



AU, UNIGE, STAM

Brussels, 28 September 2026

Digital Twins for Metro Planning and Operations



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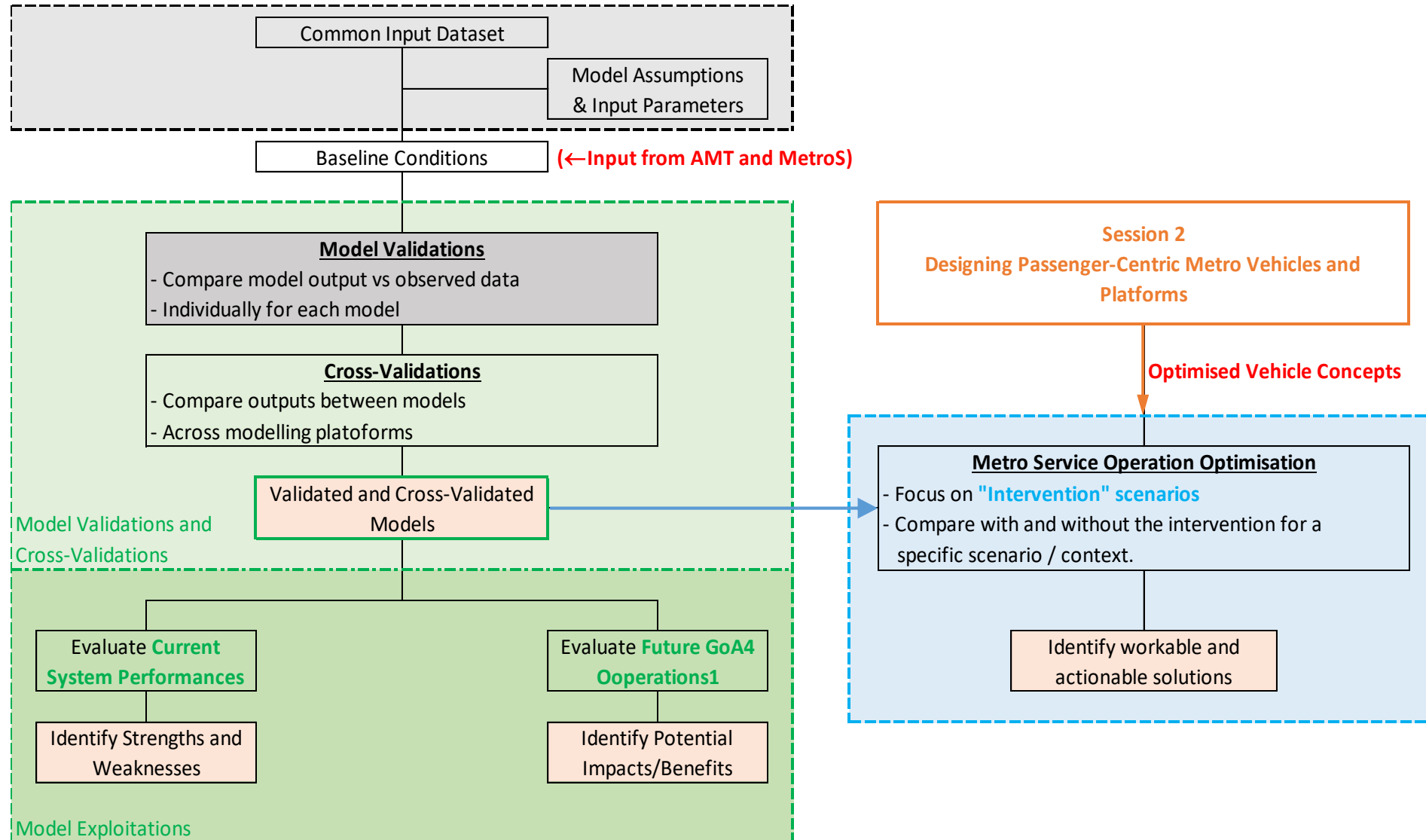


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Agenda

- Overview
- NEXUS Metro Simulation Tool
- Metro Service Operation Optimisations

Overview



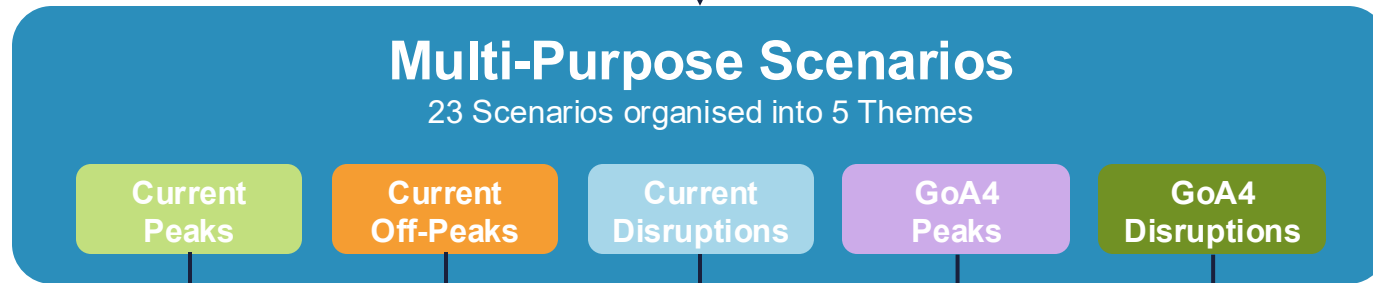
NEXUS Metro Simulation Tool: Overview

- **Primary Contributors:** AU, UNIGE, STAM
- Supported by: ATM, MetroS, VTU, TUW, SIME
- **Objectives** of the Tool:
 - Assess Current (as-is) Metro **System Performances**
 - Evaluate Potential **Impacts of Future GoA4 (to-be)** Operations
- **Completed** in March 2026 and **Approved** in July 2026

Notes: Technical details of GoA4 operations please refer to Session 1



Validated and Cross-Validated Metro Simulation Models



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Metro in Genoa, Italy



Metro in Sofia, Bulgaria



Network Models Validations:



Exact Match

Total Number of Trains



$\pm$ 4 secs

Train Journey Times



within 1%

Inbound Passenger Flows



within 3%

Outbound Passenger Flows

Station Models Validations:



within 1%

Inbound Pax Flows (tickets)



