Ottimizzazione Semaforica e di Infrastruttura. Ottimizzazione del Trasporto Collettivo

OPTIFaaS

IL FUTURO DELLA MOBILITA' INTELLIGENTE E SOSTENIBILE

Prof. Paolo Nesi, UNIFI DISIT

Decongestion

Safety

Accessibility

Cost Reduction

Decarbonization

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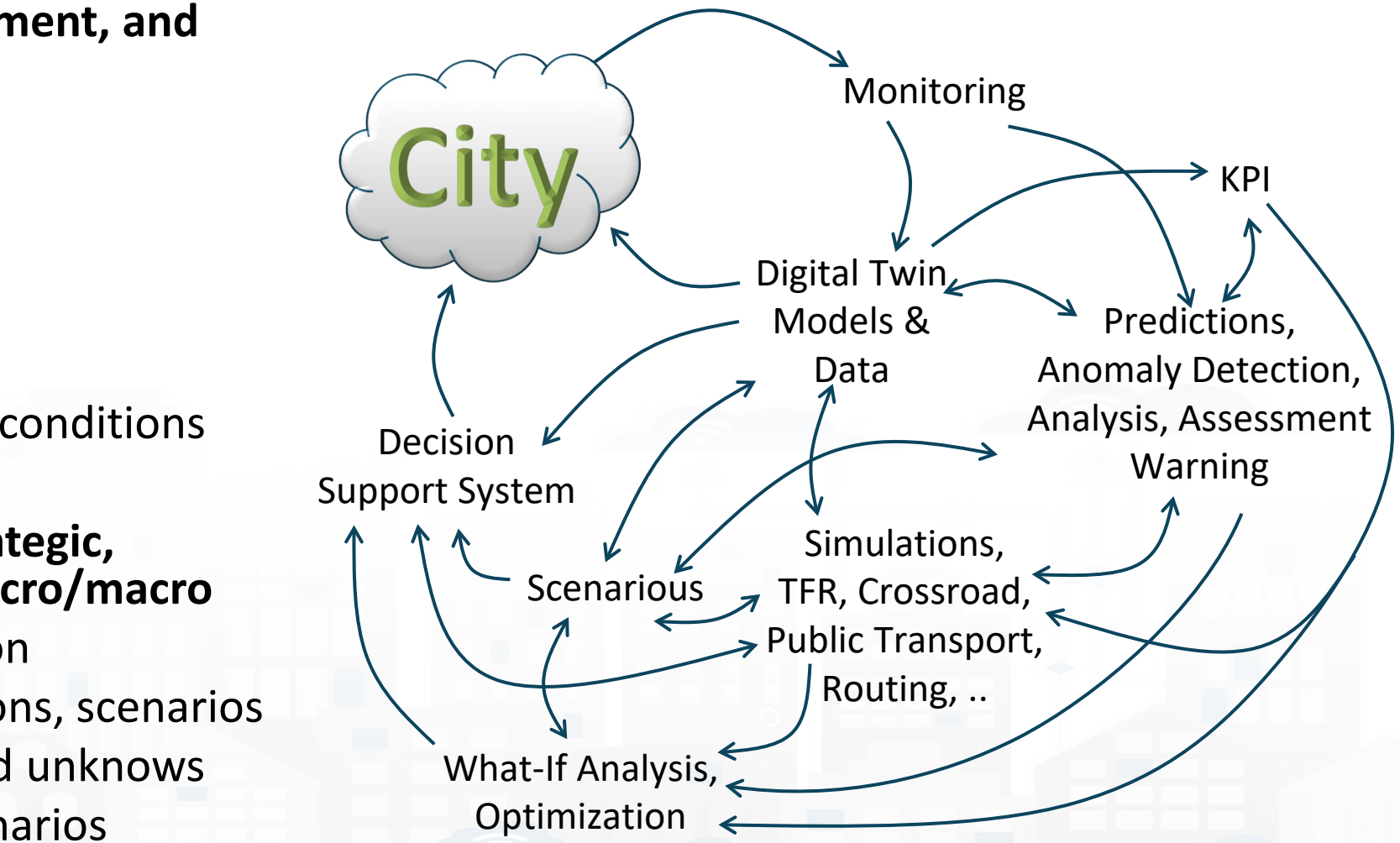
SNAP4CITY

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | MOST CENTRO NAZIONALE PER LA MOBILITÀ SOSTENIBILE

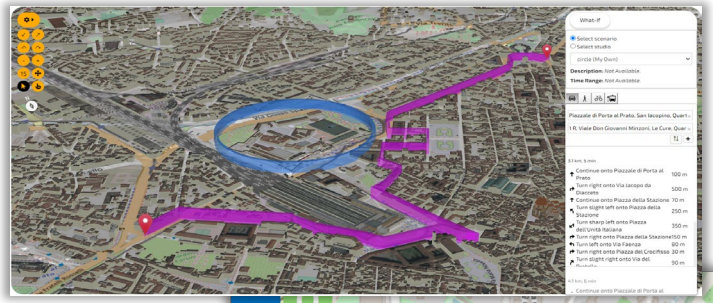
Main tasks

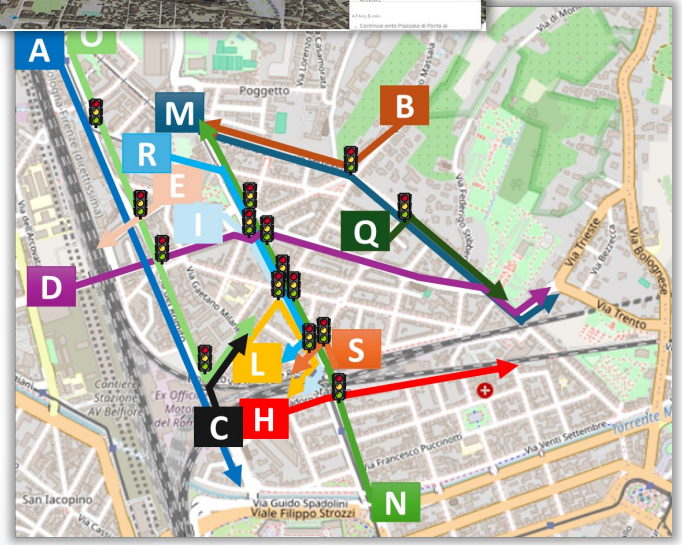
- **Controlling Status: management, and operational**
  - Monitoring via KPI
  - Predictions vs KPI
  - Anomaly detection
  - Neuro-Symbolic analysis
  - Risk assessment
  - Early warning on critical conditions
  - Fast What-if analysis
- **Making plan: tactic and strategic, medium and long range, micro/macro**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



Mobility & Transport

- **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 plans, infrastructure**
  - **Reduction**: travel time, waiting time, # stops, CO2 emissions, consume fuel, travel time for tramways and busses
- **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.**





LUTECH BRAIN MOBILITY 4 FUTURE

Operation OPTIFaaS

indietro log-out

- Home
- Traffic Monitoring
- Smart Parking
- 15 minuti index
- Urban Security

Road Monitoring

Media congestioni	Nr. congestioni	Picco congestioni	Riduzione Co2 ZTL	Emissioni medie CO2	Emissioni totali CO2
28.4 %	17 -	18:27 -	-5.2 %	282 ppm	846 ppm

Traffico in ingresso

Tot. veicoli in ingresso: 12105 Veicoli

Velocità media: 27 km/h

Traffico in uscita

Tot. veicoli in uscita: 11703 Veicoli

Veicoli totali: 7825 -

Pannello Rischi Meteo

MINIMO | BASSO | MEDIO | ALTO

Rischio Idraulico	MINIMO	Rischio Idrogeologico	MINIMO
Rischio Temporali	MINIMO	Rischio Neve	MINIMO
Rischio Ghiaccio	MINIMO	Rischio Vento	MINIMO

Viabilità

INCIDENTI	3
Chiusura Traffico	2
Chiusura Lavori	0
Limitazioni Traffico	4
Limitazioni Lavori	0
SEGNALAZIONI	7

Trasporto Pubblico

Tempo medio di attesa: 5.9 sec

Ritardo autobus: 0 %

Attesa Media Fermate

Linea 50	12 sec
Linea 11	10 sec
Linea 33	6 sec
Linea 02/	5 sec
Linea E	5 sec
Linea 19	4 sec

Sensori

15 Semafori	3
22 Videocamere	0
4 Sensori	1

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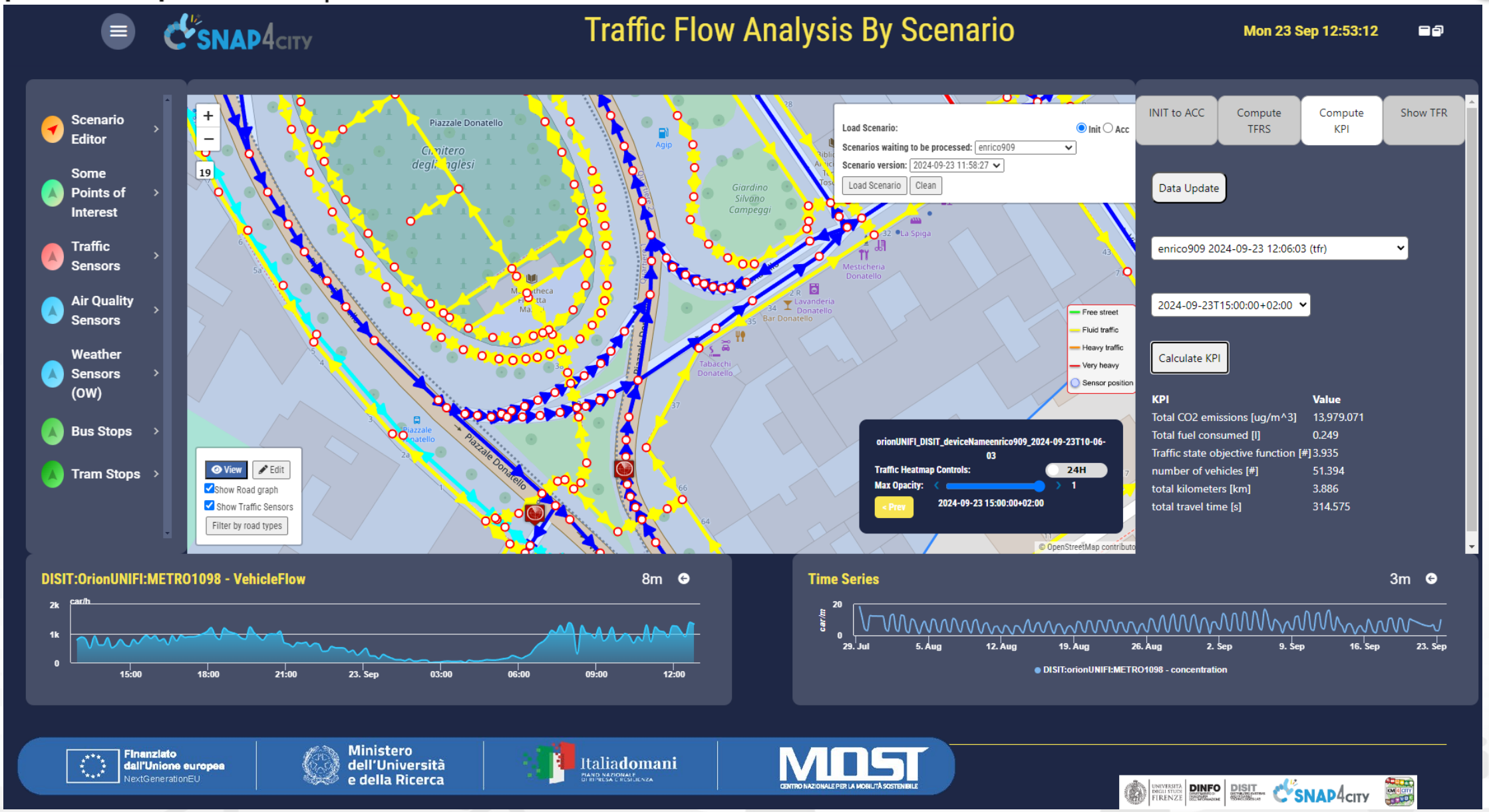
What-if on TFR



Firenze - Trafair - AirQuality Heatmaps

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

Mon 6 Apr 15:12:27

- Air Quality Sensors
- Weather Sensors
- PM10 Heatmap
- PM2.5 Heatmap
- CO Heatmap
- CO2 Heatmap
- O3 Heatmap
- NO2 Heatmap
- Europ. AQI Heatmap
- Air Humidity Heatmap
- Air Temp. Heatmap
- Wind Speed Heatmap
- Gral Pred. HM NOX (3m)
- Gral Pred. HM NOX (6m)
- Traffic Sensors
- Traffic Flow
- Cycling Paths
- Accident Heatmap
- Accident Heatmap 2
- Only HRes Anym. Gral
- Green Areas
- Schools

Air quality trends

Multi Map

Maps

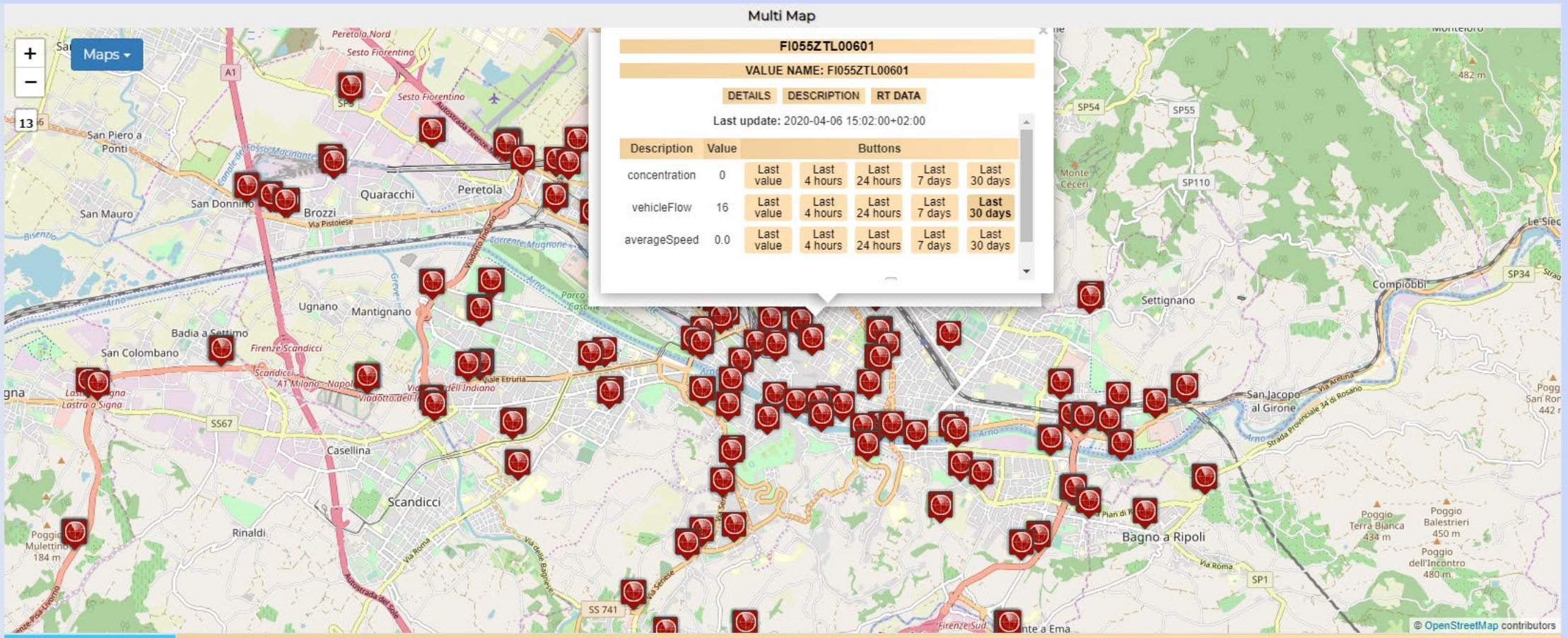
FI055ZTL00601

VALUE NAME: FI055ZTL00601

DETAILS | DESCRIPTION | RT DATA

Last update: 2020-04-06 15:02:00+02:00

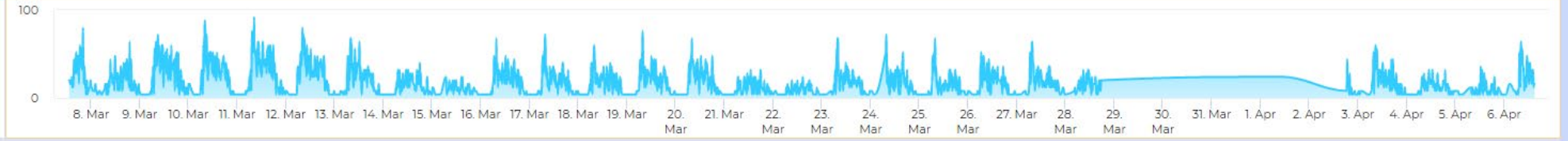
Description	Value	Buttons				
concentration	0	Last value	Last 4 hours	Last 24 hours	Last 7 days	Last 30 days
vehicleFlow	16	Last value	Last 4 hours	Last 24 hours	Last 7 days	**Last 30 days**
averageSpeed	0.0	Last value	Last 4 hours	Last 24 hours	Last 7 days	Last 30 days



Air Temperature 9m

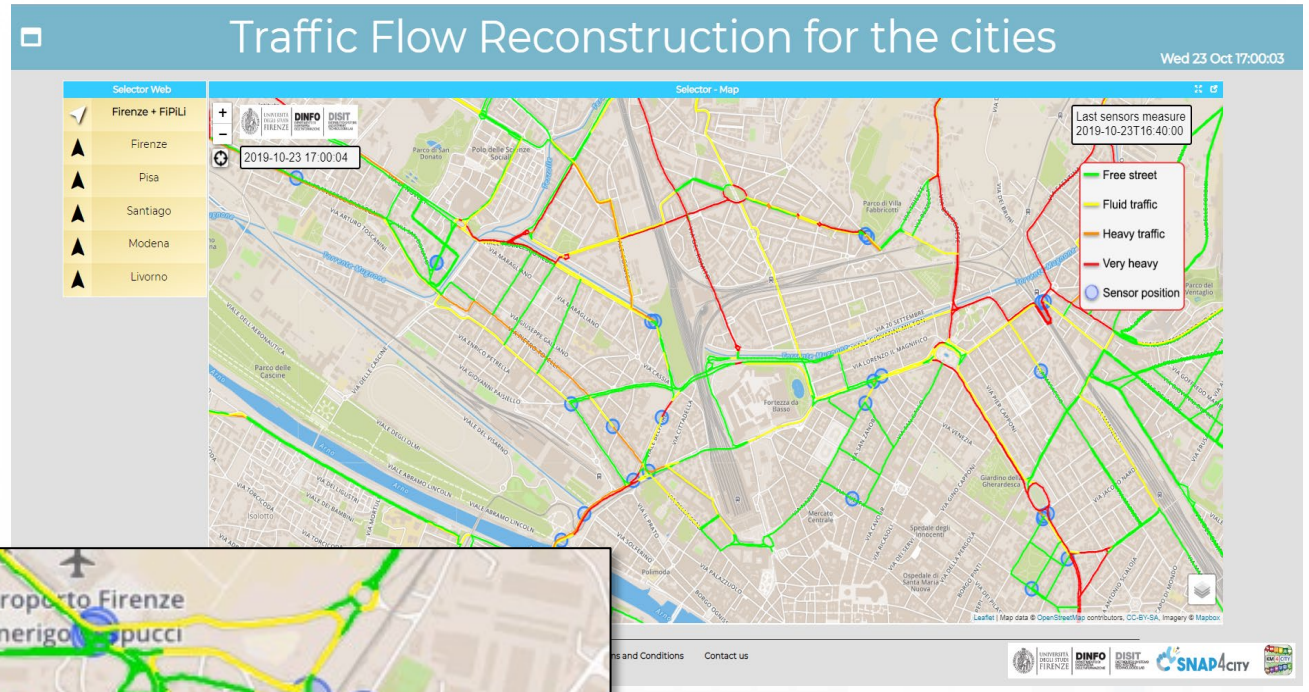
21.8 °C

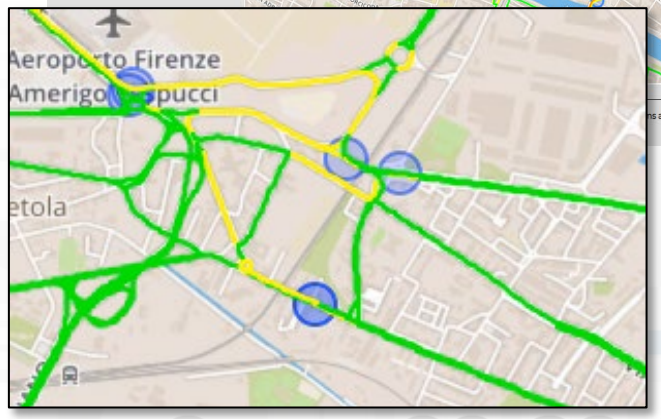
vehicleFlow - 30 days 9m



Why Dense Traffic Flow Reconstruction ?

