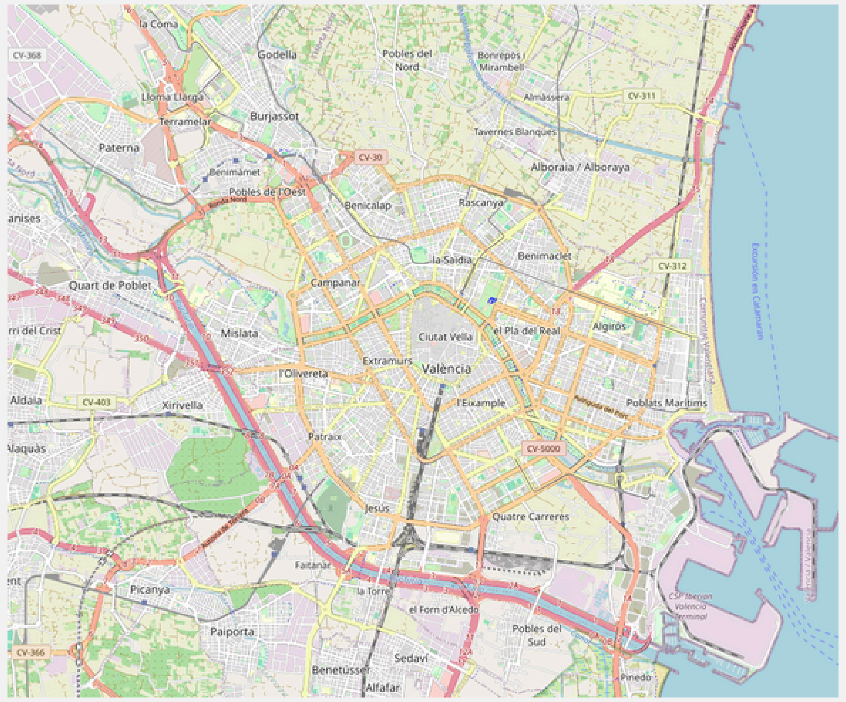
Building Traffic Networks

Problem

- Creating realistic and accurate traffic networks is essential for simulations.
- Provides basis for: Traffic flow & signal control
- NETCONVERT issues:
  - Incorrect lane directions
  - Missing/misplaced traffic signals
  - Unreliable intersection layouts
- Result: Unrealistic simulations

Solution

- Manually correction with NETEDIT
- Enhances accuracy of traffic flow simulations -> more reliable results



Open Street Map

SUMO Network

Building Traffic Networks with NETCONVERT

NETCONVERT converts real-world map data into SUMO's network format (.net.xml)

- **netconvert --osm my_osm_net.xml**

```
<net version="1.20" junctionCornerDetail="5" limitTurnSpeed="
    <location netOffset="-718110.23,-4366672.38" convBoundary
    <type id="highway.secondary" priority="11" numLanes="1" s
    <type id="highway.secondary_link" priority="6" numLanes="
    <type id="highway.service" priority="1" numLanes="1" spee
    <type id="highway.tertiary" priority="10" numLanes="1" sp
    <type id="highway.tertiary_link" priority="5" numLanes="1
    <type id="highway.track" priority="1" numLanes="1" speed=
    <type id="highway.unclassified" priority="4" numLanes="1"
    <edge id=":100994353_0" function="internal">
        <lane id=":100994353_0_0" index="0" allow="private em
    </edge>
```

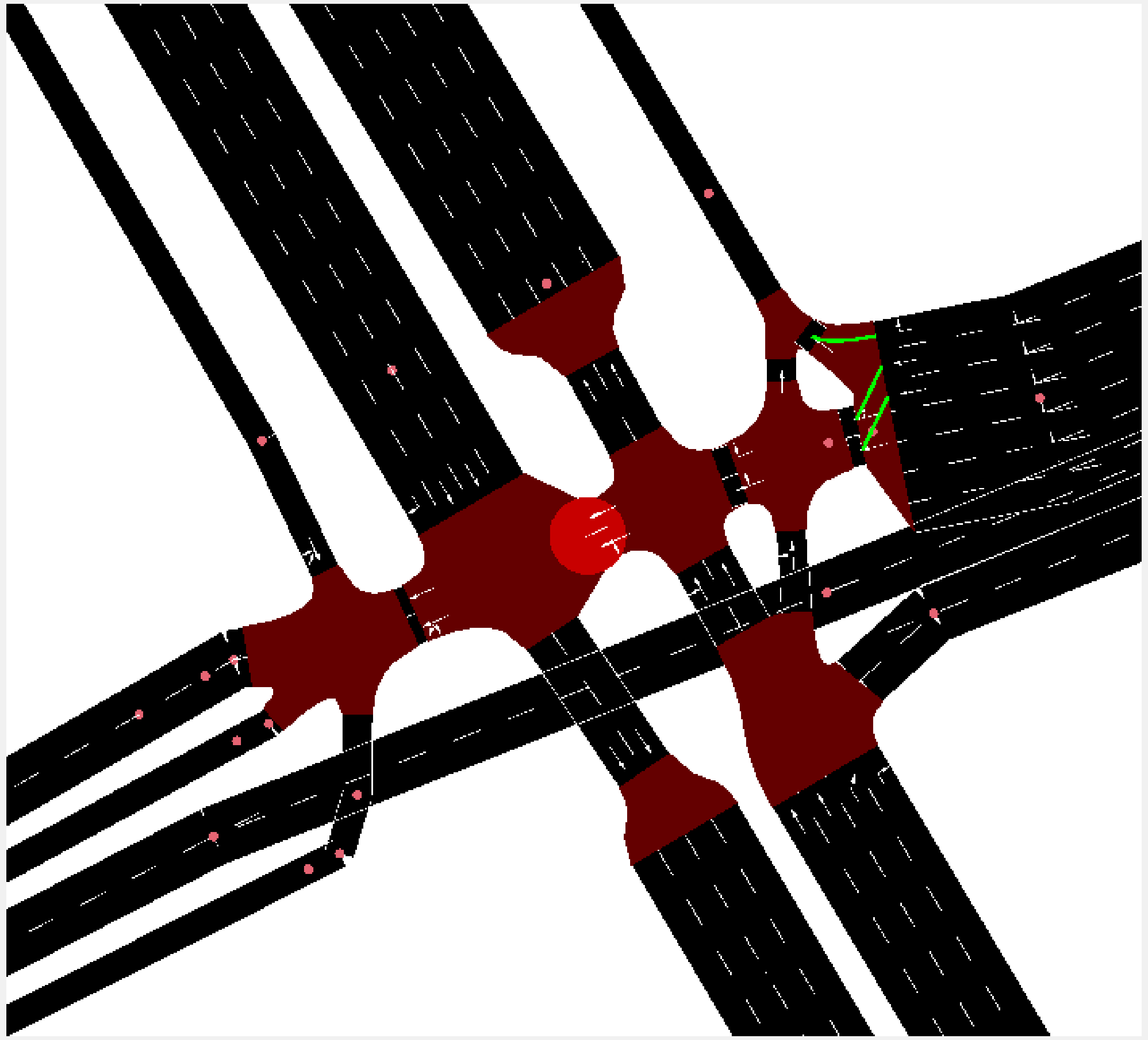
Example of .net.xml content

Key features

- Supports OpenStreetMap (OSM) data
- Generates basic network structure with roads and intersections

But, as said earlier, it introduces errors. Let's see...

