

Mobility and Transport
Operation and Plan
Digital Twin

DIGITAL TWIN SOLUTIONS TO SETUP SUSTAINABLE DECISON SUPPORT SYSTEMS AND BUSINESS INTELLIGENCE





















- Goals:
  - Decongestion, Decarbonization, costs reductions
  - Improve Accessibility to services
  - Improve Security/Safety of city users
- Operation and Plan:
  - Traffic monitoring, prediction, reconstruction, identification of critical conditions (early warning), fleet management, dynamic routing, multimodal routing, city user behaviour analysis
- Optimization and what-if analysis traffic light, infrastructure
  - Reduction: travel time, waiting time, stops, CO2 emissions, consume fuel, travel time for tramways
- Public Transport: analysis of Mobility Demand vs Offer of Transportation
- Parking Management: monitoring, prediction, any payments, on/off-road
- Sharing / Pooling Management: eShare and mobile app, bikesharing, smart bike, fleet management
- KPI: SUMI/SUMP, travel time, emissions, traffic status, accessibility, ...
- Mobile App: final users and operators
  - Info Mobility, traffic reconstruction, charging, participation,
  - Parking, payments, overparking, fine reporting, ...
- Participatory: problem reporting, ticketing, etc.
- Data Integration of any kind: env, weather. Tickets, presences, POI, sat, etc.













FREE



















**EXPERT SYSTEM, KNOWLEDGE BASE** 

SEMANTIC REASONING

**SMART DATA MODEL** 

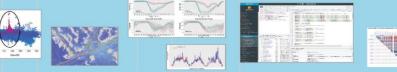
**IOT DEVICE MODELS, STORAGE** 

## **Digital Twin Solutions for Sustainability**

#### OPERATION AND PLAN - CONTROL ROOMS - DECISION SUPPORT SYSTEMS - WHAT-IF ANALYSIS - OPTIMIZATION - APPLICATIONS











VISUAL PROGRAMMING, ADAPTERS
DATA FLOWS, WORKFLOWS
PARALLEL DISTRIBUTED PROCESSING
DATA DRIVEN



- VISUAL PROGRAMMING, ML, AI, HPC
- TRAINING COURSES
- LIVING LABS
- GUI CUSTOM STYLES
- FULL APPLICATIONS, DASHBOARDS
  AND VIEWS
- · MOBILE APPS











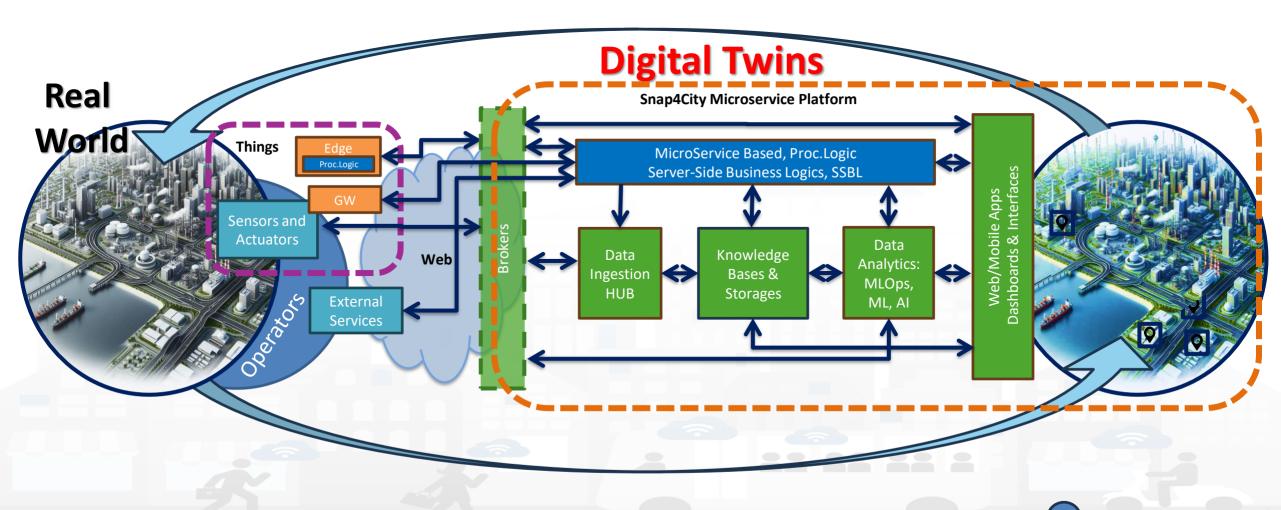








## **Digital Twin Development Platform**



## Standards and Interoperability (10/2024)

## **SNAP4**CITY

#### **Compliant with:**

- IoT: NGSI V2/LD, LoRa, LoRaWan, MQTT, AMQP, COAP, OneM2M, TheThingsNetwork, SigFOX, Libelium, IBIMET/IBE, Enocean, Zigbee, DALI, ISEMC, Alexa, Sonoff, HUE Philips, Tplink, BACnet, TALQ, Protocol Buffer, KNX, OBD2, Proximus, ..
- IoT model: FIWARE Smart Data Model, Snap4City IoT Device Models
- **General**: HTTP, HTTPS, TLS, Rest Call, SNMP, TCP, UDP, SOAP, WSDL, FTP, FTPS, WebSocket, WebSocket Secure, GML, WFS, WMS, RTSP, ONVIF, AXIS TVCam, CISCO Meraki, OSM, Copernicus, The Weather Channel, Open Weather, OLAP, VMS Milestone, TIM, HERE, ....
- Formats: JSON, GeoJSON, XML, CSV, GeoTIFF, OWL, WKT, KML, SHP, db, XLS, XLSX, TXT, HTML, CSS, SVG, IFC, XPDL, OSM, Enfuser FMI, Lidar, glTF, GLB, DTM, GDAL, Satellite, D3 JSON, ...
- Database: Open Search, MySQL, Mongo, HBASE, SOLR, SPARQL, ODBC, JDBC, Elastic Search, Phoenix, PostGres, MS Azure, ...
- Industry: OPC/OPC-UA, OLAP, ModBUS, RS485, RS232,...
- Mobility: DATEX, GTFS, Transmodel, ETSI, NeTEx, ...
- **Social**:Twitter, FaceBook, Telegram, ...
- Events: SMS, EMAIL, CAP, RSS Feed, ...
- OS: Linux, Windows, Android, Raspberry Pi, Local File System, AXIS, ESP32, etc.



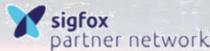






















https://www.snap4city.org/65





## High Level Types

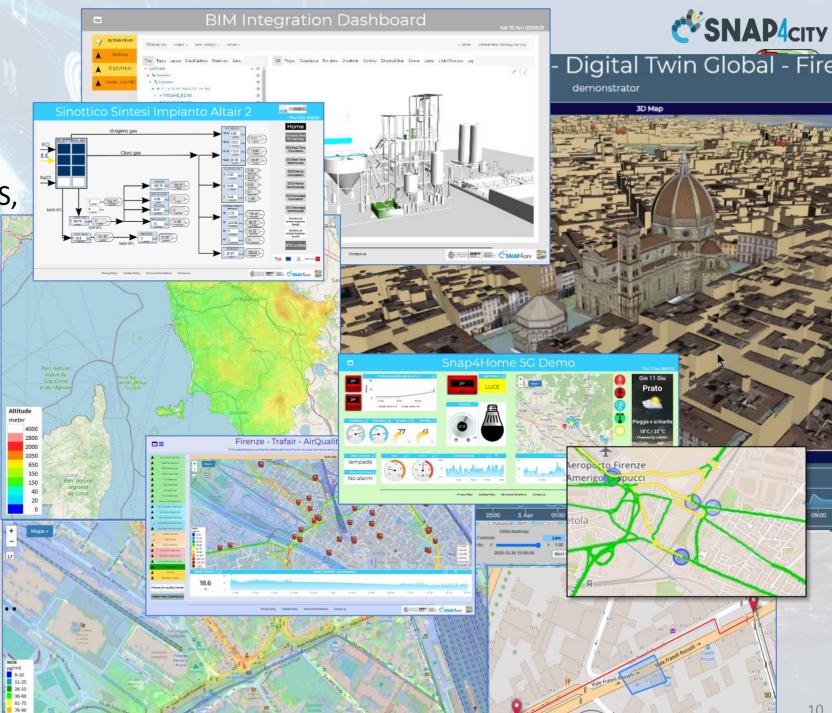
- POI, IOT Devices, shapes,...
  - FIWARE Smart Data Models,
  - IoT Device Models
- GIS, maps, orthomaps, WFS/WMS, GeoTiff, calibrated heatmaps, ..
- · Satellite data, ..
- traffic flow, typical trends, ...
- trajectories, events, Workflow, ...
- 3D Models, BIM, Digital Twins, ...
- OD Matrices of several kinds, ...
- Dynamic icons/pins, ..
- Synoptics, animations, ..
- KPI, personal KPI,...
- social media data, TV Stream,
- routing, multimodal, constraints,
- decision scenarios, ....











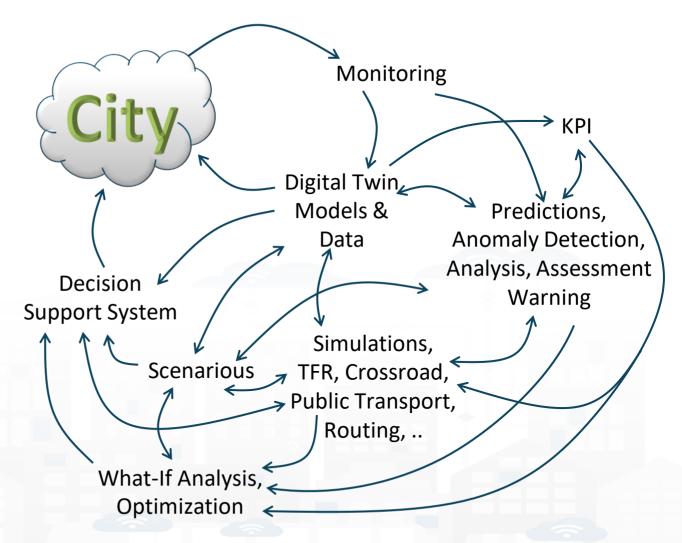




## **Main tasks**



- Controlling Status: management, and operational
  - Monitoring via KPI
  - Predictions vs KPI
  - Anomaly detection
  - Neuro-Symbolic analysis
  - Risk assessment
  - Early warning on critical conditions
  - Fast What-if analysis
- Making plan: tactic and strategic, medium and long range, micro/macro
  - Simulation & optimization
  - Generative AI Prescriptions, scenarios
  - Resilience to Unexpected unknows
  - What-if analysis wrt scenarios
  - Collaboration with stakeholders

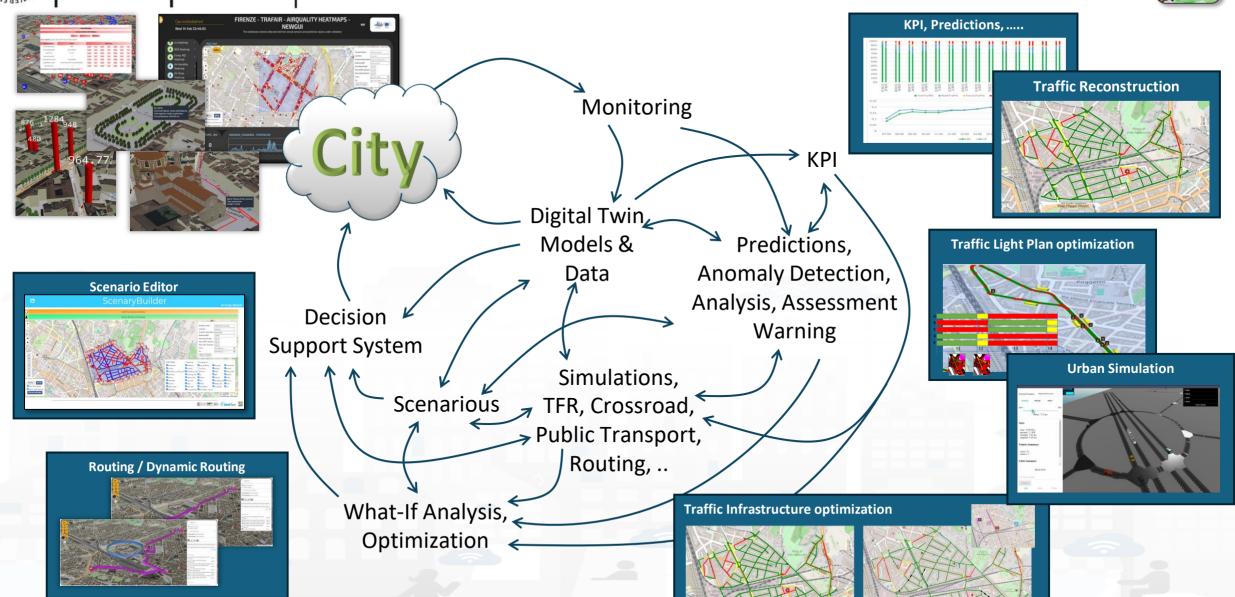












Snap4City (C)



FROM CITY DASHBOARD TO

APPLICATIONS



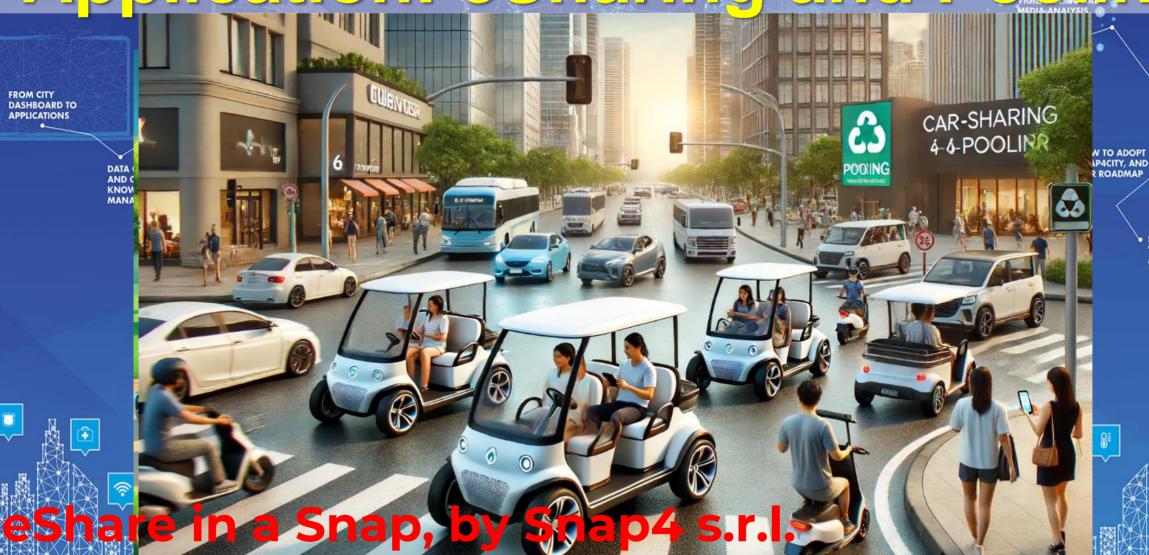
# DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB



SNAP4CITY AND KM4CITY PROJECTS

SNAP4CITY THE VIEW OF THE **ADMINISTRATORS** 



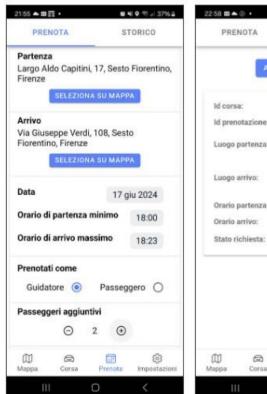


## eShare in a Snap, by Snap4

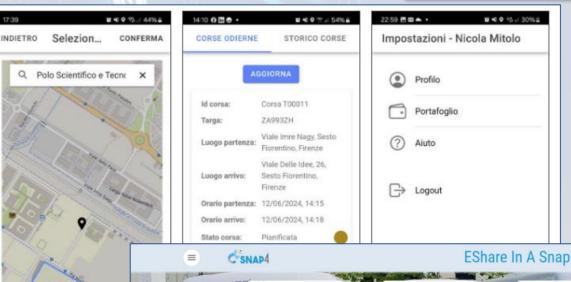


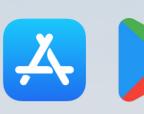
















Integrated car sharing and pooling Multiple drivers on the same means Dynamic pooling and e-sharing

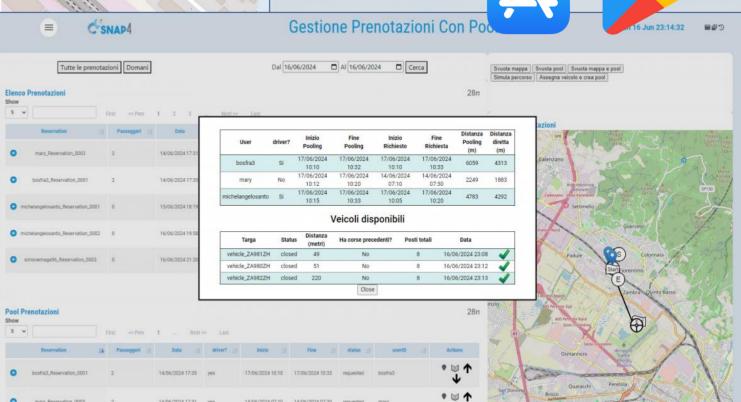
# eShare in a Snap, by Snap4











Integrated car sharing and pooling
Multiple drivers on the same means
Dynamic pooling and e-sharing

Time Trend Batteria





DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB









## **Monitoring**



- Controlling Status: management, and operational
  - Monitoring via KPI
  - Computing predictions and KPI
  - Anomaly detection, Early warning
  - Control Rooms, situation rooms
- Reacting: Computing in real time
  - Changing semaphore maps
  - Changing Dynamic signage
  - Real time Info Mobility
  - User engagement via Mobile Apps
  - What-if analysis
  - oetc.,





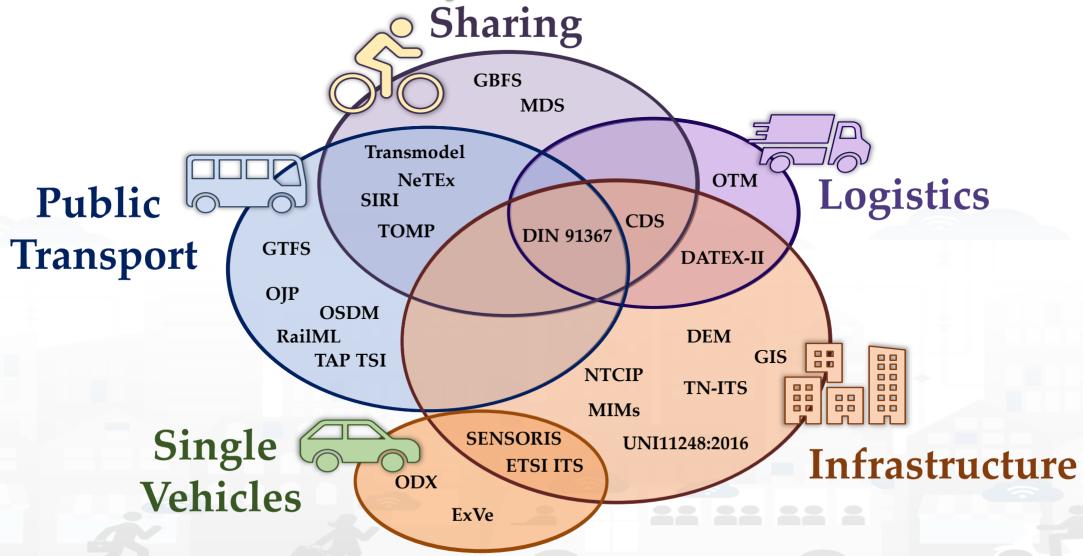












# Key Performance Indicators, KPI





• United Nations Sustainable Development Goals,
SDGs (for which cities can do more to achieve some
of the 17 SDGs, <a href="https://sdgs.un.org/goals">https://sdgs.un.org/goals</a>);



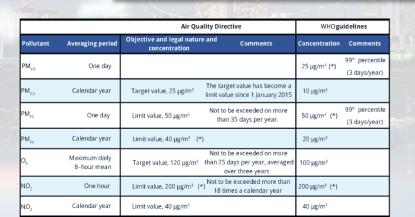
• 15 minutes cities (where primary services must be accessible within 15 minutes on foot);



 objectives of the European Commission in terms of pollutant emissions for: NO2, PM10, PM2.5 (https://environment.ec.europa.eu/topics/air\_en);



- SUMI: mobility and transport vs env
  - https://www.snap4city.org/951
- SUMP/PUMS: mobility and transport vs env.
- **ISO indicators:** city smartness, digitization, tech level.
- Low Level/Real Time: global traffic, quality of service, betweenness, centrality, queue, time to travel, etc.



Mobility

Environment

15Min



Realtime















### • 15 Minute City Index:

 13 subindexes: energy, slow mobility, fast mobility, housing, economy education, culture and cults, health, entertainment, gov, food, security...



- Optimization of car sharing/pooling
- Monitoring and Prediction of energy consumption
- Stimulating: Bike sharing, e-bikes, car charge, etc.
- Sizing energy plants



- Reduction of emission, reduction of congestion
- Smart City infrastructure: monitoring and resilience, long terms predictions
- Effective and Low cost smart solutions
- What-if analysis, Simulations
- Origin Destination matrices computation





Reduction of emission, reduction of congestion Monitoring and Predicting: NO2, NOX, CO2, Traffic flow, pollutant, landslide, waste, etc.

Traffic flow reconstruction

Demand vs Offer of Mobility analysis



- Predictive maintenance
- **Decisions Support Systems**
- Process optimization, control
- Industry 4.0 integrated solutions



- Optimization of Waste Collection
- business intelligence tools for decision makers
- Reduction production costs
- Monitoring resource consumption



- Shortening justice time
- Prediction of mediation proneness
- Assisting institution is taking legal decisions
- Anonymization and indexing legal docs.
- Ethical Explainable Artificial Intelligence

Snap4City (C), March 2025 (10/2024)

## 15MinCityIndex

What would support my neighborhood to become a 15-Minute City?

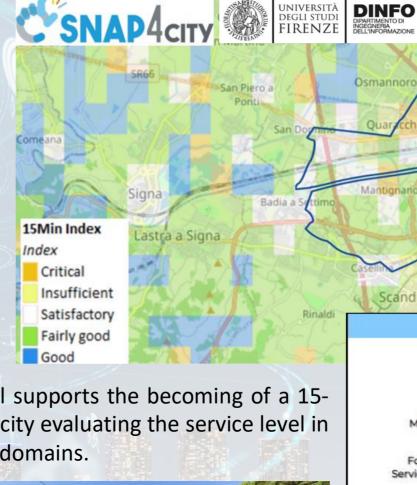
#### **Using the Open Data:**

We developed a data analytic tool based on municipal and national open data to assess services adequacy for people living in each 15 minutes areas of the city.

Good public transport services: bus, new tram line, train stations, cycle paths.

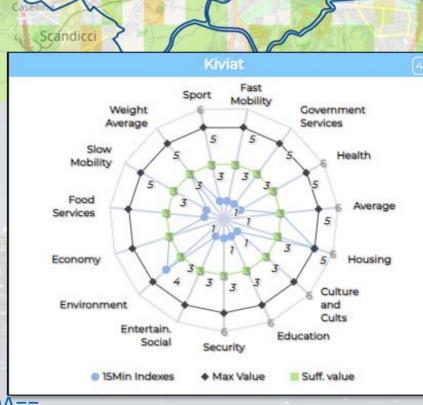


Careggi/Rifredi is a relevant district in Florence because of hosting the main Florence/Tuscany hospitals Careggi and Meyer, but also university headquarters and many other workplaces.



The tool supports the becoming of a 15-Minute city evaluating the service level in various domains.





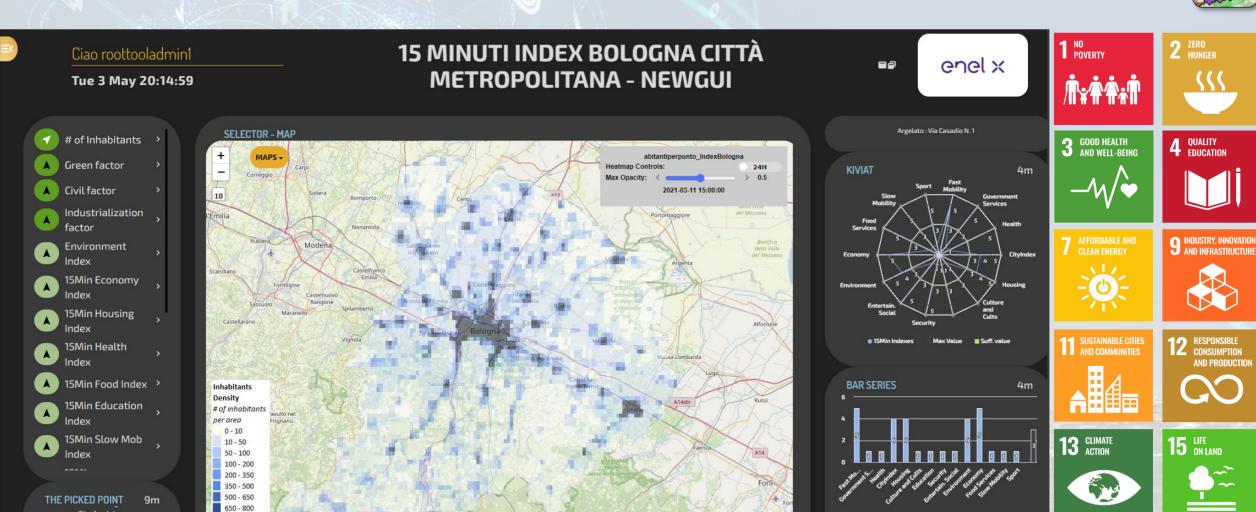
https://www.snap4city.org/dashboardSmartCity/view/index.php?iddasboard=MjkzOA==

## 15MinCityIndex on Bologna









800 - 950

>950

Address: Via Casadio N. 1

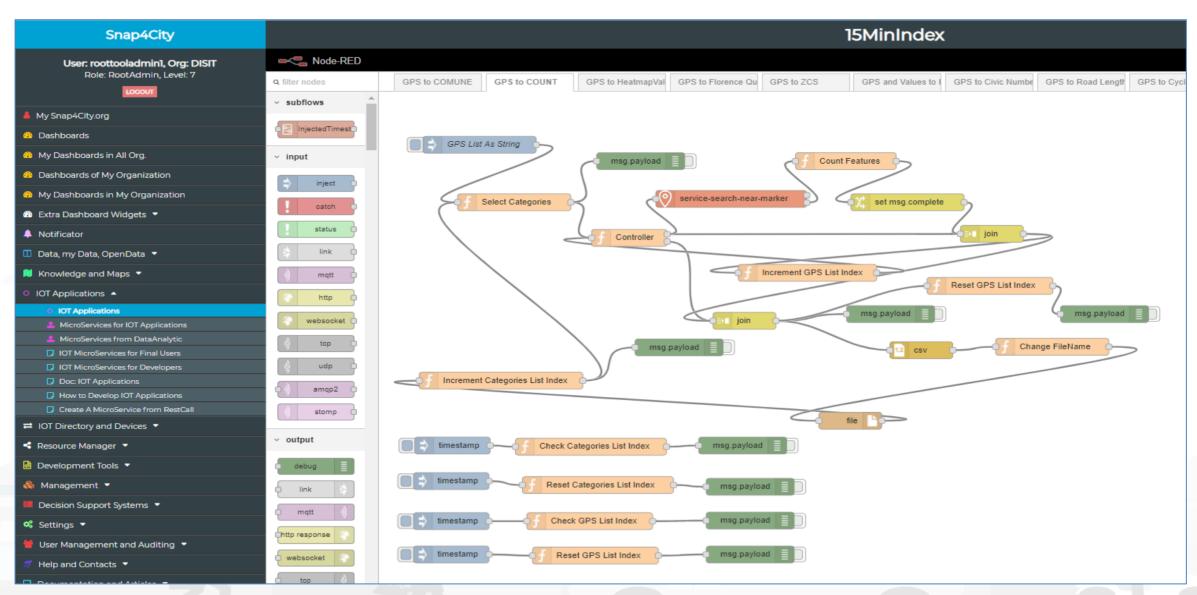












## **Smart City Control Room** Florence Metropolitan City







### Multiple Domain Data

- Thousands of Open/Private data, POI, IOT, etc.
- mobility and transport: accidents, public transport, parking, traffic flow, Traffic Reconstruction, KPI, ...
- **AND**: environment, civil protection, gov KPI, covid-19, social & social media, people flow, tourism, energy, culture, ...