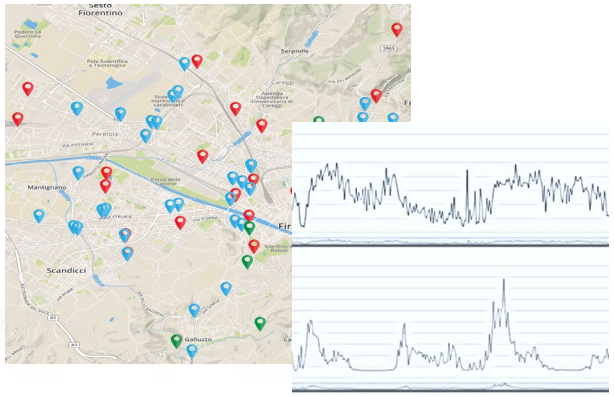
- Making decision on mobility and transport solutions → what if analysis
- Controlling pollution
- Dynamic Routing for Firebrigade, Ambulances, general public
- Planning Public Transportation routing

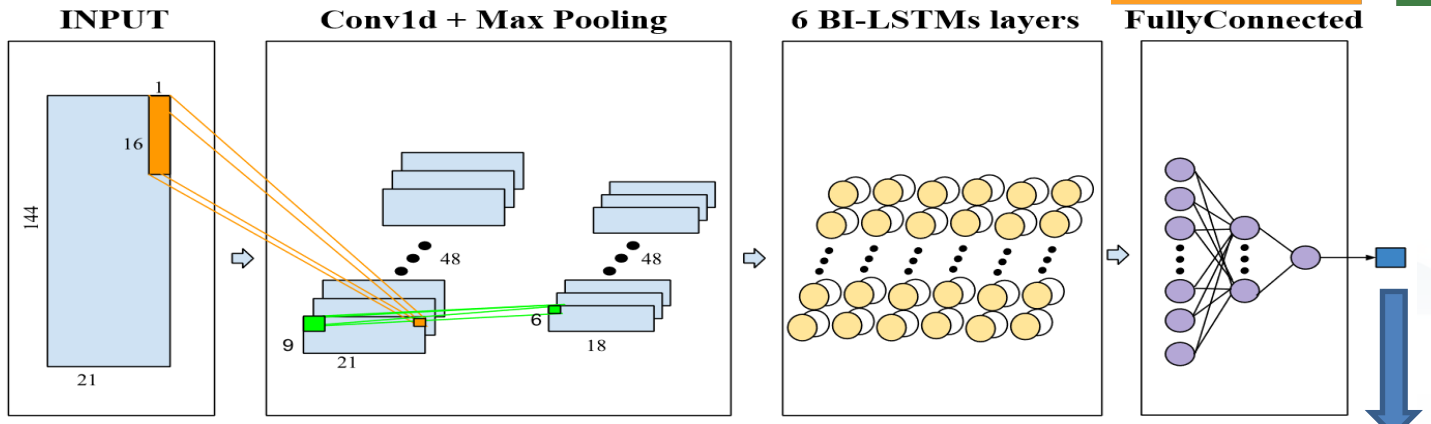




https://www.snap4city.org/dashboardSmartCity/view/index.php?iddasboard=MTc5NQ==

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



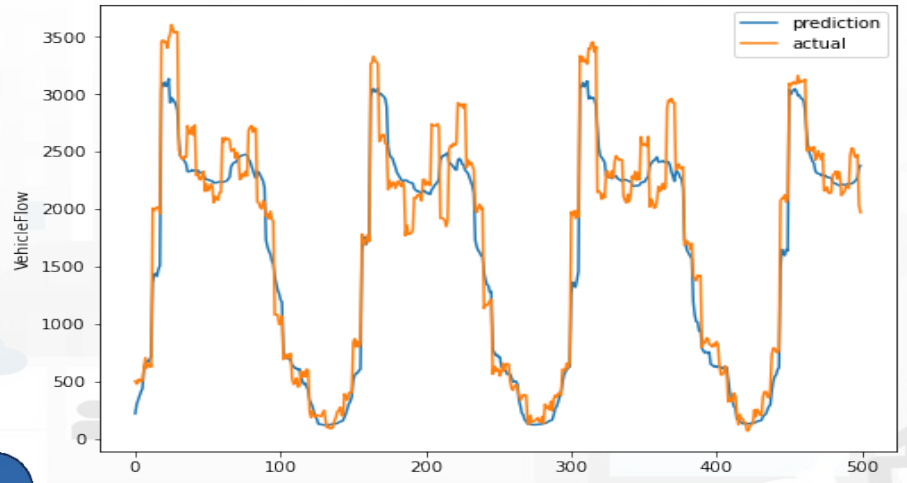


Urban data:

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

RF
XGBOOST
DNN
LSTM
BI-LSTM
Autoencoder BI-LSTM
Attention CONV-LSTM
CONV-BI-LSTM

CONV-BI-LSTM



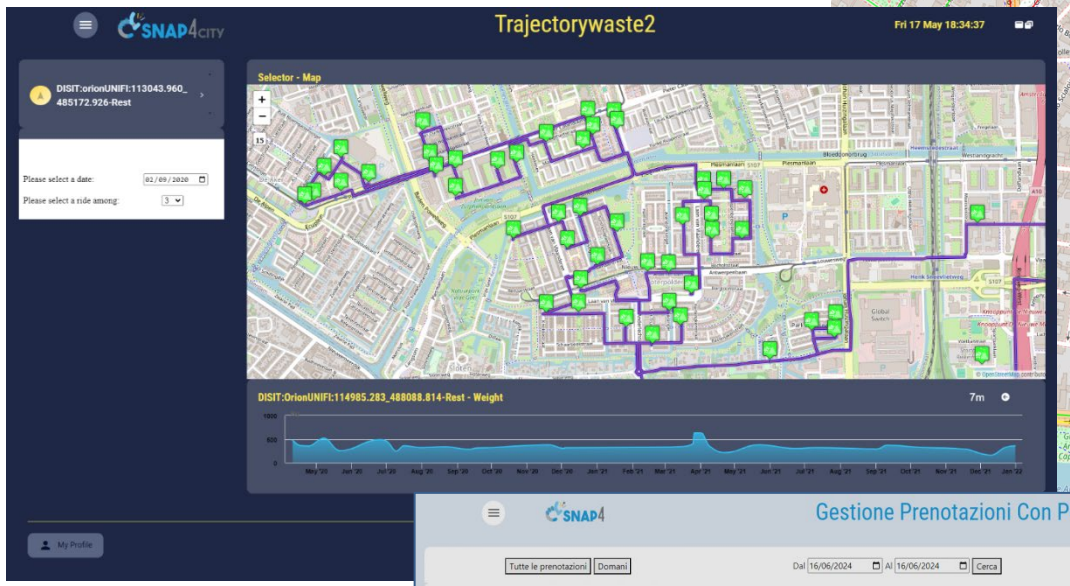
Routing Optimization

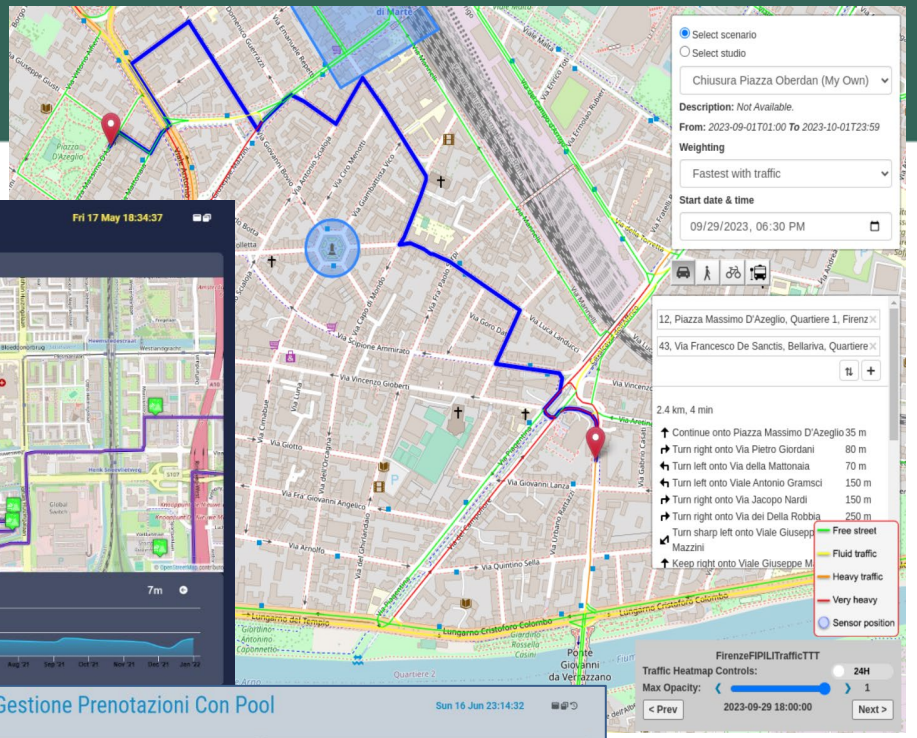
Goals on planning:

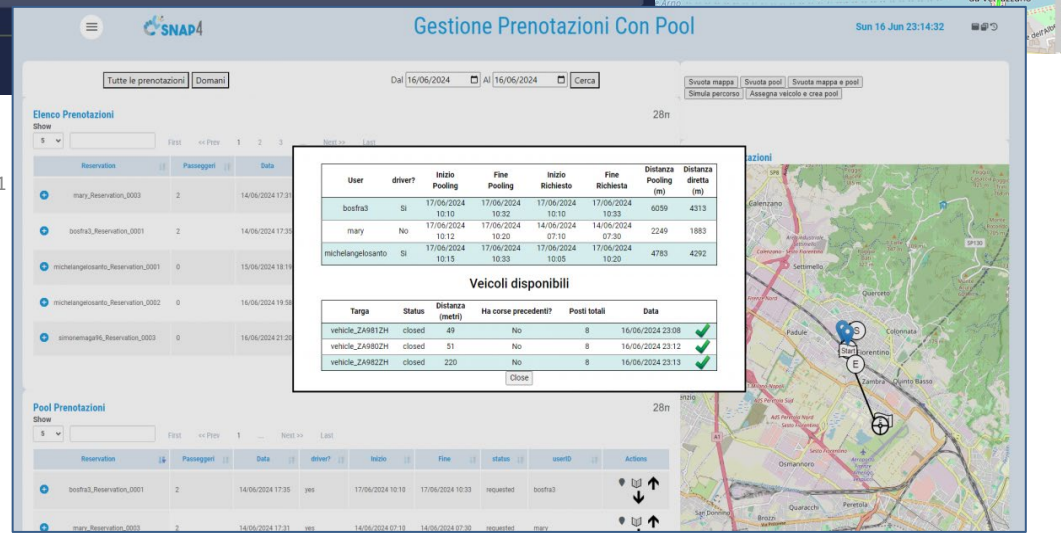
- Reduction **of costs on plan**
- **waste collection** optimization, Reduction of Km
- **car pooling trajectories** optimization for maximize the pool usage
- **delivering optimization**, reduction of travel time, reduction of Km
- etc.

Dynamic Routing on operation:

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







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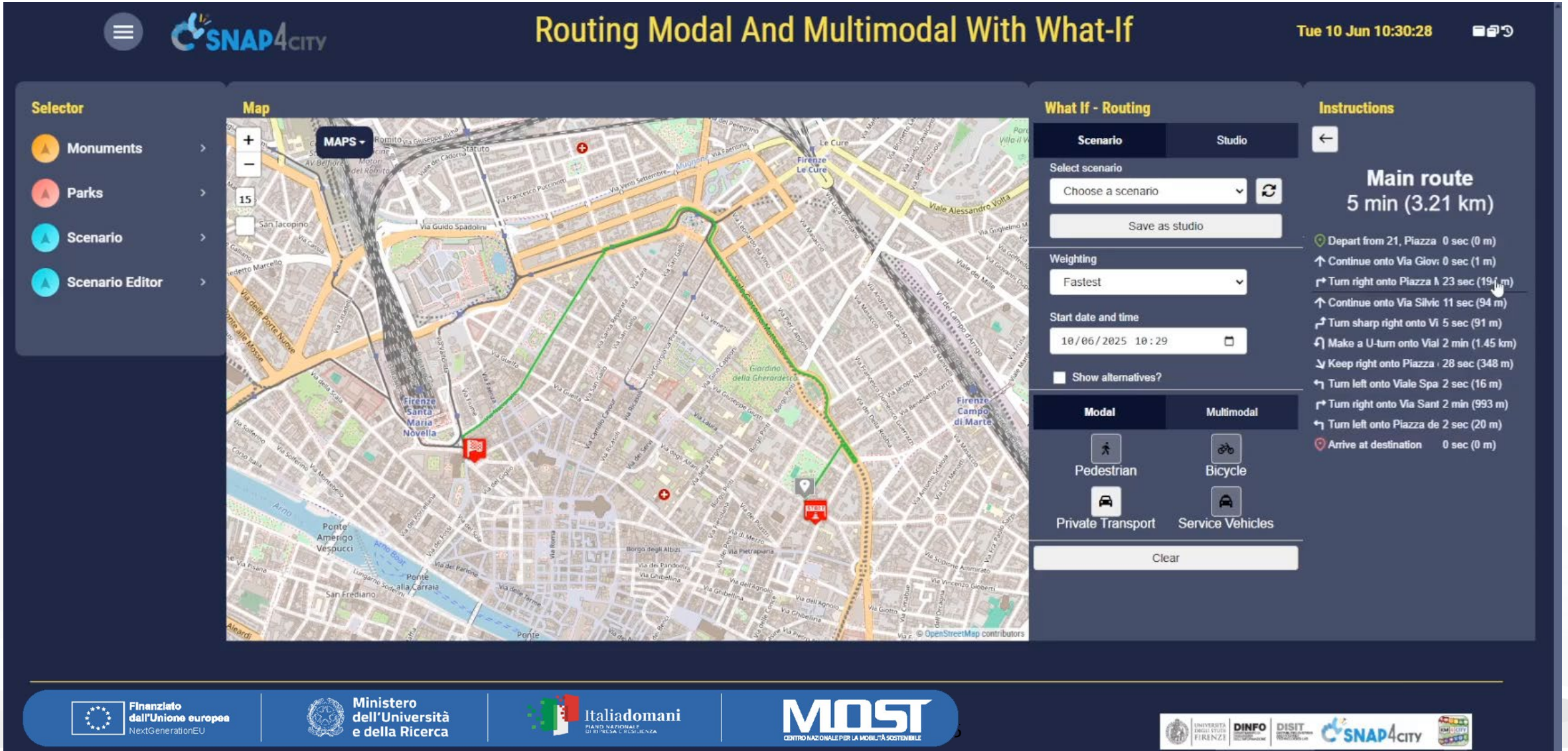
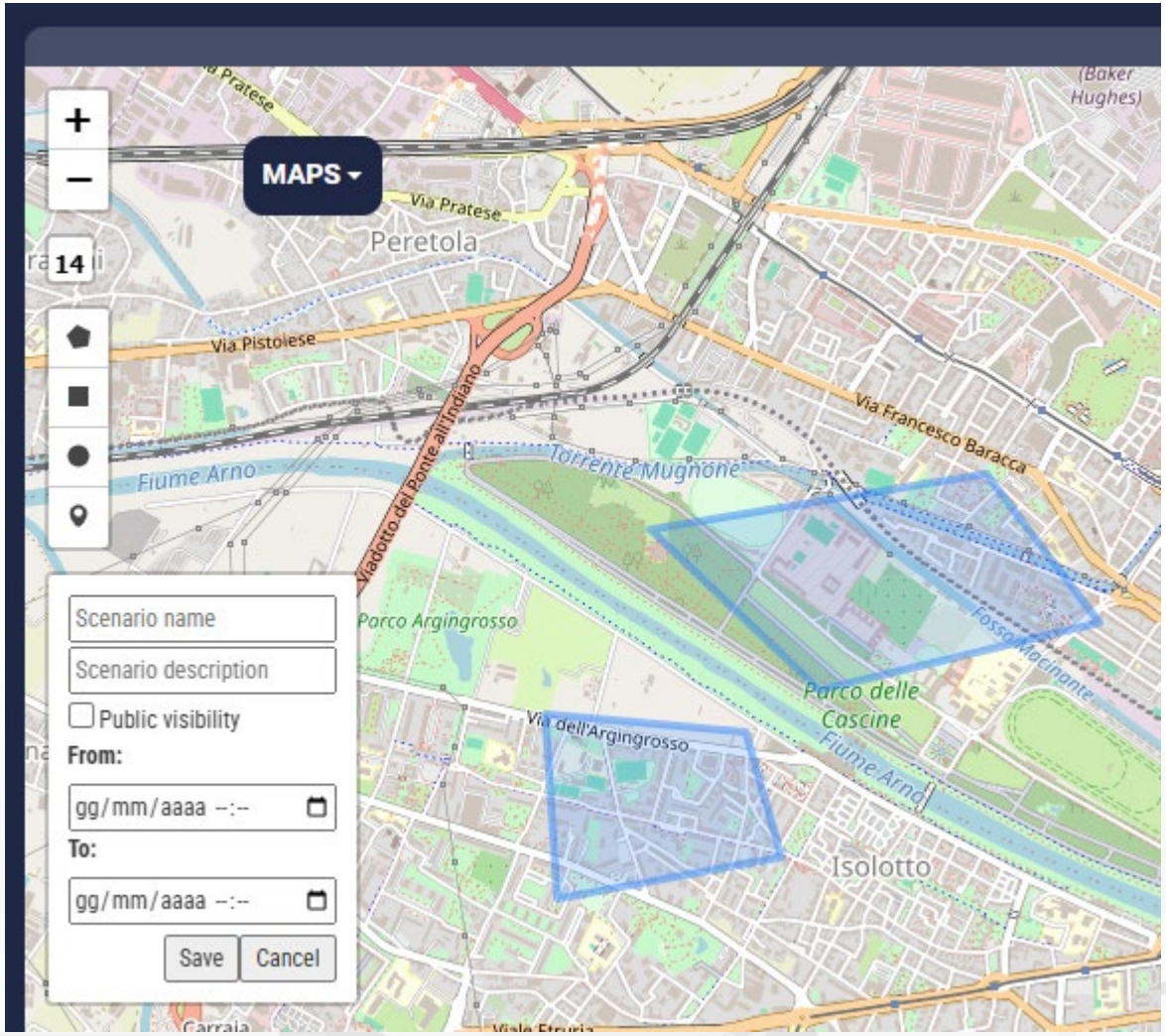
Routing Facitilities

