DES HE SESAR solution 0515 Exploratory Research Report

Deliverable ID:	**D4.2**
Project acronym:	**PRIAM**
Grant:	**101167262**
Call:	**HORIZON-SESAR-2023-DES-ER-02**
Topic:	**WA1-6**
Consortium coordinator:	**Nommon**
Edition date:	**3 July 2026**
Edition:	**02.01**
Template edition:	**01.00.00**
Status:	**Official**
Classification:	**PU**

Abstract

This Exploratory Research Report presents the validation results of the PRIAM Solution, a TRL1 Exploratory Research project that developed and validated an integrated methodology for assessing the feasibility of regional Innovative Air Mobility (IAM) services in Europe. Through six interlinked validation exercises, the project built an end-to-end pipeline and validated it in two contrasting case studies: the Catalan Pyrenees, representing mountainous-region connectivity, and the La Gomera–Tenerife corridor in the Canary Islands, representing inter-island connectivity.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Authoring & approval

Author(s) of the document

Organisation name	Date
Nommon	30/06/2026
Deep Blue	30/06/2026
HAIKAI	30/06/2026
TML	30/06/2026
ENAC	30/06/2026

Reviewed by

Organisation name	Date
Nommon	30/06/2026
Deep Blue	03/07/2026
HAIKAI	03/07/2026
TML	03/07/2026
ENAC	03/07/2026
Bluenest	03/07/2026
ARC	03/07/2026
AdC	03/07/2026

Approved for submission to the SESAR 3 JU by

Organisation name	Date
Nommon	03/07/2026

Rejected by[1]

Organisation name	Date

[1] Representatives of the beneficiaries involved in the project

© –2023– SESAR 3 JU

Document history

Edition	Date	Status	Organisation author	Justification
00.01	30/06/2026	Draft	Nommon	Initial draft consolidating the inputs from all the partners and based on version 01.00 of D3.2 ERR interim version.
01.00	03/07/2026	Final	Nommon	Final version including corrections from all the partners.

Copyright statement

© 2026 – PRIAM Consortium. All rights reserved. Licensed to SESAR 3 Joint Undertaking under conditions.

Disclaimer

The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR 3 Joint Undertaking be responsible for any use that may be made of the information contained herein.

PRIAM

PLANNING REGIONAL-SCALE MULTIMODAL OPERATIONS FOR INNOVATIVE AIR MOBILITY SERVICES

PRIAM

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101167262 under European Union's Horizon Europe research and innovation programme.

© –2023– SESAR 3 JU

Table of contents

1 Executive summary 17

2 Introduction 19

2.1 Purpose of the document 19

2.2 Intended readership 19

2.3 Background 19

2.4 Structure of the document 20

2.5 Glossary of terms 21

2.6 List of acronyms 21

3 Context of the exploratory research report 23

3.1 Project / SESAR solution 0515: a summary 23

3.2 Summary of the exploratory research plan 25

3.2.1 Exploratory research plan purpose 25

3.2.2 Summary of validation objectives and success criteria 26

3.2.3 Validation assumptions 30

3.2.4 Validation exercises list 33

3.3 Deviations 40

3.3.1 Deviations with respect to the S3JU project handbook 40

3.3.2 Deviations with respect to the exploratory research plan (ERP) 40

4 Validation results 41

4.1 Summary of project / SESAR Solution 0515 validation results 41

4.2 Detailed analysis of project / SESAR solution validation results per validation objective 46

4.2.1 OBJ-0515-TRL1-ERP-001 results 46

4.2.2 OBJ-0515-TRL1-ERP-002 Results 46

4.2.3 OBJ-0515-TRL1-ERP-003 Results 47

4.2.4 OBJ-0515-TRL1-ERP-004 Results 47

4.2.5 OBJ-0515-TRL1-ERP-005 Results 48

4.2.6 OBJ-0515-TRL1-ERP-006 Results 48

4.2.7 Results on liability and human factors 49

4.3 Confidence in validation results 51

4.3.1 Limitations of validation results 51

4.3.2 Quality of validation results 52

4.3.3 Significance of validation results 53

5 Conclusions and recommendations 54

5.1 Conclusions 54

5.1.1 Conclusions on project/ SESAR solution maturity 54

5.1.2 Conclusions on concept clarification 54

5.1.3 Conclusions on technical aspects 55

5.1.4 Conclusions on performance assessments 55

5.1.5 Conclusions on liability and human factors 56

© –2023– SESAR 3 JU

5.2 Recommendations 56
5.2.1 Recommendations for next R&I phase 56
5.2.2 Recommendations for future R&I activities 58
6 References 59
6.1 Applicable documents 59
6.2 Reference documents 59
Appendix A Validation exercise #01 report 62
A.1 Summary of the validation exercise #01 plan 62
A.2 Deviation from the planned activities 62
A.3 Validation exercise #01 results 62
A.3.1 Summary of validation exercise #01 results 62
A.3.2 Analysis of validation exercise #01 results per validation objective 63
A.3.2.1. OBJ-0515-TRL1-ERP-001 Results 63
A.3.3 Unexpected behaviours/results 76
A.3.4 Confidence in results of validation exercise #01 76
A.3.4.1. Level of significance/limitations of validation exercise results 76
A.3.4.2. Quality of validation exercises results 77
A.3.4.3. Significance of validation exercises results 77
A.4 Conclusions 77
A.4.1 Conclusions on concept clarification 77
A.4.2 Conclusions on technical feasibility 77
A.4.3 Conclusions on performance assessments 77
A.5 Recommendations 78
Appendix B Validation exercise #02 report 79
B.1 Summary of the validation exercise #02 plan 79
B.2 Deviation from the planned activities 79
B.3 Validation exercise #02 results 79
B.3.1 Summary of validation exercise #02 results 79
B.3.2 Analysis of validation exercise #02 results per validation objective 79
B.3.2.1. OBJ-0515-TRL1-ERP-002 Results 79
B.3.3 Unexpected behaviours/results 84
B.3.4 Confidence in results of validation exercise #02 84
B.3.4.1. Level of significance/limitations of validation exercise results 84
B.3.4.2. Quality of validation exercises results 85
B.3.4.3. Significance of validation exercises results 85
B.4 Conclusions 86
B.4.1 Conclusions on concept clarification 86
B.4.2 Conclusions on technical feasibility 86
B.4.3 Conclusions on performance assessments 86
B.5 Recommendations 86
Appendix C Validation exercise #03 report 88

© –2023– SESAR 3 JU

C.1 Summary of the validation exercise #03 plan 88

C.2 Deviation from the planned activities 88

C.3 Validation exercise #03 results 88

C.3.1 Summary of validation exercise #03 results 88
C.3.2 Analysis of validation exercise #03 results per validation objective 89
C.3.2.1. OBJ-0515-TRL1-ERP-003 Results 89
C.3.3 Unexpected behaviours/results 116
C.3.4 Confidence in results of validation exercise #03 116
C.3.4.1. Level of significance/limitations of validation exercise results 116
C.3.4.2. Quality of validation exercises results 117
C.3.4.3. Significance of validation exercises results 117

C.4 Conclusions 118

C.4.1 Conclusions on concept clarification 118
C.4.2 Conclusions on technical feasibility 118
C.4.3 Conclusions on performance assessments 118

C.5 Recommendations 119

Appendix D Validation exercise #04 report 120

D.1 Summary of the validation exercise #04 plan 120

D.2 Deviation from the planned activities 120

D.3 Validation exercise #04 results 120

D.3.1 Summary of validation exercise #04 results 120
D.3.2 Analysis of validation exercise #04 results per validation objective 121
D.3.2.1. OBJ-0515-TRL1-ERP-004 Results 121
D.3.3 Unexpected behaviours/results 151
D.3.4 Confidence in results of validation exercise #04 151
D.3.4.1. Level of significance/limitations of validation exercise results 151
D.3.4.2. Quality of validation exercises results 152
D.3.4.3. Significance of validation exercises results 152

D.4 Conclusions 153

D.4.1 Conclusions on concept clarification 153
D.4.2 Conclusions on technical feasibility 154
D.4.3 Conclusions on performance assessments 154

D.5 Recommendations 155

Appendix E Validation exercise #05 report 156

E.1 Summary of the validation exercise #05 plan 156

E.2 Deviation from the planned activities 156

E.3 Validation exercise #05 results 156

E.3.1 Summary of validation exercise #05 results 156
E.3.2 Analysis of validation exercise #05 results per validation objective 157
E.3.2.1. OBJ-0515-TRL1-ERP-005 Results 157
E.3.3 Unexpected behaviours/results 185
E.3.4 Confidence in results of validation exercise #05 186
E.3.4.1. Level of significance/limitations of validation exercise results 186

© –2023– SESAR 3 JU

Co-funded by the European Union

E.3.4.2. Quality of validation exercises results 187
E.3.4.3. Significance of validation exercises results 187

E.4 Conclusions 188
E.4.1 Conclusions on concept clarification 188
E.4.2 Conclusions on technical feasibility 188
E.4.3 Conclusions on performance assessments 188

E.5 Recommendations 189

Appendix F Validation exercise #06 report 190

F.1 Summary of the validation exercise #06 plan 190

F.2 Deviation from the planned activities 190

F.3 Validation exercise #06 results 190
F.3.1 Summary of validation exercise #06 results 190
F.3.2 Analysis of validation exercise #06 results per validation objective 191
F.3.2.1. OBJ-0515-TRL1-ERP-006 Results 191
F.3.3 Unexpected behaviours/results 222
F.3.4 Confidence in results of validation exercise #06 222
F.3.4.1. Level of significance/limitations of validation exercise results 222
F.3.4.2. Quality of validation exercises results 223
F.3.4.3. Significance of validation exercises results 223

F.4 Conclusions 223
F.4.1 Conclusions on concept clarification 223
F.4.2 Conclusions on technical feasibility 224
F.4.3 Conclusions on performance assessments 224

F.5 Recommendations 224

List of figures

Figure 1. PRIAM framework 23

Figure 2. PRIAM Solution components 24

Figure 3. Graphical representation of the Catalan Pyrenees (left) and La Gomera-Tenerife (right) case studies 25

Figure 4. OBJ-0515-TRL1-ERP-001 methodology 63

Figure 5. Extraction mobility patterns from MND 89

Figure 6. Trip purpose identification methodology 90

Figure 7. Monthly trips between Tenerife and La Gomera (both directions) in 2024 91

Figure 8. Proportion of passengers travelling from Tenerife (upper) to La Gomera (bottom) by ferry (left) and plane (right) 92

© –2023– SESAR 3 JU

Figure 9. Trip flows between Tenerife–La Gomera connection (left) and intra-Gomera (right), segmented by transport modes (ferry in blue; air and road in orange). 93

Figure 10. Demand distribution on the ferry routes between Tenerife and La Gomera 94

Figure 11. Sociodemographic information of the travellers between Tenerife and La Gomera 95

Figure 12. Model calibration results for the Canary Islands case study. Confusion Matrix (left) and Precision-Recall Curve (right) 96

Figure 13. Feature importance for the Canary Islands model..... 97

Figure 14. Share of business trips by day of the week at Canary Islands..... 98

Figure 15. Distribution of business trips by age range at Canary Islands..... 98

Figure 16. OSM network in Tenerife (left) and La Gomera (right) 99

Figure 17. comparison between the travel cost of the trip Tenerife-La Gomera is presenting depending whether the passenger travel by plane or ferry and whether is a Canarian resident or not 101

Figure 18. Monthly trips to and from the Catalan Pyrenees in 2024..... 101

Figure 19. Monthly trips to the municipality of Baqueira in 2024 102

Figure 20. Catalan Pyrenees 102

Figure 21. Trips to the Catalan Pyrenees 103

Figure 22. Origin of the trips to the Catalan Pyrenees within Catalonia..... 103

Figure 23. Origin of the trips to the Catalan Pyrenees within Spain (excluding Catalonia) 104

Figure 24. Passenger flows between the two main urban areas (Barcelona and Lleida) and the Catalan Pyrenees (left), and the intra-regional flows within the Catalan Pyrenees (right), segmented by mode. 104

Figure 25. Model calibration results for the Catalan Pyrenees case study. Confusion Matrix (left) and Precision-Recall Curve (right) 105

Figure 26. Feature importance for the Catalonia model..... 106

Figure 27. Share of business trips by day of the week in the intra-Pyrenees trips..... 108

Figure 28. Share of business trips during weekdays (left) and weekends (right) in the intra-Pyrenees trips according to the EMQ APA survey 2025 108

Figure 29. Share of business trips by day of the week in the Lleida-Pyrenees corridor 108

Figure 30. Share of business trips by day of the week in the Barcelona-Pyrenees corridor..... 109

© –2023– SESAR 3 JU

Figure 31. Share of business trips during weekdays (left) and weekends (right) in the trips between the Pyrenees and external areas according to the EMQ APA survey 2025 109

Figure 32. Share of business trips by age in all the corridors of the Catalan Pyrenees trips 110

Figure 33. Bus stops within Catalonia (left) and bus stops and routes within the study areas (right) 111

Figure 34. Main bus trips detected from MND 112

Figure 35. Modal share for trips within the Pyrenees (left) and between the Pyrenees and external areas (right) according to the EMQ APA survey 2025 113

Figure 36. OSM network in Catalonia 113

Figure 37. R3 Line between Barcelona and Puigcerdá 114

Figure 38. Average travel time from the different zones considered in the Barcelona area and the Catalan Pyrenees 116

Figure 39: Hybrid modelling framework for modal shift towards IAM 124

Figure 40: Optimised selected vertiport locations in the Canary Islands 129

Figure 41: Optimised selected vertiport locations in Catalonia 129

Figure 42. Feature importance for willingness to use IAM 134

Figure 43. IAM willingness to adopt IAM by income (a), age (b) and IAM familiarity (c) 135

Figure 44. Income per age group 136

Figure 45. Scenario 1: South of Tenerife to San Sebastián de la Gomera (~70 km) 137

Figure 46. Scenario 2: Intra-Gomera 137

Figure 47. Scenario 3: Andorra la Vella to the airport of La Seu d'Urgell (22 km) 138

Figure 48. Scenario 4: Puigcerdà to Barcelona (118km) 138

Figure 49. Scenario 5: Lleida to Andorra la Vella (124km) 139

Figure 50. Observed vs Predicted Modal share: Tenerife to San Sebastián de la Gomera 141

Figure 51. Observed vs Predicted Modal share: Intra-Gomera 141

Figure 52. Sources of Predicted IAM Users by Original Mode (Tenerife to San Sebastián de la Gomera) 142

Figure 53. Sources of Predicted IAM Users by Original Mode (Intra-Gomera) 142

Figure 54. OD flows (observation) for Tenerife to San Sebastián de la Gomera 142

Figure 55. OD flows (prediction) for Tenerife to San Sebastián de la Gomera 143

© –2023– SESAR 3 JU

Co-funded by the European Union

Figure 56. OD flows (observation) for La Gomera airport to San Sebastián de la Gomera 143

Figure 57. OD flows (prediction) for La Gomera airport to San Sebastián de la Gomera 144

Figure 58. Observed vs Predicted Modal share: intra-Pyrenees 145

Figure 59. Observed vs Predicted Modal share: Puigcerdà to Barcelona 146

Figure 60. Observed vs Predicted Modal share: Lleida to Pyrenees 146

Figure 61. Sources of Predicted IAM Users by Original Mode (intra-Pyrenees) 147

Figure 62. Sources of Predicted IAM Users by Original Mode (Puigcerdà to Barcelona) 148

Figure 63. Sources of Predicted IAM Users by Original Mode (Lleida to Pyrenees) 148

Figure 64. OD flows observed (left) and predicted (right) for intra-Pyrenees 148

Figure 65. OD flows observed (left) and predicted (right) for Puigcerdà to Barcelona 149

Figure 66. OD flows observed (left) and predicted (right) for Lleida to Pyrenees 149

Figure 67. Trip Distribution Model 150

Figure 68: Vertiport location tool high-level architecture diagram 158

Figure 69: Possible vertiport/vertihub layouts 159

Figure 70: PRIAM case study initial zonings. 160

Figure 71: PRIAM case study floor prices. 160

Figure 72: Usable days in the two PRIAM case studies 161

Figure 73. Vertiport network demand with respect to IAM price and number of vertiports. Scenarios for 2050 165

Figure 74. Vertiport network profits with respect to IAM price and number of vertiports. Scenarios for 2050 166

Figure 75. Annual demand of the vertiport network with respect to the number of vertiports for the 4€/km scenario for 2050. 167

Figure 76. Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports for the 4€/km scenario for 2050. 167

Figure 77. Location of the selected vertiports 168

Figure 78. Cost & Revenue (top) and Operational days (bottom) analysis per vertiport for the 4€/km scenario for 2050 169

Figure 79. Yearly IAM demand across the routes connecting the selected vertiports 170

© –2023– SESAR 3 JU

Co-funded by the European Union

Figure 80. Vertiport network demand with respect to IAM price and number of vertiports. Scenarios for 2035 171

Figure 81. Vertiport network profits with respect to IAM price and number of vertiports. Scenarios for 2035. 172

Figure 82. Annual demand of the vertiport network with respect to the number of vertiports for the 5€/km scenario for 2050 172

Figure 83. Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports for the 5€/km scenario for 2050 173

Figure 84. Location of selected vertiports for the 5€/km scenario for 2035 173

Figure 85. Yearly IAM demand across the routes connecting the selected vertiports 174

Figure 86. Cost & Revenue (top) and Operational days (bottom) analysis per vertiport for the 5€/km scenario for 2035 174

Figure 87: Vertiport network profits with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2050 176

Figure 88: Vertiport network demand served with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2050 176

Figure 89: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario without discount for 2050. Above figure 4€ per km and below figure 5€ per km 177

Figure 90: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario with discount for 2050. Above figure 16€ per km and below figure 20€ per km 178

Figure 91: The 8 most profitable vertiports between la Gomera and Tenerife and the respective demand between pairs for 2050. 179

Figure 92: Vertiport network demand served with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2035 180

Figure 93: Vertiport network profits with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2035 181

Figure 94: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario without discount for 2035. Above figure 4€ per km and below figure 5€ per km 182

Figure 95: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario with discount for 2035. Above figure 16€ per km and below figure 20€ per km. 183

© –2023– SESAR 3 JU

Co-funded by the European Union

Figure 96: The 7 most profitable vertiports between la Gomera and Tenerife and the respective demand between pairs for 2035. 184

Figure 97: Profits (upper) and demand (bottom) difference with respect to the same vertiport network assuming the eVTOL characteristics of 2035 and 2050. 185

Figure 98. Workflow of the validation exercise #06. 192

Figure 99. Optimisation cycle. 193

Figure 100. The framework of the heuristic method. 193

Figure 101. Time-expanded transport network graph construction 194

Figure 102. Single IAM vehicle routing with departure constraints. The blue solid edges represent the original route of the IAM vehicle. The black dotted edges denote candidate edges that the vehicle may traverse. The red dotted edges indicate high-priority edges. The red solid edges represent the optimised route of the IAM vehicle. The green dotted edges represent the auxiliary edges directed to a virtual vertex 197

Figure 103. The public transport stations within Catalan Pyrenees. Each black dot denotes a bus station. There are totally 8742 stations. 204

Figure 104. Node merging by combining functionally similar nodes. 205

Figure 105. The results of node merging process. Nodes connected by the same line are considered functionally similar and are merged together. After the merging process, there remain 6,204 nodes. 205

Figure 106. Performance variation with different resolution values. 206

Figure 107. The results of node clustering based on Leiden algorithm. Different colours denote distinct clusters. 206

Figure 108. The public transport network graph of Catalan Pyrenees. Each black dot denotes an abstract node, and each pink edge denotes an edge. The graph has 105 nodes and 152 edges. 207

Figure 109. The potential vertiports of Catalan Pyrenees. Each red star denotes a key area, and each blue star denotes a civil heliport. There are totally 42 potential vertiports in Catalan Pyrenees. 209

Figure 110. The population distribution of Catalan Pyrenees. White pixels indicate areas classified as unsettled, while coloured pixels represent settled areas. The intensity of red corresponds to population density — the deeper the red, the higher the number of people settled. 210

Figure 111. Population assignment for each node using the Voronoi diagram. 211

Figure 112. Aggregated Voronoi regions after abstract node substitution. Each merged region corresponds to an abstract node composed of multiple original nodes. The colour gradient reflects the total population within each region — the warmer the colour (e.g., red or orange), the higher the accumulated population. 212

© –2023– SESAR 3 JU

Figure 113. Key public transport services in Tenerife. 214

Figure 114. The potential vertiports of Tenerife and La Gomera. Each purple star denotes a potential vertiport. 215

Figure 115. Accessibility improvement after adopting IAM service. While coastal and plain areas experience only modest gains, mountainous areas—benefit substantially, highlighting the IAM service's pronounced impact where accessibility was previously limited. 217

Figure 116. Impact of unit distance cost ratio on demand met rate. 217

Figure 117. Time consumption of the two methods under the same scenario. 218

Figure 118. Evolution of the optimisation performance over time. 219

Figure 119. Passenger satisfaction rates across different scenarios. The denominator is the total number of passengers within three hours. 220

List of tables

Table 1. Main links to other SESAR multimodality and U-space projects 19

Table 2. Glossary of terms 21

Table 3. List of acronyms 22

Table 4. Validation objective OBJ-0515-ERP-001 27

Table 5. Validation objective OBJ-0515-ERP-002 27

Table 6. Validation objective OBJ-0515-ERP-003 28

Table 7. Validation objective OBJ-0515-ERP-004 29

Table 8. Validation objective OBJ-0515-ERP-005 29

Table 9. Validation objective OBJ-0515-ERP-006 30

Table 10: Validation assumptions overview 33

Table 11. Validation exercise TVAL.01.0-PRIAM-0515-TRL1 34

Table 12. Validation exercise TVAL.02.0-PRIAM-0515-TRL1 36

Table 13. Validation exercise TVAL.03.0-PRIAM-0515-TRL1 37

Table 14. Validation exercise TVAL.04.0-PRIAM-0515-TRL1 38

Table 15. Validation exercise TVAL.05.0-PRIAM-0515-TRL1 39

Table 16. Validation exercise TVAL.06.0-PRIAM-0515-TRL1 40

© –2023– SESAR 3 JU

Co-funded by the European Union

Table 17. Summary of validation exercises results 45

Table 18. Validation exercise #01 results 63

Table 19. IAM services 66

Table 20. IAM identified challenges 69

Table 21. IAM scenarios 71

Table 22. Impact assessment framework PIs and their relevance according to the EEAB 73

Table 23. PRIAM high-level requirements summary 76

Table 24. Validation exercise #02 results 79

Table 25. Stated preference survey questions 80

Table 26. Cluster results 84

Table 27. Validation exercise #03 results 88

Table 28. Model calibration results for the Canary Islands case study. Precision, recall and F-Score .. 96

Table 29. Trip purpose assignment process results to the Canary Islands trips 97

Table 30. Processing and dwell times considered in the Canary Islands case study 99

Table 31. Travel time and travel cost of the different ferry routes between Tenerife and La Gomera 100

Table 32. Travel time and travel cost of the different ferry routes within La Gomera 100

Table 33. Travel time and travel cost of the plane trips between Tenerife and La Gomera depending on the fare 100

Table 34. Model calibration results for the Catalan Pyrenees case study. Precision, Recall and F-Score 106

Table 35. Estimated share of business trips in the three analysed corridors of the Catalan Pyrenees 106

Table 36. Bus share in the three analysed corridors 112

Table 37. Distance and cost of the shortest and the longest trip possible in the R3 line 114

Table 38. Distance and cost of the different routes in the Catalan Pyrenees considered 114

Table 39. Validation exercise #04 results 120

Table 40: IAM and eVTOL assumptions 128

Table 41. MND Value of Time 131

© –2023– SESAR 3 JU

Co-funded by the European Union

Table 42. Discrete Choice model results for Canary Islands 140

Table 43. Discrete Choice model results for Catalan Pyrenees 144

Table 44. Induced Demand Model Estimation 149

Table 45. Induced Demand Model Results (Tenerife) 150

Table 46. Induced Demand Model Results (Catalonia) 150

Table 47. IAM total demand in case studies 153

Table 48. Validation exercise #05 results 156

Table 49: common parameters across simulations. 163

Table 50: eVTOL characteristics. 164

Table 51. Validation exercise #06 results 191

Table 52. Temporal information in transportation 195

Table 53. Notations 197

Table 54. Scalability of decision variables. ($\mathcal{T} \approx \mathbf{50}$, $\mathcal{V} \approx \mathbf{150}$, $\mathcal{V}$air $\approx \mathbf{50}$, $\mathcal{I} \approx \mathbf{30}$, and $\mathcal{G} \approx \mathbf{25\,000}$) 201

Table 55. Scalability of decision variables after sparsification. ($\mathcal{T} \approx \mathbf{50}$, $\mathcal{V} \approx \mathbf{150}$, $\mathcal{V}$air $\approx \mathbf{50}$, $\mathcal{I} \approx \mathbf{30}$, $\mathcal{G} \approx \mathbf{25\,000}$, and $\mathcal{A} \approx \mathbf{460}$) 203

Table 56. Geographic location data of key areas 207

Table 57. The existing civil heliport data 208

Table 58. The potential vertiport data 214

Table 59. Enhancement of multi-modal services enabled by IAM (IAM capacity = 10, unit distance cost ratio=20) 216

© –2023– SESAR 3 JU

Co-funded by the European Union

1 Executive summary

The PRIAM Solution is an innovative data analytics and modelling toolset designed to enable the passenger-centric integration of Innovative Air Mobility (IAM) services into multimodal regional transport networks across Europe. PRIAM aims to support evidence-based planning and decision-making for IAM deployment by addressing key challenges such as infrastructure coordination, demand estimation, network optimisation, and impact assessment. The solution will serve as a strategic enabler to align IAM development with broader mobility goals, fostering more resilient, efficient, and sustainable transport systems.

The project addressed this objective through six interlinked validation exercises, jointly establishing an end-to-end pipeline that links problem definition, demand characterisation, behavioural modelling, network optimisation, and multimodal coordination, and tested it across two contrasting case studies: the Catalan Pyrenees, representing IAM applications in mountainous regions, and the La Gomera–Tenerife connection in the Canary Islands, representing inter-island connectivity.

The work began by establishing the conceptual and analytical foundation for the project: through desk research, stakeholder interviews, and the 1st PRIAM Stakeholder Workshop, eight regional connectivity challenges, five types of potential IAM services, and four core deployment scenarios were identified and validated by the EEAB, alongside an Impact Assessment Framework.

Building on this foundation, PRIAM developed a methodology to characterise IAM adoption potential through stated preference surveys and unsupervised learning, identifying behavioural user segments and the key variables (privacy concerns, transport habits, environmental awareness, and multimodal travel behaviour) most influential to adoption. In parallel, the project enriched Mobile Network Data (MND) with trip-purpose and segmentation by road-mode (bus vs road), achieving strong classification performance (0.97 accuracy) and confirming MND as a reliable, scalable source of behavioural and modal data for IAM demand analysis.

This enriched mobility data fed directly into discrete choice models estimating IAM captured (modal-shift) and induced demand, calibrated separately for each case study and achieving strong statistical performance (McFadden's rho-squared of 0.648 and 0.622). Results confirmed that IAM functions as a complementary mobility option for specific corridors with poor existing connectivity, not a mass transport mode, with modal shift dominating over induced demand.

These demand outputs in turn drove the vertiport network optimisation tool, which combined MND-based demand, the calibrated logit models, and an optimisation algorithm to identify vertiport locations maximising operator profit or captured demand. The tool consistently produced coherent, explainable network configurations and identified financially viable fare ranges, meeting the performance expectations of a TRL1 proof of concept. A complementary multimodal coordination exercise compared exact and heuristic optimisation approaches for integrating IAM with ground transport, finding the heuristic method offers the more practical trade-off between solution quality and computational efficiency for real-time operational use.

Across all six exercises, results were validated through technical performance metrics, expert review, and stakeholder workshops, confirming that the PRIAM methodology behaves as a coherent, integrated whole. While certain limitations are inherent to this exploratory research maturity level, these are well understood, bounded, and do not undermine the validity of the project's conclusions.

© –2023– SESAR 3 JU

Overall, PRIAM establishes a robust, validated, and transferable methodological foundation for regional IAM planning in Europe. The project demonstrates that IAM is best understood as a targeted, corridor-specific connectivity solution rather than a mass transport mode, with seamless multimodal integration central to its viability. These findings, together with the technical and behavioural evidence base developed across the project, provide a solid platform upon which future SESAR research activities can build to support the progressive deployment of regional IAM services in Europe.

© –2023– SESAR 3 JU

2 Introduction

2.1 Purpose of the document

PRIAM is a data analytics and modelling toolset designed to support the passenger-centric integration of IAM into multimodal regional transport networks across Europe. The main objective of this document is to present the results of the validation exercises performed within the project, aiming at progressing the proposed SESAR solution from pre-TRL1 to TRL1.

The present ERR constitutes the final version of the document.

2.2 Intended readership

This document is intended for a diverse audience engaged in the development of regional IAM. It is particularly relevant to the SESAR3 Joint Undertaking and regional authorities, who can use its insights to guide strategic decisions and support IAM implementation. Potential end users such as drone operators, vertiport operators, and U-space service providers (USSPs) may benefit from the project's demand monitoring and planning tools, helping advance IAM solutions toward higher readiness levels. Policy makers and regulatory bodies can draw on PRIAM's findings to shape supportive legislation, while other SESAR projects may benefit from methodological synergies. The scientific community, especially those researching IAM and U-space, can leverage the results for further innovation.

2.3 Background

PRIAM builds on the research outputs of previous and ongoing R&I initiatives and has established cross-fertilisation links with parallel SESAR 3 projects, with particular emphasis on passenger experience, multimodality and U-space research. The PRIAM Consortium includes partners from ongoing and past SESAR multimodality projects (**MAIA**, **MultiModX, SIGN-AIR** and **Travel Wise**) and from many SESAR U-space initiatives (e.g., **MUSE**, **EUREKA**, **SPATIO**, **USEPE, Metropolis 2** and **AI4Hydrop**).

The following table outlines the main links to other SESAR multimodality and U-space projects:

Table 1. Main links to other SESAR multimodality and U-space projects

SESAR Project	Description and link to PRIAM	PRIAM partners involved
MultiModX	PRIAM builds upon the multimodal evaluation framework developed in MultiModX, extending it to IAM use cases.	Nommon, ARC
MAIA	The algorithms for modelling IAM demand and estimating the induced demand effects of IAM services using the demand modelling framework developed under the MAIA project. In PRIAM, the methodologies, insights, and modelling tools from MAIA serve as the foundation for building the IAM induced demand models. These established components have been adapted and extended to suit the regional-scale	Nommon (coordinator), TML

© –2023– SESAR 3 JU

	IAM use cases addressed in PRIAM, ensuring methodological consistency and leveraging the proven capabilities of the MAIA framework.	
SIGN-AIR	PRIAM has considered the frameworks developed by SIGN-AIR as an enabling technology for the coordination mechanisms proposed by the multimodal optimisation models.	ENAC
TRANSIT	PRIAM has used and evolved TRANSIT's set of multimodal KPIs, data analysis methods and transport simulation tools for analysing IAM services.	Nommon (coordinator), ENAC
MODUS	PRIAM build on MODUS' passenger archetypes to segment IAM demand.	ENAC
X-TEAM D2D	X-TEAM D2D developed a concept of operations for the seamless integration of ATM into a transport intermodal network to enable the D2D connectivity, including UAM services. Its outputs will be incorporated to PRIAM's conceptual framework.	-
EUREKA	EUREKA develops complete arrival, departure and turnaround processes for vertiports. EUREKA solutions will inform the IAM and vertiport operation constraints to be considered in PRIAM.	ENAC, Deep Blue, Bluenest
MUSE	PRIAM has built on the KPIs and evaluation methods developed in MUSE for understanding the impact of UAM, and has adapted them when possible to IAM regional use cases.	Nommon (coordinator)
ImAFUSA	PRIAM has considered the "Impact and capacity Assessment Framework for U-space Societal Acceptance" developed in ImAFUSA and has extended this framework to regional-scale IAM use cases	-
OperA	PRIAM has considered the operating conditions outlined by OperA in the definition of the addressed IAM services.	-
CORUS-XUAM	PRIAM has considered the most recent U-space ConOps from this project and its continuation when defining the service models and requisites for IAM operations.	-
EALU-AER	PRIAM has leveraged the human factors and social acceptance research expected within the demonstration to inform its IAM adoption models.	Deep Blue

Additionally, the dynamic analysis of population required to estimate IAM has been carried out using Nommon's Mobility Insights tool, which leverages MND for monitoring mobility patterns and travel behaviour. As part of PRIAM, this tool has been enhanced identify key characteristics relevant to assess the potential adoption of IAM services. This solution has been successfully applied and continuously improved in several previous SESAR ER projects such as **BigData4ATM**, **TRANSIT**, **IMHOTEP**, and **MultiModX**.

Beyond the SESAR programme, the algorithm for optimal vertiport location developed in the **Engage Vertiport Location** project (coordinated by Nommon) will be reused and enhanced in PRIAM. This, together with the leading position of Deep Blue in **Engage 2**, will help PRIAM incorporate the most recent relevant research.

2.4 Structure of the document

The content of this document is organised as follows:

© –2023– SESAR 3 JU

- Chapter 1 presents the executive summary of the document.
- Chapter 2 provides an introduction, including general information about the scope and objectives of this Exploratory Research Report.
- Chapter 3 provides the context of the Exploratory Research Report, describing the proposed solution, outlining the exploratory research plan, and noting any potential deviations.
- Chapter 4 provides a high-level summary of the result of the validation exercises.
- Chapter 5 presents the set of conclusions and recommendations derived from validation results.
- Chapter 6 lists the references and applicable documents.
- Appendices provide detailed information on the validation exercises.

2.5 Glossary of terms

Term	Definition	Source
eVTOL	Vertical Take-off and Landing aircraft that uses electric power to hover, take-off and land. They can be manned or unmanned (piloted remotely or autonomously).	Mixed sources
Innovative Air Mobility (IAM)	Innovative Air Mobility (IAM) refers to the integration of new aerial transport solutions into regional and urban mobility systems. This includes the use of emerging technologies such as electric vertical take-off and landing (eVTOL) aircraft, drones, and other advanced air vehicles to provide on-demand, efficient, and sustainable air transport services. IAM is particularly focused on improving connectivity in underserved regions, reducing travel times, and complementing existing ground transport networks.	Mixed sources

Table 2. Glossary of terms

2.6 List of acronyms

Term	Definition
ATM	Air traffic management
DES	Digital European Sky
EEAB	External Experts Advisory Board
EXE	Exercise
GTFS	General Transit Feed Specification
GA	Grant agreement
IAM	Innovative Air Mobility
KPA	Key performance area
KPI	Key performance indicator

© –2023– SESAR 3 JU

MND	Mobile Network Data
PI	Performance indicator
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking
TRL	Technology Readiness Level
UAM	Urban Air Mobility
USSP	U-Space Service Provider

Table 3. List of acronyms

© –2023– SESAR 3 JU

3 Context of the exploratory research report

3.1 Project / SESAR solution 0515: a summary

The European transport policy aims to connect 90% of travellers within four hours using a multimodal strategy that includes high-speed rail and air travel ([8]; [9]). While effective for inter-city connections and reducing emissions, this approach struggles to ensure accessibility in rural, mountainous, and insular areas due to high costs and environmental impacts ([10]; [11]; [12]; [13]) Novel aircraft with electric, hybrid, or hydrogen propulsion and vertical take-off and landing capabilities are emerging as promising solutions for regional connectivity; ([14]; [15]). Initially framed under Urban Air Mobility (UAM), the concept is evolving into IAM to serve rural and suburban ([16]) potentially improving multimodal integration, resilience, and environmental performance ([17]; [18]).

However, IAM still faces key uncertainties regarding integration with other transport modes, passenger acceptance, induced demand, and weather-related reliability ([19]; [20]; [21]). A multicriteria analysis is needed to address these complexities ([22]; [23]). To enable a data-driven, regional-scale implementation of IAM in Europe, the PRIAM project has been launched to fill this gap.