### Multiple dash/tool Levels & Decision Makers

• Real Time monitoring, Alerting, quality assess.

Predictions, KPI, DSS, what-if analysis

#### Historical and Real Time data

Billions of Data

### Services Exploited on:

Multiple Levels, Mobile Apps, API

Since 2017













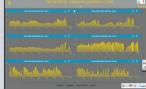










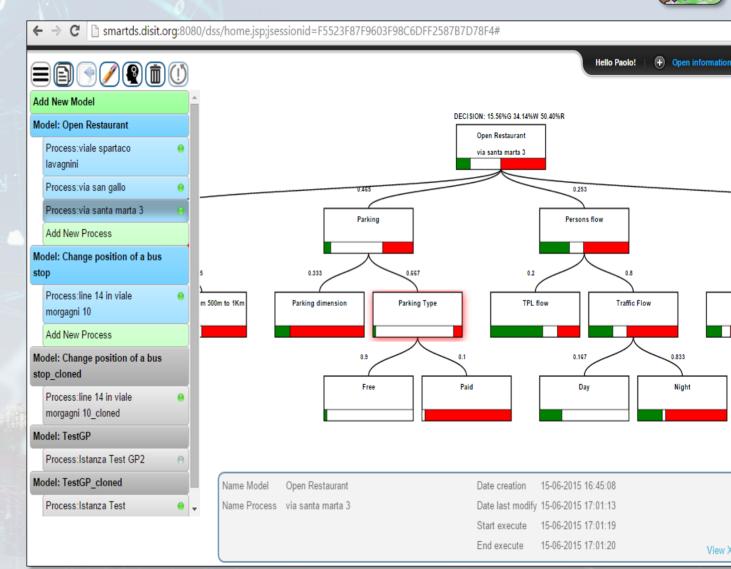








- Smart Decision Support System based on System Thinking plus
- Actions to city reaction, resilience, smartness, ...
- Enforcing Mathematical model for propagation of decision confidence..
- · Collaborative work, ...
- Processes connected to city data: DB, RDF Store, Twitter, etc.
- Production of alerts/alarms
- Data analytics process
- Twitter Processes
- reuse, copy past, ...



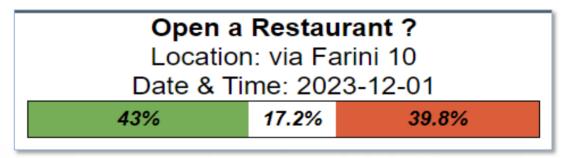








- Supports the definition of the Decision Tree Model, DTM, in terms of System Thinking, with Italian Flag and combinations
- Allows the statistic composition of subDecisions probabilities
- Generating a DTM as an IoT App,
- IoT Apps with DTM can
  - be customized
  - compute root values in real time in any context: location, parameters, etc.
    - Single DTM root value can be produced on Dashboard
    - Several DRM root values can be represented on dashboard as heatmaps for Green/White/Red values





## Routing Optimization SNAP4CITY

### Goals on planning:

- Reduction of costs on plan
- waste collection optimization, Reduction of Km
- car pooling trajectories optimization for maximize the pool usage
- delivering optimization, reduction of travel time, reduction of Km

etc.

Snap4City (C), March 2025

#### **Dynamic Routing on operation:**

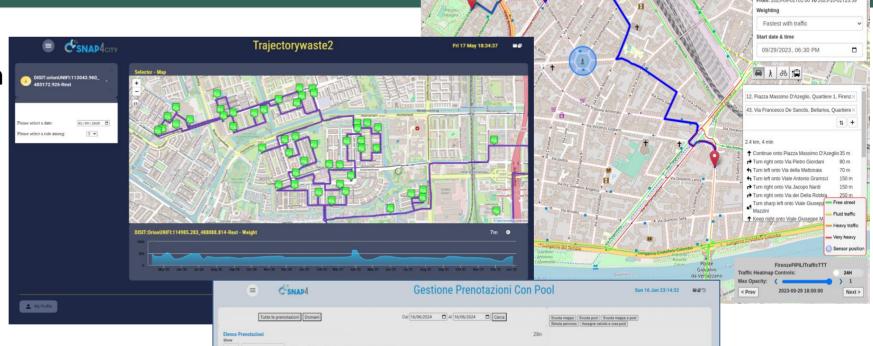
- React in operation to define immediate routing solutions: rescue teams, ambulance, etc.
- Recovery from failure



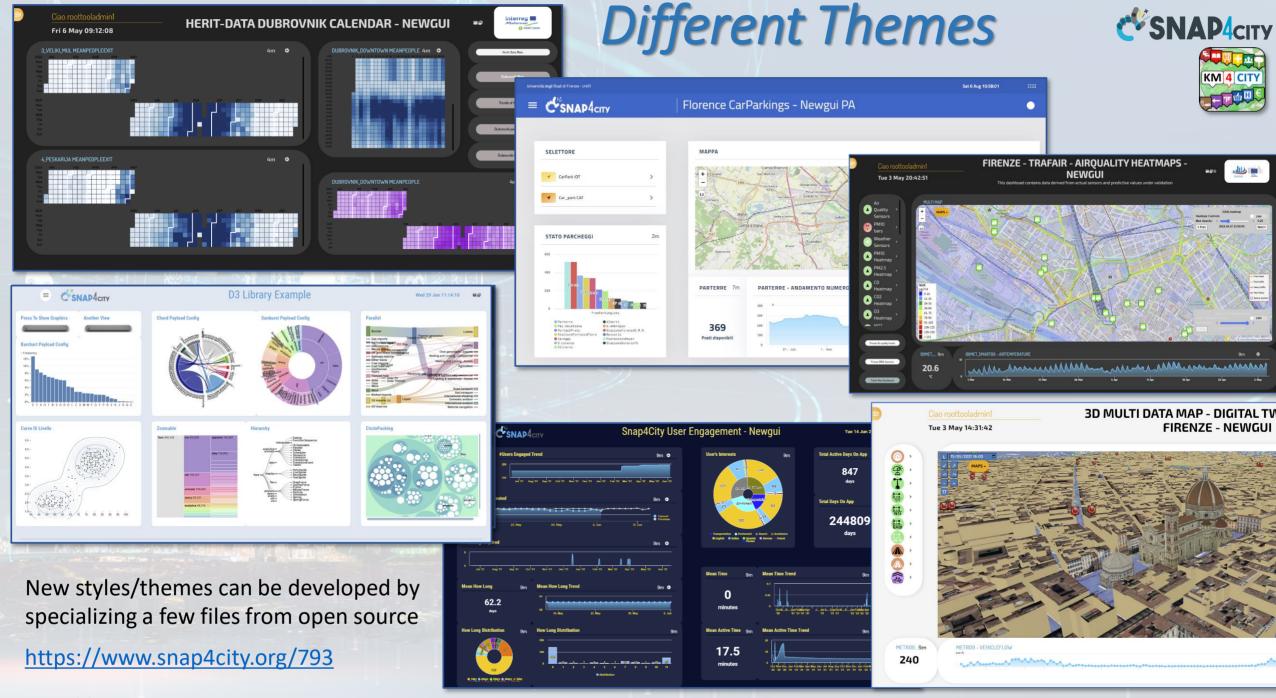












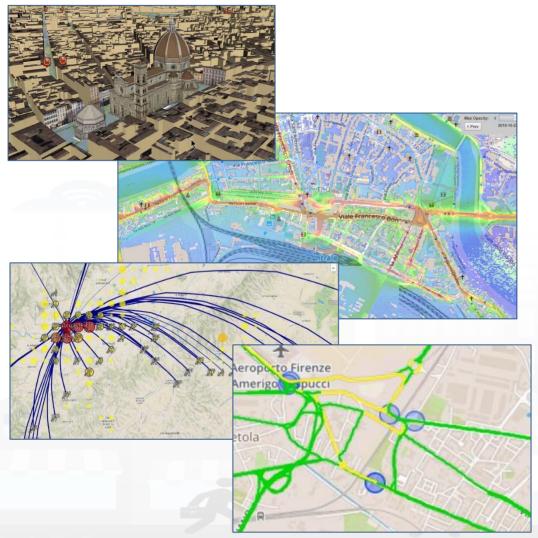








## **Smart City Digital Twin**



## City Digital Model with...

- Intuitive platform
- Any Data TYPE, any data source, any protocol
- Data storage seamless
- Data analytics → artificial intelligence, AI/XAI
- Data Ethics, AI Ethics, GDPR
- Interactive Data Representation, any kind
- Key Performance Indicators, any kind
- What-IF analysis Simulation, prediction, 2D/3D
- Micro, Meso e macro scales
- Operation, planning tactic and strategic / optimization
- Collaborative and shared representation
- Sustainable, shared, open source 100%

#### Complex and heterogeneous information, interoperability

- o GIS, ITS, AVM, IoT, BIM, CKAN, etc.
- Satellite services
- MaaS, last-mile delivery HUBs
- o etc.





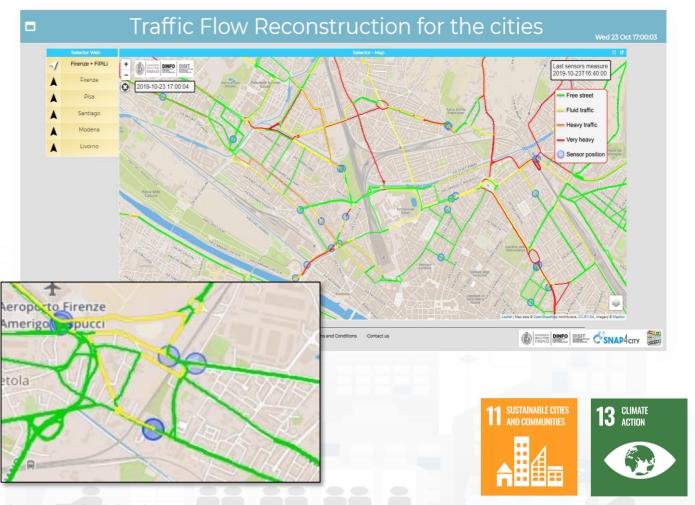






## Why Dense Traffic Flow Reconstruction?

- Controlling pollution
- Dynamic Routing for Firebrigade, Ambulances, general public
- Planning Public
   Transportation routing

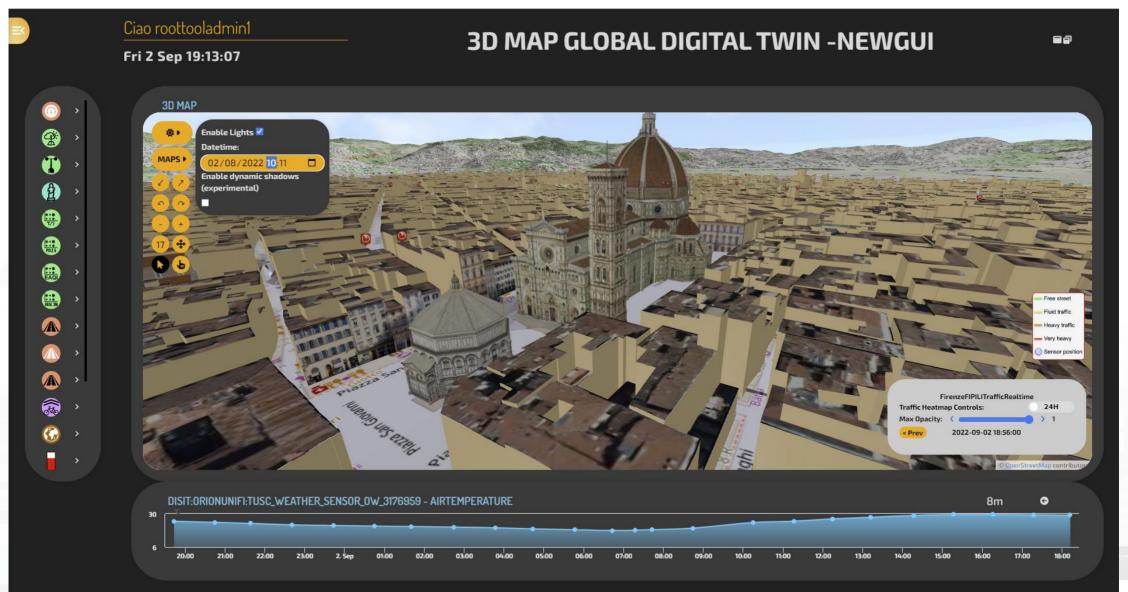


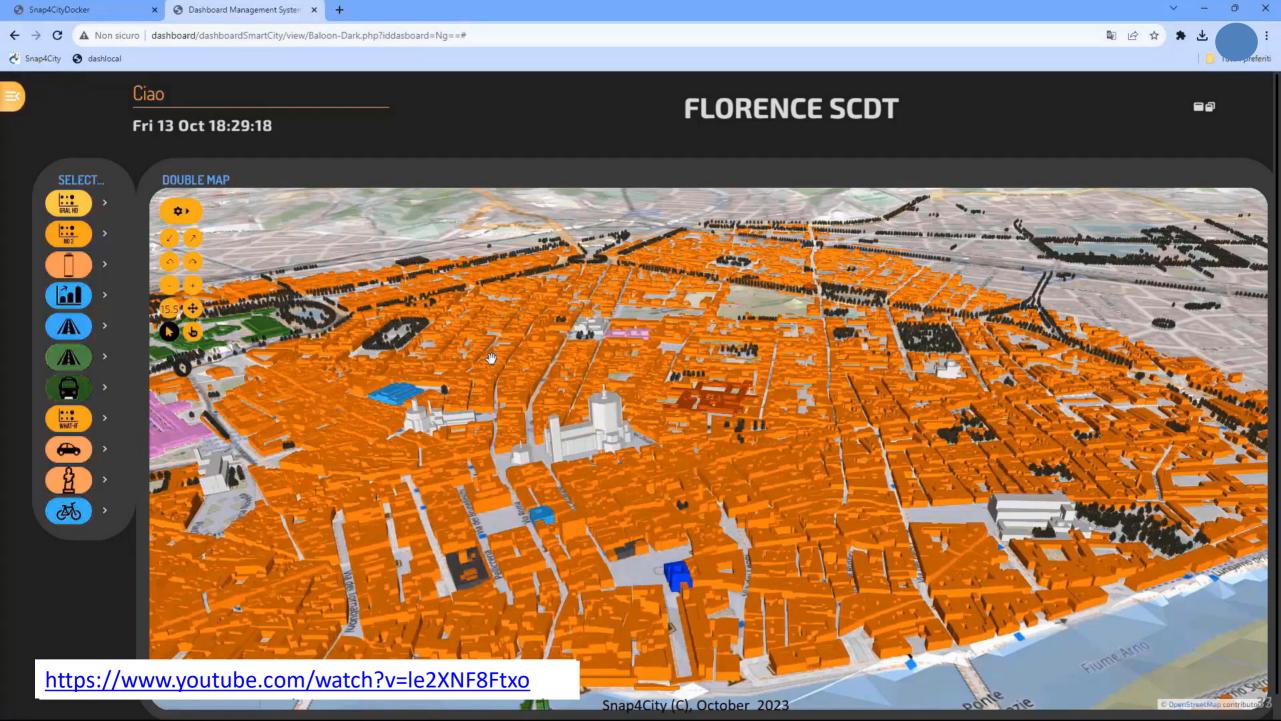
https://www.snap4city.org/dashboardSmartCity/view/index.php?iddasboard=MTc5NQ==













**DINFO** 



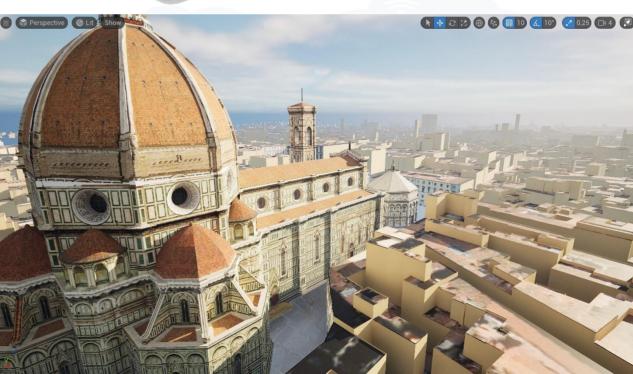


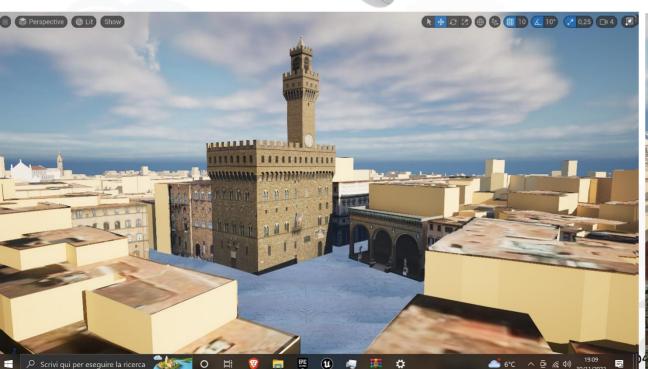


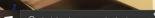
## **OCULUS**





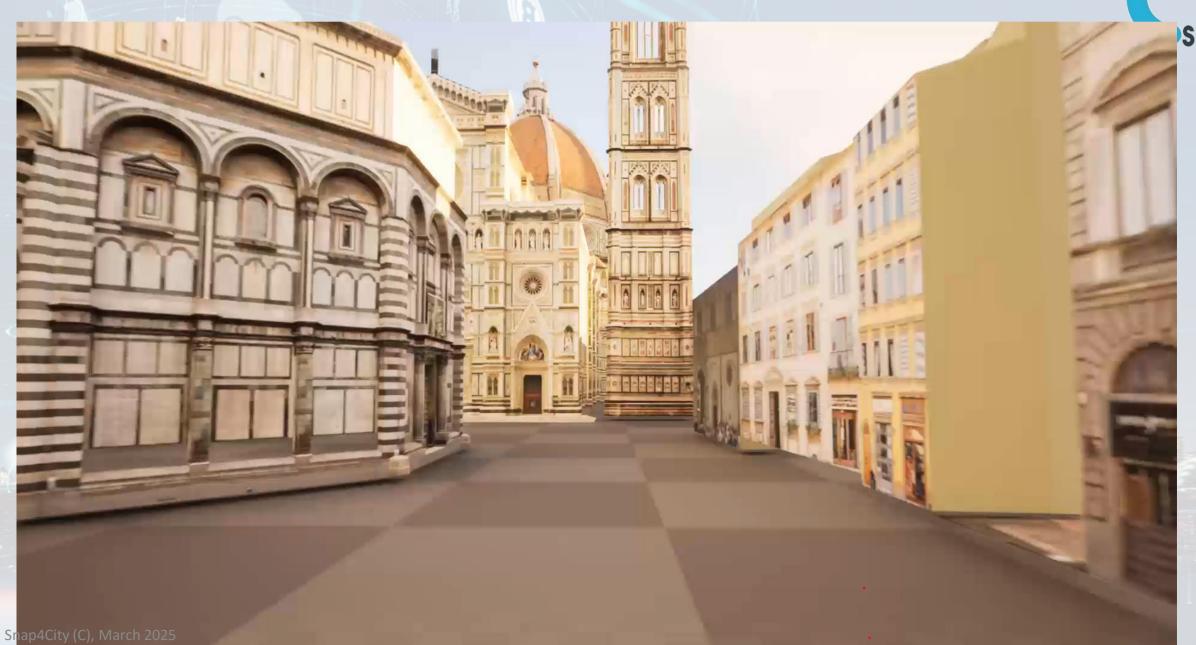






**OCULUS** 

https://www.youtube.com/watch?v=Rcf B2 GOio



SNAP4

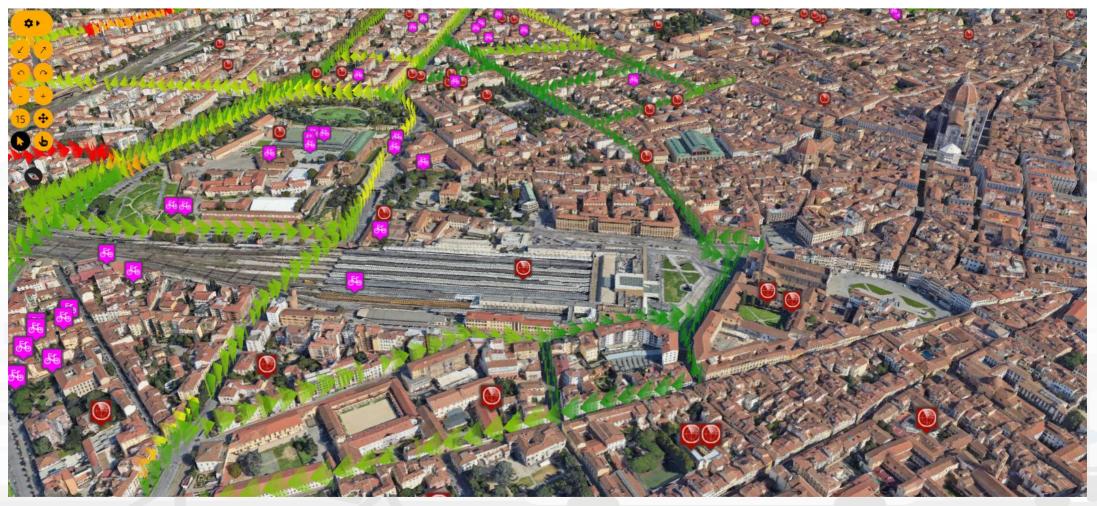








## **Snap4City Digital Twin Engine and data + 3D Google Data**



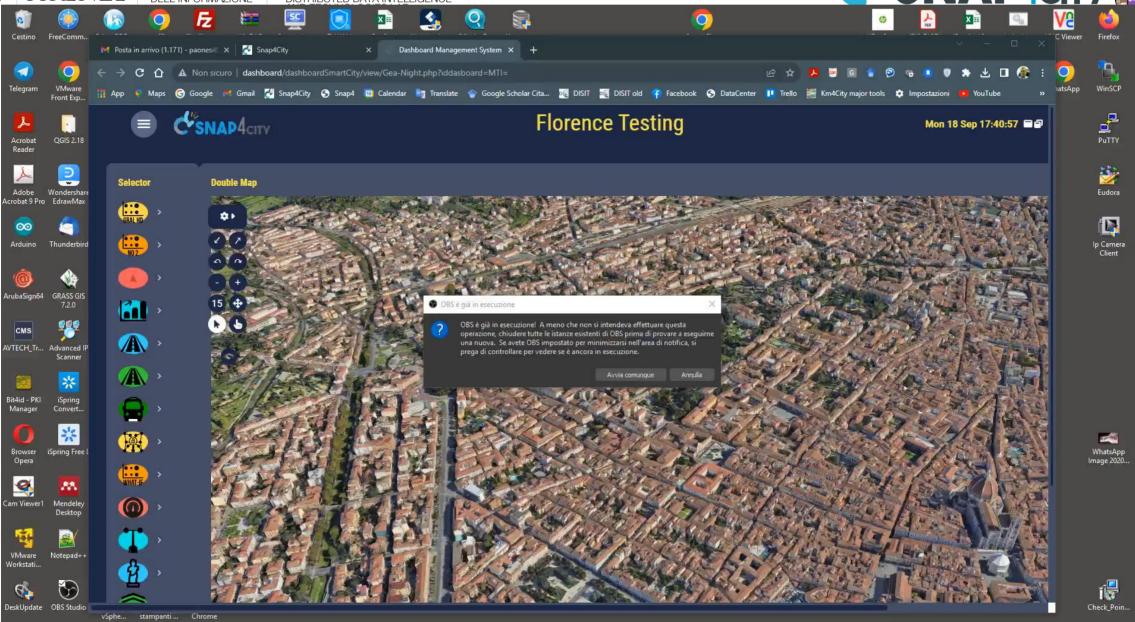


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INTERNET TECHNOLOGIES LAB
DISTRIBUTED DATA INTELLIGENCE

## **Firenze**





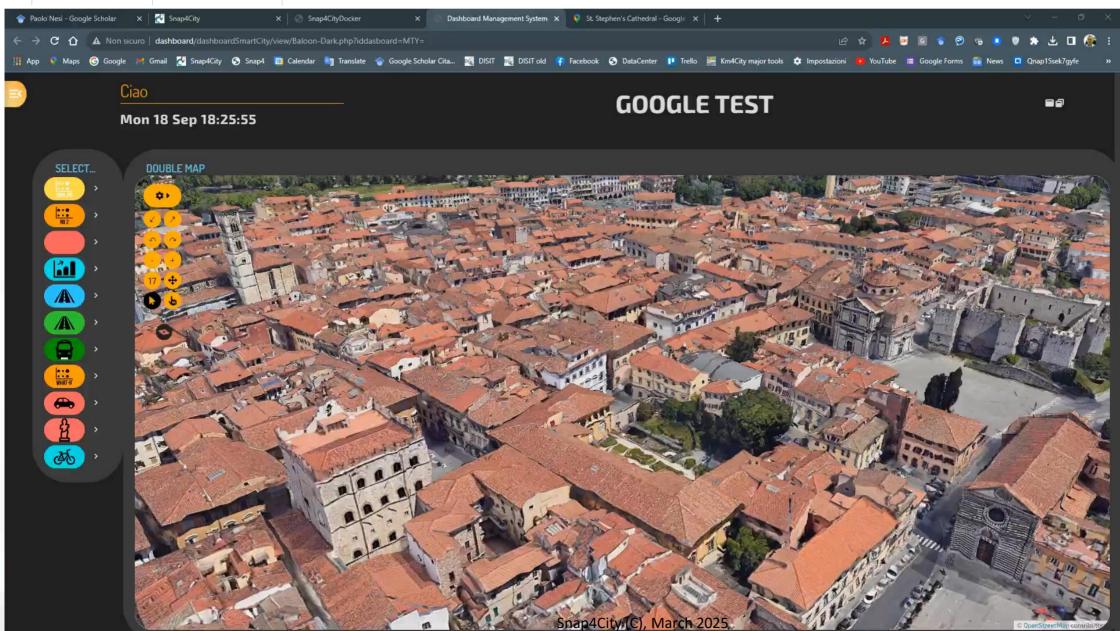


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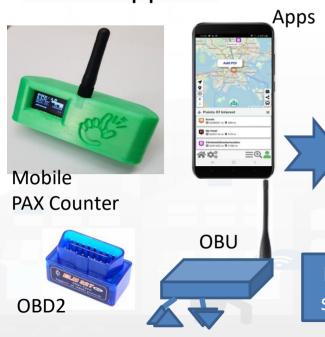


