IMHOTEP
Candidate SESAR Solution

Project consortium
Maturity gate, Brussels, 11 November 2022

EUROPEAN PARTNERSHIP

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Problem statement

Problem statement

European High-Level vision depicts:

A **passenger-centric system** that takes travellers from their origin to their destination in a seamless, efficient, predictable, environmentally-friendly and resilient manner

An air transport system thoroughly i**ntegrated with other transport modes**

The airport of the future is expected to become a **multimodal connection platform**:

- Creating the conditions for travellers to reach their destination by the most efficient and sustainable combination of modes
- Allowing the airport and its surrounding region to make a better use of their resources

Achieving this vision calls for **enhanced modal integration** not only in terms of physical infrastructure, but also of business models, operational processes and information systems

Problem statement

IMHOTEP
Integrated Multimodal Airport Operations for Efficient Passenger Flow Management

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Airport Collaborative Decision-Making (A-CDM) is enhancing the efficiency of airport operations thanks to information sharing and common situational awareness between airports, airspace users (AUs), ground handlers and air navigation service providers (ANSPs), but the concept has so far focused on aircraft turnaround and pre-departure sequencing.

Total Airport Management (TAM) is a more holistic concept that foresees closer integration of landside and airside processes, but the passenger access and egress legs are still absent from the picture

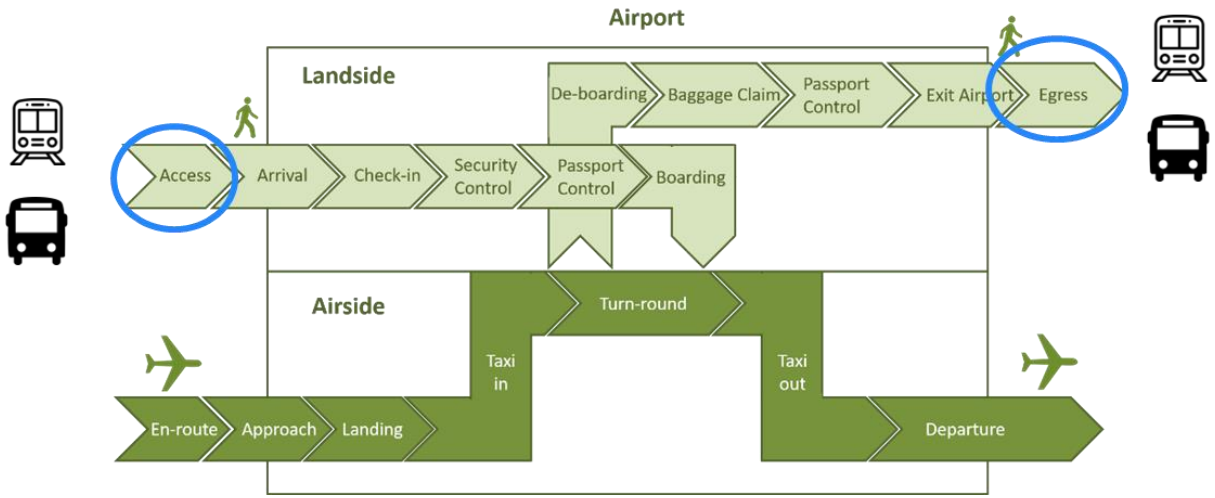
IMHOTEP aims to seize these opportunities and **close the gap in information sharing** between airport and ground transport modes

Develop a set of enabling technologies able to provide a holistic view of the airport processes, the ground transport system and the passenger flows, with the ultimate purpose of improving the quality, efficiency and resilience of the door-to-door passenger journey.

IMHOTEP Solution description

Concept of operations

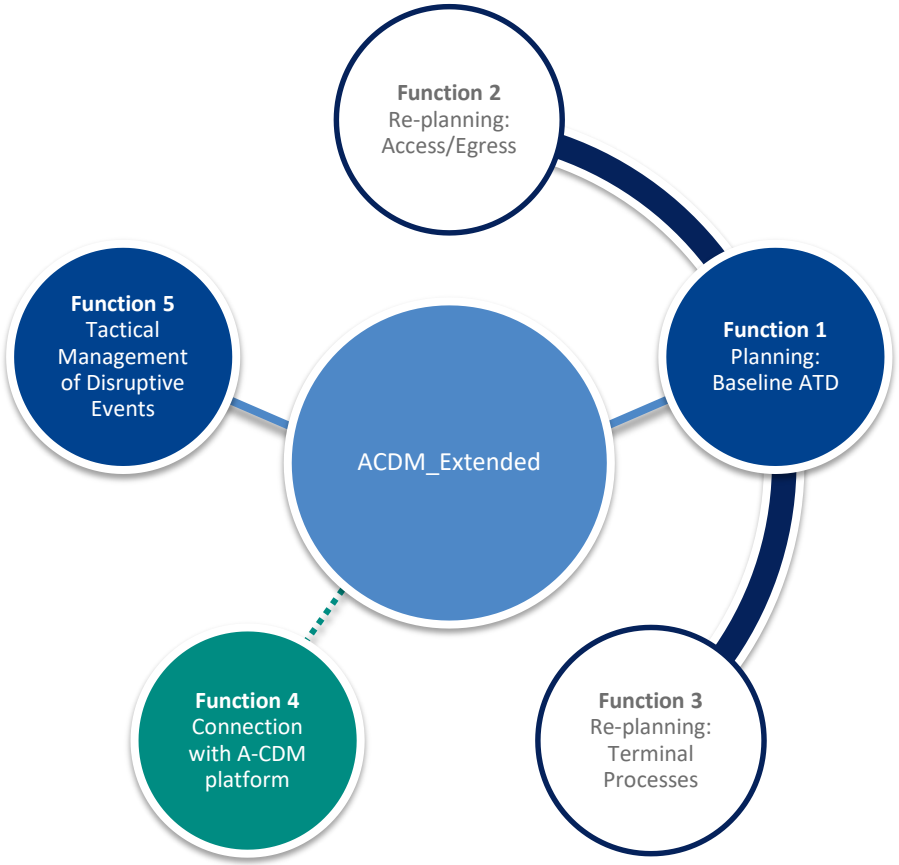
- The IMHOTEP ConOps extends collaborative decision-making to **integrate surface transport stakeholders**
- The concept shifts from flight to **passenger-centricity** based on an updated view of the passenger journey, using the concept of Passenger Activity-Travel Diary (ATD)
- The **integration of different sources of information**, not conventionally used in the airport context, enables a novel assessment of the door-to-gate and gate-to-door journey
- The concept can be applied to both **A-CDM and non-CDM** airports



Concept of operations

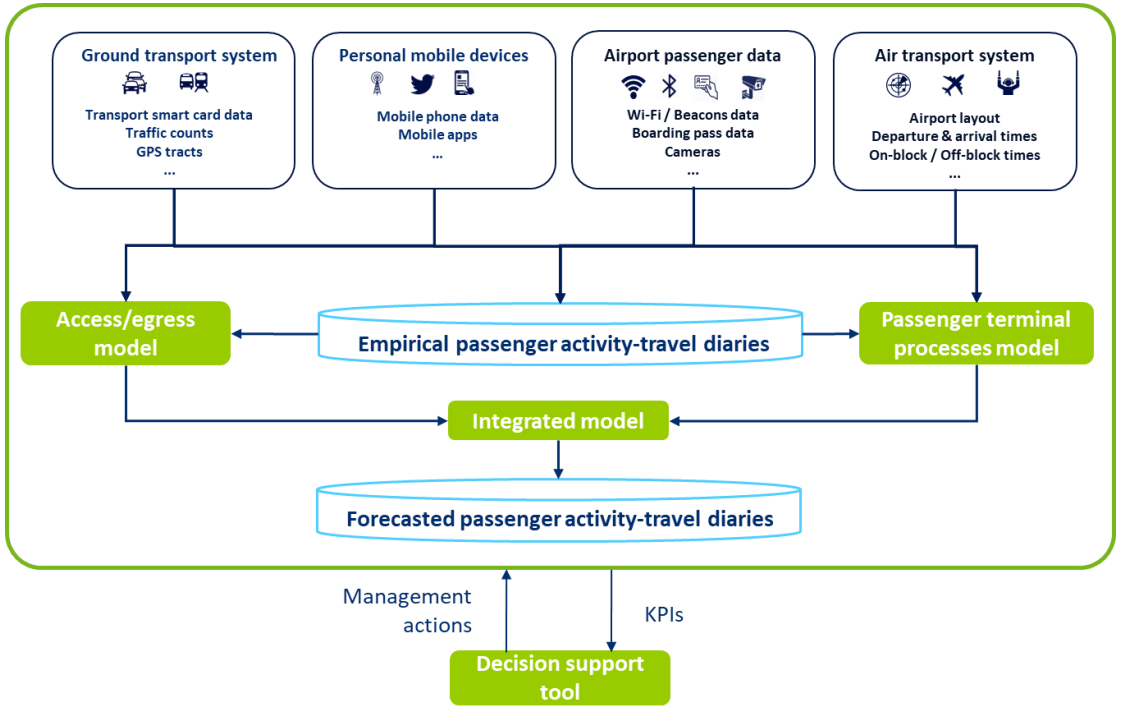
The concept is based on **five Functions**

- **Function #1** provides an initial picture of the passenger flows prior to the day of operations, allowing the different stakeholders (e.g., ground transport operators, airport operators, AUs etc.) to allocate their resources more efficiently.
- **Function #2** updates the passengers access/egress leg during the day of operations with real-time data.
- **Function #3** updates the passengers terminal leg during the day of operations with real-time data.
- **Function #4** connects the ACISP with the A-CDM_Extended so both platforms can exchange information (A-CDM airports).
- **Function #5** allows the tactical management of disruptive events enabling the simulation of 'what-if' scenarios aimed at mitigating the impact of the disruption.



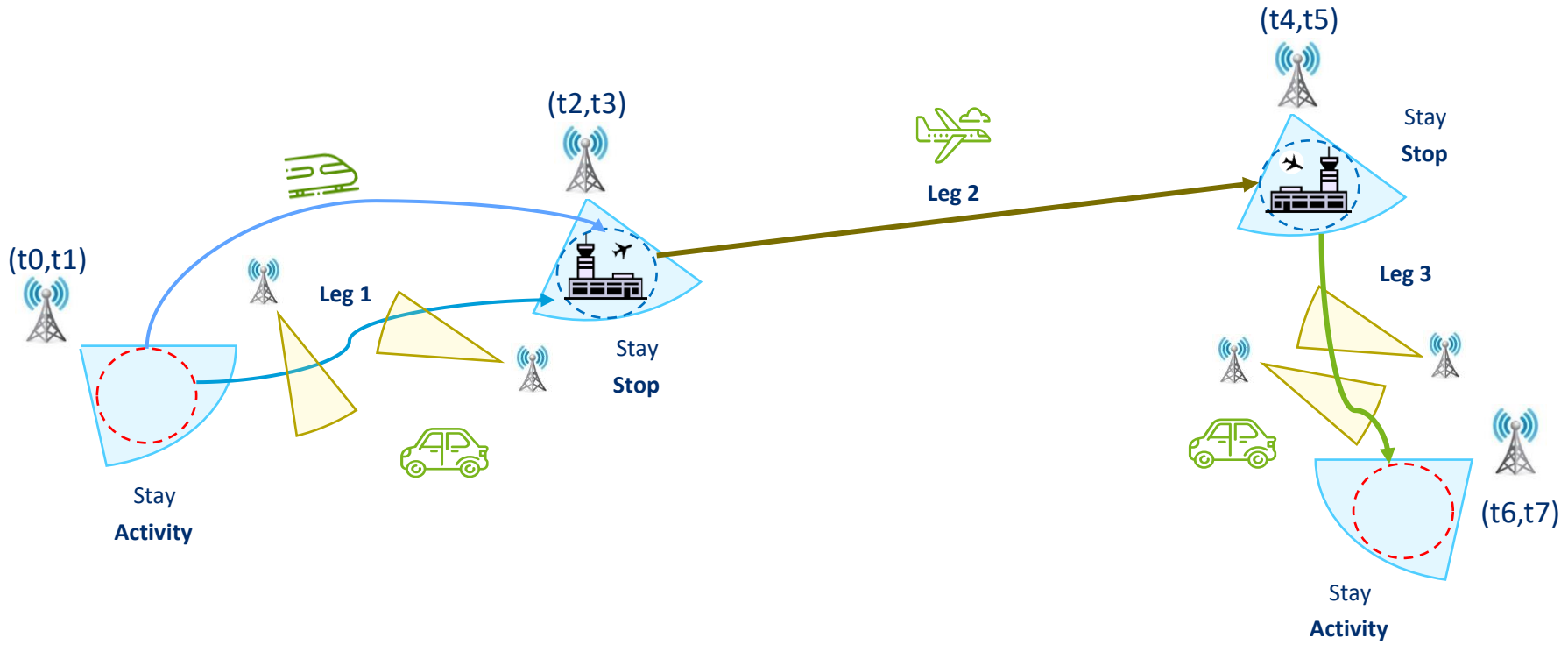
Implementation of the concept

- **Data analysis techniques** for the reconstruction of the passenger activity-travel diaries in order to build, validate and feed the predictive models
- **Development and validation of predictive models** able to short-term forecast passenger flows for:
  - airport terminal
  - surface access and egress legs
- **Model integration** aimed at provide a holistic view of the door-to-gate and gate-to-door flows
- **Visualisation and decision support tool** to assess the operational impact of different management measures
- **Evaluation of the ConOps** through a set of case studies in Palma de Mallorca and London City airports



Data analysis and fusion techniques

Reconstruction of door-to-door multimodal trips (**Activity-Travel diaries**) from anonymised mobile network data