PRIAM aims to define an overall methodology for planning regional-scale IAM services, aiming at optimising the overall transport network. **The PRIAM Solution is structured as an integrated framework composed of four interdependent components**, as presented in Figure 1.

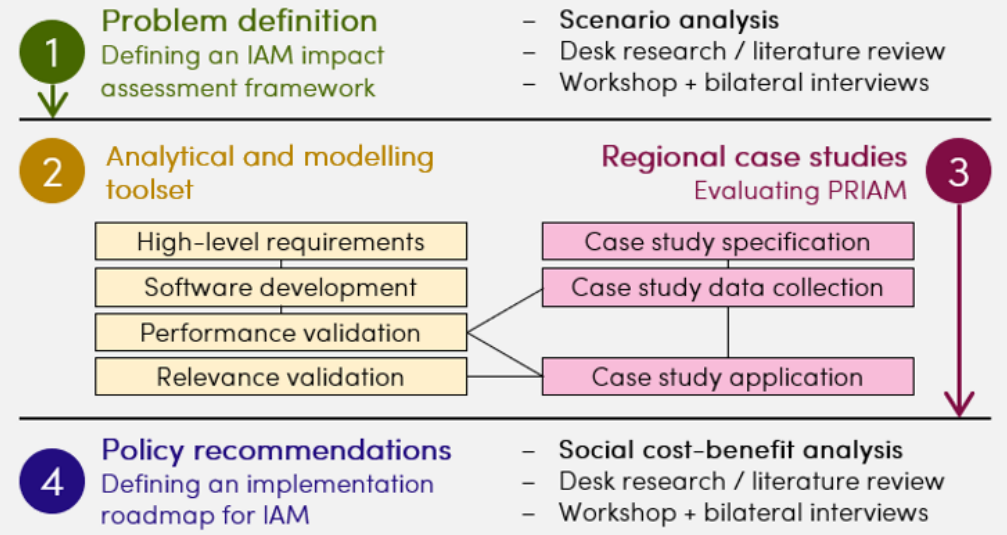


Figure 1. PRIAM framework

The components of the framework are as follows:

1. **Problem definition**. This component includes a comprehensive problem analysis, which will serve as the foundation for subsequent phases of the project. It will establish a set of **high-level requirements** that identify the key needs that IAM must address, while also guiding the technical design of the proposed solution to ensure alignment with SESAR performance objectives and regional mobility demands. It will also include the definition of an **impact assessment framework** to evaluate IAM services across key performance areas such as passenger experience, capacity, sustainability, and cost-efficiency.

© –2023– SESAR 3 JU

2. **Analytical and modelling toolset.** It is composed of five elements, as presented in Figure 2.
    - **IAM adoption models.** AI-based techniques have been used to segment potential IAM users based on survey responses, supporting clustering and profiling of user groups to better understand acceptance drivers such as cultural and geographic factors.
    - **Potential demand monitoring tools.** Geolocation big data sources such as MND have been used to monitor current mobility patterns providing a better understanding of the passenger behaviour in regional areas.
    - **IAM demand models.** Advanced discrete choice models combining the outputs from the previous components (stated preference survey data and demand data derived from MND) have been used to estimate IAM modal share by estimating modal shifts to IAM and IAM induced demand.
    - **IAM network planning support tools.** A multicriteria evaluation method has supported the robust planning of the vertiport network using demand model outputs from the previous component, but also considering other factors such as land use, weather, etc.
    - **IAM service optimisation tools.** Optimisation algorithms have been developed to synchronise IAM with ground transport modes, aiming to minimise transfer times and maximise service performance across integrated multimodal systems.

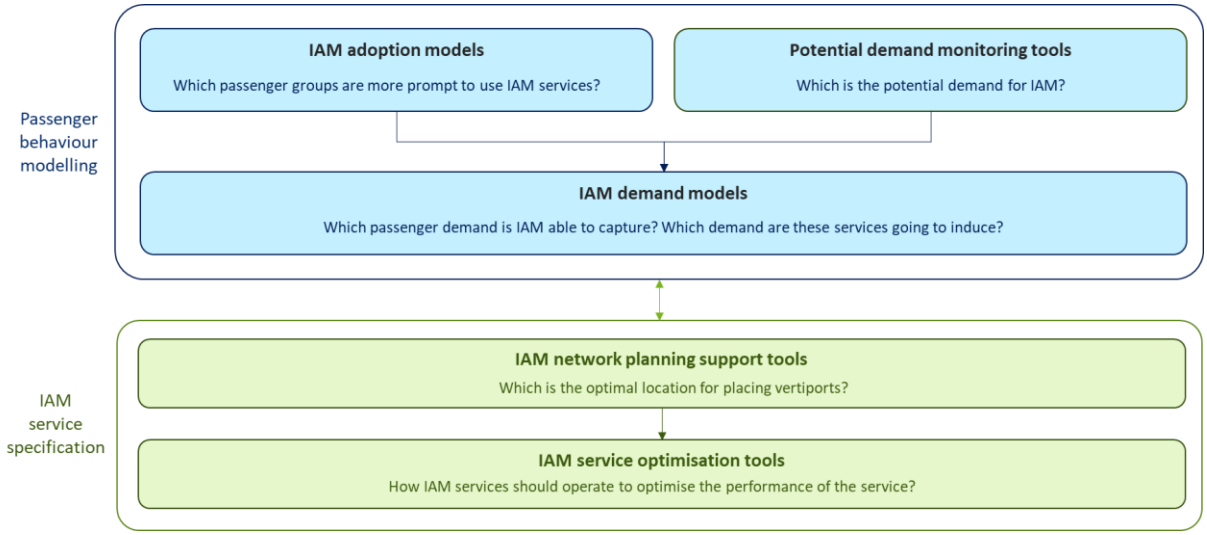


Figure 2. PRIAM Solution components

3. **Regional case studies.** This component includes the application of the PRIAM solution to a set of regional case studies across different European territories, aimed at providing real-world data and operational scenarios to test and validate the performance, flexibility, and relevance of the PRIAM tools, ensuring their applicability in diverse geographic and socio-economic contexts. Two case studies have been selected to validate the PRIAM Solution (see Figure 3):
    - The **Catalan Pyrenees**, representing a mountainous and sparsely populated area with limited transport infrastructure and significant seasonal tourism flows, making it an ideal setting to explore how IAM can enhance connectivity in complex terrains.

© –2023– SESAR 3 JU

- The **Tenerife–La Gomera** connection, focusing on inter-island mobility within an insular territory, where current transport options are constrained by geography and travel time. This scenario allows the project to assess the potential of IAM services to improve accessibility between islands and within remote communities.



Figure 3. Graphical representation of the Catalan Pyrenees (left) and La Gomera-Tenerife (right) case studies

These regions were chosen for their distinctive mobility challenges and strategic relevance to regional IAM deployment. Together, these cases provide diverse and complementary conditions to evaluate the flexibility and impact of the PRIAM Solution

4. **Policy recommendations.** Drawing on the insights gained from the results derived from the case studies, this component will deliver evidence-based policy recommendations and an implementation roadmap of regional-scale IAM services across Europe based on a social cost-benefit analysis.

The current exploratory research report focuses on presenting the validation results aimed at assessing each component of the PRIAM Solution. These exercises will evaluate the validity of the assumptions considered within the problem definition phase, the technical feasibility of the proposed solution, the expected benefits it delivers, and the robustness of the implementation roadmap.

3.2 Summary of the exploratory research plan

3.2.1 Exploratory research plan purpose

The Exploratory Research Plan has been designed to provide a thorough pathway to advance the proposed SESAR solution from pre-TRL1 to TRL1. To ensure a thorough and solid development process, the validation of PRIAM is organised into six main phases, each focusing on a key step in the research and innovation journey.

The first phase, focuses on defining the problem and developing the impact assessment framework (TVAL.01.0-PRIAM-0515-TRL1). This step lays the groundwork by identifying the main opportunities, challenges, and context for integrating IAM. It involves creating the high-level requirements and the impact assessment framework, based on both desk research and input from stakeholders.

© –2023– SESAR 3 JU

The main technical components of the project will be validated individually in Exercises 2 to 6. Each tool has undergone internal validation by project members to ensure robustness and consistency of results, followed by external validation in a stakeholder workshop. The toolkit encompasses modelling the factors influencing IAM adoption, estimating both captured and induced demand, identifying optimal vertiport locations, and analysing the integration of IAM with ground transport. These case studies will demonstrate PRIAM's capacity to generate valuable insights for real-world IAM implementation.

By completing these phases, PRIAM has reached TRL1, delivering a well-designed, data-driven toolset prepared for further advancement. The outcomes of this Exploratory Research Plan will shape future research and support a coordinated, integrated rollout of IAM throughout European regions.

Considering the target maturity level of the solution (TRL-1), the planned experiments are sufficient to validate the premised in the R&D needs outlined in Section 3.3 of the ERP. This milestone will be verified with the maturity self-assessment to be completed at the Maturity Gate. The set of questions that compose the self-assessment will help the project to monitor the achievement of the target maturity level.

For more detailed information about the ERP, please refer to latest version of PRIAM Exploratory Research Plan.

3.2.2 Summary of validation objectives and success criteria

[OBJ]

Identifier	OBJ-0515-ERP-001
Objective	To validate the high-level requirements of the PRIAM tool and the impact assessment framework for the implementation of regional-scale IAM services in Europe. To this end, the project will analyse key regional connectivity challenges, passenger needs, and emerging vehicle concepts and business models, and will define relevant implementation scenarios. This analysis will lead to the derivation of high-level requirements for data analytics and modelling tools. Based on these insights, the project will design an impact assessment framework to evaluate IAM operations across passenger experience, social, environmental, and operational dimensions, aligned with SESAR performance management approaches and related projects (e.g., MUSE, TRANSIT, MultiModX).
Title	Problem definition and development of an impact assessment framework for regional IAM services
Category	<performance>, <acceptability>, <operational feasibility>
Key environment conditions	Nominal conditions, European regional scope
TRL	TRL1

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	0515

© –2023– SESAR 3 JU

[OBJ Suc]

Identifier	Success Criterion
CRT-0515-TRL1-ERP-001.001	Identification of at least 5 challenges for regional connectivity across Europe.
CRT-0515-TRL1-ERP-001.002	Identification of at least 5 types of potential regional-scale IAM services.
CRT-0515-TRL1-ERP-001.003	Identification of at least 4 scenarios for regional-scale IAM operations in Europe.
CRT-0515-TRL1-ERP-001.004	Definition of a set of KPIs in at least 5 areas (passenger experience, capacity, environmental sustainability and operational and cost efficiency)
CRT-0515-TRL1-ERP-001.005	Identification of a set of high-level requirements for data analytics and modelling tools with implications for PRIAM developments.

Table 4. Validation objective OBJ-0515-ERP-001

[OBJ]

Identifier	OBJ-0515-ERP-002
Objective	To validate the algorithms for identifying the human factors that explain IAM adoption, based on Artificial Intelligence techniques that exploit survey data.
Title	Validation of AI algorithms for estimating IAM adoption levels
Category	<performance>, <acceptability>, <operational feasibility>, <technical feasibility>
Key environment conditions	Nominal conditions, European regional scope
TRL	TRL1

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	0515

[OBJ Suc]

Identifier	Success Criterion
CRT-0515-TRL1-ERP-002.001	The AI-based algorithms developed to identify human factors influencing IAM adoption have been validated through a combination of expert stakeholder reviews and quantitative methods, including cluster evaluation techniques and feature importance analysis, ensuring both their reliability and interpretability.

Table 5. Validation objective OBJ-0515-ERP-002

© –2023– SESAR 3 JU

[OBJ]

Identifier	OBJ-0515-ERP-003
Objective	To validate algorithms for estimating the potential demand for regional-scale IAM services from the fusion of heterogeneous data sources, including geolocation data from personal mobile devices and mobility surveys.
Title	Validation of algorithms for monitoring potential IAM demand
Category	<performance>, <acceptability>, <operational feasibility>, <technical feasibility>
Key environment conditions	Nominal conditions, European regional scope
TRL	TRL1

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	0515

[OBJ Suc]

Identifier	Success Criterion
CRT-0515-TRL1-ERP-003.001	The mobility indicators derived from the algorithms for monitoring potential demand for IAM services through the fusion of MND and other data sources are consistent with the expected mobility behaviour. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.

Table 6. Validation objective OBJ-0515-ERP-003

[OBJ]

Identifier	OBJ-0515-ERP-004
Objective	To validate the algorithms for modelling the induced demand effects and modal shifts derived from regional-scale IAM services under different territorial settings, competing transport modes and operational configurations.
Title	Validation of algorithms for estimating IAM captured and induced demand
Category	<performance>, <acceptability>, <operational feasibility>, <technical feasibility>
Key environment conditions	Nominal conditions, European regional scope
TRL	TRL1

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	0515

© –2023– SESAR 3 JU

[OBJ Suc]

Identifier	Success Criterion
CRT-0515-TRL1-ERP-004.001	The discrete choice and induced demand models are calibrated using the survey data to ensure they accurately reflect observed and potential travel behaviour. Model validation is carried out through established statistical tests for discrete choice modelling, including the likelihood ratio test, McFadden's R-squared, adjusted R-squared, and significance of estimated parameters. Predictive performance is further assessed using hold-out validation or cross-validation techniques where applicable. Models are deemed successful if they demonstrate statistical significance, robustness of estimated coefficients, and goodness-of-fit values consistent with standards in travel behaviour research. Additionally, the plausibility of induced and switching demand estimates is checked against external benchmarks and expert stakeholder review, ensuring that the models are representative of the real population and suitable for policy and planning applications.

Table 7. Validation objective OBJ-0515-ERP-004

[OBJ]

Identifier	OBJ-0515-ERP-005
Objective	To validate the algorithms for performing a multicriteria evaluation of the integration of IAM infrastructure networks into multimodal transport systems.
Title	Validation of algorithms for vertiport location optimisation
Category	<performance>, <acceptability>, <operational feasibility>, <technical feasibility>
Key environment conditions	Nominal conditions, European regional scope
TRL	TRL1

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	0515

[OBJ Suc]

Identifier	Success Criterion
CRT-0515-TRL1-ERP-005.001	The results of the multicriteria evaluation methods for the optimisation of IAM infrastructure networks are consistent with the expected behaviour. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.

Table 8. Validation objective OBJ-0515-ERP-005

© –2023– SESAR 3 JU

[OBJ]

Identifier	OBJ-0515-ERP-006
Objective	To validate the algorithms for optimising the coordination of IAM services with other modes.
Title	Validation of algorithms for IAM and ground transport services optimisation
Category	<performance>, <acceptability>, <operational feasibility>, <technical feasibility>
Key environment conditions	Nominal conditions, European regional scope
TRL	TRL1

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	0515

[OBJ Suc]

Identifier	Success Criterion
CRT-0515-TRL1-ERP-006.001	The optimisation algorithms for IAM service coordination with other modes are assessed in terms of computational efficiency, robustness under varying operational conditions, and scalability within a European regional scope. Validation has been carried out through simulation-based testing, ensuring that the results are aligned with operational feasibility, technical feasibility, and performance requirements. Additionally, the results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.

Table 9. Validation objective OBJ-0515-ERP-006

3.2.3 Validation assumptions

Category	ID	Title	Description	Justification	Impact Assessment
Technological advancements in IAM	AS-01	Vehicle propulsion	Electric, hybrid, and/or hydrogen propulsion systems will mature and become viable for short-haul and long-haul IAM.	Current advances on propulsion systems are on track for this	Delay on the development of this technology could affect the proposed timeline (2035 & 2050)
	AS-02	Certification of eVTOLs	Development and certification of novel aircraft types with short or vertical take-off and landing capabilities (STOL, VTOL) suitable for regional passenger transport will be achieved by 2035.	Several companies are already in the process of certification	Delay or difficulties in the completion of the certification process could affect the proposed timeline (2035 & 2050)

© –2023– SESAR 3 JU

Category	ID	Title	Description	Justification	Impact Assessment
	AS-03	IAM operations	Development of reliable sensor technology will enable IAM operations in diverse environmental conditions, including night-time and adverse weather.	Technology advancement points in this direction	Delay on the development of this technology could affect the proposed timeline (2035 & 2050)
	AS-04	Battery and charging	Enhancements in battery range, charging time, and safety will support viable regional IAM operations by 2035, with further advancements by 2050. Battery swapping may emerge as an alternative solution.	Battery performance is an active area of research and is improving year by year	Delay on the development of this technology could affect the proposed timeline (2035 & 2050)
	AS-05	Automation of eVTOLs	Advanced automation technologies enabling autonomous eVTOL operations will be available by 2050, contingent on regulatory approval and robust safety features.	Both the desk research and the interview performed assured us that this timeline is realistic	Delay on the development of this technology could affect the proposed timeline (2035 & 2050)
Development of supporting infrastructure and services	AS-06	Vertiport availability	Establishment of vertiports in regional areas, potentially upgrading existing infrastructure like heliports, by 2035. This includes the development of vertiport design and management tools.	Both the desk research and the interview performed assured us that this timeline is realistic	Lagging development of vertiport technologies poses a risk to meeting the proposed milestones set for 2035 and 2050.
	AS-07	U-space	U-space will be implemented by 2035 when the first passenger drone operations take place.	The successful implementation of U-space services, integrated with existing ATM, is crucial for managing IAM operations, particularly in very low-level airspace.	Delay on the implementation of U-Space could affect the proposed timeline (2035 & 2050)
	AS-08	Data availability	Establishment of data spaces and AI tools to support IAM decision-making, including demand prediction, network planning, and service optimisation.	This assumption aligns with the desk research and the latest SESAR master plan	The unavailability of the data required by the PRIAM solution could affect the implementation of the solution in specific cases.

© –2023– SESAR 3 JU

Category	ID	Title	Description	Justification	Impact Assessment
	AS-09	Data sharing	Evolution of data sharing and passenger information systems to facilitate seamless integration of IAM with other transport modes.	This assumption aligns with the desk research and the latest SESAR master plan	Delay on the development of this technology or unwillingness to the different actors to share data could difficult the integration between modes of transport in the future.
Economic and business viability	AS-10	Business models	Development of business models for regional IAM services that balance operating costs with fares and potential subsidies, achieving competitive pricing compared to existing transportation methods.	This assumption aligns with the desk research and the interviews	The lack of viable and effective business models could significantly hinder the deployment of IAM services.
	AS-11	IAM recognition	The aviation sector will recognise IAM's potential to create sustainable value, offering new business opportunities for airlines and infrastructure providers.	This is needed for IAM integration in airports	The lack of recognition of IAM's potential could limit industry engagement, leading to reduced investment and delayed deployment of services.
Societal acceptance	AS-12	Societal acceptance	Societal acceptance of IAM services will grow as passengers gain confidence in the safety and reliability of new technologies. Factors like accessibility and connectivity are expected to positively influence acceptance.	This assumption aligns with the desk research and the stakeholder interviews	Social reluctancy to IAM may result in a reduced demand.
Regulatory framework	AS-13	Regulatory framework	Regulatory frameworks will evolve to enable safe and efficient IAM operations, covering aspects like vehicle certification, airspace management (including U-space), and vertiport standards.	This assumption is necessary to ensure eVTOLs can operate	Delay on the establishment of a regulatory framework could affect the proposed timeline (2035 & 2050)

© –2023– SESAR 3 JU

Category	ID	Title	Description	Justification	Impact Assessment
Multimodal integration	AS-14	IAM coordination with traditional modes	There is willingness between the relevant stakeholders to enable effective integration of novel IAM services with existing ground transport modes within regional multimodal transport networks, leveraging mechanisms such as data sharing.	This assumption aligns with the desk research and the stakeholder interviews	A lack of interest in intermodal coordination would hinder the seamless integration of IAM services into regional transport networks.
PRIAM toolset	AS-15	Data availability	Data required for the proper work of the PRIAM solution (demand data to provide the current mobility patterns in the region of study, and IAM adoption surveys to model the level of adoption of these services) will be in place for the implementation of the solution in different contexts.	Demand data is widely used in Europe to analyse mobility patterns. If MND is not available, travel surveys, commonly conducted across European countries, can serve as an alternative. In the absence of IAM adoption surveys, they can be conducted or estimated using heuristic approaches.	The unavailability of this data can limit the application of the solution to other geographical contexts.
	AS-16	Data quality	The quality of the data is sufficient to ensure that the outputs of the PRIAM solution are reliable.	Quality of data can be good enough to accurately represent the current mobility patterns and the IAM adoption trends.	Bad quality data can lead to non-reliable results.
	AS-17	Data representati-veness	The data sample is representative of the behaviour of the total population, and is sufficient to ensure that the outputs of the PRIAM solution are reliable.	Data should be representative, ensuring that all the passenger segments are equally represented.	Non-representative data can lead to biases and to achieving non-reliable results.

Table 10: Validation assumptions overview

3.2.4 Validation exercises list

[EXE]

Identifier	TVAL.01.0-PRIAM-0515-TRL1
Title	Validation of the problem definition and the impact assessment framework

© –2023– SESAR 3 JU

Description	The objective of this validation exercise is to address the validation objective OBJ-0515-ERP-001. This exercise will validate the high-level requirements derived from the identified challenges related to regional connectivity across Europe, assess the relevance of potential regional-scale IAM service types and operational scenarios, and evaluate the applicability of the impact assessment framework developed within the project. The validation will be carried out through expert judgement provided by the EEAB and other external stakeholders, as part of the project's planned stakeholder engagement activities.
KPA/TA addressed	<Environment>, <Demand>, <Capacity>, <Cost Efficiency>, <Operational Efficiency>, <Passenger experience>
Addressed expected performance contribution(s)	N/A
Maturity level	<TRL1>
Use cases	N/A
Validation technique	<Expert Group>
Validation platform	N/A
Validation location	1st PRIAM Stakeholder Workshop, Airport Regions Council (ARC) facilities, Brussels, Belgium
Start date	01/01/2025
End date	30/04/2025
Validation coordinator	Deep Blue
Status	<OK>
Dependencies	TVAL.02.0-PRIAM-0515-TRL1 TVAL.03.0-PRIAM-0515-TRL1 TVAL.04.0-PRIAM-0515-TRL1 TVAL.05.0-PRIAM-0515-TRL1 TVAL.06.0-PRIAM-0515-TRL1

[EXE Trace]

Linked Element Type	TVAL.01.0-PRIAM-0515-TRL1
<SESAR Solution>	0515
<Project>	PRIAM
<Sub-Operating Environment>	N/A
<Validation Objective>	OBJ-0515-ERP-001

Table 11. Validation exercise TVAL.01.0-PRIAM-0515-TRL1

[EXE]

© –2023– SESAR 3 JU

Identifier	TVAL.02.0-PRIAM-0515-TRL1
Title	Validation of the algorithms for developing new AI-based methods for identifying human factors behind IAM adoption.
Description	This validation exercise addresses the validation objective OBJ-0515-ERP-002. It focuses on validating the AI techniques used for identifying human factors that affect IAM adoption, and clustering passengers into groups according to what extent are they more or less favourable and inclined to become IAM users in the future. The validation will be conducted by analysing the clustering results and ensuring its consistency. This process will involve several complementary steps. First, the number of clusters will be determined using the Elbow method, followed by the application of the Silhouette method to assess whether the clusters generated and selected are adequately separated and meet acceptable minimal values. Feature selection and importance will then be examined through Random Forest models, which will help measure the reduction in residual errors from the cluster centroids and assess the level of convergence of features across clustering, regression trees, and logistic or multiple regression models. In addition to these quantitative approaches, validation will also draw on expert judgement from external stakeholders, incorporated as part of the project's planned stakeholder engagement activities.
KPA/TA addressed	<Environment>, <Demand>, <Capacity>, <Cost Efficiency>, <Operational Efficiency>, <Passenger experience>
Addressed expected performance contribution(s)	These algorithms help understand the human factors that affect the level of acceptance and adoption of IAM services.
Maturity level	<TRL1>
Use cases	N/A
Validation technique	<Analytical Modelling> and <Expert Group>
Validation platform	N/A
Validation location	2nd PRIAM Workshop Location (Madrid)
Start date	01/10/2025
End date	31/12/2025
Validation coordinator	HAIKAI
Status	<OK>
Dependencies	TVAL.01.0-PRIAM-0515-TRL1 TVAL.03.0-PRIAM-0515-TRL1 TVAL.04.0-PRIAM-0515-TRL1 TVAL.05.0-PRIAM-0515-TRL1 TVAL.06.0-PRIAM-0515-TRL1

[EXE Trace]

Linked Element Type	TVAL.02.0-PRIAM-0515-TRL1

© –2023– SESAR 3 JU

<SESAR Solution>	0515
<Project>	PRIAM
<Sub-Operating Environment>	N/A
<Validation Objective>	OBJ-0515-ERP-002

Table 12. Validation exercise TVAL.02.0-PRIAM-0515-TRL1

[EXE]

Identifier	TVAL.03.0-PRIAM-0515-TRL1
Title	Validation of the algorithms for developing new methods of monitoring potential demand for IAM services.
Description	This validation exercise addresses the validation objective OBJ-0515-ERP-003. It focuses on validating the algorithms for estimating the potential demand for regional-scale IAM services from the fusion of heterogeneous data sources, including geolocation data from personal mobile devices and mobility surveys. The validation will be carried out by deeply analysing a set of mobility indicators to assess its consistency with the expected passenger behaviour, as well as through expert judgement from external stakeholders, as part of the planned stakeholder engagement activities.
KPA/TA addressed	<Environment>, <Demand>, <Capacity>, <Cost Efficiency>, <Operational Efficiency>, <Passenger experience>
Addressed expected performance contribution(s)	These algorithms provide an accurate view of the current passenger behaviour and mobility patterns within the area of study. This provides an initial idea of the potential demand of the IAM services, and allows the application of discrete choice models to estimate IAM adoption.
Maturity level	<TRL1>
Use cases	N/A
Validation technique	<Analytical Modelling> and <Expert Group>
Validation platform	N/A
Validation location	2nd PRIAM Workshop Location (Madrid)
Start date	01/10/2025
End date	30/05/2026
Validation coordinator	Nommon
Status	<OK>
Dependencies	TVAL.01.0-PRIAM-0515-TRL1 TVAL.02.0-PRIAM-0515-TRL1 TVAL.04.0-PRIAM-0515-TRL1 TVAL.05.0-PRIAM-0515-TRL1 TVAL.06.0-PRIAM-0515-TRL1

[EXE Trace]

© –2023– SESAR 3 JU

Linked Element Type	TVAL.03.0-PRIAM-0515-TRL1
<SESAR Solution>	0515
<Project>	PRIAM
<Sub-Operating Environment>	N/A
<Validation Objective>	OBJ-0515-ERP-003

Table 13. Validation exercise TVAL.03.0-PRIAM-0515-TRL1

[EXE]

Identifier	TVAL.04.0-PRIAM-0515-TRL1
Title	Validation of the methodology for developing new models for predicting IAM demand, including induction and modal shift effects.
Description	This validation exercise addresses the validation objective OBJ-0515-ERP-004. It focuses on validating the discrete choice and induced demand models aimed at estimating the IAM captured and induced demand. The validation will be carried out by extracting a set of validation tests and metrics, such as the likelihood ratio test and McFadden's R-squared, to evaluate the model's performance and its capability to precisely replicate observed travel behaviour. Additionally, expert judgement validation will be carried out from external stakeholders, as part of the planned stakeholder engagement activities.
KPA/TA addressed	<Environment>, <Demand>, <Capacity>, <Cost Efficiency>, <Operational Efficiency>, <Passenger experience>
Addressed expected performance contribution(s)	These algorithms help understand the influence of new modes on regional mobility.
Maturity level	<TRL1>
Use cases	N/A
Validation technique	<Analytical Modelling> and <Expert Group>
Validation platform	N/A
Validation location	2nd PRIAM Workshop Location (Madrid)
Start date	01/10/2025
End date	30/05/2026
Validation coordinator	TML
Status	<OK>
Dependencies	TVAL.01.0-PRIAM-0515-TRL1 TVAL.02.0-PRIAM-0515-TRL1 TVAL.03.0-PRIAM-0515-TRL1 TVAL.05.0-PRIAM-0515-TRL1 TVAL.06.0-PRIAM-0515-TRL1

© –2023– SESAR 3 JU

[EXE Trace]

Linked Element Type	TVAL.04.0-PRIAM-0515-TRL1
<SESAR Solution>	0515
<Project>	PRIAM
<Sub-Operating Environment>	N/A
<Validation Objective>	OBJ-0515-ERP-004

Table 14. Validation exercise TVAL.04.0-PRIAM-0515-TRL1

[EXE]

Identifier	TVAL.05.0-PRIAM-0515-TRL1
Title	Validation of the novel multicriteria evaluation methods for IAM infrastructure network optimisation.
Description	This validation exercise addresses the validation objective OBJ-0515-ERP-005. It focuses on validating the multicriteria evaluation method for the optimal integration of IAM infrastructure in multimodal transport networks The validation will be carried out by ensuring the model results are consistent the expected behaviour. The outcomes of the vertiport site optimisation model will be evaluated and the identified locations will be assessed to ensure that they are consistent, reasonable, and aligned with the model's intended objectives. Additionally, a validation based on expert judgement will be conducted from external stakeholders, as part of the planned stakeholder engagement activities.
KPA/TA addressed	<Environment>, <Demand>, <Capacity>, <Cost Efficiency>, <Operational Efficiency>, <Passenger experience>
Addressed expected performance contribution(s)	• Improved passenger experience through the reduction of travel times to regional areas and enhanced connectivity. • Reduced environmental impact due to the use of new clean modes (e.g., eVTOLs) • Maximisation of IAM passenger demand through the optimisation of the vertiport location and the IAM service characteristics
Maturity level	<TRL1>
Use cases	N/A
Validation technique	<Analytical Modelling> and <Expert Group>
Validation platform	N/A
Validation location	2nd PRIAM Workshop Location (Madrid)
Start date	01/10/2025
End date	30/05/2026
Validation coordinator	Nommon
Status	<OK>
Dependencies	TVAL.01.0-PRIAM-0515-TRL1

© –2023– SESAR 3 JU

	TVAL.02.0-PRIAM-0515-TRL1 TVAL.03.0-PRIAM-0515-TRL1 TVAL.04.0-PRIAM-0515-TRL1 TVAL.06.0-PRIAM-0515-TRL1

[EXE Trace]

Linked Element Type	TVAL.05.0-PRIAM-0515-TRL1
<SESAR Solution>	0515
<Project>	PRIAM
<Sub-Operating Environment>	N/A
<Validation Objective>	OBJ-0515-ERP-005

Table 15. Validation exercise TVAL.05.0-PRIAM-0515-TRL1

[EXE]

Identifier	TVAL.06.0-PRIAM-0515-TRL1
Title	Validation of the algorithms for developing new models for optimising IAM service coordination with other modes.
Description	This validation exercise addresses the validation objective OBJ-0515-ERP-006. It focuses on validating the optimisation techniques developed for coordinating IAM services with other modes. The exercise will assess the algorithms' ability to enhance multimodal integration, improve passenger demand satisfaction, and ensure that IAM services complement rather than compete with ground transport options. Specific attention will be given to evaluating computational efficiency, robustness under varying operational conditions, and scalability within a European regional scope. Validation will be carried out through simulation-based testing, ensuring that the results are aligned with operational feasibility, technical feasibility, and performance requirements. Additionally, external validation from external stakeholders will be carried out as part of the planned stakeholder engagement activities.
KPA/TA addressed	N/A
Addressed expected performance contribution(s)	• Improved passenger experience through the reduction of travel times due to higher coordination between modes. • Maximisation of IAM passenger demand through the optimisation of the coordination between modes.
Maturity level	<TRL1>
Use cases	N/A
Validation technique	<Analytical Modelling> and <Expert Group>
Validation platform	N/A
Validation location	2nd PRIAM Workshop Location (Madrid)
Start date	01/10/2025

© –2023– SESAR 3 JU

End date	30/05/2026
Validation coordinator	ENAC
Status	<OK>
Dependencies	TVAL.01.0-PRIAM-0515-TRL1 TVAL.02.0-PRIAM-0515-TRL1 TVAL.03.0-PRIAM-0515-TRL1 TVAL.04.0-PRIAM-0515-TRL1 TVAL.05.0-PRIAM-0515-TRL1

[EXE Trace]

Linked Element Type	TVAL.06.0-PRIAM-0515-TRL1
<SESAR Solution>	0515
<Project>	PRIAM
<Sub-Operating Environment>	N/A
<Validation Objective>	OBJ-0515-ERP-006

Table 16. Validation exercise TVAL.06.0-PRIAM-0515-TRL1

3.3 Deviations

3.3.1 Deviations with respect to the S3JU project handbook

There are no deviations with respect to the S3JU project handbook.

3.3.2 Deviations with respect to the exploratory research plan (ERP)

There are no deviations with respect to the ERP.