- **modal routing: private vehicles, bikes, pedestrian**
  - with start, end and multiple intermediate points
  - selecting: shorter, faster, quitter, etc..
  - dynamic conditional routing taking into account the effective traffic flow status, or typical traffic flow status
  - dynamic conditional routing taking into account eventual blocked areas (by scenario) for example for street working, restoring, etc. (what-if cases and analysis)
- **multimodal routing** for the city users to walk and take the public collective transport
- **modal routing for public administrations** (ambulance, fire brigade, police, busses, etc.) exploiting the reserved lanes, etc.
- **a combination of cases**.
- **Full API for exploitation from your applications**

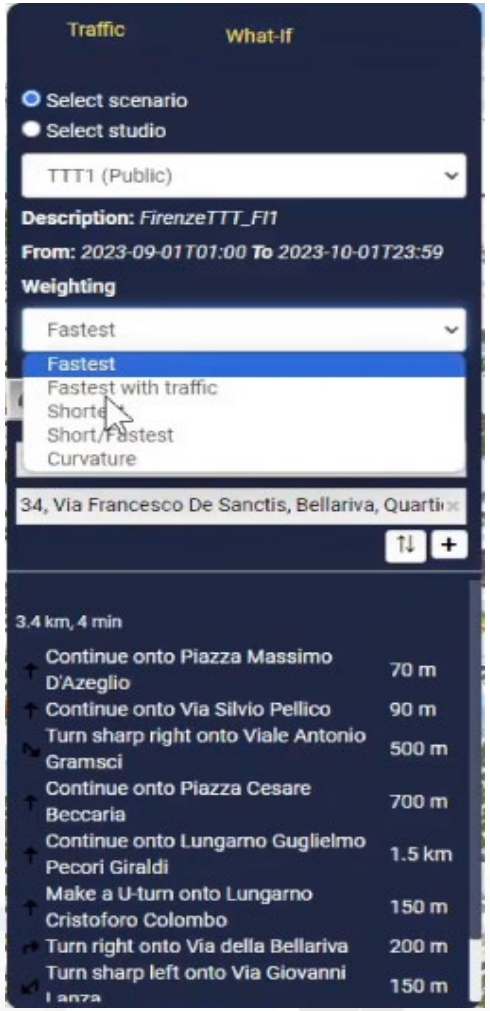
Some Routing Service Capabilities



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



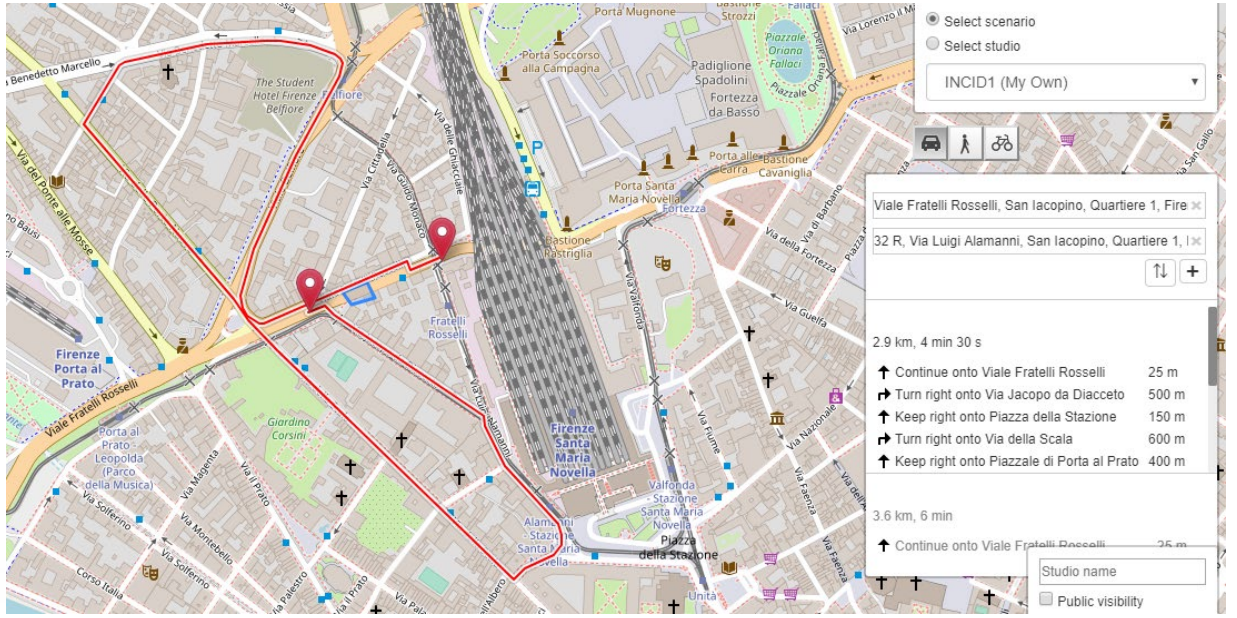
What-If Analysis

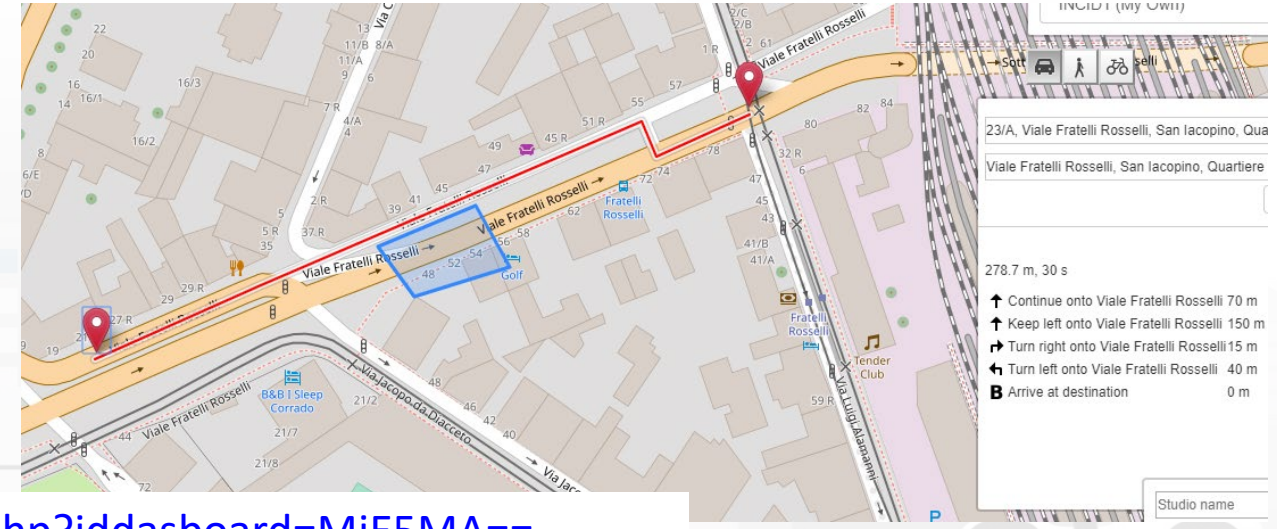
Accidents and elements blocking Points and Shapes taken into account for:

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

Assessment on the basis of changes:

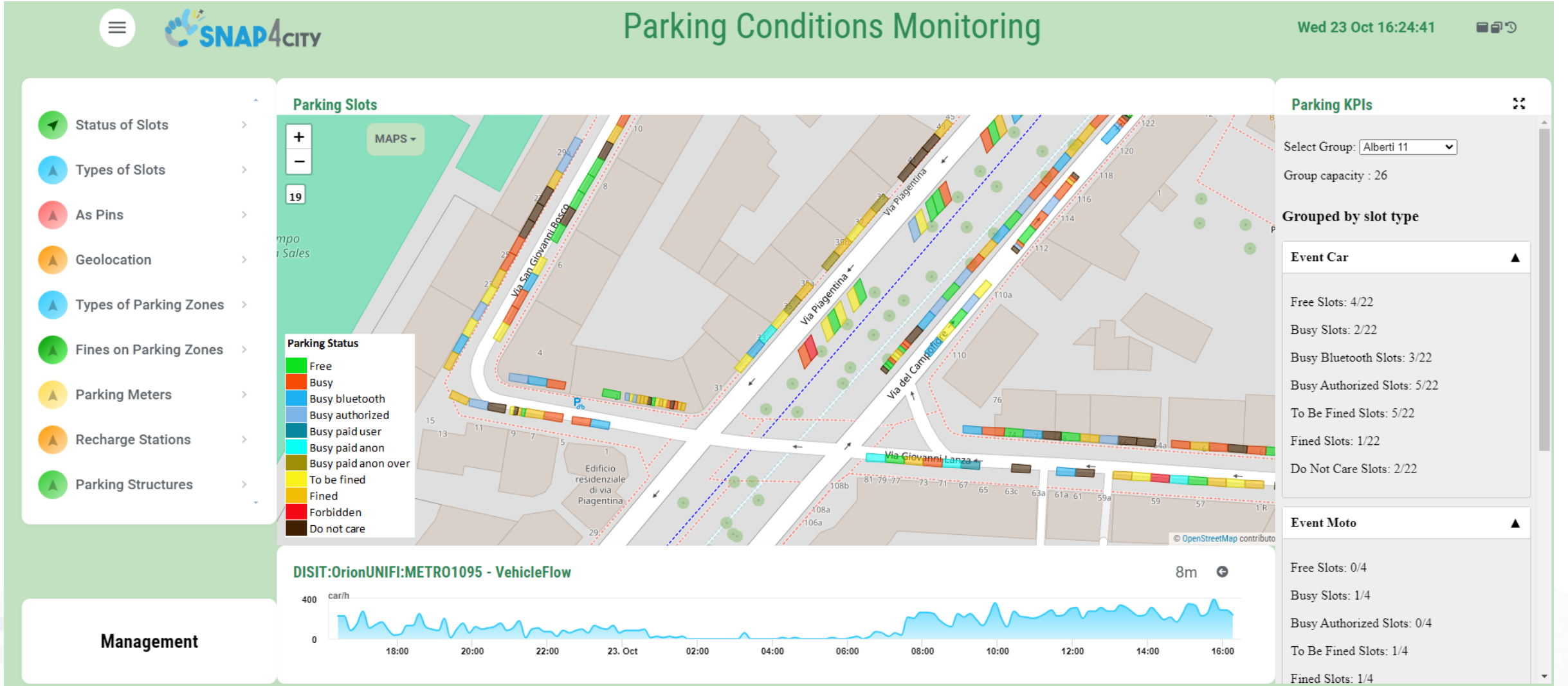
- Mobility demand assessment
- Mobility Offer assessment



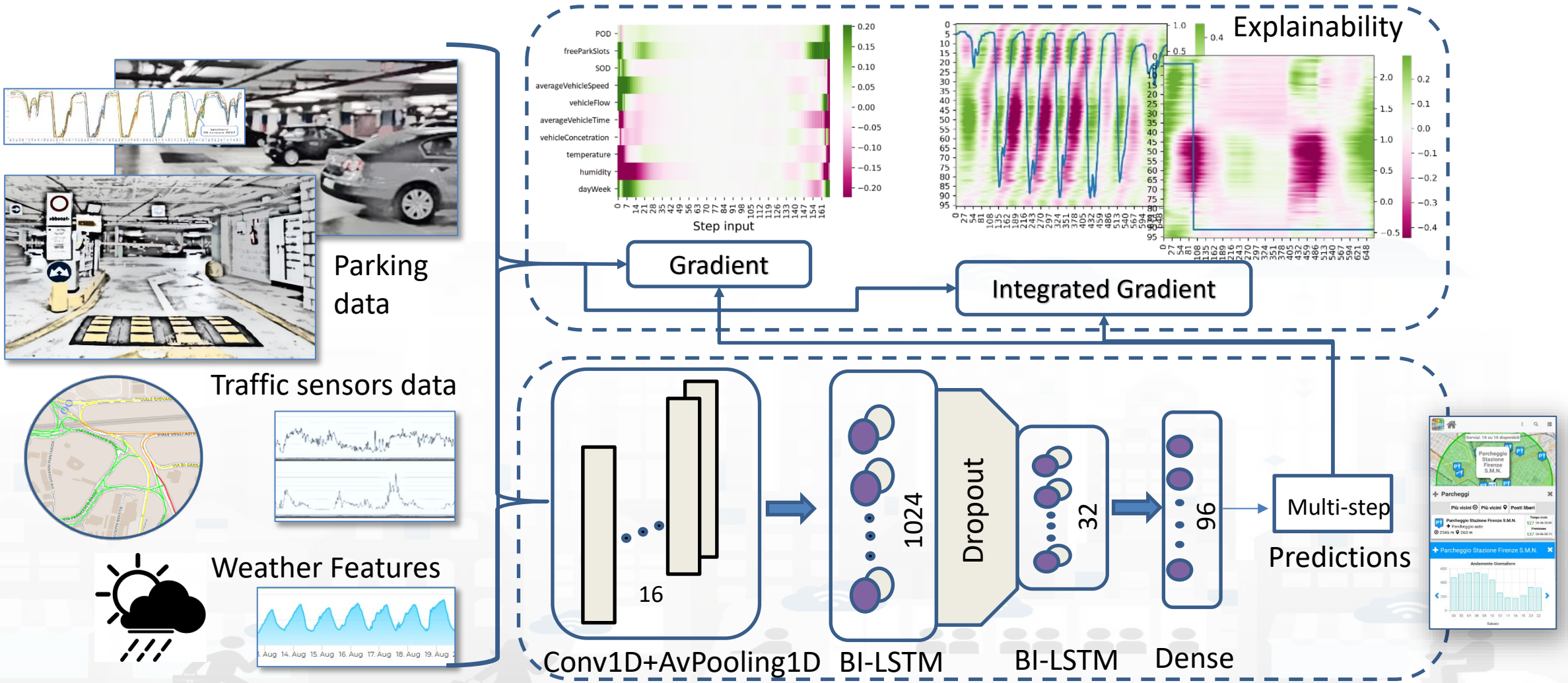


https://www.snap4city.org/dashboardSmartCity/view/index.php?iddasboard=MjE5MA==

Road Parking

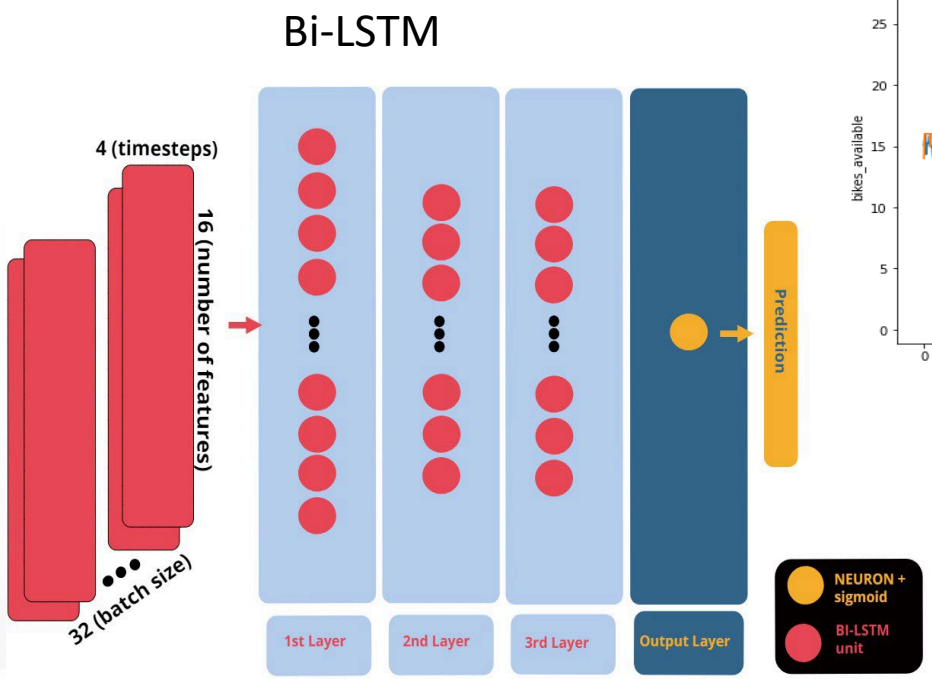


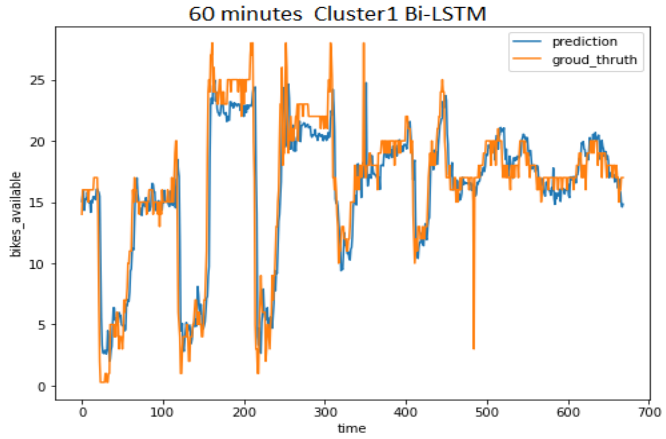
Deep Learning AI to surely Park!

