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Regional-Scale Multi-Modal Service Optimization for Innovative Air Mobility

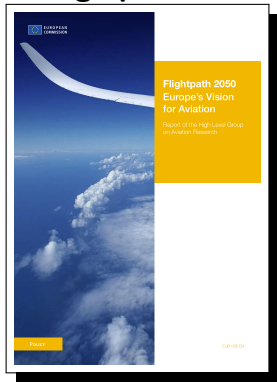
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Ecole Nationale de l'Aviation Civile

Overview

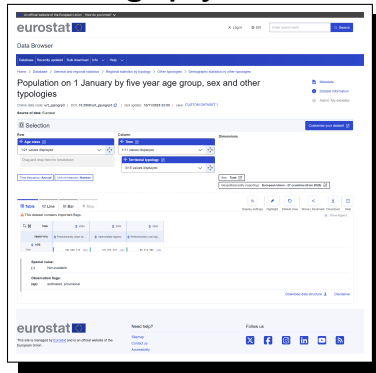
Background

Flightpath2050



Goal: 90% of travelers within Europe are able to complete their journey, door-to-door within 4 hours.

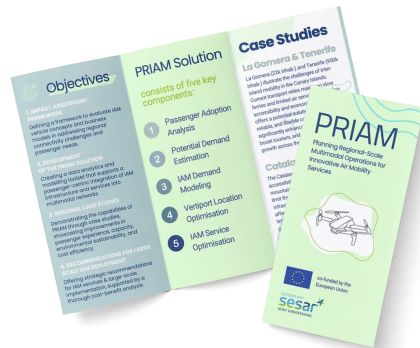
Demography statistics



Challenge: 19.2% of the population lives in rural areas with limited accessibility.

To improve rural accessibility, the SESAR Joint Undertaking launched **PRIAM**: Planning Regional-Scale Multimodal Operations for Innovative Air Mobility (IAM) Services.

- IAM expands Urban Air Mobility (UAM) beyond cities;
- IAM improves connectivity with minimal infrastructure vs traditional modes;
- etc.



IAM integration in multi-modal networks reduces to two **NP-hard** problems:

Directed Steiner Tree Problem

IAM dispatching:

IAM must connect multiple OD pairs by constructing a minimum-cost directed tree.

Obj.: Minimize operational cost

Var.: Node & Edge selection

Multi-Commodity Flow Problem

Passenger routing:

Each passenger is a separate commodity; flows are optimized to minimize cost within vehicle capacities.

Obj.: Minimize operational cost

Var.: Flow of each commodity

Joint optimization of IAM dispatching and passenger flows mirrors ATFM, where sector configurations and traffic flows must be coordinated, making the problem more complex.

1

**Simulation
environment
establishment**

No demand
elasticity or mode-shift
analysis yet

2

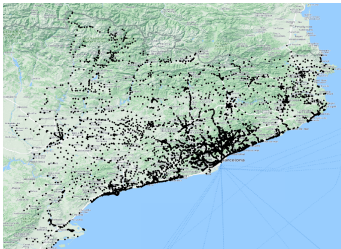
**IAM service
optimization
framework**

3

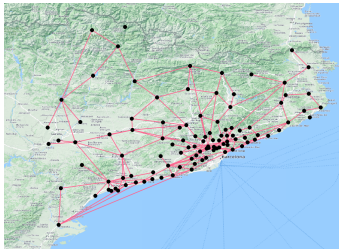
**Experiments
and
recommendations**

Simulation Environment Establishment

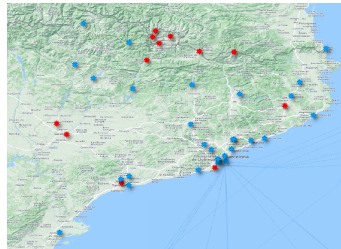
Supply modeling



collect 8742 public transport stations within the Catalan Pyrenees



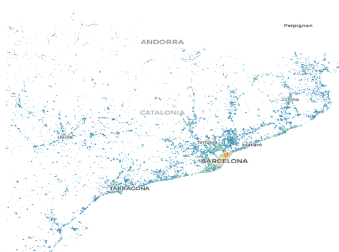
construct a public transport network graph and **compress** nodes with Leiden



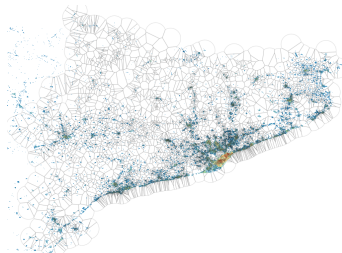
configure potential vertiports
★: projected IAM use cases
★: existing heliports

Simulation Environment Establishment

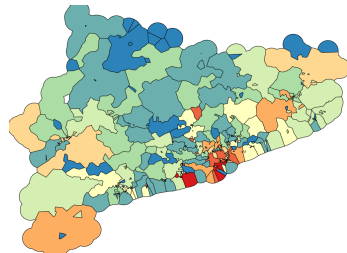
Demand modeling



acquire population distribution
of the Catalan Pyrenees



assign populations to
stations/vertiports via Voronoi



aggregated Voronoi regions
based on node compression

Demand between nodes estimated using the **Radiation Model** based on population and distance. While it ignores demand elasticity or mode shifts, it is sufficient for preliminary research.