© –2023– SESAR 3 JU

Co-funded by the European Union

4 Validation results

4.1 Summary of project / SESAR Solution 0515 validation results

Validation objective ID	Validation objective title	Success criterion ID	Success criterion description	Validation results	Validation objective status
OBJ-0515-ERP-001	Problem definition and development of an impact assessment framework for regional IAM services	CRT-0515-TRL1-ERP-001.001	Identification of at least 5 challenges for regional connectivity across Europe.	Based on an extensive desk research (e.g. literature review), semi-structured interviews with key stakeholders and the 1st PRIAM Stakeholder Workshop, 8 challenges for regional connectivity across Europe have been identified and validated by stakeholders.	OK
		CRT-0515-TRL1-ERP-001.002	Identification of at least 5 types of potential regional-scale IAM services.	5 types of potential regional-scale IAM services have been identified from a literature review (passenger transportation, medical services, access to and from airports, etc.) and have been validated by stakeholders.	OK
		CRT-0515-TRL1-ERP-001.003	Identification of at least 4 scenarios for regional-scale IAM operations in Europe.	Based on the literature review, interview results with key stakeholders and activities during the first PRIAM Stakeholder Workshop, 4 main scenarios have been identified: IAM for mountainous regions and IAM for intra/inter islands connectivity, in two different timeframes with different characteristics: 2035 and 2050.	OK
		CRT-0515-TRL1-ERP-001.004	Definition of a set of KPIs in at least 5 areas (passenger experience, capacity, environmental sustainability and operational and cost efficiency)	Based on extensive research, including previous projects, an Impact Assessment Framework has been developed, with KPIs in 6 areas (passenger experience, capacity, demand, environmental sustainability, operational efficiency and cost efficiency).	OK

© –2023– SESAR 3 JU

Validation objective ID	Validation objective title	Success criterion ID	Success criterion description	Validation results	Validation objective status
		CRT-0515-TRL1-ERP-001.005	Identification of a set of high-level requirements for data analytics and modelling tools with implications for PRIAM developments.	A set of different high-level requirements has been identified through desk research, interviews and 1st PRIAM Stakeholder Workshop. These requirements fall within different areas.	OK
OBJ-0515-ERP-002	Validation of AI algorithms for estimating IAM adoption levels	CRT-0515-TRL1-ERP-002.001	The AI-based algorithms developed to identify human factors influencing IAM adoption have been validated through a combination of expert stakeholder reviews and quantitative methods, including cluster evaluation techniques and feature importance analysis, ensuring both their reliability and interpretability.	Validation of AI clustering via: 1) Elbow method to determine the optimal number of clusters (2 clusters with SSE < 30k) 2) Silhouette Score: 0.53. Indicates a good clustering solution. It defines how well our data points fit into the clusters they've been assigned measuring both quality of cluster cohesion and separation.	OK
OBJ-0515-ERP-003	Validation of algorithms for monitoring potential IAM demand	CRT-0515-TRL1-ERP-003.001	The mobility indicators derived from the algorithms for monitoring potential demand for IAM services through the fusion of MND and other data sources are consistent with the expected mobility behaviour. The achieved results have been validated through expert reviews conducted by external stakeholders as part of	The mobility patterns derived from MND reproduce the expected demand behaviour across both case studies: clear seasonal peaks during summer and holiday periods, increased activity during the ski season in resort areas, proximity effects with neighbouring municipalities generating more trips between them, a higher concentration of demand in larger municipalities, and mode-specific flows capturing demand from adjacent areas, as seen in the Tenerife–La Gomera connection. The developments introduced to improve trip characterisation provide valuable additional information for assessing IAM adoption: the trip-purpose classifier achieves strong performance (0.92 F-score),	OK

© –2023– SESAR 3 JU

Validation objective ID	Validation objective title	Success criterion ID	Success criterion description	Validation results	Validation objective status
			the project's planned engagement activities.	reliably reproducing the expected temporal, seasonal, and demographic patterns of business travel, and independently validated by the EMQ APA 2025 survey; while the bus-detection algorithm yields modal shares comparable in order of magnitude to the survey. Overall, the enriched mobility data are consistent with expected behaviour and with independent references, and are therefore considered valid as a basis for the subsequent IAM demand and market-potential analysis.	
OBJ-0515-ERP-004	Validation of algorithms for estimating IAM captured and induced demand	CRT-0515-TRL1-ERP-004.001	The discrete choice model accurately represents observed travel behaviour. Appropriate tests for discrete choice models, such as the likelihood ratio test and McFadden's R-squared, are used to evaluate the model's performance and its capability to precisely replicate observed choices. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.	Two discrete choice models were developed, one for Catalonia and one for Tenerife. Both models are statistically significant and meet the selected model validation indicators. The McFadden's rho-squared values are 0.648 for Catalonia and 0.622 for Tenerife, indicating strong model performance. All estimated model variables are statistically significant. In addition, a regression model was developed to estimate induced demand. The model achieved an R-squared value of 0.94, indicating an excellent goodness-of-fit and a strong ability to explain the observed variation in travel demand. This high R-squared value provides confidence in the statistical fit of the induced demand model under the adopted assumptions.	OK
OBJ-0515-ERP-005	Validation of algorithms for vertiport	CRT-0515-TRL1-ERP-005.001	The results of the multicriteria evaluation methods for the optimisation of IAM infrastructure networks are consistent with the	The results of the IAM network optimisation are consistent with the expected behaviour. Across the two case studies, the tool produced coherent and explainable vertiport configurations, with demand, cost, and revenue outputs aligning with the MND-derived	OK

© –2023– SESAR 3 JU

Validation objective ID	Validation objective title	Success criterion ID	Success criterion description	Validation results	Validation objective status
	location optimisation		expected behaviour. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.	mobility patterns. The consistency between the IAM demand, the vertiport profitability, and the location of the selected vertiports confirms the tool behaves as intended. Additionally, these results have been validated through expert reviews conducted with external stakeholders as part of the project's planned engagement activities. A workshop session, complemented by individual meetings, was used to validate the key modelling assumptions and the preliminary results, confirming that the assumptions and outputs were reasonable and plausible, and provided feedback that informed the refinement of the tool. Taken together, the consistency of the results with expected behaviour and their validation by external experts demonstrate that the objective of this validation exercise has been successfully achieved.	
OBJ-0515-ERP-006	Validation of algorithms for IAM and ground transport services optimisation	CRT-0515-TRL1-ERP-006.001	The optimisation algorithms for IAM service coordination with other modes are assessed in terms of computational efficiency, robustness under varying operational conditions, and scalability within a European regional scope. Validation has been carried out through simulation-based testing, ensuring that the results are aligned with operational feasibility, technical	This validation objective successfully demonstrated the optimisation algorithms for IAM and ground transport service coordination. The developed framework, including both heuristic and exact optimisation methods, was implemented and evaluated in two case studies. Comprehensive multimodal transport network graphs were generated from GTFS data and integrated with IAM operational constraints to support realistic simulation and assessment. The validation results confirmed the capability of the proposed methods to coordinate passenger routing and IAM vehicle dispatch while complementing existing public transport services. Comparative analyses highlighted the trade-off between computational efficiency and solution quality, with the heuristic	OK

© –2023– SESAR 3 JU

Validation objective ID	Validation objective title	Success criterion ID	Success criterion description	Validation results	Validation objective status
			feasibility, and performance requirements. Additionally, the results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.	approach providing faster solutions and the exact method achieving higher optimality. The assessment further demonstrated the applicability of the framework across different regional transport contexts and network structures. These results provide a validated basis for analysing multimodal IAM operations, supporting transport planning and decision-making, and facilitating the future deployment of IAM services within European regional mobility systems. The findings were reviewed by stakeholders and experts, whose feedback confirmed the relevance and practical value of the proposed approach	

Table 17. Summary of validation exercises results

© –2023– SESAR 3 JU

4.2 Detailed analysis of project / SESAR solution validation results per validation objective

4.2.1 OBJ-0515-TRL1-ERP-001 results

This validation objective focused on assessing the scenarios, high-level requirements and the impact assessment framework developed during the first phase of the project. This process aimed to ensure that the conceptual foundations of the PRIAM Solution are robust, contextually relevant, and aligned with both the realities of regional mobility needs and the strategic objectives of European transport policy. By critically testing these elements at an early stage, the validation provides a solid basis for the subsequent technical development and modelling activities.

The validation followed a structured methodology combining desk research, stakeholder interviews, and a final stakeholder workshop. The desk research provided a comprehensive review of the state of the art in IAM, covering vehicle concepts, business models, connectivity, passenger needs, and social acceptance. These findings were further refined through semi-structured interviews with members of the EEAB, which helped consolidate knowledge and identify remaining gaps. Together, these steps laid the foundation for the preliminary definition of IAM challenges, scenarios, high-level requirements, and an initial impact assessment framework.

The validation process confirmed eight key regional connectivity challenges in Europe, including geographical barriers, sparse population density, sustainability constraints, and limited medical access. In parallel, five categories of potential IAM services were identified, with stakeholders highlighting emergency medical services as the most feasible and socially valuable starting point, followed by business travel and tourism. These insights supported the definition of four regional IAM scenarios, explored across two case studies—the Catalan Pyrenees (mountainous region) and La Gomera–Tenerife (inter-island)—and across two time horizons, 2035 and 2050, capturing differences in regulatory maturity, vehicle automation, and operational readiness.

Another major outcome was the consolidation of the PRIAM Impact Assessment Framework. This framework is structured into six KPAs: passenger experience, demand, cost efficiency, environment, operational efficiency, and capacity. Within each KPA, a set of PIs was developed to provide a structured basis for assessing IAM integration in regional transport systems.

The 1st PRIAM Stakeholder Workshop acted as the central validation step, bringing together external experts to review, test, and validate all previous findings. Through interactive discussions and group activities, stakeholders confirmed the relevance of the identified challenges, refined the IAM service categories and scenarios, validated the KPAs and KPIs of the impact assessment framework, and contributed to the definition of high-level requirements for the PRIAM toolset. Their feedback ensured that the validation process was comprehensive, robust, and strategically aligned with European mobility objectives.

4.2.2 OBJ-0515-TRL1-ERP-002 Results

This validation objective successfully validated the algorithms for estimating IAM adoption levels. The investigation established a well-structured, reproducible data preprocessing pipeline and applied clustering techniques to the responses of a stated preference survey. This survey collected demographic information, mobility habits, and IAM-related preferences, enabling the creative engineering of valuable composite features—specifically Adoption Level and Propensity Level—to effectively explore passenger heterogeneity. The finalised clustering process demonstrated solid

success in identifying distinct groups of passengers with similar characteristics and behavioural patterns. Final findings, supported by random forest feature importance rankings, confirm that variables such as regional travel modes, environmental concerns, and age are the most influential factors shaping the likelihood of adopting IAM services. These insights, built upon a strong foundational pipeline, successfully validated the algorithm's predictive capacity and generated robust user profiles. The complete analysis of these validation results, including a detailed examination of demographic factors and adoption behaviours, is presented in full within this deliverable

4.2.3 OBJ-0515-TRL1-ERP-003 Results

This validation exercise assessed algorithms for monitoring potential IAM demand from MND, enriched with a trip-purpose classifier and a bus-mode detection algorithm.

The mobility patterns derived from MND are consistent with expected demand behaviour across both case studies: clear seasonal peaks during summer and holiday periods, increased activity during the ski season, proximity effects with neighbouring municipalities, higher demand concentration in larger municipalities, and mode-specific flows such as the Tenerife–La Gomera connection.

The trip-purpose classifier was calibrated on survey data and validated against the EMQ APA 2025 survey. In both case studies, the calibration of the model provides an overall accuracy of 0.97 and a macro-averaged F-score of 0.92 (business-class F-score 0.86 in both cases). The inferences reproduce expected temporal, seasonal and demographic signatures of business travel: concentration on weekdays with significantly reduced volumes at weekends, higher relative business share in winter, and concentration within the working-age population. In the Catalan Pyrenees case study, the weekday/weekend pattern and the higher business presence on external corridors are independently corroborated by the EMQ APA 2025 survey.

The bus-detection algorithm yields modal shares comparable in order of magnitude to survey references (EMQ APA 2025): an intra-Pyrenees bus share of approximately 23% from MND against 18% from the survey, and 2–3.8% on external corridors against a combined survey figure of 5.4%.

Overall, the enriched mobility data are consistent with expected behaviour and with independent references, and are considered valid as a basis for the subsequent IAM demand analysis.

4.2.4 OBJ-0515-TRL1-ERP-004 Results

This validation objective aims to validate the algorithms developed for estimating IAM captured demand through modal shift and IAM induced demand. The methodology was fully implemented by combining stated preference survey data with MND. Two discrete choice models were developed, one for the Canary Islands and one for the Catalan Pyrenees, to estimate the potential modal shift towards IAM. In addition, an induced demand model was developed to estimate the number of additional trips generated by reductions in generalised cost. The full methodology and detailed results are provided in annex 4 of this deliverable.

The final results show that IAM captures a limited but measurable share of total travel demand in both case study regions. In the Canary Islands, IAM is estimated to capture 100,993 trips through modal shift, corresponding to 2.15% of total annual demand. An additional 2,381 trips are estimated as induced demand, corresponding to 0.05% of total demand. This results in a total IAM demand of 103,374 trips, or 2.21% of total annual trips in the case study area. In the Catalan Pyrenees, IAM is

© –2023– SESAR 3 JU

estimated to capture 140,299 trips through modal shift, corresponding to 0.47% of total annual demand, while no induced demand is observed under the tested assumptions.

The validation indicators confirm the robustness of the modelling framework. The discrete choice models achieved McFadden's rho-squared values of 0.622 for the Canary Islands and 0.648 for the Catalan Pyrenees, indicating strong model performance. The estimated generalised cost coefficients are negative and statistically significant, which is consistent with transport demand theory. In addition, the induced demand model achieved an R-squared value of 0.94, indicating a strong relationship between trip frequency and generalised cost.

Overall, the results confirm that IAM is unlikely to function as a mass transport mode in the analysed regions. Instead, it is more likely to act as a complementary transport option serving specific corridors and user segments where travel time savings, direct connectivity, and service quality provide sufficient added value. The results also show that IAM demand is mainly generated through modal shift from existing modes, while induced demand remains very limited and occurs only in the Canary Islands case study under the adopted assumptions.

4.2.5 OBJ-0515-TRL1-ERP-005 Results

This validation exercise validated the multicriteria evaluation tool for IAM vertiport network optimisation. The tool integrates the outputs of Component 2, an estimation of mobility demand from MND, and Component 3, a calibrated logit modal-choice model, allowing to estimate, for each trip and each candidate vertiport pair, the probability of shifting to IAM. These estimates are subsequently used by an optimisation algorithm to identify the vertiport network that maximises either operator profit or captured demand. The optimisation problem is NP-hard.

The tool was applied end to end in both case studies and multiple IAM pricing scenarios. Results are coherent and explainable in both cases: demand, cost and revenue figures behave consistently with the expected behaviour and MND-derived mobility patterns. In the Catalan Pyrenees, demand concentrates on central and eastern corridors within the Pyrenees while peripheral locations and larger routes show lower demand due to higher costs. In the Canary Islands, intra-Gomera demand is predominant due to the high underlying MND-derived flows and the significant time savings achievable on short but road-constrained routes. In both cases, the different output views (IAM route demand, per-vertiport profitability, and spatial distribution of selected locations) are internally consistent and aligned with the demand.

External validation was carried out through a stakeholder workshop and individual expert meetings. Participants confirmed that the modelling assumptions regarding demand, costs, operational constraints and the modal-shift mechanism were reasonable and representative, and that the preliminary results were plausible and consistent with expert expectations. Feedback from this process informed refinements to the cost model and the usable-day estimation.

The validation establishes not only the specific results for each case study, but the broader finding that the full integrated methodology, from MND-derived demand through logit-based modal-shift modelling to vertiport network optimization, is coherent, operational, and applicable end to end to realistic case studies.

4.2.6 OBJ-0515-TRL1-ERP-006 Results

© –2023– SESAR 3 JU

This exercise developed and tested optimisation algorithms for coordinating IAM and ground transport services within a European regional context, comparing an exact optimisation method against a heuristic approach. The exact method served as a benchmark, providing optimal solutions but at significantly higher computational cost, while the heuristic method consistently achieved substantially lower computation times with stable, reliable behaviour across all tested scenarios.

Performance results showed that, while the exact method achieved slightly higher passenger satisfaction, it came with greater variability and computational burden; the heuristic method offered a more balanced trade-off between solution quality and computational efficiency, with both approaches showing similar overall performance trends across scenarios. The conceptual framework underlying the integration, including the explicit distinction between IAM-supported and conventionally served trips, was confirmed as solid and traceable, with the heuristic method recommended as the more suitable approach for practical and real-time operational deployment.

4.2.7 Results on liability and human factors

As part of the societal acceptance assessment, the validation activities also focused on evaluating the integration of accountability, liability and human factors considerations within the operational concepts developed for future IAM ecosystems [33].

To understand and analyse concerns about Liability and Human Factors in relation to the PRIAM solution, DBL organised a focused consultation within the framework of the 2nd Stakeholder Workshop. The purpose of this activity was to assess PRIAM as a holistic solution. The data was collected using Mentimeter, taking into account views of 12 participants, who represent a variety of stakeholders, including vertiport operators, municipalities, and others involved in aviation.

Given the profound transformation that IAM introduces to aviation architectures, infrastructures, and governance frameworks, a Liability According to Design (LAD) ([33]) approach was applied to identify and address potential legal uncertainties from the earliest validation stages (TRL1). This proactive approach supports the development of conceptual solutions that are robust, legally sound, and aligned with the socio-political realities of low-altitude urban operations.

The assessment adopted an integrated methodology combining a top-down review of the regulatory framework and relevant legal literature with stakeholder-driven inputs collected through a survey involving key contributors to the PRIAM operational concepts. The resulting findings were analysed and cross-compared to establish a preliminary high-level understanding of possible liability and human factors issues within IAM ecosystems. This provided the basis for addressing liability challenges proactively, by design and by default, while leveraging the lessons learned throughout the PRIAM project.

The top-down assessment fused a thematic review of the literature with an analysis of the evolving regulatory framework for IAM, integrating public law perspectives, transport policy studies, and civil aviation standards ([34]; [35]; [36]; [37]; [38]; [39]). This analysis provided the basis for the preliminary legal risk assessment framework and enabled the identification of four systemic accountability and liability challenges relevant to future IAM operations. First, the increasing use of self-adaptive software may erode traditional product liability defences by increasing exposure to series defects under existing jurisprudence. Second, the strong digital interdependency of IAM systems introduces the risk of cross-sector cybersecurity contagion, potentially generating cascading liabilities across interconnected

© –2023– SESAR 3 JU

sectors. Third, dual-governance spatial friction may arise from the interaction between local or municipal competences over low-altitude urban space and the exclusive responsibilities of national aviation authorities for safety oversight. Fourth, the non-deterministic behaviour of highly automated systems may complicate failure attribution and the clear allocation of responsibility among the actors involved. To address these challenges, the literature identifies several regulatory safeguards. Smart-contract auditability emerged as a key mechanism for preserving traceability of operational intent, complemented by the definition of a centralized fleet manager standard of care and the implementation of dynamic telemetry-based decision logging.

The bottom-up assessment captured stakeholder perceptions regarding the adoption of the PRIAM solution, preferred deployment approaches, perceived barriers to implementation, legal concerns, and stakeholder exposure to potential risks. Overall, respondents expressed a positive attitude towards the adoption of the PRIAM solution, with a mean reception index score of 5.4 out of 7. Regarding deployment preferences, most respondents indicated a preference for implementing PRIAM as a set of individual components rather than as a fully integrated solution, with 10 out of 14 respondents selecting the modular approach (71%) and 4 favouring full integration (29%). The most frequently identified barriers to successful adoption were the coordination between different stakeholders and the accuracy of criteria and availability of data, as well as the need of having an easy-to-use interface able to handle complex airspace and vertiport data while not adding cognitive load. When asked about potential legal risks associated with the PRIAM solution, respondents highlighted issues related to personal data treatment, certification of data quality, data integration, safety and noise regulations, environmental responsibility, noise and downwash impacts, operational challenges in hostile and congested and/or variable weather environments, and uncertainty associated with future regulatory developments. Stakeholders were also asked to assess which actors could be more exposed to these risks. Vertiport operators, regional and airport authorities, and passengers received the highest average exposure score (4.5 out of 7). These were followed by eVTOL pilots and operators (4.3), manufacturers (4.2), and local and regional governments (4.2). Civil society received an average score of 3.9, while Air Navigation Service Providers (ANSPs) were perceived as the least exposed stakeholders, with an average score of 3.1.

The analysis revealed a high degree of convergence between theoretical legal risks and operational stakeholder anxieties. For instance, the stakeholder-identified barrier of coordination directly converges with the top-down legal challenge known as the "Problem of Many Hands" within highly fragmented IAM value chains comprising USSPs, CIS providers, and fleet operators. Furthermore, stakeholder concerns regarding data accuracy align with the top-down challenge of non-deterministic failure attribution and algorithmic opacity, or "black box" causation, inherent in highly automated, self-adaptive cyber-physical systems. Finally, the erosion of product liability defences due to self-adaptive software featured in the literature corroborates the high-risk scores assigned by stakeholders to manufacturers and operators, confirming a mutual concern regarding systemic software behaviour and liability shifting.

Notwithstanding the low TRL, the validation activities highlighted that accountability, liability, and human factors considerations are already relevant at the earliest stages of IAM concept development. The assessment identified potential challenges related to stakeholder coordination, data governance, and the allocation of responsibilities and risks across an increasingly interconnected ecosystem. These challenges are expected to become more significant as individual services and operational components are progressively integrated, increasing the complexity of interactions, data exchanges, and interdependencies among stakeholders. In this context, the results support the adoption of a LAD

© –2023– SESAR 3 JU

approach to proactively address accountability, liability and human factors aspects throughout future developments of the PRIAM solutions.

4.3 Confidence in validation results

4.3.1 Limitations of validation results

Validation Exercise #01 did have several limitations. The Impact Assessment Framework developed in this phase was designed with a strategic-level focus, which means that tactical KPIs were not included within the current scope. This limitation is justified by the project's limited modelling capabilities and by the fact that, at this early TRL stage, the PRIAM toolset is conceived as a strategic rather than operational instrument. Therefore, tactical assessment of passenger IAM operations will need to be researched in further R&I stages. In addition, strategic KPIs related to visual and noise pollution are not directly measured in the project. Nonetheless, they have been acknowledged for completeness, incorporated as mitigation elements, and validated during the first PRIAM stakeholder workshop.

Another limitation lies in the relatively small number of experts consulted through interviews. To mitigate potential biases, the questions were carefully designed and experts from different fields were selected. Importantly, the consistency observed between the interview results and the desk research strengthens confidence that the findings are sufficiently representative for the objectives of the PRIAM project.

Validation Exercise #02 also presented some limitations. They mostly come down to the dimension of the available sample of only 211 subjects. With this small sample dimensionality in clustering is somewhat less robust than expected. Also, potential overfitting during clustering is possible as a trained a Random Forest Classifier (to detect feature importance), extracted the top 18 features that then defined those clusters, and then re-clustered the data using only those features. Also, the visual Elbow Method is somewhat limiting as it relies on a single metric for a small dataset leaving the model potentially vulnerable to some degree of random noise.

The main limitation of Validation Exercise #03, is the restricted capability to compare the estimated results for trip purpose classification and bus-mode identification against ground-truth data (e.g., bus occupancy or ticketing data) due to its unavailability. For this reason, validation has relied on behavioural analysis and comparison with alternative data sources; however, these approaches also present certain limitations.

Additionally, regarding the calculation of travel times, the current road-based estimates derived from OpenStreetMap do not account for traffic congestion or variations in travel time across different days of the week or times of day. As a result, these estimates may be less realistic in situations where congestion is significant.

For Validation Exercise #04, the discrete choice model and induced demand model results should be interpreted in light of the assumptions and limitations of the methodology. First, all modal shift and induced demand results are conditional on the assumptions adopted for IAM travel time, travel cost, access and egress conditions, waiting time, and vertiport locations. Since IAM is not yet commercially available at scale, these inputs are scenario-based and may change as the technology, operational models, and market conditions evolve.

The induced demand methodology also relies on the assumption that a reduction in generalised cost leads to an increase in travel demand, and that this relationship can be represented using an

© –2023– SESAR 3 JU

exponential impedance function. Although this provides a transparent and practical modelling approach, it remains an aggregate approximation of travel behaviour. The model estimates induced demand from changes in generalised cost, but it does not explicitly represent full mode choice, destination choice, or activity generation behaviour.

In addition, the current generalised cost formulation does not include all possible components that may influence the attractiveness of IAM. Elements such as parking costs, waiting time, transfer time, schedule-delay penalties, service reliability, and other service-quality factors are not explicitly included. These factors may be relevant for IAM, particularly where access and egress conditions or transfer penalties affect the total door-to-door experience. Finally, although the stated preference survey sample represents the best achievable data collection within the project constraints, the sample size remains limited and may not fully capture the diversity of future IAM users.

Validation Exercise #05 tool demonstrates a solid proof of concept appropriate for TRL1, capable of identifying optimal vertiport and vertihub locations and supporting high-level cost–benefit and sensitivity analyses across scenarios. However, its results should be interpreted with caution due to its conceptual nature and several simplifying assumptions.

Key limitations include the use of urban land prices that may not reflect actual available sites, simplified visibility modelling based on sparse weather station data, and demand estimates that do not account for behavioural changes or induced demand and has only been validated qualitatively through expert workshops. The current infrastructure model is also based on generic operating assumptions (e.g., 3 gates for a vertiport, 6 for a vertihub, 100% charger coverage, 12 daily operating hours, and a 15-minute passenger-processing time) rather than site-specific layouts and resource constraints. Finally, the current framework focuses solely on the vertiport operator perspective, without fully incorporating aircraft operator economics, which limits the completeness of the overall financial assessment. Results should therefore be interpreted as vertiport-network profitability under the model assumptions, rather than as evidence of total IAM service viability.

Finally, Validation Exercise #06 provides indicative evidence of the proposed methods' performance under the selected scenarios, but results should be interpreted considering the underlying modelling assumptions and experimental setup. The analysis is based on a limited set of representative cases, uses predefined system parameters, and relies on simplified demand representations with only partial stochastic variability, which may affect the generalisability of the outcomes across different operational contexts.

These limitations are well understood, bounded, and consistent with the expected maturity of a TRL1 exploratory research activity; none of them undermine the validity of the conclusions drawn, but they should be considered when interpreting absolute figures and when planning future research and development phases.

4.3.2 Quality of validation results

The quality of the validation results is supported by multiple evidence across the PRIAM pipeline. The methodology consistently achieved or exceeded the success criteria defined for all six validation exercises, with strong statistical performance metrics: classification accuracy of 0.97 (macro-averaged F-score of 0.92) for trip-purpose detection, McFadden's rho-squared values of 0.648 and 0.622 for the Catalan Pyrenees and Canary Islands modal-shift models respectively, and an R-squared of 0.94 for the

© –2023– SESAR 3 JU

induced-demand regression. These values indicate a strong and behaviourally consistent fit between the models and observed or stated travel behaviour.

Beyond statistical fit, the results were independently triangulated through multiple validation channels: expert reviews with the EEAB, the PRIAM Stakeholder Workshops, individual meetings with external stakeholders, and comparison against independent survey-based estimates (e.g. trip purpose and bus modal shares). This combination of quantitative model performance and qualitative expert validation strengthens confidence that the results are not only statistically sound but also behaviourally and operationally plausible.

The results also demonstrate internal coherence across the pipeline: outputs from one stage (e.g. MND-derived demand) align consistently with outputs from downstream stages (e.g. vertiport network configuration, profitability), and this cross-stage consistency was itself confirmed through expert review. This is a strong quality indicator, since it shows the solution behaves as an integrated system rather than as disconnected components individually tuned to look reasonable in isolation.

Overall, the quality of the validation results is considered appropriate for, and consistent with, the expectations of a TRL1 exploratory research solution.

4.3.3 Significance of validation results

The validation results are significant both methodologically and in terms of their early policy and planning implications.

Methodologically, the results demonstrate that an integrated pipeline combining MND, behavioural modelling based on stated preference surveys, and network optimisation can be built and applied end to end to support regional IAM planning. This confirms the technical and conceptual feasibility of an approach that had not previously been validated in this combined form, and establishes a transferable methodological foundation, evidenced by its successful application across two distinct territorial contexts (the Catalan Pyrenees and the Canary Islands).

From a planning and policy perspective, the results provide an early but meaningful evidence base for understanding the likely role of regional IAM in Europe. The finding that IAM demand is dominated by modal shift rather than induced demand, and that it remains concentrated in specific corridors and user segments, is significant for informing realistic expectations among policymakers and infrastructure planners: IAM is best understood as a targeted regional connectivity solution rather than a mass transport mode. This has direct implications for infrastructure investment prioritisation, subsidy and viability assessments, and multimodal integration planning.

While the absolute figures carry the uncertainty associated with TRL1 maturity, the consistency of these findings across two contrasting case studies, and their alignment with stakeholder expectations gathered through expert review, supports the conclusion that the underlying patterns identified (IAM as a complementary, corridor-specific service; the centrality of multimodal integration; the sensitivity of viability to fare levels) are robust enough to meaningfully inform the next phase of research and the broader SESAR R&I roadmap for regional IAM.

© –2023– SESAR 3 JU

5 Conclusions and recommendations

5.1 Conclusions

5.1.1 Conclusions on project/ SESAR solution maturity

The PRIAM project has successfully achieved its objective as a TRL1 (Exploratory Research) activity, establishing the foundational scientific and methodological basis for assessing the deployment of regional IAM services in Europe. The project has demonstrated that MND, combined with modal-shift logit modelling, and optimisation techniques, can be integrated into a coherent end-to-end methodology capable of informing early-stage strategic decisions on vertiport network design and regional IAM demand potential.

At this maturity level, PRIAM provides proof-of-concept evidence rather than an operationally validated tool: the underlying models, data sources, and assumptions have been shown to be technically sound and internally consistent, but have not yet been tested across the diversity of contexts, scales, and operational conditions that would be required to progress to TRL2. The two case studies developed, the Catalan Pyrenees and the Tenerife-La Gomera connection, provide sufficient evidence to confirm the validity of the exploratory research hypothesis, while also clearly identifying the additional research needed (further detailed in Section 5.2) to advance the methodology toward higher maturity levels, including broader geographic validation, richer behavioural data, more refined cost and siting models, and a coherent user interface.

5.1.2 Conclusions on concept clarification

The validation activities confirm that the PRIAM concept, an integrated, end-to-end methodology for assessing and planning regional IAM services, is well defined, internally coherent, and validated by stakeholders and technical implementation.

The concept links different components into a single coherent pipeline. It starts from assessing IAM adoption level based on unsupervised learning techniques applied to stated preference surveys. It then uses MND with enriched behavioural and modal information (trip purpose and road-mode detection) to characterise who travels, why, and how they might shift to IAM. This feeds into behavioural modelling of IAM demand, distinguishing modal shift from induced demand. Finally, this demand and behavioural evidence drive a network optimisation layer that selects vertiport locations and configurations, and a multimodal coordination layer that integrates IAM with existing transport services under operational constraints.

Each stage was shown to connect cleanly to the next: MND-derived demand feeds the behavioural models, behavioural model outputs feed the network optimisation, and the resulting vertiport and demand profiles feed the multimodal integration analysis. This traceability across the pipeline, from raw mobility data to actionable network and operational decisions, was confirmed across two distinct case studies (the Catalan Pyrenees and the Canary Islands), demonstrating that the concept holds together as a single methodology rather than as a set of disconnected components.

© –2023– SESAR 3 JU

Overall, the concept clarification work confirms that PRIAM provides a coherent, validated, and transferable approach to regional IAM planning, spanning the full chain from demand characterisation to network and operational decision-making.

5.1.3 Conclusions on technical aspects

The technical pipeline developed under PRIAM has demonstrated the feasibility of integrating heterogeneous data sources and modelling techniques into a single, reproducible workflow for regional IAM assessment.

Key technical achievements include:

- The developed AI algorithms successfully identified behavioural profiles associated with IAM adoption.
- The trip-purpose classifier and bus-detection algorithm operate at scale on MND-derived data across two distinct case studies with strong and consistent performance.
- The discrete choice models successfully combine stated preference surveys data with MND calibration, producing behaviourally consistent and statistically robust estimates.
- The vertiport network optimisation pipeline was successfully implemented and executed in both case studies, producing stable and reproducible results for an NP-hard problem.
- The IAM–ground transport coordination algorithms are technically operational, with the heuristic method providing a practical solution for real-time or large-scale deployment.

The proposed analytical framework allows behavioural modelling, mobility monitoring and strategic performance assessment to be integrated into a common decision-support environment. The pipeline has proven technically robust at exploratory scale, handling the computational demands of large datasets and producing internally consistent results across both case studies. At the same time, the technical work has showed clear areas requiring further development before the methodology can support operational decision-making. These technical limitations, presented in Section 4.3.1, identified through direct implementation experience, define a concrete and well-scoped technical roadmap for the next R&I phase (Section 5.2.1).

5.1.4 Conclusions on performance assessments

The performance results across the PRIAM pipeline are consistent with the expectations for a TRL1 exploratory research solution: the methodology produces coherent, interpretable, and behaviourally plausible outputs end to end, while absolute figures remain conditioned by the data limitations and exploratory-scale samples inherent to this maturity level.

Taken as a whole, the pipeline demonstrates strong internal performance at each stage and consistency across stages. The behavioural and data-enrichment components (trip-purpose classification, road-mode detection, and adoption segmentation) achieve high accuracy and produce outputs that align with independent survey references, providing a reliable empirical foundation for the demand models built on top of them. The modal-shift and induced-demand models built on this foundation achieve strong goodness-of-fit, translating into IAM demand estimates that are modest but plausible in scale (0.47% of total annual trips in the Catalan Pyrenees, 2.21% in the Canary Islands),

© –2023– SESAR 3 JU

confirming IAM's role as a targeted regional connectivity solution rather than a mass transport mode. These demand outputs in turn drive a vertiport network optimisation tool that consistently identifies coherent, explainable vertiport configurations and captures the sensitivity of profitability to fare levels, and a multimodal coordination layer that offers a viable, computationally efficient trade-off between solution quality and runtime for practical application.

Critically, the performance of each stage is consistent with and reinforces the others: demand, cost, and revenue outputs from the network optimisation align with the MND-derived mobility patterns that feed it, and the behavioural model parameters remain plausible across both case studies despite their different scales and characteristics. This cross-stage consistency, validated through expert review and stakeholder workshops, is itself a key performance result — it confirms that the solution behaves as an integrated whole rather than as a collection of independently accurate but disconnected components.

The principal performance limitations identified: input-data granularity for vertiport siting (land availability and prices, access, electrical-grid connection, weather, visibility, obstacle environment and airspace/procedural compatibility), the simplicity of the current generalised cost formulation, and the computational cost of exact optimisation at scale, are understood, bounded, and do not prevent the solution from fulfilling its intended purpose at this maturity level. They define a clear and well-evidenced basis for the refinements proposed for the next R&I phase.

Overall, the performance evidence supports the conclusion that PRIAM, as a single integrated solution, is technically sound and produces results consistent with expected IAM behaviour, while clearly identifying the path required to progress toward higher TRL levels.

5.1.5 Conclusions on liability and human factors

- There is strong convergence between theoretical legal risks and actual stakeholder concerns, particularly regarding algorithmic opacity (data accuracy), liability shifting for automated software, and the complex stakeholder coordination.
- Stakeholders positively view the PRIAM solution but favour a modular deployment over a fully integrated system.
- Successful adoption faces significant barriers regarding data governance, system interoperability, and the need for user interfaces.
- Even at early development stages, accountability and human factors are critical. As individual services integrate, the complexities of data exchange and liability allocation will only increase.

5.2 Recommendations

5.2.1 Recommendations for next R&I phase

Building on the methodological foundation established by PRIAM, future R&I activity should be structured in three phases, each building on the outputs of the previous one.

Phase 1: Consolidate the methodology and its underlying data and evidence base

© –2023– SESAR 3 JU

- **Extending methodological validation.** Apply the full PRIAM pipeline to additional case studies and territorial contexts. This would allow the methodology to be tested under more diverse geographic, demographic, and infrastructural conditions, improving its transferability and strengthening the robustness and validity of the results across a broader range of environments and conditions.
- **Strengthening the behavioural evidence base.** Apply the methodology to larger and more geographically targeted stated preference surveys. While the current sample was sufficient for exploratory model development, a larger sample would improve representation across user groups, trip purposes, income levels, and regional contexts, strengthening behavioural robustness and supporting more detailed policy conclusions on IAM adoption, modal shift, and induced demand.

Phase 2: Increase model sophistication using the outputs of Phase 1

- **Enriching MND-derived mobility data.** Enhance the attributes extracted from MND to better support IAM shift assessment, including finer segmentation by traveller and trip profile to provide a more informative basis for estimating willingness to pay and modal-shift potential. The road-mode detection algorithm should also be improved to identify additional modes, particularly taxi, given that taxi users represent one of the segments most likely to shift to IAM.
- **Forecasting demand evolution.** Forecast demand growth and structural changes in passenger behaviour over the medium and long term, rather than relying solely on current mobility patterns as a baseline.
- **Enhancing travel time and reliability modelling.** Include road congestion and travel time variability by day of week and time of day. Reliability could also be captured by representing travel time as a probability distribution rather than a fixed value, with variance calibrated to these temporal factors.
- **Refining the generalised cost formulation.** Incorporate additional cost and service-quality components such as parking costs, transfer time, schedule-delay penalties, reliability, and comfort, since IAM competitiveness depends on the full door-to-door travel experience, not only in-vehicle travel time.
- **Improving vertiport micro-location.** The current tool identifies vertiport locations based on aggregated demand zones. Future work should extend this capability to a two-stage hierarchical approach: a first stage operating on aggregated demand zones to identify high-potential areas, followed by a second stage that zooms into those selected areas to fine-tune exact vertiport locations and resolve detailed site-specific costs (land availability, surface access, electrical-grid connection capacity and lead time, construction, obstacle environment, airspace/procedural compatibility, emergency access and local permitting). This requires more refined siting models, including fine-grained weather modelling (particularly wind effects, since wind exposure and turbulence are critical constraints on vertiport feasibility and safety) together with more granular land and construction cost data to better capture site-specific economic viability.

Phase 3: Extend the strategic-level approach toward operational application and prepare the tool for broader, non-technical use

© –2023– SESAR 3 JU

- **Adding an operational layer.** Complement the current strategic-level perspective with a more operational view capable of analysing day-to-day service performance and operational constraints, requiring more detailed, higher-resolution models. This layer should explicitly represent the time-dependent capacity of FATOs/pads, stands, chargers, passenger-processing resources and available electrical power, together with turnaround, queueing, staffing and curfew/noise constraints. Such modelling is needed to test whether the demand identified annually can be served within the operational window of each infrastructure configuration.
- **Improving tool usability and accessibility.** Reduce computational times through more efficient algorithms or solvers, and improve the user interface to allow non-technical users to configure scenarios, run simulations, and visualise results independently

5.2.2 Recommendations for future R&I activities

Beyond the next phase of methodological and technical development, future research should continue building integrated methodologies capable of supporting regional IAM deployment throughout the full planning process, from strategic network design to operational implementation.