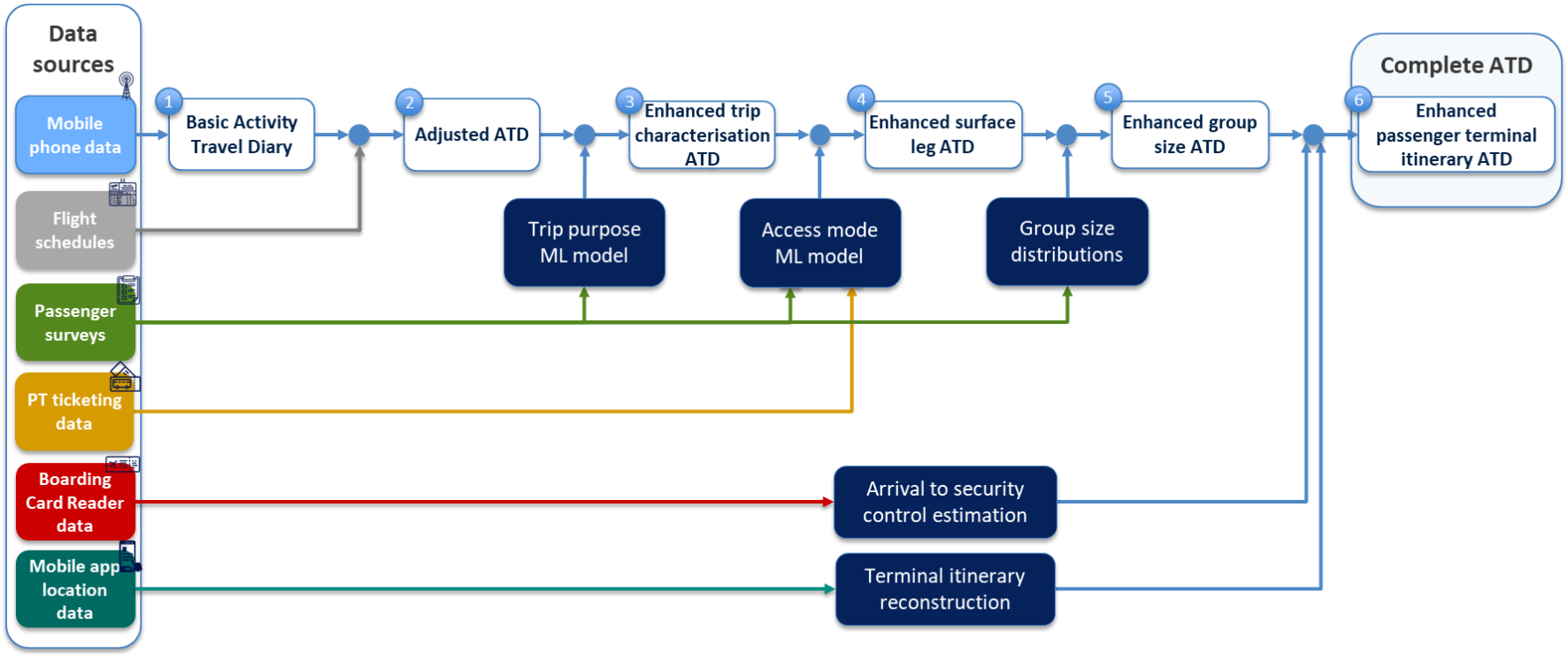


Data analysis and fusion techniques

Data analysis and fusion techniques

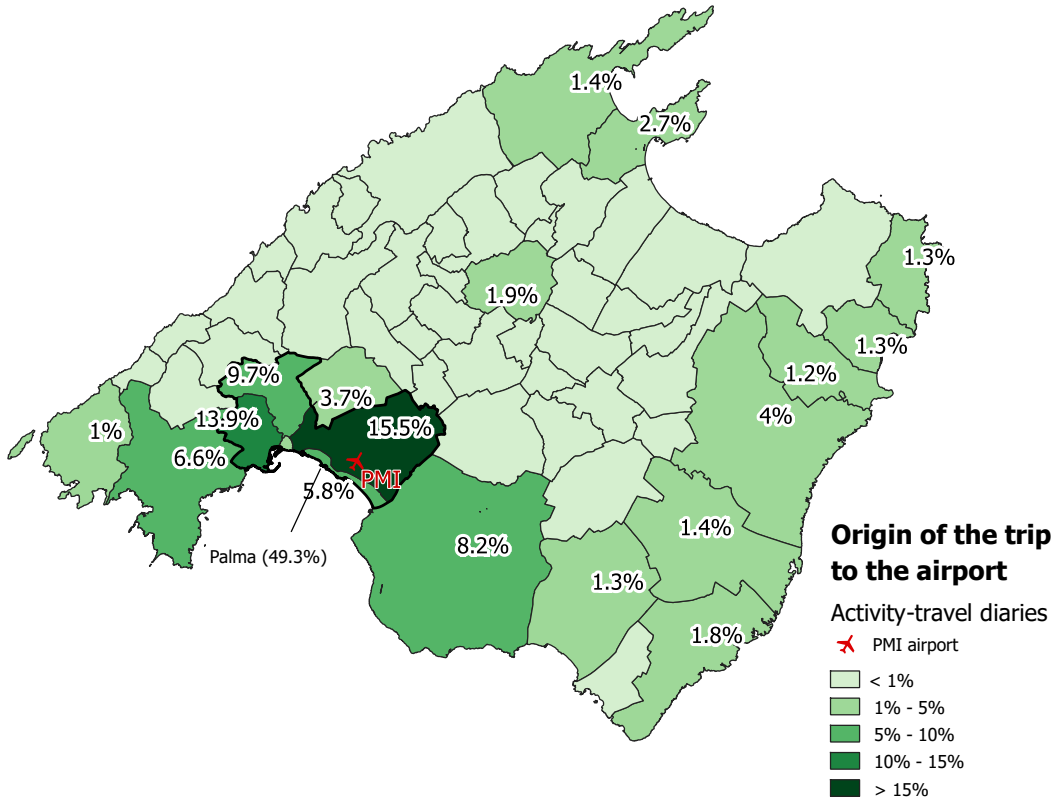
Enhancement of mobile network data detected trips through the fusion with a wide range of data sources in order to:

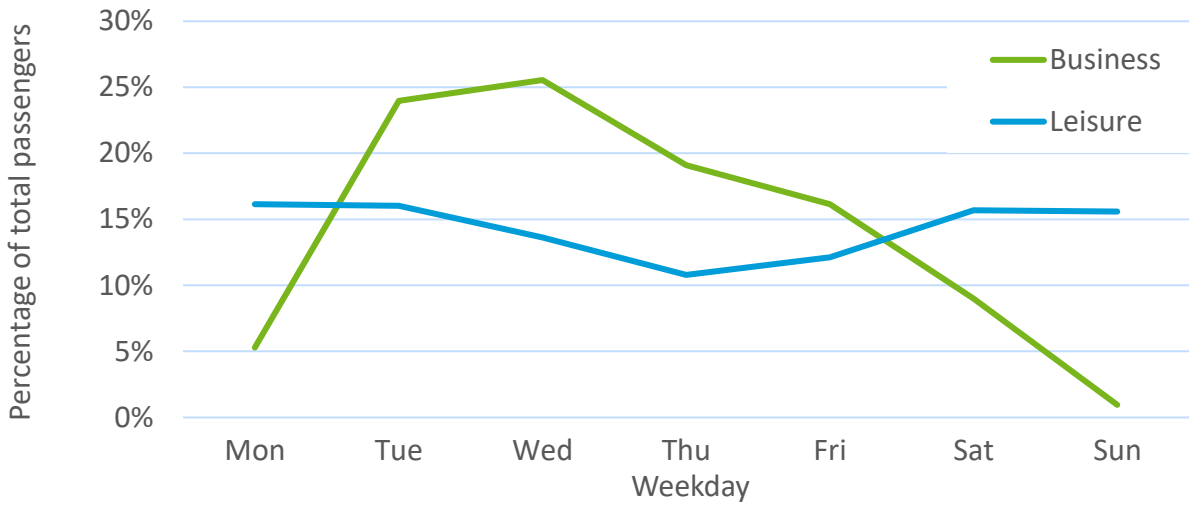
- Adjust the number of trips to the actual number of airport users and add airport-specific data (flight number, gate, etc.)
- Add passenger and trip characteristics (trip purpose, access/egress mode and group size)
- Describe the passenger terminal itinerary within the airport terminal

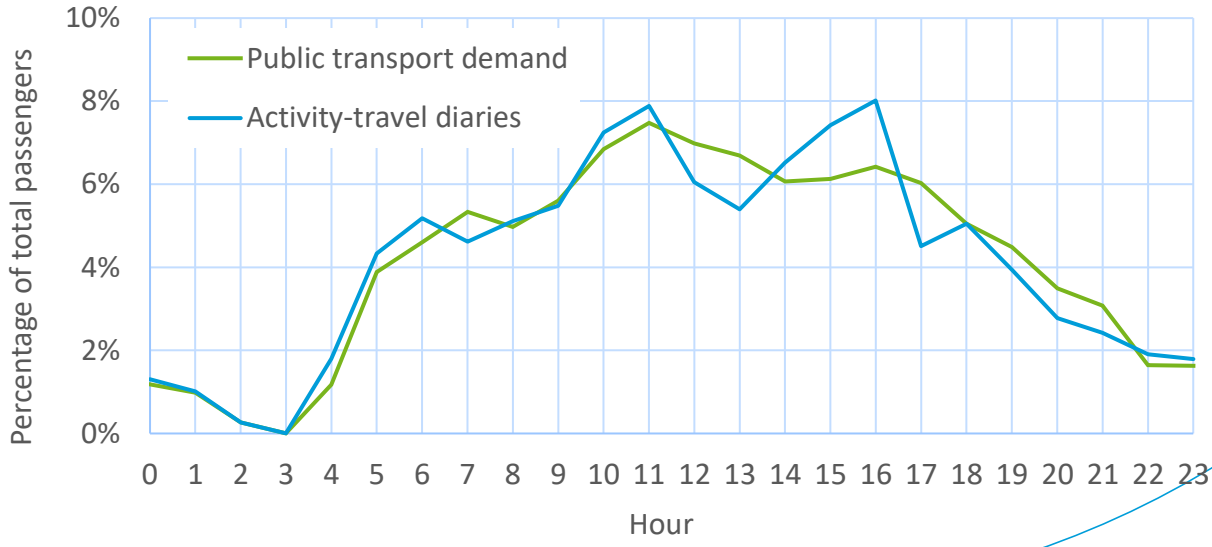


Data analysis results

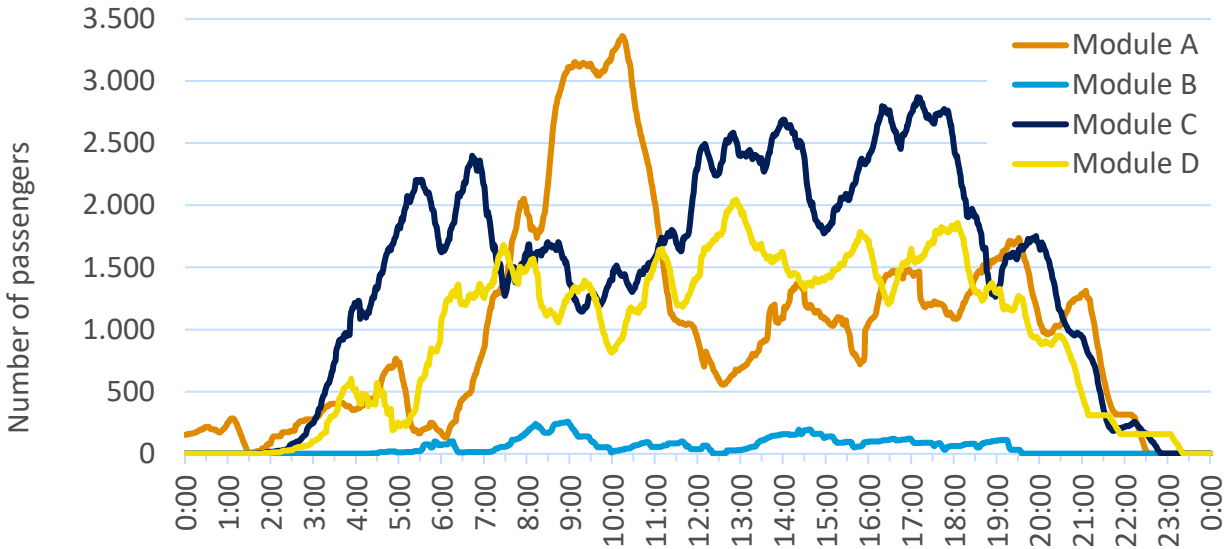
- Extraction of relevant indicators for both the terminal leg and the access/egress leg
- These indicators will be later on used to build and calibrate the predictive models