within 1%

Outbound Pax Flows



within 1%

Transfer Pax Flows

Macroscopic – Network Operational Performance

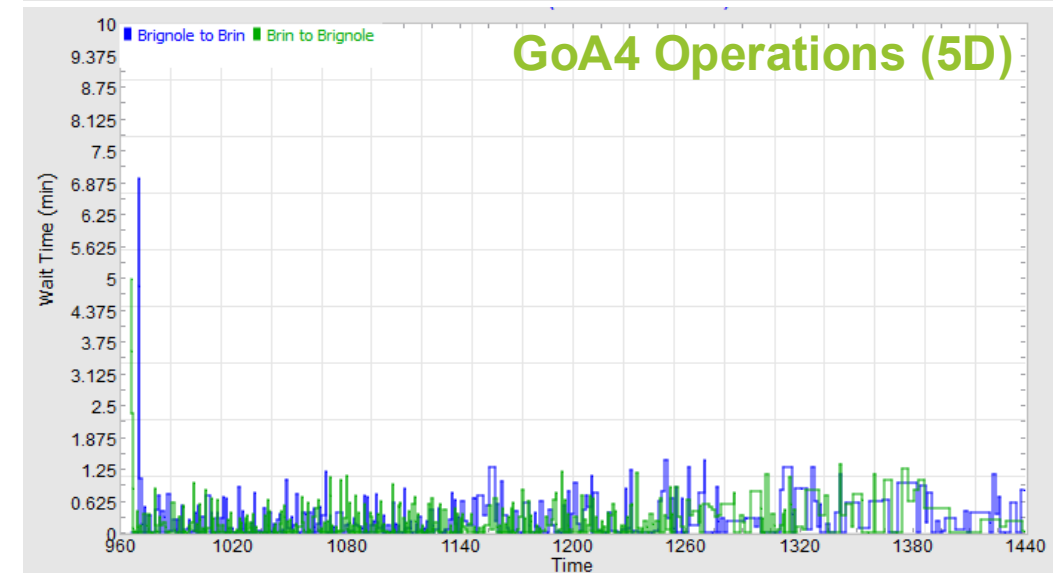
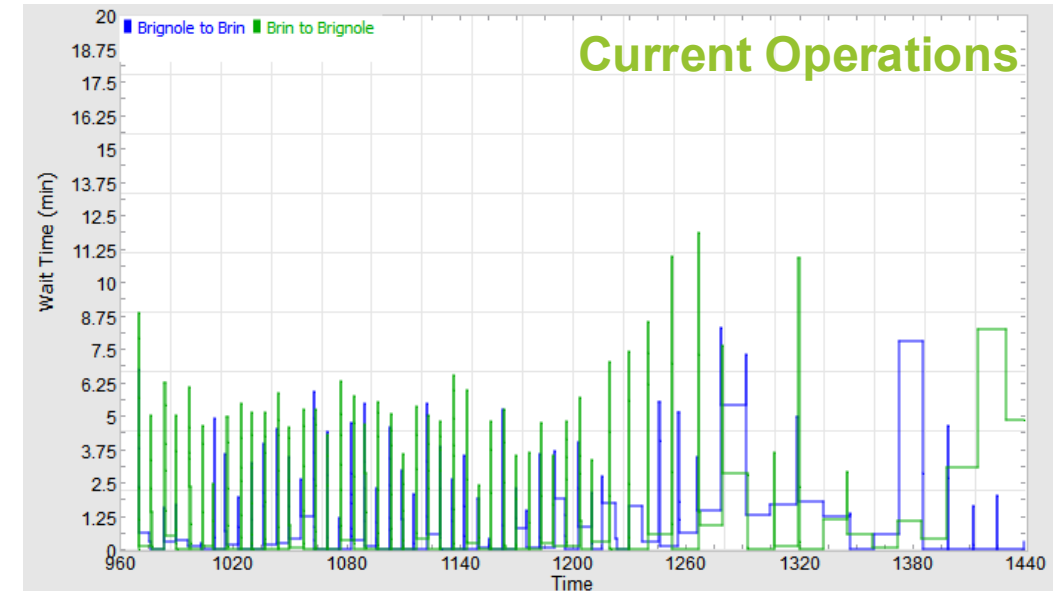
- **AM peak** most stressed, approaches **comfort-critical** levels.
- **Reliable schedule** – waiting time stable all daytime
- During disruptions, AMT showed solid **structural resilience**
- **GoA4 Impacts:**
 - Greatly **reduce pax waiting time** (up to 50%) and train saturation
 - Significantly **reduce peak-hour concentration** due to shortened headway
 - Effects are most visible under disruption
- In a multi-line network, ***GoA4 is most effective as a disruption-mitigation tool.***

Meso: Station Performance (Network)

- Significantly affected by **frequency**
- Minor impacts for AMT disruption scenarios
- GoA4 operations performed significantly better versus current operations

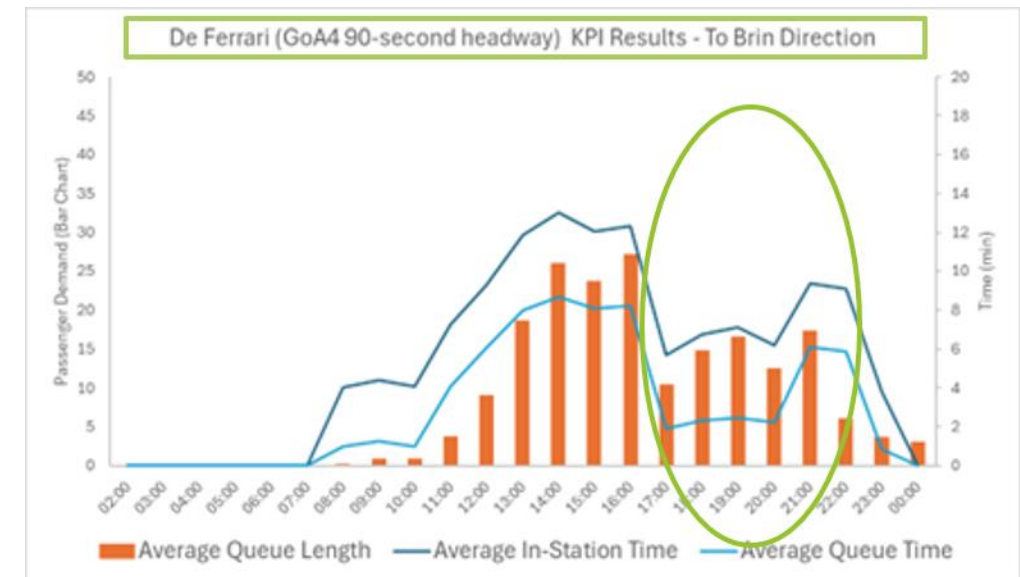
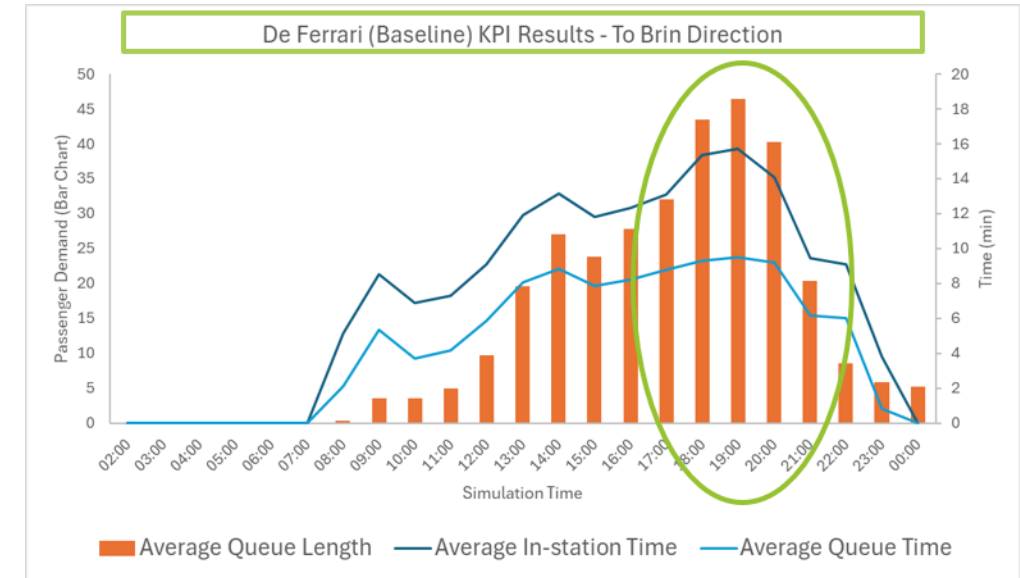
Meso: Line Performance (Network)