A central principle for this future work is to **adopt Legal, Accountability and Human factors by Design (LAD)**: legal, accountability, and human factors frameworks should be proactively and systematically integrated by design and by default throughout all future developments of PRIAM solutions, rather than addressed retrospectively. For infrastructure-focused applications, this should include a responsibility matrix that defines the allocation of responsibilities among the vertiport operator, aircraft operator, VMS provider, charging provider, USSP/CIS provider, ANSP and public authority for data quality, passenger handling, charging, service disruption, emergency response and closure/diversion decisions. As the methodology matures and approaches closer-to-deployment maturity levels, embedding these considerations from the outset will be essential to ensure that resulting tools and models are not only technically robust but also trustworthy, transparent, and aligned with regulatory and societal expectations for the operation of regional IAM services in Europe.

More broadly, future R&I activities should aim to progressively close the gap between strategic-level planning and operational deployment, ensuring that the evidence, models, and tools developed through PRIAM and its successors remain transferable across territorial contexts, adaptable to evolving regulatory frameworks, and accessible to the full range of stakeholders involved in the planning and operation of regional IAM networks, including public authorities, infrastructure planners, and operators.

Overall, the PRIAM project provides a robust methodological foundation upon which future SESAR research activities can build to support the progressive implementation of regional IAM services in Europe.

© –2023– SESAR 3 JU

6 References

6.1 Applicable documents

This ERR complies with the requirements set out in the following documents:

Content integration

[1] Content Integration - Executive Overview, 16/02/2023, 00.01

Content development

[2] SESAR operational concept document 2023, 14/07/2023, 02.00.00

Performance management

[3] PJ19 D4.4 – 874473 DES Performance Framework, 29/06/2023, 01.00

Validation

[4] DES HE requirements and validation / demonstration guidelines, 15/09/2023, 03.00

Programme management

[5] 101167262 PRIAM Grant Agreement, 25/06/2024

[6] SESAR 3 JU Project Handbook – Programme Execution Framework, 11/04/2022, 01.00

[7] SESAR 3 DES Solutions slides, 31/10/2023, 01.00

6.2 Reference documents

[8] European Commission (2011). Flightpath 2050. Europe's Vision for Aviation. Report of the High-Level Group on Aviation Research.

[9] European Commission (2022). Fly the Green Deal: Europe's Vision for Sustainable Aviation. ACARE Report

[10] Kim, H., Sultana, S.: The impacts of high-speed rail extensions on accessibility and spatial equity changes in South Korea from 2004 to 2018 (2015). J. Transp. Geogr. 45, 48–61.

[11] Grimme, W., Paul, A., Maertens, S., & van Wensveen, J. (2020). The prospects of hybrid-electric regional air transport-an assessment of travel time benefits of domestic short-haul flights in Germany with 19-seater aircraft. Transportation Research Procedia, 51, 199-207.

[12] Cascetta, E., Cartenì, A., Henke, I., & Pagliara, F. (2020). Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: 10 years expost evaluation and future perspectives. Transportation Research Part A: Policy and Practice, 139, 412-428.

© –2023– SESAR 3 JU

[13] Sörensen, L., Bossert, A., Jokinen, J. P., & Schlüter, J. (2021). How much flexibility does rural public transport need? Implications from a fully flexible DRT system. Transport Policy, 100, 5-20.

[14] EASA (2021). Study on the societal acceptance of Urban Air Mobility in Europe

[15] Garrow, L. A., German, B., Schwab, N. T., Patterson, M. D., Mendonca, N., Gawdiak, Y. O., & Murphy, J. R. (2022). A Proposed Taxonomy for Advanced Air Mobility. In AIAA AVIATION 2022 Forum (p. 3321)

[16] European Commission (2022b). A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe, COM (2022) 652.

[17] SESAR JU (2020a). Strategic Research and Innovation Agenda – Digital European Sky. Publications Office of the European Union.

[18] Pukhova, A., Llorca, C., Moreno, A., Staves, C., Zhang, Q., Moeckel, R. (2021). Flying taxis revived: Can Urban air mobility reduce road congestion? Journal of Urban Mobility, 1, 100002

[19] Ploetner, K. O., Al Haddad, C., Antoniou, C., Frank, F., Fu, M., Kabel, S., ... & Zhang, Q. (2020). Long-term application potential of urban air mobility complementing public transport: an upper Bavaria example. CEAS Aeronautical Journal, 11, 991-1007.

[20] Rimjha, M., Hotle, S., Trani, A., & Hinze, N. (2021). Commuter demand estimation and feasibility assessment for Urban Air Mobility in Northern California. Transportation Research Part A: Policy and Practice, 148, 506-524.

[21] Schweiger, K., & Preis, L. (2022). Urban air mobility: Systematic review of scientific publications and regulations for vertiport design and operations. Drones, 6(7), 179.

[22] Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K.-D., Kaiser, J., Plötner, K.O. (2020). An overview of current research and developments in urban air mobility–setting the scene for UAM introduction. J. Air Transp. Manag. 87, 101852.

[23] Misté, G. A., Venturelli, G., & Benini, E. (2021). Mobility Impact Assessment of Innovative Aircraft inside the European Multimodal Transport Network. In AIAA AVIATION 2021 FORUM (p. 2952).

[24] Blasco, J., Blasco, C., Jordá, R., Burrieza, J., Cantú Ros, O. G., Mocholí, D. (2022). Data fusion for the analysis of air travel behavior: Application to Palma de Mallorca Airport. Proceedings of the 12th SESAR Innovation Days.

[25] Burrieza, J., Jordá, R., Gregg, A., Ruiz, P., Rodríguez, R., Sala, M.J., Torres, J., García-Albertos, P., Cantú Ros, O.G., Herranz, R. (2022). A methodology for understanding passenger flows combining mobile phone records and airport surveys: Application to Madrid-Barajas Airport after the COVID-19 outbreak. Journal of Air Transport Management, Volume 100.

[26] García-Albertos, Pedro & Ros, Oliva & Herranz, Ricardo. (2019). Analyzing door-to-door travel times through mobile phone data: A case study of Spanish airports. CEAS Aeronautical Journal. 11. 10.1007/s13272-019-00432-y.

[27] A. Moreno, C. Llorca, Q. Zhang, R. Moeckel, and C. Antoniou, “Modeling Induced Demand by Urban Air Mobility,” in mobil. Tum-International Scientific Conference on Mobility and Transport, 2019.

© –2023– SESAR 3 JU

[28] D. Zhang, S. Luchian, J. Raycroft, and D. Ulama, “Induced travel demand modeling for high-speed intercity transportation,” Transp Res Rec, vol. 2673, no. 3, pp. 189–198, 2019.

[29] R. Gorham, Demystifying induced travel demand. The Ministry, 2009.

[30] R. B. Noland and L. L. Lem, “A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK,” Transp Res D Transp Environ, vol. 7, no. 1, pp. 1–26, 2002.

[31] P. B. Goodwin, “Empirical evidence on induced traffic: A review and synthesis,” Transportation (Amst), vol. 23, no. 1, pp. 35–54, 1996.

[32] DES HE SESAR Solution 0396 Exploratory Research Report, MAIA SESAR Project, 2025.

[33] Contissa, G. (2014). “Automation and liability”. *i-lex*, *11*(1).

[34] Emanuilov, I. (2017, November 28–30). “Autonomous systems in aviation: Between product liability and innovation” [Conference paper]. Seventh SESAR Innovation Days, EUROCONTROL.

[35] Cohen, A. P., Shaheen, S. A., & Farrar, E. M. (2021). “Urban air mobility: History, ecosystem, market potential, and challenges.” IEEE Transactions on Intelligent Transportation Systems, *22*(9), 6074–6087.

[36] Bassi, E. (2024). “New steps towards a comprehensive EU legal framework for drones and innovative air mobility: U-space services, air taxis, and data sharing.” SSRN.

[37] Janian, M. N., De Silvestri, S., Tomasello, F., Van Hohf, T., Kramar, V., Capasso, P. J., Dikoun, I., Magliano, G., Van Dijck, G., Lernout, S., Oost, H., Blanca, S. A., Ania, M. A., Hernandez, E., Ponce, M. S., Sarantopoulou, A., Ariram, S., & Hanson, H. (2023). “Evaluation and regulatory assessment results” (Deliverable D6.5). Flying Forward 2020 Project.

[38] Dumortier, F., Dožić, S., Babic, D., Grandsart, D., & Van Camp, S. (2025). “Regulatory (REG) – Intermediate” (Deliverable D2.6). SIGN-AIR Project, SESAR 3 Joint Undertaking.

[39] Ingratoci, C., & Marino, A. (2025). Urban air mobility: Rules of navigation and infrastructure. In M. P. Rizzo & F. Franchina (Eds.), “Drones in the digital European sky” (pp. 97–120). Springer.

© –2023– SESAR 3 JU

Appendix A Validation exercise #01 report

A.1 Summary of the validation exercise #01 plan

As defined in the ERP SESAR Solution 0515

A.2 Deviation from the planned activities

There are no deviations from the planned activities.

A.3 Validation exercise #01 results

A.3.1 Summary of validation exercise #01 results

Exercise #01 validation objective ID	Exercise #01 validation objective title	Exercise #01 success criterion ID	Exercise #01 success criterion	Exercise #01 validation results	Exercise #01 validation objective status
OBJ-0515-ERP-001	Problem definition and development of an impact assessment framework for regional IAM services	CRT-0515-TRL1-ERP-001.001	Identification of at least 5 challenges for regional connectivity across Europe.	Based on an extensive desk research (e.g. literature review), semi-structured interviews with key stakeholders and the 1st PRIAM Stakeholder Workshop, 8 challenges for regional connectivity across Europe have been identified and validated by stakeholders.	OK
		CRT-0515-TRL1-ERP-001.002	Identification of at least 5 types of potential regional-scale IAM services.	5 types of potential regional-scale IAM services have been identified from a literature review (passenger transportation, medical services, access to and from airports, etc.) and have been validated by stakeholders.	OK
		CRT-0515-TRL1-ERP-001.003	Identification of at least 4 scenarios for regional-scale IAM operations in Europe.	Based on the literature review, interview results with key stakeholders and activities during the first PRIAM Stakeholder Workshop, 4 main scenarios have been identified: IAM for mountainous regions and IAM for intra/inter islands connectivity, in two different timeframes with different characteristics: 2035 and 2050.	OK

© –2023– SESAR 3 JU

Exercise #01 validation objective ID	Exercise #01 validation objective title	Exercise #01 success criterion ID	Exercise #01 success criterion	Exercise #01 validation results	Exercise #01 validation objective status
		CRT-0515-TRL1-ERP-001.004	Definition of a set of KPIs in at least 5 areas (passenger experience, capacity, environmental sustainability and operational and cost efficiency)	Based on extensive research, including previous projects, an Impact Assessment Framework has been developed, with KPIs in 6 areas (passenger experience, capacity, demand, environmental sustainability, operational efficiency and cost efficiency).	OK
		CRT-0515-TRL1-ERP-001.005	Identification of a set of high-level requirements for data analytics and modelling tools with implications for PRIAM developments.	A set of different high-level requirements has been identified through desk research, interviews and 1st PRIAM Stakeholder Workshop. These requirements fall within different areas.	OK

Table 18. Validation exercise #01 results

A.3.2 Analysis of validation exercise #01 results per validation objective

A.3.2.1. OBJ-0515-TRL1-ERP-001 Results

The methodology followed for this validation exercise is depicted in Figure 4 and described below:

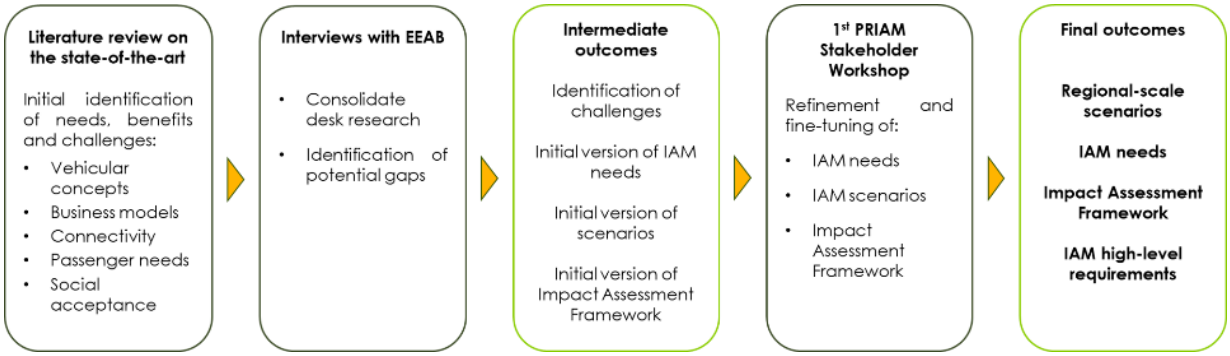


Figure 4. OBJ-0515-TRL1-ERP-001 methodology

First, a comprehensive literature review was conducted to explore the current state-of-the-art and recent advancements in the field of IAM. This review aimed to identify key trends and insights across several IAM-related areas, including (i) Vehicular concepts, (ii) Business models, (iii) Connectivity, (iv) Passenger needs, and (v) Social acceptance.

© –2023– SESAR 3 JU

Secondly, a set of interviews were carried out with various members of the EEAB. These interviews served to consolidate the desk research and complement the findings from the literature review, while also uncovering potential gaps and challenges that may not have been identified previously.

The outcomes of these two steps led to the preliminary identification of IAM challenges and needs, the initial definition of a set of regional-scale scenarios to be developed within the project, and the development of an initial version of the impact assessment framework. These interim results were presented at the first PRIAM Stakeholder Workshop, which aimed to gather feedback from external experts in key related fields. The feedback received was instrumental in refining and finalising the regional scenarios, IAM needs, the impact assessment framework, and the high-level requirements.

This methodology allowed to achieve the different success criteria stated for this validation exercise. In the following subsections, the results achieved regarding each of the success criteria are presented.

CRT-0515-TRL1-ERP-001.001: Identification of at least 5 challenges for regional connectivity across Europe

Based on desk research conducted through an extensive review of the relevant literature and validated by five semi-structured interviews with key expert stakeholders (e.g., drone operators, infrastructure developers), a list of eight distinct challenges to regional connectivity across Europe has been identified.

The current challenges faced by regional areas regarding connectivity and accessibility and the details of how this mobility can offer solutions to overcome these challenges have been listed below ([35])

1. **Geographical barriers**: Many rural and regional areas are characterised by natural obstacles such as mountains and rivers, which make the development of road or rail networks costly and inefficient. These barriers limit accessibility and make it difficult to connect remote communities to essential services.
2. **Limited public transport infrastructure**: Rural regions often have underdeveloped public transport systems with fewer routes and lower frequency compared to urban areas. This lack of public transportation leaves many rural residents reliant on private vehicles, creating problems for those without access to cars and contributing to isolation.
3. **Sparse population density**: Low population density in rural areas makes it economically unfeasible to develop traditional public transportation systems, such as buses or trains. As a result, transportation options are limited, leaving rural populations with fewer mobility choices.
4. **Cross-border connectivity issues**: In many border regions, transport services are fragmented, with differing infrastructure and regulations between countries. This lack of harmonised systems creates inefficiencies in cross-border travel, making regional transport more challenging.
5. **Outdated or poorly maintained infrastructure**: In some regions, existing infrastructure, particularly roads and railways, is outdated and in need of modernisation. Poor maintenance further exacerbates connectivity issues, with many routes becoming impassable during adverse weather conditions.
6. **Environmental and sustainability concerns**: Over-reliance on road transport contributes to environmental degradation in many regions. This is particularly true in rural areas where

© –2023– SESAR 3 JU

sustainable transport options, such as electric buses or rail systems, are often unavailable. As a result, greenhouse gas emissions remain high.

7. **Emergency medical services**: Rural and remote areas often lack access to emergency medical services due to the time-consuming nature of ground transport. In critical situations, delays in receiving medical care can lead to negative health outcomes, further illustrating the need for more efficient transport solutions.
8. **Economic barriers to infrastructure development**: Developing and maintaining transportation infrastructure in remote or rural areas is costly, and governments often prioritise urban areas with higher populations. This leaves regional areas underserved and hinders their economic development.

These challenges were systematically discussed with key stakeholders through two complementary engagement formats: semi-structured interviews (held online) and the PRIAM 1st Stakeholder Workshop, held in Brussels with the EEAB. The workshop provided a valuable setting for stakeholders from diverse sectors, as mentioned above, to engage directly with the preliminary findings of the desk research. Through interactive sessions and facilitated group activities (e.g. debriefing sessions using a Miro board for inputs), participants were allowed to critically assess, reflect upon, and validate the identified challenges based on their own expertise and practical experience.

Within the framework of the PRIAM project, while some challenges emerged as more pressing or critical than others—based on their perceived impact and urgency—all eight were consistently recognised by stakeholders as relevant and legitimate barriers to regional connectivity across Europe. This comprehensive validation process reinforces the credibility of the research outcomes and underlines the significance of addressing these challenges in the development of effective, inclusive, and future-oriented regional mobility solutions.

CRT-0515-TRL1-ERP-001.002: Identification of at least 5 types of potential regional-scale IAM services

Based on the outcomes of the desk research—subsequently validated through interviews with key stakeholders and during the First PRIAM Stakeholder Workshop—five categories of potential regional-scale IAM services for people have been identified and assessed. These include, among others, business travel and emergency medical services.

The definition of these services reflects both current regional mobility needs and broader connectivity challenges for passenger transportation. Their identification was grounded in stakeholder perspectives and a review of structural gaps in existing transport networks. Table 19 provides a summary of the proposed service types along with their expected benefits in addressing regional accessibility and connectivity constraints for passengers.

IAM services	Benefits
Business travellers' transportation	By offering direct connections between smaller regional cities and major urban hubs, IAM services save time, and enhance convenience. This not only improves the efficiency of business travel but also supports regional economic integration by improving access to larger commercial centres. Key features of business travel transportation include strategically located access points that minimise first- and last-mile delays, and reduced waiting times through optimised scheduling. These elements create a fast, reliable, and user-friendly mobility solution tailored to the needs of time-sensitive travellers.

© –2023– SESAR 3 JU

IAM services	Benefits
	IAM can enhance productivity, improve work-life balance, and can also contribute to boarder goals such as economic cohesion and reduced environmental impact.
Leisure passengers' transportation	In tourist destinations like Tenerife and the Pyrenees, integrated transport solutions—connecting air, sea, and land—can lead to substantial time savings when moving between islands or accessing various points of interest. IAM services not only improve the convenience and attractiveness of the public transport network for visitors but also support a more sustainable tourism model. Moreover, the economic implications are equally noteworthy. Improved transport connectivity can lead to increased tourist flows, as travellers are more likely to explore multiple destinations within a region when efficient transportation options are available.
Emergency services (transportation of medical goods and patients)	Travel to hospitals or specialised medical facilities in predominately rural areas often involves long, complex journeys over limited transport networks. This can pose serious risks, particularly in emergencies or for patients requiring regular treatment. The implementation of IAM services offers a highly effective solution to these challenges. Indeed, they can facilitate the rapid and reliable delivery of medical goods, including life-saving equipment, blood supplies, vaccines, and pharmaceuticals, to remote locations. This significantly reduces delivery times compared to conventional transport methods. Eventually, in the future, this service can be extended to passengers, which could be patients who need a transfer to a nearby hospital.
Travellers to/from airports transportation	IAM services powered by eVTOL aircrafts provide a high-speed, direct, and congestion-free alternative to conventional ground-based transport from and to airports. By enabling vertical take-off and landing from strategically located urban vertiports, these services can drastically reduce the time required to access or depart from airport facilities. Beyond the convenience for individual travellers, these services also support broader policy goals such as reducing road congestion, and lowering carbon emissions.
Communities in small and/or rural areas	As the technology matures, operating costs decrease, and infrastructure becomes more widespread, IAM services can evolve into a viable and inclusive mode of transportation for residents of rural and underserved areas. These communities often face significant challenges in accessing major transportation hubs or essential services due to geographic isolation, limited public transport infrastructure, or inadequate road connectivity. IAM services can provide an efficient and time-saving alternative for these populations, enabling them to connect with larger urban centres, healthcare facilities, educational institutions, and economic opportunities. In this context, IAM services could enhance connectivity, providing long-term value for citizens living in less-connected regions who stand to benefit significantly from faster, and more reliable transportation options.

Table 19. IAM services

As discussed during the 1st PRIAM Stakeholder Workshop activities, emergency services—particularly the transport of medical goods—were identified by key stakeholders as the most viable initial application. This use case can serve as a foundation for broader IAM deployment, offering early proof of concept and high societal value. This service, indeed, is driven by fewer regulatory and infrastructural barriers compared to passenger operations, and therefore offers a practical and socially impactful starting point.

© –2023– SESAR 3 JU

Passenger transport services are expected to follow, beginning with high-spending, time-sensitive users such as business travellers. Their early adoption can help demonstrate commercial viability and build momentum for expanding IAM services to wider segments of the population as the technology becomes more accessible and cost-effective.

CRT-0515-TRL1-ERP-001.003: Identification of at least 4 scenarios for regional-scale IAM operations in Europe

Building on the findings of the desk research, contributions from project partners, interviews with key stakeholders, and discussions held during the 1st PRIAM Stakeholder Workshop, four distinct scenarios have been identified for the potential deployment of IAM services at a regional scale within Europe.

However, the development and operationalisation of regional IAM services are not without significant challenges. As highlighted in Table 20, a number of critical issues have been considered when identifying the 4 scenarios, particularly in relation to vehicle concepts and the current regulatory frameworks. These include both the certification processes for new vehicle technologies—such as eVTOLs—and the operational regulations governing their integration into existing airspace and transport networks.

Topic	Desk research	Interview
Regulation approval and issues	Regulatory Hurdles: A primary obstacle is the lack of established regulations governing eVTOL certification, operation, and infrastructure. Additionally, the cautious approach of authorities towards autonomous technology further complicates the certification process. A supplemental challenge is depicted by the U-space (a set of services designed to ensure a safe and efficient use and access to airspace for drones), since drones, to operate, need U-space level 4, but research is still at level 1. This poses a regulatory and technical challenge.	The interview results are in line with the desk research results. Indeed, regulatory issues are the main challenge for eVTOLs, especially when passenger transportation is involved (safety relevance). From a technological point of view, it would be possible to have operating eVTOLs even before 2035. Operations with eVTOLs that might have more difficulty obtaining regulatory approval are: • Night-time operations: for pilot flights, there will be a need to use Visual Flight Rules, so at first, there will be no night flights. When the drones become autonomous, they will perform these kinds of operations. • Over-water operations: these will need even more regulations, so they will not be the first use cases for eVTOLs. Additionally, stakeholders highlighted during the interviews: • need for integration with ATM (prerequisite) need for segregated space, high levels of automation and safe spaces for collision tests.

© –2023– SESAR 3 JU

Topic	Desk research	Interview
Automation	There are up to 5 levels of automation for IAM vehicles: • **Level 0 (No automation)**: they operate completely under human control, and pilots are responsible for all flight aspects. • **Level 1 (Assisted automation)**: the system assists in certain tasks (such as stability control or basic navigation), but the pilot remains primarily in control. • **Level 2 (Enhanced automation)**: the system performs major flight operations (such as take-off and landing on pre-defined routes) automatically under specific conditions but the pilot remains as a supervisor. • **Level 3 (High automation)**: the system is responsible for all flight aspects in most common scenarios, taking care also of real time decision making and obstacle avoidance. • **Level 4 (Full automation)**: the system is fully autonomous and doesn't require a pilot, not even in emergency scenarios. • **Level 5 (Swarm automation)**: the system is fully autonomous and can operate collaboratively with other eVTOLs, responding adaptively. These automation levels are similar to the automation levels classification provided by EASA, from level 1A to level 3B, going from an increasing automation to a full automation. However, the eVTOL automation levels add a next step, where the vehicle can collaborate with other eVTOLs.	The interviews were less in detail than the desk research, mainly because they didn't go into technical details. From a technological point of view, technology might be ready for the timeframe 2025-2030, so indeed 2035 is a conservative timeframe. A stakeholder thinks that eVTOLs will not be fully autonomous till 2040-2050 (in line with PRIAM envision and desk research results). From a U-space perspective, if the eVTOL is flying with a pilot, then it's going to use regular airspace, and just cross U-space, but if the eVTOL is autonomous, then integration with U-space is needed. Based on a stakeholder's expertise, the level of the U-space must be 4, especially if they are flying over cities (N.B. this is needed also to create a good market). Additionally, stakeholders highlighted during the interviews: • Two ongoing research projects: IAI (Israel) and Estratopuerto (Fuerteventura). They are very advanced in terms of automation. However, IAI has a fleet of drones still not suitable for passenger transportation, therefore not usable. Increasing the size of drones means increasing difficulties for automation. Operations with pilots will serve as a baseline for autonomous operations, contributing to the development of a more mature and secure.
Vehicular concepts	As previously mentioned, because of their important goal and future implementation, many companies have invested money in eVTOLs technologies, leading to the commercialisation and development of numerous eVTOLs design and configurations. At the moment the three primary eVTOLs configurations have these characteristics: • Multirotor eVTOLs: rely primarily on multiple rotors for lift during cruise, with restricted or no wing usage. They can operate in a confined area and for short journeys, since they have limited endurance	Stakeholders agreed that vectored thrust eVTOLs might be the best suitable eVTOL configuration for passenger transportation.

© –2023– SESAR 3 JU

Topic	Desk research	Interview
	and speed that make them unsuitable for long trips. They are the most recognised and mature configuration of eVTOLs because of its simple control method and its low manufacturing cost ([28]). A representative product is, for example, Ehang 216. • Compound wing (lift + cruise) eVTOLs: they have wings that provide lift during cruising and distinct lift and cruise thrusters. Due to the incorporation of both cruising and vertical lift systems they face a challenge in terms of dead weight and complexity ([28]). They can do small distance journey; therefore, they are suitable for cargo transportation. A representative product is, for example, CityAirbus NextGen. Vectored thrust eVTOLs: they have wings and one or more vectored thrusters, for example tilt-wings, tilt-rotors and tilt-ducts for lift and cruise. When they reach a certain speed they switch to a horizontal position, but because of that they necessitate an efficient control system for a precise and stable control of thrust direction ([28]). They are adapted for long distance journeys and, therefore, the most suitable configuration for passenger transportation. A representative product is, for example, Hyundai SA1 eVTOL ([14]).	

Table 20. IAM identified challenges

These challenges were further discussed and validated through the semi-structured interviews conducted with key stakeholders, during which they shared their insights, perspectives, and professional judgements.

Once these challenges and considerations were validated, four scenarios were defined, structured across two time horizons (**2035** and **2050**) and two geographic contexts: the **Catalan Pyrenees**, representing IAM applications in mountainous regions, and the **La Gomera–Tenerife connection**, representing IAM applications for inter-island connectivity.

The Catalan Pyrenees offer a valuable example of the accessibility challenges faced by mountainous areas. Geographical barriers limit the ability to provide high-quality road infrastructure and high-speed rail (HSR) links. While predominantly rural, the region attracts large tourist flows (particularly in the winter season) and acts as the door to the country of Andorra (80k inhab.). Andorra has no airport due to lack of space and the complicated orography, but the existing heliports could be upgraded to vertiports in order to enable IAM connectivity with Spain and France.

The La Gomera–Tenerife case study represents IAM applications for inter-island connectivity. The UE counts over 60 islands with populations exceeding 5,000 inhabitants, many of which are part of archipelagos characterised by a hierarchical settlement pattern. In these regions, smaller islands rely

© –2023– SESAR 3 JU

heavily on efficient and continuous connections to larger islands and their urban centres in order to support residents' quality of life and drive socioeconomic growth.

A notable example of these dynamics can be found in the Canary Islands, particularly between La Gomera (population approximately 22,000) and Tenerife (population approximately 950,000). This pairing illustrates the complexities of inter-island mobility. La Gomera is linked to Tenerife via maritime transport from the southern port of Los Cristianos to its main town, as well as through limited air service. The air connection operates between Tenerife Norte Airport and La Gomera Airport (IATA code: GMZ). Currently, Binter airline offers two daily flights—one in the morning and one in the evening—using ATR-72 aircraft with a capacity of 70 passengers. Bluenest has launched trials involving cargo eVTOLs for the transportation of medical supplies both within and between the islands, representing an innovative approach to addressing regional mobility and logistics challenges

The four scenarios were identified and subsequently validated through a collaborative process involving both project partners and key stakeholders. This validation took place through a series of interviews, debriefing sessions, and the 1st PRIAM Stakeholder Workshop, during which participants engaged in structured activities aimed at assessing the relevance and feasibility of each scenario. These activities were supported by graphic representations, which facilitated a clearer understanding and comparison of the scenarios under discussion. Table 21 presents a summary of each scenario.

Scenario	2035	2050
Catalan Pyrenees: IAM for mountainous regions	The primary objectives include the establishment of certified, piloted eVTOL operations in mountainous regions, leveraging existing infrastructure for vertiports to minimise initial investment costs. Operations will be conducted within controlled airspace and fully integrated with existing Air Traffic Management (ATM) systems to ensure the highest levels of safety and regulatory compliance. Given the early stage of implementation and the regulatory and operational constraints, the volume of flights within this timeframe is expected to remain limited.	A transition toward autonomous eVTOL operations—including operations during nighttime—is anticipated within the defined timeframe. To support this advancement, the implementation of U-space Level 4 services is expected, enabling efficient, automated, and safe management of airspace. As a result, eVTOL operations will be extended across both controlled and uncontrolled airspace, marking a significant step toward broader integration of advanced air mobility solutions. This development will allow for a higher volume of flights, thereby enhancing regional connectivity and expanding accessibility to underserved and remote communities.

© –2023– SESAR 3 JU

Scenario	2035	2050
Intra/Inter-Island connectivity	The objective, within this timeframe, is to introduce piloted eVTOL services to enhance connectivity both within and between islands, addressing key transport challenges for residents, tourists, and healthcare services. Initial operations will make use of existing airfields and upgraded heliports, enabling cost-effective route deployment. Operations will be conducted primarily within **controlled airspace** over coastal and over-water regions, with close coordination with maritime authorities to ensure safety and compliance. Initial traffic volumes will remain low, focusing on short-haul routes between islands to establish a reliable and efficient transport alternative.	The goal, within this timeframe, is to transition to autonomous eVTOL operations to increase service frequency between islands and reduce operational costs. This will enable the provision of affordable, reliable transport solutions for both residents and tourists in insular regions. Operations will take place primarily within **controlled airspace** over coastal and over-water areas, with full integration of U-space Level 4 services to ensure safe, efficient autonomous flight management. A higher volume of autonomous eVTOL flights is expected, supporting diverse flight profiles including night-time operations and extended over-water routes, thus enhancing regional connectivity and accessibility.

Table 21. IAM scenarios

CRT-0515-TRL1-ERP-001.004: Definition of a set of KPIs in at least 5 areas (passenger experience, capacity, environmental sustainability and operational and cost efficiency)

The PRIAM impact assessment framework supports PRIAM's objective of developing a suite of data analytics and modelling tools from a strategic perspective, with a particular focus on high-level evaluation and decision-making processes.

As a result, the following assumptions have been made regarding the impact assessment framework:

- The impact assessment framework has been designed from a strategic perspective, focusing on high-level evaluation metrics. As a result, tactical KPIs, which are part of operational and short-term decision-making, have not been included in the scope of this assessment, such as predictability, reliability, etc.
- While a comprehensive set of strategic KPIs has been identified, some of them—such as noise and visual pollution indicators—require specialised modelling tools that are beyond the scope of this project. Consequently, these KPIs will be incorporated into the framework for reference and future application but will not be calculated within the project.

Importantly, the framework has been designed to remain flexible and scalable, allowing for the integration of additional Key Performance Indicators (KPIs) as new data sources, methodologies, and analytical tools become available in subsequent phases of the project.

The Impact Assessment Framework, validated by key stakeholders during the 1st PRIAM Stakeholder Workshop, and enriched by their perspectives and expert judgments, addresses 6 Key Performance Areas (KPAs).

- **Passenger Experience**. This is at the centre of recent advances in transportation. As passenger experience is not easy to measure directly, it is often assessed through travel time, as the optimisation of travel time is one of the most important factors contributing to a positive passenger experience.

© –2023– SESAR 3 JU

- **Demand**. This area focusses on measure the impact on the future IAM demand, including both the demand that IAM will capture from other modes and the induced demand (i.e., people that were previously not travelling and are now using IAM).
- **Cost efficiency.** IAM passenger services are likely to have a high price, especially at the start of their operations. To account for the price change and the comparison with other modes, indicators have been included to compare the situation before and after the inclusion of IAM services as well as the different time-frames considered in the experiments. Comparing different itineraries is useful for assessing the added cost of IAM.
- **Environment**: IAM is a clean technology with the potential to significantly decarbonise the transport sector. However, its environmental footprint extends beyond emissions, including noise, visual pollution, and land-use impacts related to take-off, landing, and storage. While life-cycle emissions from manufacturing and disposal are beyond the scope of the PRIAM project, these primary environmental effects are acknowledged due to their relevance. Given the low TRL nature of this project, the PRIAM toolset has limited modelling capabilities to capture all environmental impacts of IAM. However, to acknowledge all the potential environmental impacts, the PIs developed by the SESAR project MUSE will be added to the impact assessment framework. They are not included here for simplicity.
- **Operational efficiency**: For a multimodal network to be successful, it has to be coordinated. One of the aims of the PRIAM project is to help integrating IAM services in a meaningful way in a multimodal framework. Connection and coordination of a multimodal network is often measured by accounting for waiting times, especially between different transportation modes. This is why the waiting times KPIs have been included here rather than in passenger experience, although short waiting times are associated with greater passenger experiences. Another important factor to take into account for an efficient network, are maintenance repair and overhaul times (MRO), along with battery charging for eVTOLs. These KPIs are out of the scope of the PRIAM project, but they could be included in future version of the Impact Assessment Framework.
- **Capacity:** Since this project is centred on the addition of IAM to an existing transportation network, the capacity of the IAM segments of the network will be the focus. This will allow to quantify how many more passenger IAM services are able to carry. As a result of the 1st PRIAM stakeholder workshop, since air operations are safety-critical, route capacity and vertiport capacity have to be accounted vehicle-wise as well.

Table 22 presents the 6 KPAs, the PIs included in each area and the results of the validation of the 1st PRIAM Stakeholder Workshop. During the workshop, the stakeholders were asked to validate the PIs rating their relevance from 1 (not relevant) to 5 (extremely relevant).

KPA	KPI	Average relevance (1 to 5)
Passenger Experience	Average travel time per OD pair	4.6
	Average travel time per itinerary per OD pair	4.1
	IAM Average access/egress travel time to vertiport	4.3
	IAM in-flight travel time ratio	3.8
	IAM access/egress travel time ratio	3.8

© –2023– SESAR 3 JU

KPA	KPI	Average relevance (1 to 5)
Demand	Demand per OD pair	4.8
	Demand per mode per OD pair	4.5
	IAM captured demand per OD pair	4.5
	IAM induced demand per OD pair	4
	Modal shift	4.1
	Vertiport catchment area	3.6
	Population-based potential demand	3.3
Cost efficiency	Average passenger-km cost per OD pair	4.2
	Average passenger-km cost per itinerary per OD pair	4.5
Environment	CO_2 per passenger-km	4.6
Operational efficiency	Waiting time between modes	4.8
	Waiting time ratio	3.6
Capacity	IAM passenger route capacity	4
	IAM vehicle route capacity	-
	IAM passenger vertiport capacity	4.5
	IAM vehicle vertiport capacity	-

Table 22. Impact assessment framework PIs and their relevance according to the EEAB

When relevant, the KPIs may be disaggregated by trip purpose or other passenger characteristics, to deeply analyse the impact of IAM in different passenger profiles.