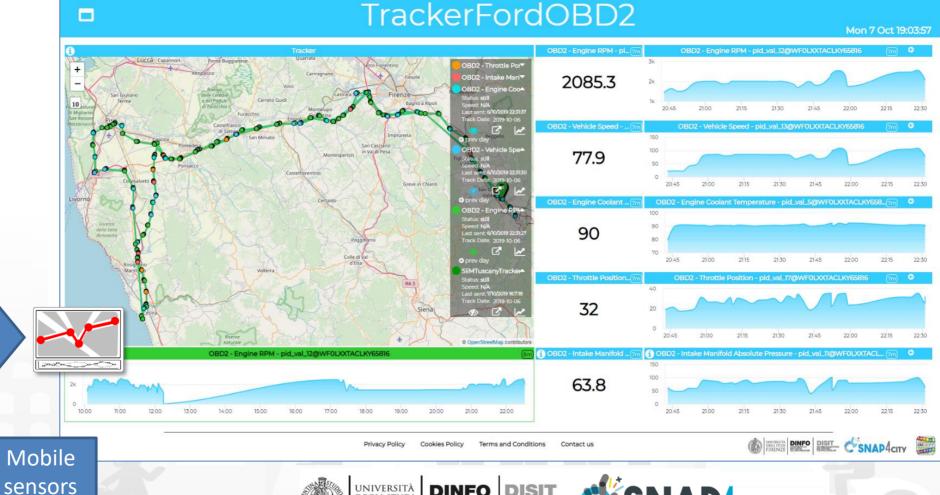




# MyKPI: Tracking of Devices and Mobiles • Real Time Trajectories for

- - Mobile Phone
  - Moving IOT Devices
  - OBU, Vehicular Kits
  - Multiple tracks
  - Day by day
- Micro Application







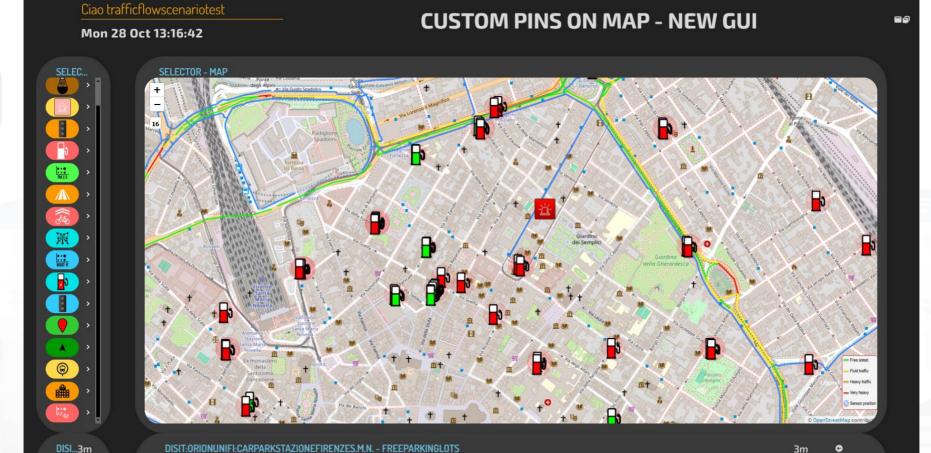


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## **Custom Dynamic Pins**



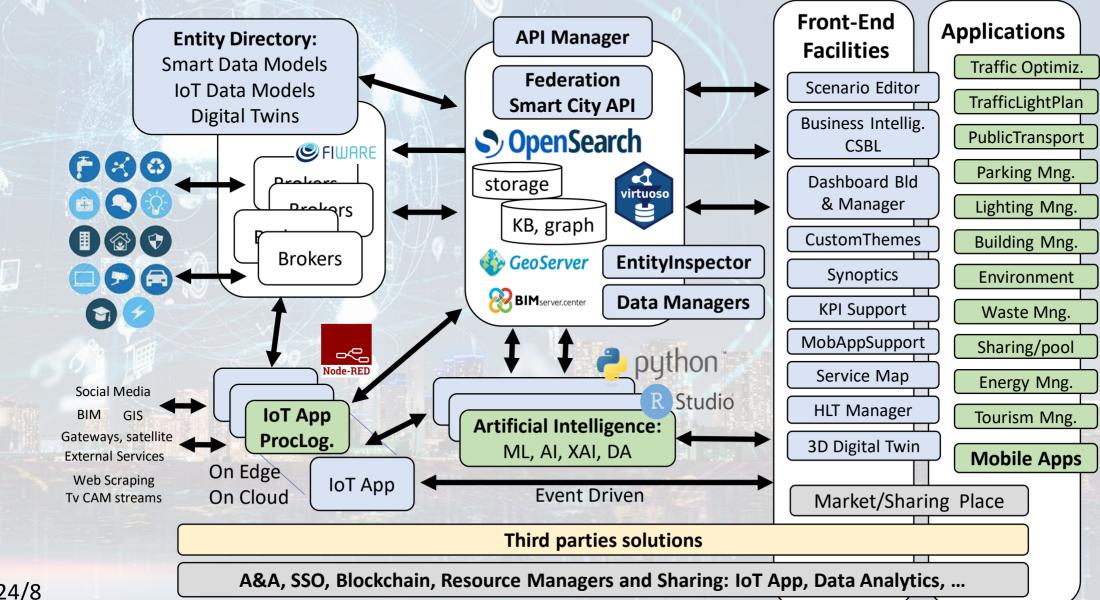




#### **Technical Architecture**







# Decision Support System:

Immed MANAGOR OPEN CESPONSE and Tacticist and Architecture and Architectur

DASHROARD TO

Plains Via What-if Analysis Stakeholders

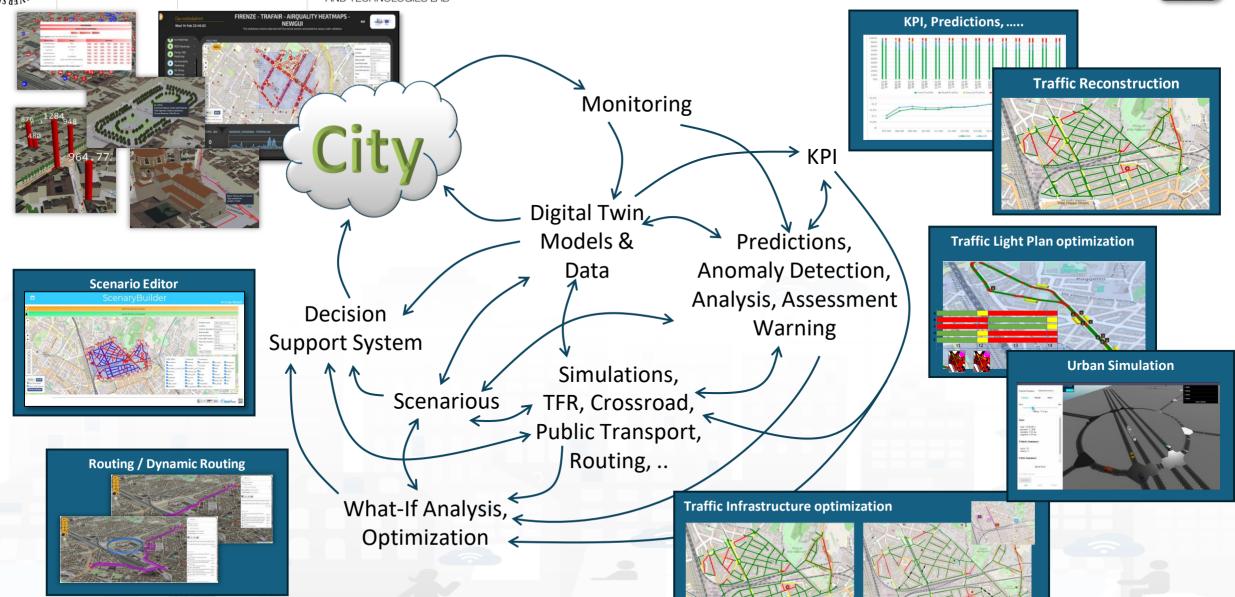






# DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB





Snap4City (C)

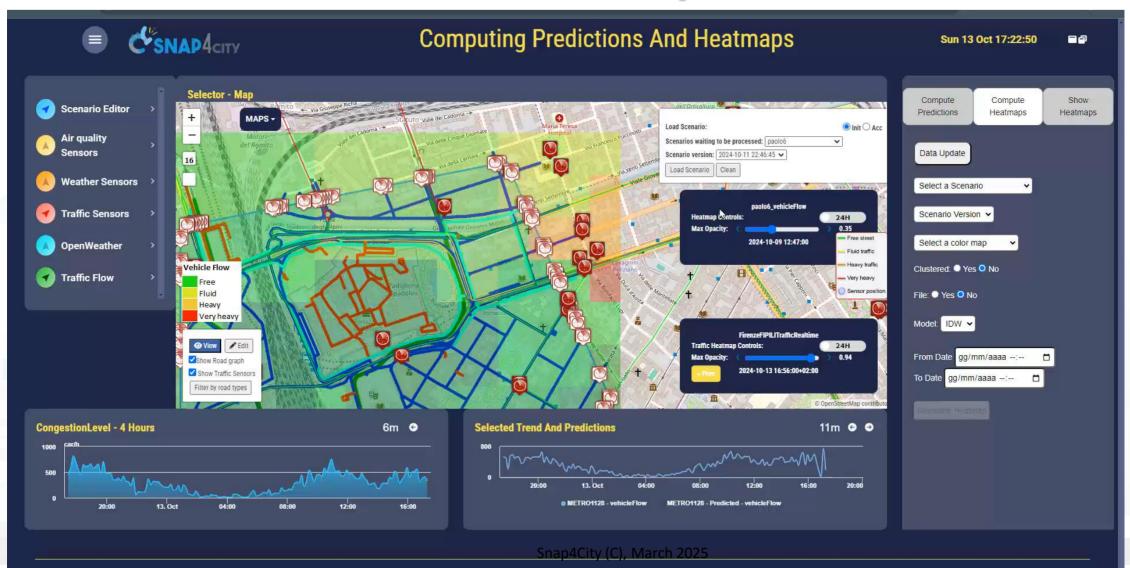








### **Predictions and Heatmaps in Real Time**



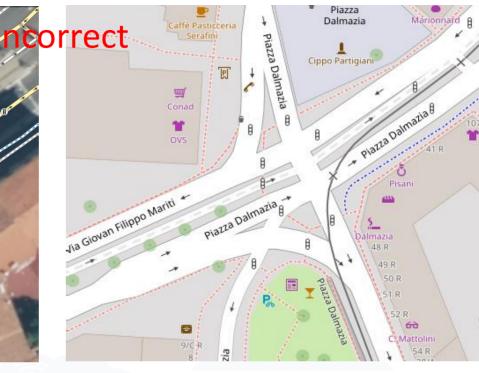






OSM data with non correct viability in Piazza Dalmazia, Firenze





After Correction of OSM data defining a correct viability of Piazza Dalmazia, Florence. Regeneration of the TILEs for the maps









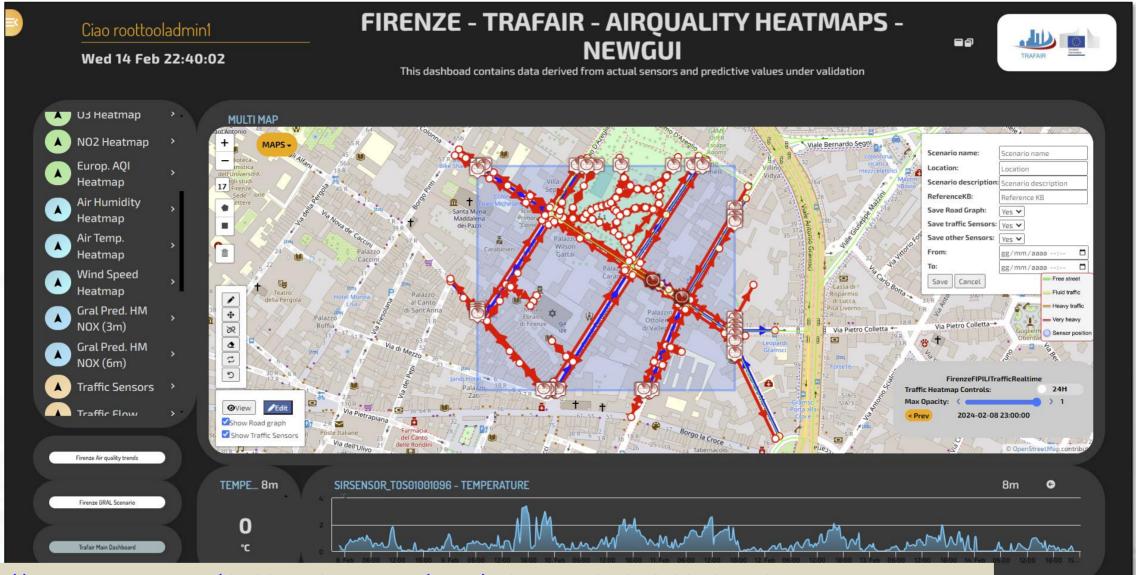




## DISIT DISTRIBUTED SYSTEMS SCENARIOUS Editor CSNAP4CITY KM/4 CITY TECHNOLOGIES LAB SCENARIOUS Editor CSNAP4CITY















Select map 700m

Scenario name Scenario name Location: Scenario description: Scenario description ReferenceKB: Reference KB Save Road Graph: Yes V Save traffic Sensors: Yes Save other Sensors: Yes v gg/mm/aaaa --: **Fdit Road** Show Summary | Cancel Segment Category Street: primary Nr.Lanes: Speed Limit (km/h): Direction: Positive direction > Restrictions: Select or create restriction Update identifier + composition S elemLocation Unselect All Select All elementClass ☑bus guideway☑bus stop ✓ bridleway Construction C elevator disused Corridor crossing elementType ✓emergency access point emergency bay ✓ island ☑living street c length **☑**motorway motorway link no ✓ platform operatingStatus ✓ primary primary link ✓ private ✓ raceway razed speedLimit residential ☑ rest area ✓ secondary link ✓ service **Ø** Edit View services dertiary trafficDir ✓ steps ✓ tertiary link 
✓ track Show Road graph ✓ traffic island tram **Itrunk** link ☑unclassified ☑via ferrata width Show Traffic Sensors ☑bus\_guideway ☑ohm:military:Trench secondary highwayType Filter by road types route

**New Scenario** 

**Editing** Drag & drop Split & Join Delete Do and Undo











#### **Micro Simulation**













#### **Decision Support Systems, What-if**

Snap4City (C), March 202

#### Event planning, via what-if analysis

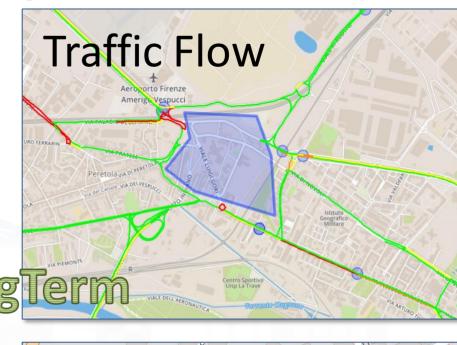
- Change in the graph structure of the city
- Impact on the flow of people and vehicles
- Adaptation: public transport, traffic, pedestrian management, etc.

#### Immediate reaction to natural events or not

- Everything is ready and updated in real time
- Each view is contextualized in terms of data: descriptive and prescriptive

#### Digital Twin

- More detail in the context integrated data
- Greater realism in deductions and representations
- Less fragmentation and non-uniformity in the views to support decisions





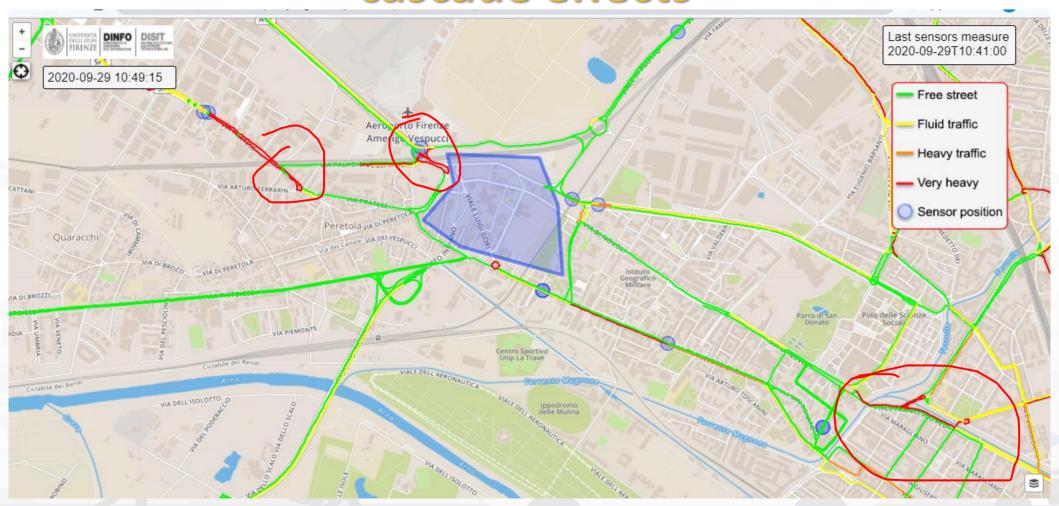








# Computation of Traffic Flow Evolution, cascade effects





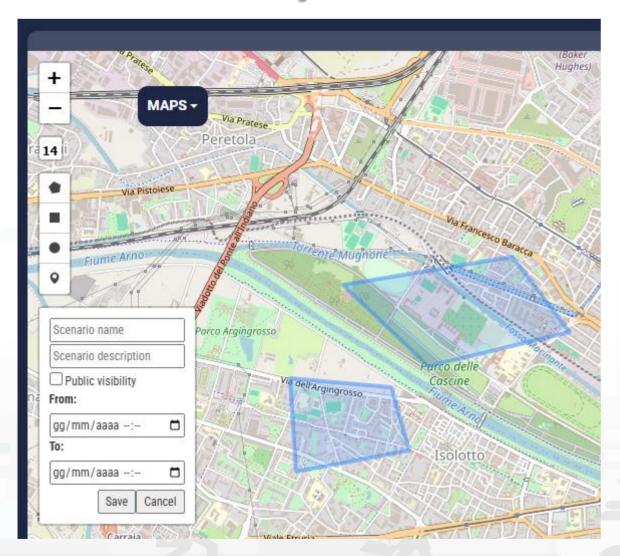








### What you can do with advanced tools



#### **Basic Scenario editor**

Single and multiple blocked areas, which can be shared among users

#### What-if analysis tool

- Ready to use tools for exploiting Basic Scenarios as blocked areas and simulating/
- computing in real time routing, in different traffic conditions













### What you can do with advanced tools

#### **Advanced Scenario Editor**

- Create complex and full detailed scenario, with road graph, sensors, of any kind, even new roads, restrictions, parameters, etc.
- Exploit these scenarios to create
  - Simulation
  - Business intelligence tools and visual/business analytic tools also working in real time
  - Traffic flow reconstruction
  - Traffic infrastructure optimisation
  - Traffic light plan optimization
  - Pedestrian analysis and simulation
  - Match demand vs Offer, simulation and analysis
  - Computation of SUMI, SUMP, 15 Min City Indexes, etc.
  - Heatmaps computation
  - Etc. etc.



#### What-if-Analysis and Infrastructure Optimization ....



#### Aim of Decongestion, Sustainability

- Reduction of emissions, # stops
- Reduction of travel time

#### What-if analysis on Operation/Plan

- Working by scenarios making Hyp.
- Simulating the results on conditions
  - Generative AI and/or neuro-Symbolic
- Computing KPI and providing suggestions

#### **Optimisation on Plan**

- Making Scenario for the context
- Defining constraints and conditions
- Asking to AI to generate best solutions
- Offering Optimal Solution in terms of
  - Solutions and Explanations



Traffic Flow Analysis By Scenario









CSNAD4CITY







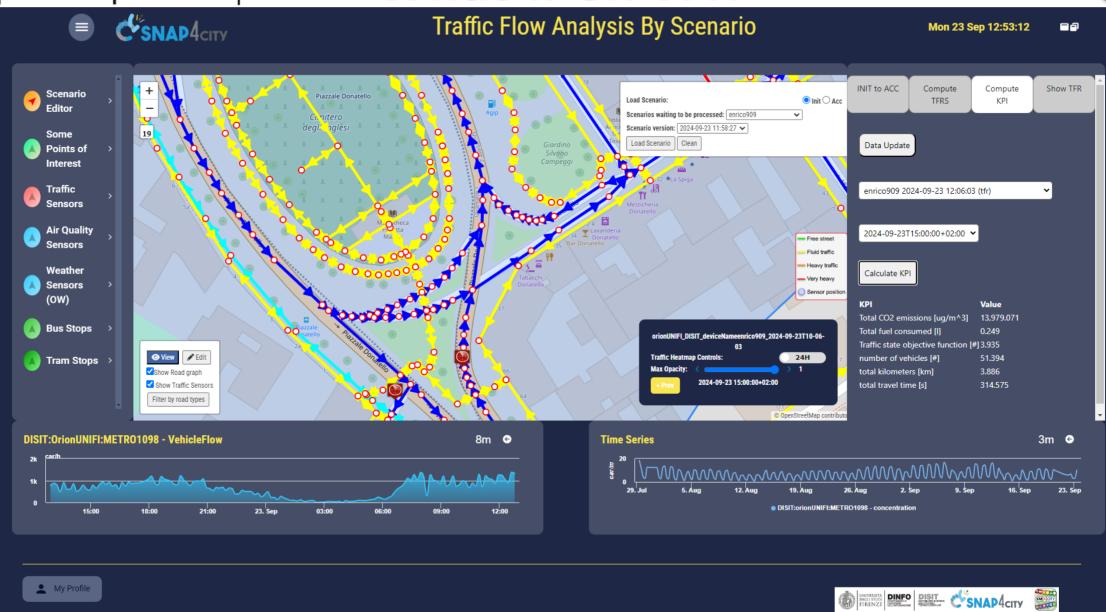
#### università degli studi FIRENZE



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#### What-if on TFR







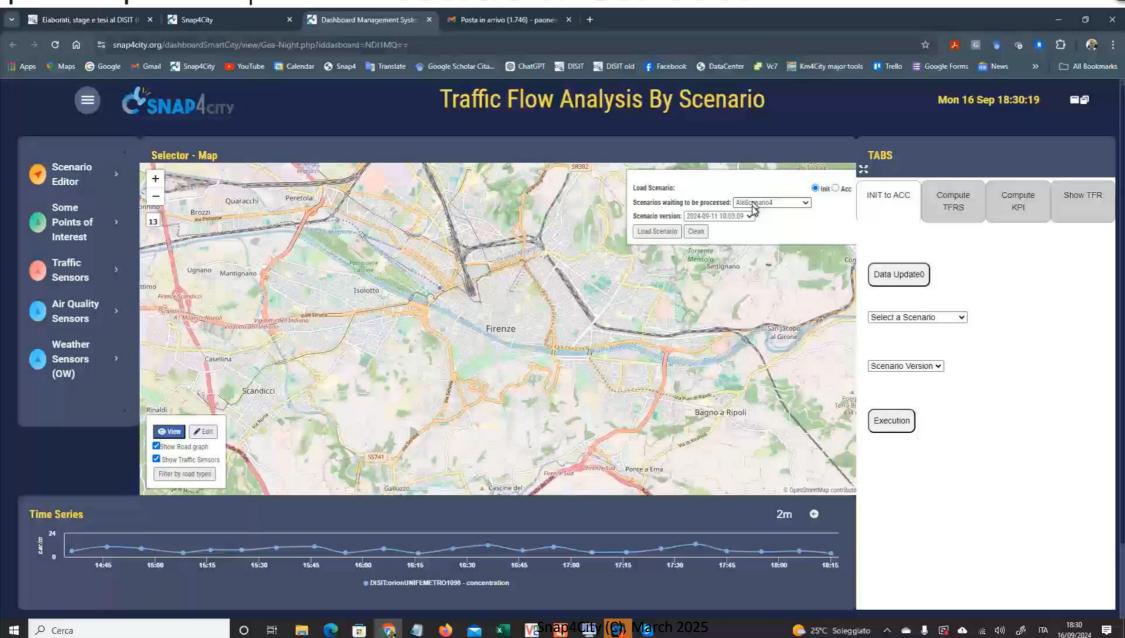
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#### **What-if on TFR**

















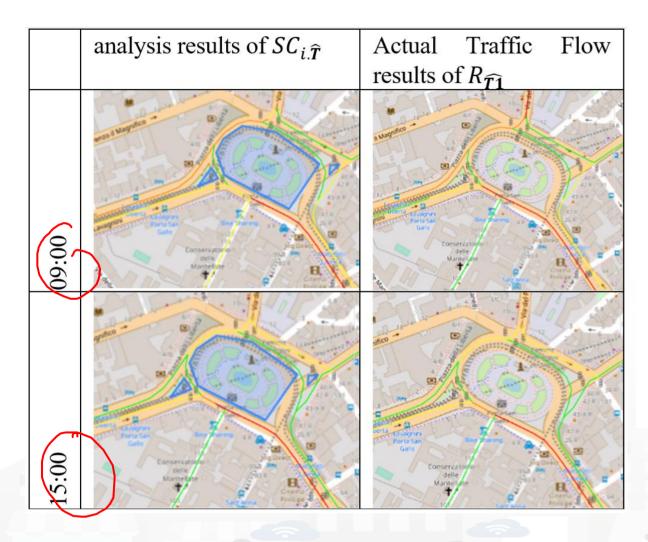


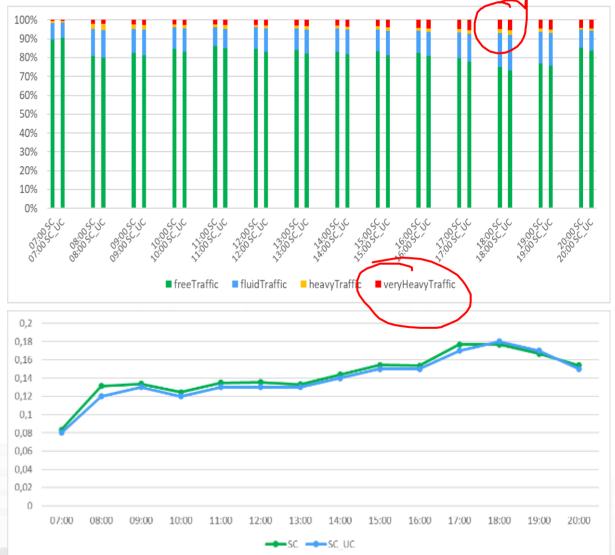




#### What-if











### What-If Analysis SNAP4city



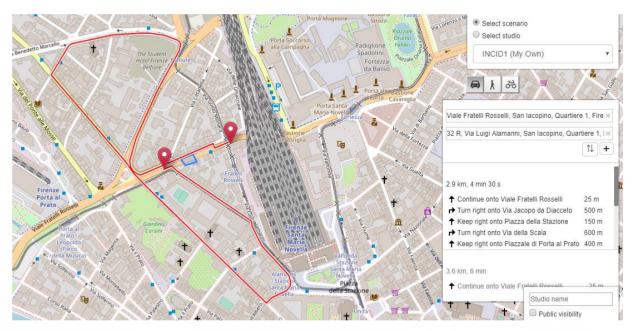


Accidents and elements blocking Points and Shapes taken into account for:

- Routing
- Traffic Flow reconstruction
- Evacuation paths
- Rescue team paths

Assessment on the basis of changes:

- Mobility demand assessment
- Mobility Offer assessment





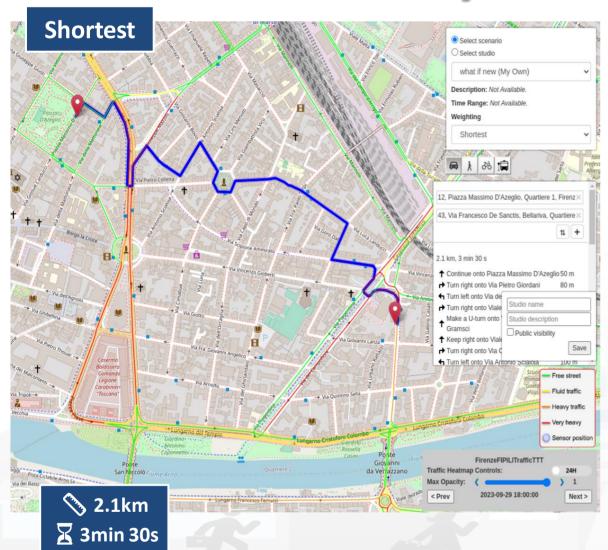


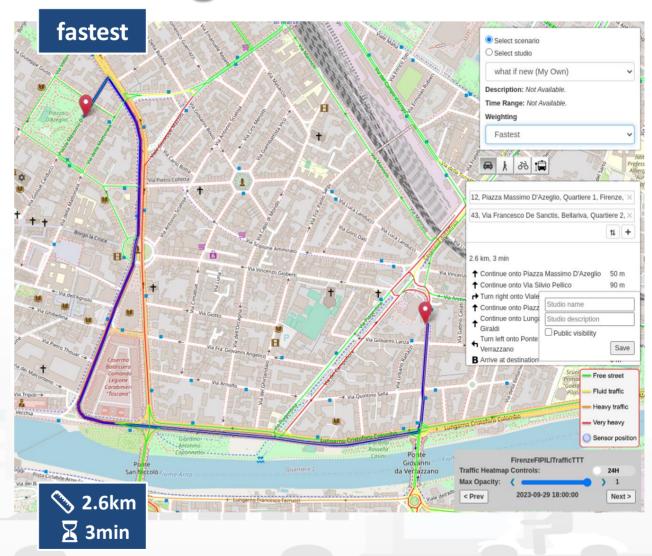






### **Constrained Dynamic Routing: Traffic Flow**





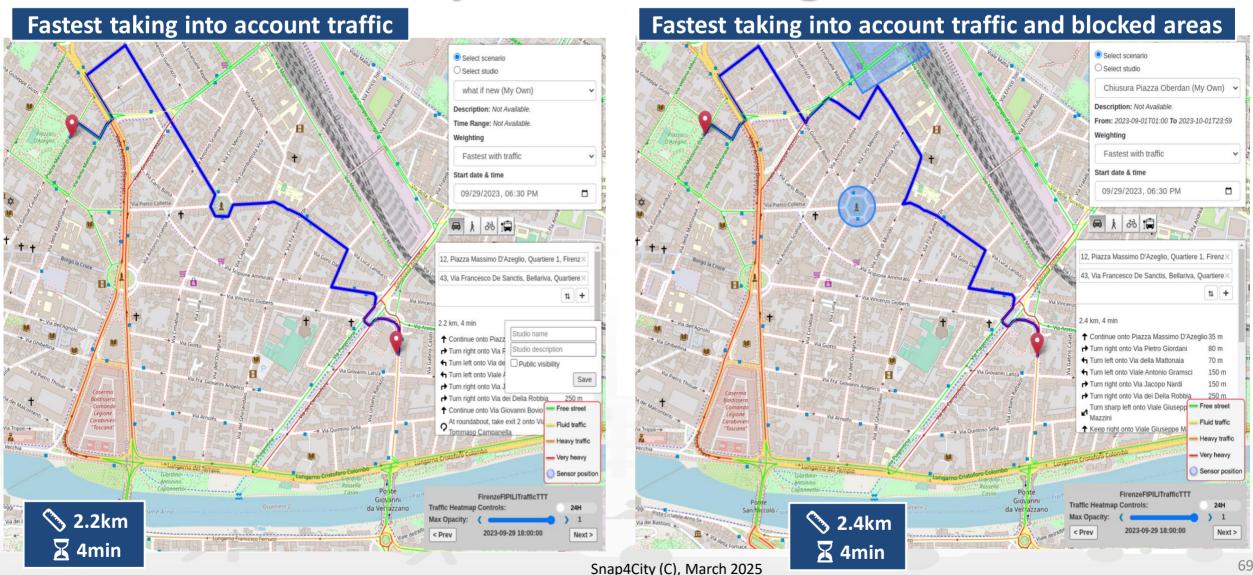








### **Constrained Dynamic Routing: Traffic Flow**



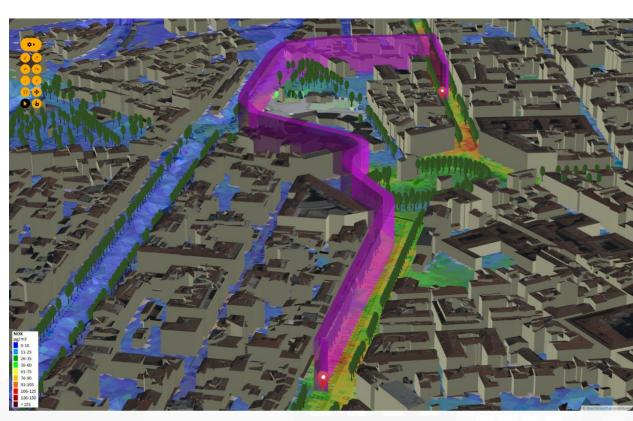


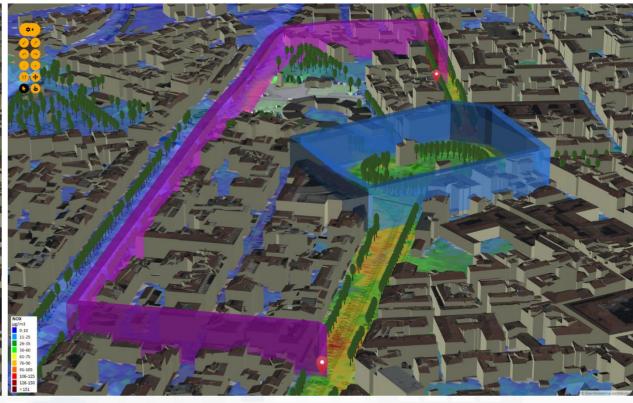


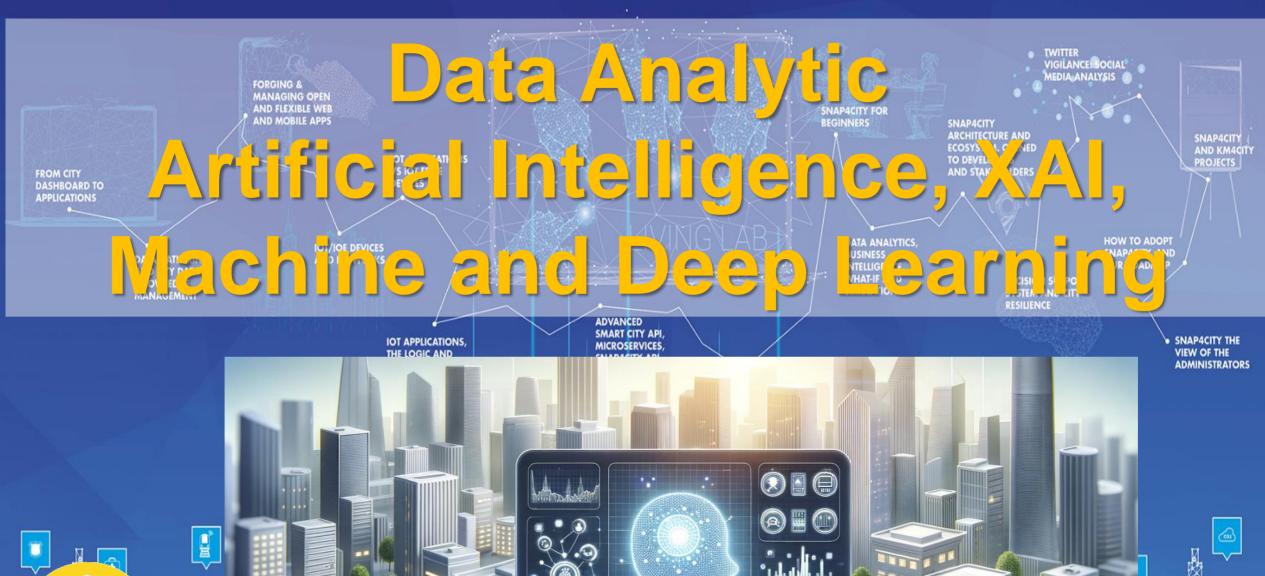




### **Dyamic Routing in 3D space**











### Available AI Solutions on Snap4City

SNAP4city

KM 4 CI

https://www.snap4city.org/997

More than 80 Available Solutions & 300 Al applic.

- Mobility and Transport
- Environment, Weather, Waste, Water
- City Users Behaviour and Social analysis
- Energy and Control
- Tourism and People
- Security and Safety
- High Level Decision Support Solutions
  - Asset management
  - Resilience and Risks Analysis
- Low level Techniques

https://www.snap4city.org/download/video/course/p4/





https://www.snap4city.o rg/download/video/DPL SNAP4SOLU.pdf







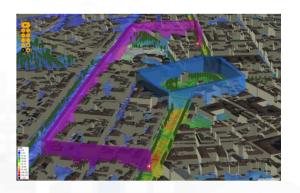




### Mobility and Transport Domain (2024/8)

- Goals:
  - Decongestion
  - Decarbonization
  - Accessibility to services
  - Security/Safety of city users
- Solutions for Operation (monitoring, managing, mobile apps, digital signages, control rooms)
  - Monitoring traffic, parking, people flow, services, boats, ports, beaches, etc.
  - Early detection/warning of critical conditions: traffic, congestion, security/safety
  - Managing Smart Parking, transportation services, fines, etc.
  - Managing fleets: personal, sharing, waste collection, maintenance, etc.
  - Managing E-sharing, pooling services, MaaS, etc.
  - Managing entrances in city areas: restricted areas, touristic busses, etc.
  - Production of suggestions, recommendations, nudging
  - Computing predictions of any kind
- Solutions for Planning (optimization and what-if analysis)
  - Reduction of traffic congestion, via optimization: traffic light plans, viability, routing
  - Reduction of Pollutant Emissions, via optimization: traffic light plans, viability
  - Optimization of transportation offers wrt multimodal mobility demand
- Algorithms and computational solutions, see next slide











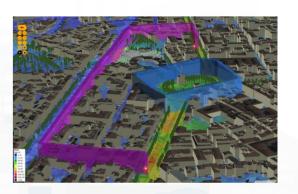


# Tools for Mobility and Transport (2024/8)

- Optimisation of viability of an area for reducing congestion, waiting time, stops
- Optimisation of Traffic Light Plans, synchronization, in an area for reducing congestion, waiting time, stops
- **Predictions** for: traffic flow, smart parking, smart bike sharing, people flows, etc. (ML, DL)
- What if analysis: routing, traffic flow, demand vs offer, pollutant, etc. (Simulation + ML)
- Traffic flow reconstruction from sensors and other sources (simulation + ML)
- Public Transportation: Ingestion and modelling of GTFS. Transmodel. NeTEx. etc. (DP)
  - Analysis of the demand mobility vs offer transport of according to public transportation and multiple data sources (Simulation)
  - Assessing quality of public transportation (analysis)
- Accidents heatmaps, anomaly detection (analysis, ML)
- Road light controlled by traffic conditions
- Tracking fleets, people, via devices: OBU, OBD2, mobile apps, etc. (DP)
- Routing and multimodal routing (multistop travel planning), constrained routing, dynamic routing (DA)
- Computing Origin Destination Matrices from different kind of data (analysis, DP, DP)
- Computing typical trajectories on the basis of tracks (analysis, ML)
- Fleet management, monitoring, booking, allocation, maintenance
- Computing Messages for Connected drive (DP)
- Slow and Fast Mobility 15 Minute City Indexes (analysis, DP, ...ML)
- Computing and comparing traffic flow on devices and at the city border (analysis)
- Typical time trends for traffic flow and IoT Time series. (analysis, ML)
- Impact of COVID-19 on mobility and transport
- Computing SUMI, PUMS, etc. (mainly DP)
- **Definition of Scenarios:** traffic, road graph, conditions, etc.
- Etc.







# Mobility and Transport Traffic Flow Analysis

- Multiple Domain Data
  - Traffic Flow sensors, city structure, weather
- Decision Makers Multiple Locations
  - Real time Monitoring, predictions
  - Traffic Flow Predictions,
  - Traffic Reconstructions, routing
  - Dashboards, What-IF analysis
  - Mobile App, people flows
- Historical and Real Time data
- Services Exploited on:
  - Dashboards, Mobile App
- Since 2017, 2019

Cities: Firenze, Pisa, Livorno, Modena, Santiago di Compostela









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#### **Traffic Light Optimization**





#### **Aims, Multiple Objectives**

- Decongestion, reduction of emission
- Reduction of travel time
- Synchronization, green wave
- public and private traffic, tramway priority
- Micro and Macro Scales

#### AI: Genetic Algorithms, Reinforced Learning

- Multiple Traffic Light Plan generation
- Fixed and Actuated Cycles
- Adjusted on Demand, in operation

#### Validation/integ. with SUMO simulation

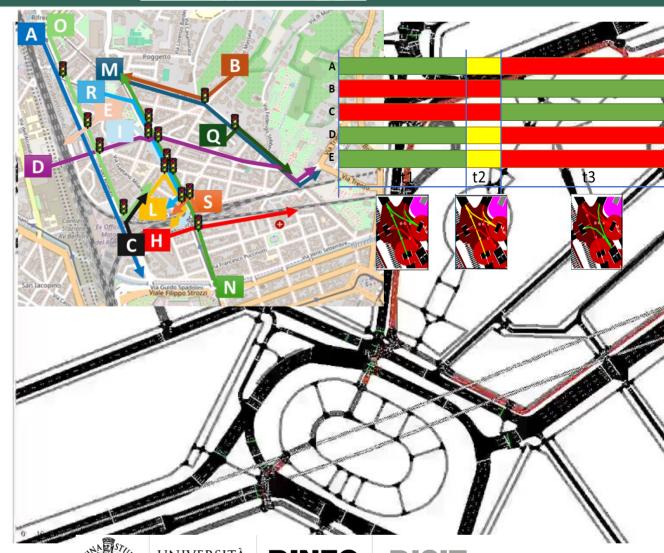
- Travel Time, waiting time, waiting count
- Specific travel time on directions
- CO2 emissions, etc.

**Reductions from 5% to 15%** 













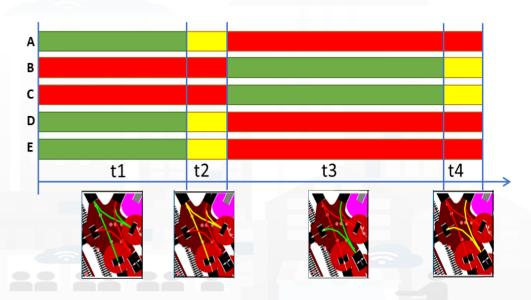




### **Traffic Light Plan Optimisation, Digital Twin**

- Match Multiple Objectives and Synchronization:
  - public and private traffic, tramway priority
  - Micro and Macro Scales
  - AI: Genetic Algorithms, Reinforced Learning
    - Fixed and Actuated Cycles
    - Adjusted on Demand
- Validation/integ. with SUMO simulation
  - Travel Time, waiting time, waiting count
  - Specific travel time on directions
  - CO2 emissions, etc.
- Reductions from 5% to 15%





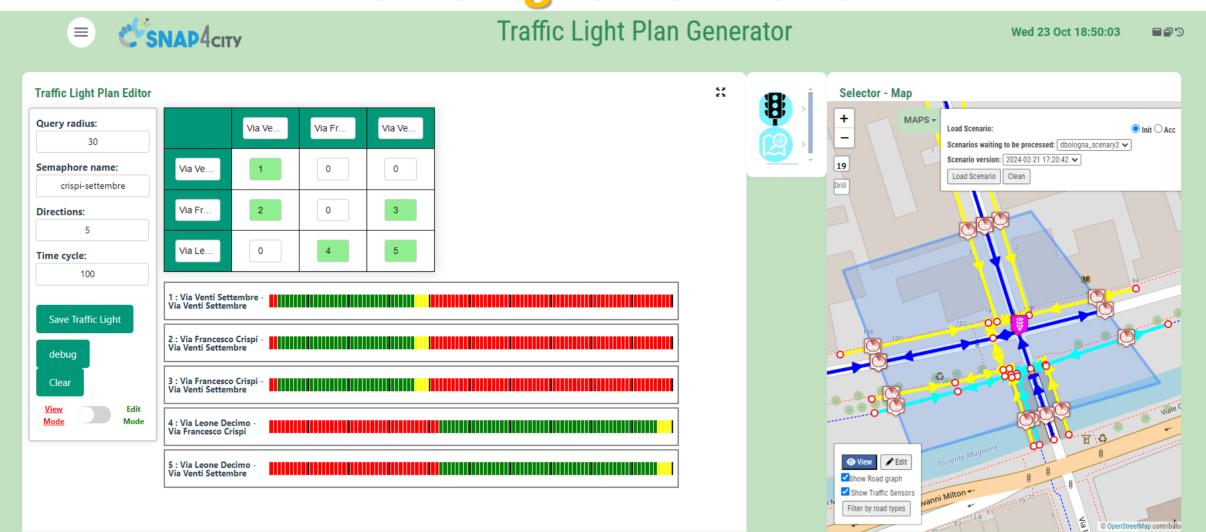








### **Traffic Light Plan Editor**



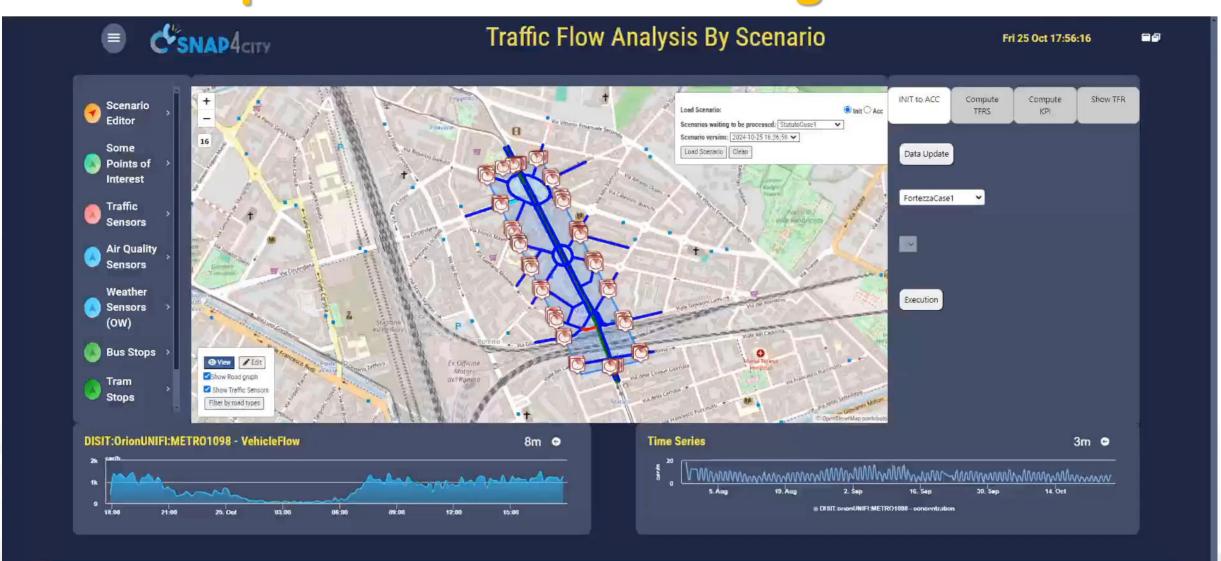








### **Optimization of Traffic Light Plan**

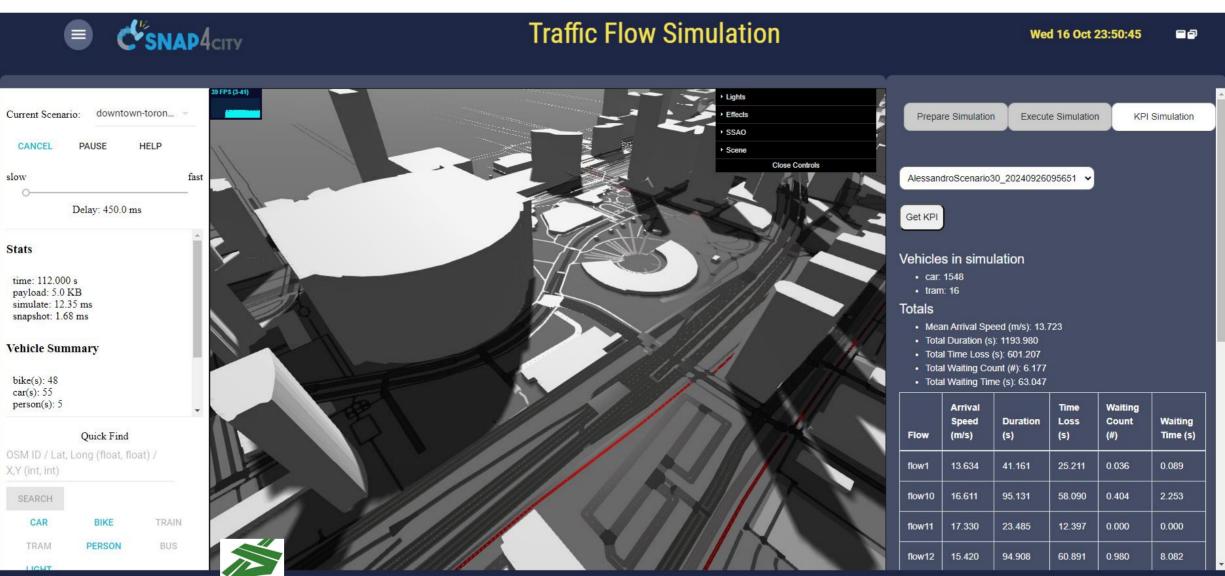






# DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB







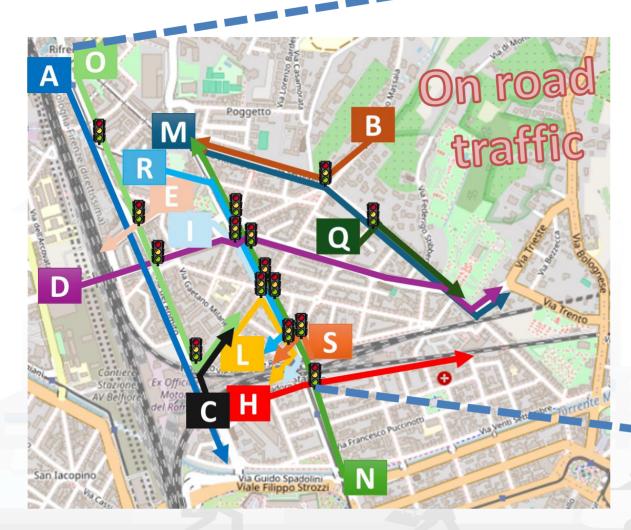


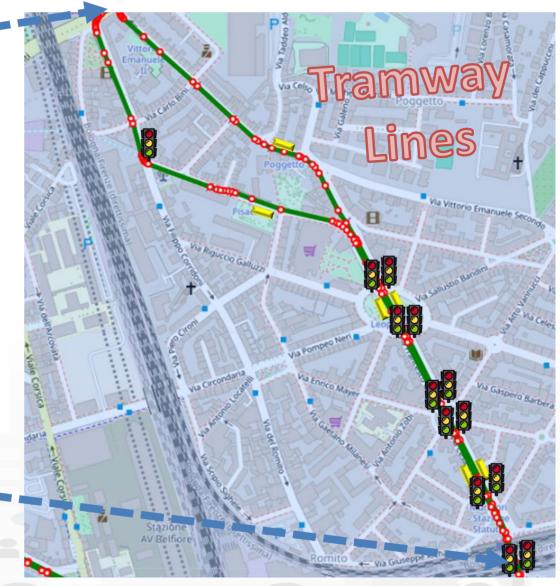
# DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB





## Example, main paths













#### **Mean Travel Time**

	Traffic Load	MTTall	MTT dir_N	MTT dir_M	MTT dir_A	MTT TW Careggi	MTT TW Costanza
4TW-NTNS-MWD-P	1.5	3542.50	198.90	242.14	197.64	436.00	427.00
4TW-NTNS-MWD-A	1.5	3242.71	178.33	243.28	195.79	436.00	427.00
4TW-NTNS-MWD-P-A	1.5	3242.71	178.33	243.28	195.79	436.00	427.00
2TW-NTNS-MWD-P	1.5	4538.02	207.40	456.14	615.00	436.00	427.00
2TW-NTNS-MWD-A	1.5	3940.07	179.30	428.67	481.53	436.00	429.75
2TW-NTNS-MWD-P-A	1.5	4380.63	182.05	456.59	654.21	436.00	427.00
SUMO Actuated	1.5	3409.13	280.09	515.34	200.66	497.54	499.81
Webster	1.5	6474.95	465.45	441.93	210.50	1379.25	493.87
WebsterAdjusted	1.5	4035.08	195.82	441.09	205.66	463.87	447.06
		-5%	-8%	-45%	-3%	-6%	-4.5%