- Train headway determinations:
 - **trade-off between reducing wait-time and improving train capacity utilisation.**
- Minor impacts during disruption scenarios
- GoA4 could substantially increase average number of train services



Microscopic: Crowd Management

- Performing satisfactorily;
- **PM Peak the most critical.**
- **De Ferrari station**, pax are served within
 - **15 mins** at peak; and
 - **5 to 10 mins** outside the peak.
- **Serdica station**, pax are served **<12 mins**.
- **GoA4 Impacts:**
 - Effectively *reduces queue time and queue lengths*.
 - Actual benefits vary (20% to 80%+ reduction), on a case-by-case basis.

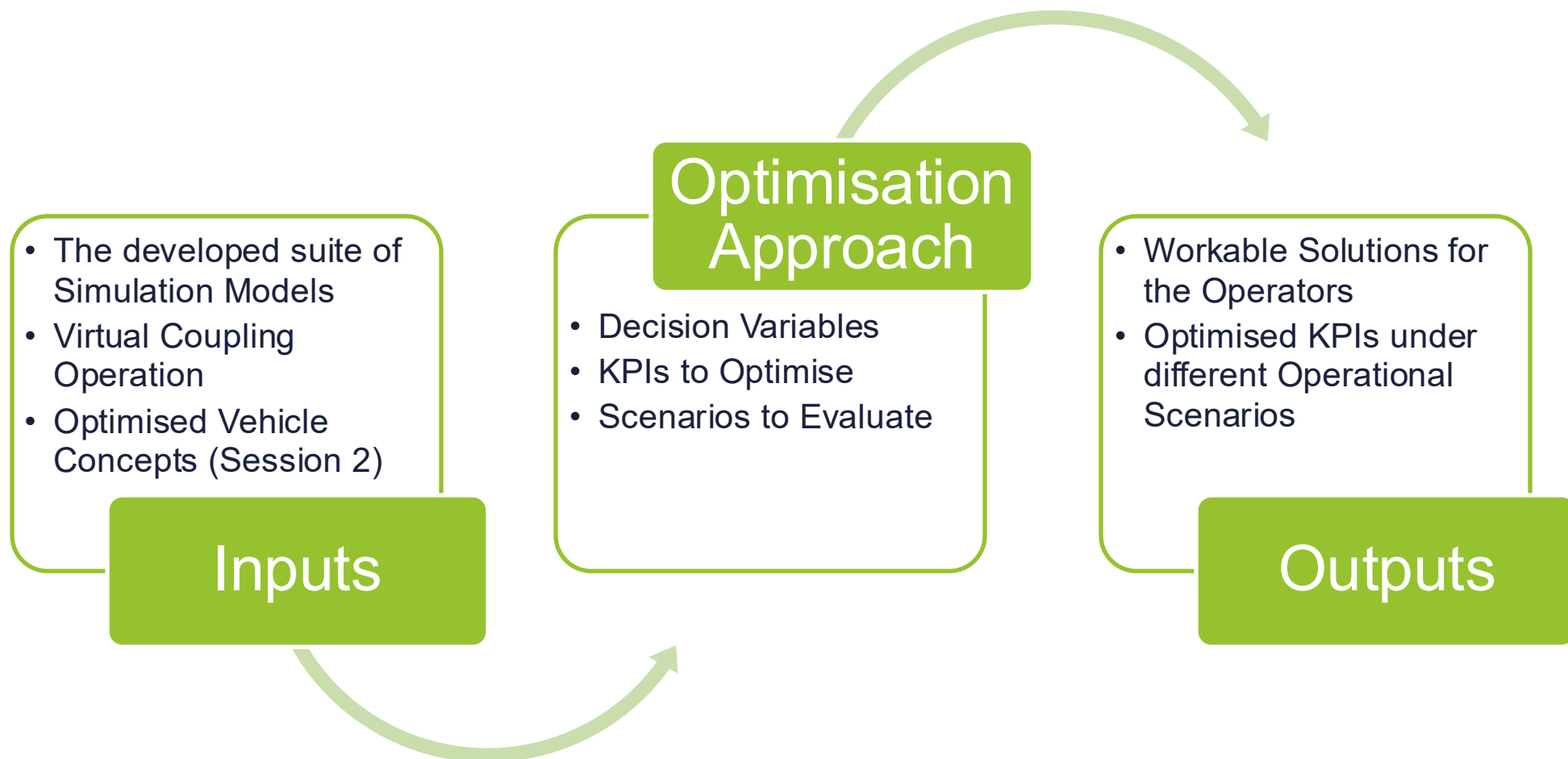


Metro Service Operation Optimisations: Overview

- **Primary Contributors:** AU, UNIGE, STAM
- Supported by: ATM, MetroS, VTU, TUW, SIME
- **Objectives** of the Optimisations:
 - Optimisation of dwell time and headway for (as-is), (what-if) and (to-be) scenarios
 - Evaluate Potential **Impacts of Future GoA4 (to-be)** Operations using Virtual Coupling
- **Completed** in August 2026 and **Ready** for **External Review**

Notes: Technical details of GoA4 operations please refer to Session 1

Overview



Validated and Cross-Validated Metro Simulation Models

Simulation-Based Optimisation

Stochastic Search

 Parameter Sweeping/MILP

 2-Stage MILP Optimisation


Optimisation Approaches

Multi-Purpose Scenarios

Current

Future

GoA4

Objectives
 Dwell Time & Headways
 Resource Optimisation
 (Virtual Coupling)