CRT-0515-TRL1-ERP-001.005: Identification of a set of high-level requirements for data analytics and modelling tools with implications for PRIAM developments.

The set of high-level requirements will serve as the foundation for the simulation activities and, as such, must be specific to the PRIAM context.

These requirements have been identified through a comprehensive, multi-phase process, as presented in Figure 4. Initially, extensive desk research was conducted, drawing on a wide range of sources including academic publications, articles, and other relevant literature. The findings were then refined and validated through a series of semi-structured interviews with subject matter experts. These interviews focused on uncovering gaps, challenges, and key insights across the various thematic areas.

The final validation step involved the 1st PRIAM Stakeholder Workshop. During this workshop, key stakeholders reviewed and assessed the preliminary high-level requirements. They provided valuable feedback, offering recommendations on which elements should be retained, revised, or removed to better align with the project's objectives.

High level requirements are divided in 4 areas: IAM vehicular concepts, IAM business model, IAM connectivity, IAM passenger needs. The high-level requirements are key elements that the IAM system to be modelled should incorporate. They represent a basis for the simulations to be realised.

© –2023– SESAR 3 JU

The following set of high-level requirements are presented in Table 23.

Topic	Sub-topic	High-level requirements
IAM vehicular concept	Vehicular concept	eVTOLs should be certified and suitable for passenger transportation (e.g., in terms of size, manoeuvrability, luggage transportation or comfort).
	Regulation	• Regulatory approval for piloted eVTOL operations should be implemented by 2035. • Regulatory approval for autonomous eVTOLs with specific operations (nighttime, over-water, and high altitudes) should be implemented by 2050
	Automation	• Autonomous eVTOLs should be specifically designed for passenger transportation. • Remote pilots should be considered as an intermediate part of the transition to autonomous vehicles • Level 4 U-space for autonomous eVTOL operations should be implemented by 2050. • To fully deploy automation, three main areas must be considered: operating vehicle, operating environment (e.g., U-Space and ATM integration), and operating mode (e.g., flight rules, flight procedures and operating procedures).
	Technical aspects	• Battery technologies should be advanced to improve weight, battery consumption, and battery life. • Electric eVTOLs should be developed to minimise explosion hazards compared to fuel/hydrogen alternatives. • Adequately sized eVTOLs should be ensured in terms of autonomy, landing spots, and passenger transportation capacity. • The number of engines should be considered (if one of them stops working, another one should be available). • Weather conditions should be considered, especially in developing some parts of the eVTOLs (metal parts in case of extreme heat and/or lightning).
	Vertiports	• Existing infrastructure, such as heliports, should be utilised for eVTOLs by 2035. As an example, Andorra already has usable heliports. • Additional infrastructure should be created with minimal impact on people's lives and the environment by 2050. • Safety issues should be considered when developing new infrastructure, including urban areas, second landing spots, and safe access. • Geographical and environmental considerations such as sea proximity, weather predictability, air traffic density, and nearby airports should be factored in for new infrastructure. • Vertiport management and booking systems should be established.

© –2023– SESAR 3 JU

Topic	Sub-topic	High-level requirements
	Operational environment	• The vehicle operating environment should be addressed along with the operating mode (flight rules and procedures) • eVTOL operations should not affect regular runway operations. Therefore, safe but operational and economically feasible standards should be defined. • High digitalisation for communication with ATC and other airspace users should be ensured.
IAM business models	Main elements	• Technical proof of concept for commercial eVTOL operations should be provided. • Commercial certification for eVTOLs should be obtained by 2035. • OEM companies should pursue commercial certification for autonomous eVTOLs by 2050. • Direct costs should be addressed, including vertiport development (using existing infrastructure where possible by 2035), investments, insurance, maintenance, storage and operator costs (with piloted eVTOLs having higher initial costs until autonomous operations are established by 2050). • Indirect costs should be addressed, such as marketing (to attract investors), ticketing and reservations, and administration fees. • High initial ticket prices may be set to cover initial expenses unless administrative support covers some costs by 2035. • Profit margins could be increased by offering cheaper ticket prices if eVTOLs become autonomous and demand rises by 2050.
	Main factors	• eVTOL configurations suitable for passenger transportation (e.g., vectored thrust, regent aircraft, VX4) should be certified. • Existing infrastructure (e.g., heliports) and storage should be upgraded for eVTOL compatibility. • Vertiport operators and eVTOL operators responsible for ground operations and vehicle maintenance should be identified and trained by 2035. • eVTOL pilots should be identified and trained by 2035. • Locations with a higher demand for eVTOL services should be identified using surveys and mobile data to inform demand and service frequency.
	Frequency of the service	• Service frequency should be enhanced based on the demand.
IAM Connectivity	Infrastructure	• eVTOL services should connect remote locations (e.g., rural, mountainous, or island) to cities or points of interest (e.g., hospitals) • Existing infrastructure (i.e., heliports) should be upgraded.
	Geography	• Regulations and procedures for over-water and high-altitude eVTOL operations should be developed and implemented
	Population density	• High-demand locations (e.g., based on surveys, mobile data) should be identified.

© –2023– SESAR 3 JU

Topic	Sub-topic	High-level requirements
IAM Passenger needs	Mobility needs	• The service should provide availability, frequency, perceived safety, and total travel time savings. • The service should also consider comfort (e.g., luggage storage inside eVTOLs in case of leisure passengers).
	Accessibility	• The eVTOLs should be accessible to various user categories. • Users should perceive the value of eVTOLs' service. • The service should be designed to ensure ease of use for passengers.
	Affordability	• Ticket pricing should be affordable to increase demand.
	Acceptance	• Trust and acceptance of eVTOLs among users should be enhanced. • Visual landscape and environmental noise impact during operations should be minimised.

Table 23. PRIAM high-level requirements summary

A.3.3 Unexpected behaviours/results

No unexpected behaviours or results have been identified in the context of validation exercise #01.

A.3.4 Confidence in results of validation exercise #01

A.3.4.1. Level of significance/limitations of validation exercise results

The results of Validation Exercise #01 are considered both significant and sufficiently representative to inform future integration at the SESAR solution level. These findings are grounded in a combination of extensive literature research and expert judgement gathered through semi-structured interviews. As such, they are particularly suited for high-level strategic use, especially within the European context.

The limitations of the validation exercise are the following:

- The Impact Assessment Framework developed as part of this exercise has been designed with a strategic-level focus, and as a consequence, tactical KPIs have not been included within the current scope. The limited modelling capabilities of the project and the fact that at this stage of TRLs the PRIAM toolset is meant as a strategic tool justify this limitation. Moreover, tactical assessment of passenger IAM operations is not needed in the short term according to the progress of the industry and regulations.
- As previously explained, strategic KPIs related to visual and noise pollution will not be measured in the project. However, they have been acknowledged for completeness as a mitigation measure and validated in the first PRIAM stakeholder workshop.
- The limited number of experts consulted for the interviews also represents a constraint. The interview questions have been designed with personal biases in mind in order to minimise the risk of having an incomplete image of the IAM situation in Europe. Additionally, experts of different fields were interviewed. Since the results of the interviews and of the literature review are very much in line, we consider that the results of this phase of the project are representative enough for the PRIAM project.

© –2023– SESAR 3 JU

Co-funded by the European Union

A.3.4.2. Quality of validation exercises results

The level of confidence in the results obtained is considered to be appropriate. This statement is supported by multiple reinforcing factors.

Firstly, the findings are grounded in extensive desk research that synthesised a broad range of academic literature, technical studies, and policy documents. This comprehensive approach ensured that the analysis was informed by well-established knowledge and up-to-date insights relevant to the evolving landscape of IAM services.

Secondly, the validation of assumptions and scenarios was enriched by the outcomes of previous European research and innovation projects, such as TRANSIT (2020) and others, which provided a valuable foundation and continuity in terms of methodological approaches and thematic alignment. These projects contributed not only data but also structured frameworks that informed the current analysis.

Thirdly, a key strength of the assessment lies in the expertise and diversity of the stakeholders consulted throughout the process. Their input—gathered through interviews, debriefings, and workshop discussions—was instrumental in refining the assumptions, contextualising and validating the findings. The involvement of stakeholders with specialised knowledge in air mobility, transport planning, regulation, and regional development added depth and credibility to the conclusions drawn.

Taken together, these elements contribute to a high degree of confidence in the robustness and strategic relevance of the results, particularly within the European context.

A.3.4.3. Significance of validation exercises results

In the context of this project, the significance of the results is understood primarily in a qualitative sense, rather than in terms of statistical or operational significance. No quantitative simulation or experimental validation exercises were carried out as part of Validation Exercise #01. Consequently, statistical and operational significance cannot be assessed.

A.4 Conclusions

A.4.1 Conclusions on concept clarification

The EEAB approved the initial concept and impact assessment framework for PRIAM. The conclusions derived from Validation Exercises #02 to #06, which addresses the validation of the technical components, will feed and refine future versions of the Concept Outline, based on the findings.

A.4.2 Conclusions on technical feasibility

The EEAB's response to the initial concept and impact assessment framework was generally positive. The comprehensive feedback provided by the experts will inform future versions of the Concept Outline. Detailed elaboration on technical aspects will be included in the rest of appendices of the document, following the performance of the rest of validation exercises.

A.4.3 Conclusions on performance assessments

While the EEAB offered positive feedback on the concept and impact assessment framework of PRIAM, it should be noted that Validation Exercise #01, being qualitative, did not measure the solution's performance impact. The assessment of PRIAM solution’s actual performance contributions will be

© –2023– SESAR 3 JU

addressed in the Validation Exercises #02 to #06, which addresses the validation of the technical components. Currently, the concept and KPIs are acknowledged for their prospective benefits, yet they do not provide an evaluation of system or human performance.

A.5 Recommendations

As discussed in previous sections, the development of the impact assessment framework has been approached from a strategic perspective, in alignment with the project's objectives and scope. The focus has been placed on high-level evaluation metrics, while tactical indicators typically associated with operational performance and short-term decision-making have been excluded from the current assessment. As a result, one key recommendation is to extend this framework in future research phases by incorporating indicators in key tactical areas such as predictability, reliability, and others. These indicators were frequently highlighted during discussions with external experts at the 1st PRIAM Stakeholder Workshop and are essential for a more comprehensive assessment of IAM systems at later stages.

Additionally, although a comprehensive set of strategic KPIs has been defined, the quantification of certain indicators requires specialised modelling tools that are out the scope of this project (e.g., noise and visual pollution indicators). These KPIs have been included in the framework for reference and future integration, but they will not be assessed within the current project. Accordingly, a further recommendation for subsequent research phases is to address the development of these modelling tools, enabling a more detailed and complete application of the framework.

© –2023– SESAR 3 JU

Appendix B Validation exercise #02 report

B.1 Summary of the validation exercise #02 plan

As defined in the ERP SESAR Solution 0515

B.2 Deviation from the planned activities

There are no deviations from the planned activities.

B.3 Validation exercise #02 results

B.3.1 Summary of validation exercise #02 results

Exercise #02 validation objective ID	Exercise #02 validation objective title	Exercise #02 success criterion ID	Exercise #02 success criterion	Exercise #02 validation results	Exercise #02 validation objective status
OBJ-0515-ERP-002	Validation of AI algorithms for estimating IAM adoption levels	CRT-0515-TRL1-ERP-002.001	The AI-based algorithms developed to identify human factors influencing IAM adoption have been validated through a combination of expert stakeholder reviews and quantitative methods, including cluster evaluation techniques and feature importance analysis, ensuring both their reliability and interpretability.	Validation of AI clustering via: 1) Elbow method to determine the optimal number of clusters (2 clusters with SSE < 30k) 2) Silhouette Score: 0.53. Indicates a good clustering solution. It defines how well our data points fit into the clusters they've been assigned measuring both quality of cluster cohesion and separation.	OK

Table 24. Validation exercise #02 results

B.3.2 Analysis of validation exercise #02 results per validation objective

B.3.2.1. OBJ-0515-TRL1-ERP-002 Results

This validation objective aims to validate the algorithms for estimating IAM adoption levels. These algorithms use as input a stated preference survey, therefore it has been designed and conducted within the project.

A total of 48 questions divided in 4 sections were designed, gathering information on respondents' socio-demographic characteristics (age, gender, nationality, etc.), current travel behaviour (frequency

© –2023– SESAR 3 JU

of travel, mode used, etc.), perceptions towards IAM (familiarity with IAM, concerns, etc.), and stated preferences under different IAM service configurations. You can find a list of the questions in Table 25.

Table 25. Stated preference survey questions

Category	Question	Possible answers
Socio demographics	What is your age group?	– 18-24 – 25-34 – 35-44 – 45-54 – 55-64, – 65+
	What is your gender?	– Male – Female – Other – Prefer not to say
	What is your yearly net salary (in euros)	– Less than 15,000€ – 15,000€-24,999€ – 25,000€-39,999€ – 40,000€-59,999€ – 60,000€ or more – Prefer not to say
	What is your nationality?	Short text answer
	In which city or village do you currently live?	Short text answer
	What type of area do you live in?	– Urban – Suburban – Small town – Rural area
	Do you have a driving license?	Yes/No
	Do you have access to a private vehicle in your household?	Yes/No
Travel patterns	In the past 3 months, how many regional trips have you made?	– None – 1 to 3 trips – 4 to 7 trips – 8 to 13 trips – More than 13 trips
	How often do you perform regional trips?	– Every week, – Every two weeks – Monthly, every two months – A few times a year

© –2023– SESAR 3 JU

Category	Question	Possible answers
	What type of regions does your regional trips usually involve?	Multiple choice answer: – Between islands – Between mainland towns/cities – To/from mountainous or remote areas – Urban-to-urban trips
	Which transport modes have you used for these regional trips?	Multiple choice answer: – Private car (driver) – Private car (passenger), – Car sharing (like BlaBlaCar) – Bus – Taxi, – Plane – Train, – Bike – Other
	How important are these factors when selecting a transport mode for a leisure/work related regional trip? ***Factors**: Travel time, price, schedules/ convenience and environmental factors*	Likert scale from not important (1) at all to extremely important (5)
Air taxi awareness	Would you consider making regional trips if air taxis were available?	– Yes definitely – Yes probably – Maybe – No
	Have you heard of new transport technologies like air taxis before?	Yes/No
	How familiar are you with air taxis?	Likert scale from not familiar at all (1) to extremely familiar (5)
	Would you consider making new trips that you currently do not make if air taxis were available?	– Yes definitely – Yes probably – Maybe – No
	How important are these factors in your decision to use air taxis? Factors: travel cost, travel time, safety, comfort and convenience, environmental impact, better regional connectivity	Likert scale from not important at all (1) to extremely important (5)
	How concerned are you about following air taxi challenges? ***Challenges**: safety, security, cost, accessibility, noise, visual pollution, privacy*	Likert scale from not concerned (1) to extremely concerned (5)

© –2023– SESAR 3 JU

Category	Question	Possible answers
	How likely are you to use air taxis in the future?	Likert scale from not likely at all (1) to extremely likely (5)
	Should air taxi be available right now…	– I would use them right away. – I would use them rather soon but not immediately. – I would wait until I am fully confident with the idea to travel with one. – I would rather wait to use it and check how it is performing during its first year into service. – I would never use them.
	If air taxis could reduce your travel time by half, how much would you be willing to pay for the trip?	– I would not pay extra – 1.25 times my current price – 1.5 times my current price – 2 times my current price – More than 2 times my current price.
	How often would you use air taxis for regional trips?	– Multiple times per week – Weekly – Monthly – A few times a year – Rarely or never
Case study 1: La Gomera Tenerife	Which travel option would you choose when travelling for *leisure/work* from the south of Tenerife to San Sebastián de la Gomera?	– Ferry | Duration: 1h50 | Cost: 45€ – Plane | Duration: 2h40 | Cost: 70€ – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from the south of Tenerife to San Sebastián de la Gomera?	– Ferry | Duration: 1h50 | Cost: 45€ – Plane | Duration: 2h40 | Cost: 70€ – Air taxi | Duration: *Variable* | Cost: *Variable* – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from la Gomera airport to San Sebastián de la Gomera?	– Ferry + Walk | Duration: 1h50 | Cost: 15€ – Ferry + Taxi | Duration: 55 min | Cost: 25€ – Taxi | Duration: 50 min | Cost: 25€ – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from la Gomera airport to San Sebastián de la Gomera?	– Ferry + Walk | Duration: 1h50 | Cost: 15€ – Ferry + Taxi | Duration: 55 min | Cost: 25€ – Taxi | Duration: 50 min | Cost: 25€ – Air taxi | Duration: *Variable* | Cost: *Variable* – I would not travel
Case study 2: Catalan Pyrenees	Which travel option would you choose when travelling for *leisure/work* from Andorra la Vella to the airport of la Seu d'Urgell?	– Bus + Walk | Duration: 2h30 | Cost: 11€ – Taxi | Duration: 40min | Cost: 45€ – I would not travel

© –2023– SESAR 3 JU

Category	Question	Possible answers
	Which travel option would you choose when travelling for *leisure/work* from Andorra la Vella to the airport of la Seu d'Urgell?	– Bus + Walk | Duration: 2h30 | Cost: 11€ – Taxi | Duration: 40min | Cost: 45€ – Air taxi | Duration: *Variable* | Cost: *Variable* – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from Puigcerdà to Barcelona?	– Bus | Duration: 2h50 | Cost: 24€ – Taxi | Duration: 2h | Cost: 200€ – Train | Duration: 3h10 | Cost: 12€ – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from Puigcerdà to Barcelona?	– Bus | Duration: 2h50 | Cost: 24€ – Taxi | Duration: 2h | Cost: 200€ – Train | Duration: 3h10 | Cost: 12€ – Air taxi | Duration: *Variable* | Cost: *Variable* – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from Lleida to Andorra la Vella?	– Bus | Duration: 2h15 | Cost: 25€ – Taxi | Duration: 2h | Cost: 200€ – I would not travel
	Which travel option would you choose when travelling for *leisure/work* from Lleida to Andorra la Vella?	– Bus | Duration: 2h15 | Cost: 25€ – Taxi | Duration: 2h | Cost: 200€ – Air taxi | Duration: *Variable* | Cost: *Variable* – I would not travel

User propensity and adoption level were generated as composite measures calculated by a non-weighted linear combination of specific Likert scale items of the survey.

User propensity was generated by the questions *i- Would you consider making regional trips if air taxis were available?* (4 options), *ii- Would you consider making new trips that you currently do not make if air taxis were available?* (4 options*), iii- If air taxis could reduce your travel time by half, how much would you be willing to pay for the trip?* (5 options), and, *iv- How often would you use air taxis for regional trips?* (5 options). Each item was converted in a numerical value from 1 to 4 or 5 depending on the question. The user propensity indicator is therefore sum of all the items, ranging from 4 to 18.

Adoption level was generated by the questions: *i- How likely are you to use air taxis in the future?* (5 options), and*, ii- Should air taxis be available right now*... (complete the sentence), (5 options). The items answers were transformed in numerical values in the same way, thus generating a number ranging from 2 to 10.

User propensity, service adoption and other input features from the survey were exposed to Clustering via the K-means method. K-means is an unsupervised Machine Learning method were n variables are assigned to one of k clusters, grouping the data around centroids. In this way, the model decides what is the optimal number of groups for the given data. A total of 18 features were used for clusterization, selected via a feature importance analysis.

For this preliminary run, the model suggests grouping the answers in two clusters, both of them with relatively high adoption and propensity levels. The mean values of the adoption level and user propensity indicators along with the mode of the main features used for clustering is presented in Table 26.

© –2023– SESAR 3 JU

Table 26. Cluster results

Feature	Cluster 1 (Higher Adoption & Propensity)	Cluster 0 (Lower Adoption & Propensity)
Propensity Level	Slightly higher (6.94)	Slightly lower (6.86)
Adoption Level	Slightly higher (5.82)	Slightly lower (5.69)
Mode used in regional trips	Uses multiple modes (driver, passenger, taxi)	Uses only private car (driver)
IAM privacy concerns	Slightly concerned	Moderately concerned
Frequency of regional trips	Monthly	Every two weeks
IAM environmental concerns	Very important	Moderately important
IAM cost concerns	Extremely important	Very important

The clustering analysis revealed two distinct groups with different attitudes toward IAM services. Cluster 1 consists of individuals who appear more open to adopting IAM solutions and demonstrate a slightly stronger behavioural inclination to do so. This group is characterised by a higher degree of flexibility in their travel choices, as they use a wider variety of transport modes and show lower levels of privacy concerns, which may increase their comfort with new technologies. Although they tend to travel less frequently, this behaviour may indicate that they value efficiency and cost savings more when they do choose to travel. Furthermore, their decisions are strongly influenced by environmental impact and affordability, suggesting a more conscious and value-driven approach to adoption.

In contrast, individuals in Cluster 0 display more conservative travel habits and are generally more privacy-conscious. Their motivation to adopt IAM is less strongly tied to environmental or cost considerations, which may result in a more cautious or reserved stance toward this new mode of transport.

Overall, despite the small sample available, we see that clustering analysis can provide meaningful insights in IAM adoption. These results will be extended to further analyse features that might influence adoption and propensity, map profiles to given areas using demographic census information, in order to discover IAM business models that maximize service adoption.

B.3.3 Unexpected behaviours/results

No unexpected results have been identified.

B.3.4 Confidence in results of validation exercise #02

B.3.4.1. Level of significance/limitations of validation exercise results

The validation exercise demonstrates the feasibility of using stated preference surveys combined with unsupervised machine learning techniques to identify potential user segments and estimate IAM adoption propensity. The clustering analysis successfully identified two distinct behavioural profiles,

© –2023– SESAR 3 JU

providing initial evidence that differences in travel behaviour, privacy concerns, environmental awareness, and transport mode usage influence the willingness to adopt IAM services.

However, the significance of the results is constrained by several limitations. The main one is related to the small sample (211 respondents) used for the analysis, which limits the statistical robustness and representativeness of the identified clusters.

Furthermore, the analysis is based entirely on stated preferences for a transport mode that is not yet commercially available. As with any stated preference study, respondents' intentions may differ from their actual behaviour once IAM services become operational.

Consequently, the current validation should be considered an initial proof of concept rather than a definitive assessment of future market adoption.

B.3.4.2. Quality of validation exercises results

The validation exercise was performed using a structured survey specifically designed for the project, covering socio-demographic characteristics, travel behaviour, perceptions towards IAM, and realistic stated preference scenarios for the selected case studies. The survey provides a comprehensive dataset that captures both behavioural and attitudinal variables relevant to IAM adoption.

The clustering methodology produced coherent and interpretable user profiles that are consistent with expected behavioural patterns. Individuals with greater multimodal travel experience, lower privacy concerns, and stronger environmental awareness exhibited higher adoption propensity than more conservative travellers. These findings increase confidence that the selected variables capture meaningful behavioural differences.

Nevertheless, the relatively limited sample size reduces the stability of cluster centroids and the generalisability of the results. Additional survey responses would improve model robustness, allow more detailed segmentation, and facilitate validation of the identified behavioural patterns.

B.3.4.3. Significance of validation exercises results

The validation exercise confirms that combining stated preference surveys with machine learning techniques constitutes a suitable methodology for analysing IAM user acceptance and market segmentation.

Although the differences between the identified clusters are moderate, the analysis demonstrates that behavioural and attitudinal characteristics can be used to distinguish user groups with different levels of adoption propensity. This provides valuable information for future demand modelling, service design, pricing strategies, and market targeting.

The results also demonstrate that adoption cannot be explained solely by socio-demographic characteristics, highlighting the importance of factors such as travel behaviour, privacy perceptions, environmental awareness, and transport flexibility.

Overall, the validation provides a solid methodological basis for further refinement of the adoption models as larger and more representative datasets become available.

© –2023– SESAR 3 JU

B.4 Conclusions

B.4.1 Conclusions on concept clarification

The validation exercise successfully clarified the proposed concept for estimating IAM adoption through the integration of stated preference surveys, behavioural indicators, and unsupervised learning techniques. The methodology allows user acceptance to be characterised beyond simple willingness-to-use metrics by incorporating travel behaviour, attitudes towards technology, and perceived service attributes.

The developed framework establishes a scalable approach that can be applied across different geographical contexts and mobility scenarios while supporting future integration with demographic and territorial information.

B.4.2 Conclusions on technical feasibility

The validation confirms the technical feasibility of the proposed methodology. The survey design successfully generated the required input variables, while the definition of composite indicators for user propensity and adoption enabled straightforward implementation of clustering algorithms.

The K-means clustering approach effectively identified meaningful behavioural groups using the selected feature set, demonstrating that the proposed analytical workflow can be implemented with standard machine learning techniques and expanded as larger datasets become available.

Future improvements may include testing alternative clustering algorithms, feature weighting methods, and predictive models to further improve segmentation accuracy.

B.4.3 Conclusions on performance assessments

The performance assessment indicates that the methodology is capable of extracting relevant behavioural patterns from survey data despite the limited sample size. The generated clusters are internally coherent and provide interpretable explanations of differences in IAM adoption propensity.

The preliminary results suggest that privacy concerns, transport habits, environmental awareness, and multimodal travel behaviour are among the most influential variables affecting adoption potential. These findings support the use of behavioural segmentation as an input for future demand estimation and business model development.

Performance metrics and assessments are proving that the clustering results are reliable and generalizable as a tool. The SSE levels in the selection of the Clusters via the Elbow method as well as the Silhouette levels are showing promising results.

Although the quantitative differences between clusters remain relatively small, the exercise successfully demonstrates the operational capability of the proposed methodology and provides a foundation for more robust analyses using larger dataset

B.5 Recommendations

The following recommendations are proposed for future development and validation activities:

- Application of methodology to bigger survey sample sizes to improve the statistical significance and representativeness of the identified user segments.

© –2023– SESAR 3 JU

- Application of methodology across different regions and demographic groups to capture greater variability in travel behaviour and IAM perceptions.
- Investigate weighted formulations of the propensity and adoption indicators to better reflect the relative importance of individual survey questions.
- Compare K-means clustering with alternative unsupervised learning techniques, such as hierarchical clustering or Gaussian mixture models, to assess segmentation robustness.
- Incorporate additional behavioural, socioeconomic, and spatial variables into the analysis to improve prediction accuracy.
- Validate the proposed adoption models against revealed preference data when operational IAM services become available.
- Integrate the resulting user profiles with demographic census data and transport models to support regional demand forecasting and business model optimisation. The integration of machine learning-based user profiles with spatial demographic data and population projections to support both current and long-term market assessment. In the short term, the identified high-adoption and high-propensity user segments can be aggregated by geographic area to identify locations with the greatest potential for early IAM service deployment. In the longer term, combining these profiles with demographic and population forecasts would enable prediction of how adoption potential may evolve over time, supporting data-driven planning, prioritisation of service expansion, and optimisation of future IAM business models.

© –2023– SESAR 3 JU

Appendix C Validation exercise #03 report

C.1 Summary of the validation exercise #03 plan

As defined in the ERP SESAR Solution 0515

C.2 Deviation from the planned activities

There are no deviations from the planned activities.

C.3 Validation exercise #03 results

C.3.1 Summary of validation exercise #03 results

Exercise #03 validation objective ID	Exercise #03 validation objective title	Exercise #03 success criterion ID	Exercise #03 success criterion	Exercise #03 validation results	Exercise #03 validation objective status
OBJ-0515-ERP-003	Validation of algorithms for monitoring potential IAM demand	CRT-0515-TRL1-ERP-003.001	The mobility indicators derived from the algorithms for monitoring potential demand for IAM services through the fusion of MND and other data sources are consistent with the expected mobility behaviour. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.	The mobility patterns derived from MND reproduce the expected demand behaviour across both case studies: clear seasonal peaks during summer and holiday periods, increased activity during the ski season in resort areas, proximity effects with neighbouring municipalities generating more trips between them, a higher concentration of demand in larger municipalities, and mode-specific flows capturing demand from adjacent areas, as seen in the Tenerife–La Gomera connection. The developments introduced to improve trip characterisation provide valuable additional information for assessing IAM adoption: the trip-purpose classifier achieves strong performance (0.92 F-score), reliably reproducing the expected temporal, seasonal, and demographic patterns of business travel, and independently validated by the EMQ APA 2025 survey; while the bus-detection algorithm yields modal shares comparable in order of magnitude to the survey. Overall, the enriched mobility data are consistent with expected behaviour and with independent references, and are therefore considered valid as a basis for the subsequent IAM demand and market-potential analysis.	OK

Table 27. Validation exercise #03 results

© –2023– SESAR 3 JU

C.3.2 Analysis of validation exercise #03 results per validation objective

C.3.2.1. OBJ-0515-TRL1-ERP-003 Results

This validation objective aims to validate the algorithms for understanding passenger behaviour from geolocation data. The use of MND for analysing mobility patterns has become increasingly common in recent years, offering valuable insights into population movements over time and space. This type of data is now widely used to monitor travellers' behaviour at large scales, supporting a range of applications in transport planning and management. By providing anonymised, continuous, and large-scale observations, MND allows authorities and planners to better understand travel demand, optimise transport infrastructure, and enhance network performance.

Despite these advantages, MND also presents several limitations. One key challenge is the difficulty of directly inferring the mode of transport used by individuals. The spatio-temporal characteristics of MND allow the identification of long-distance travel modes that use different transport networks such as road, rail, or air, through map-matching techniques. However, distinguishing between modes that share the same infrastructure, such as private vehicles and buses on the road network, is considerably more complex, as traditional map-matching methods are not effective in such cases.

The work developed in PRIAM address this limitation by developing an improved methodology capable of distinguishing between road-based trips made by private vehicles and those made by bus. This advancement aims to enhance the potential of MND for multimodal transport analysis and expand its applicability in comprehensive transport planning frameworks.

Methodology

This process will encompass two phases:

1. **Extraction of passenger behaviour and mobility patterns from MND**. The use of big data and advanced analytics techniques to leverage the potential of anonymised MND to monitor the passenger behaviour in regional contexts. This process is depicted in Figure 5. The output of this process consists of relevant information on the movement of people between different areas, also including some passenger information and journey attributes, such as age, gender, nationality, purpose of the trip, etc. For further information, please refer to [24], [25] and [26].

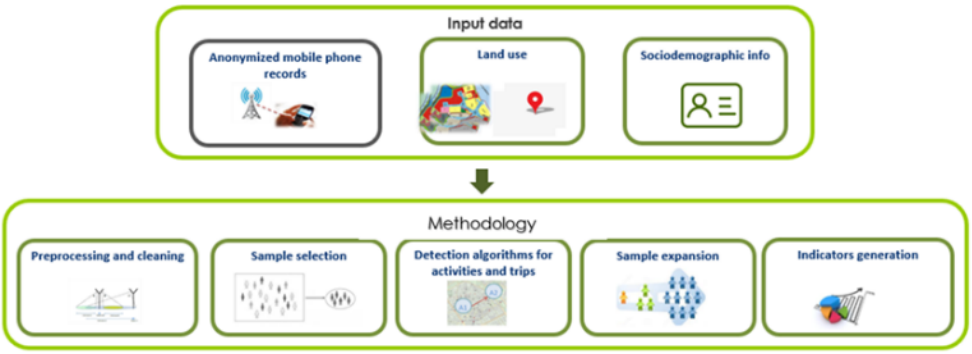


Figure 5. Extraction mobility patterns from MND

2. **Enhance passenger profile characterisation**. While the information extracted during Phase 1 already provides valuable inputs to IAM demand modelling activities, the characterisation of

© –2023– SESAR 3 JU

potential demand for regional-scale IAM services can be further enhanced by incorporating additional passenger attributes:

1. **Trip purpose identification.** Trip purpose is a key determinant of IAM adoption, as travellers with different travel purposes (e.g., business versus leisure) are expected to exhibit different willingness-to-pay levels and mode-choice behaviours. Since trip purpose cannot be directly inferred from MND, the proposed methodology combines MND-derived demand information with publicly available travel surveys containing trip purpose information.

   These survey datasets are used to train and calibrate machine learning models capable of predicting trip purpose based on observable travel characteristics. Once calibrated, the models are applied to the MND-derived demand datasets generated in Phase 1, enabling the inference of trip purpose categories (e.g., business and leisure) for individual trips. This enriched segmentation provides a more accurate representation of potential IAM users and supports the development of more robust demand forecasts. This methodology is depicted in the following Figure.

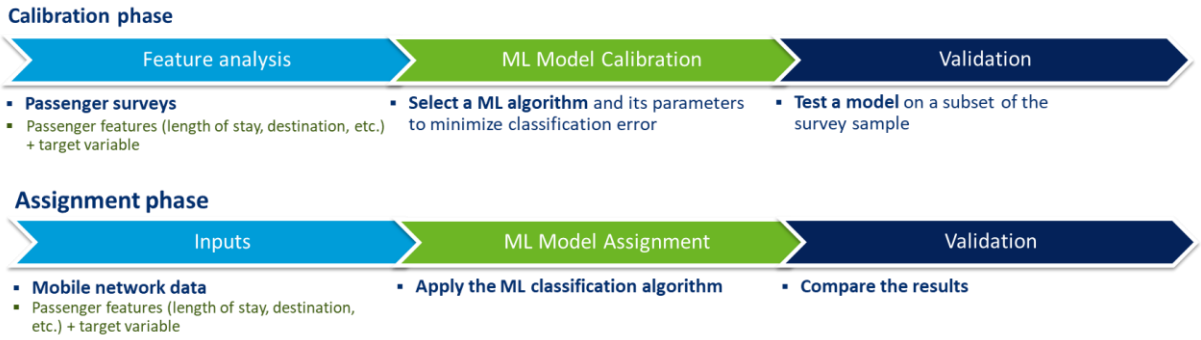


Figure 6. Trip purpose identification methodology

2. **Road transport mode identification.** The potential modal shift towards IAM services is strongly influenced by the transport mode currently used by travellers. Consequently, estimating the original mode of transport is a prerequisite for accurately assessing IAM demand and mode substitution patterns.

   For some transport modes, mode identification can be achieved through map-matching techniques, which directly compare the spatial trajectories derived from MND with transport network infrastructures. This approach is particularly effective for modes operating on distinct networks, such as rail, aviation, and road transport. However, distinguishing between modes that share the same infrastructure, such as private cars and buses, remains a significant challenge.

   To address this limitation, advanced data analytics have been developed to identify bus trips directly from MND. These methods will complement conventional map-matching approaches by including bus network information (bus stop locations, routes, schedules, etc.) to improve mode classification accuracy for trips occurring on shared road infrastructure. The algorithm computes a probability that a given trip was made by bus, based on the proximity of its trajectory to bus stops connected by an existing route and on the consistency between the time of the trip and the scheduled service, ensuring that a viable connection was actually available when the trip took

© –2023– SESAR 3 JU

place. The resulting transport mode information will provide a more reliable basis for estimating modal shift probabilities and assessing the market potential of IAM services.

This has only been applied to the Catalonia case study, since the bus modes are not relevant for the Canary Islands case study.

3. **Travel time and travel cost estimation.** To subsequent phases of the project it is necessary to estimate the travel time and travel cost of the different trips. The way of estimating these values will depend on the transport mode used, while road travel times and cost will rely on using OSM to calculate travel times and estimate travel costs using a cost per km, the travel times on other modes will depend on available travel times and schedules depending on the specific services of the corridor analysed, as well as the different route pricing.

The validation of these algorithms has consisted in the analysis of the mobility patterns derived from MND in order to assess is consistency with the expected passenger behaviour, as well as its comparison with other available data sources when possible. The validation results are presented in the following subsection.

Tenerife – La Gomera case study

Extraction of passenger behaviour and mobility patterns from MND

Figure 7 presents the monthly number of trips between Tenerife and La Gomera (in both directions) throughout the year 2024. As shown, the volume of trips remains relatively stable across the year, with a noticeable minimum in November (approximately 152,000 trips) and a peak in August (exceeding 230,000 trips). The summer months represent the busiest period, with over 227,000 trips recorded in each of June, July, and August.