Reductions of Travel time of 3-45% and elimination of the #stops for the tramways

**4TWD-NTNS-MWD-P-A**: optimization by prioritizing traffic **directions**, the normalized number of **vehicles stops**, *NTNS*, **the mean waiting delay** *MWD*, for all traffic lights, and post synchronization, with Penalty and Adjust dynamically performed





# DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB



SNAP4CITY THE VIEW OF THE **ADMINISTRATORS** 

# Traffic Infrastructure Optimization



DATA G

















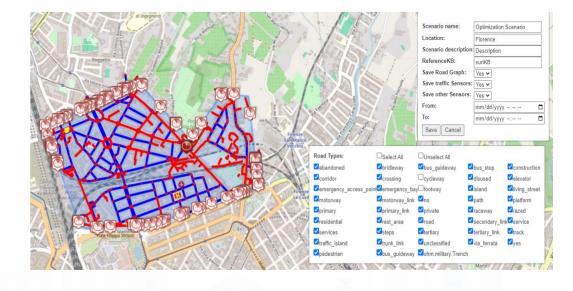






### Traffic Infrastructure Optimisation, Digital Twin

- Identification of Scenario (Scenario Editor), any changes
  - Definition of traffic loads by flows
- What-if or Automated Optimisation
- Automated Optimisation:
  - Stochastic Relaxation, Simulated Annealing, Traffic Flow Reconstruction
  - Multiple objectives targeting
    - Travel time, emissions, fuel consumption, traffic status
  - Limiting the number of changes





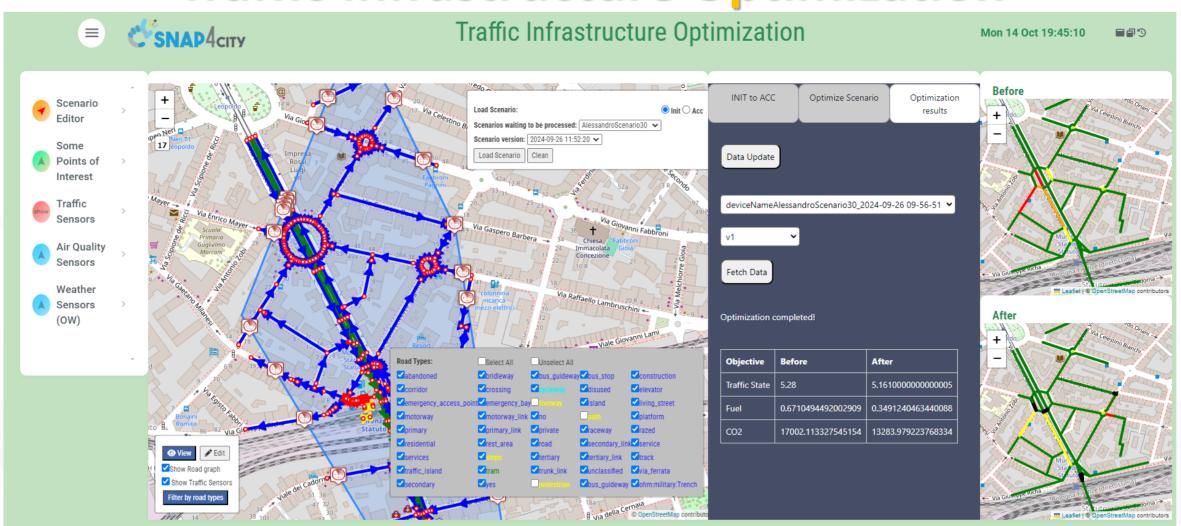








#### **Traffic Infrastructure Optimization**





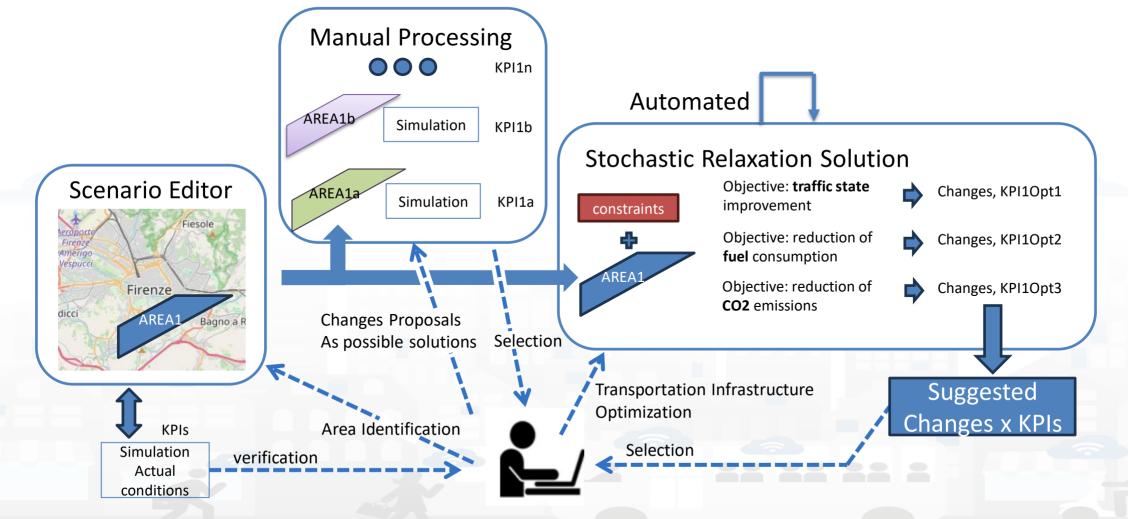






## **Traffic Infrastructure Optimisation**









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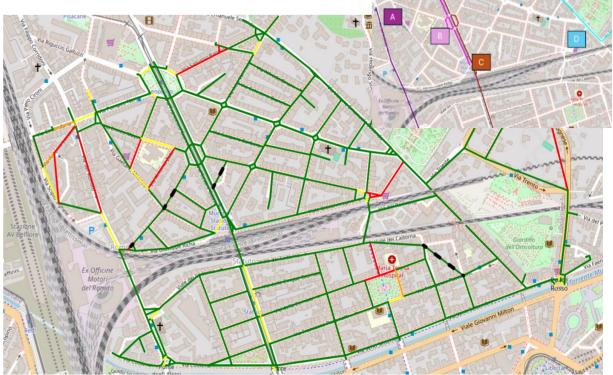




**Optimization Results** 



Case max 4 changes	KPI estimation on the best solution					
Optimization Target	Traffic State	Fuel	CO2			
Optim 4 Traffic State	91.341- <b>21</b> %	17.964	128536			
Optim 5 Fuel	91.514	16.633 <b>-35</b>	<b>%</b> 128227			
Optim 6 CO2	92.859	19.192	127876 - <b>23</b> 9			
Original	115.475	25.680	165822			



Travel Time [s]	Path A	Path B	Path C	Path D	Total Time
Original Scenario	183.2	59.6	80.9	132.5	456.4
Optim 4 Traffic State	93.2	60.0	63.7	96.0	313.1
Optim 5 Fuel	89.6	51.2	59.7	96.4	296.9
Optim 6 CO2	89.5	53.2	58.4	100.1	301.3

-28%









TOP

# Traffic Flow











## **Traffic Flow Tools**

Spire and Virtual Spires (cameras), Bluetooth, ...
Specifically located: along, around, on gates, on x...



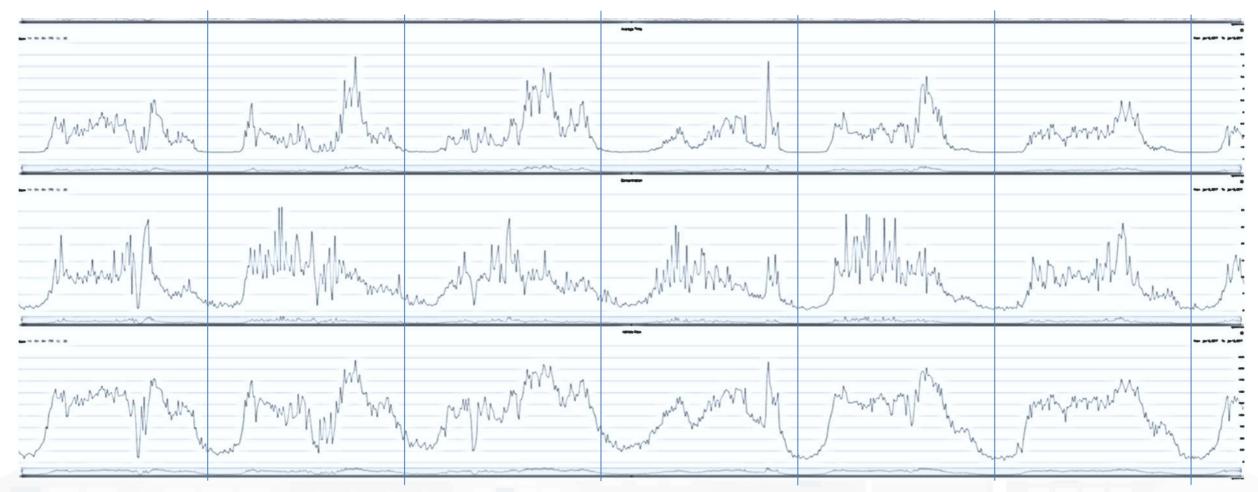
Snap4City (C), March 2025











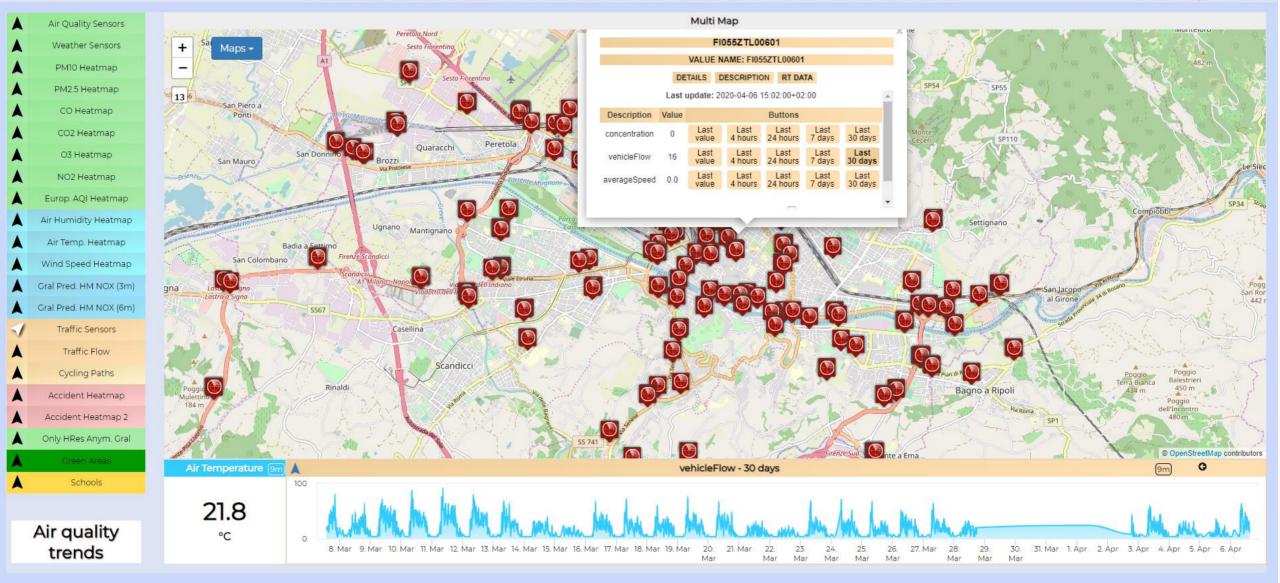
Day by day traffic flow, on the week data from 3 sensors



#### Firenze - Trafair - AirQuality Heatmaps

This dashboad contains data derived from actual sensors and predictive values under validation

Mon 6 Apr 15:12:27

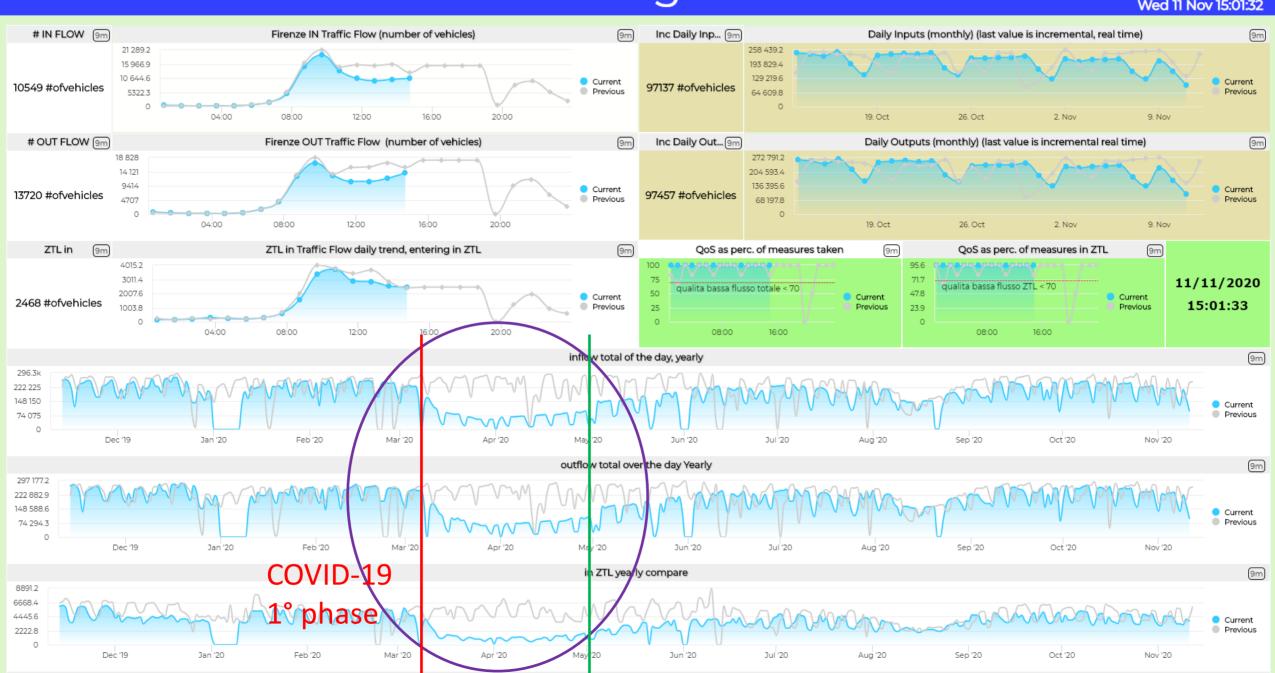








#### Traffic Flow Monitoring - Firenze - Cloned2



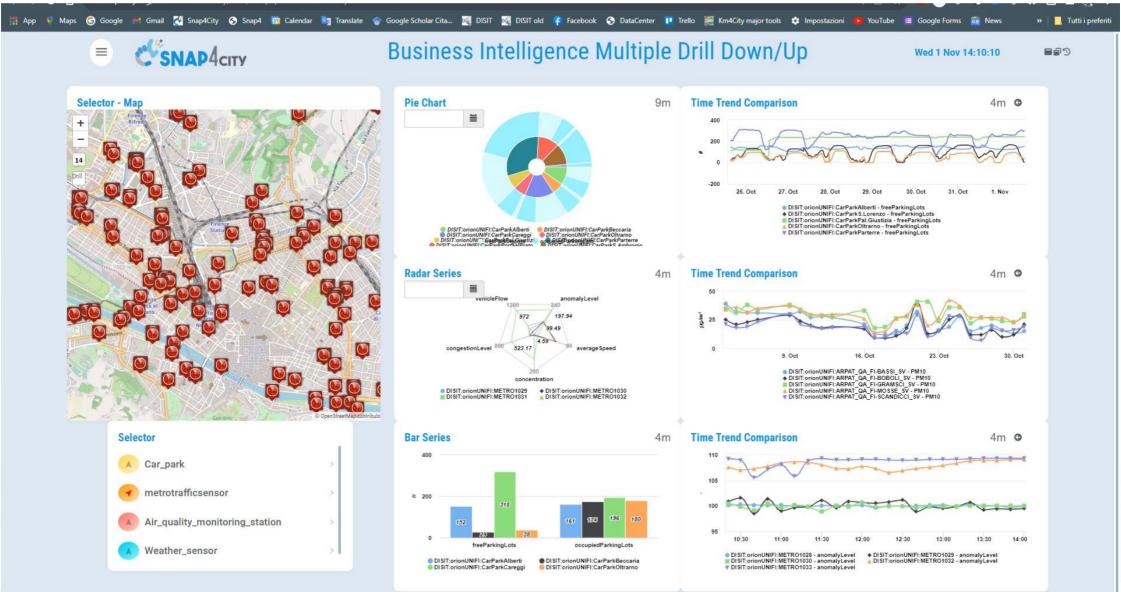






#### BI on data











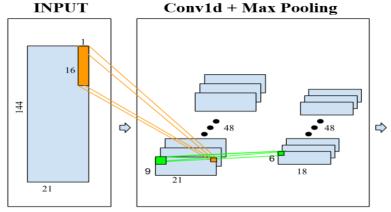


# Short-Term Prediction of City Traffic Flow via Convolutional Deep Learning

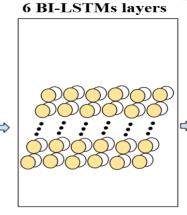


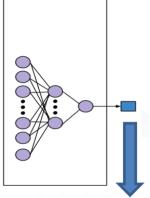






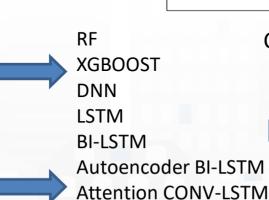
**CONV-BI-LSTM** 





#### Urban data:

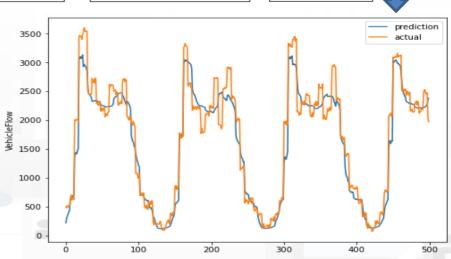
- Date-time
- Traffic
- Temporal
- Seasonality
- Pollution
- Weather



**CONV-BI-LSTM** 







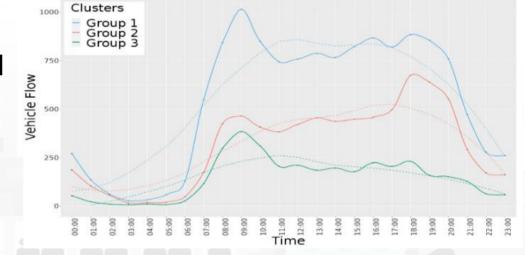




#### **Clustering traffic flow sensors**

- The clustering has been performed on the basis of the time trend H24, considering the normalized vehicle flow measures.
- The optimal number of clusters turned out to be 3 and it has been identified by using elbow criteria
- K-means clustering method has been applied to identify clusters
  - The optimal number of clusters resulted to be equal to 3, and it has been identified by using the Elbow criteria

# Figure 2 Scandice Scandi



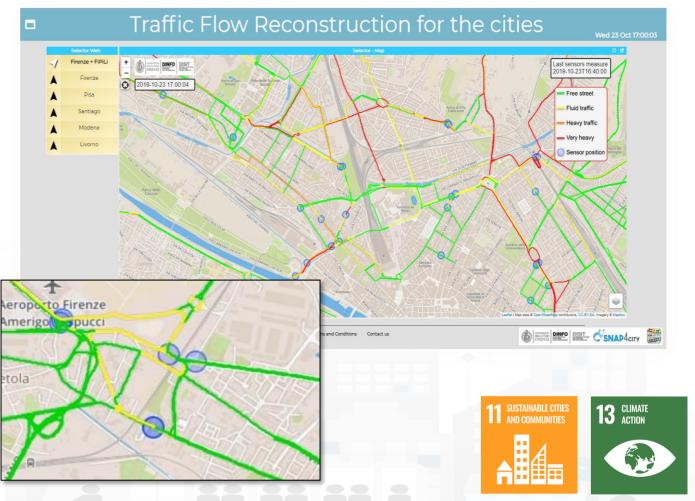
# Best compromize



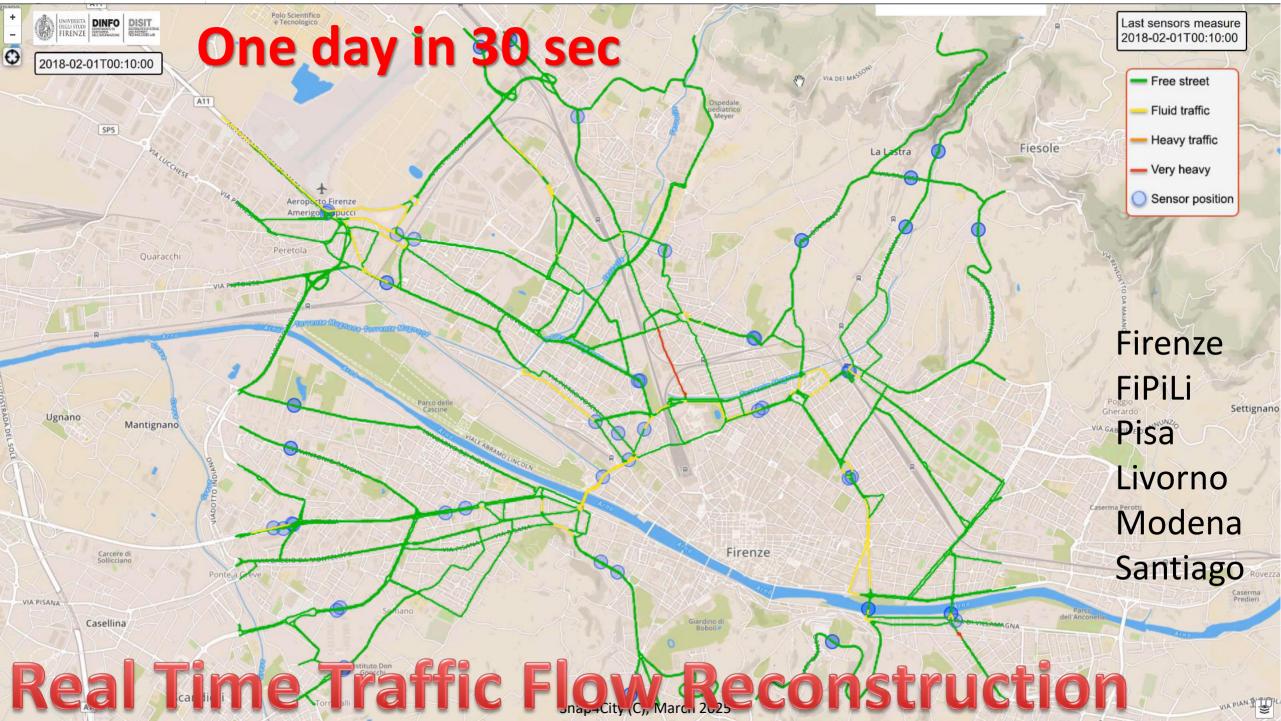


## Why Dense Traffic Flow Reconstruction?

- Controlling pollution
- Dynamic Routing for Firebrigade, Ambulances, general public
- Planning Public
   Transportation routing