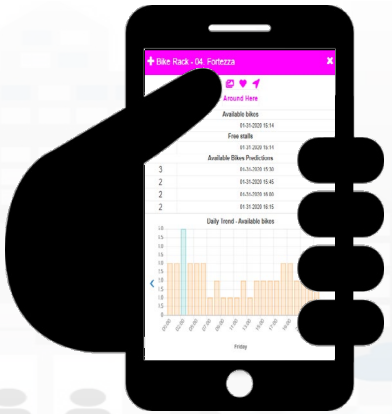


Compared with: BRANN, RNN, CNN-GRU, CNN-LSTM

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



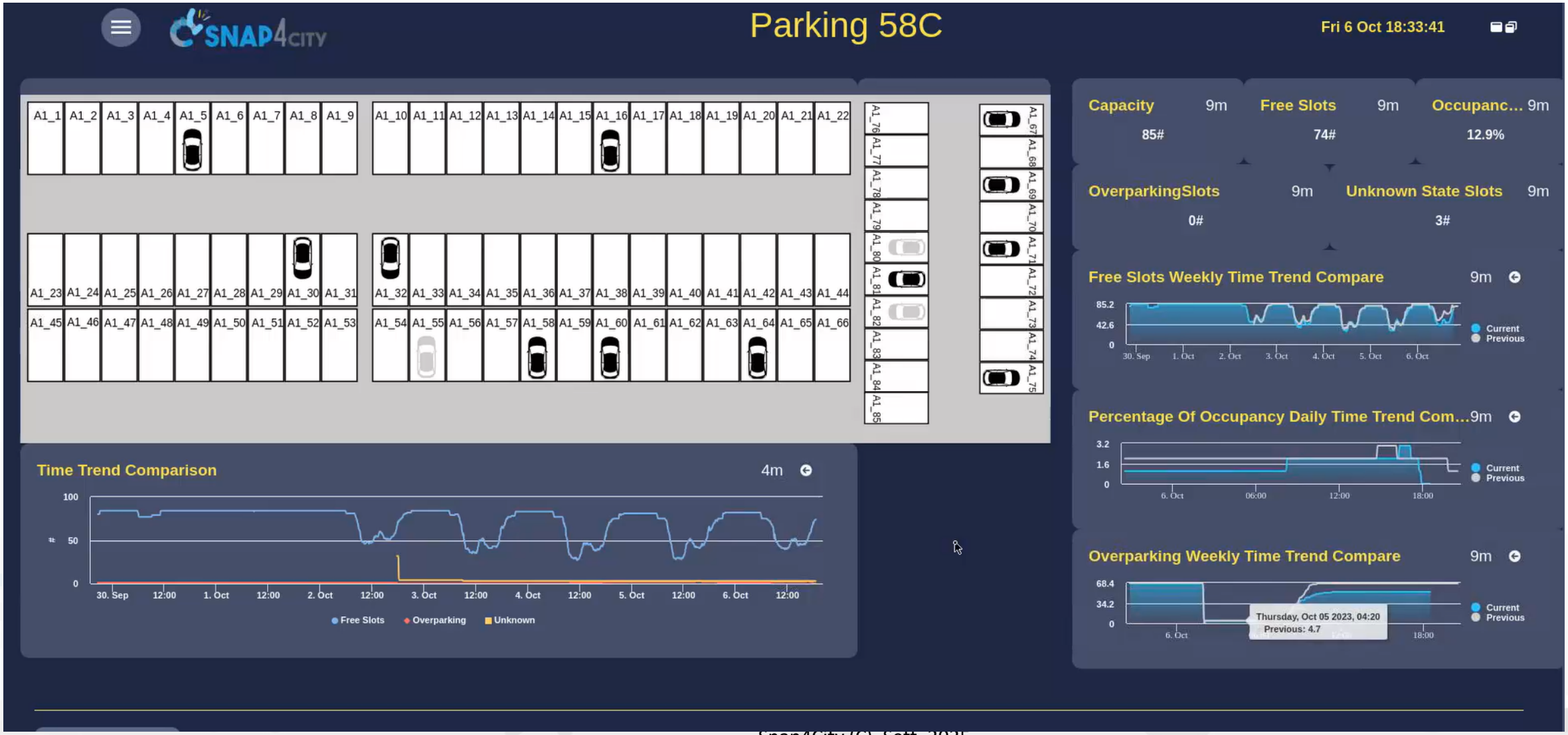




E. Collini, P. Nesi and G. Pantaleo, "Deep Learning for Short-Term Prediction of Available Bikes on Bike-Sharing Stations," in *IEEE Access*, vol. 9, pp. 124337-124347, 2021, doi: 10.1109/ACCESS.2021.3110794.
https://ieeexplore.ieee.org/abstract/document/9530580

Comp: RF, XGBoost, DNN, LSTM

Snap4ISPRA Parking: ISPRA JRC



LUTECH BRAIN MOBILITY 4 FUTURE

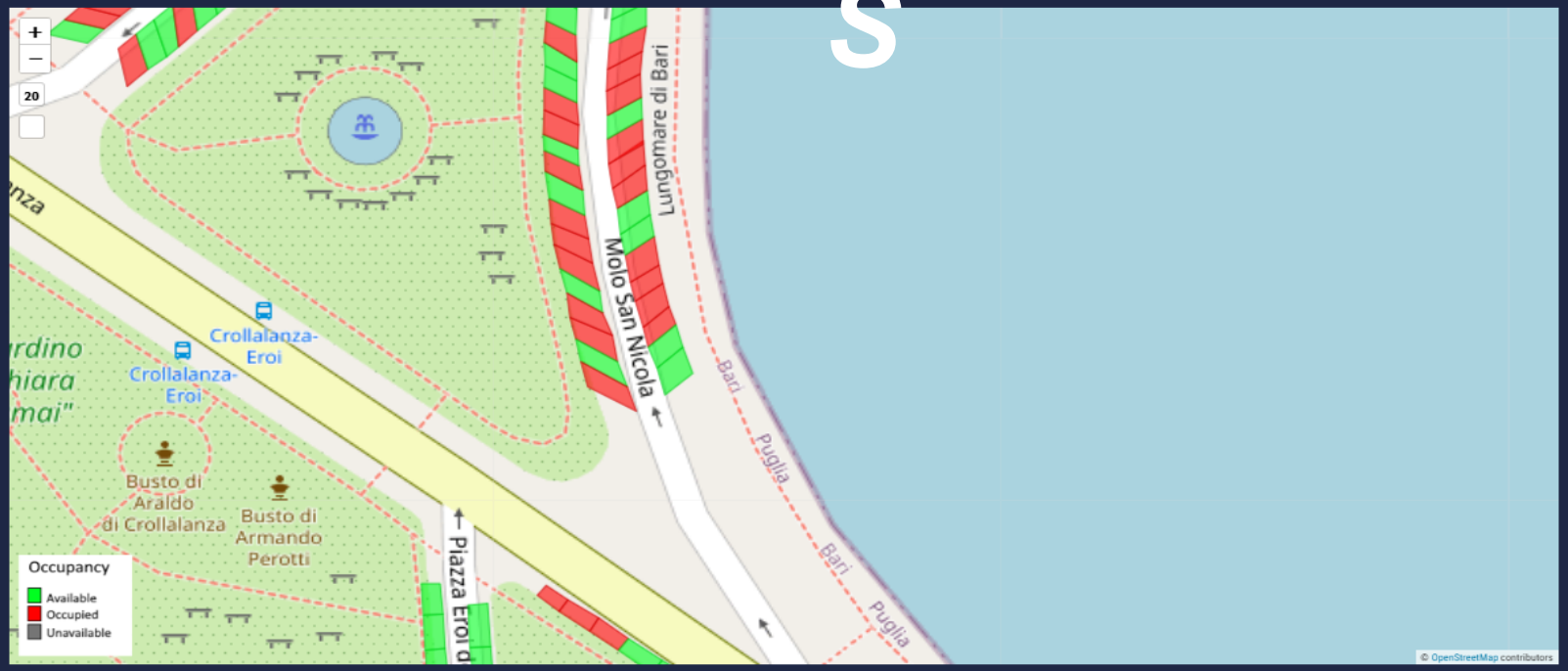
Smart parking

OPTIFaaS

indietro log-out

- Home
- Traffic Monitoring
- Smart Parking
- 15 minuti index
- Urban Security

- Posto auto
- Posto auto per tipologia parcheggio
- Posto auto per tipologia veicolo



Disponibilità parcheggi

Liberi	Occupati
20 stalli	26 stalli

Non disponibili
0 stalli

Tipologia parcheggio

Gratuiti	A pagamento	Residenti
3 stalli	35 stalli	0 stalli

Prioritari	Disabili	Carico/Scarico
4 stalli	4 stalli	0 stalli

Tipologia veicolo

Auto	Moto	Bici
46 stalli	0 stalli	0 stalli

Camion	Camper
0 stalli	0 stalli

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MOST Centro Nazionale per la Mobilità Sostenibile
Università degli Studi Firenze DINFO DISIT
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eSharing and Pooling

eShare in a Snap, by Snap4 s.r.l.

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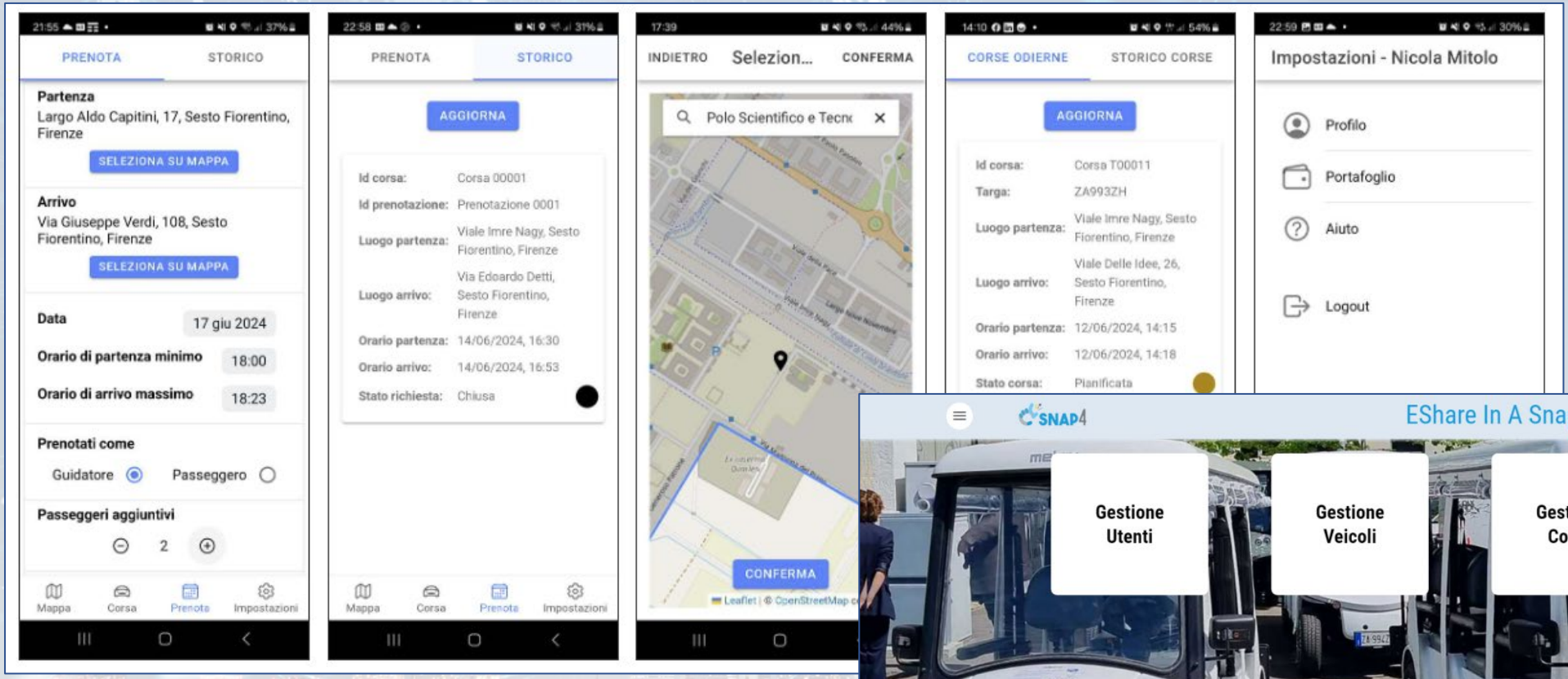
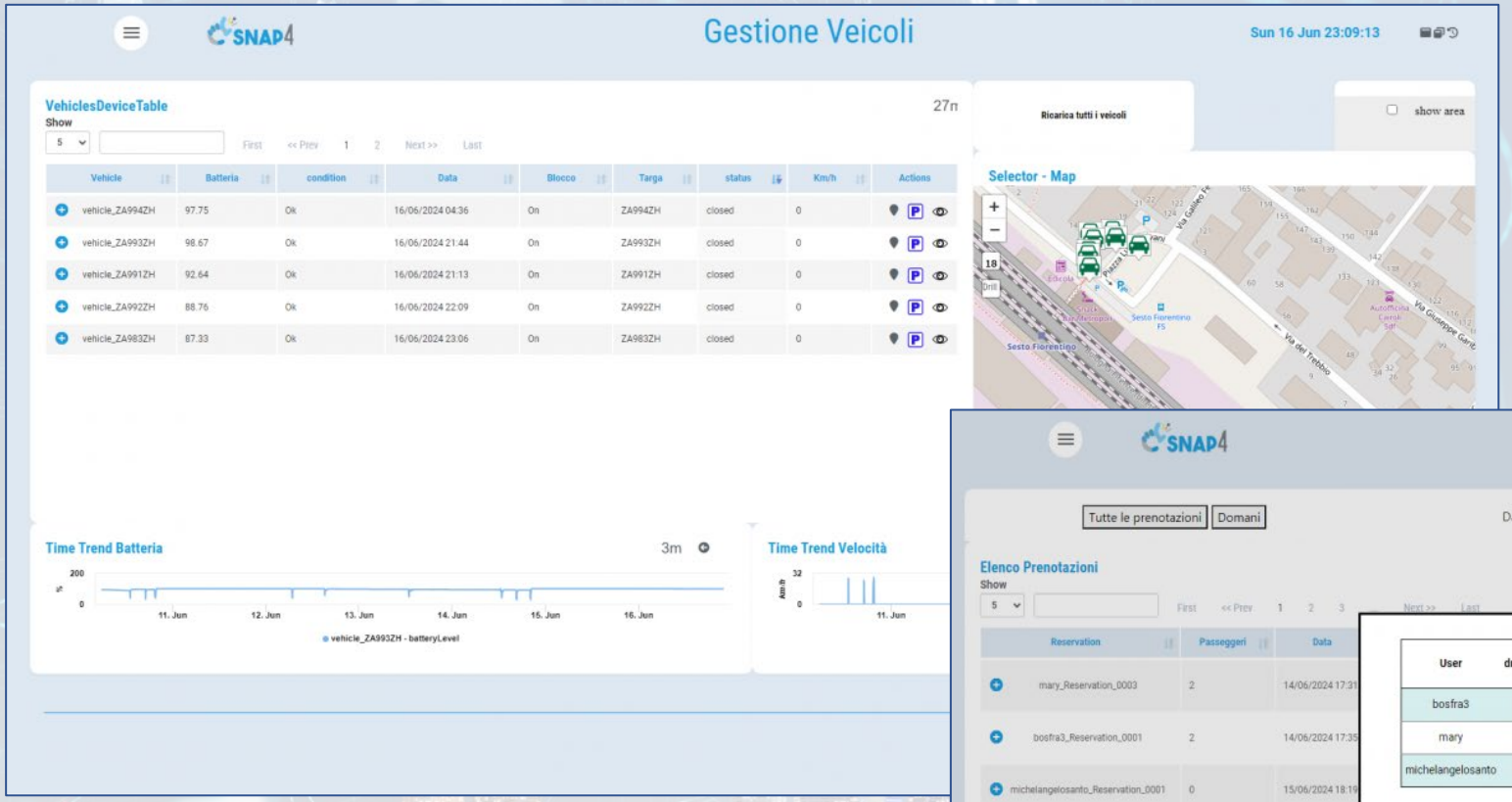
eShare in a Snap, by Snap4



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

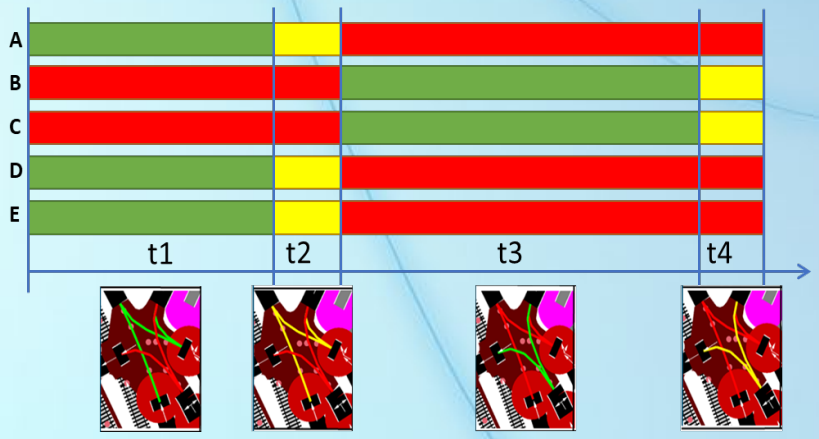
eShare in a Snap, by Snap4



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

Trucks' Plates and Container ID Recognition

- **Managing Gates to Salerno Port**
- Gates: in/out
- **Recognition and decoding**
  - BIC code: TSSU 204006
  - ISO code: 22G1
  - Seal status: on/off
  - Multi-national Plates: 74-0771