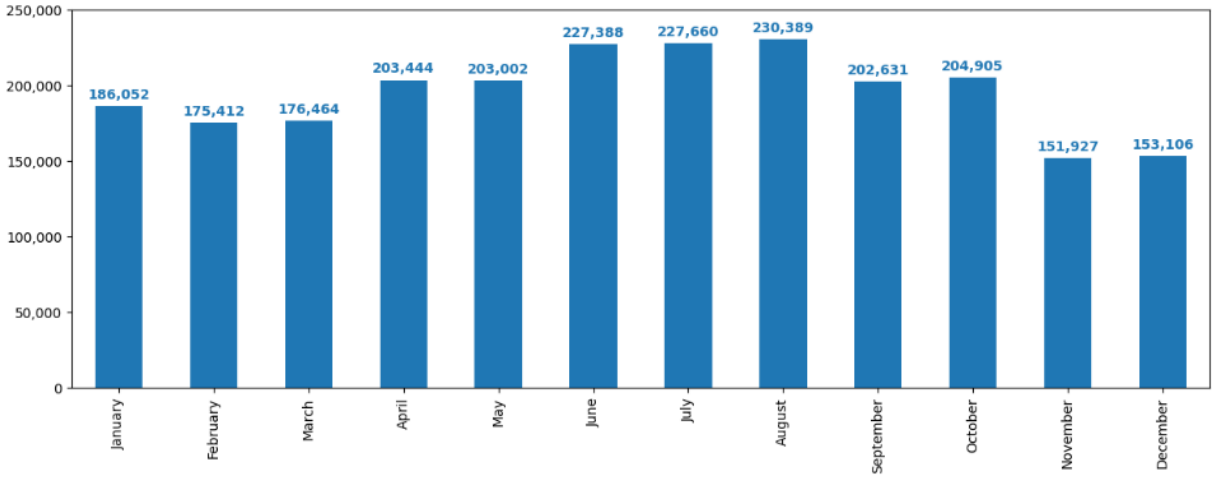


Figure 7. Monthly trips between Tenerife and La Gomera (both directions) in 2024

The analysis of the mode used exposed that 98.9% of passengers travelled between Tenerife and La Gomera in Ferry, while just a 1.1% travelled by air. In the following images, it is presented the start/end location of the trips between Tenerife and La Gomera, segmented by the transport mode used.

© –2023– SESAR 3 JU

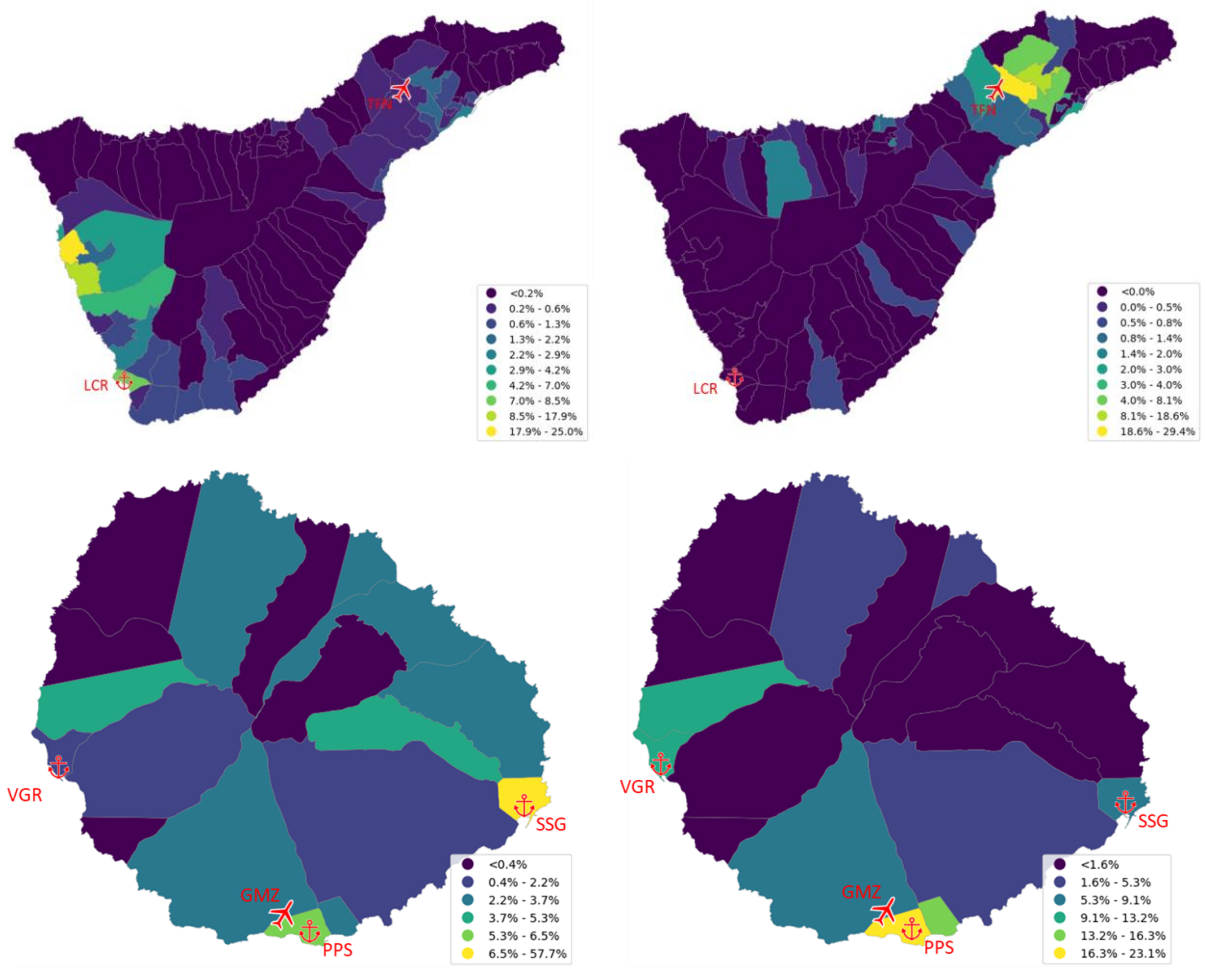


Figure 8. Proportion of passengers travelling from Tenerife (upper) to La Gomera (bottom) by ferry (left) and plane (right)

It can be seen that the small proportion of passengers preferring travelling by plane, tend to start/end their trip in the north of the Tenerife Island where the Tenerife Norte (TFN) airport is located as well as in the south of La Gomera, next to Playa Santiago, where the Gomera Airport (GMZ) is located.

Meanwhile, passengers starting their trip in the south of Tenerife tend to prefer travelling by ferry, as the port is also located in the south. Similarly, most passengers using ferry start/end its trip next to San Sebastian de La Gomera, the capital city of La Gomera, where the main port is located.

The figure below presents the flows of passengers, distinguishing the Tenerife–La Gomera connection (left column) and the intra-Gomera mobility (right column), separating the transport modes in each case (ferry in blue; air and road in orange). It should be noted that the flows have been normalised per transport mode: although the maps may suggest comparable volumes across modes, air trips represent only 1.9% of the total of the trips between Tenerife and La Gomera, as stated above. The normalisation is applied purely for visualisation purposes, to render the spatial behaviour of each mode legible.

© –2023– SESAR 3 JU

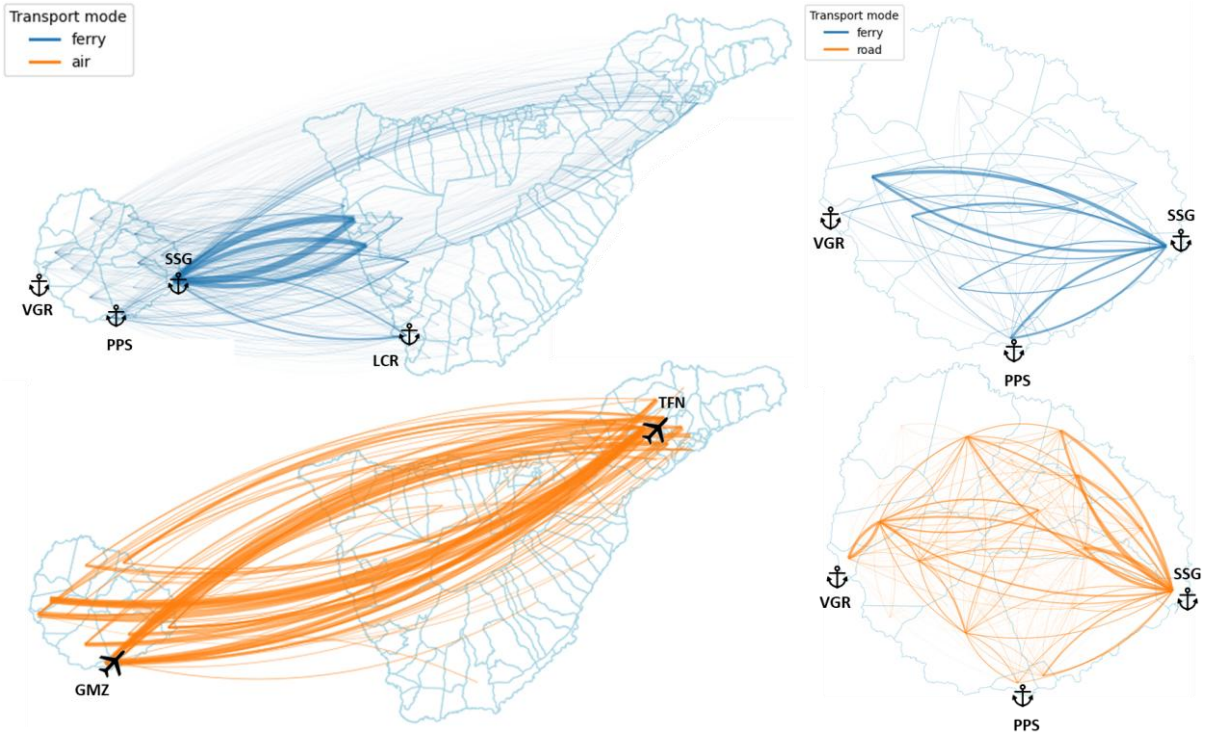


Figure 9. Trip flows between Tenerife–La Gomera connection (left) and intra-Gomera (right), segmented by transport modes (ferry in blue; air and road in orange).

For the Tenerife–La Gomera corridor, both maps show a strong, highly channelled flow structure. The ferry flows (top-left) are mainly concentrated between the south of Tenerife and San Sebastián de La Gomera, the island's capital city, and, to a lesser extent, Playa de Santiago in the south of La Gomera. It is particularly noteworthy that most of the demand in Tenerife does not originate in Los Cristianos, where the departure port is located, but in Arona, an area situated slightly northern along the coast. The air flows (bottom-left) are centred on connections from the north of Tenerife, where the airport is located, towards La Gomera, mainly to Playa de Santiago (the airport area), but trips are distributed more disperse across all La Gomera than the ferry trips.

For **intra-Gomera mobility**, the pattern is quite different. The within-island ferry flows (top-right) are limited to a small number of coastal links connecting San Sebastián de La Gomera, where the main port is located, with other areas on the south of the island served by the remaining ports, consistent with the marginal, complementary role of maritime transport for movements internal to the island. Road transport (bottom-right), by contrast, constitutes the backbone of intra-island mobility: it forms a distributed mesh of connections reaching across the whole of La Gomera, with no single dominant corridor but rather a network of comparable links between the island's zones, reflecting the dispersed settlement pattern and the role of the road network in serving everyday internal travel.

Figure 10 shows the most common ferry routes used by the passengers. As it can be seen, the main ferry route is from Los Cristianos (ESLCR) to San Sebastian de La Gomera (ESSSG). While the route between Los Cristianos and Playa de Santiago (ESPPS) also present a significant demand (21%), the last route, going from Los Cristianos to Valle Gran Rey (ESVGR) just account for around a 3% of the trips. These two last routes have an intermediate stop in San Sebastian de La Gomera

© –2023– SESAR 3 JU

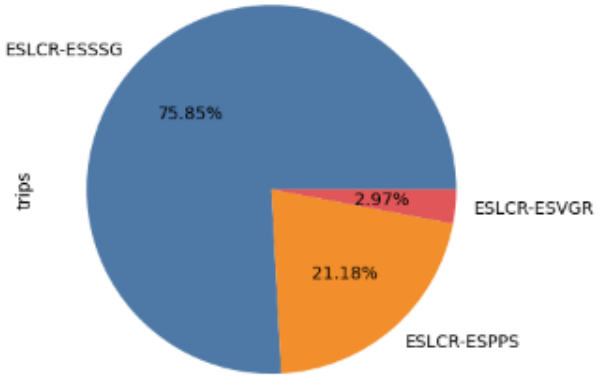


Figure 10. Demand distribution on the ferry routes between Tenerife and La Gomera

The figure below shows sociodemographic information of the travellers between Tenerife and La Gomera. As presented, the sociodemographic composition is strongly dominated by national residents, who account for 90.8% of trips in January and 96.1% in August, with foreign visitors representing a residual and seasonally declining share (9.2% in January, falling to 3.9% in August). Among national travellers, residents of La Gomera (GO) constitute the largest group, although their relative weight varies markedly across seasons: from 74.4% in January, when the corridor is used predominantly by the island's own residents, to 50.1% in August, when travellers resident in Tenerife (TF) rise to 40.4% and visitors from the rest of Spain also increase (from 3% to 9.5%). This shift reflects the summer inflow of mainland and Tenerife-based travellers towards La Gomera during the holiday period. Regarding the foreign segment, the composition is led throughout the year by German (DE) and British (UK) visitors, together close to two-thirds of foreign trips in January (39.6% and 26.9%), followed by the rest of Europe, with the French (FR) share rising notably in August (to 12.6%). Overall, the corridor exhibits a markedly local and national profile, with foreign tourism playing a secondary and predominantly Central-European role that is most visible in the winter season.

© –2023– SESAR 3 JU

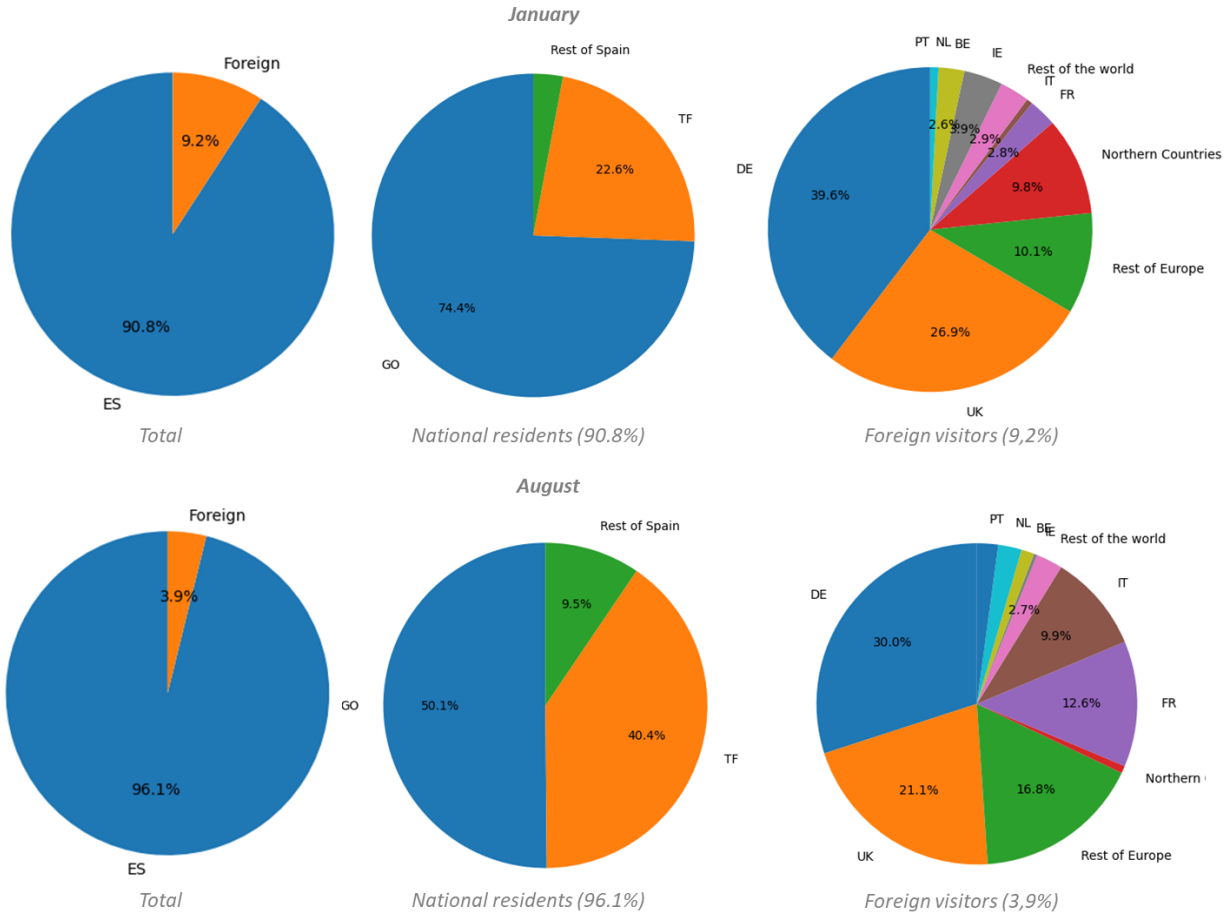


Figure 11. Sociodemographic information of the travellers between Tenerife and La Gomera

Trip purpose identification

The results application of the methodology for the trip purpose models calibration based on population surveys are presented below for the case of the Canary Islands.

The model achieves an overall accuracy of 0.97 and an average precision of 0.95, with macro-averaged precision, recall, and F-score of 0.94, 0.91, and 0.92 respectively. Performance is strongest on the majority leisure class, which is identified almost perfectly. The minority business class is classified with high precision (0.90) but somewhat lower recall (0.83), yielding an F-score of 0.86. The confusion matrix clarifies the nature of these errors: of the 181 leisure trips, 179 are correctly classified and only 2 are assigned to the business class; of the 23 business trips, 19 are correctly identified and 4 are misclassified as leisure. The model therefore tends to under-detect business travel rather than over-predict it, which is the expected behaviour given the limited number of business examples available for training and the inherent difficulty of separating the two purposes when their observable characteristics overlap. The shape of the precision–recall curve is consistent with this: precision remains close to 1.0 across most of the recall range and degrades only at the highest recall levels, indicating that the model maintains reliable positive predictions until it is pushed to recover the most ambiguous business cases.

© –2023– SESAR 3 JU

The feature importance analysis identifies trip type (TIPOVIAJ) as by far the dominant predictor, accounting for 0.60 of the total importance. This feature characterises the temporal context of the trip, whether it took place on weekdays, weekends, or during holiday periods, so its strong association with travel purpose is expected, since business and leisure trips follow markedly different temporal patterns. It is followed by traveller age (EDAD, 0.16) and number of overnight stays (NPERNOC, 0.09). This ranking is broadly consistent with domain expectations, with trip characteristics and traveller profile carrying most of the discriminative signal, while temporal and geographic variables play a secondary, supporting role.

Overall, the results indicate that the model reliably distinguishes travel purpose and is well suited to support the downstream segmentation of demand by trip purpose. The principal limitation is the modest under-detection of the business segment, which stems primarily from the small size of the minority class in the test set; this should be borne in mind when interpreting business-related outputs.

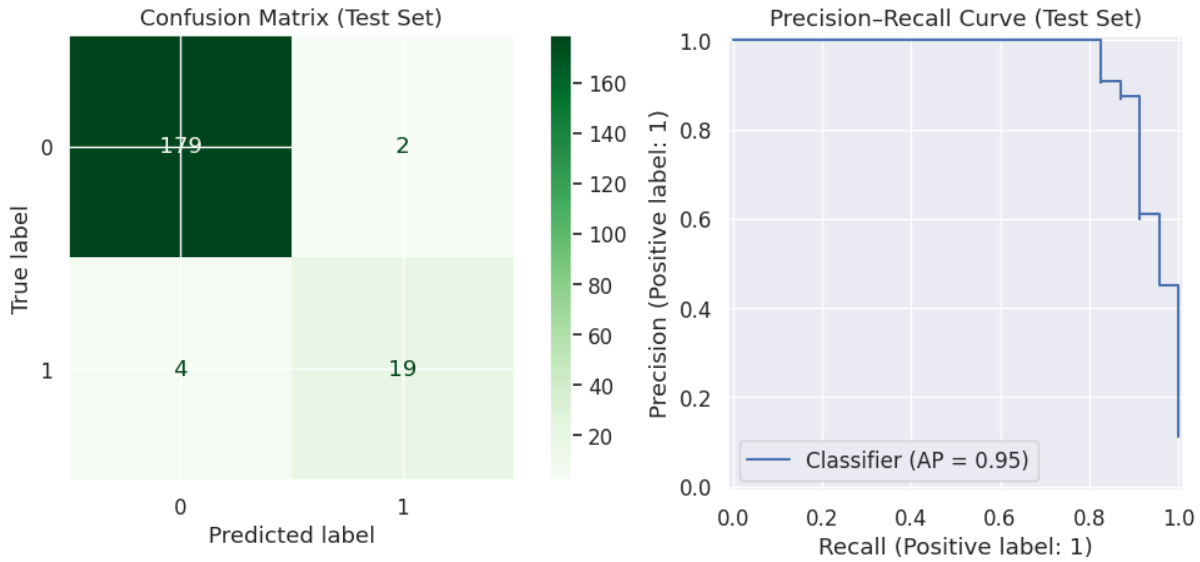


Figure 12. Model calibration results for the Canary Islands case study. Confusion Matrix (left) and Precision-Recall Curve (right)

Table 28. Model calibration results for the Canary Islands case study. Precision, recall and F-Score.

	Precision	Recall	F-Score
Leisure	0.98	0.99	0.98
Business	0.90	0.83	0.86
Average	**0.94**	**0.91**	**0.92**
Accuracy	**0.97**		

© –2023– SESAR 3 JU

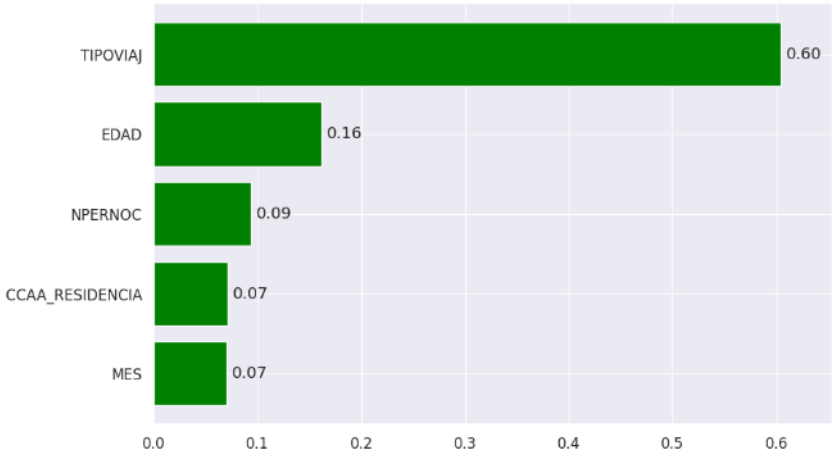


Figure 13. Feature importance for the Canary Islands model

Once calibrated, the model was applied to the MND-derived trips in order to infer the travel purpose of trips within the Canary Islands. The resulting share of inferred business trips is presented in the following table. As shown, the winter season exhibits a higher proportion of business trips, which is consistent with the seasonal behaviour. During the summer, the volume of tourists travelling for leisure increases notably, thus reducing the relative share of business travel. Overall, however, the proportion of business trips remains low throughout the year, reflecting the strong year-round tourism orientation of the Canary Islands noted in the previous subsection.

Table 29. Trip purpose assignment process results to the Canary Islands trips

	January	August
Tenerife-La Gomera	**2.9%**	**1.9%**
Intra-gomera	**2.6%**	**1.5%**

To validate the results, the behaviour of the inferred business passengers was analysed to confirm that it is consistent with expectations. Figure 14 presents the share of business trips by day of the week. As shown, business trips are detected exclusively on weekdays, with their share falling to zero at weekends, a pattern consistent with the expected temporal profile of business travel. Similarly, Figure 15 shows the distribution of business trips by age range. Most business trips are made by passengers in the 45–55 age range, followed by the 35–45 range, which is coherent with the demographics of the working population, while the remaining age ranges account for a more reduced share. Notably, no

© –2023– SESAR 3 JU

business trips are assigned to passengers over 65, which is again in line with expectations, as this group largely falls outside the active workforce.

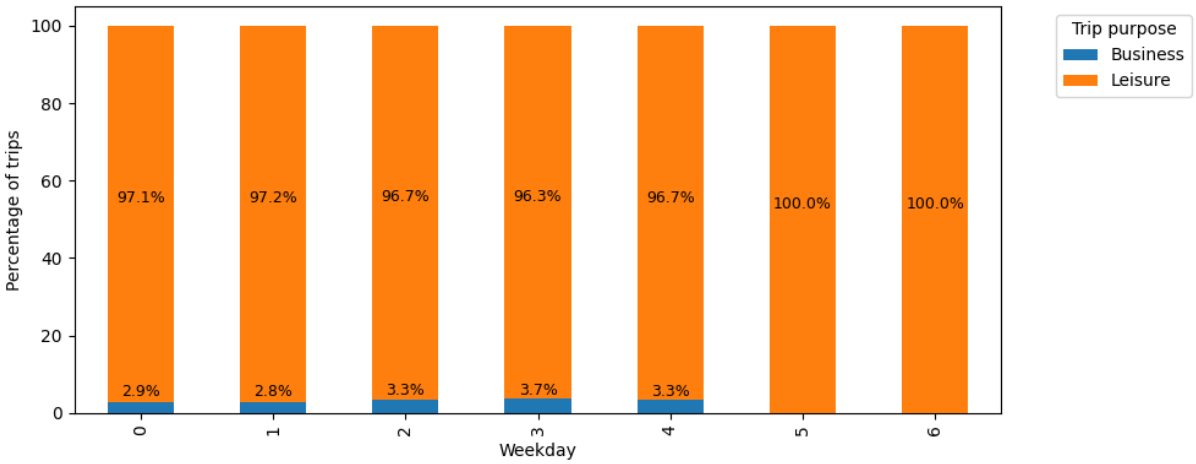


Figure 14. Share of business trips by day of the week at Canary Islands

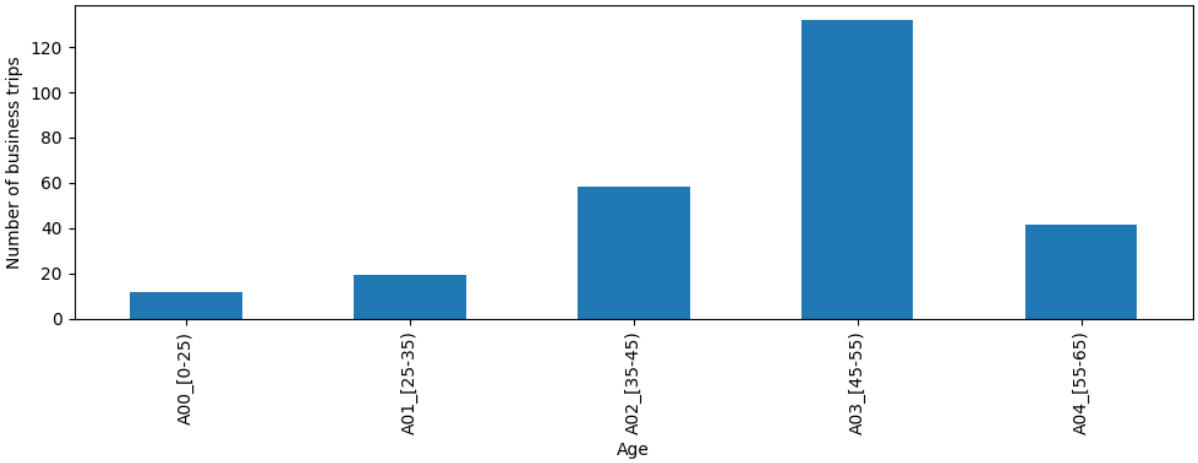


Figure 15. Distribution of business trips by age range at Canary Islands

In summary, the inferred business travel patterns are fully consistent with the expected behaviour across all the dimensions analysed (temporal distribution, seasonality, age profile, and overall volume). The model reproduces the characteristic concentration of business trips on weekdays and within the working-age population, as well as the lower year-round share of business travel associated with the strongly tourism-oriented profile of the Canary Islands. On this basis, the trip purpose inference results are considered consistent with expectations and are deemed valid for use in the subsequent stages of the analysis

Estimation of travel times and travel costs

To estimate travel time and travel cost in the Canary Islands case study, the approach varies by transport mode:

- For **road trips** (considered only on intra-Gomera trips) travel time is obtained directly from OSM, and travel cost is calculated by multiplying the road distance (also extracted from OSM)

© –2023– SESAR 3 JU

by a cost per kilometre of €0.21, as established by the Spanish Transport and Logistics Observatory (OTLE, *Observatorio del Transporte y la Logística en España*) (https://apps.fomento.gob.es/bdotle/visorBDpop.aspx?i=492)

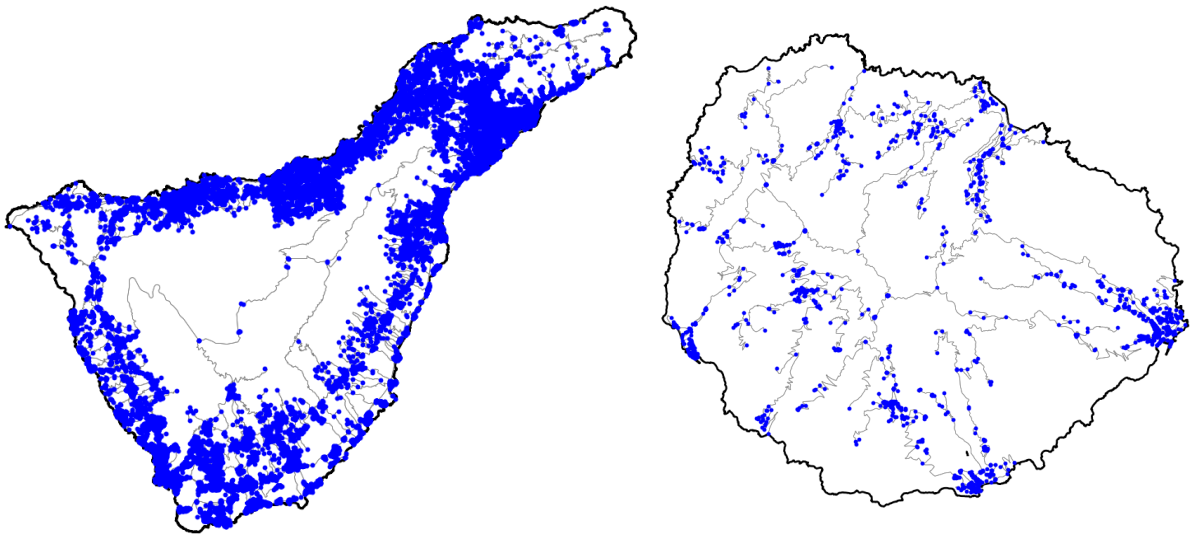


Figure 16. OSM network in Tenerife (left) and La Gomera (right)

- For all **other modes**, travel time is calculated as the sum of four components:
  - **Access time:** driving time between the trip origin and the departure transport station, computed using OSM.
  - **Processing and dwell time:** time required to complete boarding and alighting processes, including waiting time at the station or terminal. Different values are applied at different nodes, reflecting their size and traffic volume. In particular, Tenerife North airport (TFN) and La Gomera airport (GMZ) are assigned different processing times given their markedly different scales: TFN handled over 7 million passengers in 2025, compared with approximately 128,000 at GMZ, and a larger, busier airport entails longer processing times. The values adopted are presented in the table below.

Table 30. Processing and dwell times considered in the Canary Islands case study

Station	Processing + dwell time origin	Processing + dwell time destination
TFN airport	90	15
GMZ airport	60	15
Sea ports	20	5
Train and bus stations	15	5

  - **In-vehicle time:** mode-specific travel time, extracted from official operator websites and presented in Table 31, Table 32 and Table 33.
  - **Egress time:** driving time between the arrival transport station and the trip final destination, computed using OSM.

© –2023– SESAR 3 JU

Travel cost for non-road modes is calculated as the sum of the access and egress costs (obtained by multiplying the corresponding distances by the road cost per kilometre) and the fare of the transport route, extracted from official sources. Two factors introduce variability in the fare estimates. First, for air travel there is no available information on the distribution of fares across fare classes, so the average of the available fares has been used. Second, inter-island travel is subsidised for Canary Islands residents (75% discount), resulting in substantially lower fares for this group; both resident and non-resident fares are therefore considered separately. The resulting travel times and costs for each route are presented in the tables below.

Table 31. Travel time and travel cost of the different ferry routes between Tenerife and La Gomera

		Los Cristianos (LCR) - SS La Gomera (SSG)	Los Cristianos (LCR) - Playa Santiago (PPS)	Los Cristianos (LCR) - Valle Rey (VGR)
Travel time (min)		50	80	120
Travel cost (€)	**Resident**	11	15	15,5
	Non-Resident	44	59,5	62

Table 32. Travel time and travel cost of the different ferry routes within La Gomera

		SS La Gomera (SSG) - Playa Santiago (PPS)	SS La Gomera (SSG) - Valle Rey (VGR)	Playa Santiago (PPS) - Valle Rey (VGR)
Travel time (min)		30	70	40
Travel cost (€)	**Resident**	4	4,5	4
	Non-Resident	15,5	18	16

Table 33. Travel time and travel cost of the plane trips between Tenerife and La Gomera depending on the fare

		Super Promo	Promo	Economy	Flexible	FlexiMas		Average
Travel time (min)		30						
Travel cost (€)	**Resident**	8,5	12,5	15,75	21	26,25		**16.80**
	Non-Resident	34	42	63	84	105		**65.60**

Based on these inputs, travel times and travel costs have been calculated for all MND-detected trips, depending on the mode, the specific route, and the sociodemographic profile of the passenger (resident vs. non-resident).

The following Figure compares the travel cost of the Tenerife–La Gomera trip by mode and residency status. The ferry cost distribution is notably more dispersed than that of the air alternative, for two

© –2023– SESAR 3 JU

Co-funded by the European Union

reasons: the existence of multiple ferry routes with different fares, and the fact that ferry passengers are more spatially dispersed across the island (as shown previously), generating a wider range of access and egress costs. Air passengers, by contrast, are concentrated near the airport and served by a single route, resulting in a tighter cost distribution. The impact of the residency subsidy is also clearly visible, producing a sharp divergence between the cost distributions of resident and non-resident passengers

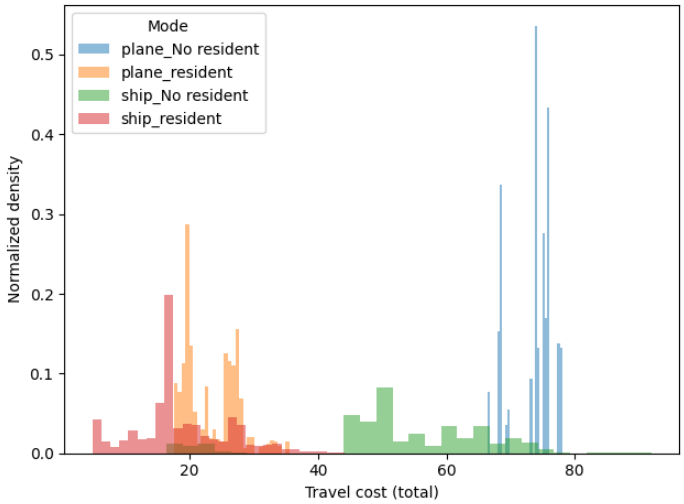


Figure 17. comparison between the travel cost of the trip Tenerife-La Gomera is presenting depending whether the passenger travel by plane or ferry and whether is a Canarian resident or not

Catalan Pyrenees case study

Extraction of passenger behaviour and mobility patterns from MND

Figure 18 present the monthly trips to and from the Catalan Pyrenees for the whole 2024. As observed, August is the busiest month, with over six million trips. July also shows high activity, exceeding five million trips. Additionally, the ski season (from December to March) records elevated demand, particularly in December and March, coinciding with the heavy snowfall events of 2024.