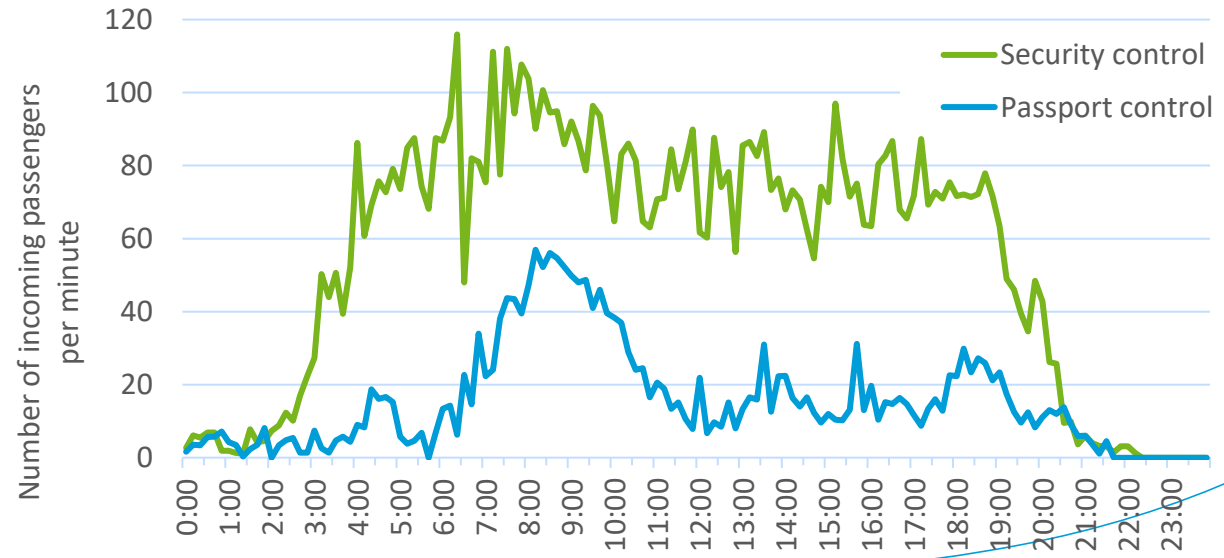






Data analysis results

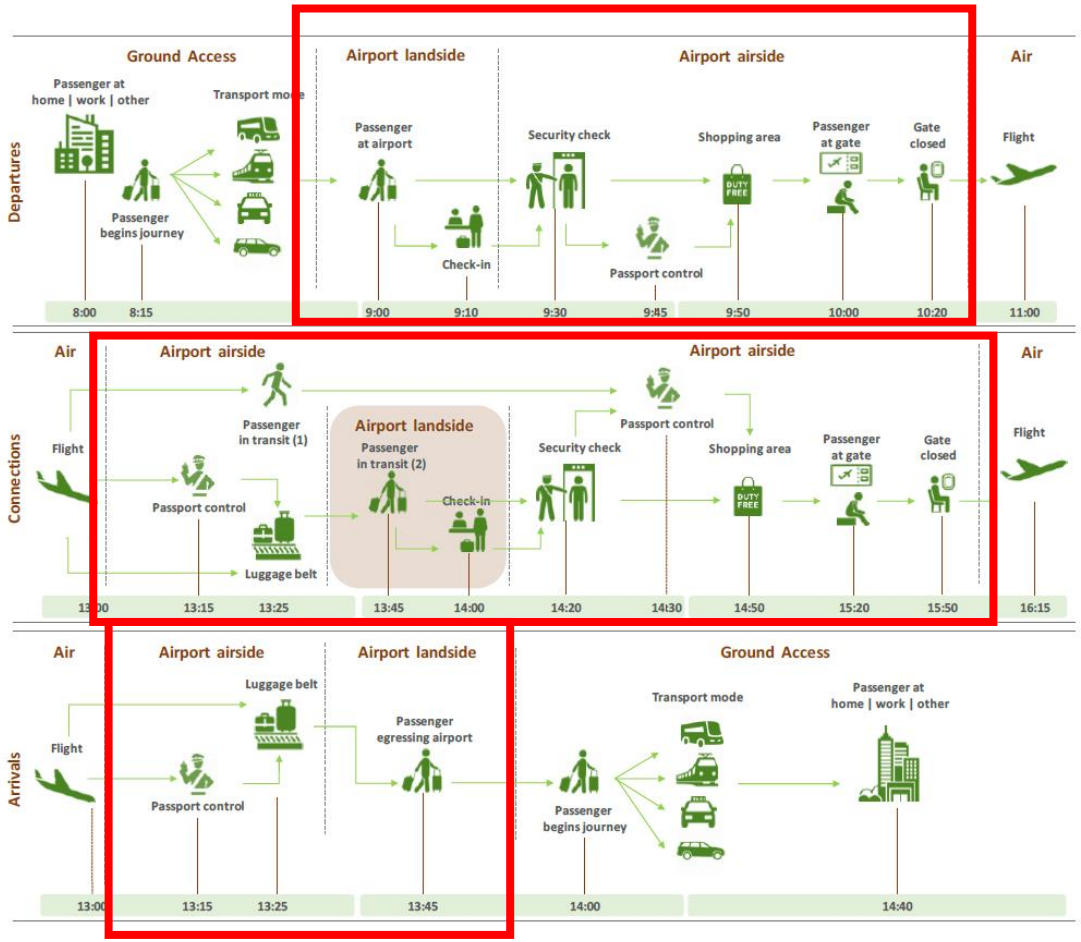




Passenger terminal model design and development

Processes modeled (PMI/LCY):

- Check-in
- Boarding pass scan
- Security check
- Passport control
- Shopping/catering areas
- Gate lounges dwelling areas
- Gate boarding
- Baggage claim



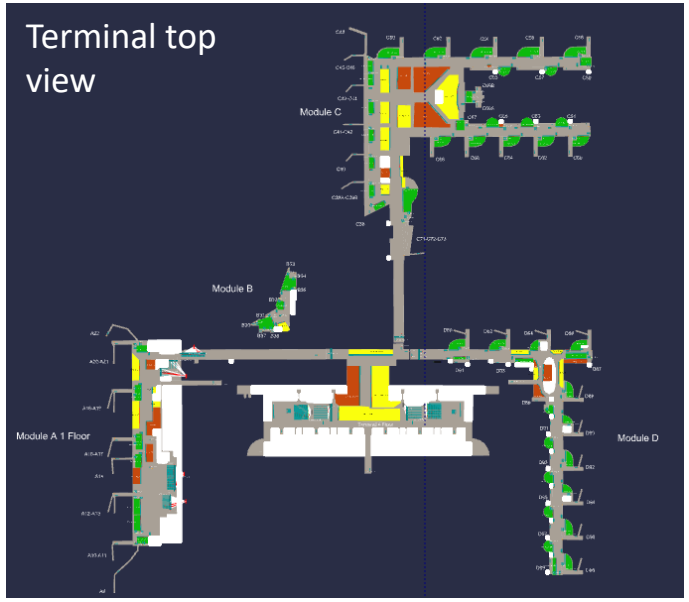
Passenger terminal model design and development

Implement dynamics for evaluating ConOps

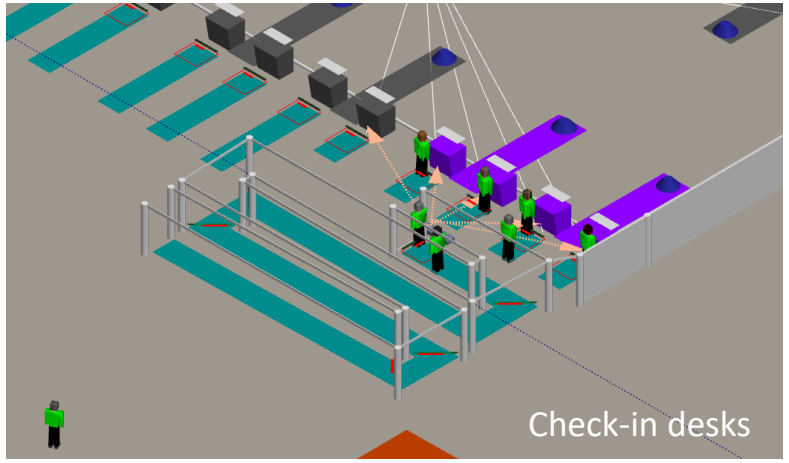
Logic implemented (PMI/LCY):

- Opening/closing check-in desks (e.g., 2 hrs for domestic and 3hrs for international flights)
- Waiting at the departure hall (e.g., for passengers that arrive too early and find the check-in desks not open yet)
- Shopping/catering services (e.g., if passengers have time left after security; they are based on passenger preferences)
- Missing a flight (e.g., for passengers arriving too late at the check-in desks or the boarding gate)
- Resources management (opening/closing facilities based on rules e.g. queue length/queuing time)

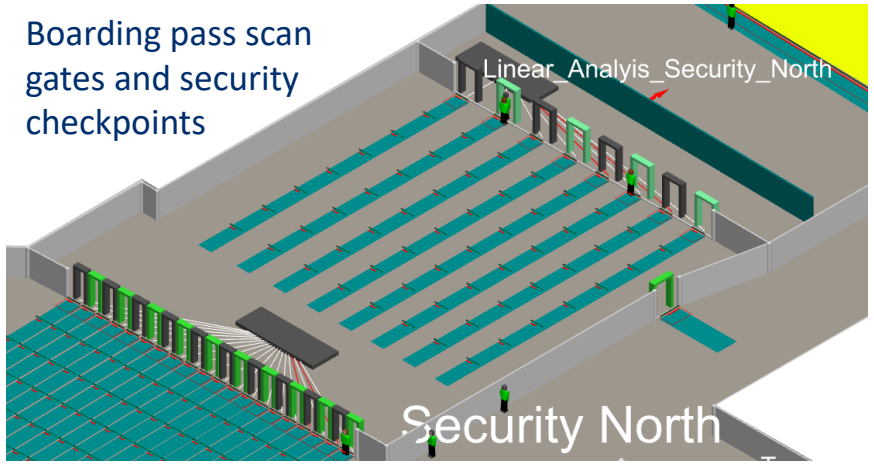
PMI terminal model



Process	Number of facilities
Check-in desks	204
Boarding pass scans	45
Security checkpoints	19
Passport control desks/gates	- 6 Passport control manual desks for departing passengers - 12 Passport control manual desks for arriving passengers
	- 40 Passport control automated gates for departing passengers - 40 Passport control automated gates for arriving passengers
Gate boarding	86
Baggage claim	19



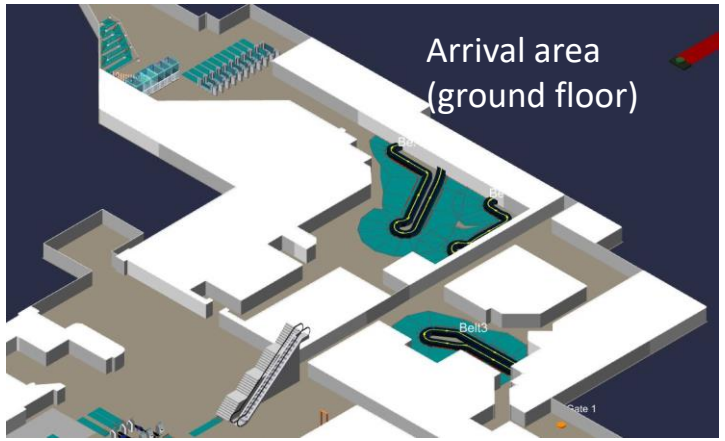
Boarding pass scan gates and security checkpoints

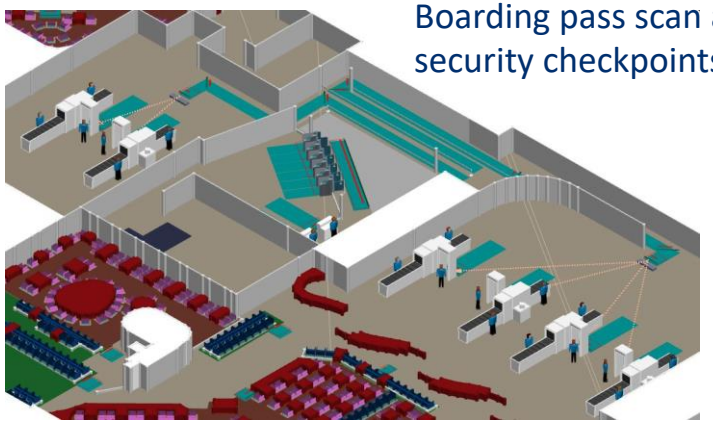


PMI terminal model video example

LCY terminal model

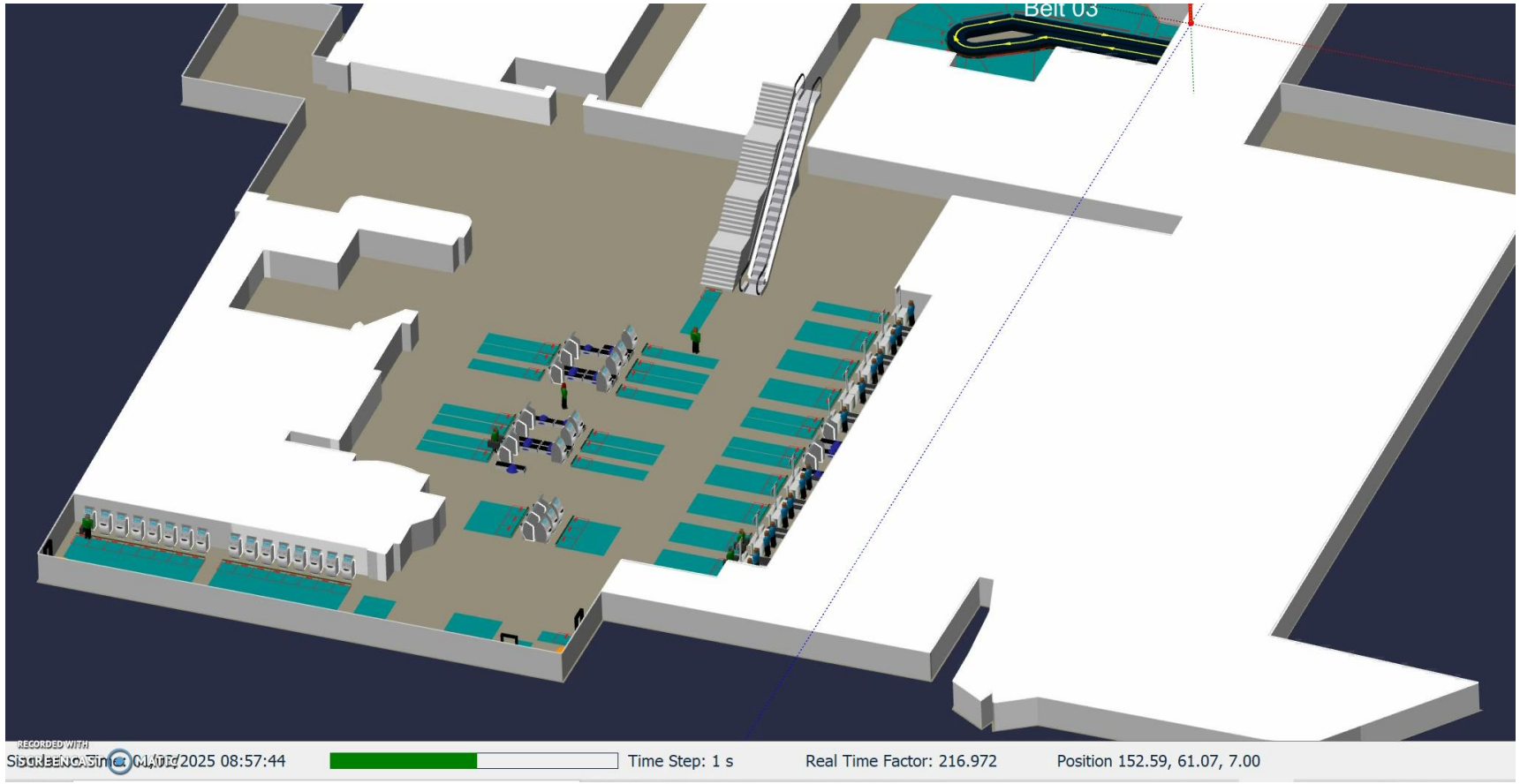
Process		Number of facilities
Check-in	Manned counter	19
	Self-service baggage drop (SSBD)	17
	Kiosk	27
Boarding pass scan	Manned counter	2
	E-Gates	6
Security check	Preparation area	1
	Lanes	6
Passport control	Manned counter	6
	E-Gates	10
Gate boarding		16
Baggage claim		- 2 international belts - 1 domestic belt