Common Issues with NETCONVERT



NETCONVERT

REAL

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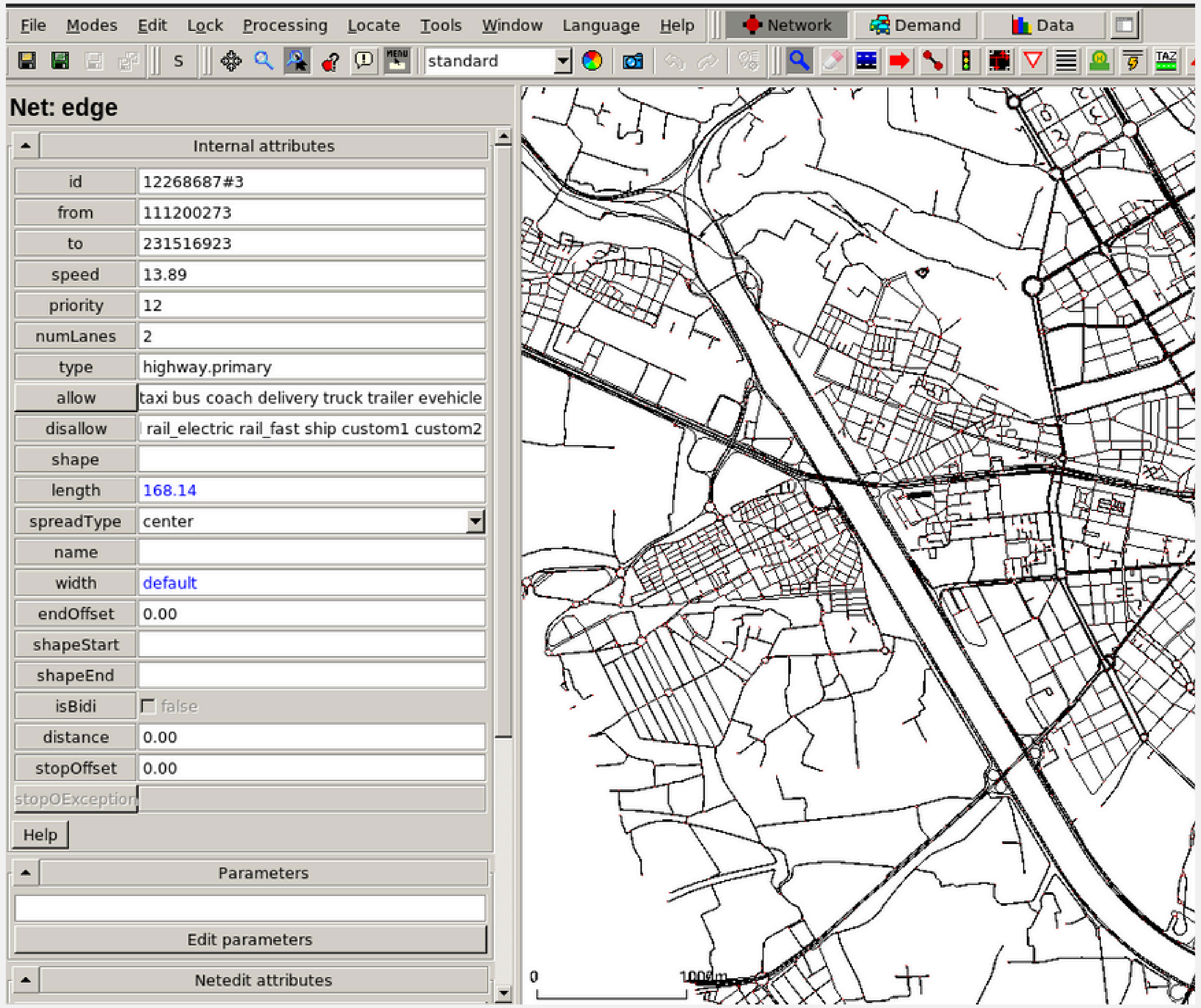
Refining Networks with NETEDIT

NETEDIT allows you to manually correct network errors by:

- Adjusting lane directions
- Adding or fixing traffic signals
- Correcting turn restrictions
- Changing street max. allowed speed
- Adding/removing number of lanes



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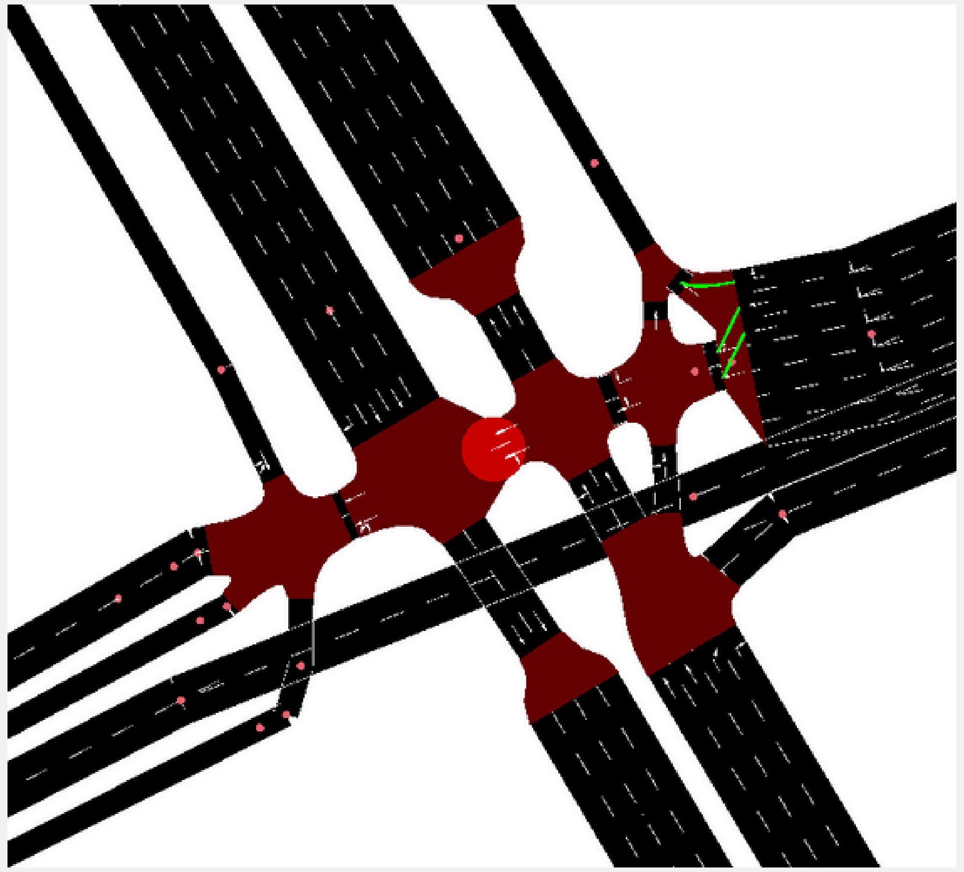
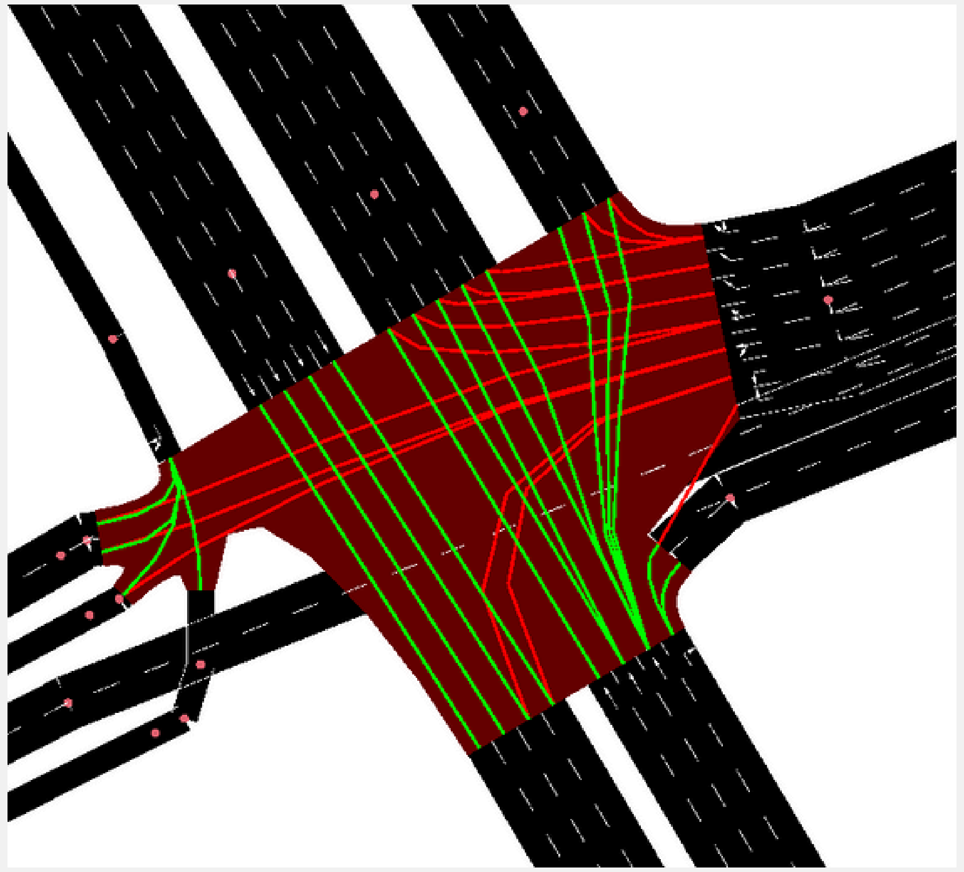
Practical Example: Network Refinement