Operators' Input

Impacts over KPIs

Minimisation

Wait Time, Queue Lengths, Travel Times

Maximisation

System Capacity, Train Occupancy

Optimisation

Timetables, Number of Carriages

Optimised Parameter Settings

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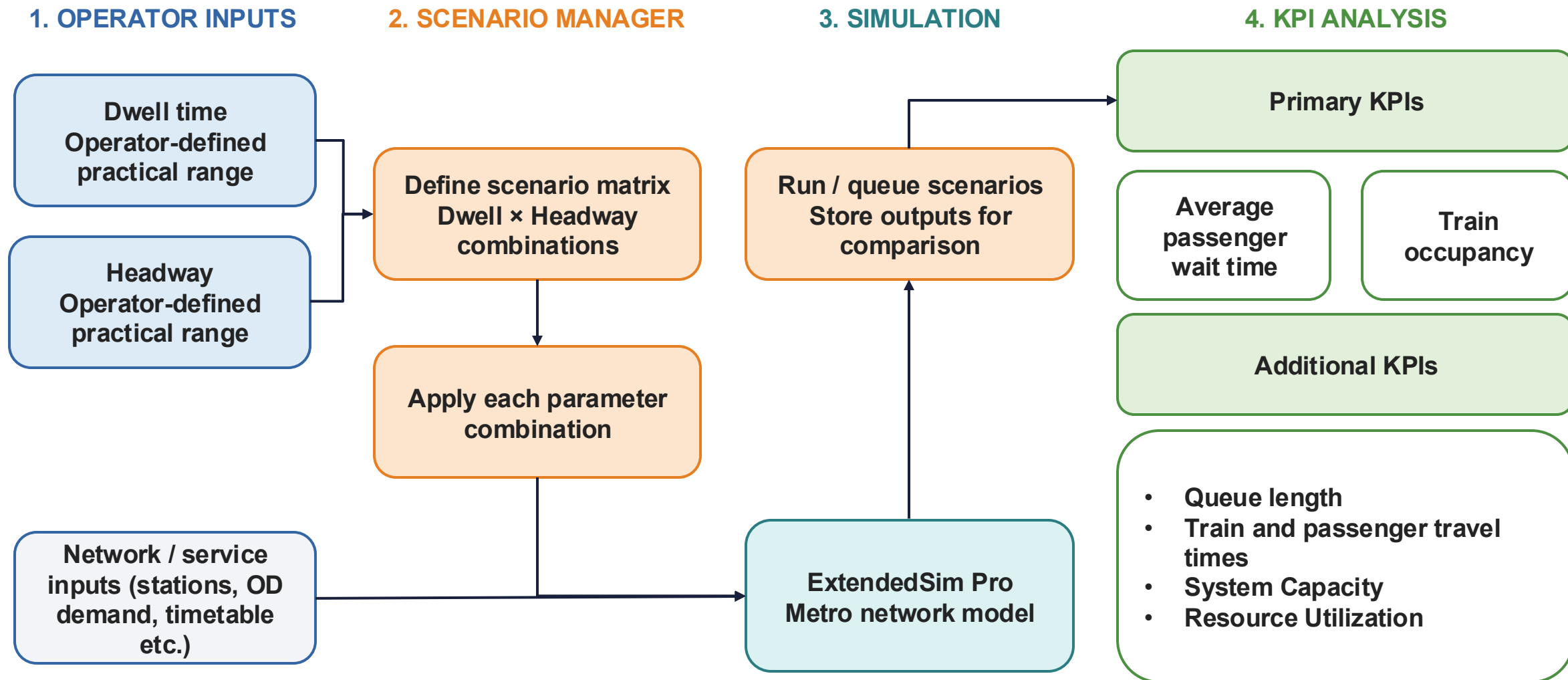
AMT
 MOBILITÀ E INNOVAZIONE

Metro in
 Genoa, Italy

M

Metro in Sofia,
 Bulgaria





- Limited influence over dwell time ranging between 15 to 26 seconds (Genoa) and 10 to 31 seconds (Sofia)
- Headway is highly sensitive to operational conditions with shorter headways during peak periods (around 6 min for Genoa and 6 to 8 min for Sofia) and longer headways during off-peak periods (around 6 to 14 min for Genoa and 9 to 13 min for Sofia)
- Increase OD shows the similar trend of baseline conditions, Optimised vehicle layouts results in much shorter headways (3 to 4 minutes)
- The balance between dwell time and headway depends on the operational priorities and interests of metro operators and stakeholders.



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 **extendSim.**



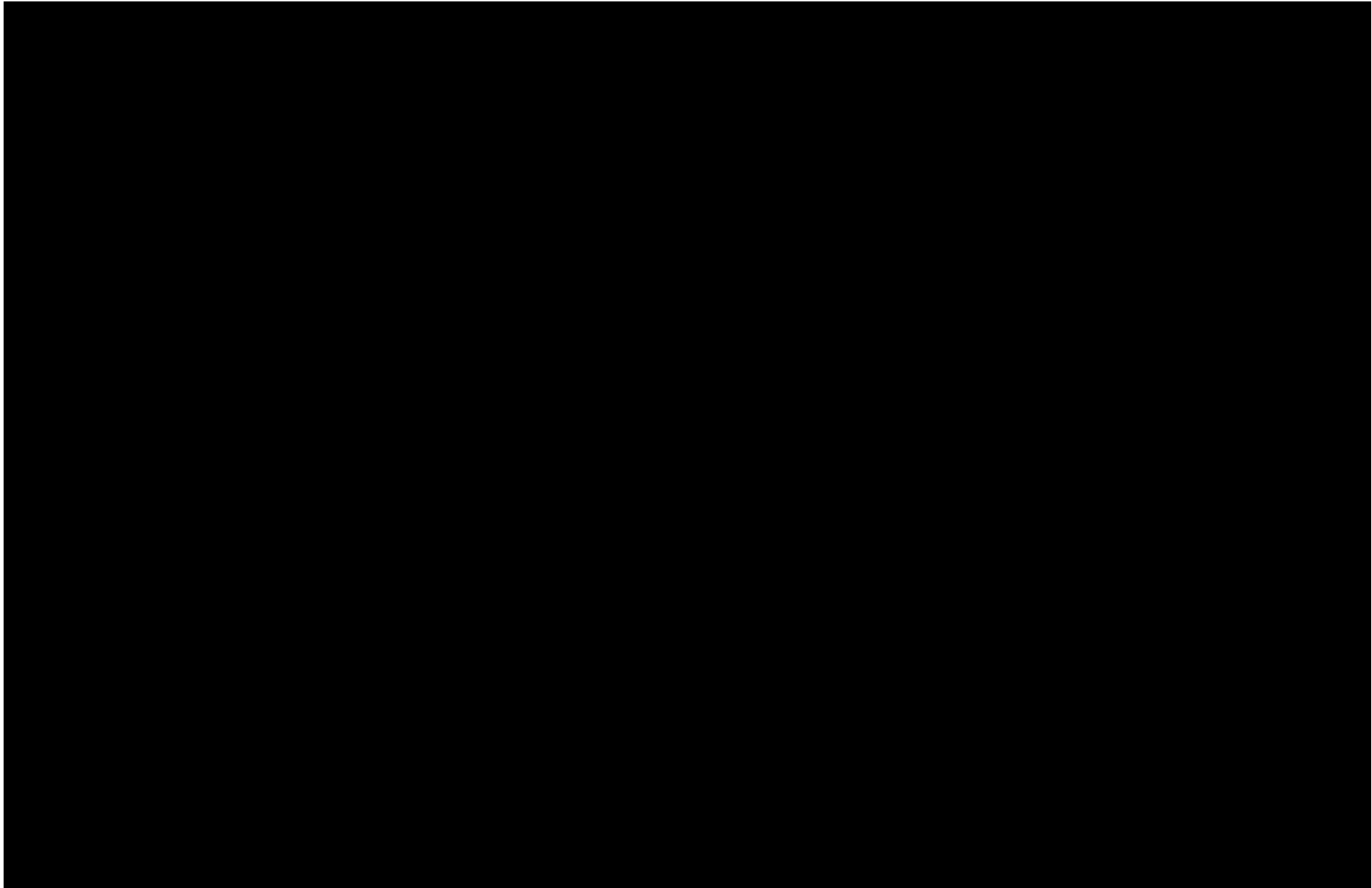


MOBIUS

Mobius is a network planning platform that turns raw operations data into optimised, ready-to-run service plans.