Boarding pass scan and security checkpoints

LCY terminal model video example

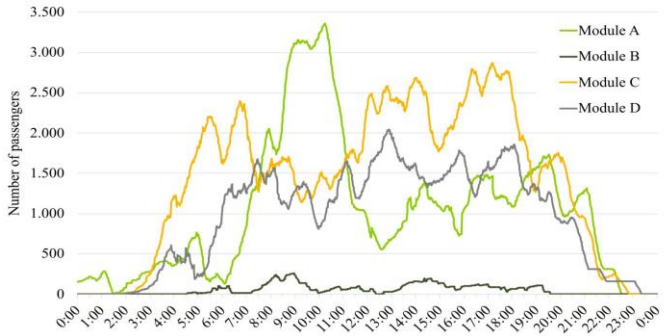


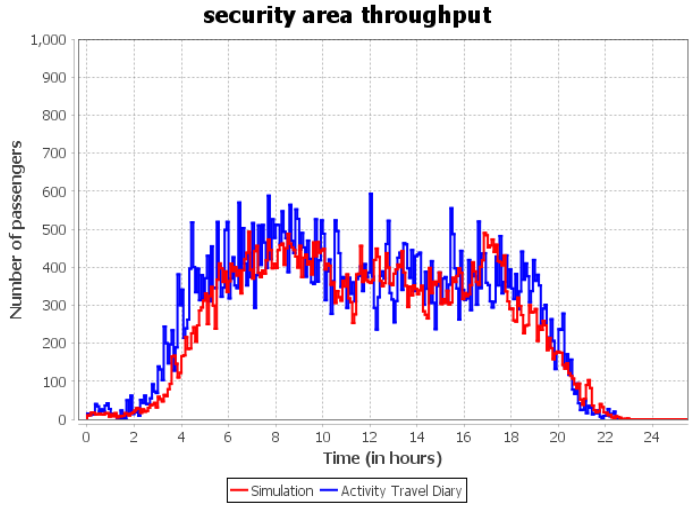
Passenger terminal model validation

- Coordinated with the data analysis tasks. Validation method:
  - Compare the outcome from the simulation model and the outcome from the reconstructed passenger ATD
- Type of data used for validation:
  - number of passengers in specific areas (check-in, security check point, after security)
  - dwelling time in specific areas

Simulation outcome

Data analytics outcome

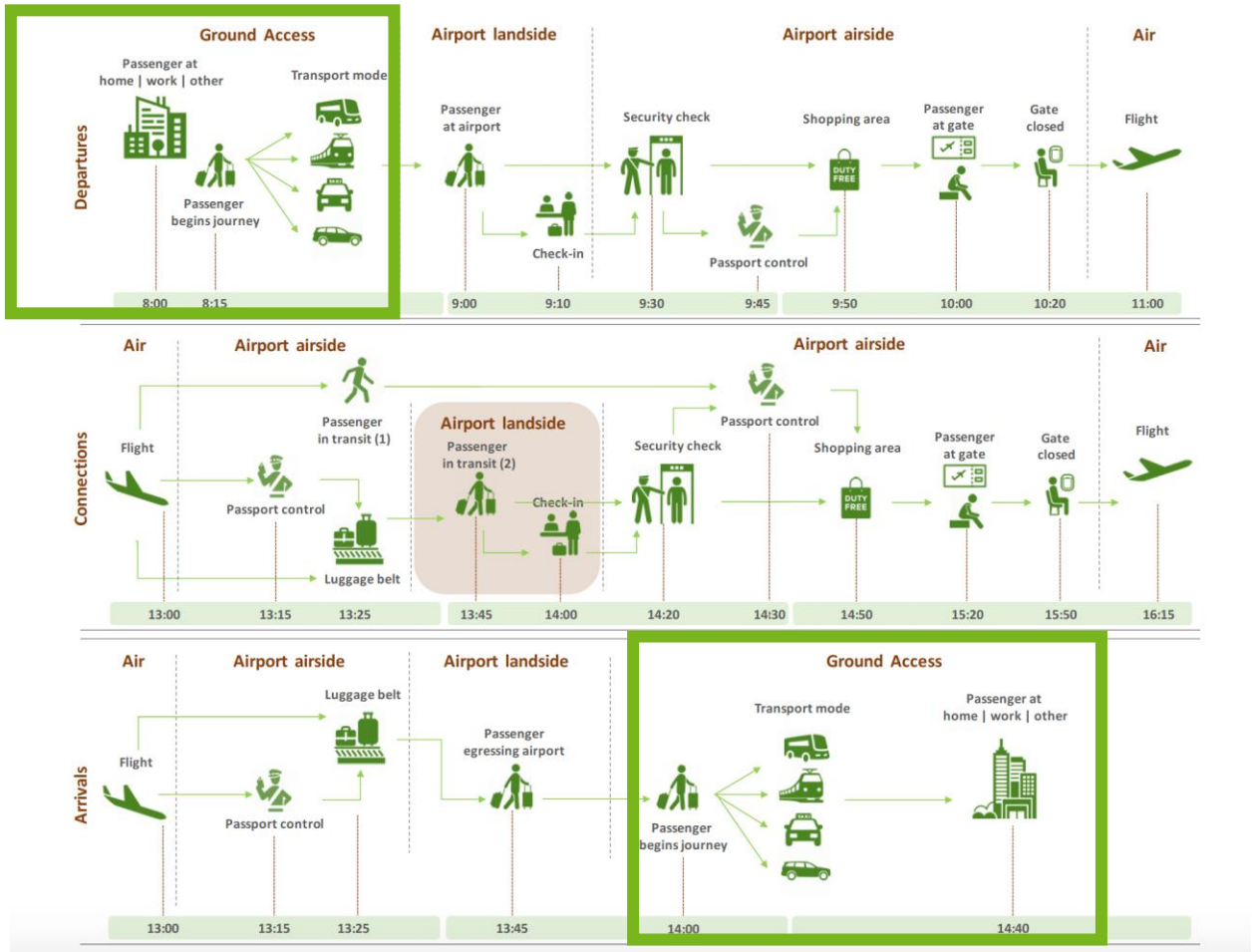




***Scala, et al., 2022, "A novel validation approach for validating the simulation model of a passengers' airport terminal: case PMI", in Proc. of EMSS, 2022, Rome, Italy*

Access / egress modelling

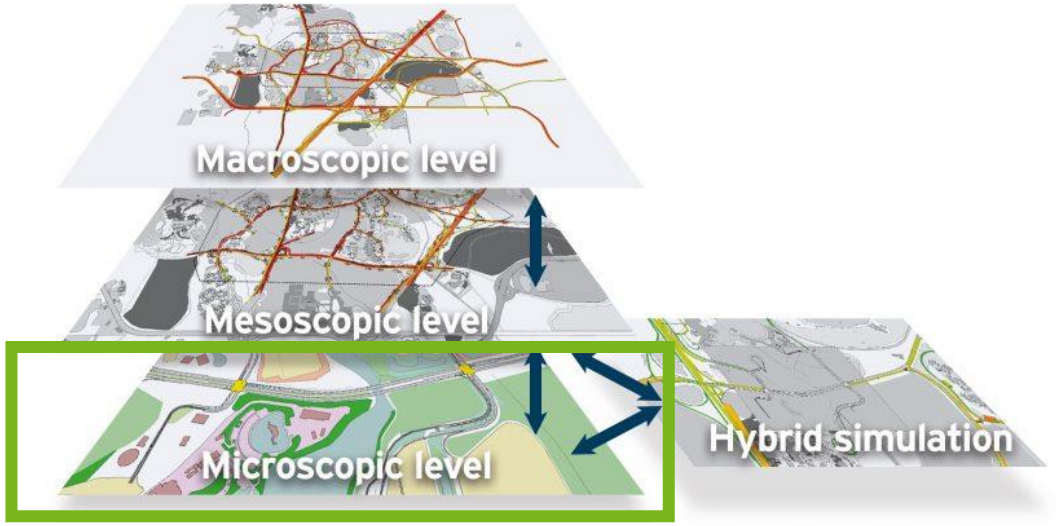
- Access and egress legs from the trip origin to the terminal and from the terminal to final destination
- Modeling of private traffic:
  - Private cars
  - Rental cars
  - Taxi / ride-sharing services
  - Coach (tour operators)
- Modeling of public transportation:
  - EMT lines serving the PMI airport



Access / egress modelling

Development of access/egress models

- Aimsun Next model
- Microscopic simulation selected
- Characterise the traffic supply of ground transport system
  - Roads as a set of sections composed by lanes and nodes
  - Traffic signal control definition
  - Public transport lines and timetables
- Traffic demand
  - Historical Origin- Destination trips matrices
  - Traffic counts



Access / egress modelling

IMHOTEP Integrated Multimodal Airport Operations for Efficient Passenger Flow Management

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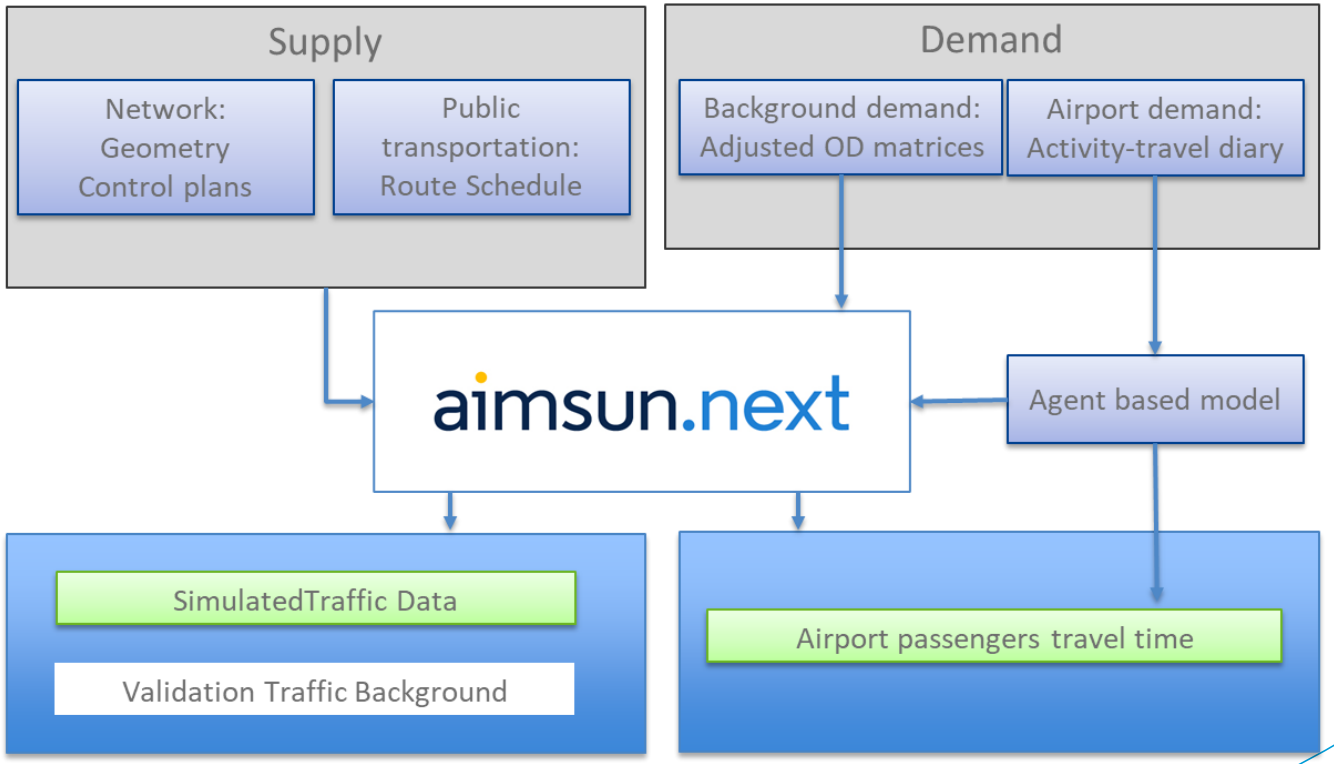
Agent-based modelling

- Passenger travel information is available in the activity-travel diaries
- Travel time for each passenger in the ground model needs to be known
- Each passenger needs to be modelled from origin to destination
- **Agent-based simulation on top of Aimsun Next is required**
- Differences between private vehicles and public transport
  - Private is on demand
  - Public supply is fixed

Model architecture

- Developed a module to use agent based demand in aimsun.next
- Passengers (or groups of them) are simulated and tracked individually