Results from Network Refinement

Corrected lane directions, added missing traffic lights, improved realism of intersections



Raw



Refined

Real

Outline

Stage 2

Creating Traffic Demand

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Creating Traffic Demand

Data Sources

- Induction loops, GPS data, Cameras, etc.
  - Provides the basis for traffic flow and demand estimation

Problem

- Challenge: Generating realistic traffic demand without GPS or cellphone data
  - This data is often private or costly
- Camera and induction loop data is useful, but lacks complete vehicle trajectories

Creating Traffic Demand

Ideal

- Ideally, we would have complete vehicle trajectories from GPS or cellphone data
- This provides the most accurate traffic demand but is often inaccessible

Reality

- In practice, we gather data from induction loops or cameras
- This data is incomplete, so custom solutions [1] are needed to generate realistic traffic demand

Fastest way

- Start with fast, simple simulations using random trip generation tools like randomTrips.py
- This method provides a quick startup for simulations but may lack realism

1. J. D. Padrón, E. Hernández-Orallo, C. T. Calafate, D. Soler, J.-C. Cano, and P. Manzoni, "Realistic traffic model for urban environments based on induction loop data," Simulation modelling practice and theory, vol. 125, p. 102742, 2023

Creating Traffic Demand for Simulation

Steps:

1. Clean and validate traffic data
2. Define vehicle emission classes
3. Use SUMO or custom tools to generate traffic demand
    - For simplicity and compatibility, we will use randomTrips.py from SUMO.

Trip

randomTrips.py

"randomTrips.py" generates a set of random trips for a given network (option **-n**). It does so by choosing source and destination edge either as described below. The resulting trips are stored in an XML file (option **-o**, default trips.trips.xml) suitable for duarouter (which is called auto distributed evenly in an interval defined by begin (option **-b**, default 0) and end time (option **-e**, default 3600) in seconds. The number of trips 1) in seconds. Every trip has an id consisting of a prefix (option **--prefix**, default "") and a running number. Example call:

```
python tools/randomTrips.py -n <net-file> -e 50
```

The script does not check whether the chosen destination may be reached from the source. This task is performed by the router. If the netw discarded.

The option **--min-distance** *<FLOAT>* ensures a minimum straight-line distance (in meter) between start and end edges of a trip. The script v enough trips with sufficient distance are found.

Randomization

When running *randomTrips.py* twice with the same parameters, the same results will be created because the random number generator is in ness (always a different output) use the option **--random**. The option **--seed** *<INT>* can be used to set an initial value and get different but st

Edge Probabilities

The option **--fringe-factor** *<FLOAT>* increases the probability that trips will start/end at the fringe of the network. If the value *10* is given, edg 10 times more likely to be chosen as start- or endpoint of a trip. This is useful when modelling through-traffic which starts and ends at the ou

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Practical Example: Traffic Demand Creation

Results from Traffic Demand Creation

```
<routes>
    <vType id="type1" accel="0.8" decel="4.5" sigma="0.5" length="5" maxSpeed="70"/>

    <vehicle id="0" type="type1" depart="0" color="1,0,0">
      <route edges="beg middle end rend"/>
    </vehicle>

</routes>
```

.rou.xml

Results from Traffic Demand Creation

```
<additional>
    <vType id="diesel_e4" vClass="passenger" emissionClass="HBEFA4/PC_diesel_Euro-4"/>
</additional>
```

.add.xml

Outline

Stage 3

Traffic Simulation

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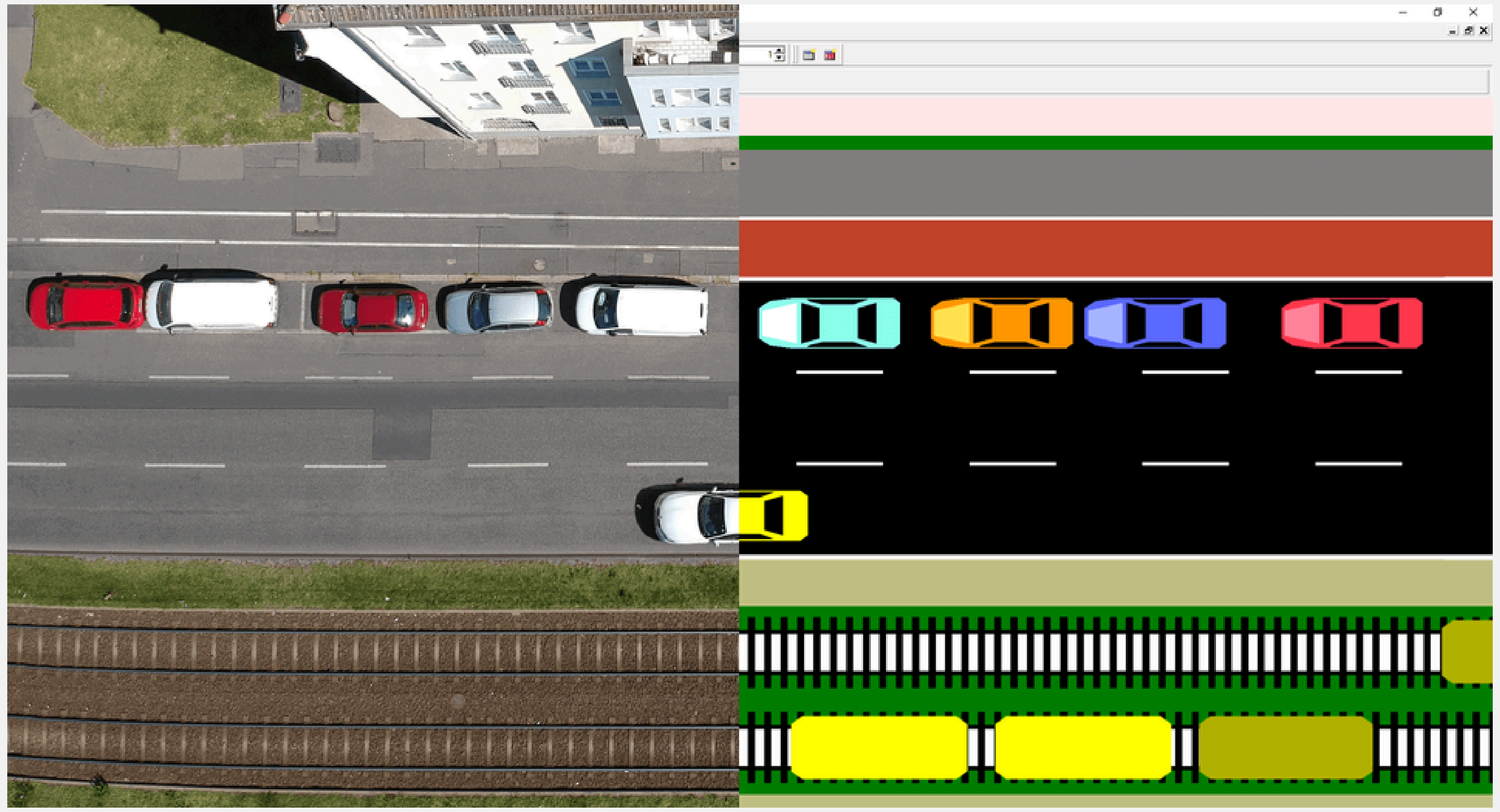
Traffic Simulation

Problem

Testing traffic management strategies in real-world scenarios can be costly and time-consuming.

- Traffic simulators provide an efficient way to model and test different strategies without real-world risks.