PTIFaaS

IL FUTURO DELLA MOBILITA'
INTELLIGENTE E SOSTENIBILE

Ottimizzazione Semaforica

Prof. Paolo Nesi, UNIFI DISIT

11 SUSTAINABLE CITIES AND COMMUNITIES

https://www.snap4city.org/1015

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Traffic Light Optimisation

- **Traffic Light Plan:**
  - General construction of Traffic Light Plans for the area
  - TLP are loaded on the basis of the expected conditions: football game, ferial and festive, school period, morning and afternoon, etc.
  - Single Junction TLP can be:
    - adjusted exploiting local data, on demand signals, etc.
    - Actuated on the basis of the measures of traffic
- **Issues:**
  - Making multijunction synchronization to keep under control of quality of Service for TRAMWAYS and/or Busses Rapid Transit, BRT/HRB

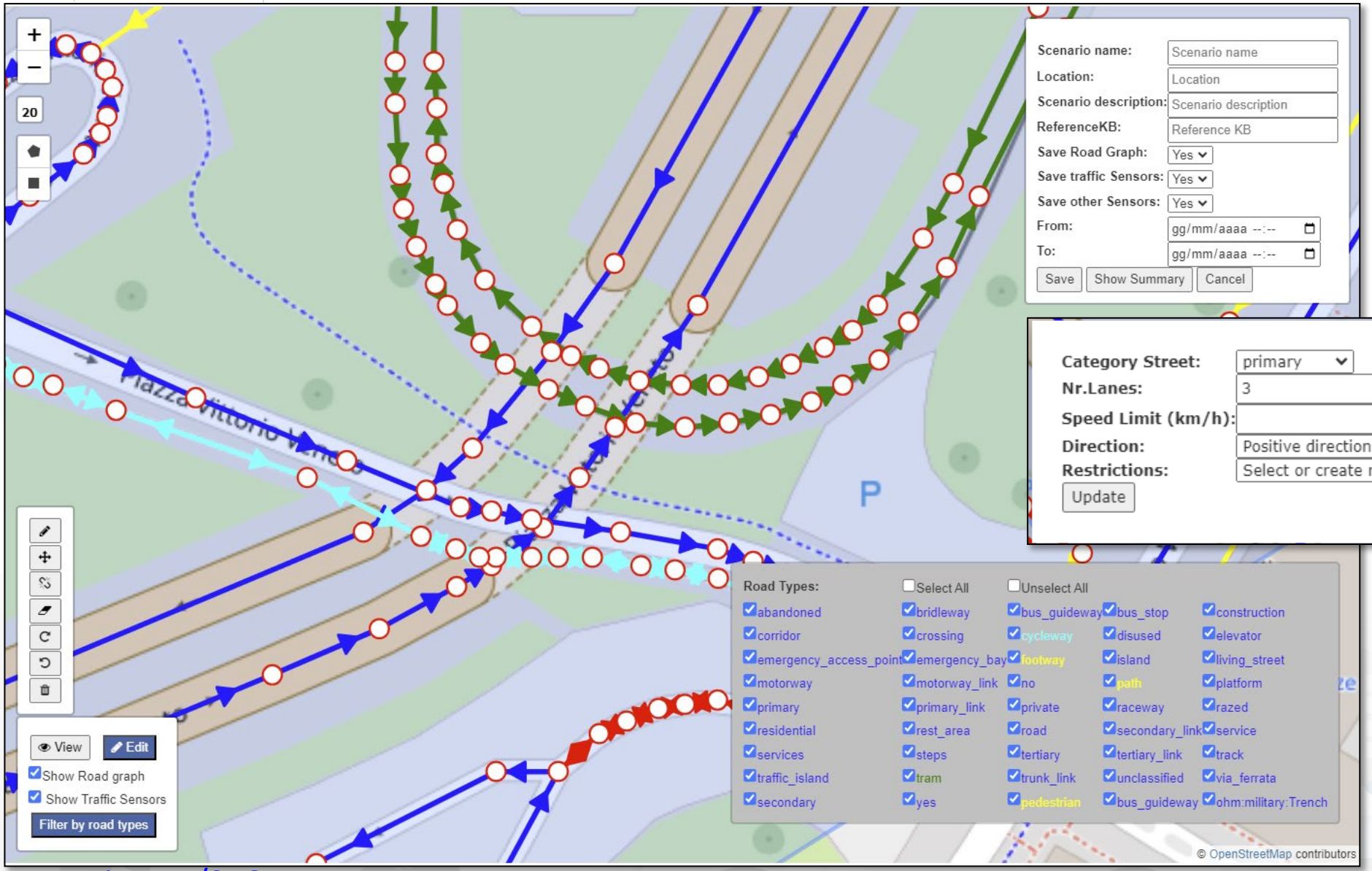
Scenario Editor

Select map

Zoom

New Scenario

Editing
Drag & drop
Split & Join
Delete
Do and Undo



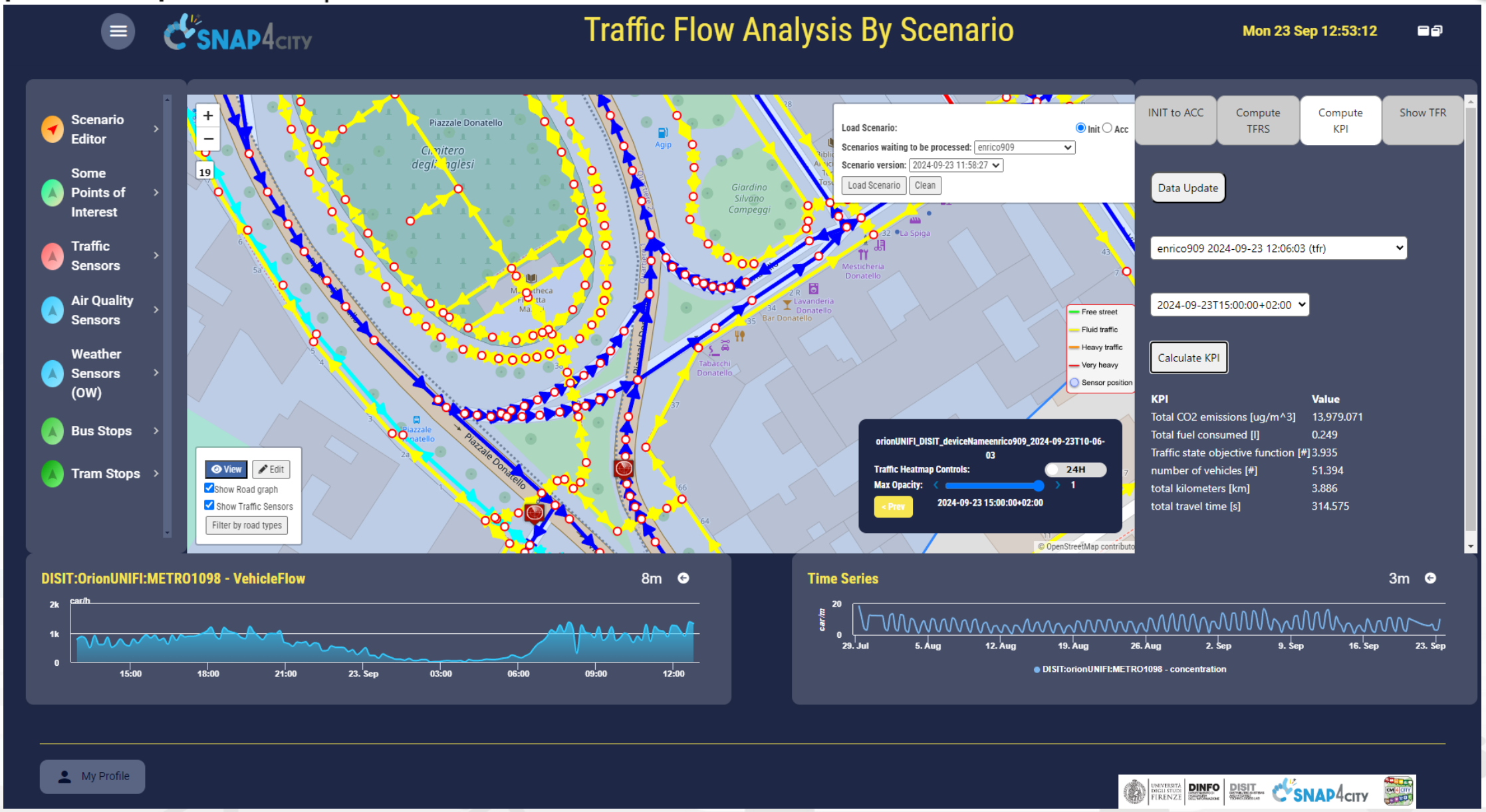
Edit Road Segment

- identifier
- composition
- elemLocation
- elementClass
- elementType
- length
- operatingStatus
- speedLimit
- trafficDir
- width
- highwayType
- route

Properties of Road Elements

https://www.snap4city.org/976

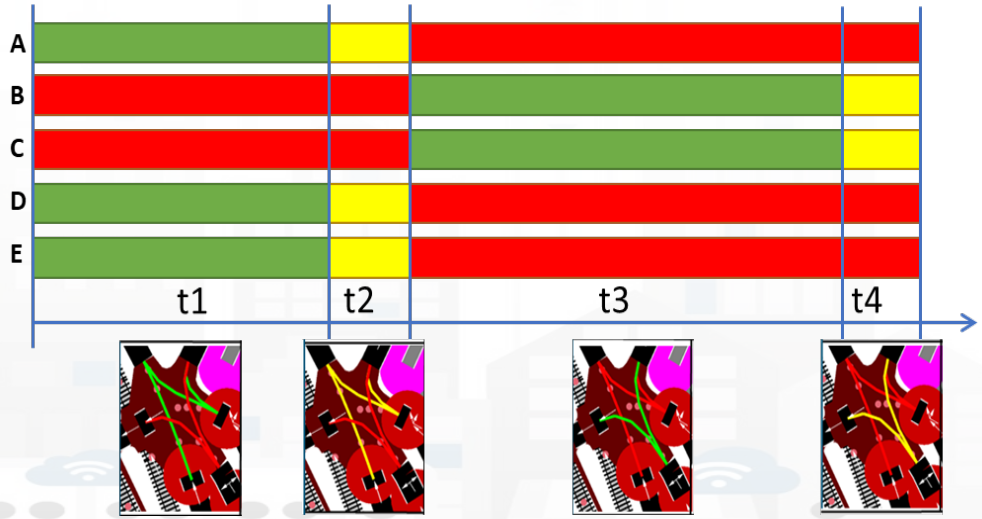
What-if on TFR



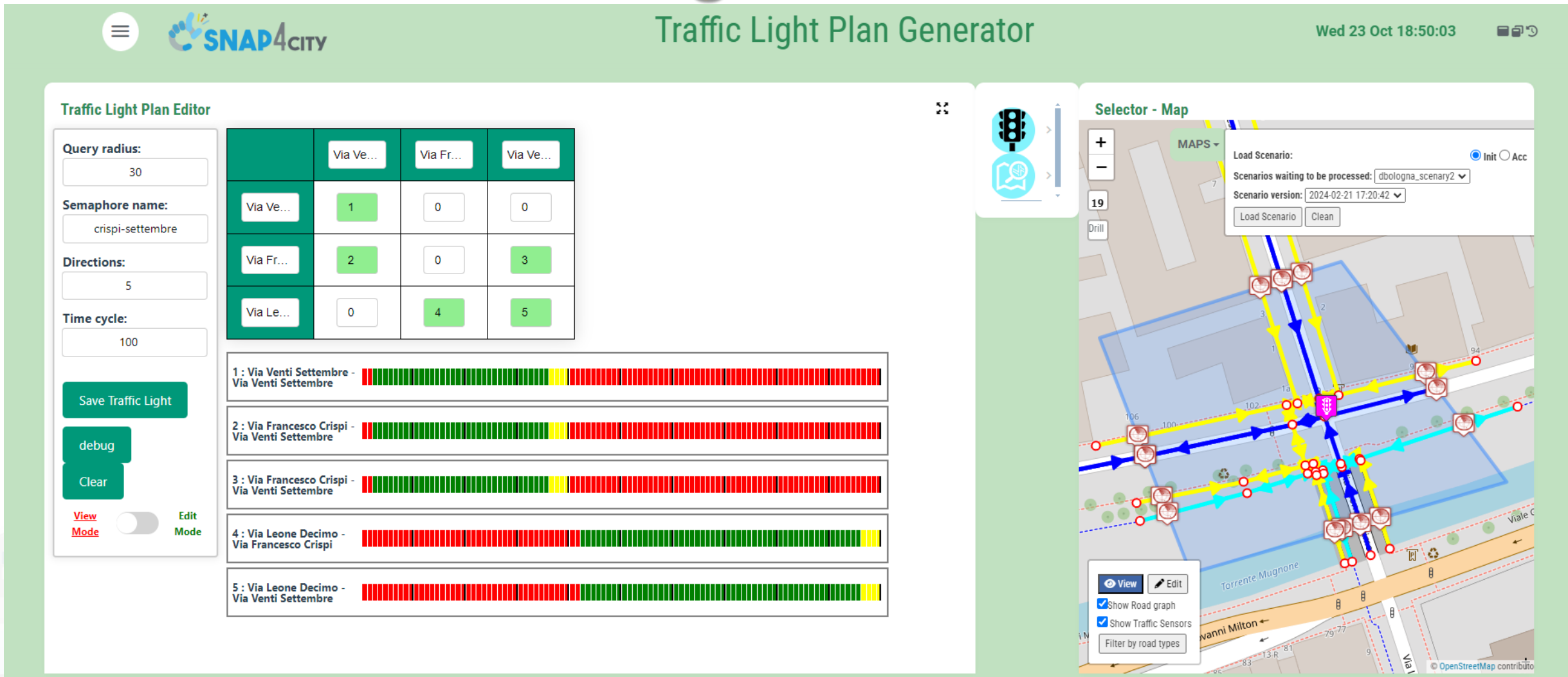
Traffic Light Plan Optimisation, Digital Twin

- **Match Multiple Objectives and Synchronization:**
  - public and private traffic, tramway priority
  - Micro and Macro Scales
  - **AI: Genetic Algorithms, Deep 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%**