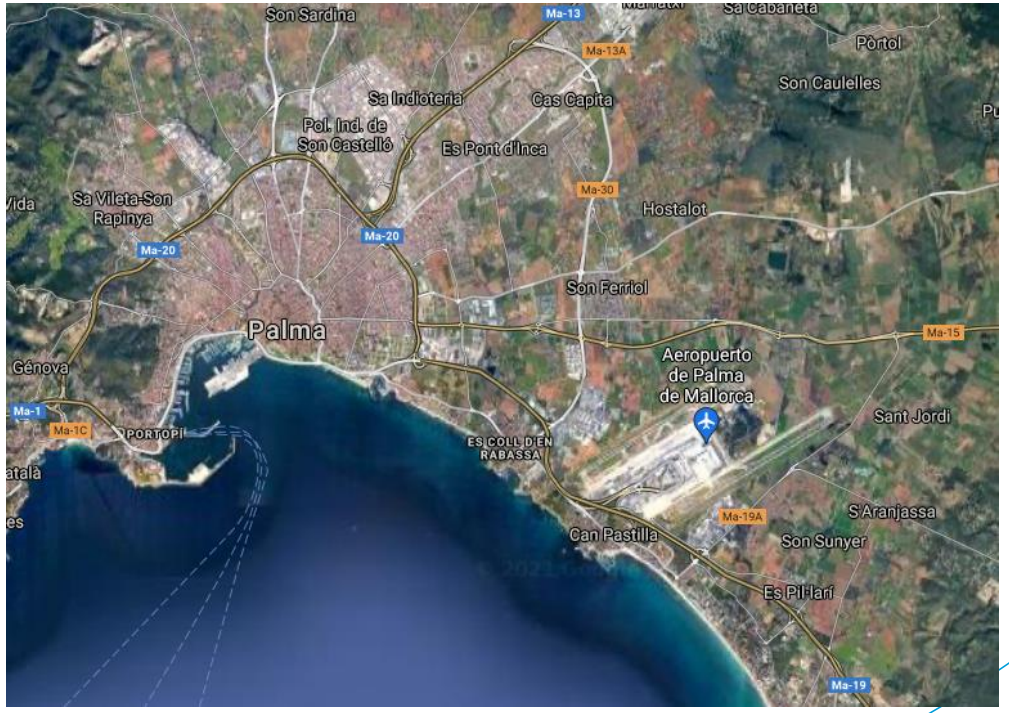
Access / egress modelling

General results

- Using this approach all users are tracked from origin to destination
- The agent-based model provides all the information regarding the trajectory of a user
- Current agent-based outputs:
  - Origin time
  - Vehicle boarding time and waiting time for PT users
  - Vehicle alighting time
  - Final destination arrival time
  - Distance travelled
- Estimation of CO_2 emissions

PMI model - Specification

Model extension determined by use-cases definition and mechanisms to simulate the transport and traffic management decision-making processes considered in the IMHOTEP ConOps



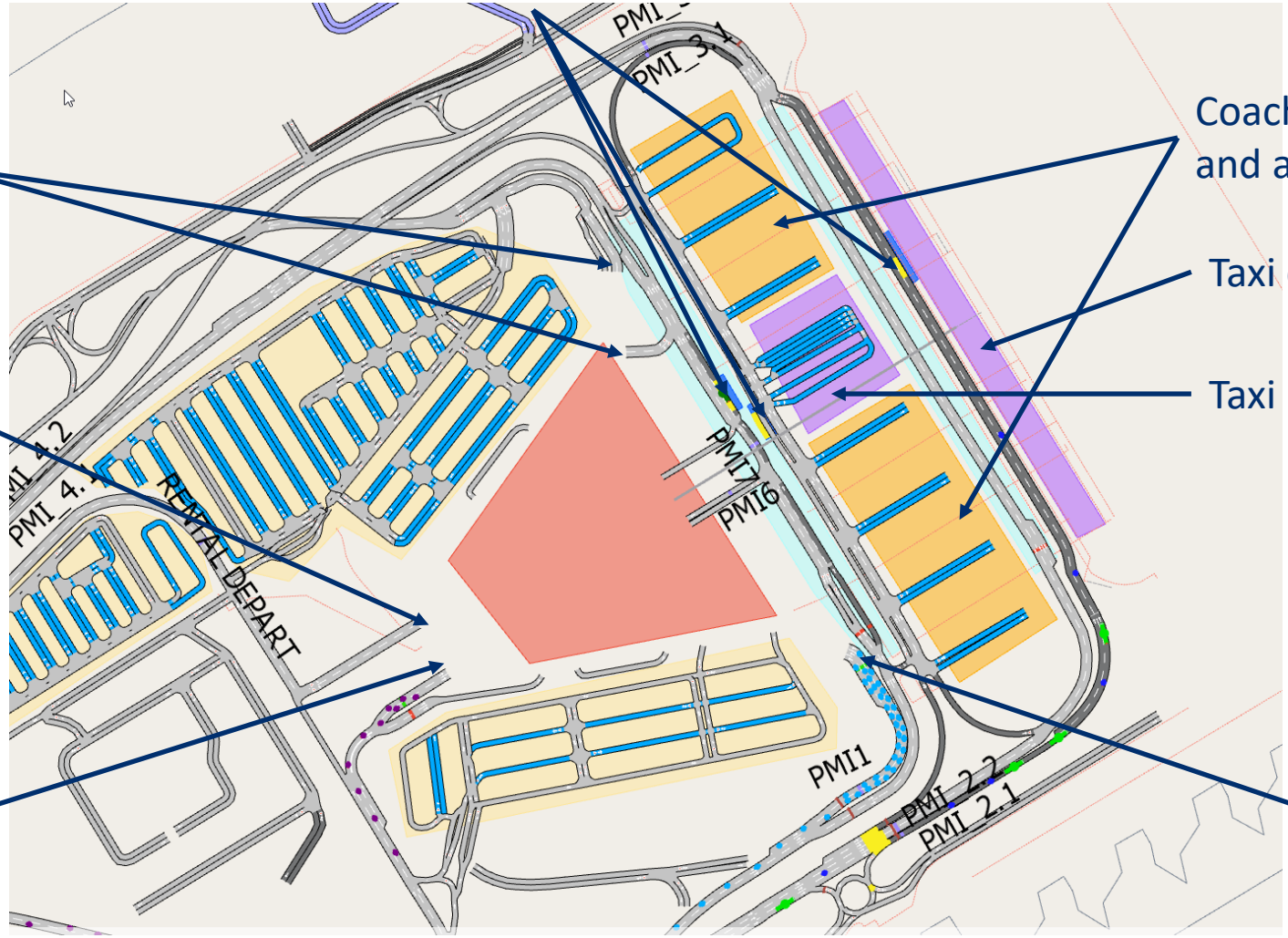
PMI model – Terminal access/egress detail