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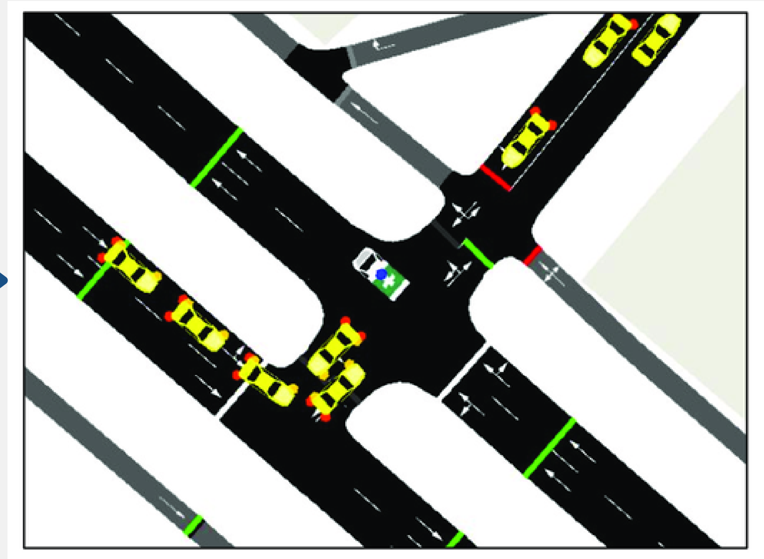
Traffic Simulation

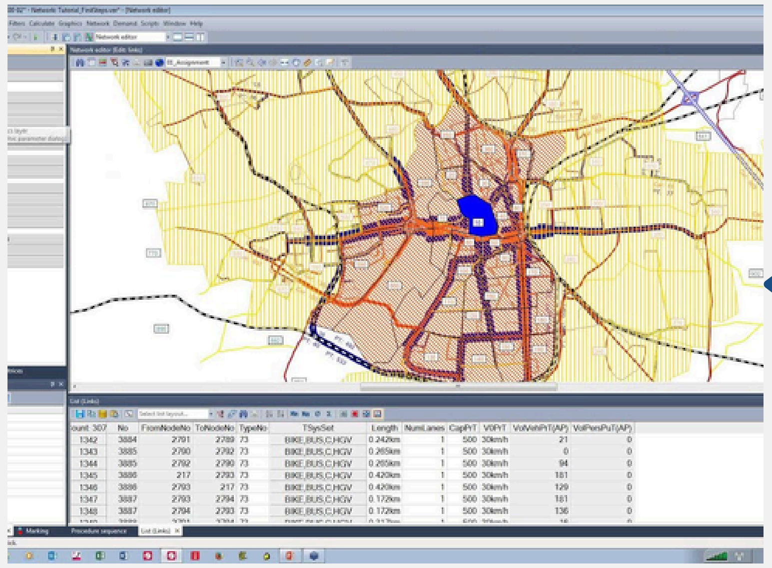
Microscopic Simulation (e.g., SUMO)

- Simulates individual vehicles
- High precision and detailed behavior analysis

Use Cases:

- Traffic signal optimization
- Testing specific vehicle behaviors
- Emissions and air quality studies





Macroscopic Simulation (e.g., VISUM)

- Models traffic as continuous flow
- Faster but less detailed

Use Cases:

- Large-scale traffic flow estimation
- Long-term urban planning
- Strategic decision-making for infrastructure

Introduction to SUMO

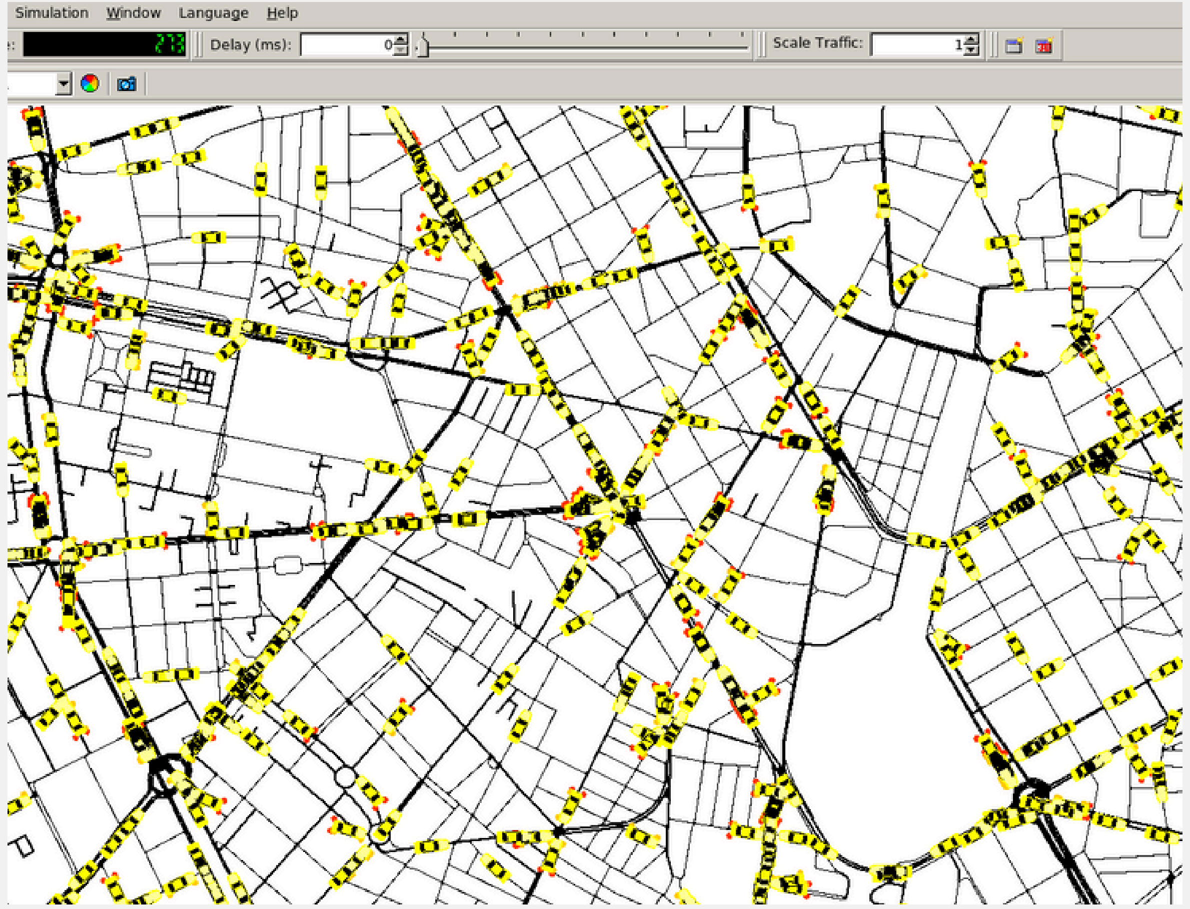
Developed by the Institute of Transportation Systems at German Aerospace Centre (DLR)

Key features

- Open-source and highly scalable
- Simulates multimodal traffic: cars, public transport, pedestrians
- Supports various traffic control mechanisms
- Integrates tools for network creation, traffic demand generation, and more

Key functionalities

- Simulates vehicle movement and traffic signal control
- Supports custom network configurations
- Emission calculations using models like HBEFA and PHEM



SUMO configuration file

To simulate we need to define a configuration file

Main components

- **Input**: Specifies the network (.net.xml), route (.rou.xml), and additional files (.add.xml) for traffic simulation.
- **Output**: Generates files with simulation results, such as trip information (.tripinfo.xml) and vehicle routes (.vehroute.xml).
- **Time**: Defines the simulation start (0s), end (3600s), and step length (1s).
- **Emissions**: Activates emission calculations for all vehicles.
- **Processing**: Handles route errors and teleporting settings.