- ✓ In-house solution (Python core + React web app)
- ✓ Deployed as a service: no software to install or maintain
- ✓ Bring your own data: Excel, db, GTFS, API
- ✓ No coding required: your team runs the analysis
- ✓ Individual passenger-level simulation, network optimisation;
- ✓ Exportable KPIs, ready for reporting and decision-making
- ✓ Hosted and maintained by STAM

One engine, any network.

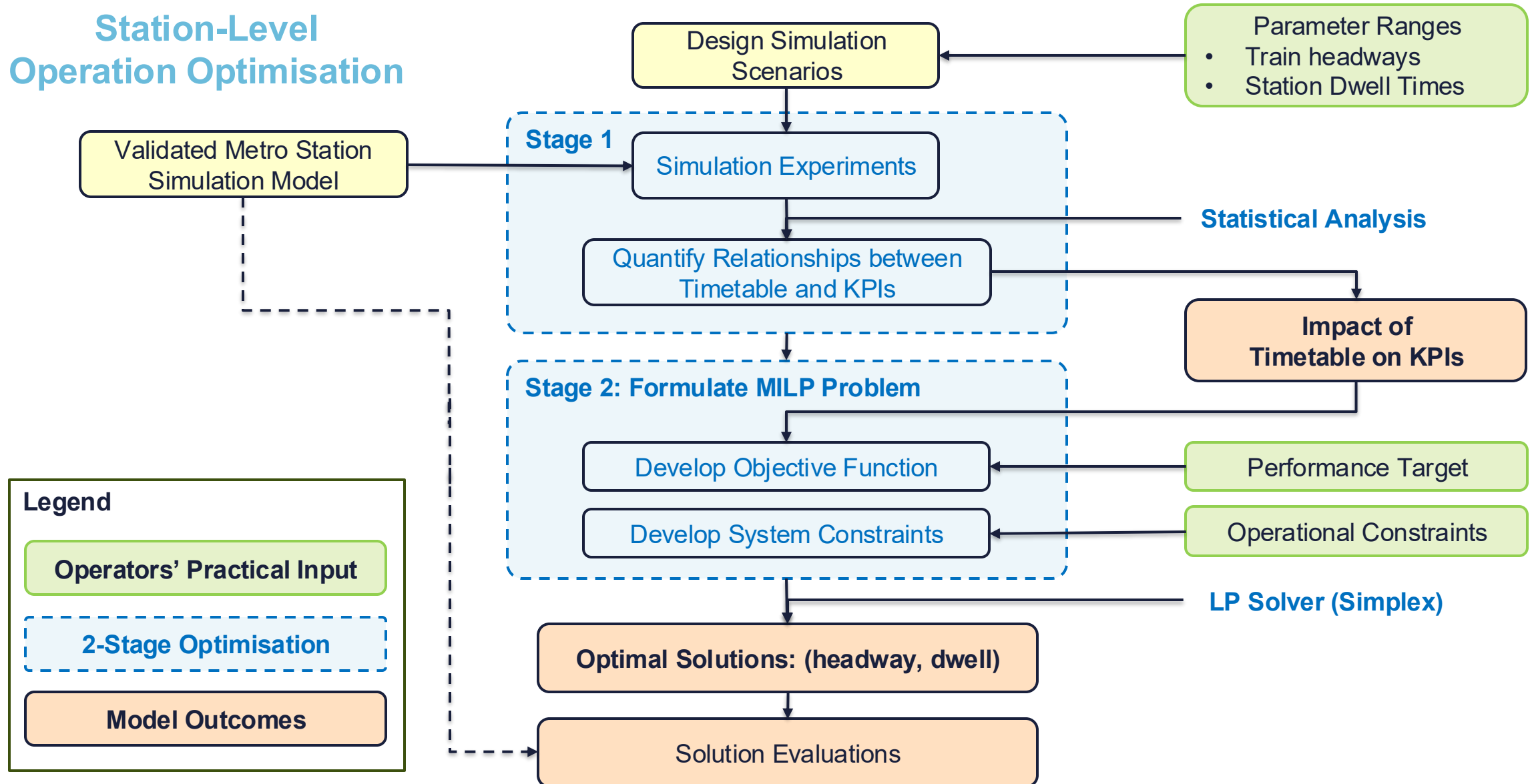


Mobius evaluates cost-vs-service trade-off in every scenario. In most cases it buys efficiency (fewer trains, lower energy) at a modest service cost, but where demand truly outpaces capacity (Sofia, future demand with optimised vehicle), the same trade-off resolves the other way, spending more to protect service instead.

Use case: AMT - Genoa				
Scenario	Trains	Energy	Wait time	Queue
Current	-12.00%	-11.80%	14.50%	23.00%
Match-Day (disrupted)	-7.90%	-7.70%	10.90%	17.30%
Future (+25% demand)	-2.40%	-2.20%	1.70%	1.30%
Future + Optimised Vehicle	-22.30%	-22.20%	31.90%	13.50%

Use case: MetroS - Sofia				
Scenario	Trains	Energy	Wait time	Queue
Current	-19.90%	-18.90%	19.70%	10.30%
Disrupted (Serdica closure)	-19.40%	-18.50%	20.60%	14.50%
Future (+25% demand)	-11.10%	-10.00%	5.70%	-3.10%
Future + Optimised Vehicle	6.20%	8.20%	-42.90%	-59.00%