Public transportation stops

Private car parking exit

Rental cars parking exit

Rental cars parking entrance



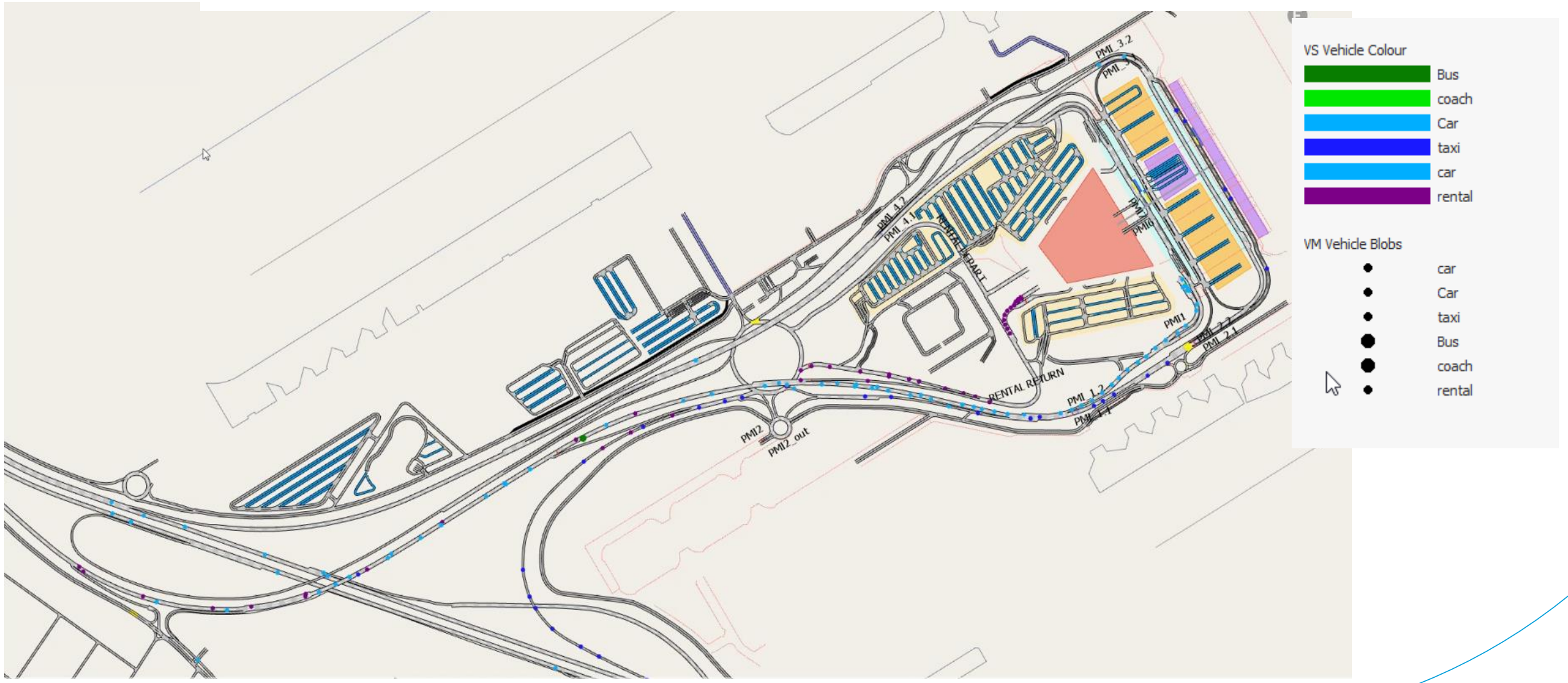
Coach boarding and alighting zones

Taxi drop off area

Taxi pick up area

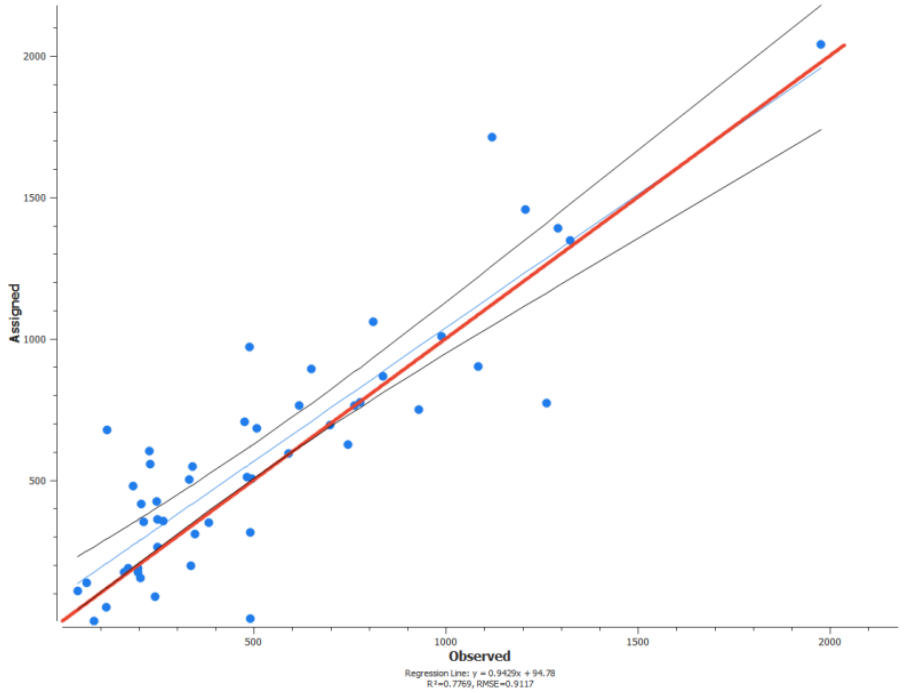
Private car parking entrance

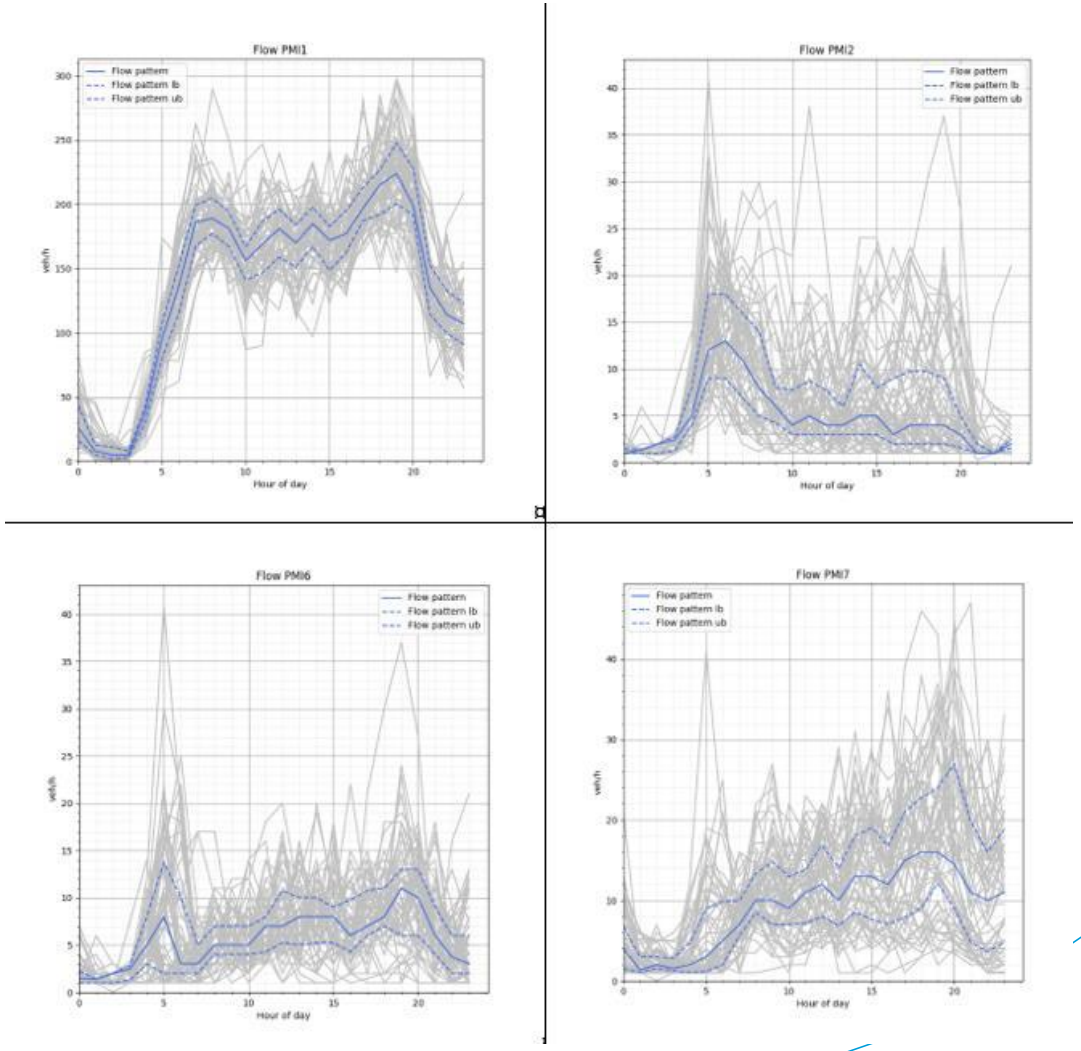
PMI model - Simulation



PMI - Validation

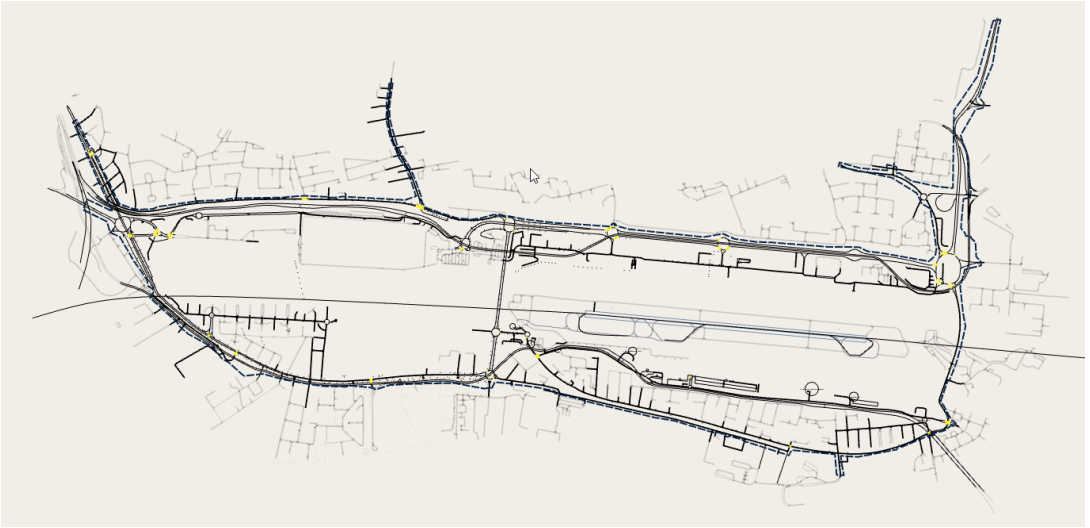
- Validation that observed flows at traffic detectors are consistent to those of the simulated environment
- Traffic detector data obtained from the Palma de Mallorca City Council



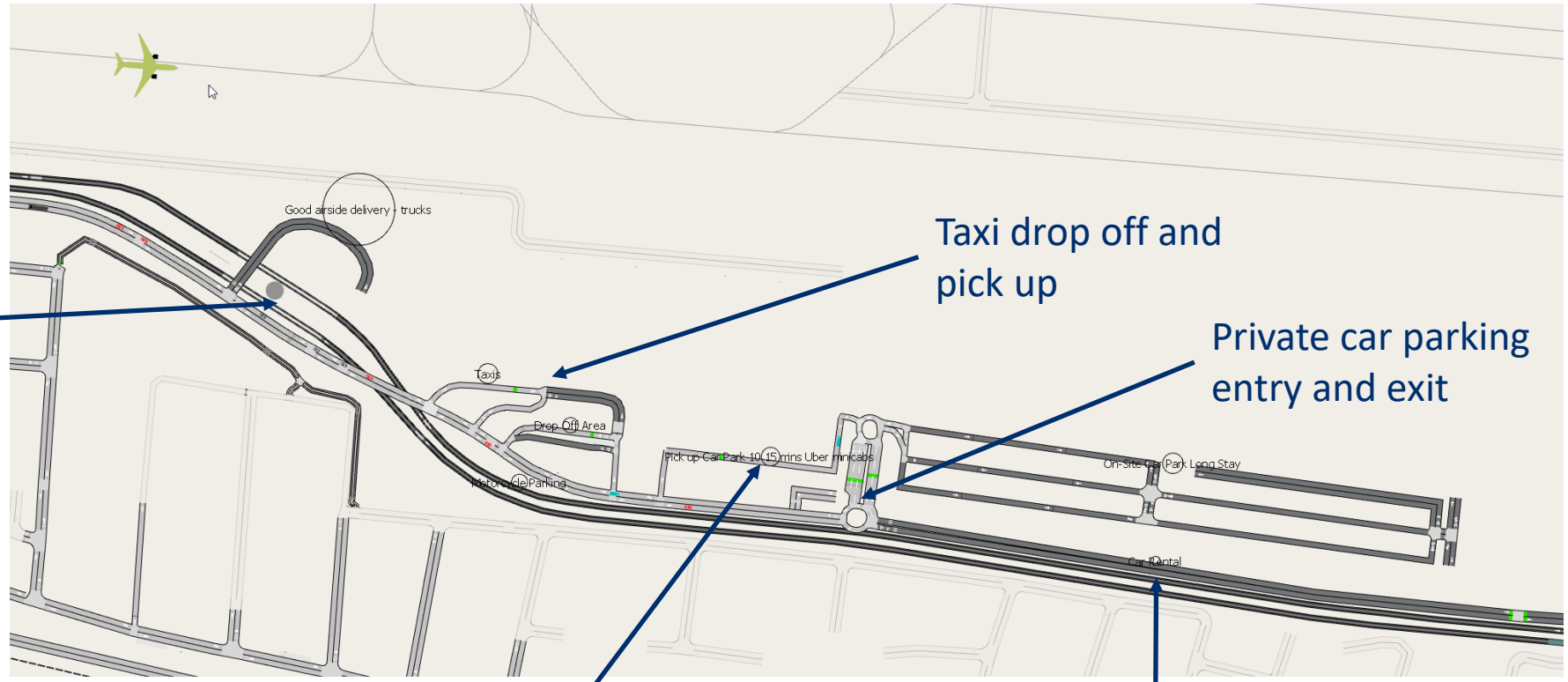


LCY model - Specification

- Network around the airport facilities to model management actions for the airport
- LCY impact on London mobility is very small



LCY model - Terminal access/egress detail



DLR stop

Taxi drop off and pick up

Private car parking entry and exit

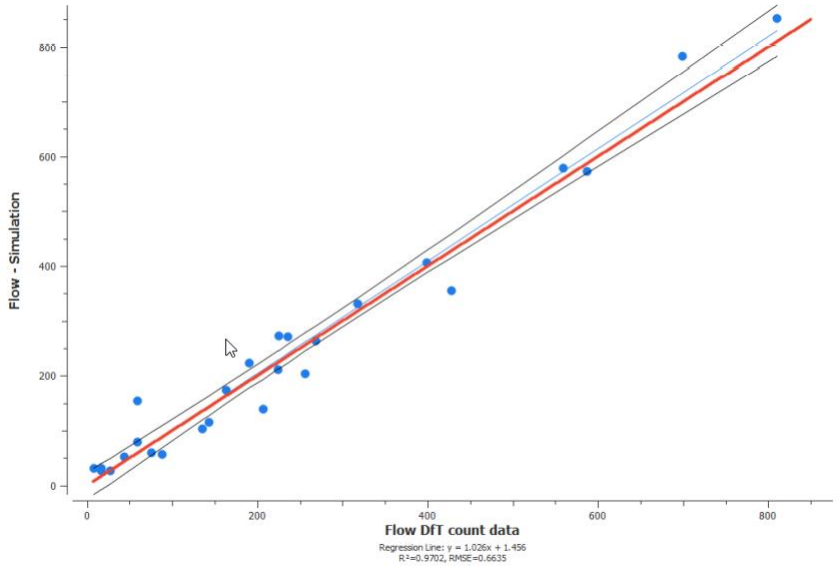
Ride-sharing services drop off and pick up

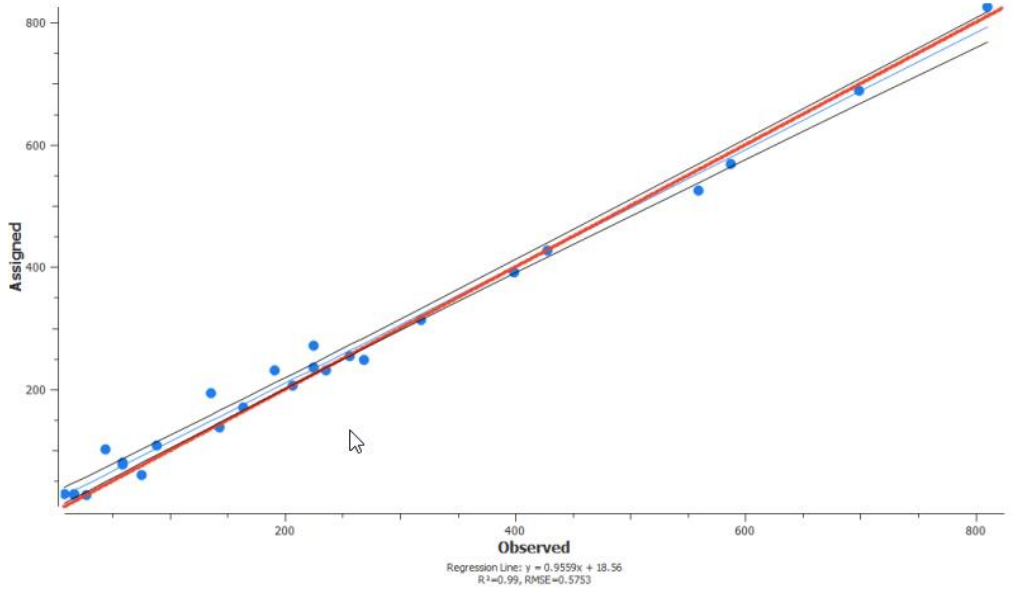
Rental car drop off and pick up

LCY model - Simulation

LCY model - Validation

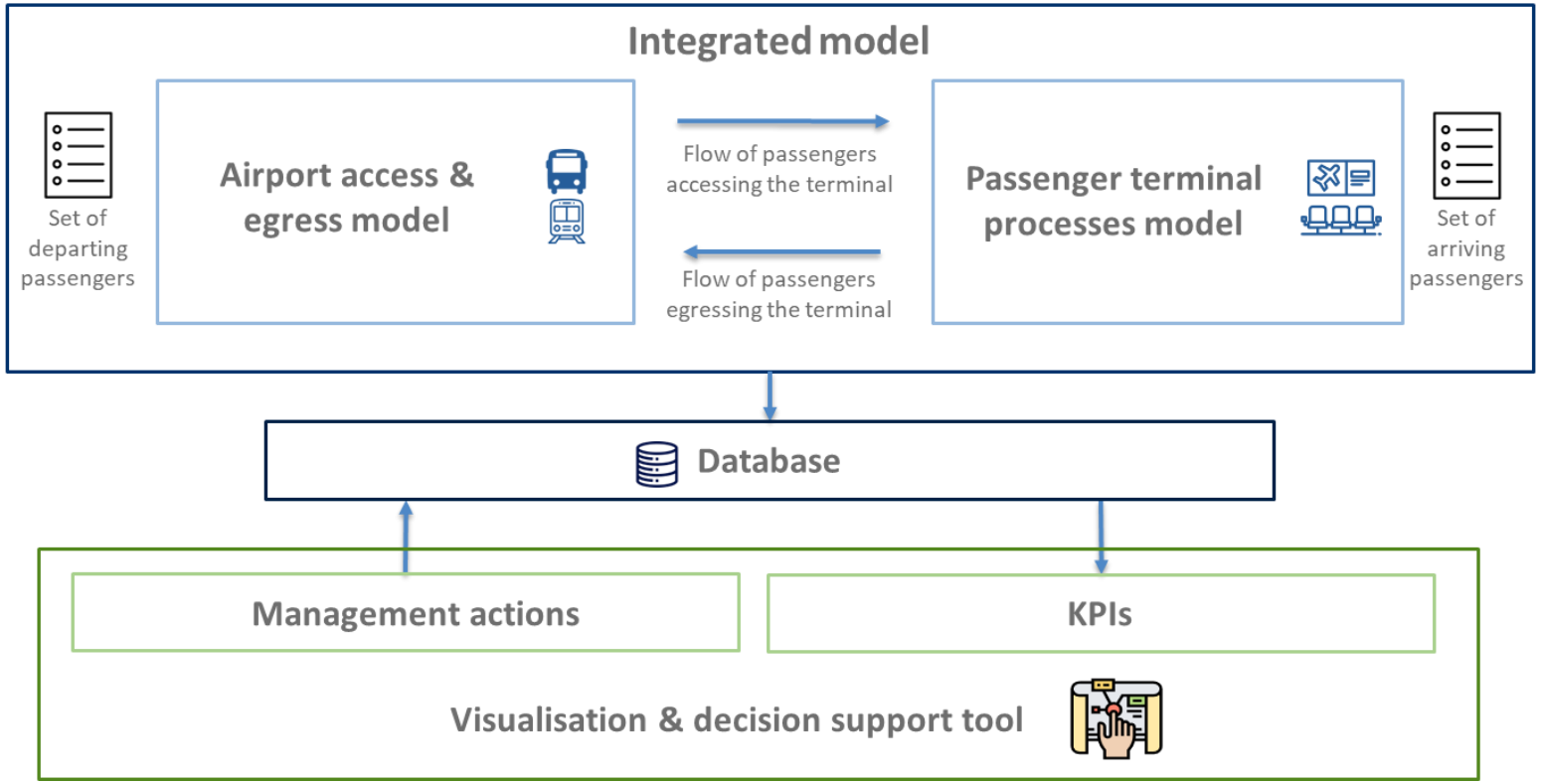
- Validation that observed flows at traffic detectors are consistent to those of the simulation environment
- Traffic detector data obtained from UK DfT open data
- Due to the network reduced size the calibration has a higher RMSE





Model integration

- Integration of access/egress and terminal models so each model can take as input the outputs of the other model