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SUMO configuration file

Example of SUMO configuration file

```
<configuration>
    <input>
        <net-file value="valencia.net.xml"/>
    <route-files value="valencia.scenario.rou.xml"/>
    <additional-files value="valencia.scenario.add.xml,"/>
    </input>
    <output>
        <tripinfo-output value="valencia.scenario.sumo.tripinfo.xml"/>
        <tripinfo-output.write-unfinished value="true"/>
        <vehroute-output value="valencia.scenario.sumo.vehroute.xml"/>
    </output>
    <time>
        <begin value="0"/>
        <end value="3600"/>
        <step-length value="1.0"/>
    </time>

    <emissions>
        <device.emissions.probability value="1"/>
    </emissions>

    <processing>
        <ignore-route-errors value="true"/>
        <time-to-teleport value="-1"/>
    </processing>
</configuration>
```

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Practical Example: SUMO Simulation

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Results from SUMO Simulation

Simulation results can provide insights such as:

- Emissions per edge → edges_emissions.xml
- Emissions per vehicle → tripinfo.xml
- Traffic related statistics per edge → edges_traffic_data.xml
- Traffic related statistics per vehicle → tripinfo.xml

With those, we can estimate:

- Congestion, effectiveness of our proposed solutions, pollutant emissions, and much more

Outline

Stage 4

Air Quality Analysis

Air Quality Analysis

Air Quality Guidelines and the Need for Concentration Estimates

- To comply with air quality guidelines and regulations, we must estimate pollutant concentrations, not just emissions in mass.
- Emissions from traffic simulators alone don't provide the full picture.
- Dispersion models are required to account for:
  - Terrain
  - Weather conditions
  - Urban complexity

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Air Quality Analysis

Air Quality and Health Impacts

- NOx, Ozone, CO, and PMx are known to cause significant harm to human health.
- High levels of these pollutants can lead to respiratory issues, heart disease, and in extreme cases, death.

Goal

- Accurately estimate air quality at different points in the city

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Air Quality Analysis

Air Quality Models and Pollutants

Related Work

- Fixed Box Model offer quick pollutant concentration estimates but lack precision in complex urban environments.
- More detailed models, like GRAL, offer particle dispersion for higher accuracy in urban areas.

Focus on NOx and PM10

- Both are modeled in SUMO and GRAL, and are in the European Environment Agency guidelines

Level of Concern	AQI Range	PM_{10} (µg/m^3)	NO_x (µg/m^3)
Good	0-50	0-20	0-40
Fair	51-100	20-40	40-90
Moderate	101-150	40-50	90-120
Poor	151-200	50-100	120-230
Very Poor	201-300	100-150	230-340
Extremely Poor	301 and higher	150-1200	340-1000

Stage 4: Air Quality Analysis

Introduction to GRAL

Developed by the Graz University of Technology

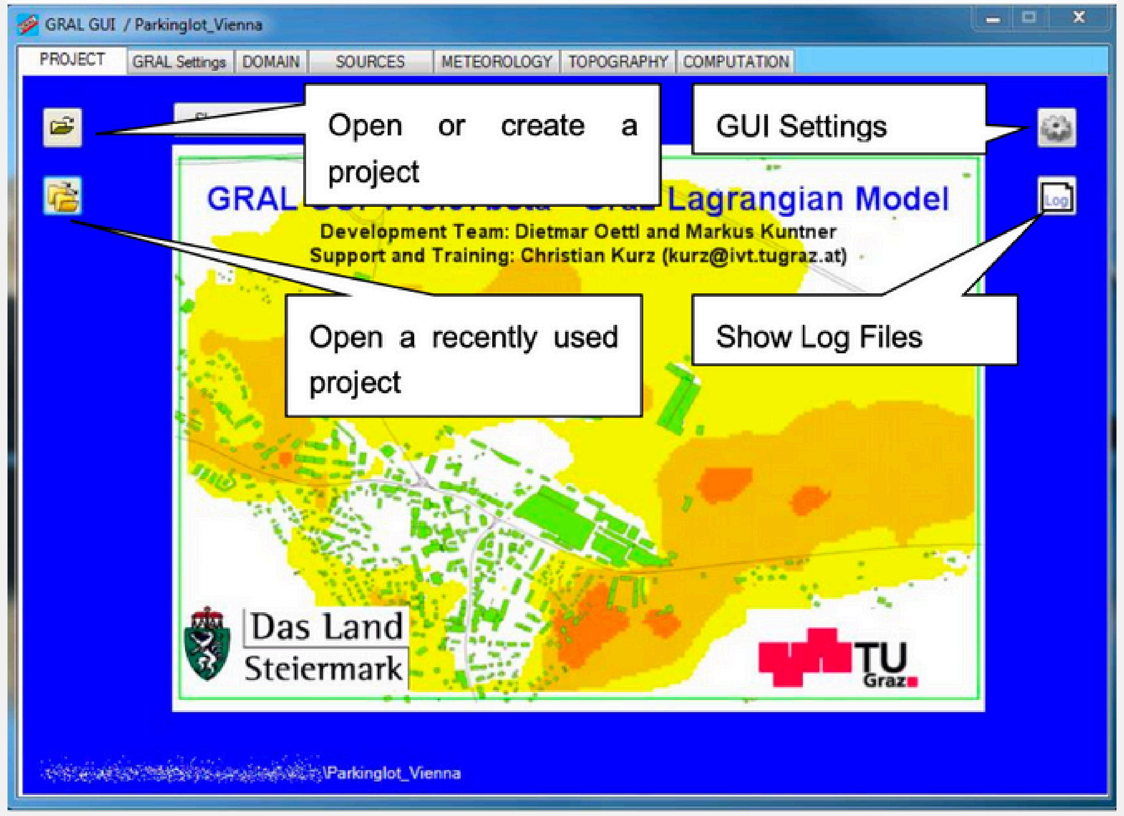
Key features

- High-precision Lagrangian model to air quality calculation
- Open-source and scalable
- Specialized handling of low-wind conditions and complex terrains, incorporating building effects on pollution dispersion