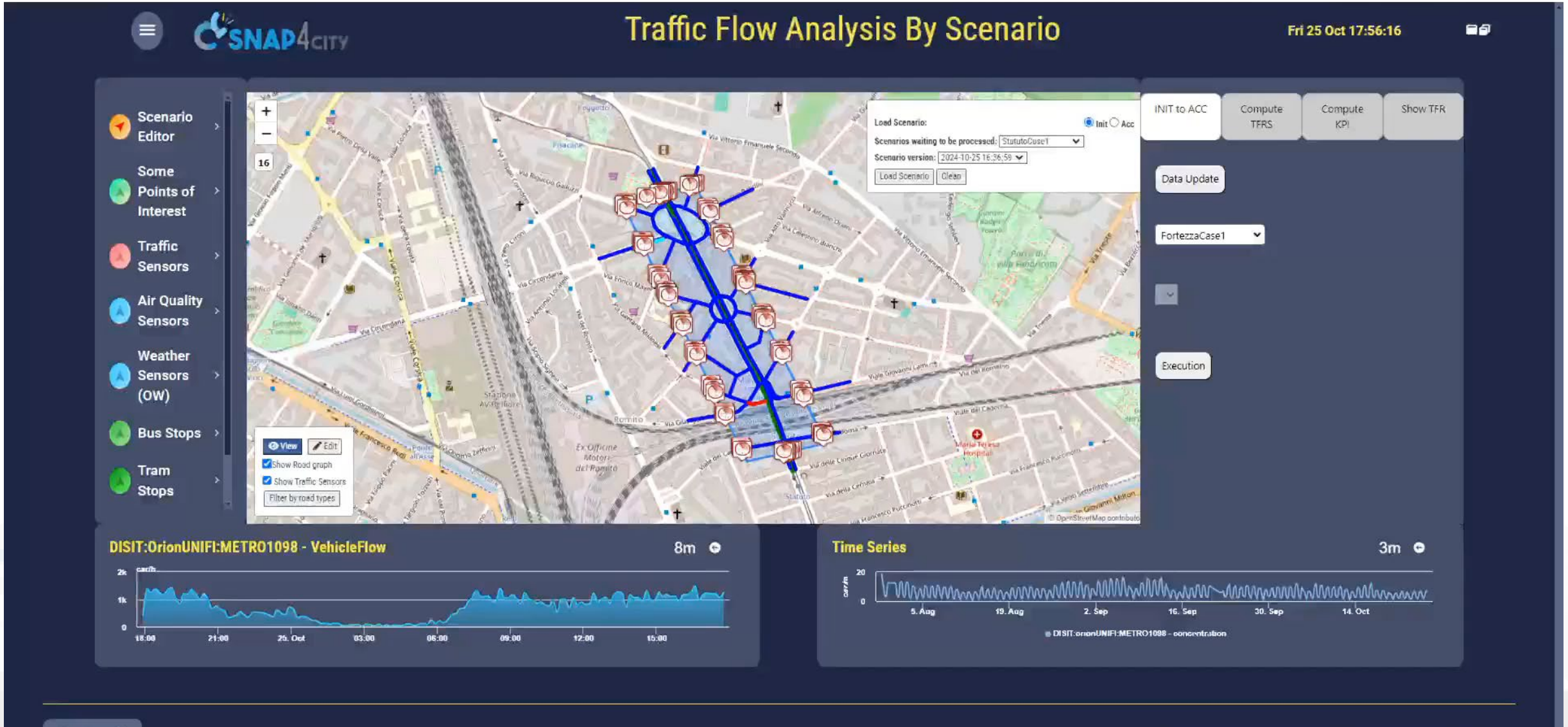
MOST CENTRO NAZIONALE PER LA MOBILITÀ SOSTENIBILE



Traffic Light Plan Editor

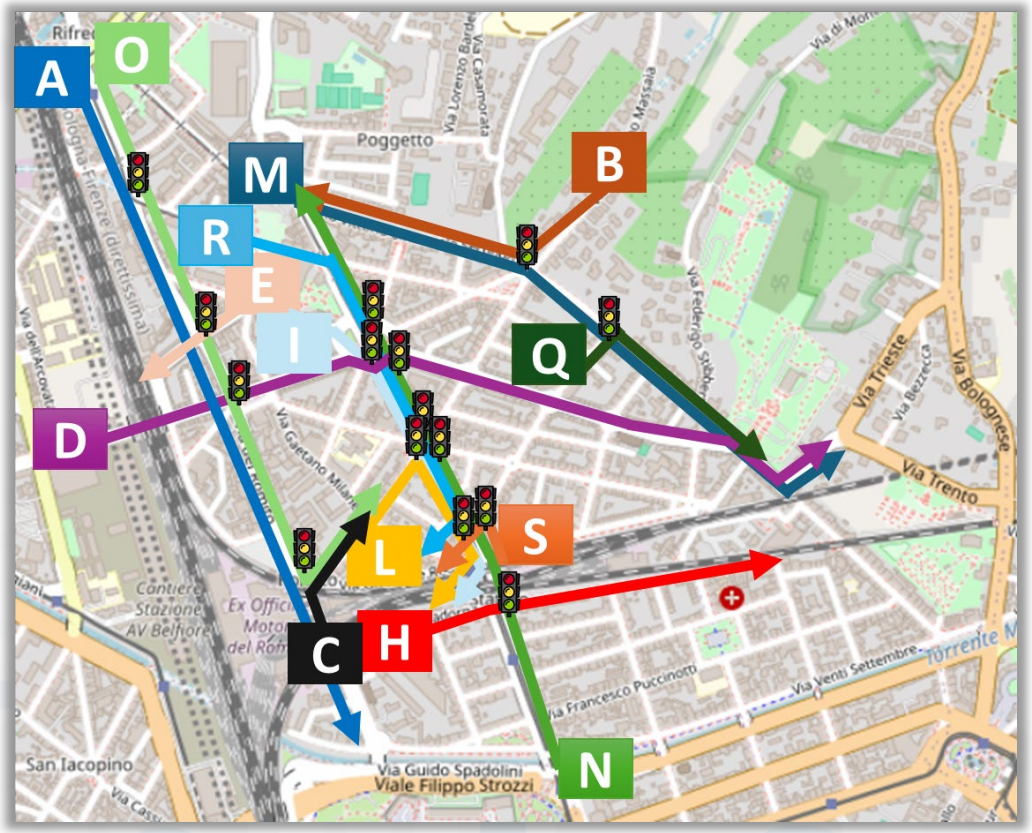


Optimization of Traffic Light Plan



Optimization Drivers

- ***MTT*, Mean Travel Time** on
  - Multiple Directions or globally
  - For specific service
- ***MWT*, Mean Waiting Time** on
  - specific direction or globally
  - For specific service
- ***MNS*, Mean Number of Stops** on
  - specific direction or globally
  - For specific service



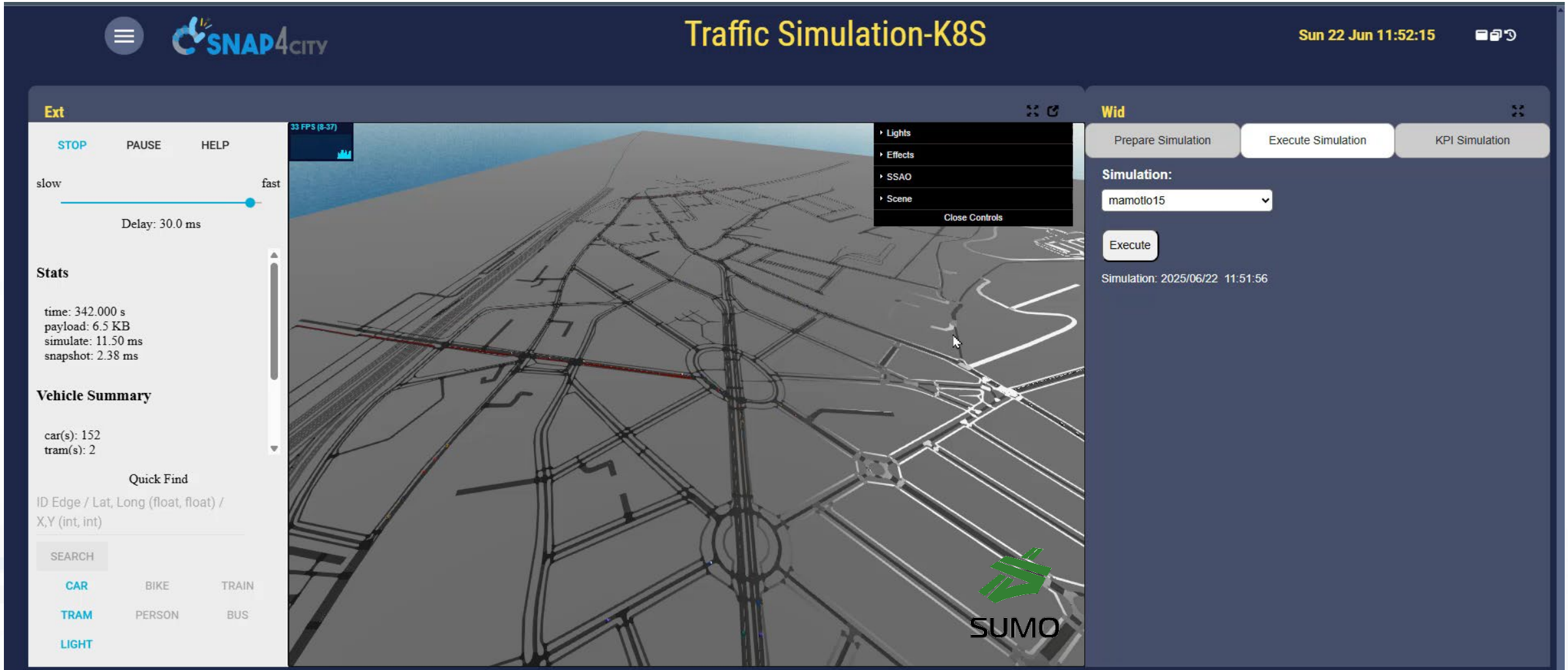
GA based: Mean Travel Time

	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

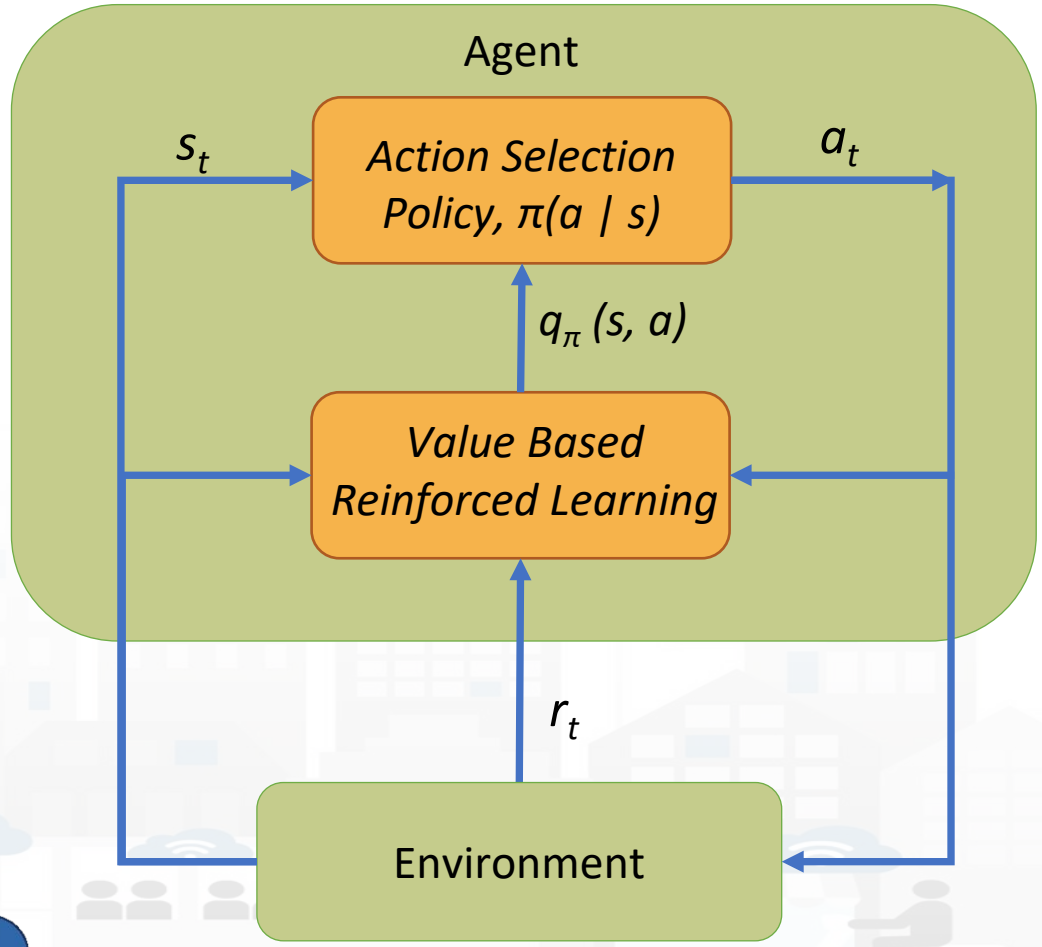
4TWD-NTNS-MWD-P-A: optimization by prioritizing traffic **directions,** the normalized number of **vehicles stops, *NTNS* , the mean waiting delay *MWD***, for all traffic lights, and post synchronization, with Penalty and Adjust dynamically performed

S. Bilotta, Z. Fereidooni, L.A. Ipsaro Palesi, P. Nesi, "Macroscopic GA-based Multi-Objective Traffic Light Optimization Prioritizing Tramways", Applied Soft Comp. Journal, Elsevier, 2025.



Multi Agent Reinforced Learning

- **Single Actuated**
  - Taking into account the status of each traffic source of each Juction
  - Compouting the best compromise of G/R ratio
  - Act on the next cycle
- **Multi Agent**
  - As Single Actuated
  - Taking into account syncronization, as condition and travel time of main specific travel means



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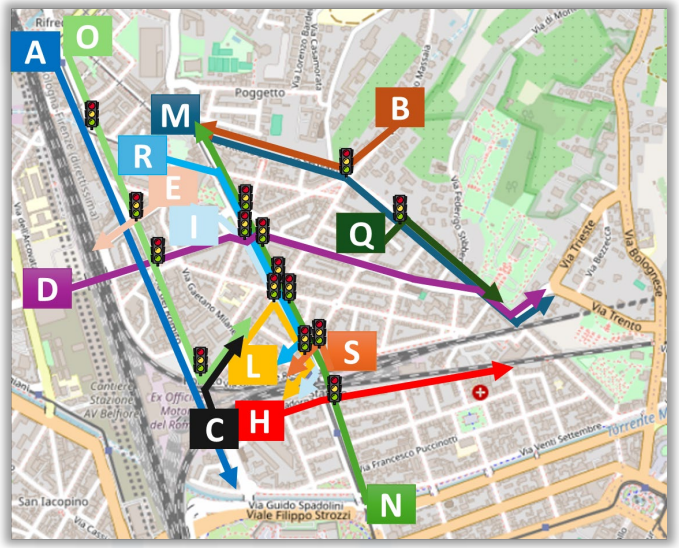
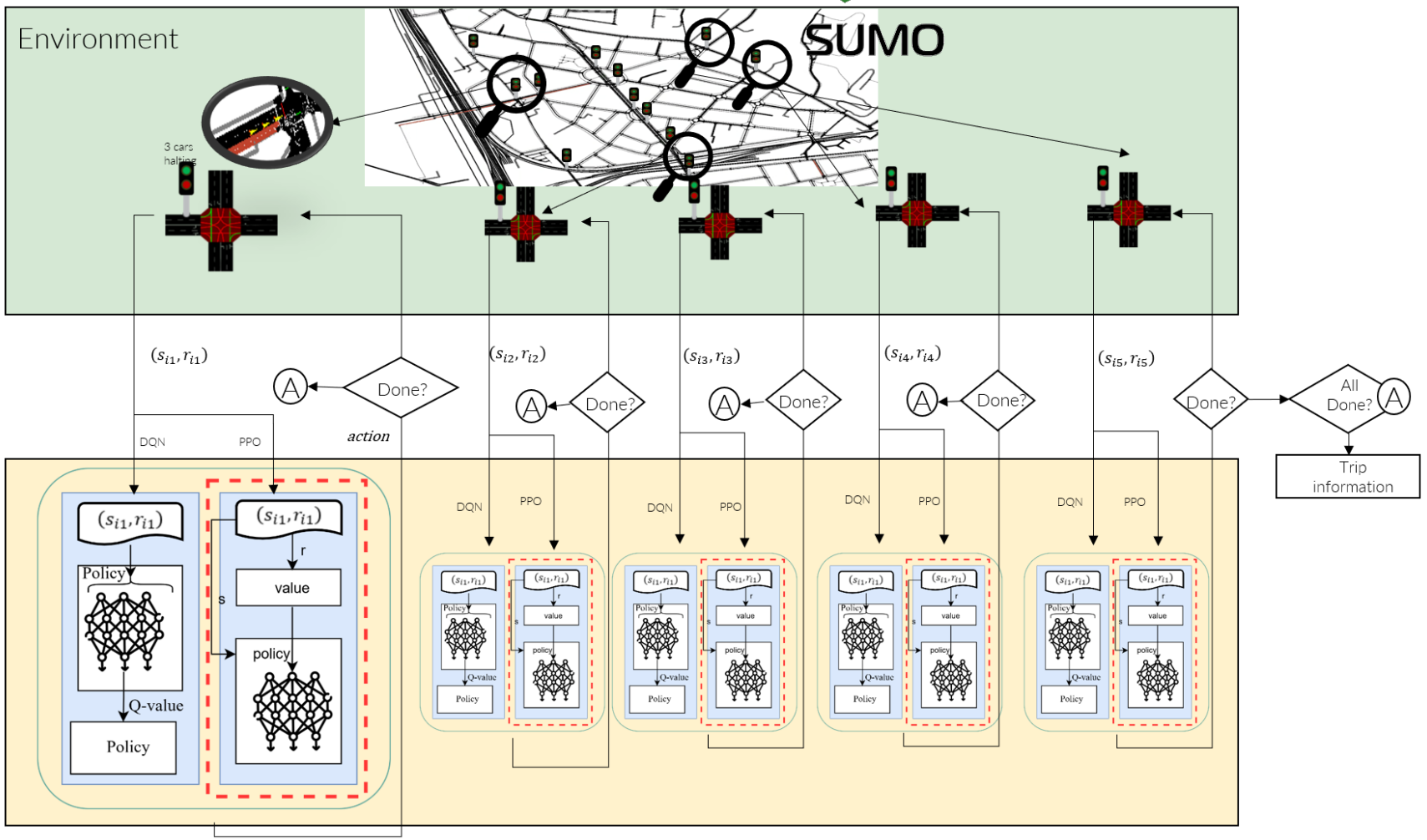
Multi Agent DRL





Z. Fereidooni, L.A. Ipsaro Plaesi, P. Nesi, Multi Agent Optimizing Traffic Light Signals Using Deep Reinforcement Learning, IEEE Access, 2025.

MTT for Multi Agent DRL for TLP

Model	TL	all	dir_N	dir_M	dir_A	dir_D	Careggi	Costanza
4TWD-NTNS-MWD-A	1	3013.85	176.93	233.75	194.46	237.65	436.00	427.00
4TWD-NTNS-MWD-P-A	1	3013.85	176.93	233.75	194.46	237.65	436.00	427.00
SUMO Actuated	1	2935.41	249.60	209.77	202.42	270.86	486.73	478.36
Webster	1	5188.87	211.66	242.32	205.46	562.31	984.00	427.00
Webster A	1	2968.90	183.50	242.67	201.27	251.76	482.27	427.00
SARL-FC DQN	1	2834.93	206.68	244.78	199.21	243.26	486.72	485.00
SARL-FC DQN A	1	2760.12	206.35	244.63	198.00	244.76	436.00	427.00
MADRL-FC DQN	1	3089.20	188.29	220.91	205.07	248.06	485.00	445.00
MADRL-FC DQN A	1	2983.69	189.11	220.70	187.00	248.79	436.00	427.00
MARL-FC PPO	1	2910.76	200.38	235.41	198.14	237.78	547.00	445.00
MARL-FC PPO A	1	2855.12	200.93	235.53	196.39	237.97	436.00	427.00
SMART A	1	2599.13	182.14	200	188.28	235.11	436.00	427.00

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INTELLIGENTE E SOSTENIBILE

Ottimizzazione Trasporto Collettivo

Prof. Paolo Nesi, UNIFI DISIT

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SNAP4CITY

In the large

- **Mobility Demand → ODM:**
  - Telecom Operator ODM, all movements on ACE Area
  - Reduction on local actual percentage and behaviour distributions
  - Matching on MGRS 200 mt, exploiting presence data of Telecom Operators
- **Transportation offer**
  - Road graph
  - GTFS/NeTex, transmodel
  - Bike sharing, carsharing, scooters, etc.