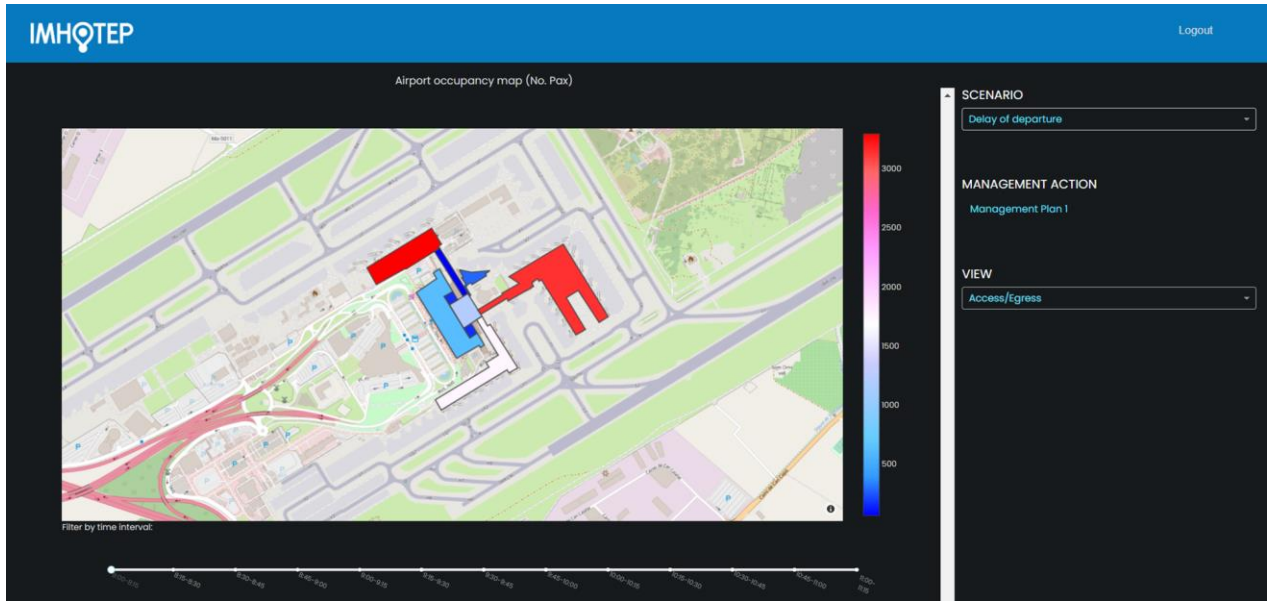


Decision support tool

Integrated Multimodal Airport Operations for Efficient Passenger Flow Management

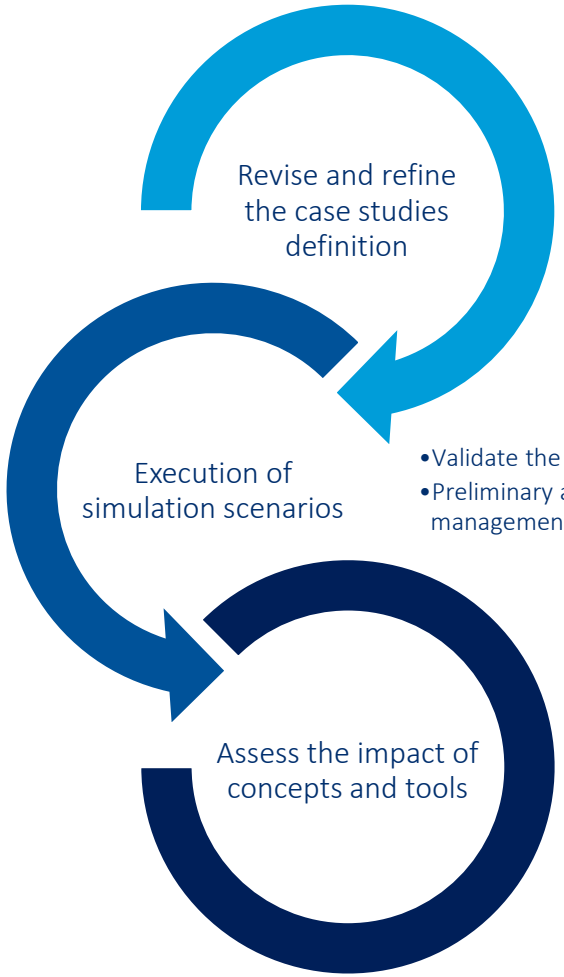
Development of a DST able to:

- Present to the user a set of KPIs, defined in close collaboration with airports and ground transport stakeholders
- Assess the operational impact of different passenger flow management measures



KPI	How to measure it?	Aggregation	Segmentation	Visualisation
Access/egress model				
Modal share	Percentage of users choosing each transport mode.	Total time window	- Passengers/Staff - Business/Leisure - Residents/Non resident	Stacked bar plot
Travel times	Probability distribution of the door-to-gate/gate-to door travel times broken down by terminal and access/egress.	Total time window	- Destination/Airline - Flight time	Histogram (bar plot)
CO_2 emissions	Total CO_2 emissions per unit of time	Total time window	N/A	Bar plot
Occupancy on the PT alternatives	Number of users in the PT vehicles every hour.	Hourly	- Passengers/Staff - Business/Leisure - Resident/Non resident	Bar plot
Productivity of the ground side transportation	Simulation totals of the passengers-km travelled by mode.	Mode of transport	- Passenger/Staff - Business/Leisure - Resident/Non resident	Bar plot
Waiting time (PT options only)	Probability distribution of the waiting time for the PT alternatives.	Total time window	N/A	Histogram (bar plot)
Terminal model				
Queuing time at the terminal facilities	Evolution of the passenger waiting time at the airport facilities.	15 minutes	- Destination - Airline	Line plot
Facilities throughput	Evolution of the passenger throughput at the airport facilities.	15 minutes	N/A	Line plot
Occupancy at airport areas	Evolution of the occupancy in the different airport areas. Occupancy is defined as: $\sum_{p=0}^{n\_pax} \frac{time\ spend\ in\ the\ area_p}{time\ interval}$ where *n_pax* is total number of passengers (*p*)	15 minutes	- Destination - Business/Leisure	Line plot and heatmap
Dwelling times at the airport areas	Evolution of the dwelling time in the different airport areas	15 minutes	- Destination - Business/Leisure	Line chart including percentiles
Missed flights	Number of passengers that missed their flights	Transport mode	- Cause (flight lost at check-in or at gate) - Flight number/Airline	Bar plot

Evaluation of the concept and the tools



Validate ConOps
Determine simulation capabilities
Initial use case conceptualisation
Validate with relevant stakeholders
Specification of simulation scenarios
Revise KPIs and management actions

- Validate the models' predictive capabilities
- Preliminary assessment of KPIs and management action plans

- Compare and contrast KPIs of simulation results
- Assess suitability of visualisation tool

- Palma de Mallorca
  - Third largest airport in Spain. Leisure trips dominate
  - Very high seasonality
  - Tour operators play a substantial role (including in access/egress)
  - Only accessible by road. **CDM-enabled** airport

- London City
  - Truly urban airport, constrained for expansion and air operations
  - Focus on quick passenger (and aircraft) processing
  - Wide variety of surface transport alternatives for access/egress. Public transport dominates
  - **Non-CDM** airport.

Case study refinement: Validated simulation scenarios

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Integrated Multimodal Airport Operations for Efficient Passenger Flow Management

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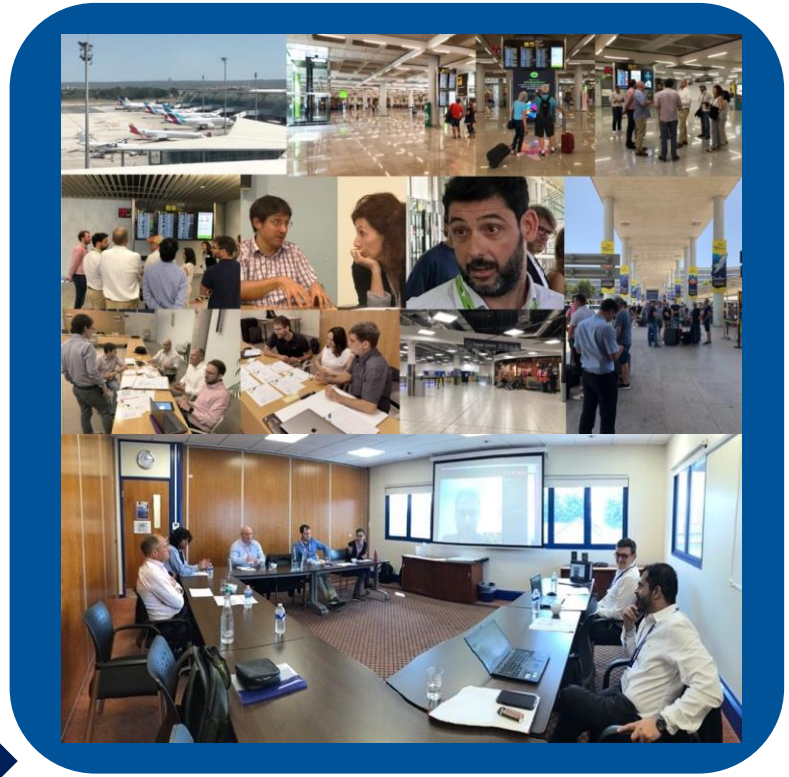
Conceptualisation of case studies

Validation workshops

Specification of simulation scenarios




Delay of arriving flights


Delay of departing flights


Disruption in surface transport

Management action plan

Delay of arrivals

- Open more manual passport control lanes
- Change frequency of public transport [PMI]
- Open Hartmann Road for taxis [LCY]

Delay of departures

- Inform passengers to delay their arrival to the airport
- Change frequency of public transport [PMI]
- “Fast track” security for delayed passengers [PMI]

Disruption in surface access

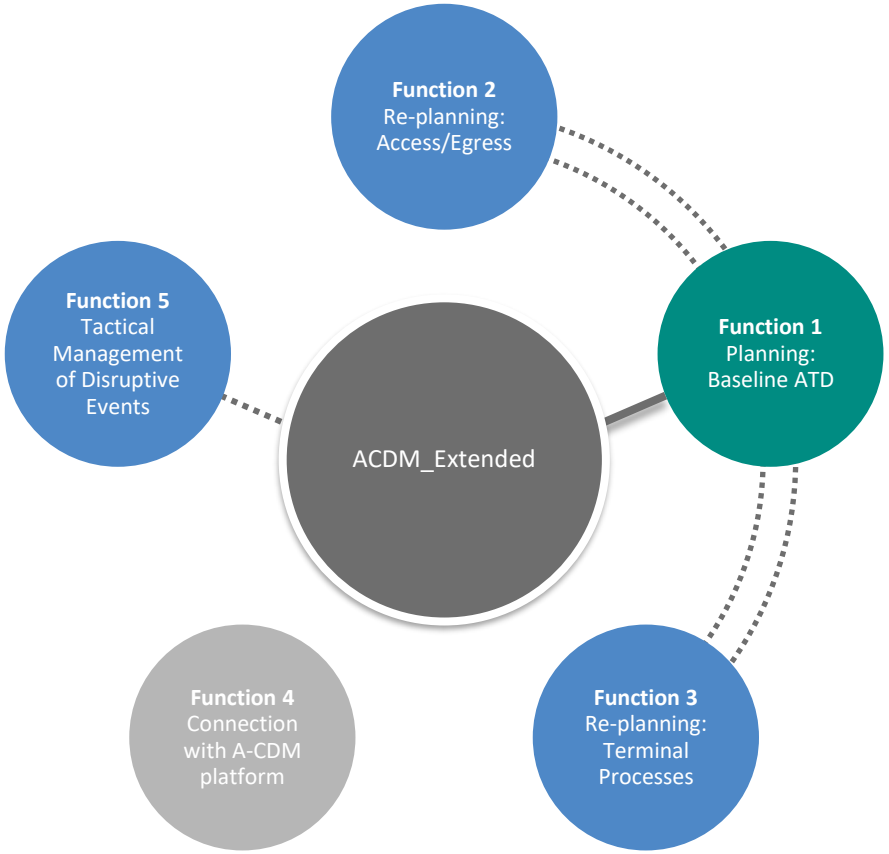
- Open Hartmann Road for taxis [LCY]
- Inform passengers to anticipate their arrival to the airport
- “Fast track” security for delayed passengers [PMI]

Results: Validation of the concept

Clearly stated acceptance of the proposed concept of operations at both validation meetings.

The more 'passenger-centric' treatment of the entire journey involving both land and air elements and processes was highly appreciated.