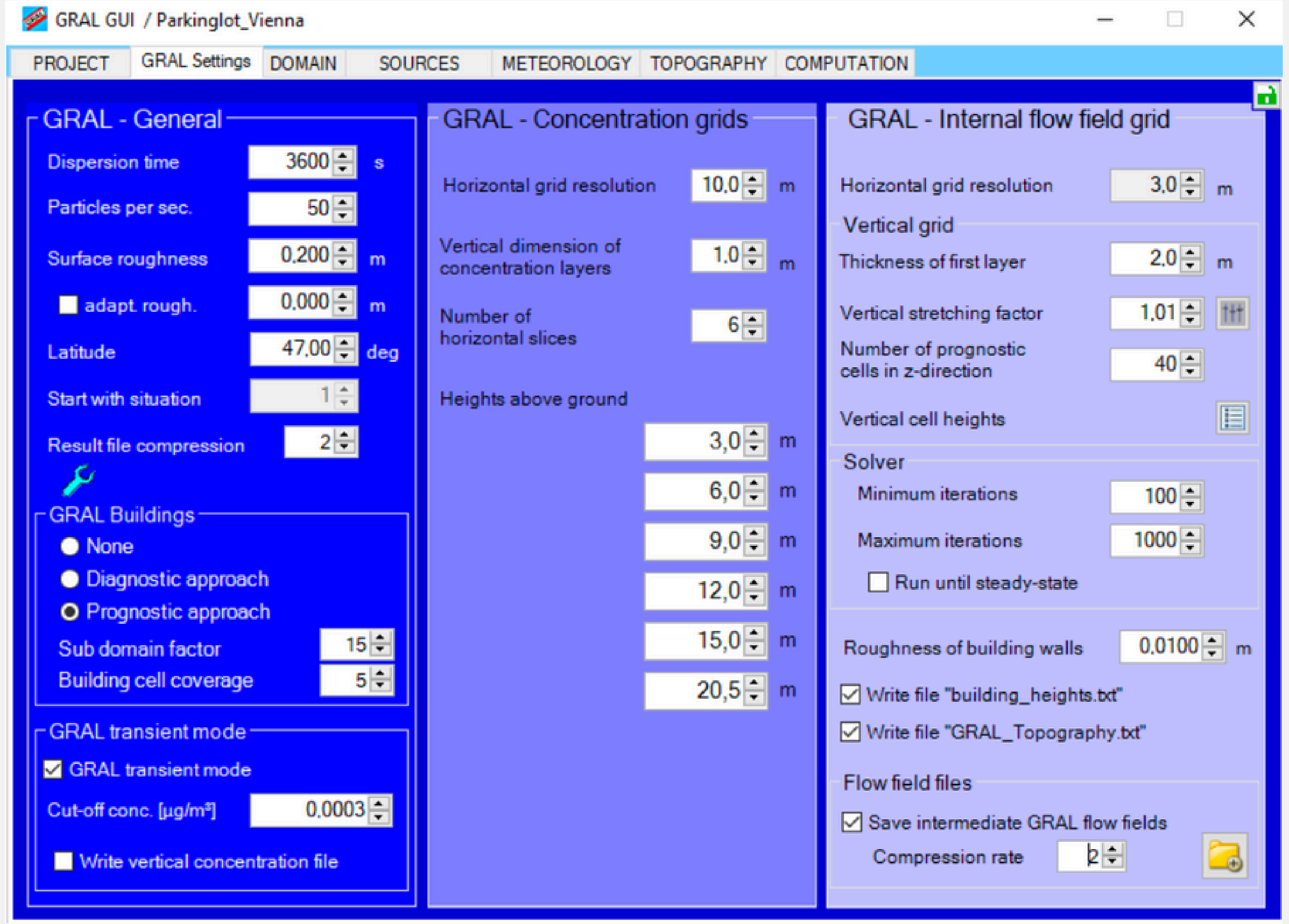
Key functionalities

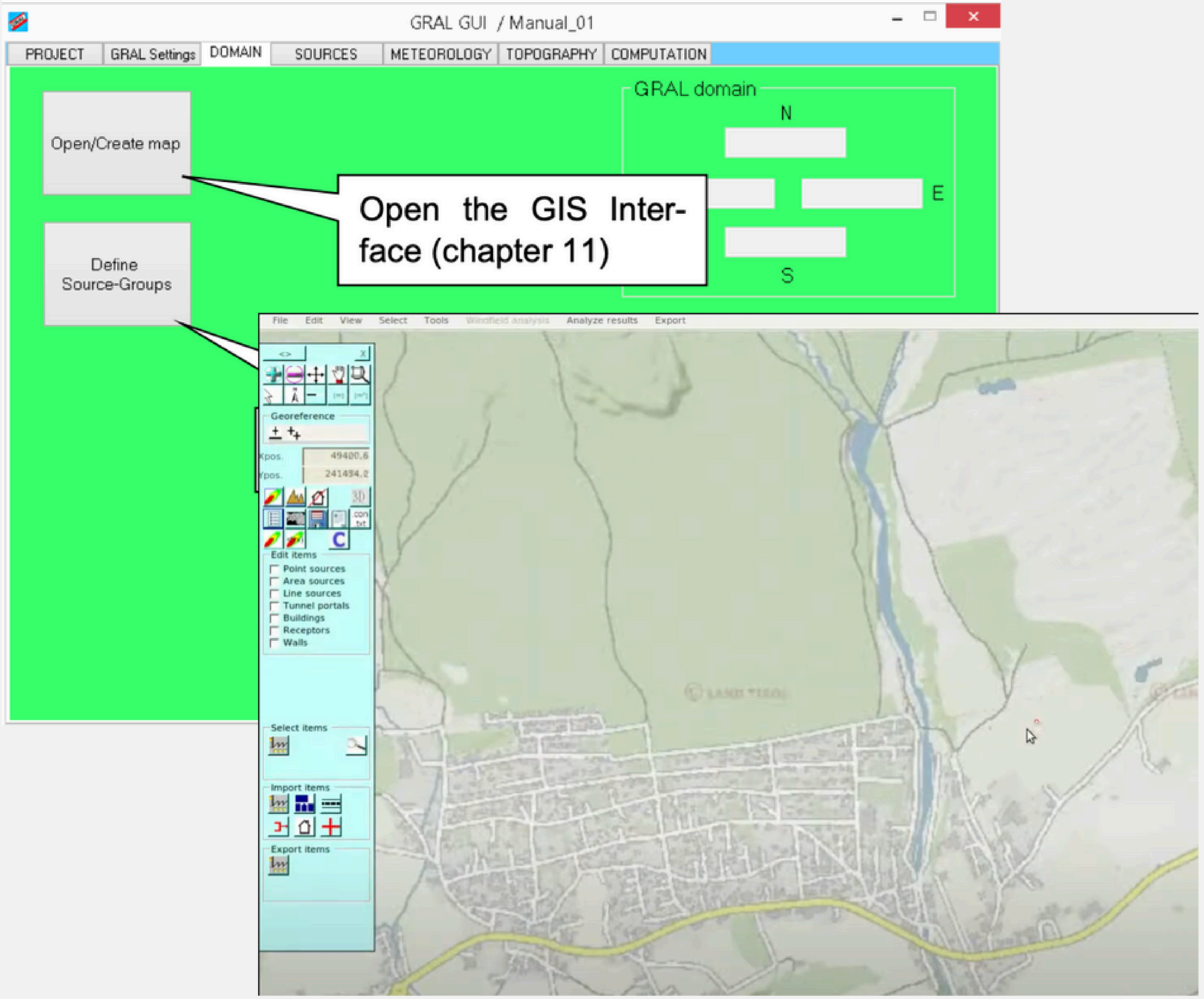
- Accurately simulates pollutant dispersion over urban areas
- Handles complex air quality scenarios based on traffic data
- Models NOx, PM10, and other pollutants