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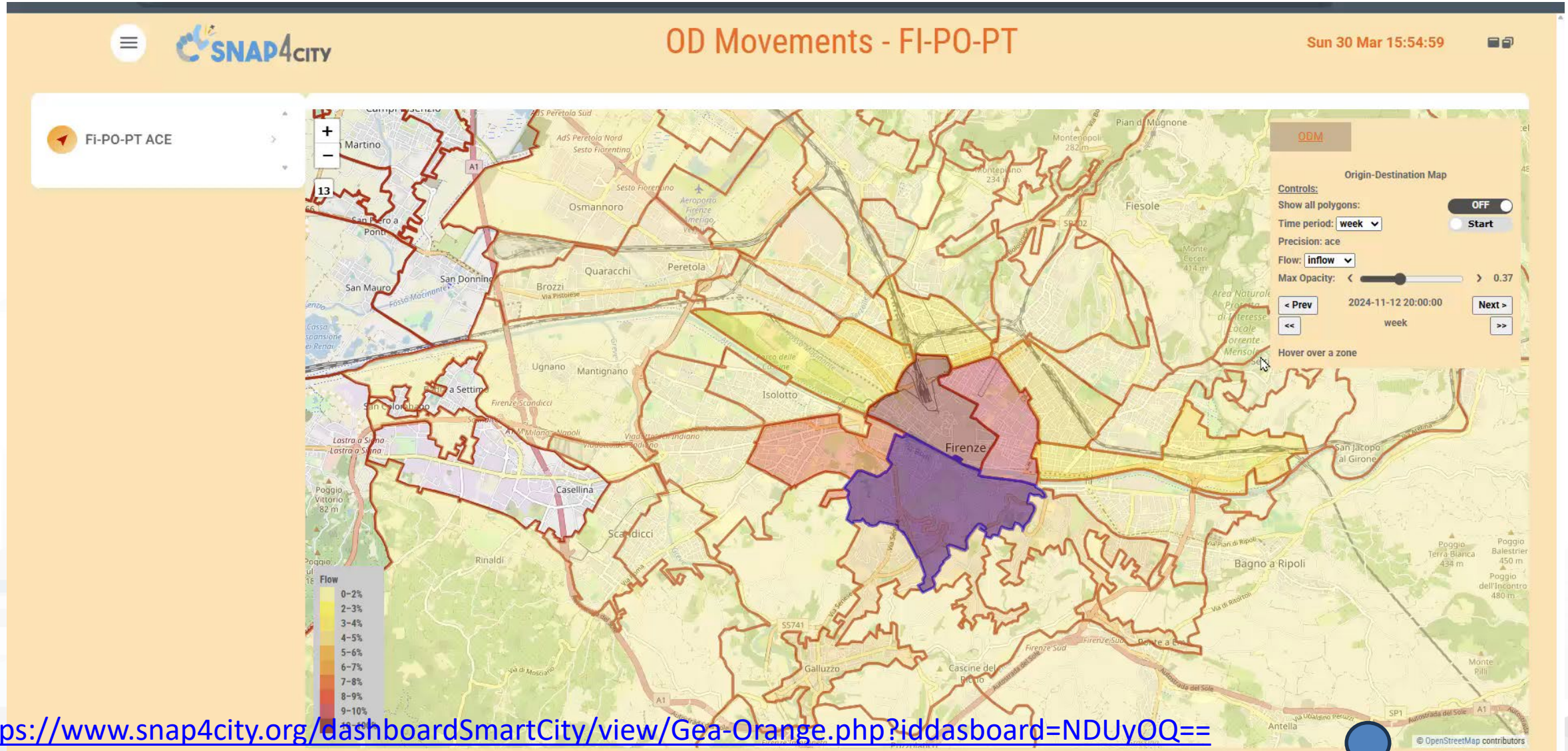
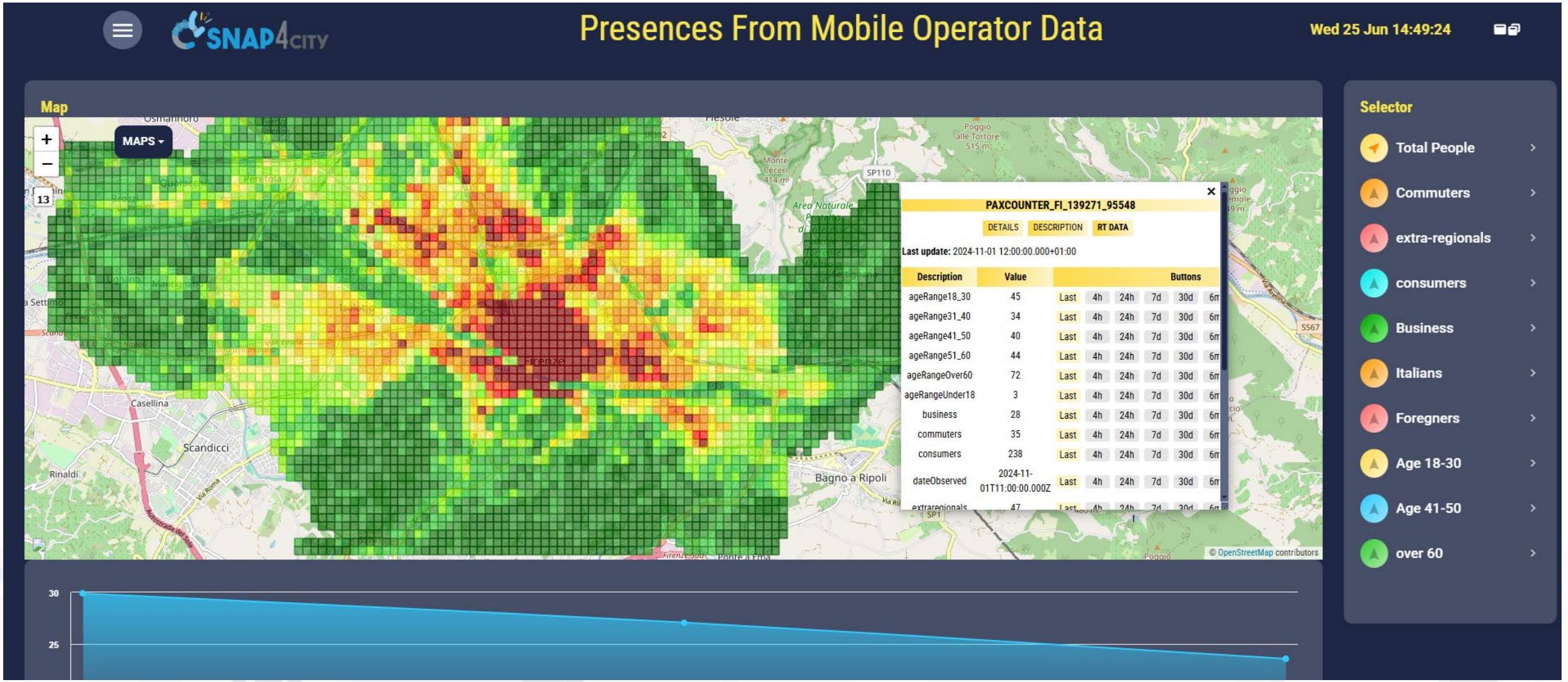
Origin Destination Matrices: Mobility Demand

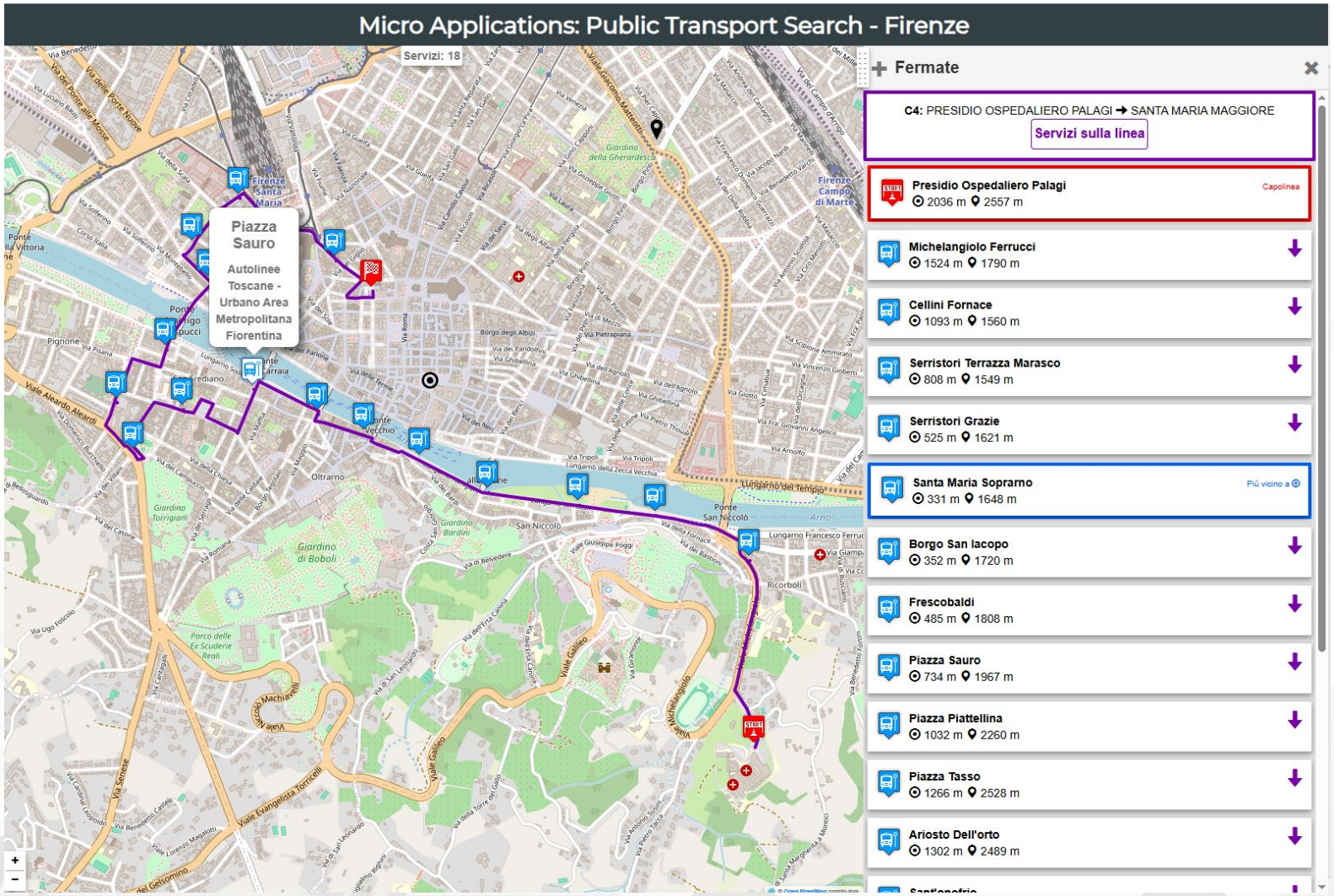


https://www.snap4city.org/dashboardSmartCity/view/Gea-Orange.php?iddasboard=NDUyOQ==

Presences from Mobile Operator



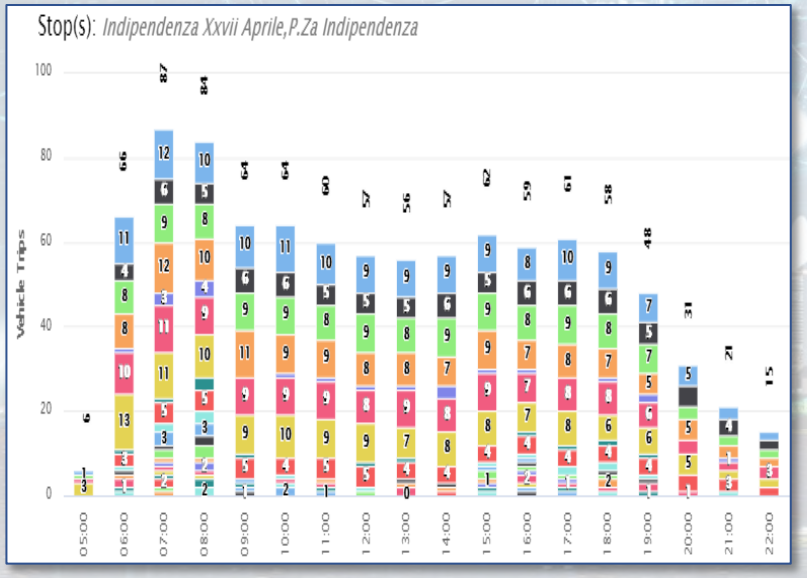
Offer of Transportation, GTFS, for example

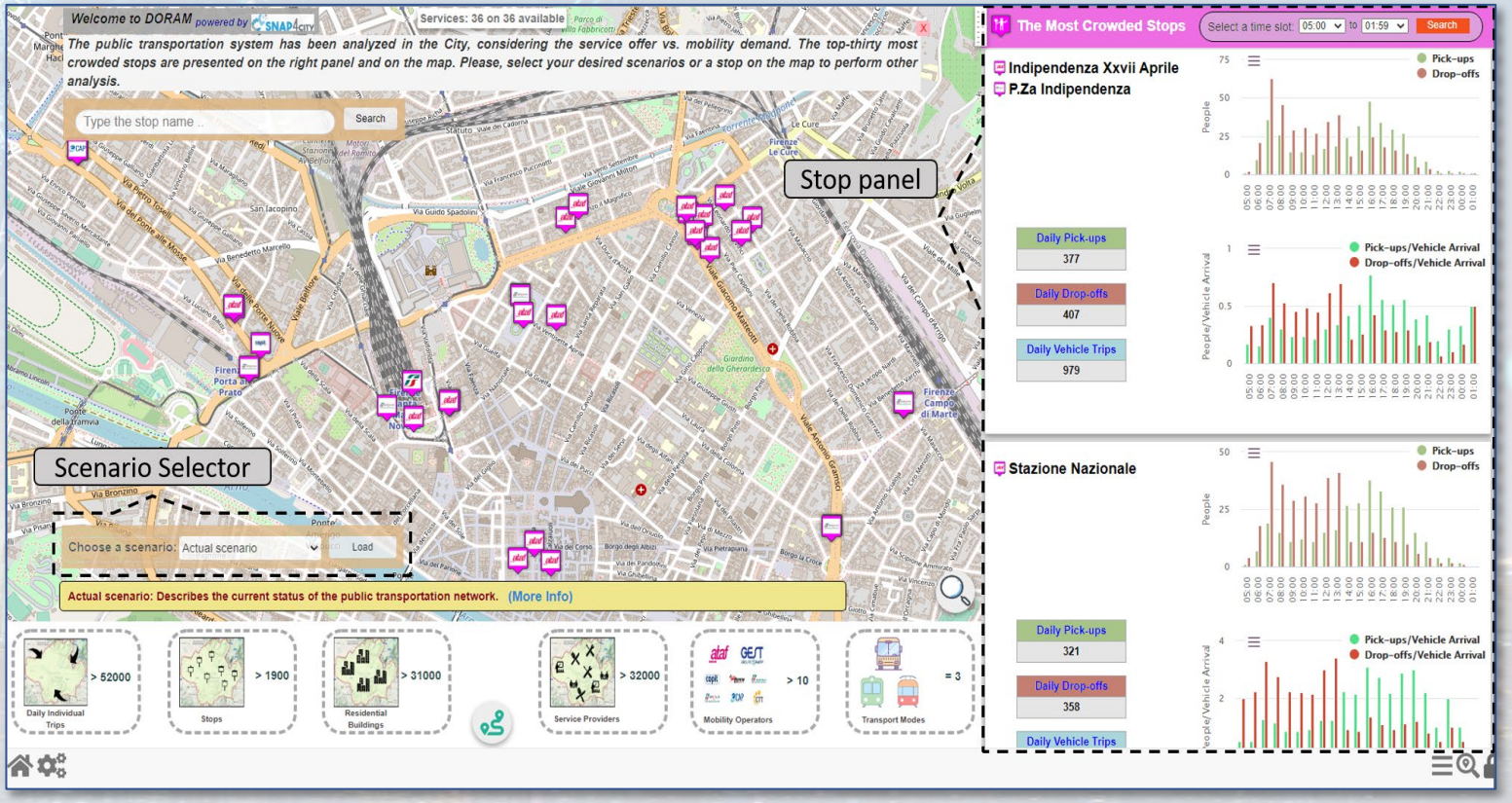


What-if Analysis on Collective Transport: DORAM

- Simulation / analysis of Mobility Demand wrt Transportation Offer
  - **GTFS/TranSmodel vs ODM**, taking into account road graph and services
- Definition of scenarios impact on
  - Traffic, Pollutant, parking, public transport, private flows, etc.
  - KPI analysis

Public Services





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DORAM

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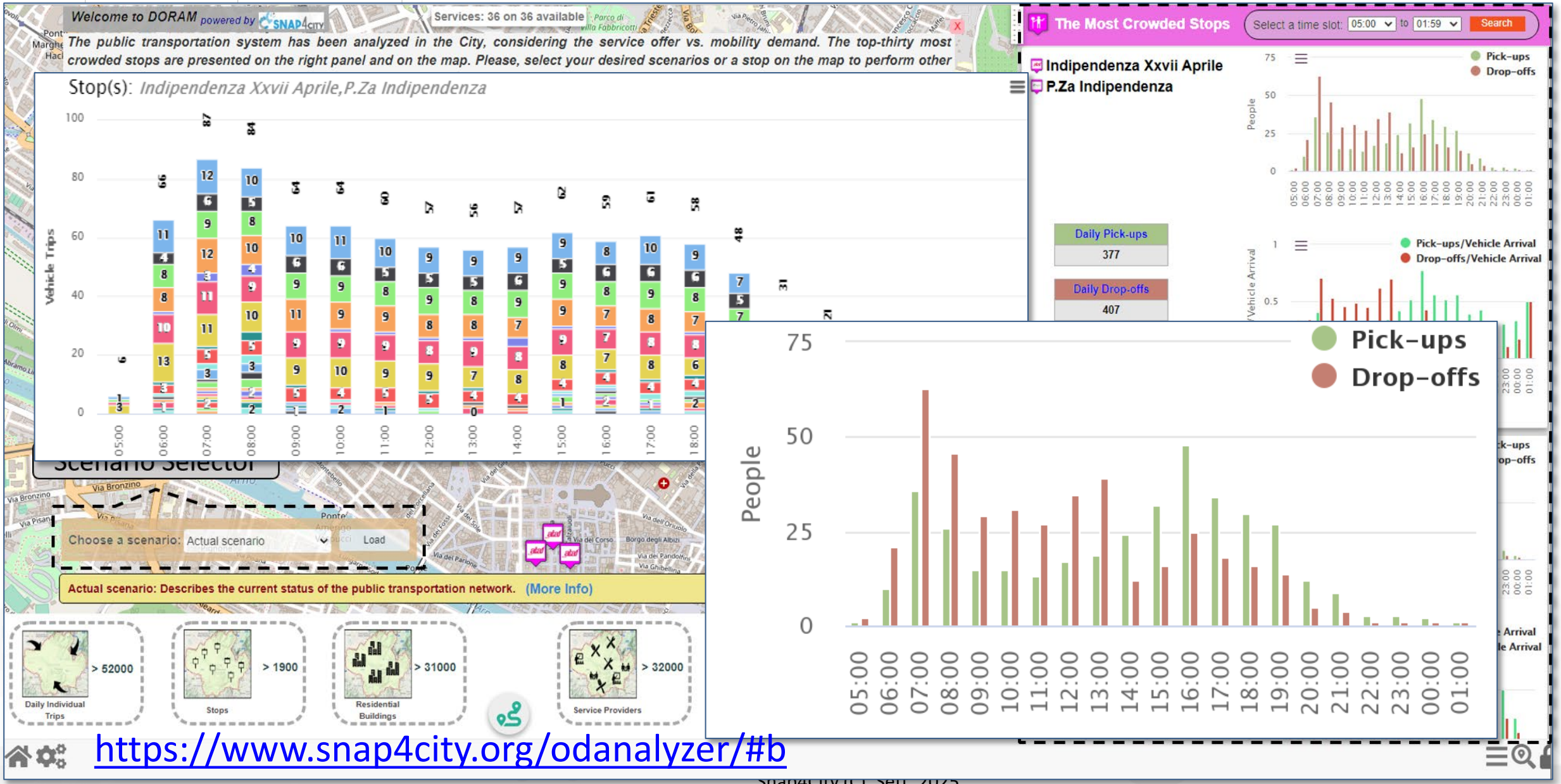
KM 4 CITY