- ✓ Function 1: integration of the different data sources and simulation models
- ✓ Function 2 and Function 3: implemented off-line as different simulation instances were created to represent actions that resulted in the re-planning of both terminal processes and access/egress alternatives
- ✓ Function 5: implemented conceptually and off-line as the final simulation scenarios chosen were selected from disruptive events that determined the management actions



Results: Assessment of simulation scenarios (I)

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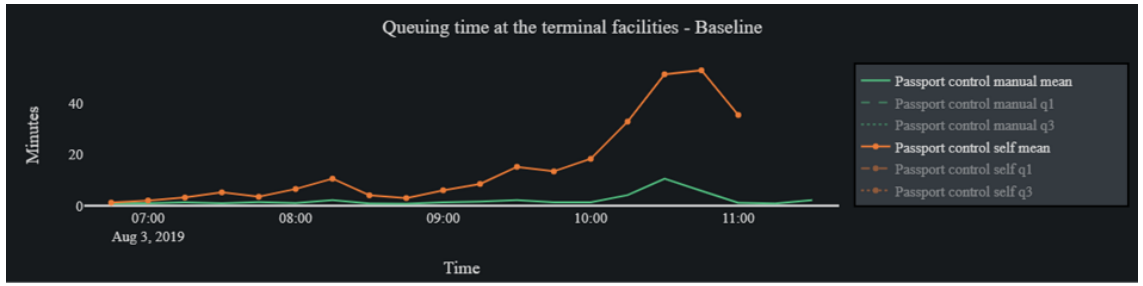
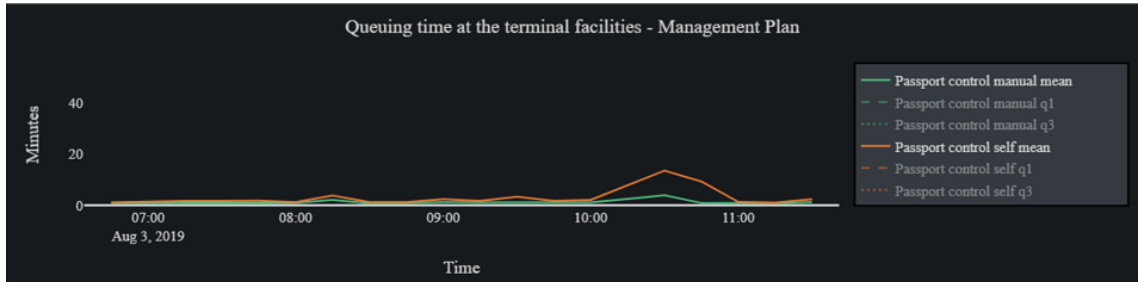
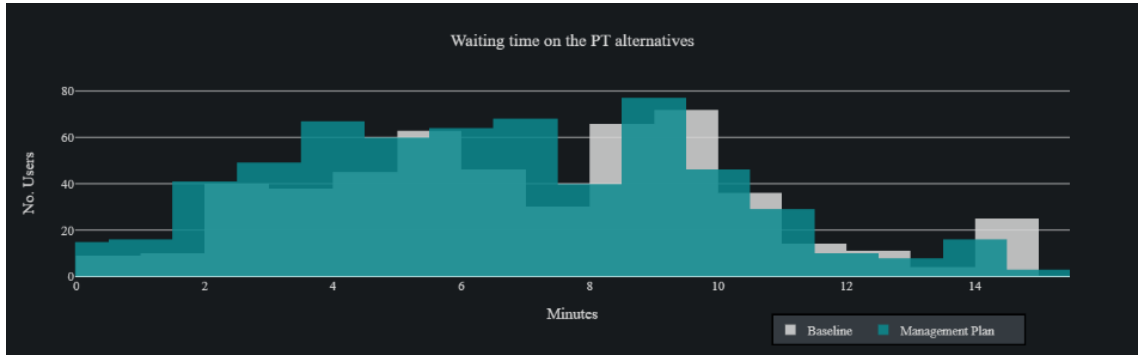
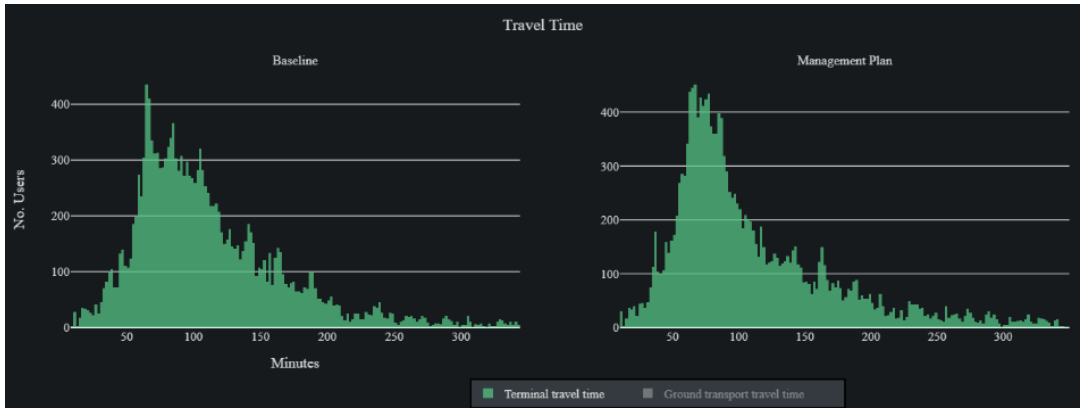
Delay of arriving flights

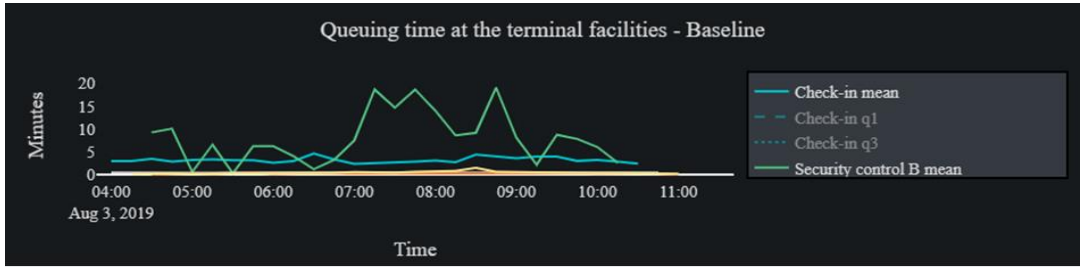






Delay of departing flights





Results: Assessment of simulation scenarios (II)

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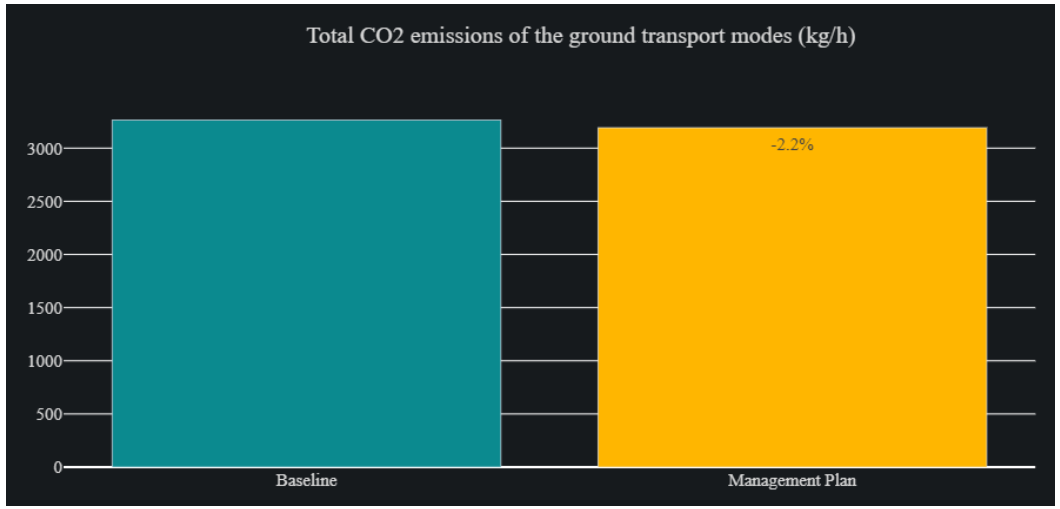
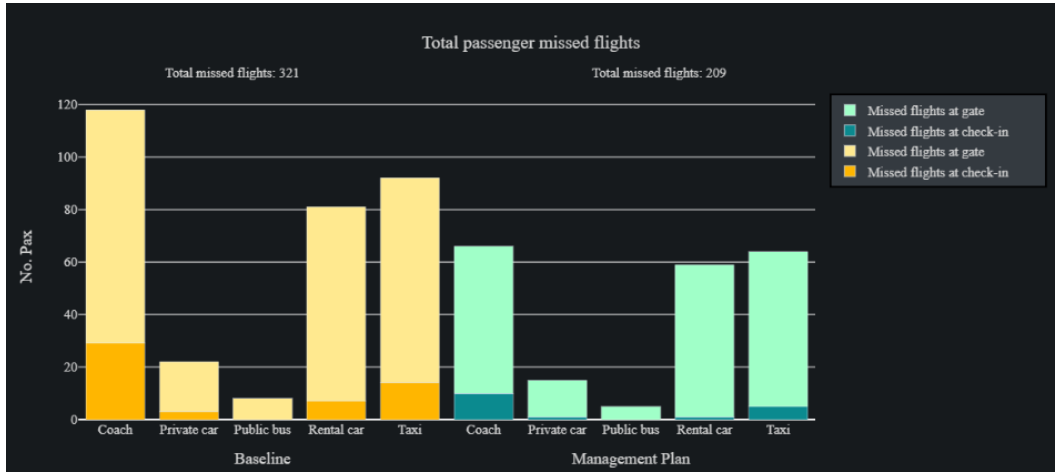
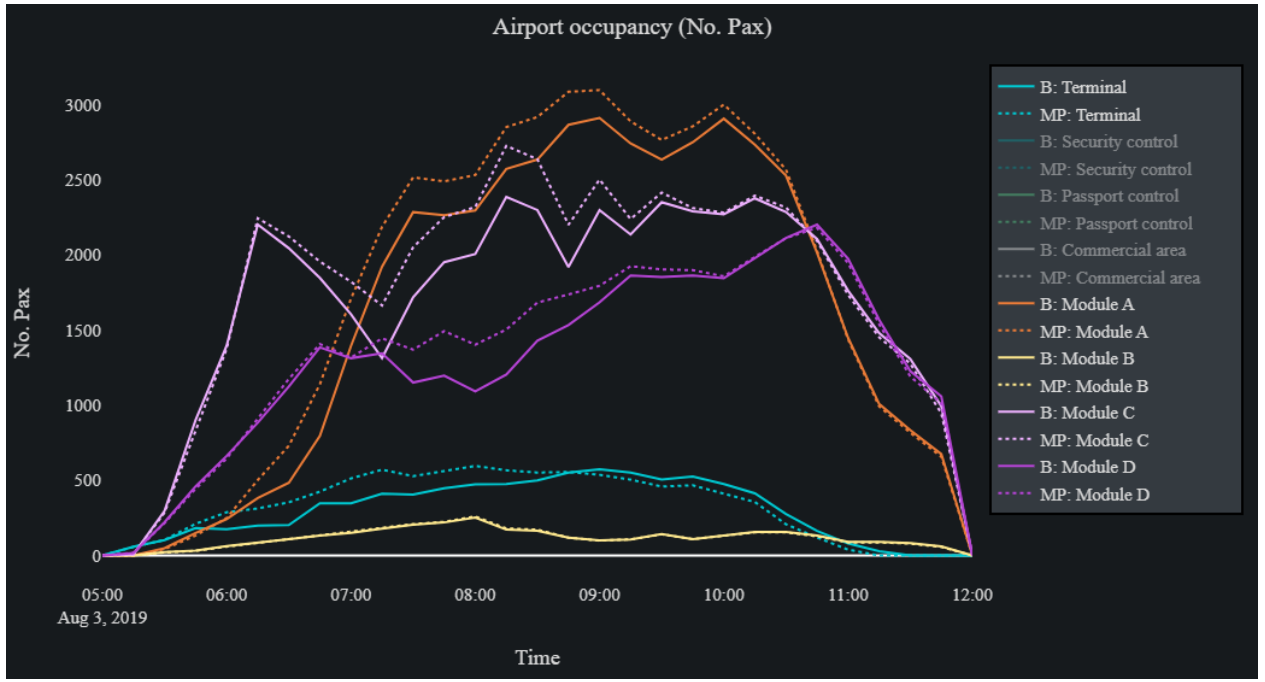
Disruption in the surface access







Results: Summary

- The scenarios presented different management challenges for the airport and ground transport stakeholders
- Each scenario demonstrated that the holistic view of the passenger flows and the coordination between the airport and the ground transport contributed to the improvement of the conditions on the transport system
- This brings significant benefits to the involved stakeholders, the passengers and the environment:
  - **Shortening of passenger waiting times** in the surface (waiting time for the PT and reduction of congestion) and the airport terminal (waiting time at the airport facilities) and **overall travel times**
  - **Reduction in the number of flights missed** due to disruptions
  - **Reduction of the congestion** on the surface, leading to a **reduction of the CO_2 emissions**
  - Better predictability of the passenger flows and the overall transport network performance, allowing the involved stakeholders to better allocate their resources

Improvement on **passenger experience**

- Improvement of the **Operational Efficiency**, **Cost-Efficiency** and **Capacity**
- Improvement of the **service provided** to the passengers

IMHOTEP Solution proposal

IMHOTEP Solution

SESAR ATM Solution Name:
Multimodal Collaborative Decision Making based on Advanced Passenger Flow Prediction

SESAR Solution Description:
Multimodal Collaborative Decision Making based on Advanced Passenger Flow Prediction enables collaborative decision-making involving both air transport and ground transport stakeholders with the aim of facilitating a more efficient management of passenger flows and enhancing passenger experience. Data on airport and surface transport operations is integrated with passenger mobility data collected from personal mobile devices to measure door-to-gate and gate-to-door passenger itineraries and provide real-time forecasts of the evolution of passenger flows under different possible management actions, supporting airports and ground transport operators in the task of determining the course of action that maximises the quality, efficiency and sustainability of the passenger journey.

Performance Benefits:
The solution will provide benefits in terms of Operational Efficiency (On-time Performance and Predictability) and Resilience — thanks to more predictable passenger flows, which will result in a reduction of the delays caused by passengers — and will also improve Airspace User Cost Efficiency, as higher predictability will help AUs optimise their operations (e.g., waiting rules for delayed passengers).

Additionally, the solution will deliver benefits for ground transport stakeholders, by improving the Operational Efficiency, Cost Efficiency, Resilience, Environment and Safety of their operations, as well as for the passengers, enhancing the Efficiency, Predictability and Resilience of the door-to-door journey.

IMHOTEP Solution

Sub-operating environment:
Airport

OI step: Multimodal Collaborative Decision Making based on Advanced Passenger Flow Prediction:
Multimodal Collaborative Decision Making based on Advanced Passenger Flow Prediction enables the participation of ground transport operators in airport collaborative decision making. By providing air and ground transport stakeholders with a shared, accurate view of the door-to-gate and gate-to-door passenger flows, the OI facilitates real-time coordinated decision making across transport modes based on a common understanding of the impact of operational decisions on the performance of the multimodal transport chain and ultimately on the passenger.

Enabler:
Integration with airport and ground transport information systems providing the required input data.
Decision Support Toolset which includes: (i) data analytics solution for the measurement and characterisation of passenger flows; (ii) predictive models able to short-term forecast passenger itineraries both in the access/egress legs and in the airport terminal; (iii) visualisation and decision support tool that allows the involved stakeholders to perform 'what-if' analyses and assess the impact of different management actions in order to determine the optimal course of action.

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THANK YOU FOR YOUR ATTENTION

EUROPEAN PARTNERSHIP

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