https://www.snap4city.org/dashboardSmartCity/view/index.php?iddasboard=MTc5NQ==



#### Traffic Flow Reconstruction for the cities

Sun 3 Nov 20:37:43



Terms and Conditions

















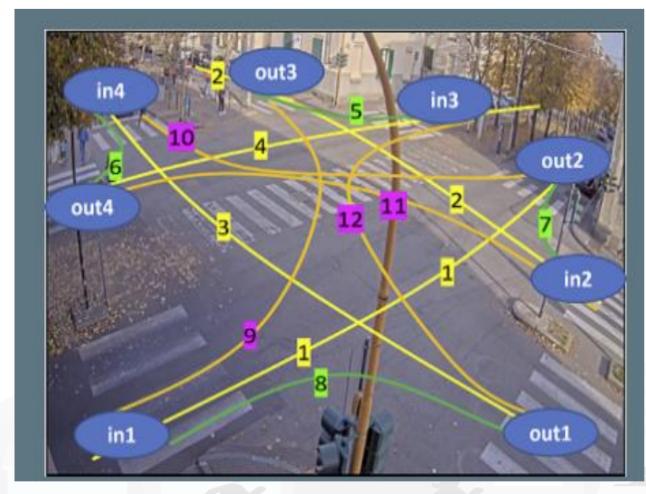


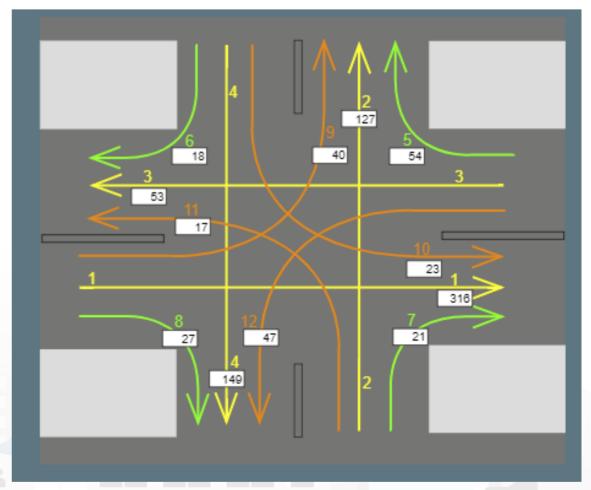






## Real time Clustering: legenda and synoptic





Legenda

Synoptic with real time data

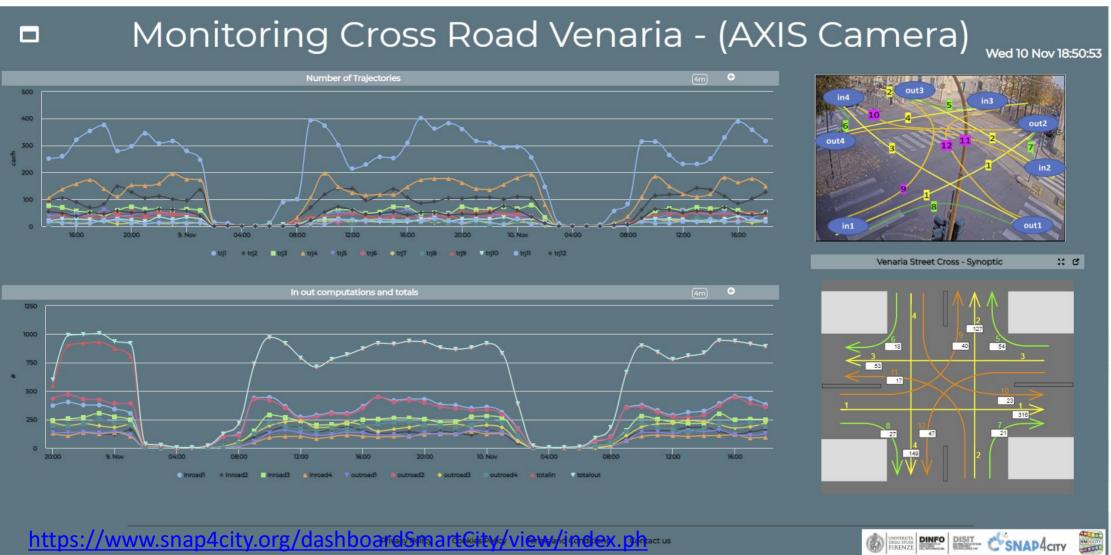






#### **Venaria Reale**



















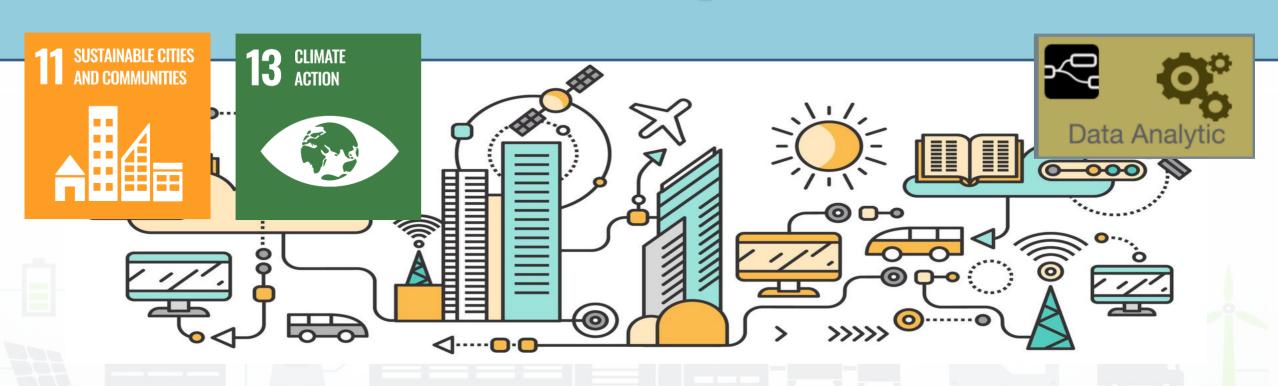






TOP

# Public Transport Offer







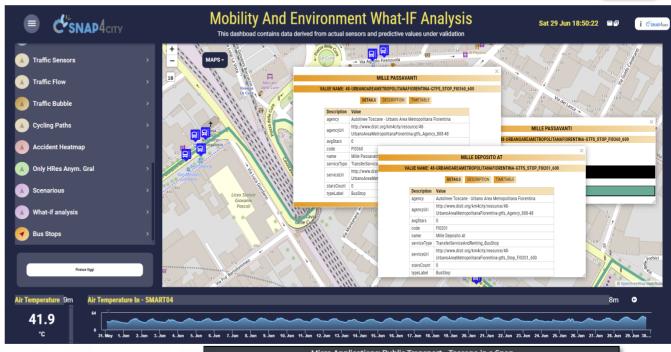




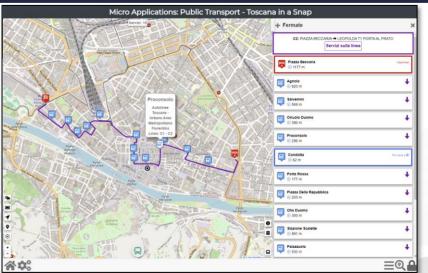
## **Public Transport Offer**

- Via
  - Dashboards
  - MicroApplications
  - Mobile Apps
  - ServiceMap













## **Public Transport Information/file/streams**

- Other sources as ODM and POI: parking, sharing, etc.
- Models used for: busses, train, ferry, metro, tramways, etc. Including:
  - Public Transport Lines, Rides with paths and timeline, stops, polylines for paths, etc.
  - real time data about the position of the vehicles: train, busses, etc.
  - Multi operator data
- Information is modelled as
  - GTFS format: multiple files in XML, Transmodel format, Netex format
- GTFS files can be ingested on Snap4City via
  - Python which takes GTFS files and convert them in triples «.n3» file for the Knowledge Base
    - https://github.com/disit/smart-city-etl/tree/master/TrasformazioneTPLBus new model/Triplification/Models
    - Former version: <a href="https://www.snap4city.org/download/snap4cityETL/TPL">https://www.snap4city.org/download/snap4cityETL/TPL</a> bus <a href="https://www.snap4city.org/download/snap4cityETL/TPL">bus <a href="https://www.snap4city.org/download/snap4cityETL/TPL">bus <a href="https://www.snap4city.org/download/snap4cityETL/TPL">https://www.snap4city.org/download/snap4cityETL/TPL</a> bus <a href="https://www.snap4cityETL/TPL">https://www.snap4cityETL/TPL</a> bus <a href="https://www.snap4cityETL/TPL">http
  - GTFS RT can be ingested via IoT App and sent to the Broker
  - Chouette and then using a Python developed by Snap4City to converter to produce Triples for the Knowledge Base, service map
    - https://github.com/disit/snap4city/blob/master/Snap4CityGTFS/chouette-gtfs-n3.py
- Transmodel (EN12896) or Neptune files can be ingested in Snap4City via
  - Chouette and then, with a certain level of adaptation,
    - using a Python developed by Snap4City to converter to produce Triples for the Knowledge Base, service map
    - https://github.com/disit/snap4city/blob/master/Snap4CityGTFS/chouette-gtfs-n3.py













#### What-if Analysis on Pub Transport









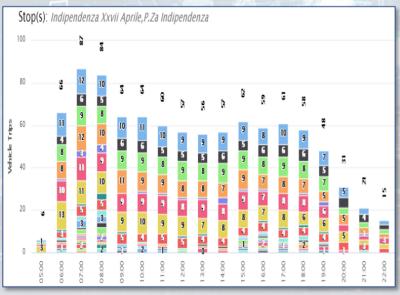


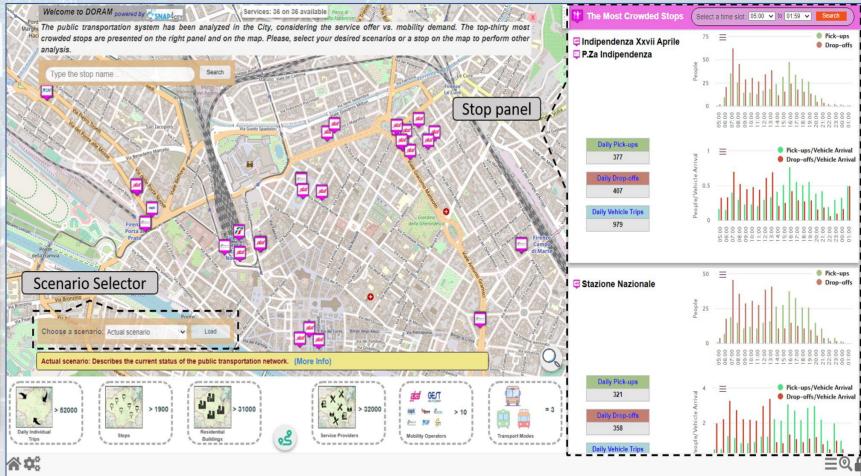
#### Simulation / analysis of Mobility Demand wrt Transportation Offer

- Definition of scenarious impact on
  - Traffic, Pollutant, parking, public transport, private flows, etc.

KPI analysis

#### **Public Services**





Snap4City (C), March 2025

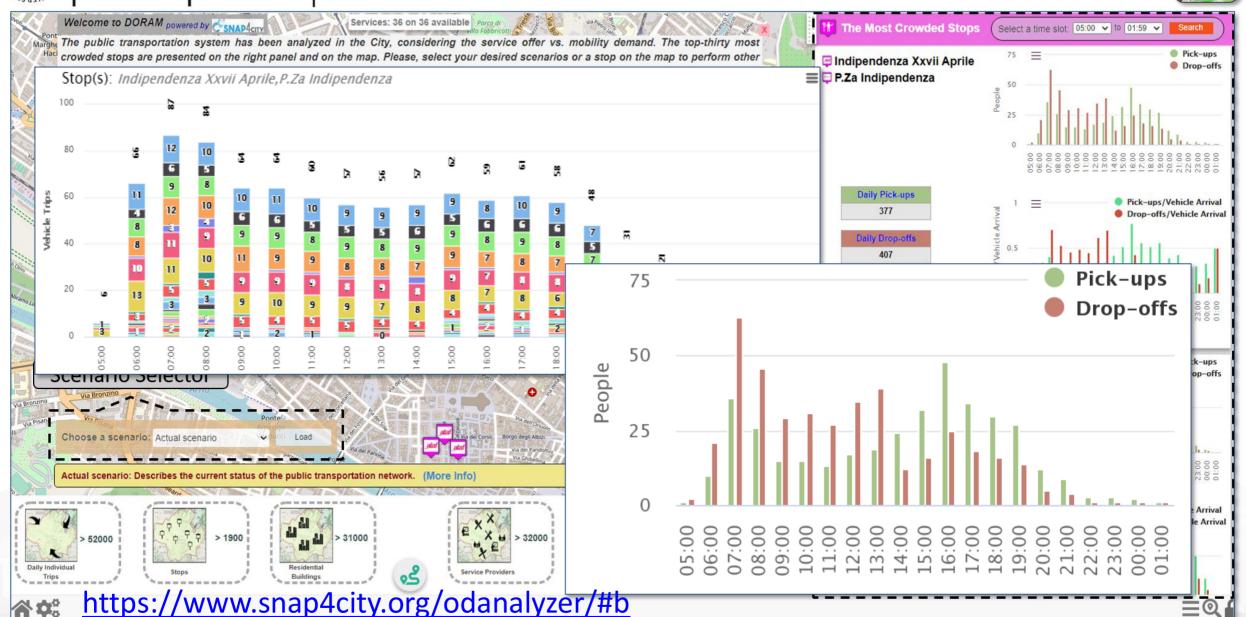


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#### **DORAM**













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# Origin Destination Matrices





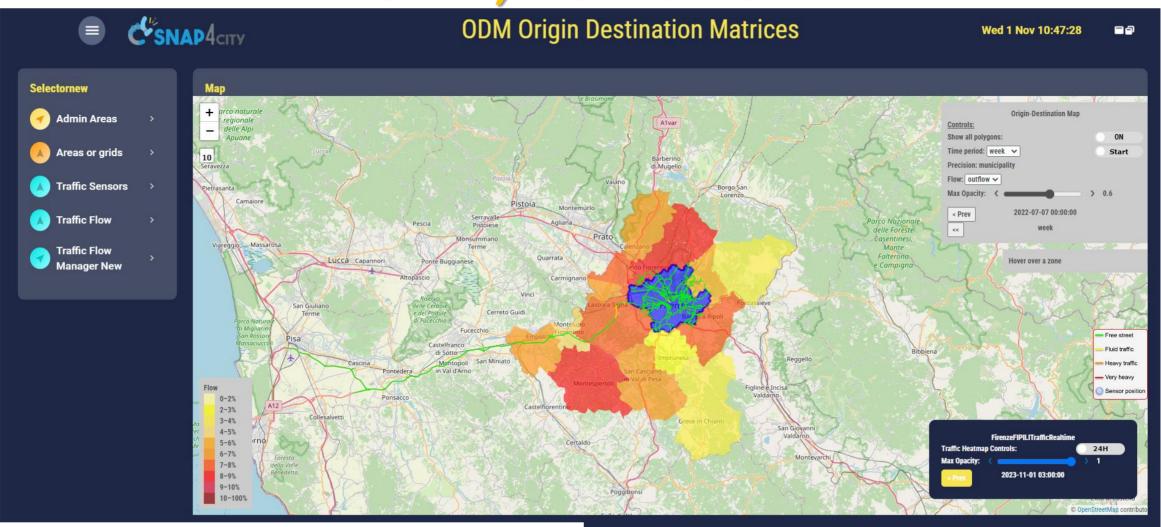








#### **ODM, Traffic Flow**



https://www.snap4city.org/dashboardSmartCity/view/Gea-Night.php?iddasboard=Mzk3Nw==







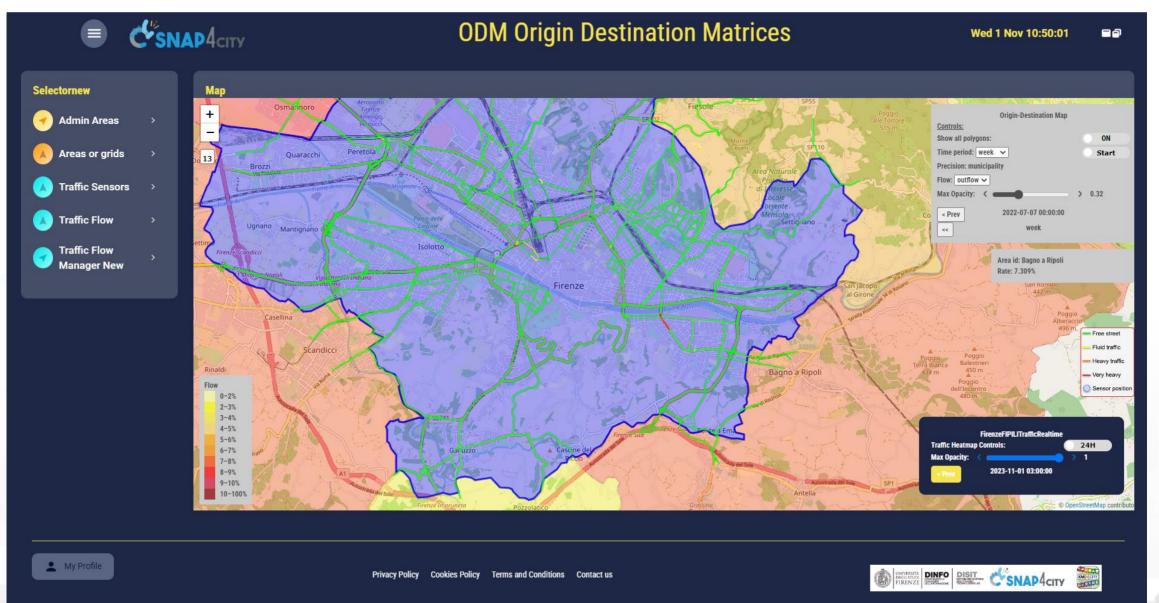




















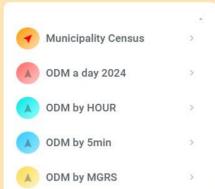


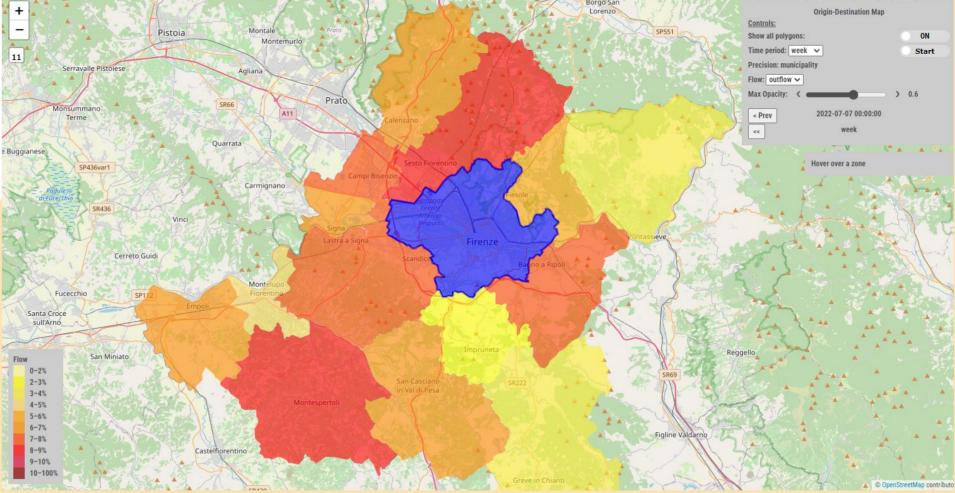


#### **Origin Destination Maps Firenze**

Thu 10 Oct 13:37:05









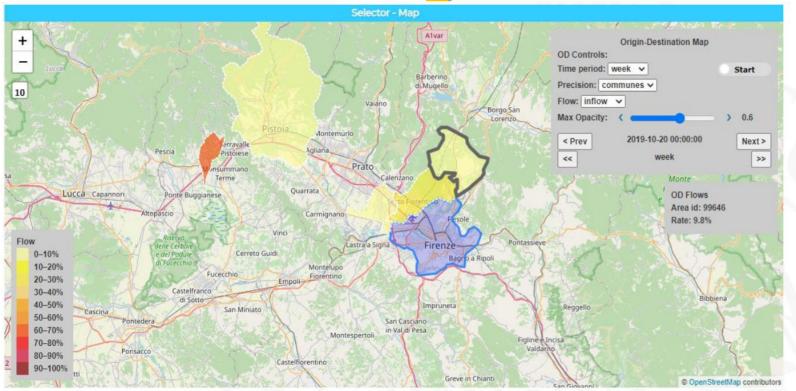




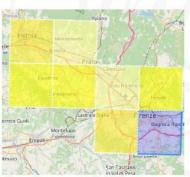


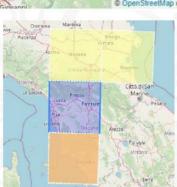


#### **Different Origin Destination Matrices**









- Get specific value
- Time window
- **Opacity**
- **Animation**
- Inflow/outflow
- Sequence of OD matrices: next/prev

#### shapes

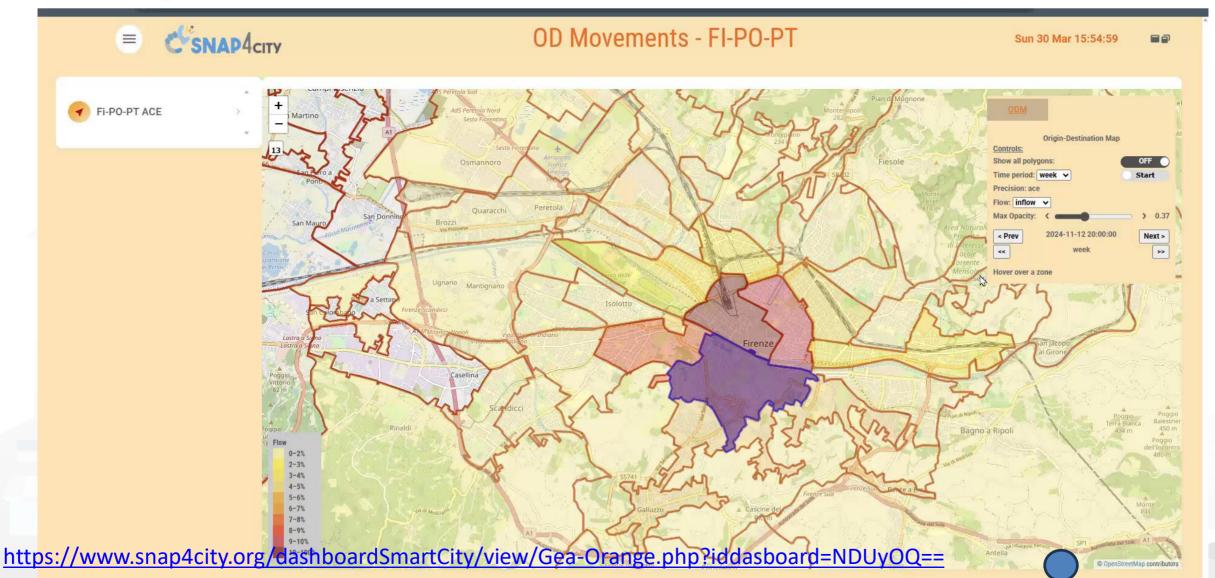
- **Shapes**: city, region, territories, etc.
  - GADM <a href="https://gadm.org/">https://gadm.org/</a>, and **ACE**
- **Squared MGRS**:
  - 1m, 10m, 100m, 1Km, 10Km, 100Km







## Origin Destination Matrices: Mobility Demand

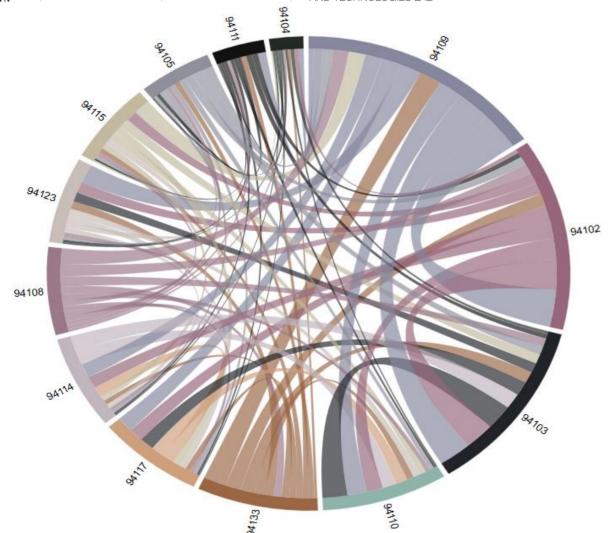






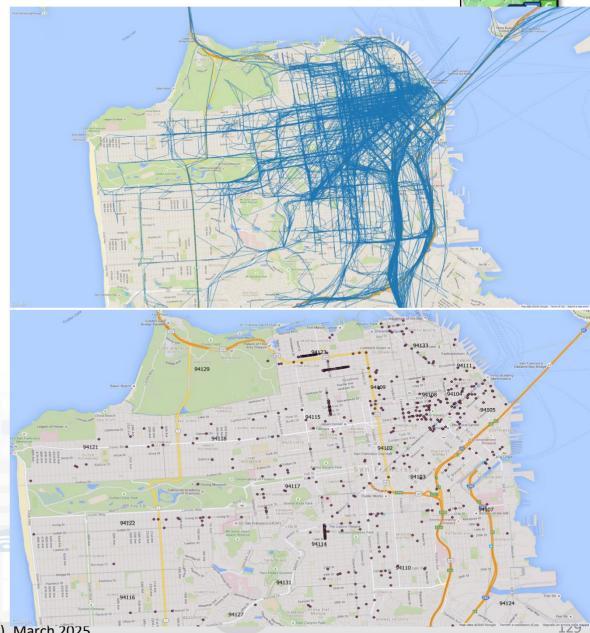
## DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB





San Francisco OD matrix as a chord diagram, from TAXI OBU data

- 13 central ZIP areas of the city (real cab flows),
- ONLY on FLOW: from to



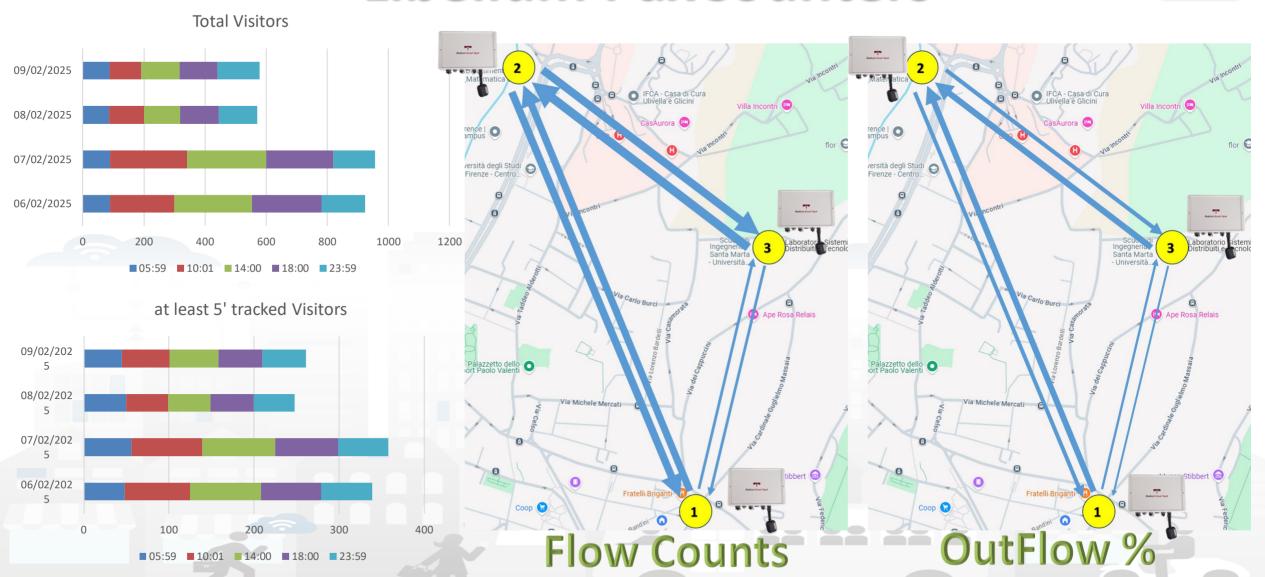






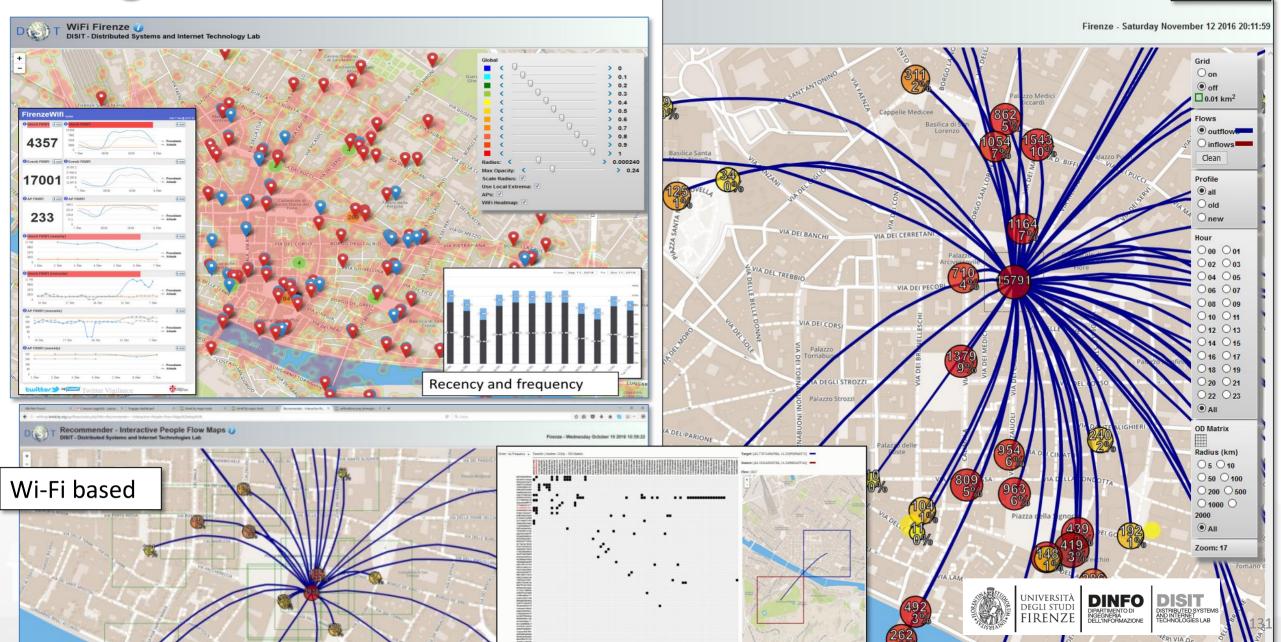


# DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB PROPERTY PAX COUNTERS



**Origin Destination Matrix Estimation** 



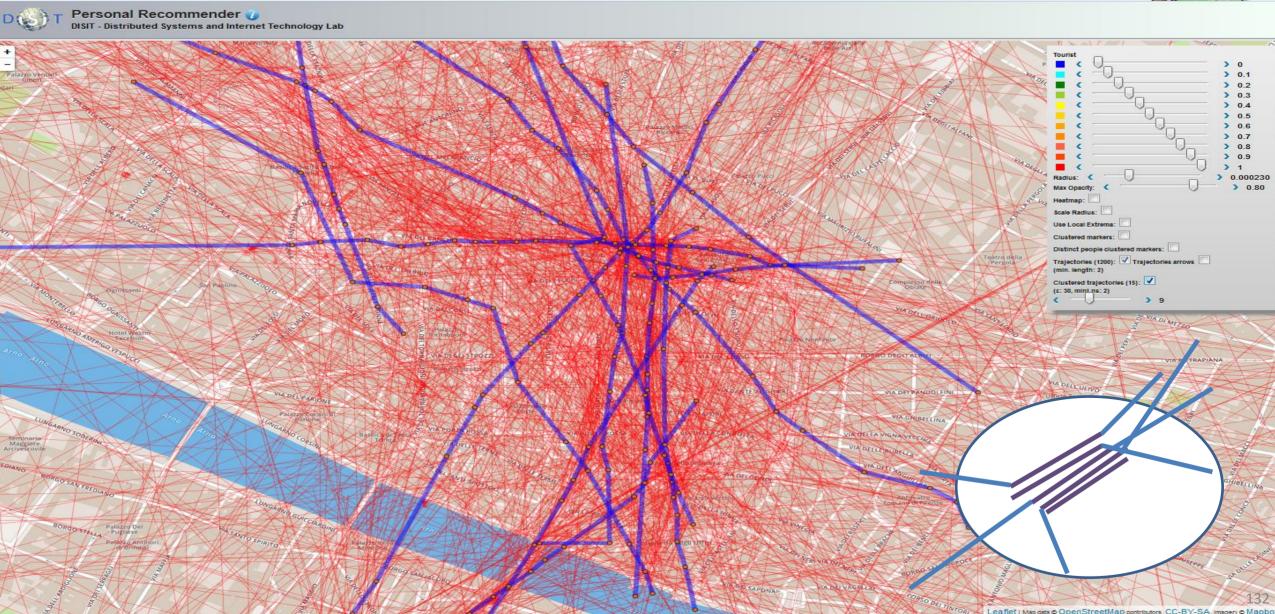






# DISIT DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB OSTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB