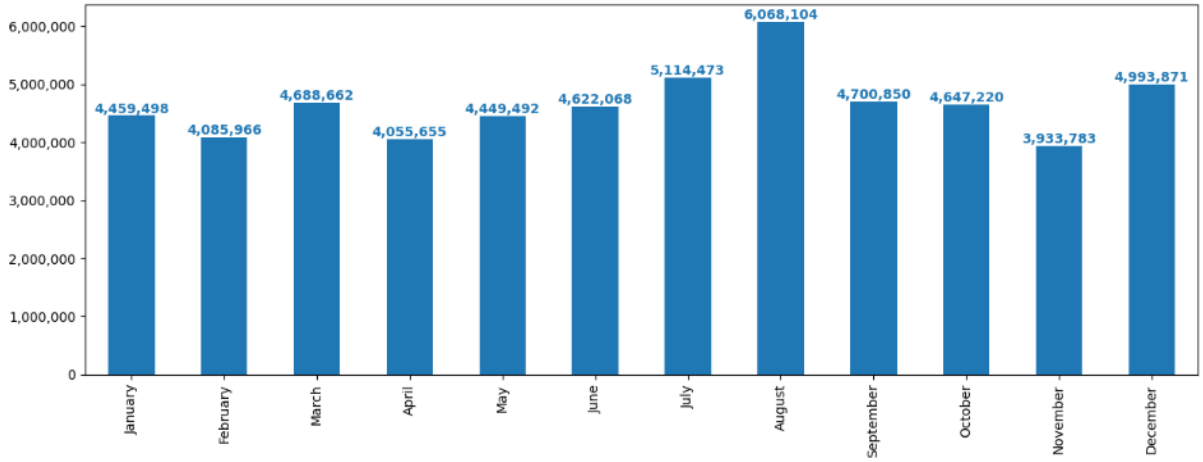


Figure 18. Monthly trips to and from the Catalan Pyrenees in 2024

The mobility patterns observed in this case study differ slightly from those seen in the Tenerife–La Gomera corridor, as they reveal two distinct high-demand seasons: one during the summer months

© –2023– SESAR 3 JU

and another during the winter. For instance, Figure 19 presents the monthly number of trips to the municipality of Baqueira, where one of the main ski resorts in the Catalan Pyrenees is located. While August remains the peak month, the period from December to March also shows significantly elevated demand compared to the rest of the year, driven by winter tourism associated with the ski season.

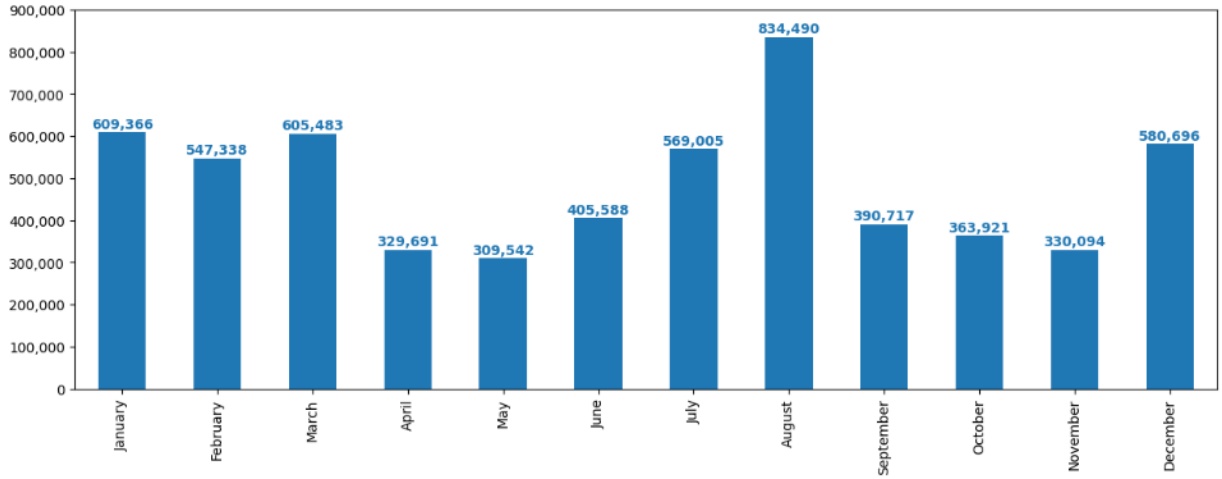


Figure 19. Monthly trips to the municipality of Baqueira in 2024

For the analysis of the Catalan Pyrenees, as initial approach, the area depicted in Figure 20was considered as the study zone for the Pyrenees.

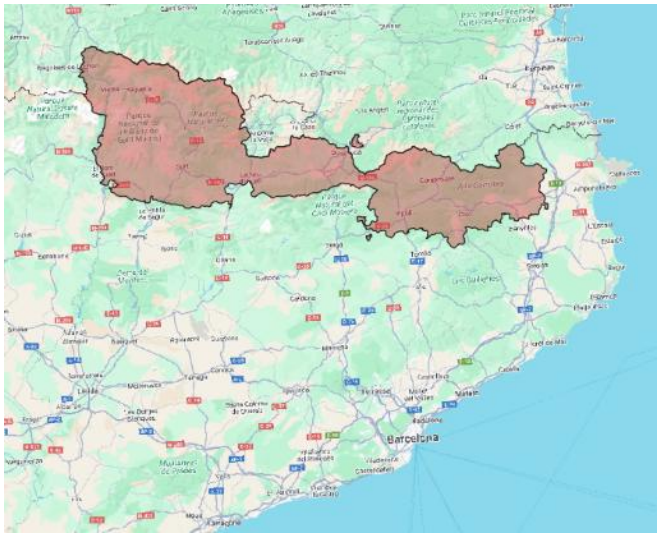


Figure 20. Catalan Pyrenees

Figure 21 presents the number of trips to different areas within the Catalan Pyrenees defined area. The zone that receives most trips is Olot, which is the biggest town in that area with around 38.000 inhabitants.

© –2023– SESAR 3 JU



Figure 21. Trips to the Catalan Pyrenees

The analysis of from which areas the passengers access the Catalan Pyrenees shows that most of the demand is coming from Catalonia itself (Barcelona, Girona, Lleida and Tarragona), which accounts for a 92.5% of the trips. Figure 22 shows from which areas within Catalonia the passengers travel to the Pyrenees. For the purpose of the study, in order to remove the impact of short trips, just trips from more than 50km are presented. As it can be seen, most travellers come from the cities of Barcelona and Lleida. Figure 23 shows from which areas within the rest of Spain the people travel to the Pyrenees. As it can be seen, most travellers come from neighbouring province of Huesca. Madrid, Zaragoza and Valencia also present a significant number of people travelling to the Pyrenees.

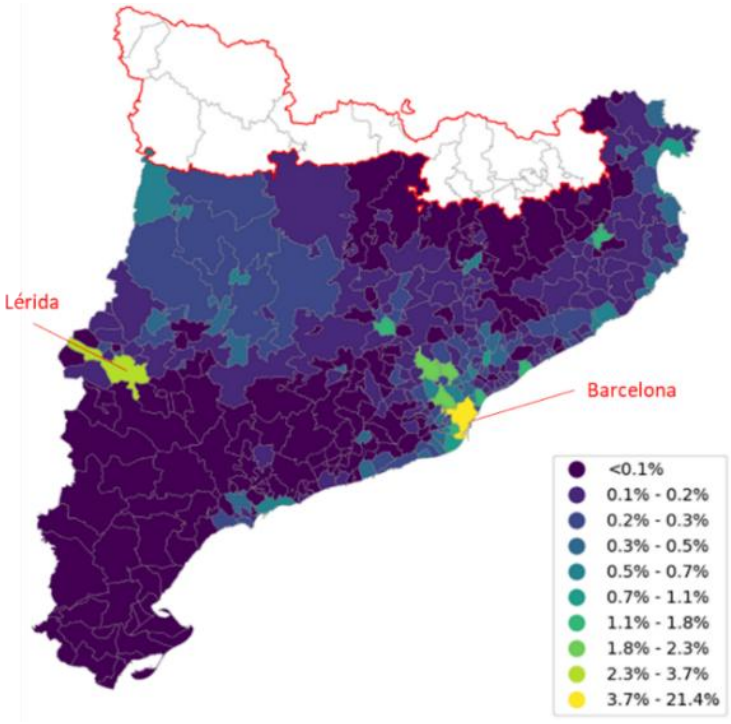


Figure 22. Origin of the trips to the Catalan Pyrenees within Catalonia.

© –2023– SESAR 3 JU

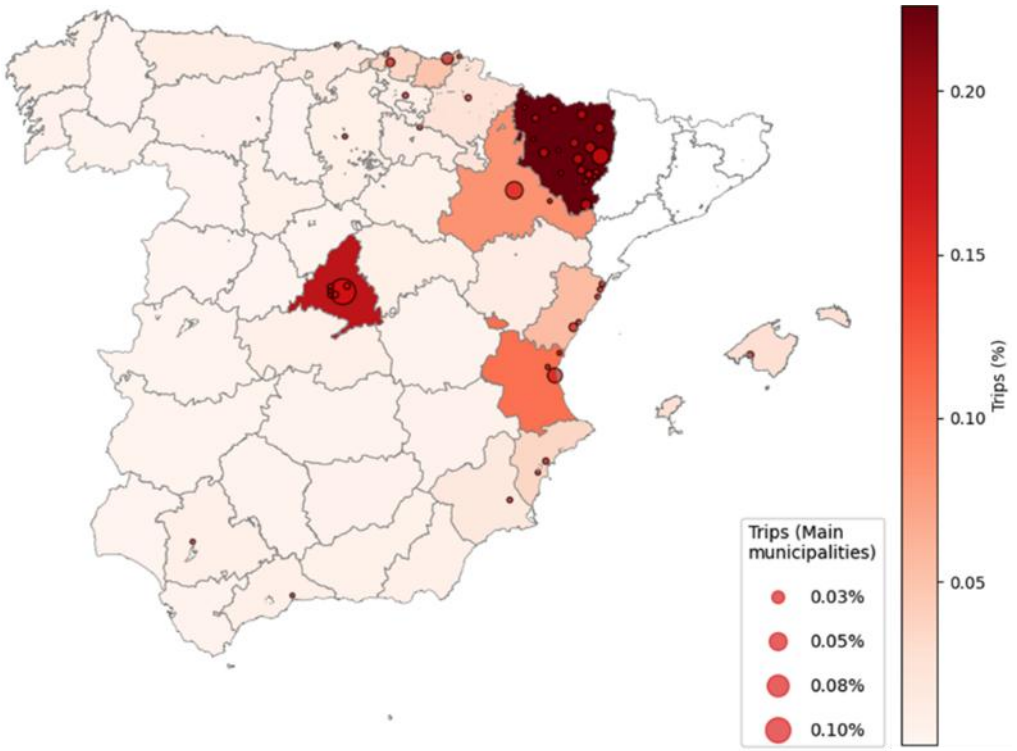


Figure 23. Origin of the trips to the Catalan Pyrenees within Spain (excluding Catalonia)

Based on the results of this analysis, the study area selected for the case study corresponds to the Pyrenees region and its connections with Barcelona and Lleida (and neighboring municipalities), as these corridors exhibit the highest observed demand levels.

The following figures illustrate passenger flows between the two main urban areas (Barcelona and Lleida) and the Catalan Pyrenees, as well as intra-regional flows within the Catalan Pyrenees, segmented by mode. As shown, rail trips are concentrated in the eastern part of the study area due to a single line within the area of study, the R3 line connecting Barcelona and Puigcerdà.

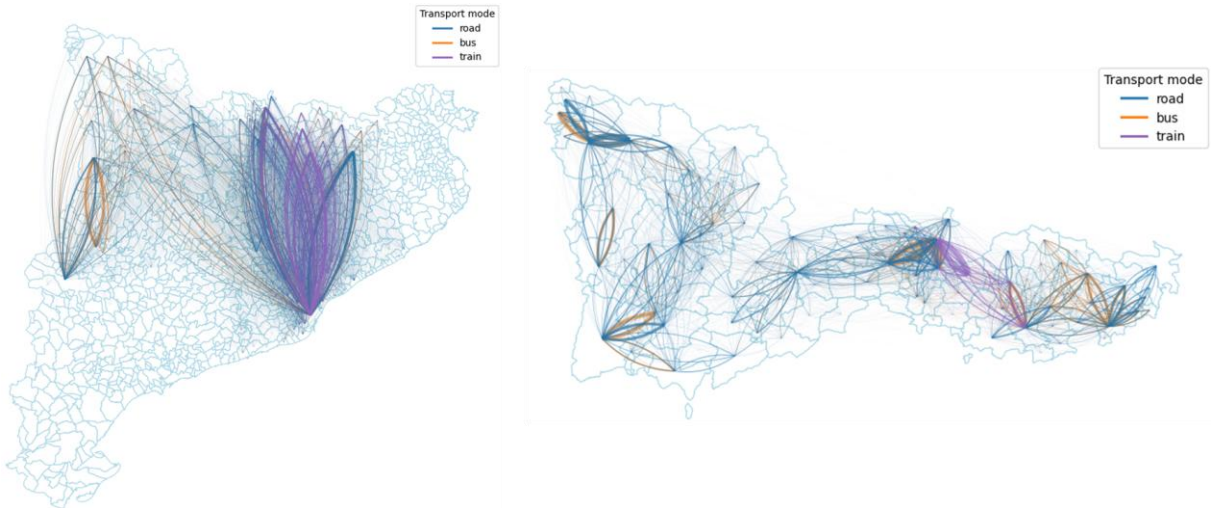


Figure 24. Passenger flows between the two main urban areas (Barcelona and Lleida) and the Catalan Pyrenees (left), and the intra-regional flows within the Catalan Pyrenees (right), segmented by mode.

© –2023– SESAR 3 JU

Trip purpose identification

For the Catalonia case study, the model achieves an overall accuracy of 0.97 and an average precision of 0.91, with macro-averaged precision, recall, and F-score of 0.92 each. Performance is strongest on the majority leisure class, which is identified almost perfectly. The minority business class is classified with solid precision (0.85) and recall (0.86), yielding an F-score of 0.86. The confusion matrix clarifies the nature of these errors: of the 815 leisure trips, 799 are correctly classified and 16 are assigned to the business class; of the 107 business trips, 92 are correctly identified and 15 are misclassified as leisure. The errors are therefore close to symmetric in relative terms, indicating that the model neither systematically over- nor under-predicts business travel. The larger number of business examples in this case study (107, compared with 23 previously) makes the minority-class metrics considerably more reliable, and the balanced error profile supports their robustness. The precision–recall curve is consistent with this picture: precision remains high across most of the recall range and degrades only at the highest recall levels, where the model is pushed to recover the most ambiguous business cases.

The feature importance analysis again yields insights similar to those observed for the Canary Islands case study. Trip type (TIPOVIAJ) is by far the dominant predictor, accounting for 0.60 of the total importance, while the remaining features play a more residual role. It is worth noting that region of residence (CCAA_RESIDENCIA) is more influential in this case (0.13, compared with 0.07 previously). This is plausibly explained by the strongly tourism-oriented profile of the area: a large share of leisure trips are made by non-resident visitors, so that residence becomes a more informative signal of travel purpose, with local residents being comparatively more likely to be travelling for business.

Overall, the results indicate that the model reliably distinguishes travel purpose in this case study and is well suited to support the downstream segmentation of demand by trip type. Performance is consistent with the parallel case study, and the larger and more balanced set of business examples lends additional confidence to the business-class results, with only a minor and roughly symmetric residual error between the two classes.

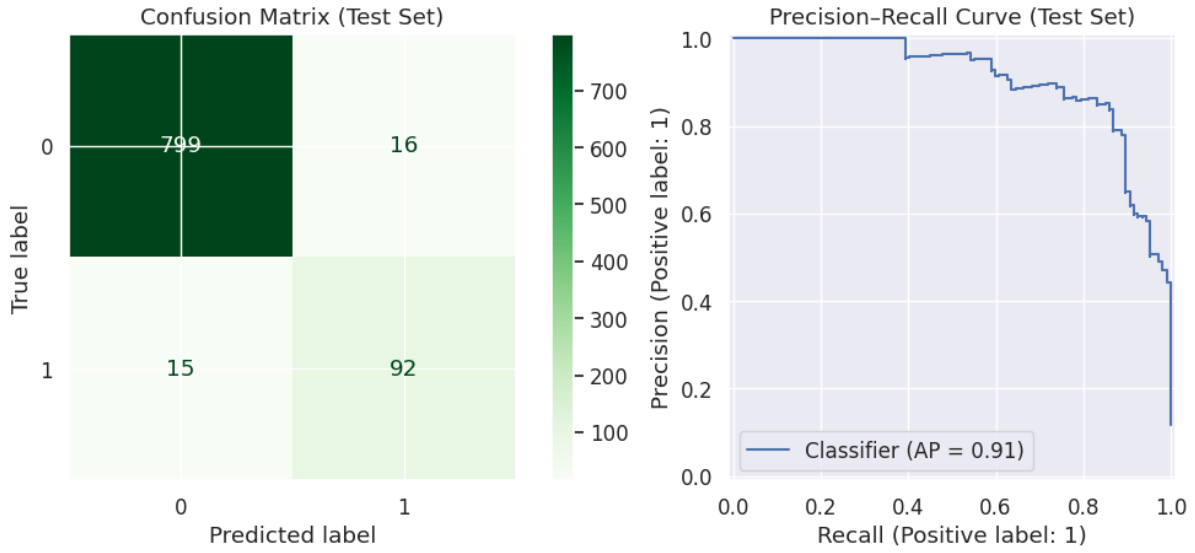


Figure 25. Model calibration results for the Catalan Pyrenees case study. Confusion Matrix (left) and Precision-Recall Curve (right)

© –2023– SESAR 3 JU

Table 34. Model calibration results for the Catalan Pyrenees case study. Precision, Recall and F-Score

	Precision	Recall	F-Score
Leisure	0.98	0.98	0.98
Business	0.85	0.86	0.86
Average	**0.92**	**0.92**	**0.92**
Accuracy		**0.97**	

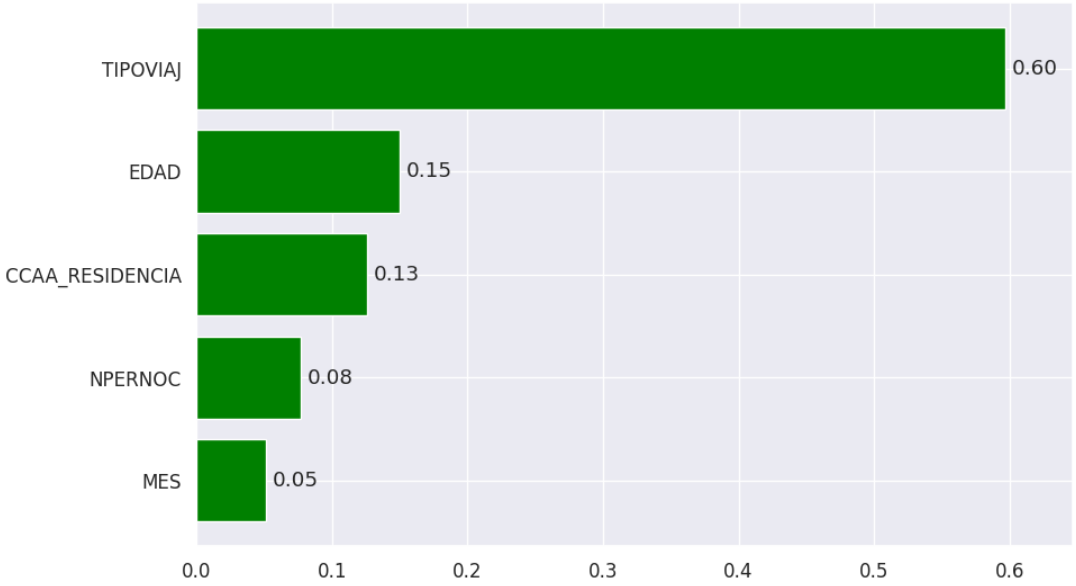


Figure 26. Feature importance for the Catalonia model

In the following table, the results of the application of the calibrated model to the MND-derived trips in the Catalonia case study are presented, distinguishing between the different corridors identified. As shown, the share of business passengers is notably higher than in the Canary Islands case, reflecting the no so turism-oriented case study. Similarly, the winter season exhibits a higher proportion of business trips, which is consistent with the expected seasonal behaviour as, during the summer, the volume of tourists travelling for leisure increases, thus reducing the relative share of business travel. However, this difference is not that notable as in the case of Canary Islands.

Table 35. Estimated share of business trips in the three analysed corridors of the Catalan Pyrenees

Corridor	January	August
Intra-Pyrenees	16.5%	15.3%
Lleida - Pyrenees	20.4%	19.4%
Barcelona - Pyrenees	17.3%	16.3%

To validate the results, the behaviour of the inferred business passengers was analysed to confirm that it is consistent with expectations. In addition, the observed behaviour was compared against the results of the *Enquesta de Mobilitat Quotidiana de l'Alt Pirineu i Aran* (EMQ APA), a survey aimed at

© –2023– SESAR 3 JU

characterising the mobility patterns and travel behaviour of the Pyrenees regions. Although its study area does not coincide exactly with the area defined in the project, most of the project zones are covered by the survey. The EMQ APA is based on a total of 7,564 interviews conducted between 5 November 2024 and 29 January 2025, and its results are publicly available at the following link: https://territori.gencat.cat/ca/01_departament/estadistica/mobilitat-infraestructures/indicadors-estadistiques-mobilitat-infraestructures/enquestes-mobilitat/enquesta-de-mobilitat-quotidiana-de-lalt-pirineu-i-aran/index.html.

Figure 23 presents the share of business trips by day of the week detected by the algorithm for the intra-Pyrenees corridors, while Figures 25 and 26 show the equivalent results for the two external corridors connecting the Pyrenees with Lleida and Barcelona, respectively. The corresponding survey references are provided in Figure 24 (intra-Pyrenees) and Figure 27 (trips between the Pyrenees and external areas). This comparison should be read as a qualitative, order-of-magnitude consistency check rather than a strict numerical match, for two reasons. First, the spatial units do not coincide exactly: the specific corridors analysed here and the zoning used by the survey are not directly equivalent — in particular, the survey reference for the external corridors aggregates all trips between the Pyrenees and external areas rather than isolating the individual Lleida and Barcelona corridors — so the two sources describe partially overlapping but not identical populations of trips. Second, the underlying definitions of the target category differ: the present analysis identifies business trips while deliberately excluding regular commuting to a fixed workplace, whereas the survey's work-mobility category ("treball I gestions de treball") captures commuting as well. The survey figures therefore constitute an upper bound on what the algorithm is designed to detect.

Notwithstanding these differences, the algorithm reproduces the expected behavioural patterns consistently across all three scopes. In every case, business travel is clearly concentrated on weekdays and drops sharply at weekends. For the intra-Pyrenees corridors, the detected weekday business share is approximately 18–22%, comparable to the survey's weekday work share of around 22% once the exclusion of commuting is taken into account. For the external corridors, the algorithm yields higher weekday business shares (of the order of 23–32% for both the Lleida–Pyrenees and Barcelona–Pyrenees corridors) which is coherent with the survey reference for Pyrenees-to-external trips, where occupational mobility together with work-related travel represents a comparable share of weekday trips. This higher business presence on the external corridors, relative to the intra-Pyrenees movements, is itself a plausible result, as longer-distance weekday trips between the Pyrenees and the main urban areas are more likely to be motivated by work or business than short internal trips. At weekends, all three corridors show the detected business share collapsing to below 1%, mirroring the pronounced reduction in occupational mobility observed in the survey. This is consistent with the definitional difference between the two sources: the residual weekend work mobility reported by the survey corresponds largely to commuting to the usual workplace (for instance among shift or weekend workers) whereas business trips to non-habitual locations, which are what the algorithm is designed to detect, become negligible at weekends.

© –2023– SESAR 3 JU

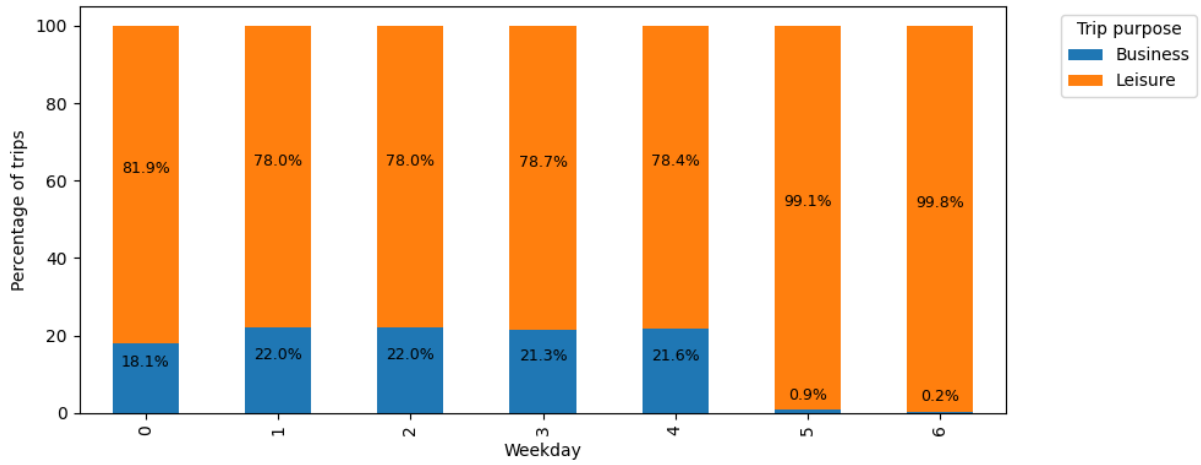


Figure 27. Share of business trips by day of the week in the intra-Pyrenees trips

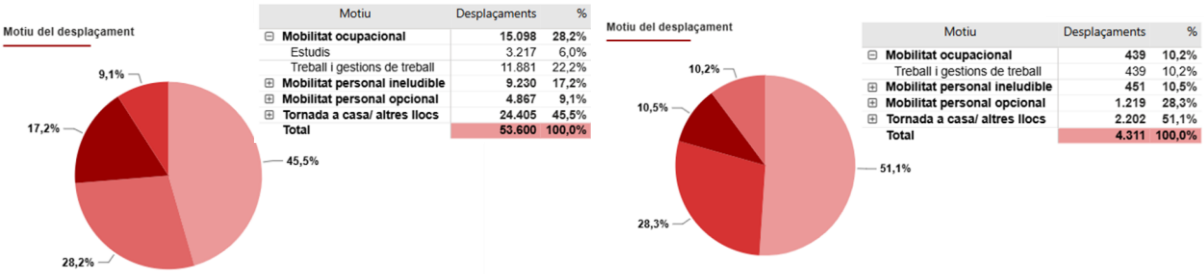


Figure 28. Share of business trips during weekdays (left) and weekends (right) in the intra-Pyrenees trips according to the EMQ APA survey 2025

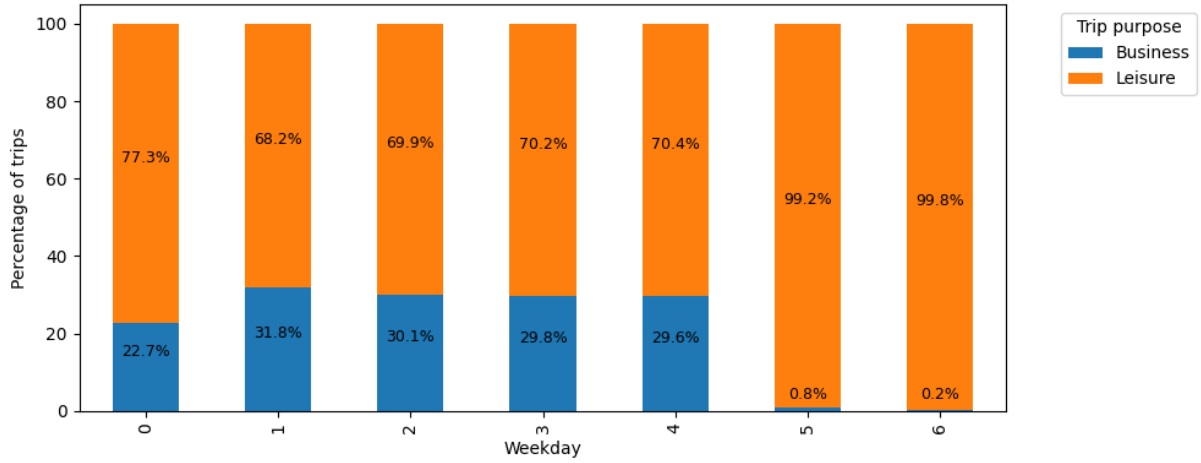


Figure 29. Share of business trips by day of the week in the Lleida-Pyrenees corridor

© –2023– SESAR 3 JU

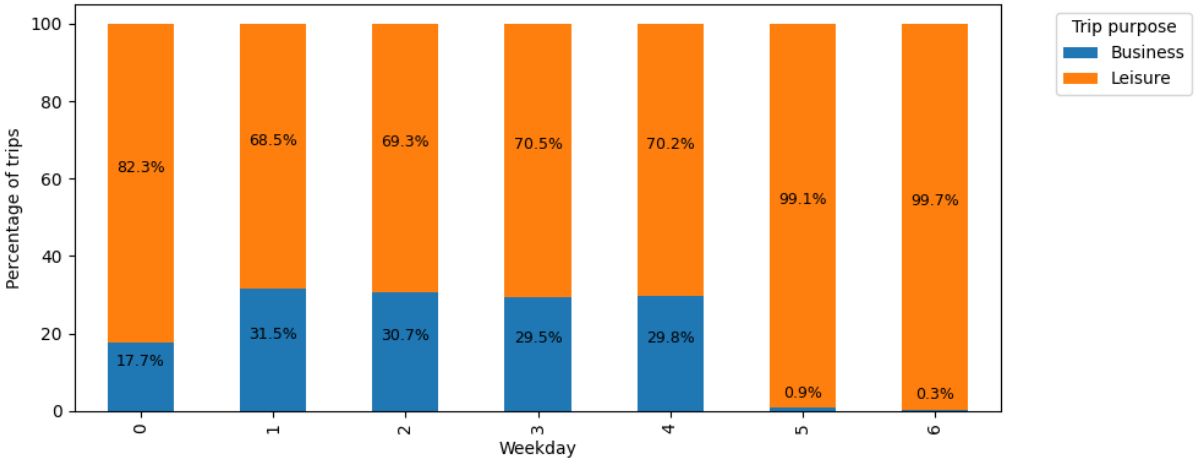


Figure 30. Share of business trips by day of the week in the Barcelona-Pyrenees corridor

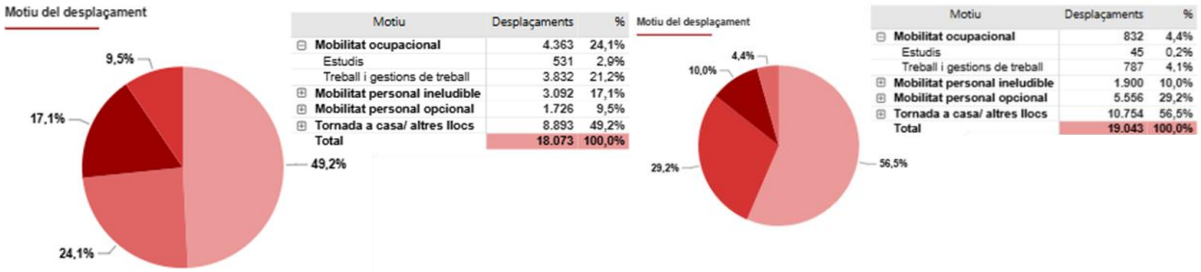


Figure 31. Share of business trips during weekdays (left) and weekends (right) in the trips between the Pyrenees and external areas according to the EMQ APA survey 2025

Finally, the inferred business trips were analysed by age range as a further consistency check. As shown in the figure below, the share of business travel is markedly lower in the youngest group (10.4% for the 0–25 range) and then stabilises at around 21% across all the working-age brackets (20.8%, 20.4%, 21.1%, and 21.0% for the 25–35, 35–45, 45–55, and 55–65 ranges, respectively). Crucially, no business trips are assigned to the oldest group (0% for passengers over 65). This distribution is fully consistent with expectations: business travel is concentrated within the economically active population, is reduced among the youngest travellers, who are largely outside the labour market or in education, and is effectively absent beyond the typical retirement age.

© –2023– SESAR 3 JU

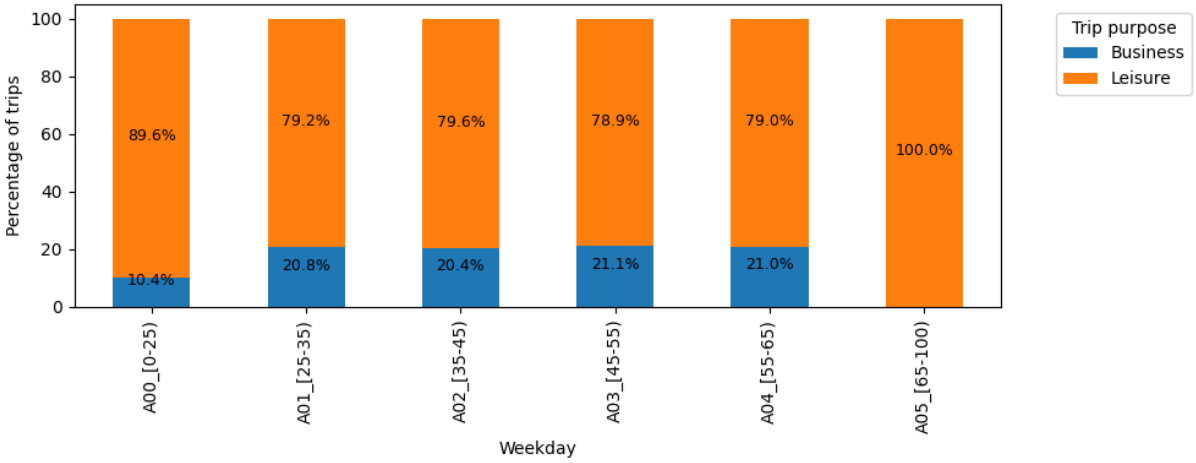


Figure 32. Share of business trips by age in all the corridors of the Catalan Pyrenees trips

The fact that the weekday concentration, the weekend reduction, and the higher relative weight of business travel on the longer external corridors are all reproduced, and that the residual quantitative discrepancies are explained by the known definitional and zonal differences rather than contradicting them, supports the conclusion that the detection algorithm captures the expected temporal and spatial signature of business travel. In addition to this temporal and spatial validation, the coherence with the demographic profile of the users reinforces the validity of the results. The comparison is therefore considered to provide satisfactory external validation of the leisure–business classification.

Road transport mode identification

For the identification of bus trips, information on the bus routes operated within Catalonia was collected from the National Access Point (NAP) (https://nap.transportes.gob.es/Files/List). Figure 33 (left) shows the bus stops within Catalonia. From these, the stops corresponding to routes serving the three corridors of analysis (Lleida–Pyrenees, Barcelona–Pyrenees, and intra-Pyrenees) were filtered. Figure 33 (right) shows the resulting filtered bus stops and routes across the different areas of study, where the colours highlight different operators. For this study, the two main operators were considered: ALSA (brown) and the interurban bus services of the Government of Catalonia (Generalitat de Catalunya, in blue).