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

Traffic Simulation-K8S

Sun 22 Jun 11:53:30

Ext

STOP PAUSE HELP

slow fast

Delay: 30.0 ms

Stats

time: 0.000 s
payload: 0.0 KB
simulate: 0.00 ms
snapshot: 0.00 ms

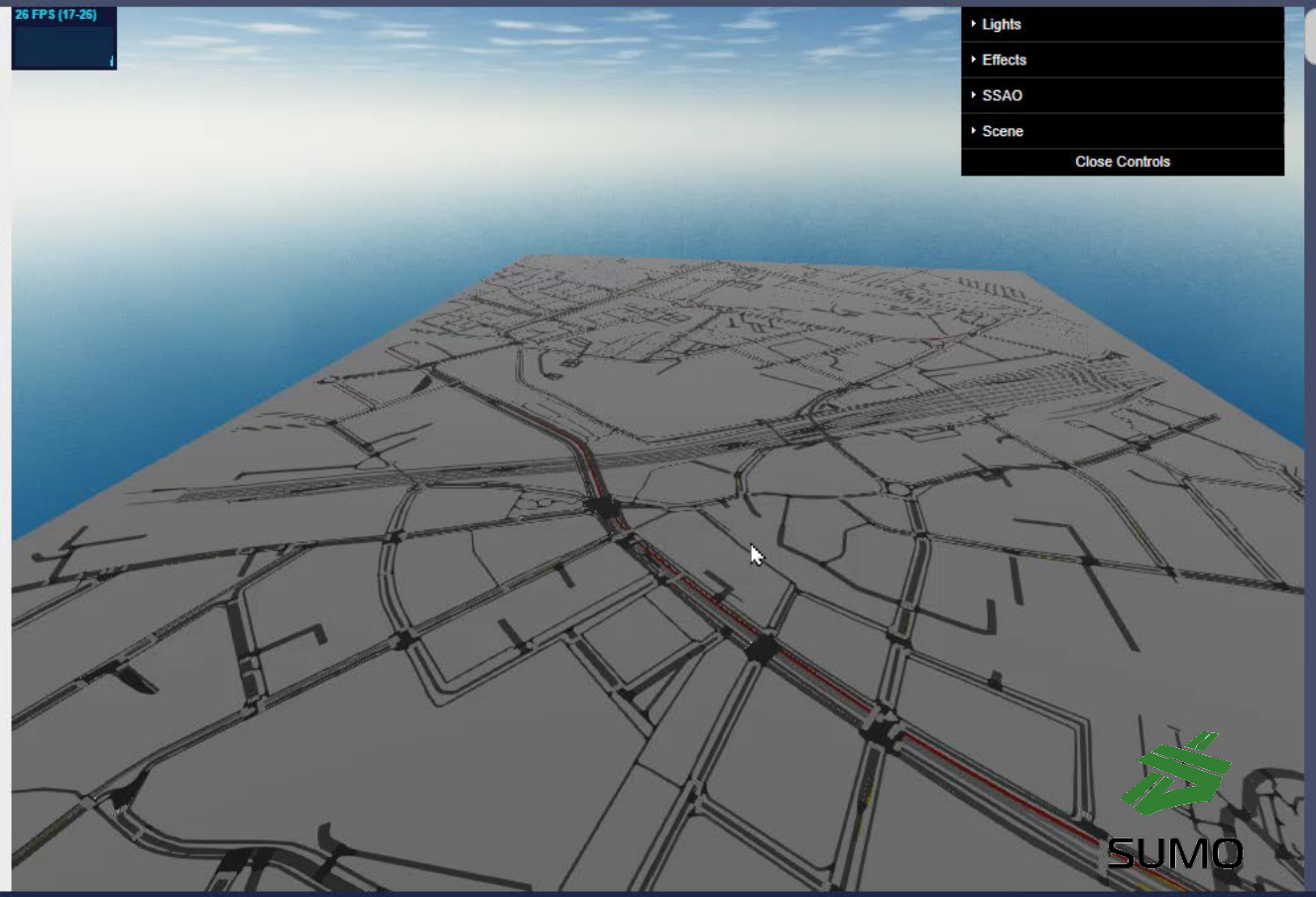
Vehicle Summary

Quick Find

ID Edge / Lat, Long (float, float) / X,Y (int, int)

SEARCH

CAR BIKE TRAIN TRAM PERSON BUS LIGHT



Wid

Prepare Simulation | Execute Simulation | KPI Simulation

Simulation:

firenzeodbus

Execute

Simulation: 2025/06/22 11:53:27

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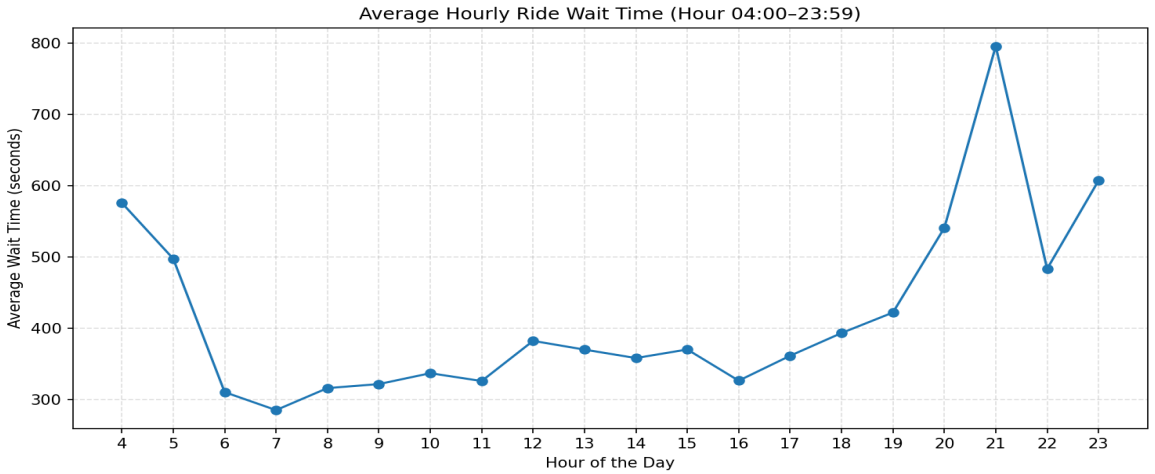
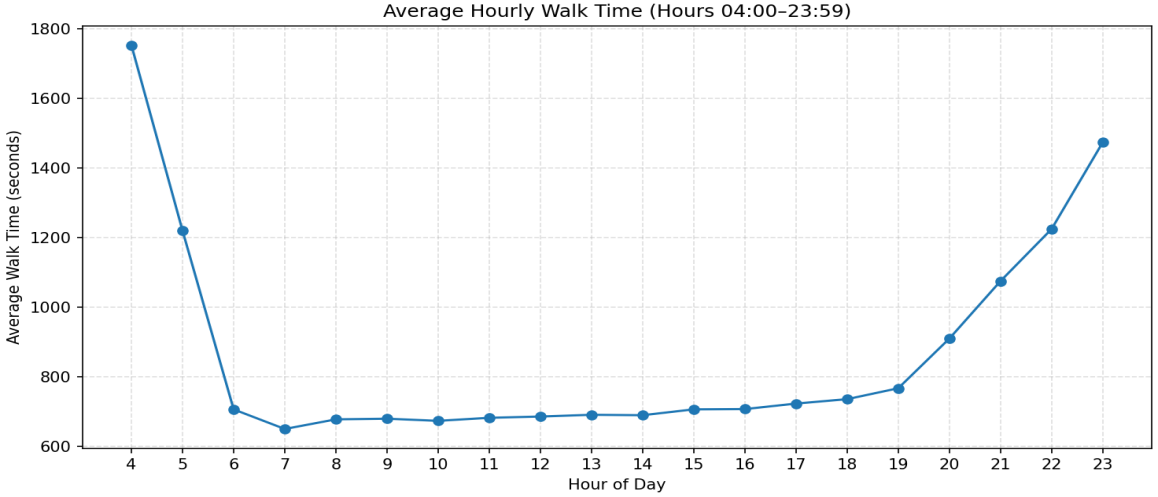
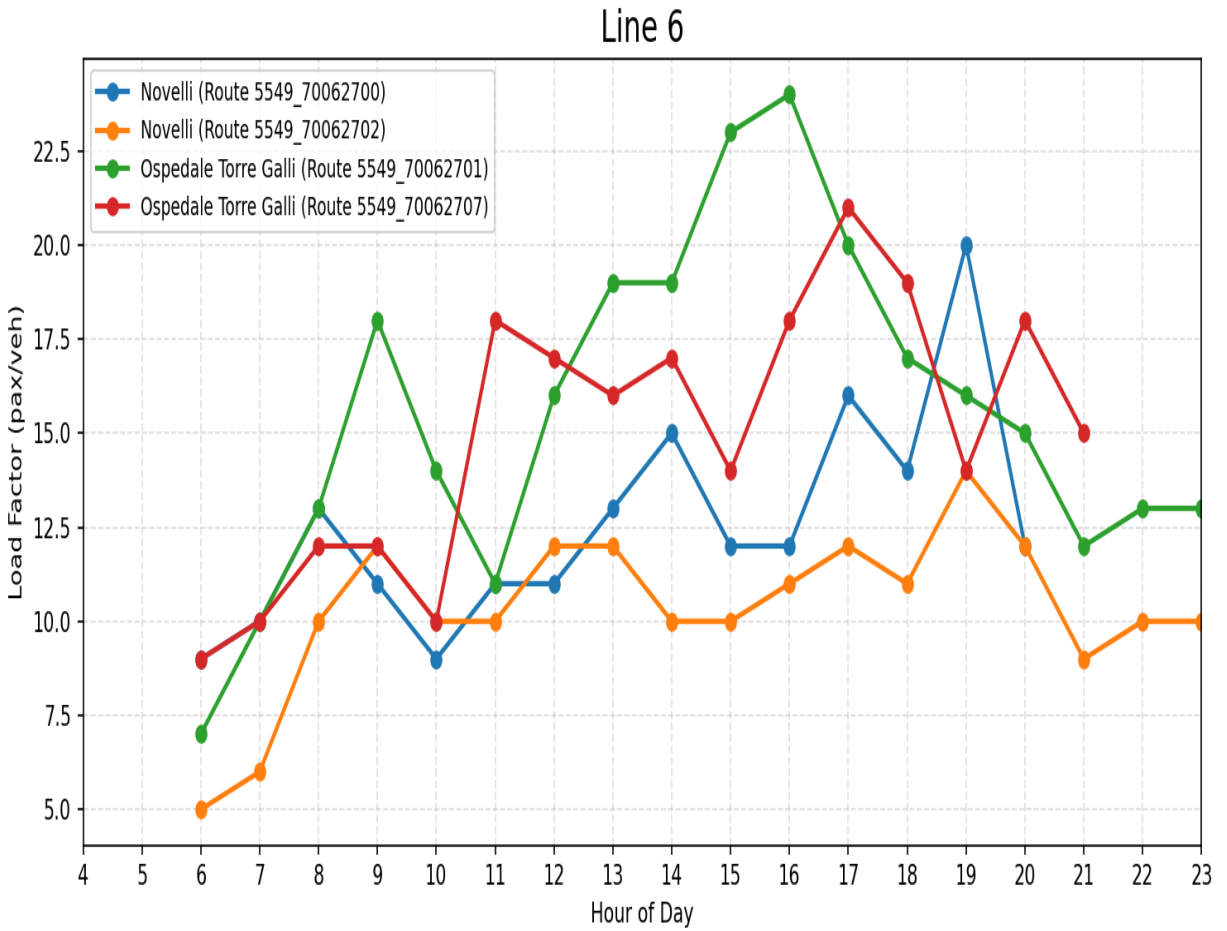
KPI on Match D-O of Collective Transport

- **On users**
  - **Unmet Demand**
    - Number of passengers who could not board their planned bus
  - **Average Walk Time**
    - The average time spent by passengers during walking before and after taking a ride from source to destination of their trip.
  - Etc.
- **On Service performance**
  - **Average Ride Wait Time**
    - The average amount of time spent by passengers at bus stops while waiting for their desired vehicle.
  - **Average Ride Duration**
    - The average time spent by passengers in a vehicle taking a ride from source to destination of their trip.
  - **Average Vehicle Occupancy**
    - The average number of people boarded in vehicles of different bus lines at different timestamps of a day.
  - **Critical Bus Lines**
    - Bus lines for which the load factor of a bus line exceeds the threshold value of 15 in the service hours.
  - **Critical Bus Stops**
    - Bus stops where the crowding ratio is highest at top 20 bus stops served by different bus lines.
  - **Average Vehicle Depart Delay**
    - Vehicles which depart later than their expected time from the bus stops.
  - **Etc.**

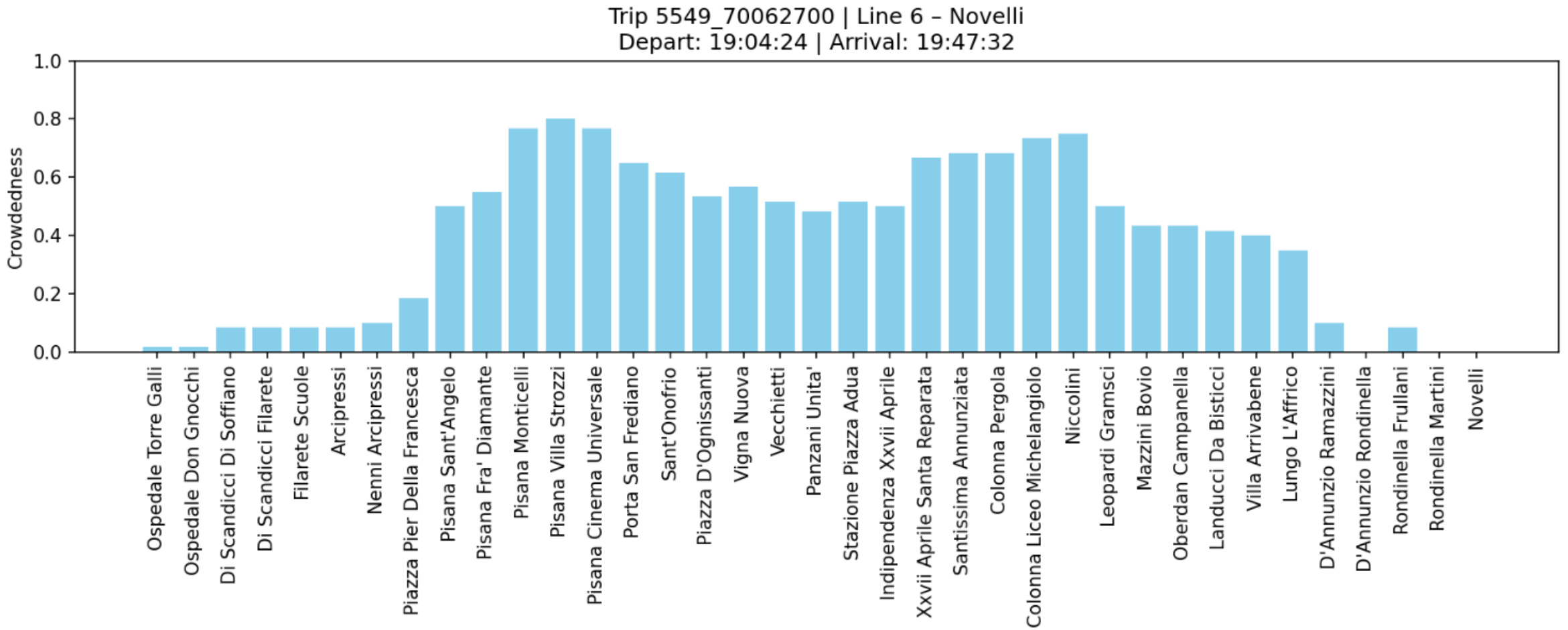
The typical working day







Crowdedness



Agenda

OPTIFaaS
IL FUTURO DELLA MOBILITA' INTELLIGENTE E SOSTENIBILE

Registrazione	10:00 - 10:30	Registrazione e Welcome Coffee
Avvio Lavori	10:30 - 10:40	Saluti - ***Prof. Paolo Nesi**, UNIFI DISIT Lab/Snap4City* - ***Franco Prampolini**,* Head of R&D and Innovative Industry Solutions Lutech Group
CN MOST SPOKE 8	10:40 - 11:00	Mobility-as-a-Service: tra integrazione e sostenibilità - ***Prof. Mario Marinelli**, Politecnico di Bari*
Overview OPTIFaaS	11:00 - 11:20	Presentazione generale e obiettivi di **OPTIFaaS** - ***Mauro Starinieri**,* Head of Smart City & Mobility Solutions CoE Lutech Group
Strumenti OPTIFaaS	11:20 - 11:50	Presentazione dell'infrastruttura - ***Prof. Paolo Nesi**, UNIFI DISIT Lab/Snap4City*
Scenario OPTIFaaS	11:50 - 12:10	Ottimizzazione del Traffico - ***Ing. Alessio Tesone**, Università degli Studi di Napoli*
Scenario OPTIFaaS	12:10 - 12:40	Ottimizzazione Semaforica e di Infrastruttura. Ottimizzazione del Trasporto Collettivo - ***Prof. Paolo Nesi**, UNIFI DISIT Lab/Snap4City*
Q&A	12:40 - 13:00	Sessione aperta
Light Lunch (offered)	13:00 - 14:00	
Incontri 1:1	14:00 -	Incontri 1:1 con i referenti di Snap4City/**OPTIFaaS** (in presenza)

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Digital Twin & Intelligenza Artificiale.
Innovazione tecnologica "As a Service "
per la gestione operativa
e la pianificazione tattico-strategica
della mobilità urbana sostenibile e interconnessa

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