# **Smart Parking**



















#### **Smart Parking**

#### Main features

- On-road and off-road, multiple sensors kinds
- Profiled parking slots: regular, residential, disable, charging, forbidden, etc.
- Multiple: areas, cities, and business models/profiles
- Multiple payment modalities and wallets
  - · Mobile apps, parking meters, etc.
- User profiling and models (regular, disabled, etc.), parking areas, etc.
- Fine detection and management, overparking, etc.
- Mobile App for City Users and on road Operators
- Smart Parking Manager: operator controller and notifications to on-road operators





#### **Road Parking**

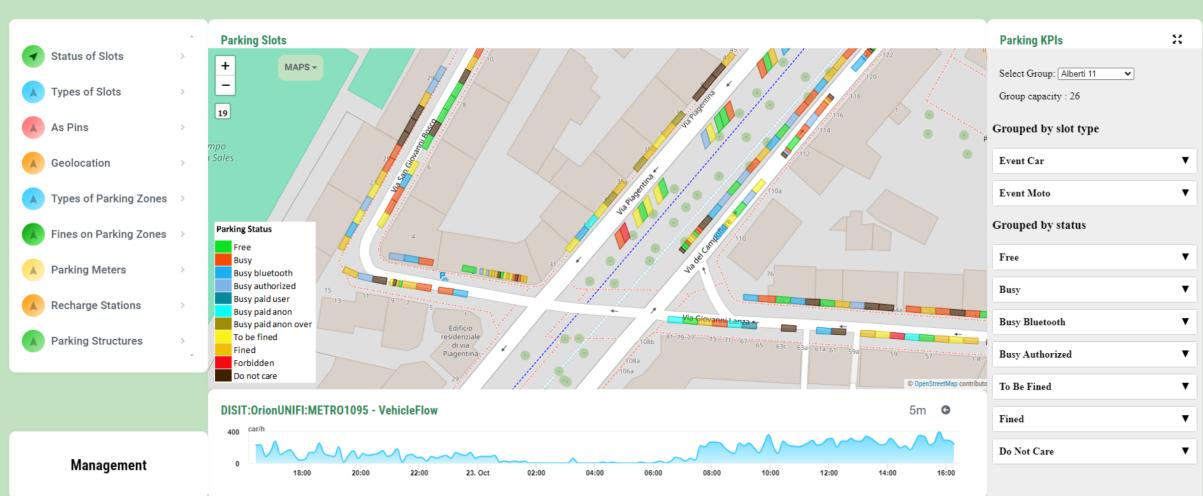




#### **Parking Conditions Monitoring**

Wed 23 Oct 16:30:45

















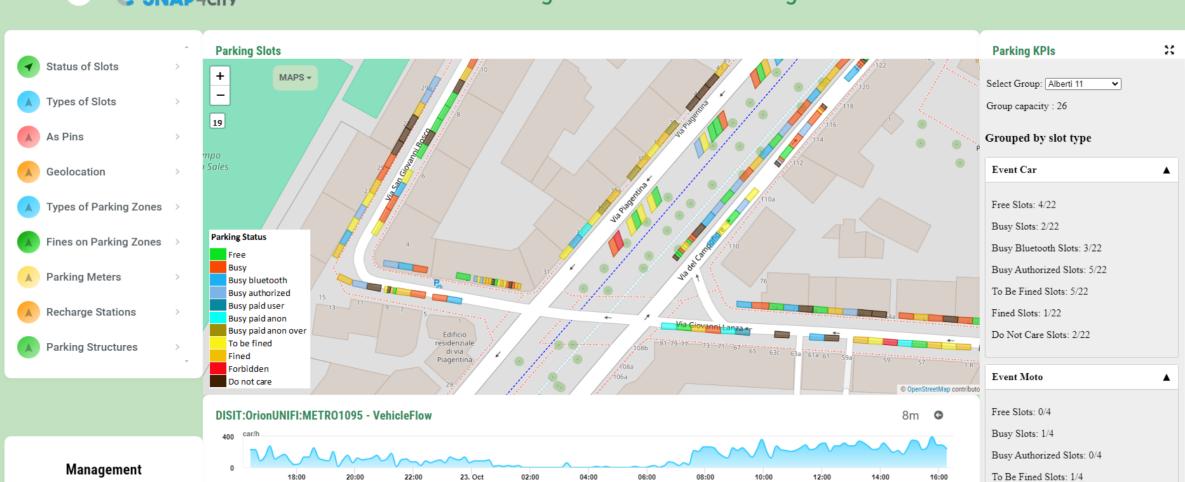
# **Road Parking**





### **Parking Conditions Monitoring**

Wed 23 Oct 16:24:41











Fined Slots: 1/4

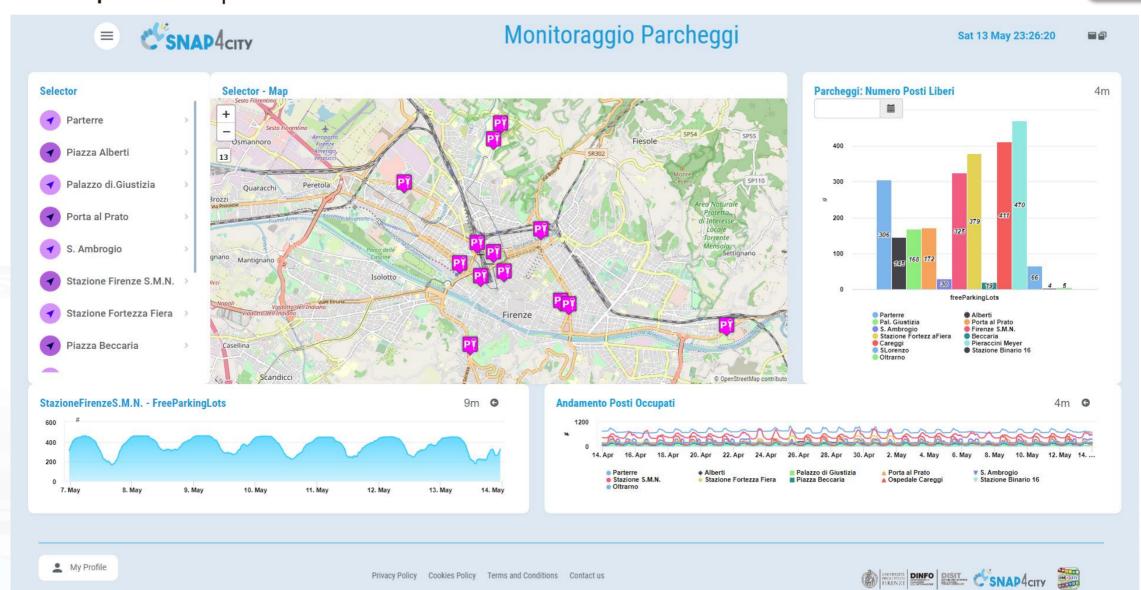












# Smart City / Smart Parking + Environment Reverberi, Lonato del Garda





DINFO DISIT C'SNAP4CITY



• Smart Parking, Environment, Wi-Fi

### Multiple Decision Makers

- City Officer, operators
- Data monitoring, alerting
- analytics

Historical and Real Time data

Dashboards

### Services Exploited on:

- · Dashboards, API
- Since 2019











# **Snap4ISPRA Parking**







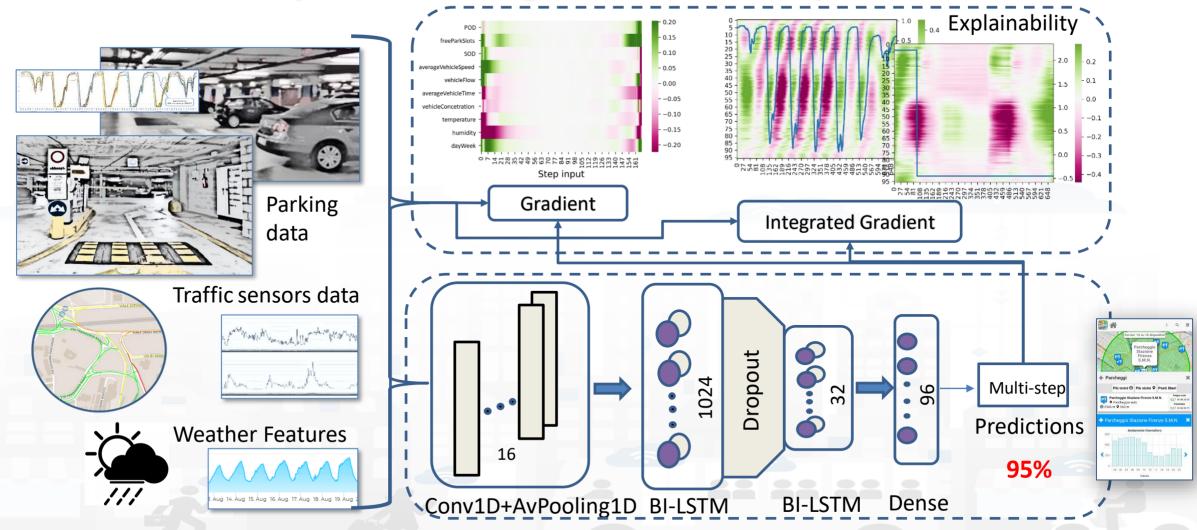








# **Deep Learning AI to surely Park!**











# Smart Bike Free Bike predictions

















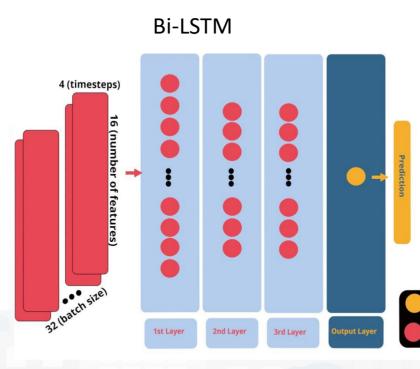


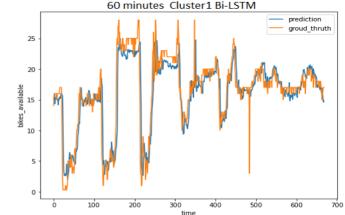


# Deep Learning for Short-Term Prediction of Available Bikes on Bike-Sharing Stations











E. Collini, P. Nesi and G. Pantaleo, "Deep Learning for Short-Term Prediction of Available Bikes on Bike-Sharing Stations," in *IEEE Access*, vol. 9, pp. 124337-124347, 2021, doi: 10.1109/ACCESS.2021.3110794.





DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB DISTRIBUTED DATA INTELLIGENCE AND TECHNOLOGIES LAB



# emand vs Transportation



# What-if Analysis on Pub Transport







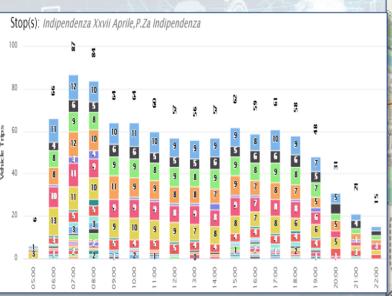


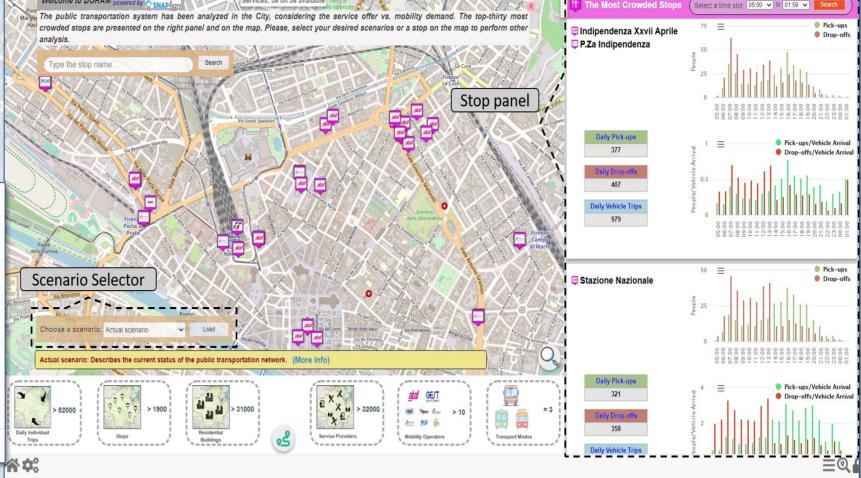


- Definition of scenarious impact on
  - Traffic, Pollutant, parking, public transport, private flows, etc.

KPI analysis

**Public Services** 





Snap4City (C), March 2025

Snap4City (C), May 2022

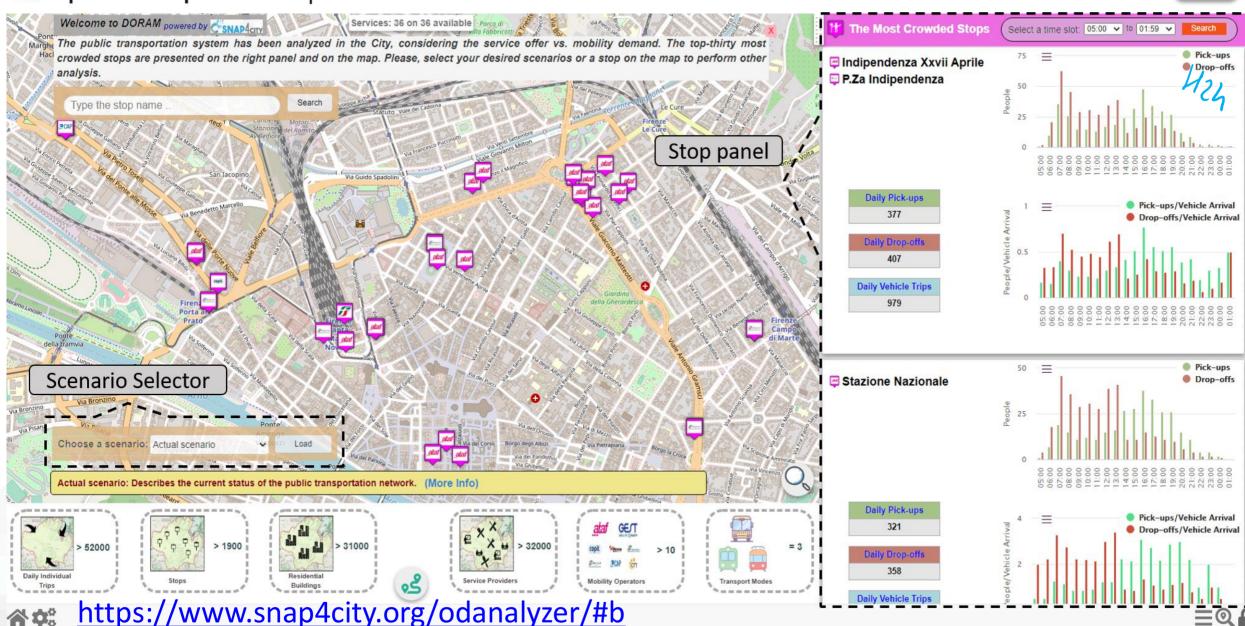


DINFO
DIPARTIMENTO DI
INGEGNERIA
DELL'INFORMAZIONE

DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB

# **DORAM**



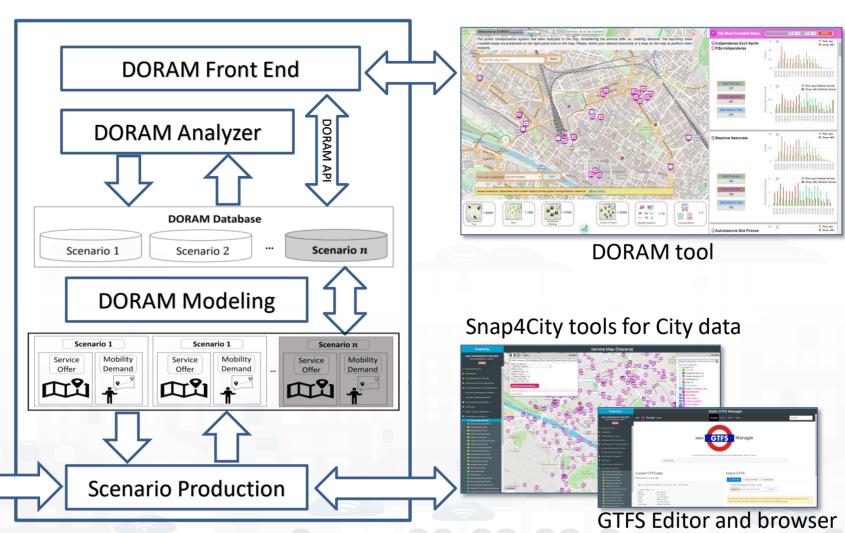






# **DORAM**





https://www.snap4city.org/odanalyzer/#b









# User Behavior Analysis





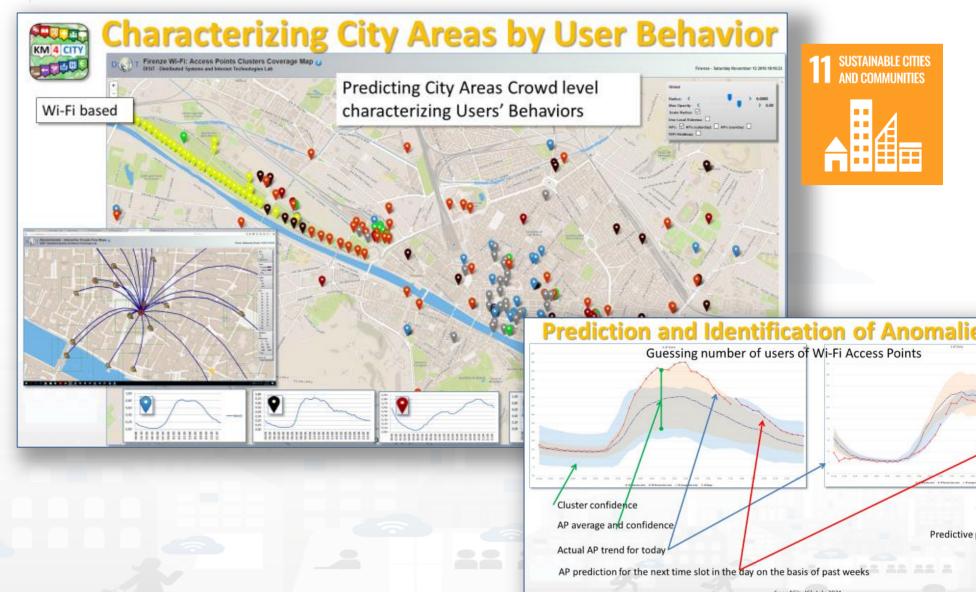






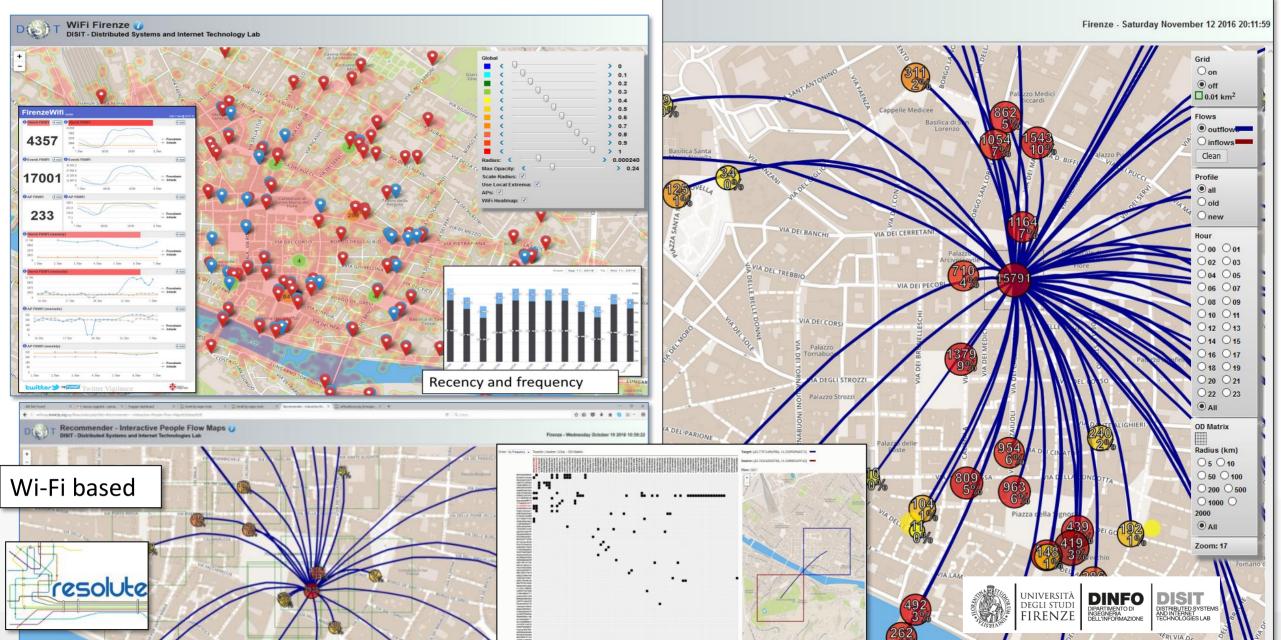


- Prediction of people flows on the basis of Wi-Fi data
- Anomaly detection
- Resolute H2020
- Classification of city areas