Station-Level Operation Optimisation



$$\text{Wait Time} = 3.261 + 0.175 * \text{Headway} - 0.015 * \text{Dwell}$$

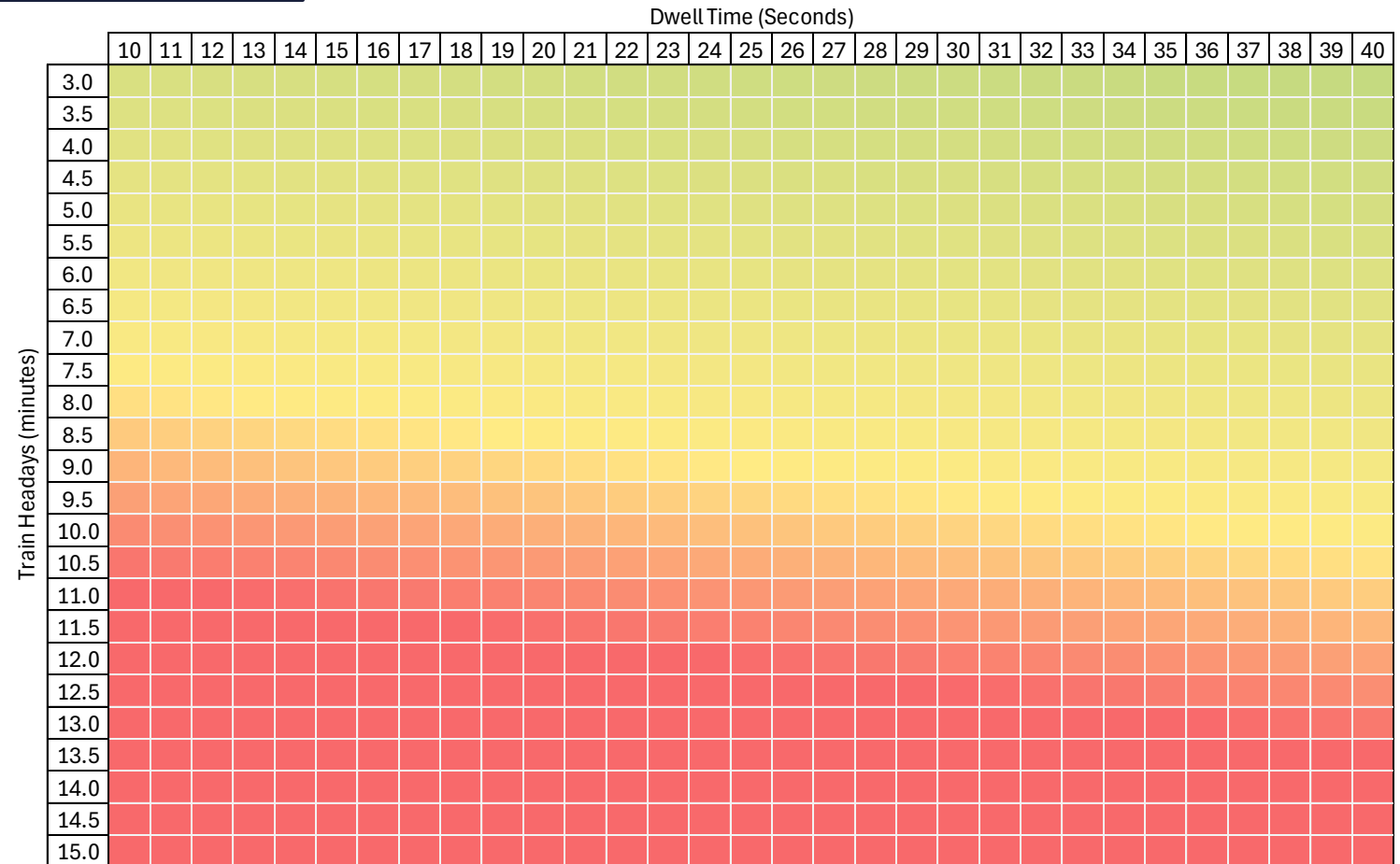
Stage 1 Example Results

Regression Map:

MetroS: Serdica Line 1

Reveal Impact of (headway, dwell)
on Passenger Waiting Time

Interpretation: For example,
If headway shortens by 1 min
⇒ wait time reduces by 0.175 min
(roughly about 10 sec)



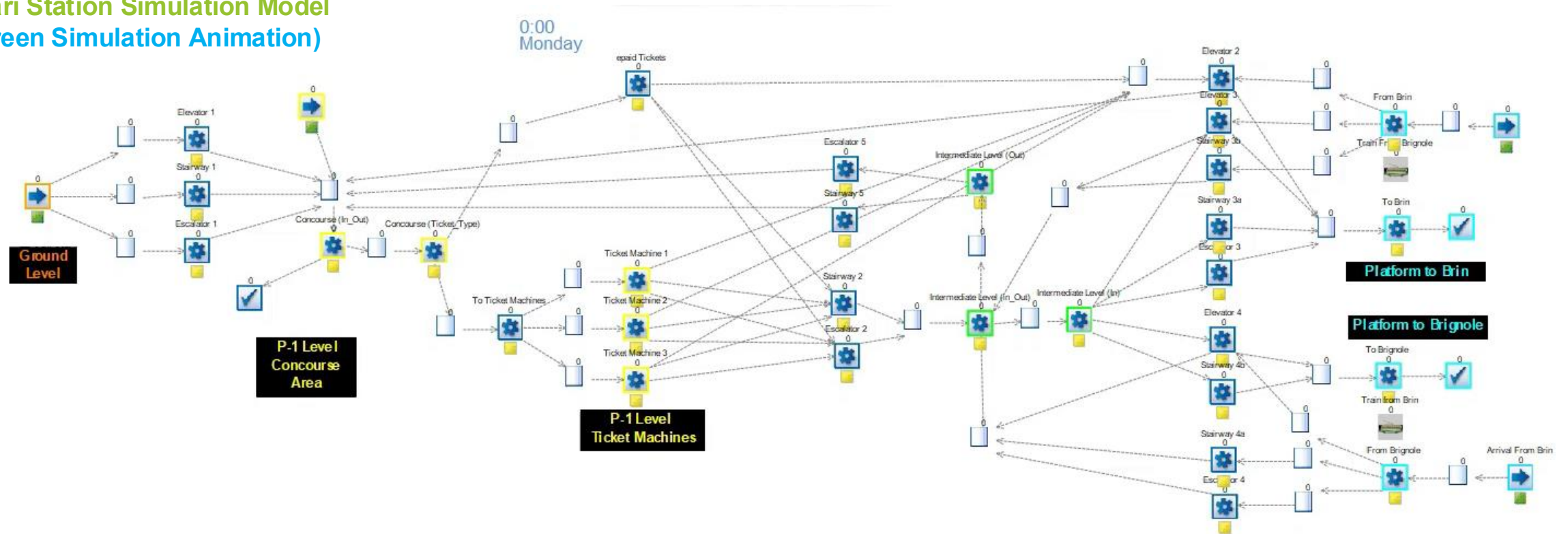
Legend: Passenger Waiting Time (mins)