No demand elasticity or mode-shift analysis yet

2

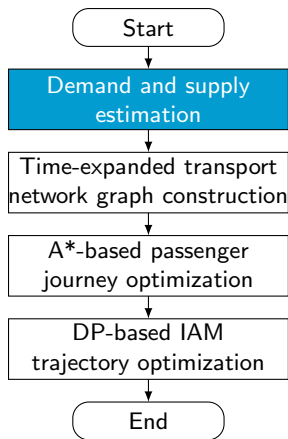
Approximate
optimization for improved
computational awareness

3

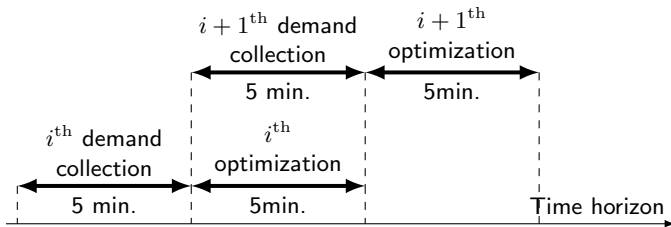
Experiments and recommendations

IAM Service Optimization framework

Staggered rolling time horizon strategy

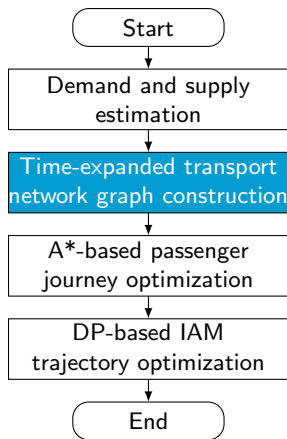


Compute demand and supply information with a **staggered rolling time horizon strategy**.

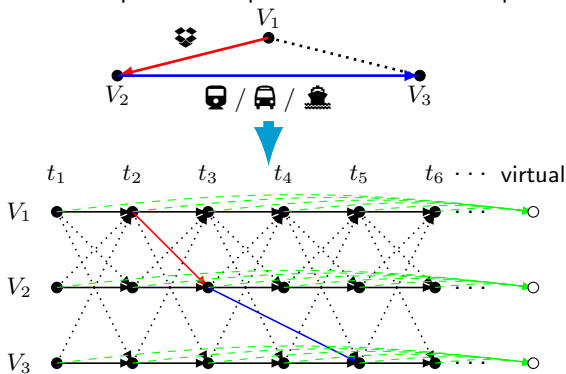


IAM Service Optimization framework

Time-expanded transport network graph

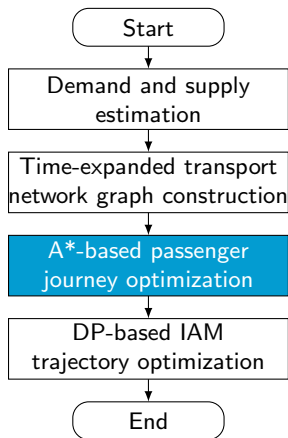


Each column represents the set of nodes at a particular time step.
Each row corresponds to a specific node across multiple time steps.



IAM Service Optimization framework

A*-based passenger journey optimization



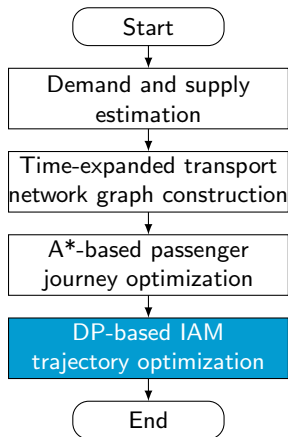
Run A* on the **time-expanded transport network graph** (Directed Acyclic Graph).

$$\text{edge cost: } c_{i,j,k} = \lambda_k \cdot \eta_{i,j} \cdot \xi_{i,j,k} \cdot \zeta_{i,j} \cdot \tau(V_i, V_j)$$

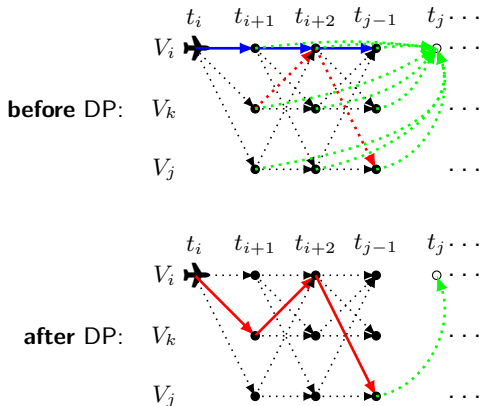
λ_k	attenuation coefficient decreases with time
$\eta_{i,j}$	mobility requirement coefficient decreases when stationary
$\xi_{i,j,k}$	supply-demand coefficient decreases when supply is high
$\zeta_{i,j}$	air-ground cost ratio (ground cost=1, air cost= Υ)
$\tau(V_i, V_j)$	travel time from V_i to V_j

IAM Service Optimization framework

DP-based IAM trajectory optimization



Apply Dynamic Programming (DP) on the Directed Acyclic Graph to dispatch IAMs and better satisfy passenger demand.