GRAL

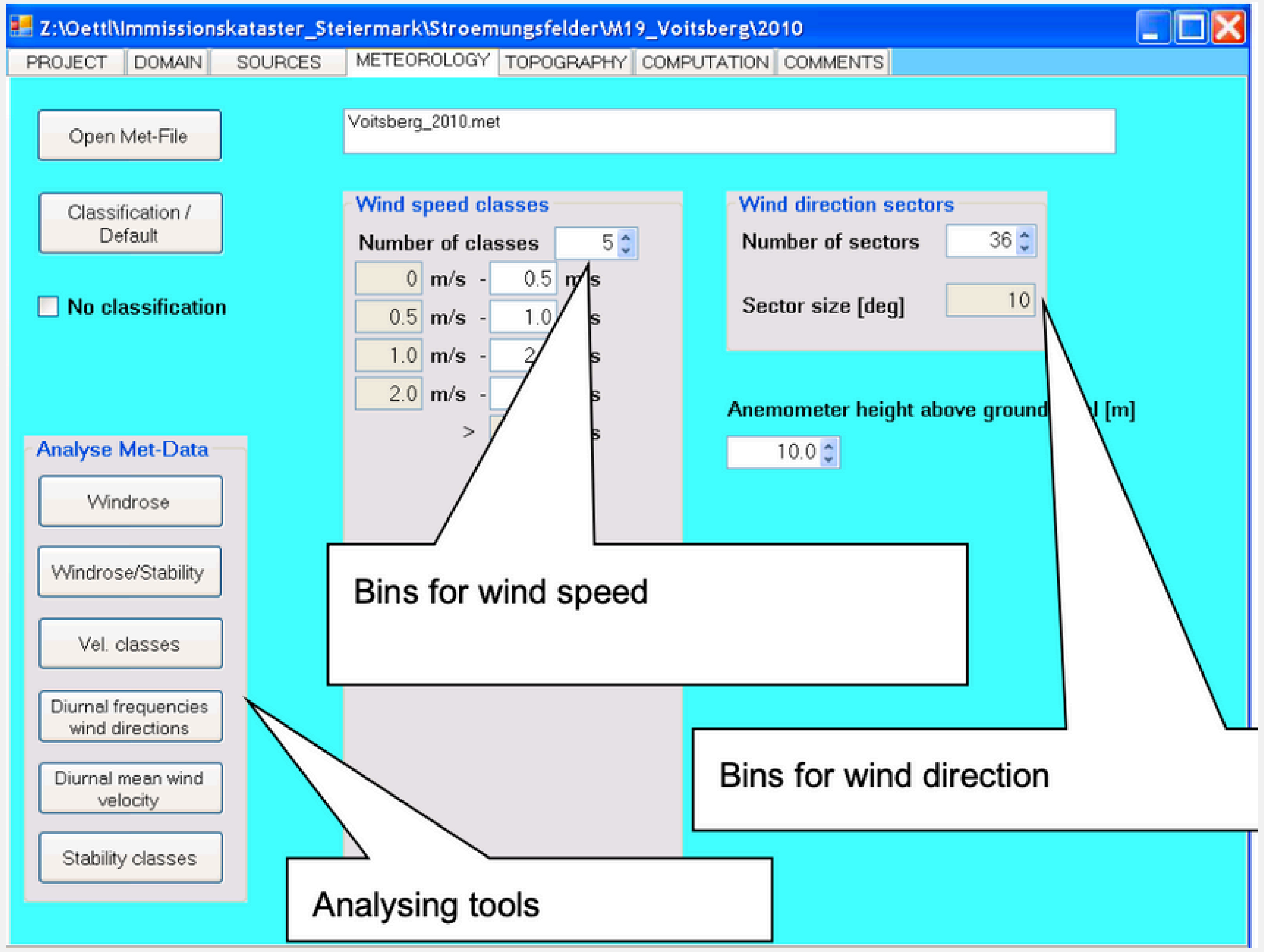


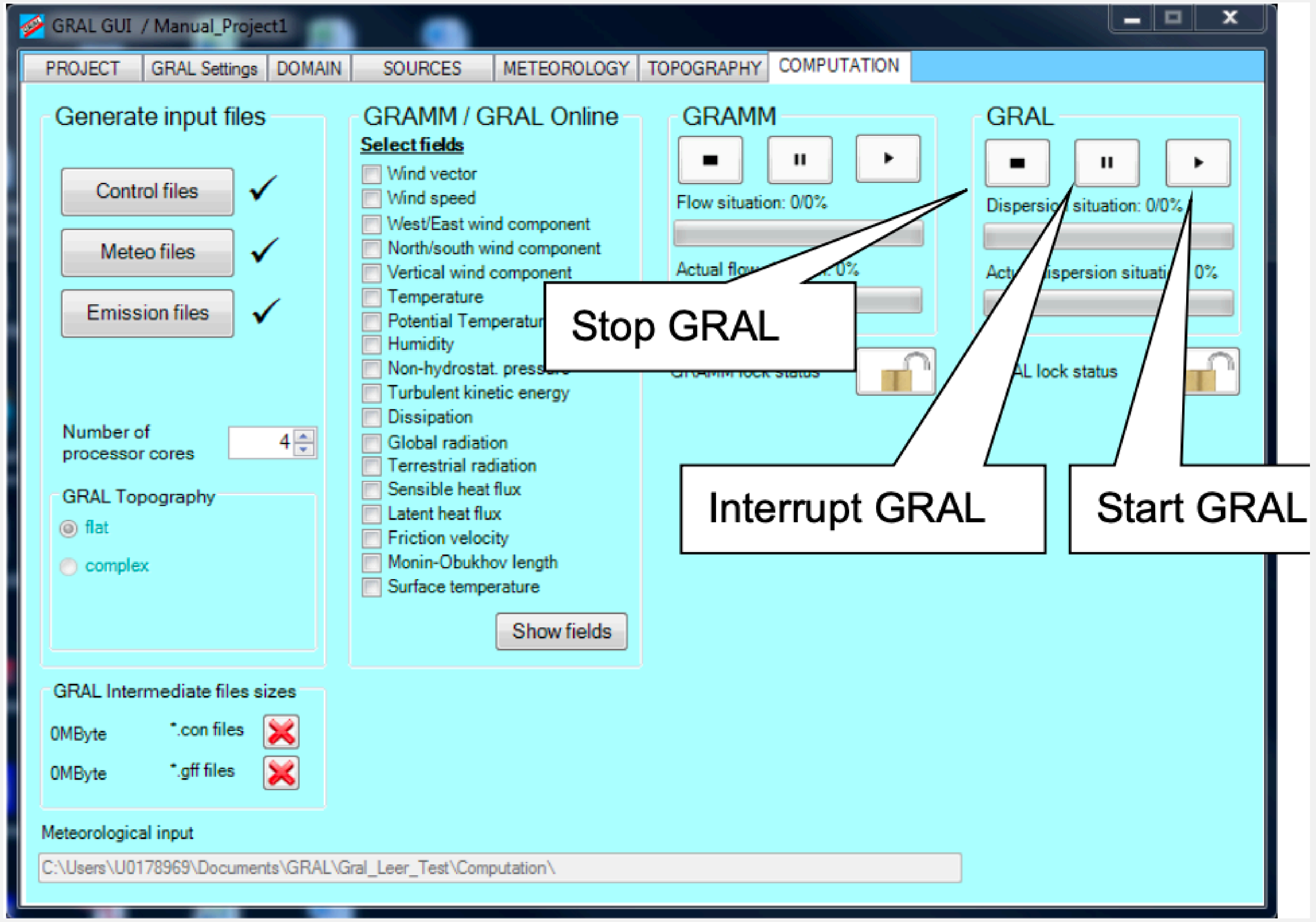
How to use GRAL





How to use GRAL





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GRAL Workflow

Convert edge emissions file to csv

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GRAL Workflow

Convert edge emissions file to csv

Integration with GIS software

Manually integrate:

- Road Network Shapefile: Obtained from OpenStreetMap (OSM).
- Building Shapefile: Generated from OSM
- Emissions Data: Merged with the road network to create a complete dataset.

GRAL Workflow

Convert edge emissions file to csv

Integration with GIS software

Importing into GRAL

- Load the Shapefiles (buildings, roads with emissions) into the GRAL GUI.
- Include Meteorological Data (wind direction, speed, stability class)

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GRAL Workflow

Convert edge emissions file to csv

Integration with GIS software

Importing into GRAL

Running GRAL

- Execute GRAL to simulate pollutant dispersion
- Output: Detailed files showing the spatial distribution of pollutant concentrations

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GRAL Workflow

- Convert edge emissions file to csv
- Integration with GIS software
- Importing into GRAL
- Running GRAL

GRAL Workflow

Convert edge emissions file to csv

Integration into software

Importing into GRAL

Running GRAL

GUI only compatible with Windows
Too tedious and repetitive
That's where SUMO2GRAL take action

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Introduction to SUMO2GRAL

- SUMO2GRAL integrates SUMO traffic data with GRAL for air quality simulations.
- Open-source, available in GitHub
- Converts SUMO emissions data into GRAL-compatible format
- Facilitates comprehensive traffic and air quality analysis