3

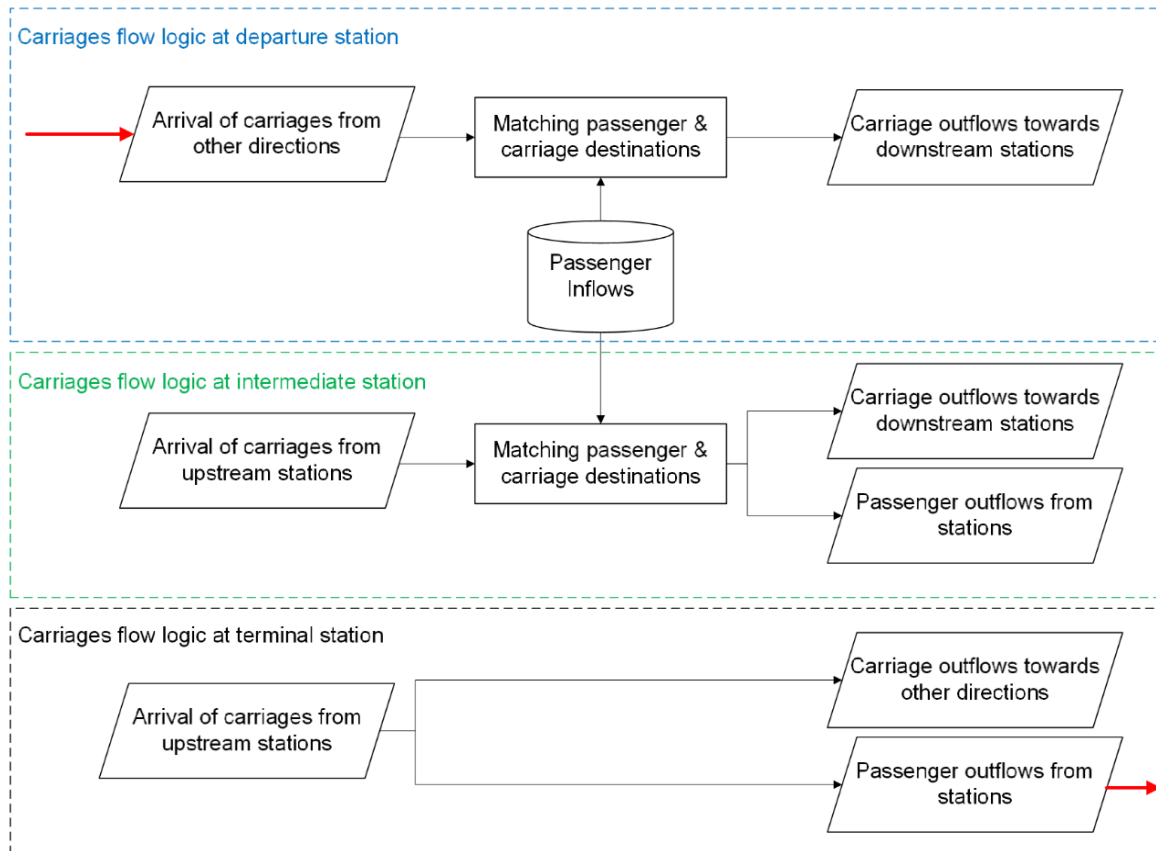
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- Carried out **station-level service optimisation**
- Simulation Experiments:
 - Evaluated impacts of headways and dwell time on waiting time and queue lengths
 - **Headway is the most influential factor**
- **Optimisation results:**
 - (headway, dwell) can **significantly reduce waiting time**
 - Several scenarios showed **> 60% reduction over baseline**
 - Performed **satisfactorily under future demand** scenarios (25% ↑) and if using **optimised vehicle concept** (from session 3)
 - **This proposed approach is practical and robust in supporting future operational planning**

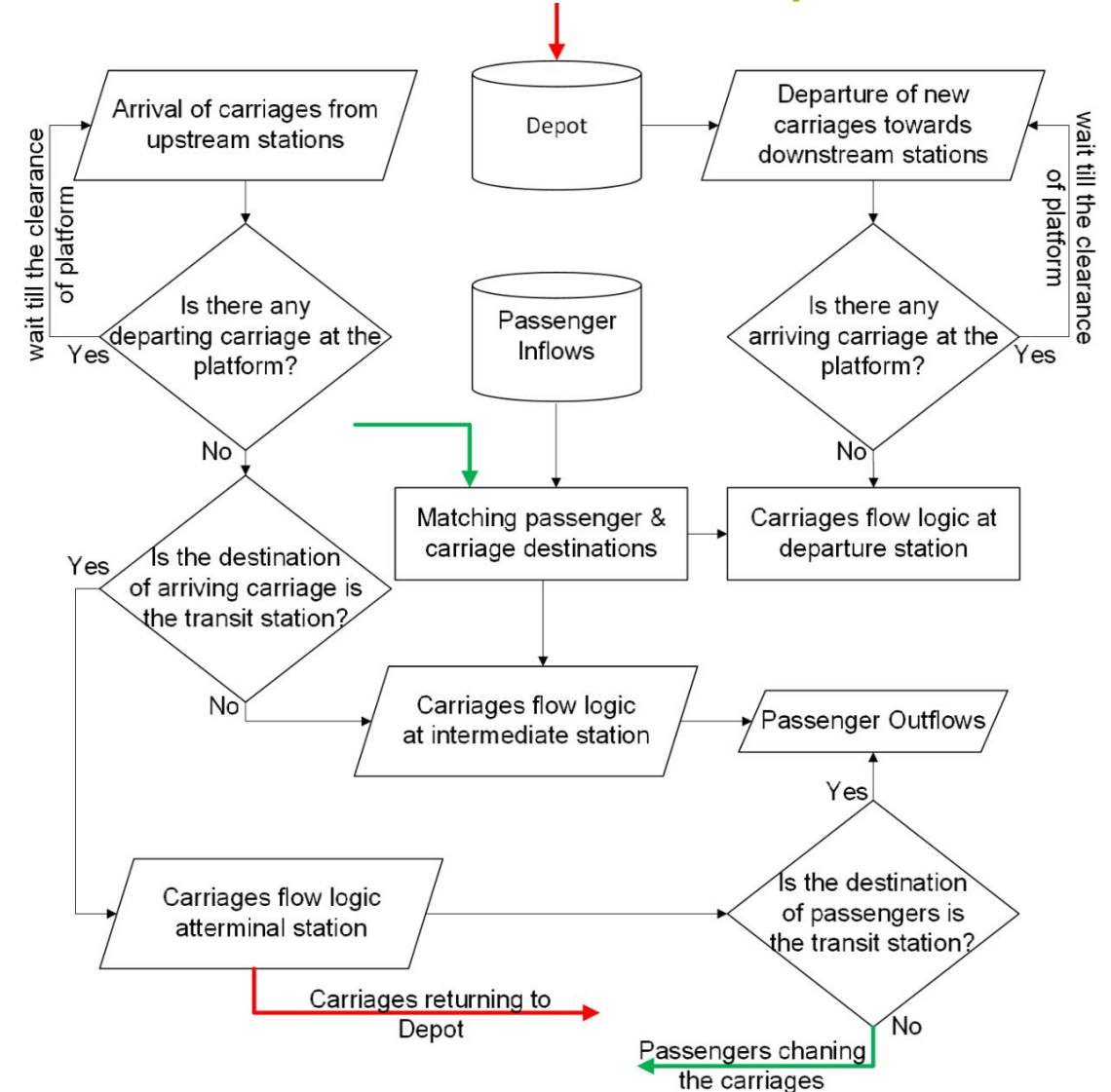
De Ferrari Station Simulation Model (On-Screen Simulation Animation)