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 ENAC

Simulation environment establishment

No demand elasticity or mode-shift analysis yet

IAM service optimization framework

Approximate
optimization for improved
computational awareness

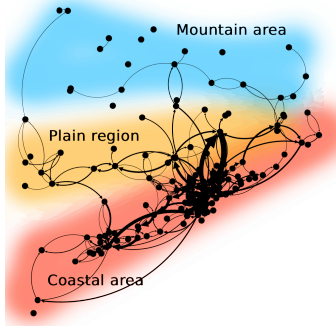
Experiments and recommendations

Catalan Pyrenees
3000 travel demand
from 8AM to 9AM

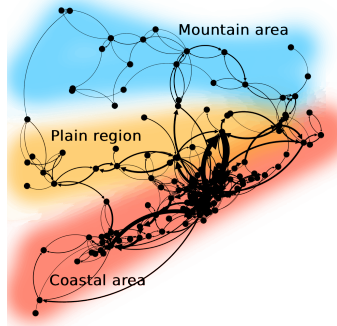
Experiments and Recommendations

Accessibility improvement

Accessibility without IAM



Accessibility with 50 IAM



Targeted coverage:

Improved accessibility in remote areas; minimal change in urban regions.
(Urban areas have cheaper transport options, making IAM less likely to be chosen.)

Experiments and Recommendations

Demand met rate improvement

Enhancement of multi-modal services enabled by IAM
(IAM capacity = 10, unit distance cost ratio=20)

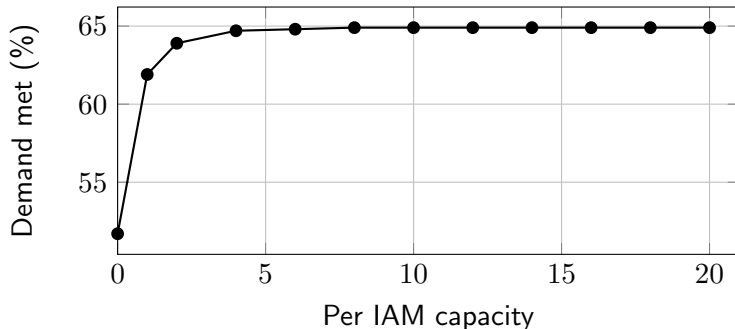
IAM fleet	Ground only passengers	IAM-served passengers	Demand met (%)	Ave. Opt. time per round(s)
0	1550	0	51.7%	57
10	1546	291	61.2%	52
20	1542	360	63.4%	52
30	1542	380	64.1%	64
40	1542	386	64.3%	56
50	1542	405	64.9%	60

Demand fulfillment:

IAM integration in multi-modal networks allows a larger share of passenger demand to be met. (Thanks to improved accessibility in remote areas.)

Experiments and Recommendations

IAM capacity recommendation

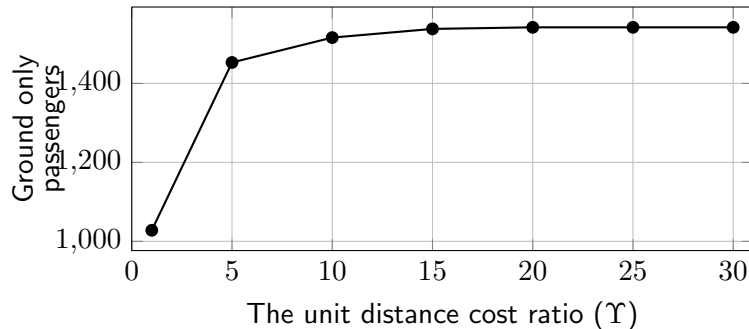


Diminishing capacity returns:

Increasing IAM passenger capacity offers limited benefits, as the low population density means large-capacity IAMs are unnecessary.

Experiments and Recommendations

Pricing policy recommendation



Ground travel per unit distance costs 1.

IAM travel per unit distance costs Υ .

Cost-based competition control:

To prevent IAM from directly competing with existing transport modes, its per-distance cost should be set to roughly twenty times that of ground transportation.

Contribution

1. Establish a simulation environment (simple yet sufficient)
2. Develop an optimization framework for IAM services (efficient and scalable)
3. Conduct experiments and summarize key recommendations (insight-oriented)

Future Work

1. Enhance simulation fidelity to generate more accurate recommendations.
2. Incorporate environmental assessments to support sustainable and responsible aviation development;

Thank you for your attention.

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