github.com/seniel98/SUMO2GRAL

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SUMO2GRAL Workflow

SUMO2GRAL

Create SUMO2GRAL config. file

Execute SUMO2GRAL

Manual method

Convert edge emissions file to csv

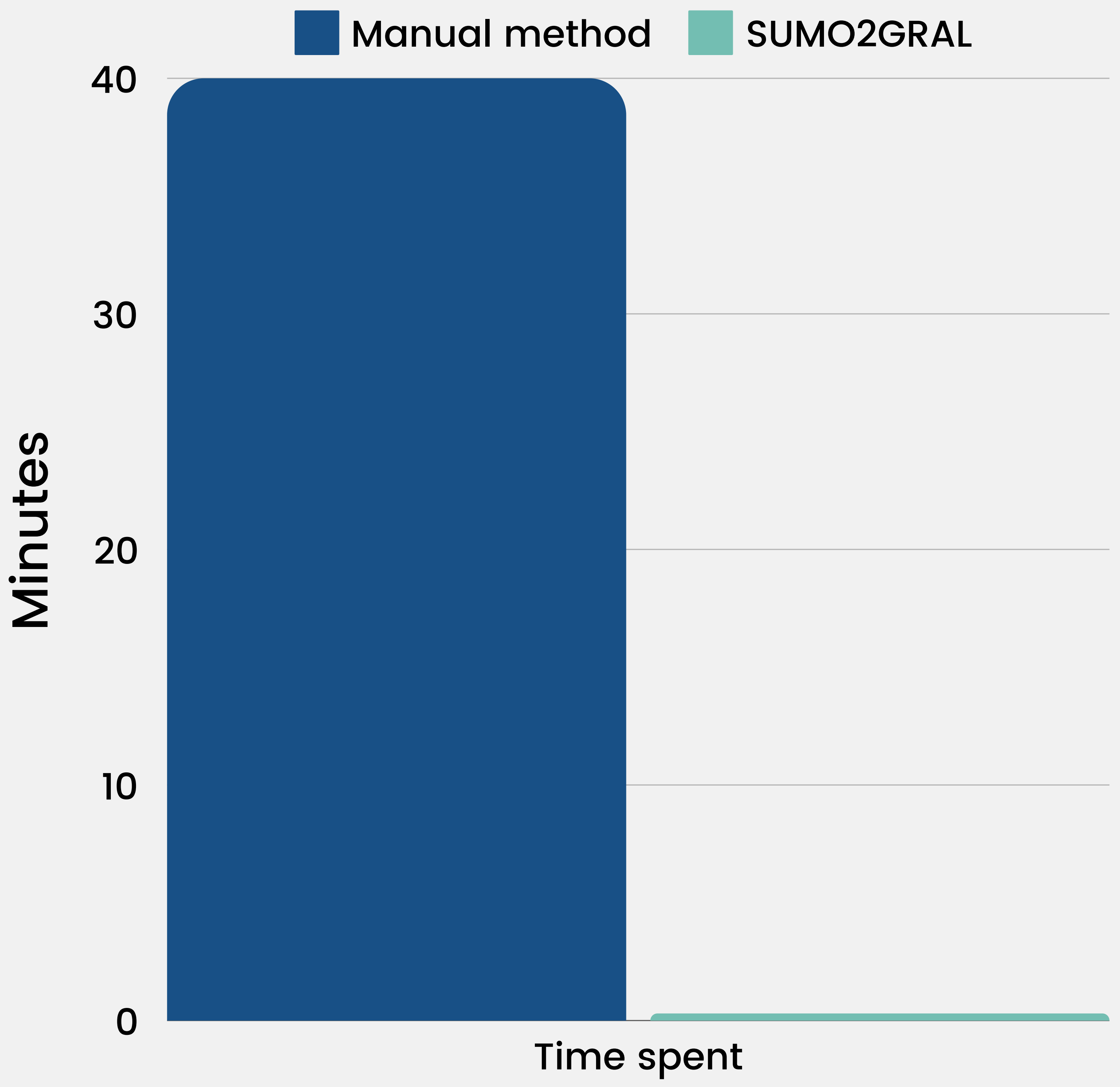
Integration with GIS software

Importing into GRAL

Running GRAL

SUMO2GRAL Workflow

- 130 times faster than the manual method
- More automation, less manual tasks



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SUMO2GRAL Configuration File

Main components of the configuration file

- **Input**: Specifies the directory and essential files like:
  - Traffic network
  - OSM data
  - Emission data
  - Weather conditions
- **Output**: Defines the shapefiles for buildings, highways, and vegetation

- **GRAL Settings**: Configures GRAL parameters, such as:
  - Pollutant to simulate (e.g., NOx)
  - Horizontal layers,
  - Number of particles
  - Dispersion time
  - Cores for parallel processing.

SUMO2GRAL Configuration File

Example of SUMO2GRAL configuration file

```
<configuration>
    <input>
        <base-directory value="/path/to/base/directory/"/>
        <net-file value="valencia.net.xml"/>
        <osm-file value="valencia.osm.xml"/>
        <emissions-file value="edges_emissions_data_agg_scenario.xml"/>
    <weather-file value="weather.csv"/>
    <met-file value="weather.met"/>
    <gral-dll value="GRAL.dll"/>
    </input>

    <output>
        <buildings-shp-file value="buildings.shp"/>
        <highways-shp-file value="highways.shp"/>
        <vegetation-shp-file value="vegetation.shp"/>
    </output>

    <gral>
        <pollutant value="NOx"/>
        <hor-layers value="3"/>
        <particles-ps value="200"/>
        <dispertion-time value="3600"/>
        <n-cores value="8"/>
    </gral>

</configuration>
```

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Practical Example: SUMO2GRAL Integration

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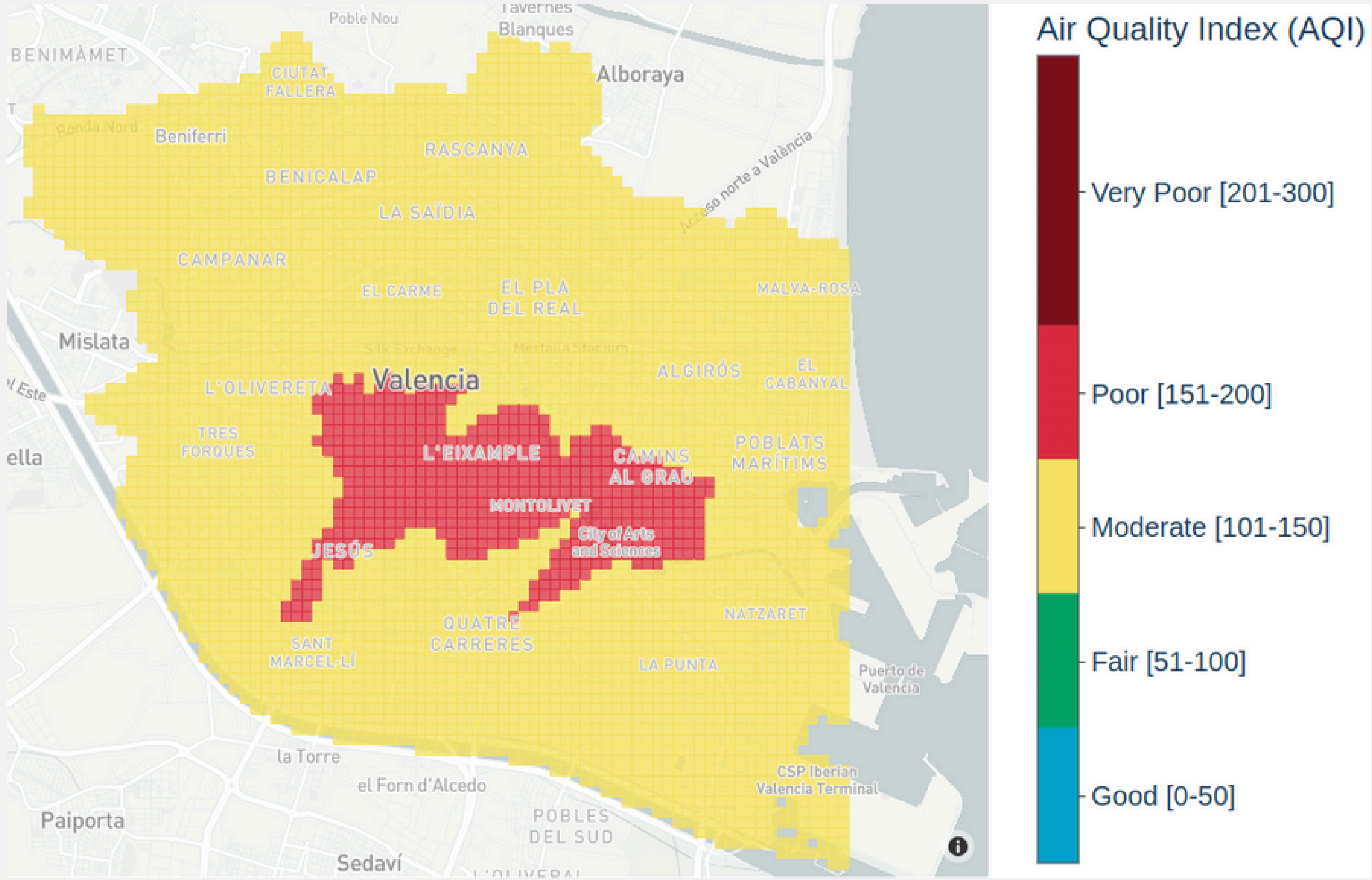
Results from SUMO2GRAL Integration

Air quality results from integrated simulations include:

- Pollutant concentrations across the city in a .txt file

With those results, we can:

- Estimate impact of traffic management strategies on air quality
- Generate Air Quality heatmaps



Key Takeaways

Today we've covered:

- Importance of refining network in SUMO with NETEDIT
- Creating traffic demand
- Going from 0 to simulate traffic and calculate pollutants concentration
    - Using SUMO for traffic simulation
    - Modeling air quality with GRAL
    - Integrating both systems via SUMO2GRAL

Real-World Implications

These tools offer insights into:

1. Optimizing traffic flow to reduce congestion
2. Improving urban air quality through better traffic management
3. Helping city administrations to assess and create better traffic strategies

Q&A time

Thank You!

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