Departure, Intermediate and Terminal Stations

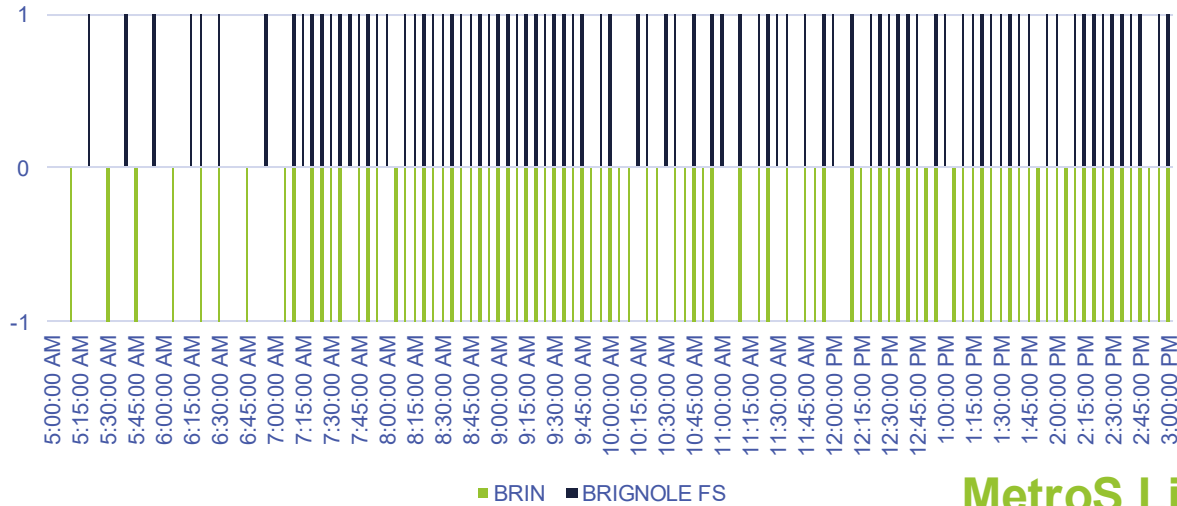


Transit Stations with depot

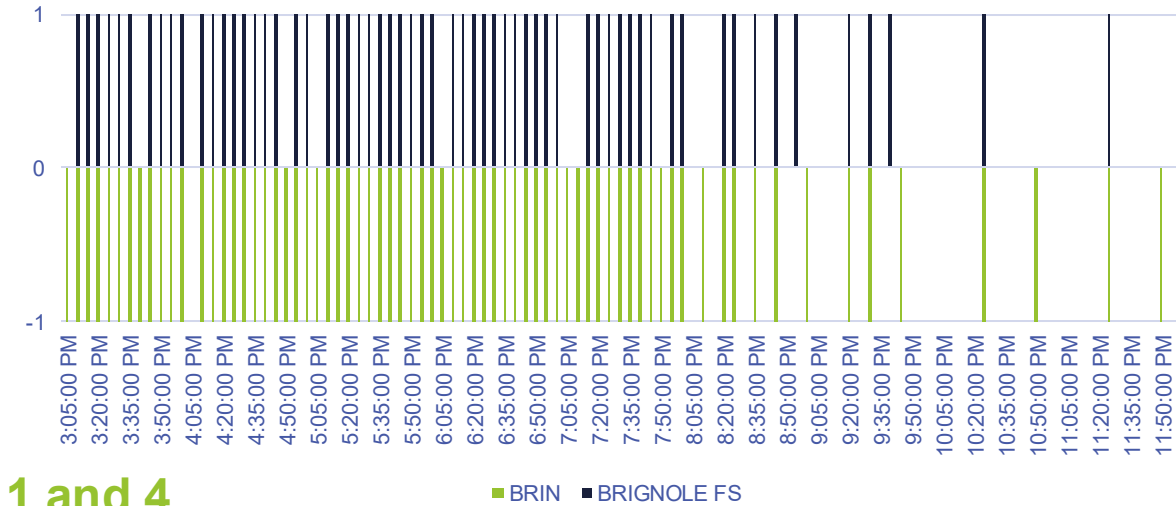


Metro Genoa

Scheduling DINEGRO from 5 to 15

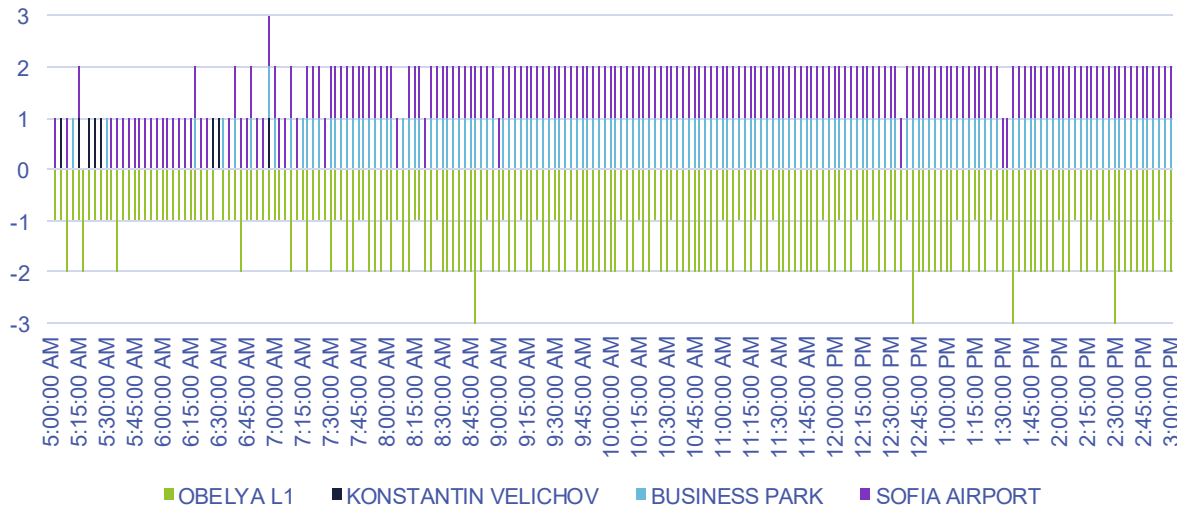


Scheduling DINEGRO from 15 to 00

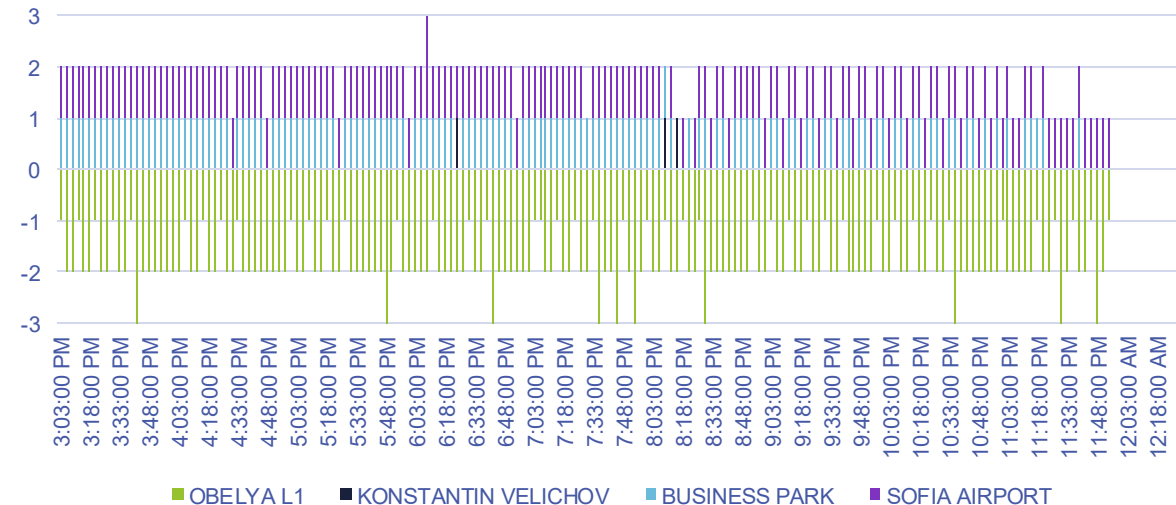


MetroS Line 1 and 4

Scheduling SLIVNITSA from 5 to 15



Scheduling SLIVNITSA from 15 to 00



THANK YOU!

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 NEXUS Project

 nexus-heproject.eu