**Origin Destination Matrix Estimation** 

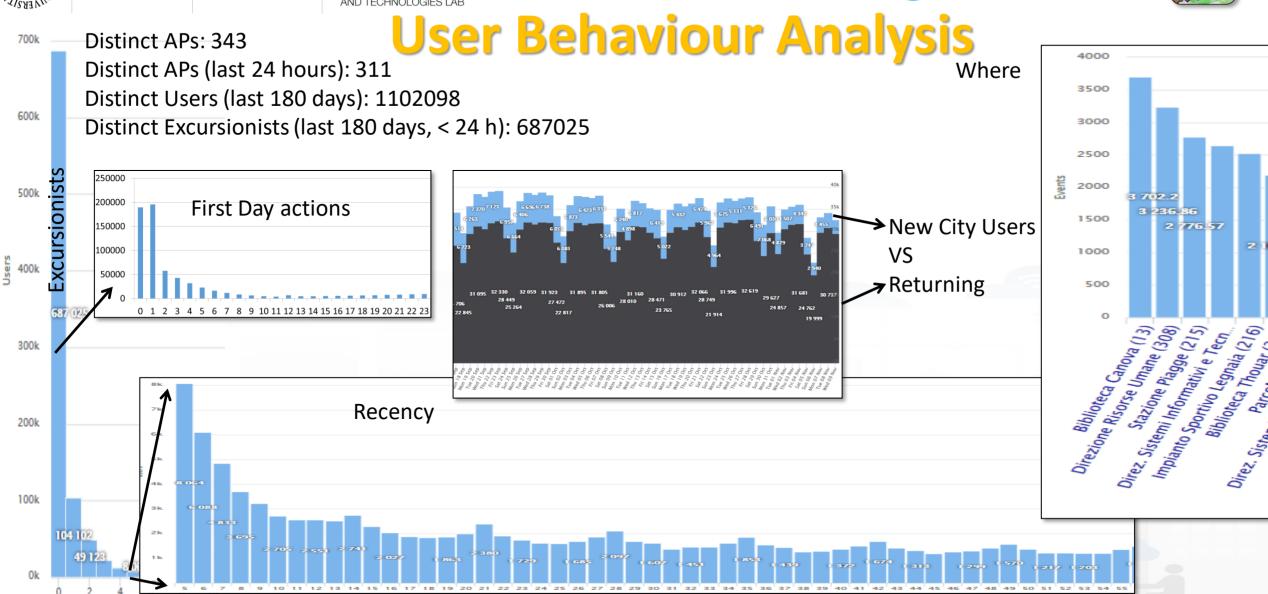








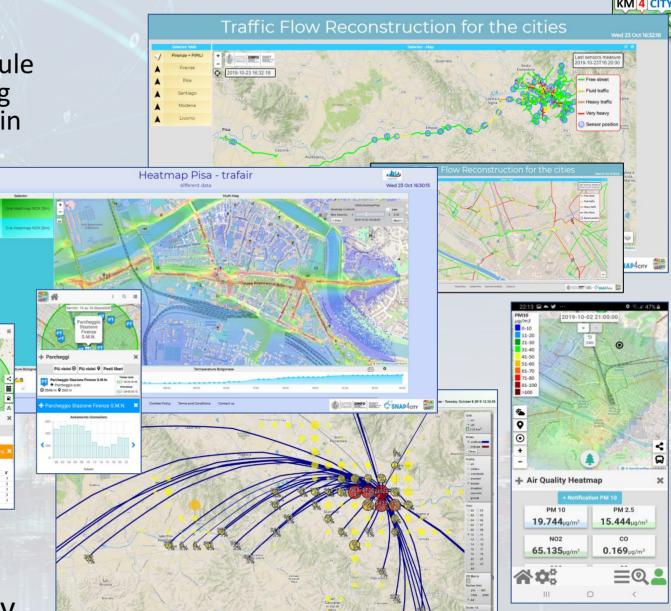


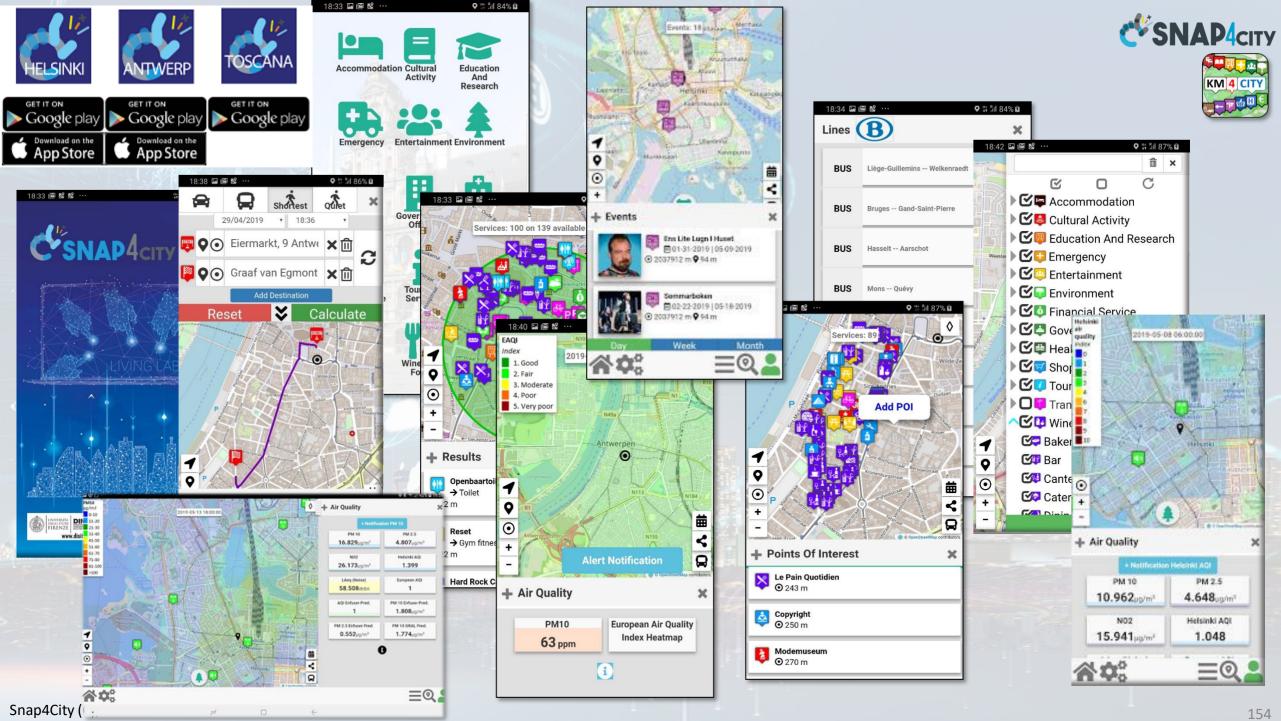


# Tuscany Region

**SNAP**4city

- Dashboards & Services:
  - Mobility: public transport operators schedule and paths, traffic Fi-Pi-Li main road, parking status and predictions, traffic sensors, Origin Destination matrix, routing, multimodal routing, etc.
  - Social: Hospitals and triage, etc.
  - Environment: sensors, heatmaps,
  - alerting,
    - Pollution Forecast: NOX, NO2
    - · Weather Forecast,
  - Culture and Tourisms
  - Etc.
- Mobile App and MicroApplications:
  - Tuscany in a Snap (all stores)
  - Tuscany where what... km4city (all stores)
- Numbers: 1.5 M complex events per day Snap4City (C), March 2025







# Citizen Engagement via Mobile Apps

KM 4 CITY

- GPS Positions
- Selections on menus
- Views of POI
- Access to Dashboards
- searched information
- Routing
- Ranks, votes
- Comments
- Images
- Subscriptions to notifications
- ....

### Produced information

- Viewed?
- Accepted?
- Performed?

• ..



Snap4City (C), March 2025



#### **Derived information**

- Trajectories
- Hot Places by click and by move
- Origin destination matrices
- Most interested topics
- Most interested POI
- Delegation and relationships
- Accesses to Dashboards
- Cumulated Scores from Actions
- Requested information
- Routing performed

• • • • •



### **Produced information**

- Suggestions
- Engagements
- Notifications

System





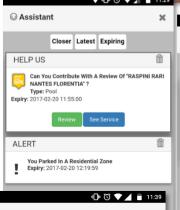




Threagement Sent (4 hours)

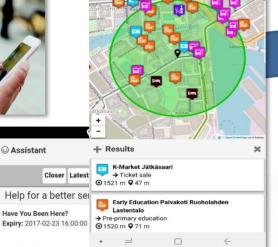






Expiry: 2017-02-20 19:35:39

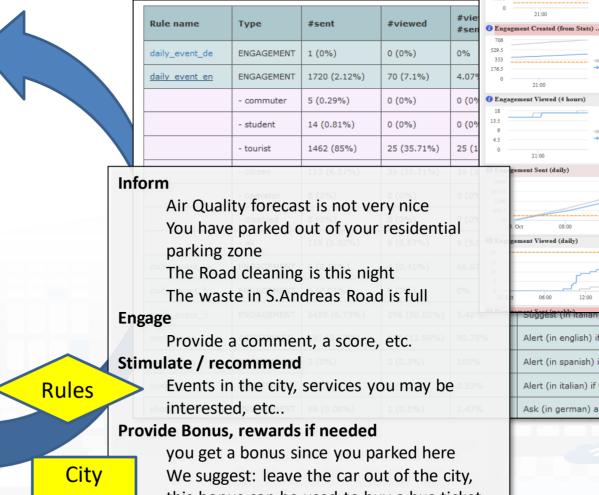
Can confirm that you LIVE around VIA TRIPOLI?



User

context

	11.55	ll .	1	2	3	4	5	
<b>⊚</b> Assistant	×							
Closer Latest Expiring				Send			Cano	:el
EVENT today								
"Gustav Klimt Experience" At MUSEO DIOCESAI SANTO STEFANO AL PONTE (Until 2017-04-02 Type: Exibition Distance: © 3336 m								
Expiry: 2017-02-21 11:32:52  Review See Service	- 1	△			0			
action and action action and action action and action	_							
Help us to provide a better service	Î							
	-							



Engagement Viewed ent Sent (daily) 19 min Precedent 29 min Precedente

Alert (in spanish) if the user parked in a re-

Alert (in italian) if the user parked in a residual

Ask (in german) a contribution for a nearby

4 min DEngagemen... 4 min

Engagement Sent

446

**Engagement Created** 

4 min DEngagemen... 4 min

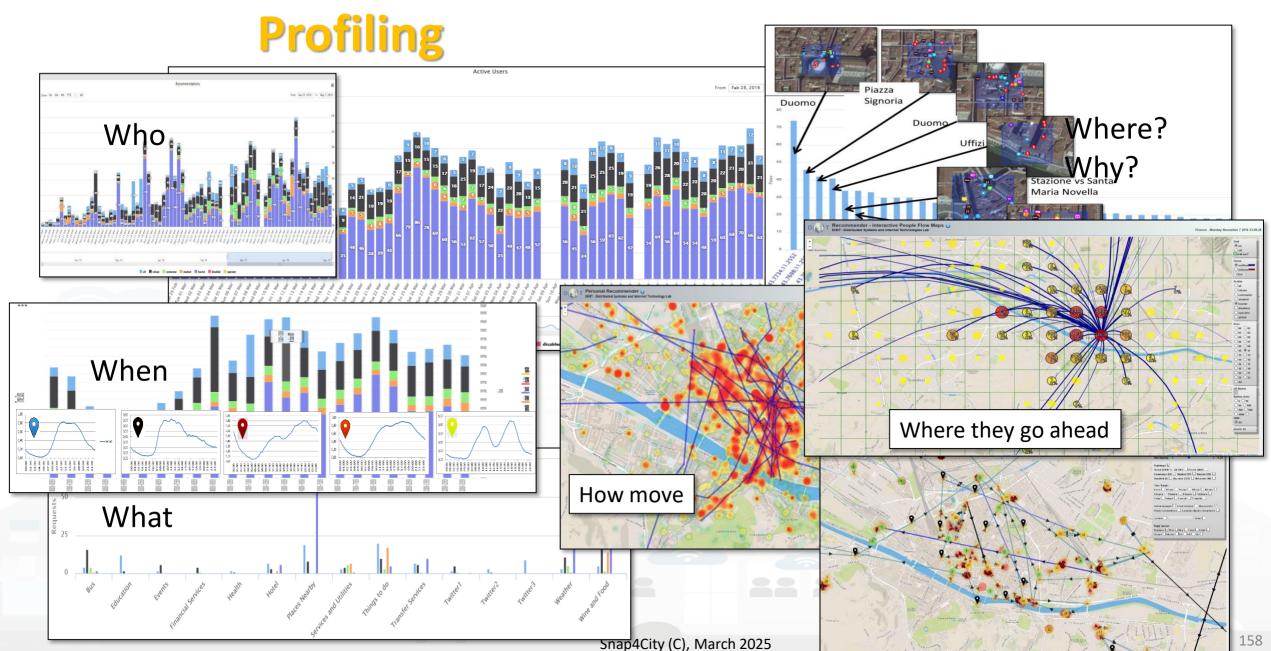
this bonus can be used to buy a bus ticket





# UNIVERSITÀ DEGLI STUDI FIRENZE DEGLI STUDI FIRENZE DEGLI STUDI DI GOMENA DI DISTRIBUTE SYSTEMS AND INTERNET DI STERBUTE DI STERBUTE



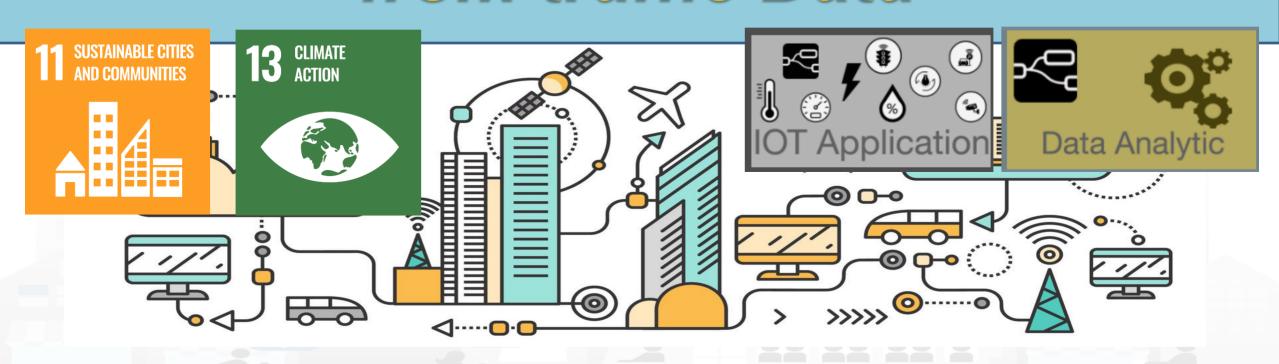








# Computing / predicting CO2/NO2 from traffic Data



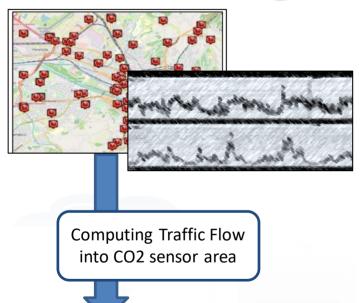








# **Estimating City Local CO2 from Traffic Flow Data**



Traffic Flow data

Traffic Flow is one the main source of CO2 (ton of CO2 x Km x Vehicle)

K1: Fluid Flow

K2: Stop and Go

Dense estimation of CO2 into the **city** is very useful to know to target EC's KPIs

Computing CO2 on the basis of





traffic flow data



CO<sub>2</sub> estimation

94% accuracy

S. Bilotta, P. Nesi, "Estimating CO2 Emissions from IoT Traffic Flow Sensors and Reconstruction", Sensors, MDPI, 2022. <a href="https://www.mdpi.com/1424-8220/22/9/3382/">https://www.mdpi.com/1424-8220/22/9/3382/</a>











### **Prediction**

- NOX Pollutant diffusion on the basis of Traffic Flow (prediction), weather and 3D structure
- NO2 progressive average (Long term)

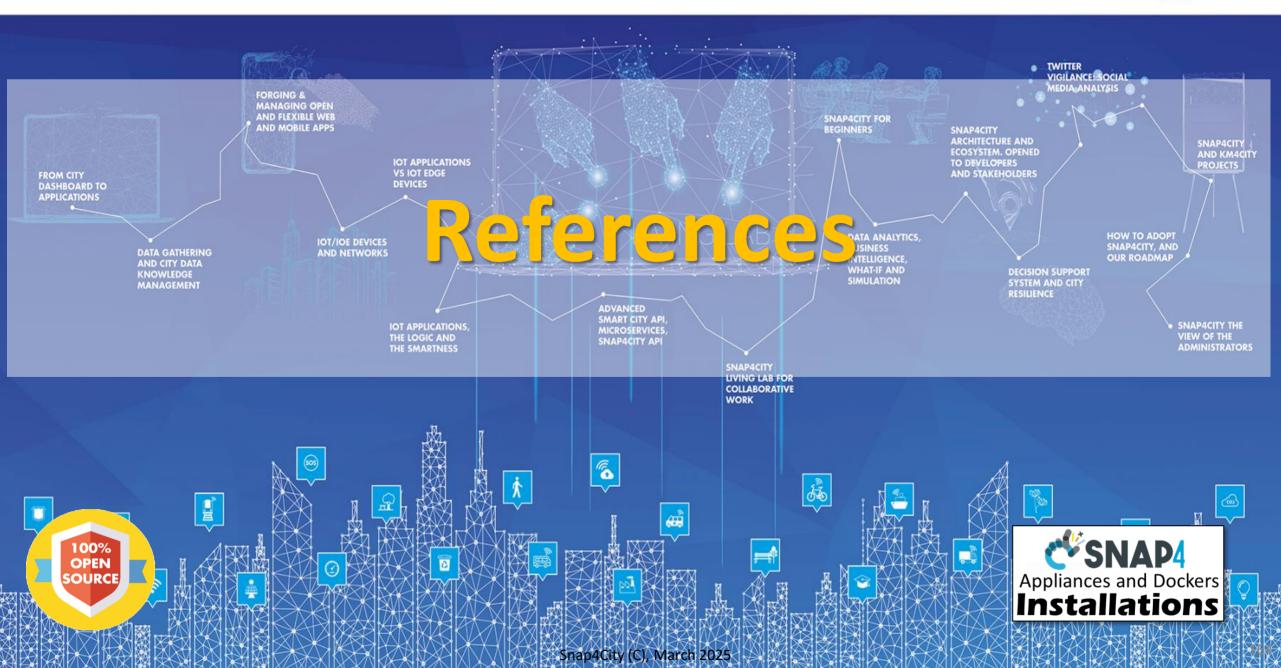
### **Project:**

- Trafair CEF EC
- Mixed solutions of Fluidinamics modeling and Al



### SCALABLE SMART ANALYTIC APPLICATION BUILDER FOR SENTIENT CITIES





### booklets

Smart City





https://www.snap4city.org /download/video/DPL\_SN AP4CITY.pdf Industry





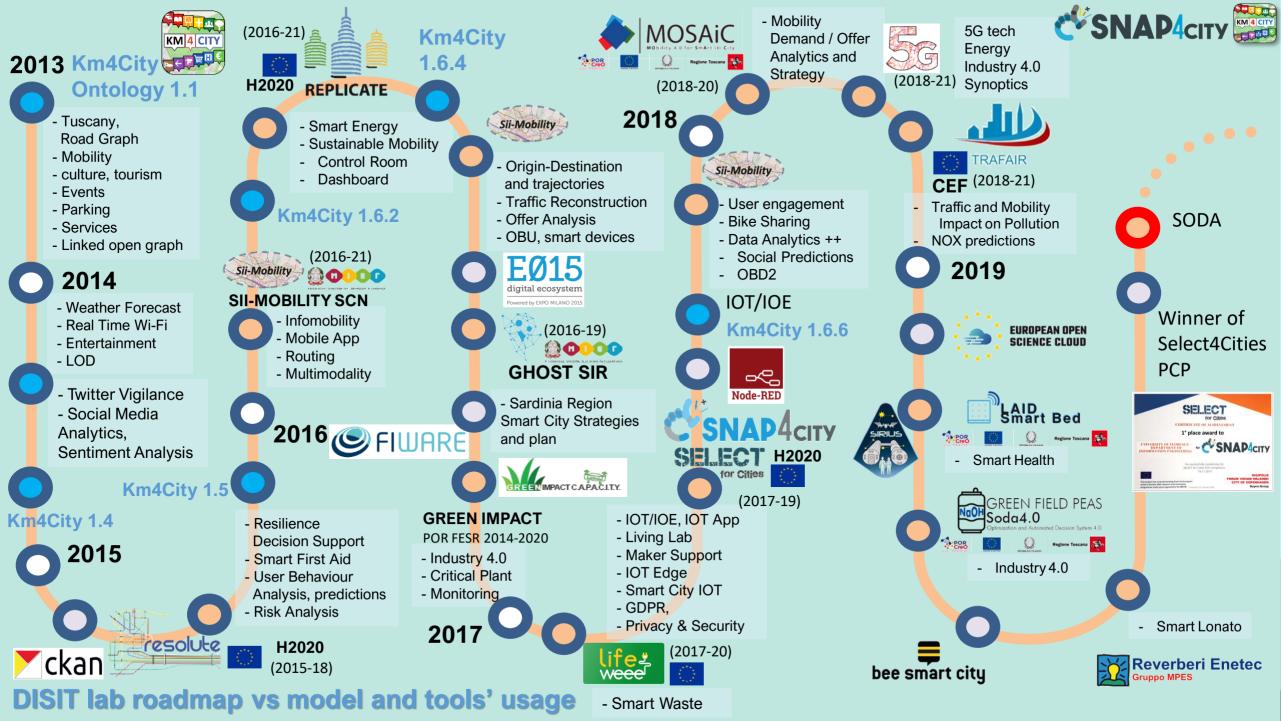
https://www.snap4city.org/download/video/DPL\_SNAP4INDUSTRY.pdf

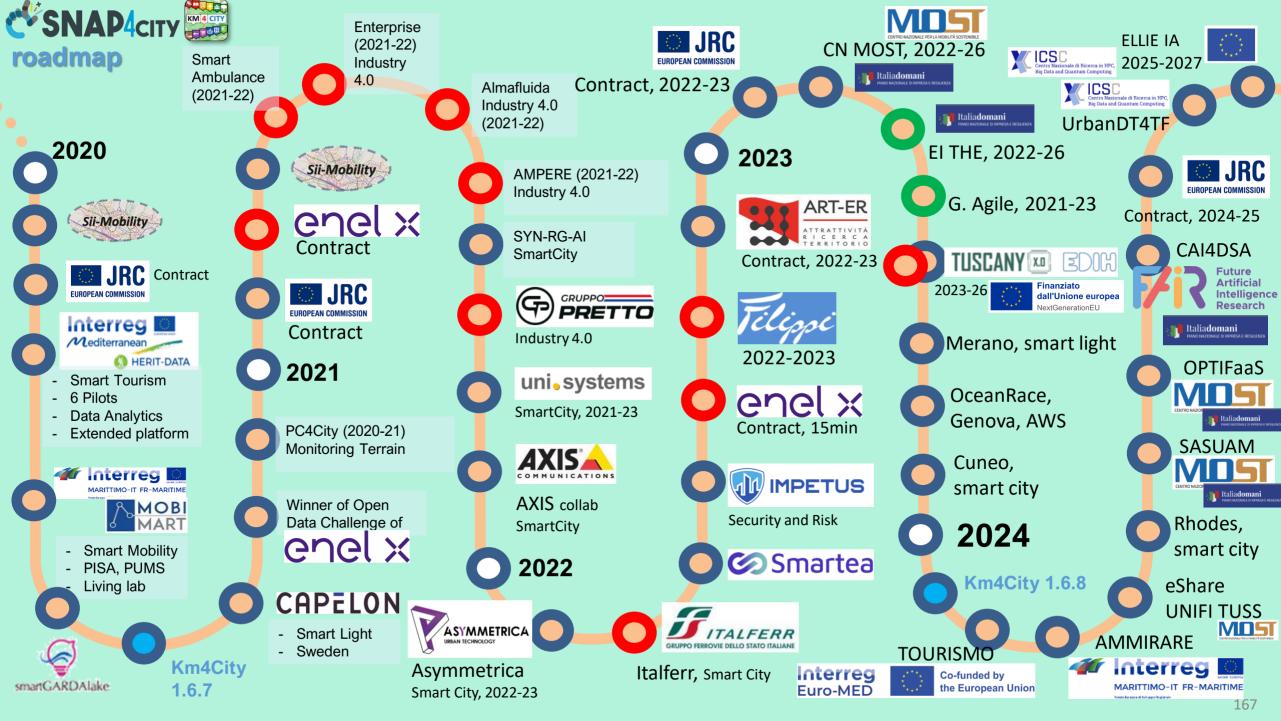
Artificial Intelligence





https://www.snap4city.o rg/download/video/DPL SNAP4SOLU.pdf















- UrbanDT4TF, CN HPC: Digital Twin mobility
- **DI-DTPlatform**, CN HPC: Digital Twin, mobility, environment
- Sasuam, CN MOST, PNRR: AI, mobility
- OPTIFaaS, CN MOST, PNRR: AI, mobility, DSS
- LeverageOPTIFaaS, CN MOST: PNRR, mobility
- TOURISMO, Interreg, EC: Tourism, NLP, DSS
- **ELLIE**, Horizon Europe, EC: AI, VR
- CN MOST, PNRR: sustainable mobility, platform
- ISPRA JRC contract, EC: DSS, SOC, control room, energy
- The IE, PNRR: AI, NLP, Legal Aspects
- AMMIRARE, Interreg, EC: AI, environment, Big Data
- CAI4DSA, FAIR PE1, PNRR: AI, Neuro-Symbolic, PINN, NG-DSS
- SADI-MIAC, RT, partner: AI, Tourism, Retail, Computer Vision
- Energia, RT, conv: AI, PINN, DSS
- RFI contract: mobility, AI, DSS
- PRIN UNICagliari: mobility, DSS
- Talent Hub, ECRF, conv: NLP, match demand vs offer

# https://www.Snap4City.org













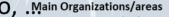
### • 11 running installations in Europe

• Snap4.city.org, Greece, Merano, Cuneo, .Main Organizations/areas Antwerp area (Be)

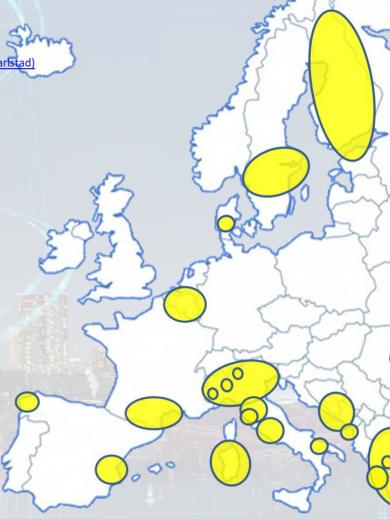
- Toscana, Pisa, Sweden, ISPRA, Snap4.eu, :
- Altair, Italmatic, M4F, Romania, ....
- 18 projects, 12 pilots on 10 Countries:
  - >40 cities/area

### Widest MULTI-tenant deploy has

- 25 Organizations / tenant
- > 8850 users on
- > 1800 Dashboards
- > 17 mobile Apps
- > 2.2 Million of structured data per day
- > 580 IoT Applications/node-RED
- > 750 web pages with training
- > 75 videos, training videos



- Bisevo, Croatia
- Bologna (I)
- Brasov (Ro), by ICEBERG
- Capelon (Sweden: Västerås, Eskilstuna, Karlst
- Cuneo (I)
- DISIT demo (multiple)
- Dubrovnik, Croatia
- Firenze area (I)
- Garda Lake area (I)
- Greece (Gr)
- Helsinki area (Fin)
- Limassol (Cv)
- Livorno area (I)
- Lonato del Garda (I)
- Malta (Malta)
- Modena (I)
- Mostar, Bosnia-Herzegovina
- Oslo & Padova (Impetus)
- Pisa area (I)
- Pistoia (I)
- Pont du Gard, Occitanie (Fr)
- Prato (I)
- Rhodes (Gr)
- Santiago de Compostela (S)
- Sardegna Region (I)
- SmartBed (multiple)
- Toscana Region (I), SM
- Valencia (S)
- Varna (Bulgaria)
- Venezia area (I)
- WestGreece area (Gr)





### **Spoke 8: MaaS & Innovative Mobility Services**

### **National Center for Sustainable Mobility**

# **OPTIFaas:** Operation and Plan, Transport Infrastructure and Facilities Support as a Service

Ecosystem to support a rapid and effective sharing of solutions and opportunities between researchers and companies belonging to MOST and Local Public Administrations, PA, and Transport Operators, TO. Marketplace-type mechanism:

- researchers and companies have an environment in which to propose and test proposals and solutions;
- **PA and TO** always use state-of-the-art solutions to solve problems and pursue their mission.

Everything is configured with as a service mode in order to minimize investments in infrastructure and personnel by PA and TO.





## Spoke 8 MaaS & Innovative Mobility Services

### **National Center for Sustainable Mobility**

**SASUAM** - Solutions for Safe, Sustainable and Accessible Urban Mobility

- Scalable methods and algorithms for urban traffic management using the macroscopic fundamental diagram (MFD) paradigm and a generative optimization solution for urban traffic decongestion, accessibility and safety.
- The solution plans to use data and validation support from the city of Bari where the extended experimentation will be performed.
- The solution has been designed to contribute to urban sustainability, through the provision of innovative traffic analysis, monitoring and optimization services.





### Generative AI optimization allows you to:

- ✓ **Decongest roads:** Optimizing traffic light timing, traffic flows and transit routes to reduce critical congestion points.
- ✓ Improve accessibility: Promoting connectivity between urban areas, improving accessibility for pedestrians, cyclists and vehicles through improved urban planning.
- ✓ Increase safety: Implementing strategies to improve road safety, for example by reducing conflict points and optimizing traffic flows.









### Be smart in a SNAP!





#### CONTACT

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