© –2023– SESAR 3 JU

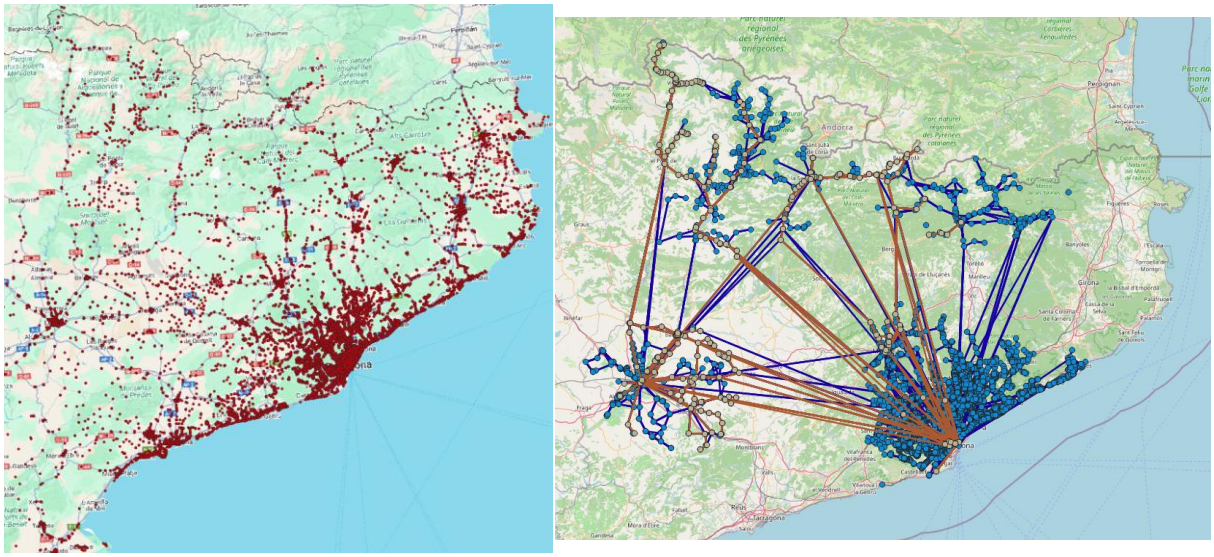


Figure 33. Bus stops within Catalonia (left) and bus stops and routes within the study areas (right)

Once the relevant routes and stops had been collected, the procedure consists of determining which MND-detected trips could have been made by bus. To this end, each trip's detected trajectory is compared against the candidate routes and stop locations, computing the distance to the nearest stops in order to assess whether the trip could feasibly have used the available services. For the trips identified as potential bus trips, the service schedule is then compared with the trip's timing to confirm that a service was actually available at that moment. Trips for which no matching service exists are discarded.

No information on bus occupancy or demand is available, so the detected bus trips cannot be compared against observed demand. To preserve consistency, a maximum occupancy per service is instead imposed, preventing the assignment of more trips to bus than the available capacity can accommodate; the resulting estimate is therefore to be interpreted as an upper bound. The assignment proceeds in order of decreasing probability: trips with the highest likelihood of having been made by bus are allocated first, progressively, until the maximum capacity is reached.

The figure below shows the main bus corridors detected from MND, defined as those carrying more than 200 passengers over the two-week study period. As can be seen, most of the demand is concentrated on specific corridors within the Catalan Pyrenees, linking Vielha, Puigcerdà, Ripoll, Olot, and Tremp with their neighbouring areas, whereas demand on longer trips, both within the Pyrenees and between the Pyrenees and external areas, is notably lower.

© –2023– SESAR 3 JU

Co-funded by the European Union



Figure 34. Main bus trips detected from MND

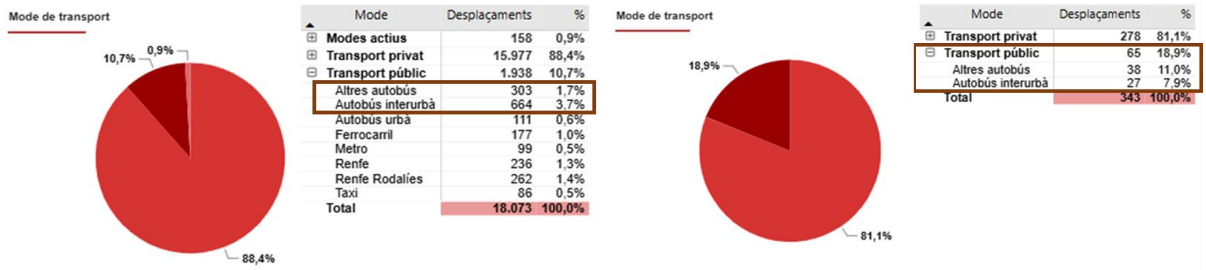
The table below presents the share of bus trips for the three analysed corridors. The corridors connecting the Catalan Pyrenees with external areas show a low bus share with just a 2-4% of the total demand. This share is lower for the Barcelona–Pyrenees connection than for the Lleida–Pyrenees one, which may be explained by the existence of a rail connection between Barcelona and parts of the eastern Catalan Pyrenees, whereas no such rail alternative is available from Lleida.

Table 36. Bus share in the three analysed corridors

Corridor	% Bus trips
Intra-Pyrenees	2.0%
Lleida - Pyrenees	3.8%
Barcelona - Pyrenees	23.9%

For validation purposes, these values were compared against the results of the EMQ APA 2025 survey. As remarked previously, this comparison must be interpreted with caution, since the areas and corridors of study do not coincide exactly, however, it provides a useful order of magnitude reference for our estimations. The figure below presents the modal share estimates derived from the survey. The image on the left shows the modal share for trips between the Pyrenees and external areas: the sum of the interurban bus categories, "Autobús interurbà" (3.7%) and "Altres autobús" (1.7%), amounts to 5.4%, which is comparable to the 2% and 3.8% obtained from MND for the corresponding corridors. The image on the right shows the modal share for intra-Pyrenees trips, where public transport is provided exclusively by bus in the study area, reaching a total of 18%, again comparable to the 23% estimated from MND.

© –2023– SESAR 3 JU



Mode	Desplaçaments	%
Modes actius	158	0,9%
Transport privat	15.977	88,4%
Transport públic	1.938	10,7%
Altres autobús	303	1,7%
Autobús interurbà	664	3,7%
Autobús urbà	111	0,6%
Ferrocarril	177	1,0%
Metro	99	0,5%
Renfe	236	1,3%
Renfe Rodalies	262	1,4%
Taxi	86	0,5%
Total	18.073	100,0%

Mode	Desplaçaments	%
Transport privat	278	81,1%
Transport públic	65	18,9%
Altres autobús	38	11,0%
Autobús interurbà	27	7,9%
Total	343	100,0%

Figure 35. Modal share for trips within the Pyrenees (left) and between the Pyrenees and external areas (right) according to the EMQ APA survey 2025

Estimation of travel times and travel costs

Similarly to the previous case study, to estimate travel time and travel cost in Catalonia, the approach varies by transport mode:

- For **road trips** travel time is obtained directly from OSM, and travel cost is calculated by multiplying the road distance by a cost per kilometre of €0.21, as established by the OTLE (https://apps.fomento.gob.es/bdotle/visorBDpop.aspx?i=492)

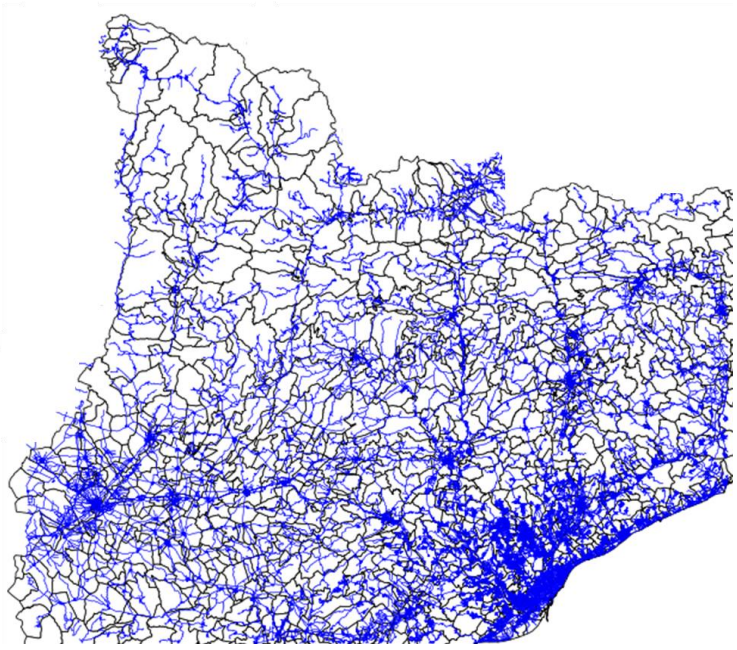


Figure 36. OSM network in Catalonia

- For all **other modes** (train and bus), travel time is calculated as the sum of: access time and egress time (assumed to be by car, as in the Canary Islands case study), processing and dwell time (considered to be 15 minutes for the station of origin and 5 minutes for the destination station) and the in-vehicle time.

  Travel cost for non-road modes is calculated as the sum of the access and egress costs (obtained by multiplying the corresponding distances by the road cost per kilometre) and the fare of the transport route, extracted from official sources.

© –2023– SESAR 3 JU

To calculate train travel costs, a price per kilometre is assumed based on the current train fares. The only line connecting the areas of study and the Pyrenees is the **Line R3 from Barcelona to Puigcerdá,** as presented in the following figure.



Figure 37. R3 Line between Barcelona and Puigcerdá

The price will depend on the number of stops, to simplify the problem, a price per kilometre is assumed by calculating the average between the shortest and the longest trip possible, as presented in the following table. Based on this, we assume a total price of **0.15€/km**

Table 37. Distance and cost of the shortest and the longest trip possible in the R3 line

	Route	Distance (km)	Price (€)	€/km
Max possible distance	Barcelona-Puigcerdá	30	6	0.20
Min possible distance	Centelles-Ripoll	120	12	0.10
Average				**0.15**

To calculate bus travel costs, a price per kilometre is computed based on the current bus fares. The price will depend on the number of stops and the route, as in the case of train, to simplify the problem, a price per kilometre is calculated by calculating the average between the shortest and the longest trip possible for each route.

The following tables present the different routes available from Barcelona and Lleida, as well as the cost for each route.

Table 38. Distance and cost of the different routes in the Catalan Pyrenees considered

Barcelona - Puigcerdá				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Navas - Guardiola	36	7	0,19
Min possible distance	Barcelona - Puigcerdá	120	24	0,20
Average				0,20

© –2023– SESAR 3 JU

Barcelona - Vielha				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Barcelona - Pont de Suert	164	38	0,23
Min possible distance	Barcelona - Vielha	202	42	0,21
Average				0,22
Barcelona – Esterri d'Aneu				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Barcelona - Tremp	104	33	0,32
Min possible distance	Barcelona - Esterri d'Aneu	170	45	0,26
Average				0,29
Barcelona - Andorra				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Manresa - Organya	52	17,5	0,34
Min possible distance	Barcelona - Andorra	130	31	0,24
Average				0,29
Barcelona - Olot				
	Route	**Distance (km)**	**Price (€)**	**€/km**
	Barcelona - Olot	100	21	0,21
Lleida - Vielha				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Alfarras - Pont de Suert	65	10	0,15
Min possible distance	Lleida - Vielha	136	17	0,13
Average				0,14
Lleida – Esterri d'Aneu				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Belaguer - Tremp	40	5	0,13
Min possible distance	Lleida - Esterri d'Aneu	120	13,5	0,11
Average				0,12
Lleida - Andorra				
	Route	**Distance (km)**	**Price (€)**	**€/km**
Max possible distance	Belaguer - Organya	60	13	0,22
Min possible distance	Lleida - La Seu d'Urgell	110	22	0,20
Average				0,21

© –2023– SESAR 3 JU

Based on these inputs, travel times and travel costs have been calculated for all MND-detected trips, depending on the mode and the specific route. The following figure shows the average travel time from the different zones considered in the Barcelona area and the Catalan Pyrenees. As shown, areas in the north, closer to the Catalan Pyrenees, present average travel times of under 45 minutes, while some areas in the south-east, which are less well connected to the corridor, show travel times exceeding two hours.

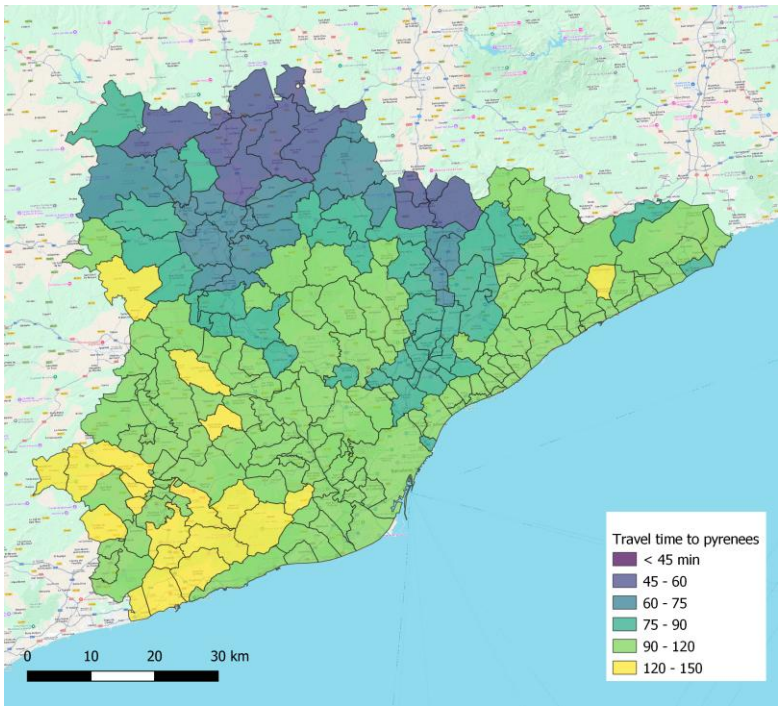


Figure 38. Average travel time from the different zones considered in the Barcelona area and the Catalan Pyrenees

C.3.3 Unexpected behaviours/results

No unexpected behaviours or results have been identified at this stage. The mobility patterns, trip-purpose inferences, and modal-detection outputs derived from MND are consistent with prior domain knowledge and with the independent reference sources used for validation. The only deviations observed between the MND estimates and the survey references are attributable to known and anticipated differences in spatial zoning and in the definition of the target categories (in particular, the exclusion of regular commuting from the business-trip category and the upper-bound nature of the bus-mode assignment), rather than to anomalous model behaviour.

C.3.4 Confidence in results of validation exercise #03

C.3.4.1. Level of significance/limitations of validation exercise results

The main limitation of the validation exercise is the restricted capability to compare the estimated results for trip purpose classification and bus-mode identification against ground-truth data, due to its unavailability. For this reason, validation has relied on behavioural analysis and comparison with alternative data sources; however, these approaches also present certain limitations.

© –2023– SESAR 3 JU

The sources used for validation do not coincide exactly with the project's spatial scope. The EMQ APA 2025 survey covers most, but not all, of the project zones, and its zoning and corridor definitions are not directly equivalent to those analysed here. The comparisons are therefore valid as order-of-magnitude consistency checks rather than as strict numerical matches.

Additionally, the definition of the business-trip category differs between sources. The trip-purpose algorithm identifies business travel while deliberately excluding regular commuting to a fixed workplace, whereas the survey's occupational-mobility category includes commuting. The survey figures consequently act as an upper bound on the quantity the algorithm is designed to detect, which explains the systematic direction of the residual differences observed.

The minority (business) class is supported by a limited number of observations (most notably in the Canary Islands test set) which increases the statistical uncertainty of the corresponding per-class metrics. The Catalonia case study, with a larger and more balanced business sample, provides more robust minority-class estimates.

The bus-mode detection is constrained by the absence of occupancy and demand data, which prevents calibration against observed demand.

Finally, regarding the calculation of travel times, the current road-based estimates derived from OpenStreetMap do not account for traffic congestion or variations in travel time across different days of the week or times of day. As a result, these estimates may be less realistic in situations where congestion is significant.

C.3.4.2. Quality of validation exercises results

The results demonstrate that the outputs derived from MND align consistently with expected behaviours across multiple independent dimensions:

The mobility patterns reproduce the expected demand behaviour: higher demand peaks during summer and other holiday periods; increased activity during the ski season in areas with ski resorts; demand distributions reflecting proximity effects, with nearby municipalities generating more trips; larger municipalities accounting for a higher share of trips; and specific modes capturing demand from neighbouring areas, as observed in the Tenerife–La Gomera connection.

The trip-purpose inference reproduces the expected temporal, seasonal, and demographic signatures of business travel: a concentration on weekdays with a near-total collapse at weekends, a higher relative share of business travel in winter (more pronounced in the strongly tourism-oriented Canary Islands than in Catalonia), a concentration within the working-age population, and a negligible business share among both the youngest and the over-65 groups. Where reference data are available (EMQ APA 2025), the weekday/weekend pattern and the higher business presence on longer external corridors are independently corroborated, with the residual quantitative gaps explained by the known definitional and zonal differences.

The bus-mode detection yields modal shares that are comparable in order of magnitude to the survey references, for example, an intra-Pyrenees bus share of approximately 23% from MND against 18% from the survey, and 2–3.8% on the external corridors against a combined survey figure of 5.4%.

These results indicate that the developed methods produce mobility, trip-purpose, and modal-split outputs of a quality sufficient to support the subsequent demand and IAM market-potential analyses.

C.3.4.3. Significance of validation exercises results

© –2023– SESAR 3 JU

The validation results are significant in that they establish the credibility of the enhanced MND-derived mobility data as an input to the IAM demand and market-potential assessment. By demonstrating that mobility patterns derived from MND, the trip-purpose classification and the bus-mode detection behave as expected and are consistent with an independent mobility survey, the exercises provide reasonable assurance that the segmentation of demand by purpose and by mode, which is the base for the estimation of modal-shift probabilities towards IAM services, rely on a consistent basis.

This is particularly relevant given that business and leisure segments differ substantially in their value of time and willingness to pay, parameters that directly drive the shift to premium modes such as IAM. The exercises therefore reduce the methodological risk associated with the demand modelling, while clearly delimiting the conditions under which the results should be used.

C.4 Conclusions

C.4.1 Conclusions on concept clarification

The work has clarified and demonstrated the concept of enriching MND-derived mobility data with two additional layers of information that are not directly observable from MND: the purpose of the trip (leisure vs business) and the use of public bus services on shared road infrastructure. The concept has been articulated end to end, from data acquisition and processing, through the calibration of a machine-learning trip-purpose classifier and the development of a route- and schedule-aware bus-detection algorithm, to the validation of the resulting outputs against independent references. This confirms that the conceptual approach of combining MND with complementary datasets (survey data for calibration and validation, NAP bus network data for mode inference) is well defined and operationally realisable.

C.4.2 Conclusions on technical feasibility

The exercises confirm the technical feasibility of the proposed methods. A trip-purpose classifier has been successfully calibrated and applied at scale to MND-derived trips in two distinct case studies, achieving high overall performance (accuracy of 0.97 in both cases, with macro-averaged F-scores of 0.92) and producing inferences consistent with expected behaviour. Likewise, the bus-detection algorithm has been demonstrated to operate on real MND trajectories by combining spatial proximity to bus stops, route connectivity, and schedule consistency, and by applying a capacity-constrained assignment in the absence of occupancy data. These results establish that the methods are technically feasible and transferable across different territorial contexts.

C.4.3 Conclusions on performance assessments

The performance assessment indicates that the developed methods meet the requirements of the intended application. The trip-purpose classifier performs strongly on the majority leisure class and adequately on the minority business class, with the larger and more balanced Catalonia sample yielding more robust business-class metrics than the smaller Canary Islands sample. The bus-detection method produces modal shares comparable in order of magnitude to independent survey estimates, with deviations consistent with its upper-bound design. The principal performance limitations — the under-detection of business trips where the minority sample is small, and the absence of occupancy data for calibrating bus demand — are understood, bounded, and do not prevent the outputs from supporting the downstream IAM demand analysis.

© –2023– SESAR 3 JU

C.5 Recommendations

Based on the work carried-out, the following recommendations are made for the continuation and consolidation of the analysis:

- Enhancing the MND-based demand data to better characterise IAM adoption. Future work should focus on enriching the mobility information extracted from MND with additional attributes relevant to the assessment of IAM shift, such as a finer segmentation by traveller and trip profile, so that the resulting data provide a more informative basis for estimating willingness to pay and modal-shift potential towards IAM services, or characterising its long-term attachment to a single mode.
- Improving the trip-purpose detection algorithm. The leisure–business classification can be strengthened by increasing the set of features derived from MND and by adopting modelling approaches more robust to the limited availability of labelled data, reducing the current dependence on a single dominant predictor and improving the reliability of the minority (business) class.
- Improving the road-mode detection algorithm. The bus-mode detection can be refined by incorporating demand data if available, or by including the sociodemographic profile of the passenger when estimating the probability of bus use, since the propensity to use these services typically varies with age, gender, or income. Such information could be derived from surveys, where available, and incorporated into the algorithm. A further valuable extension would be to detect additional road modes, in particular taxi, since taxi users represent one of the segments most likely to shift to IAM. However, since these services do not have fixed network (i.e., stops, routes, etc.) its detection would rely on surveys or comparable data sources, whose availability cannot be guaranteed for every study area.

© –2023– SESAR 3 JU

Co-funded by the European Union

Appendix D Validation exercise #04 report

D.1 Summary of the validation exercise #04 plan

As defined in the ERP SESAR Solution 0515

D.2 Deviation from the planned activities

There are no deviations from the planned activities.

D.3 Validation exercise #04 results

D.3.1 Summary of validation exercise #04 results

Exercise #04 validation objective ID	Exercise #04 validation objective title	Exercise #04 success criterion ID	Exercise #04 success criterion	Exercise #04 validation results	Exercise #04 validation objective status
OBJ-0515-ERP-004	Validation of algorithms for estimating IAM captured and induced demand	CRT-0515-TRL1-ERP-004.001	The discrete choice model accurately represents observed travel behaviour. Appropriate tests for discrete choice models, such as the likelihood ratio test and McFadden's R-squared, are used to evaluate the model's performance and its capability to precisely replicate observed choices. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.	Two discrete choice models were developed, one for Catalonia and one for Tenerife. Both models are statistically significant and meet the selected model validation indicators. The McFadden's rho-squared values are 0.648 for Catalonia and 0.622 for Tenerife, indicating strong model performance. All estimated model variables are statistically significant. In addition, a regression model was developed to estimate induced demand. The model achieved an R-squared value of 0.94, indicating an excellent goodness-of-fit and a strong ability to explain the observed variation in travel demand. This high R-squared value provides confidence in the validity and robustness of the induced demand estimation approach.	OK

Table 39. Validation exercise #04 results

© –2023– SESAR 3 JU

D.3.2 Analysis of validation exercise #04 results per validation objective

D.3.2.1. OBJ-0515-TRL1-ERP-004 Results

This validation objective aims to validate the algorithms for estimating IAM captured and induced demand. Estimating the future demand for IAM services is critically important for planners and policymakers. Accurate demand forecasts inform the viability of proposed services, infrastructure needs (e.g. number of vertiports or small regional airports), and the potential transport network benefits of IAM integration. High demand projections can justify investments and guide network design, while low demand may signal that IAM concepts require different business models or policy support. Additionally, understanding demand is necessary to quantify environmental and social impacts – for instance, how many travellers might shift from cars or diesel trains to electric air transport (reducing emissions), or how IAM could improve accessibility for underserved regions.

When introducing a new transport mode, two critical effects must be analysed: modal shift (diverted demand) and induced (latent) demand. Modal shift refers to travellers switching from one mode to another due to the new option's advantages. In other words, part of the IAM ridership will come from existing modes (car, train, bus, etc.) losing some of their demand. By contrast, induced demand refers to *additional travel that occurs specifically because the new service exists*, encompassing entirely new trips or trip frequency increases that would not have happened without IAM. It is important to distinguish these, as they have different implications: modal shift primarily redistributes existing trips among modes, whereas induced demand represents net growth in travel volume. The transportation literature provides several formal definitions and classifications of induced demand ([27], [28], and [29]). It is commonly divided into:

- Diverted demand: travellers changing their mode or route in response to improved transport conditions (e.g. choosing IAM over driving, or taking a new highway instead of an old one).
- Direct (latent) induced demand: short-term increases in trip frequency or longer trip distances (including changes in destinations) resulting from improved service levels.
- Indirect (latent) induced demand: long-term behavioural changes caused by broader effects such as land-use shifts, residential relocation, or changes in car ownership.
- Background growth: overall growth in travel driven by external factors like population growth or rising incomes, not attributable to the specific transport project.

In the context of the PRIAM project, induced demand refers primarily to direct induced trips in the short-to-medium term, generated because IAM significantly improves accessibility—for example, by sharply reducing travel times between specific origin–destination (OD) pairs. In our modelling framework, diverted demand corresponds to modal shift, where travellers would have made the trip regardless but would switch from an existing mode to IAM.

MND provides comprehensive coverage of *observed* trips, including OD flows, trip frequencies, and sometimes inferred modes. However, by design, it can only capture travel that actually occurred during the observation period. This means that MND cannot directly reveal generative demand—the new trips that would only happen if IAM existed.

Even if a person is present in the MND dataset and their socio-demographic profile is known or inferred, the data contain no direct behavioural signal indicating whether they would have made a specific trip (or any trip at all) under new transport conditions. This is particularly problematic for non-

© –2023– SESAR 3 JU

travellers or individuals without any recorded trips between a specific OD pair. The absence of recorded trips could reflect multiple realities: a true lack of interest or need, the absence of suitable travel options, or unobserved constraints such as cost or time barriers. MND alone cannot distinguish between these cases.

Therefore, latent trips—trips that do not currently exist but would be generated by IAM—cannot be identified directly from MND. To address this, the methodology estimates induced demand by analysing the sensitivity of trip generation to travel distance and generalised travel cost observed in the MND. Specifically, the MND trip data are used to calibrate a distance-decay function, which captures how trip frequency decreases with distance and thus reflects travellers' accessibility behaviour. When IAM is introduced, it effectively reduces generalized distance or travel time, shifting this calibrated distribution and increasing the total area under the curve. This change represents the additional trips generated due to improved accessibility, that is, the induced demand. The resulting growth in total trips is then combined with the SP-based discrete choice model and pivoting results to distribute both newly generated and shifted trips across all transport modes, including IAM.

Methodology

The methodology adopted in this study aims to estimate both the modal shift and induced demand for IAM services by integrating SP survey data with large-scale mobility datasets, specifically MND. The approach is designed to combine the behavioural detail obtained from SP surveys with the population coverage provided by MND, while addressing the limitations of each data source when used in isolation.

In the subsections below, each of the components used in PRIAM to calculate modal shift and induced demand is presented. These components include the survey design, the MND, the methodology used to estimate modal shift, and the methodology used to estimate induced demand. The following subsection then presents the model estimation results and the validation outcomes for each component

1. Survey Design

The first stage involved the design of a stated preference survey aimed at capturing respondents' potential travel behaviour in the presence of IAM services. The survey design followed best practices in experimental design for discrete choice modelling, ensuring variation and statistical efficiency in the presented scenarios. A total of 48 questions divided in 4 sections were designed, gathering information on respondents' socio-demographic characteristics (age, gender, nationality, etc.), current travel behaviour (frequency of travel, mode used, etc.), perceptions towards IAM (familiarity with IAM, concerns, etc.), and stated preferences under different IAM service configurations. You can find a list of the questions in Table 25 in Appendix B.3.2.1

The survey used a stated preference experimental design, in which respondents were presented with hypothetical but realistic choice situations, based on the two chosen case studies, La Gomera Tenerife and the Catalan Pyrenees. Attributes (IAM cost and travel time) were systematically varied to understand how these factors influence mode choice. In order to properly calibrate a discrete choice model, a total of eight different forms of the survey were created. These variations combined two travel purposes (work and leisure) with six different IAM cost–time scenarios:

1. Cheap cost – short travel time
2. Cheap cost – long travel time

© –2023– SESAR 3 JU

3. Average cost – short travel time
4. Average cost – long travel time
5. Expensive cost – short travel time
6. Expensive cost – long travel time

The rationale for these scenarios was to examine respondents' sensitivity to travel time and cost when considering IAM services. Each of the eight forms designed contained questions from different scenarios, so that the same respondent was presented with different situations. By observing mode choice changes across these scenarios, the survey provided behavioural insights necessary to estimate parameters such as value of time and price sensitivity. The time and cost values for IAM were derived from the assumptions used in the MAIA project, which defined realistic operational characteristics of air taxi services. For further details on the calculation of travel time and cost, readers are referred to the MAIA project methodology.

The survey also included a propensity question — *"Would you consider making new trips that you currently do not make if air taxis were available?"* — to capture respondents' potential for generating induced trips. This question, along with socio-demographic variables and attitudinal questions, was designed to feed into both the scaling factor approach and a potential hybrid discrete choice modelling framework described below.

The eight forms were randomly distributed among participants, ensuring each respondent was exposed to only one cost–time scenario for a given travel purpose/case study. The survey was conducted in July 2025 and was disseminated via multiple channels, including LinkedIn, project website, SESAR newsletter and dedicated emails to related SESAR projects representatives. It was available in English and Spanish to maximize participation. In total, 211 people completed the survey, providing a sufficiently large dataset for descriptive analysis and for informing future model development. For each scenario, respondents indicated which travel mode they would choose under current conditions and if IAM services were available (future situation). These questions allowed for the estimation of modal shift potential by comparing current mode choice with future scenarios including air taxis. This structure provided both revealed preference data (current behaviour) and stated preference data (future choices under IAM scenarios), enabling a comprehensive understanding of mode choice behaviour and the factors influencing potential IAM adoption. In the sections below the results of the survey from IAM usage likelihood to modal shift behaviour will be presented

2. Mobile Network Data

To scale behavioural predictions to population level, anonymised and aggregated MND were used to reconstruct OD flows across the study regions. Two representative "typical" weeks of 2024 were selected: 22–28 January 2024 (winter week), 19–25 August 2024 (summer week). These weeks were chosen to avoid atypical travel patterns (e.g., major holidays) and to capture both work-related and tourism-related mobility. The MND dataset provides hourly trip records (P00–P23) including origin zone, destination zone, main travel mode (motorised, non-motorised, train, plane, ship), trip purpose (home, work, frequent, non-frequent, other), and aggregated socio-demographic attributes (age bracket, income bracket, nationality, sex). Spatial disaggregation is performed at district level (7-digit zoning system), enabling detailed OD matrix construction. Unlike survey data, MND offer: full population coverage, spatially detailed OD flows, time-of-day resolution, seasonal comparability. However, IAM is not present in historical data and behavioural sensitivities are not observable.

© –2023– SESAR 3 JU

Therefore, MND are used to define baseline OD demand volumes and observed modal distributions prior to IAM introduction.

For each OD pair, travel time and cost for existing modes were computed using harmonised assumptions. Road travel times were calculated using OpenStreetMap networks (OSMnx). For public transport modes, total travel time includes access time, dwell time, in-vehicle travel time, and egress time. Travel cost assumptions were derived from publicly available fare structures and €/km values for car and taxi as well as resident/non-resident fare structures for ferry and air services. These inputs enable consistent computation of generalised cost across modes prior to applying the behavioural model. For more information on MND, please refer to the relevant sections of this deliverable.

3. Modal Shift (discrete choice model)

This study develops a hybrid modal-shift modelling framework that combines SP survey data with MND to estimate the potential demand for IAM services and the redistribution of trips across existing transport modes. The methodological rationale is that IAM is a future transport alternative for which revealed-preference observations are not yet available. Therefore, SP data are required to estimate travellers' behavioural sensitivities to IAM service attributes, such as travel time, cost, access and egress time, waiting time, service frequency, reliability, and transfer conditions. However, SP data alone are not sufficient for robust demand forecasting, because survey samples may not reproduce the actual size, spatial distribution, temporal structure, and modal composition of real travel demand. For this reason, the SP-based choice model is combined with MND, which provides large-scale empirical information on observed origin–destination movements and baseline modal patterns. The framework diagram of the methodology of this study is illustrate in Figure XXX

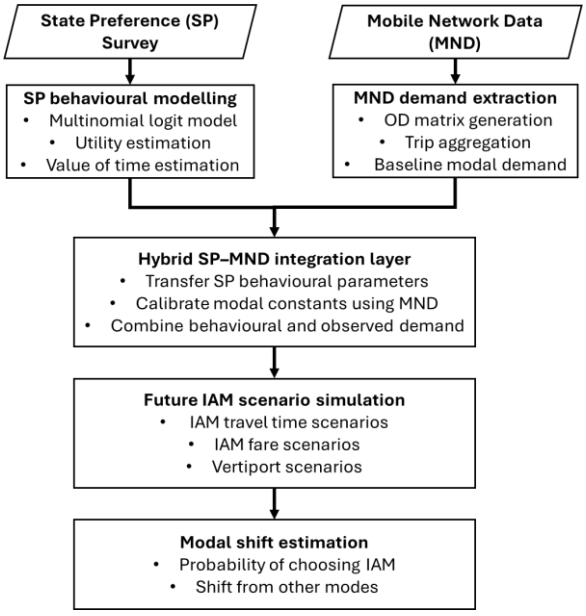


Figure 39: Hybrid modelling framework for modal shift towards IAM

Step 1: Estimation of behavioural time–cost trade-off from SP data

The first modelling step estimates a preference-space multinomial logit (MNL) model using the SP data. The purpose of this step is to recover the behavioural trade-off between travel time and travel cost,

© –2023– SESAR 3 JU

which is then translated into a value of time (VoT). The model includes alternative-specific constants and generic time and cost coefficients. The utility of each alternative j can be expressed as:

$$V_{nj} = ASC_j + \beta_{time} TT_{nj} + \beta_{cost} TC_{nj}$$

where $V_{nj}$is the systematic utility of alternative j for individual n, $ASC_j$is the alternative-specific constant, $TT_{nj}$is travel time, $TC_{nj}$is travel cost, and $\beta_{time}$and $\beta_{cost}$are the estimated marginal utilities of time and cost. The SP step in the implemented code estimates a single time coefficient and a single cost coefficient. The value of time is then computed as:

$$VoT = \left| \frac{\beta_{time}}{\beta_{cost}} \right|$$

Because travel time is expressed in hours and travel cost in euros, the resulting value is interpreted as euros per hour. This value is subsequently used to construct a generalised cost measure for each mode.

Step 2: Construction of generalised cost

After estimating the value of time from the SP model, a generalised cost variable is constructed for each alternative:

$$GC_{nj} = TC_{nj} + VoT \times TT_{nj}$$

where $GC_{nj}$is the generalised cost of alternative j for individual or trip n. This formulation expresses both travel cost and travel time in monetary terms and allows the model to represent the total perceived burden of each mode in a single variable. This is useful for the hybrid framework because the same generalised cost formulation can be applied to both SP observations and MND-derived trips. In the implemented workflow, generalised cost is computed for IAM, Bus, Car and Train, Ferry, and Plane. The code explicitly defines $GC_j = TC_j + VoT \times TT_j$, where the VoT comes from the SP preference-space estimation.

Step 3: SP-based IAM adoption model

The next step estimates an SP-based choice model in which the probability of selecting IAM is explained by the generalised cost of the alternatives together with selected socio-demographic and trip-purpose variables. Several model specifications were tested during the estimation process, including different combinations of socio-economic attributes, alternative-specific interactions, and utility structures. The tested variables included age, gender, income, and trip purpose. Different model formulations were also evaluated, including generic versus alternative-specific coefficients, alternative-specific interactions, and alternative-specific constants. The final specification was selected based on a combination of behavioural interpretability, model goodness-of-fit, and statistical robustness. In particular, only variables exhibiting theoretically consistent signs and statistically significant coefficients were retained in the final model. After testing multiple specifications, income and trip purpose emerged as the only socio-demographic variables that consistently showed both statistically significant effects and behaviourally meaningful signs and magnitudes across the estimated models. The inclusion of additional socio-demographic variables either resulted in statistically insignificant coefficients, unstable parameter estimates, incorrect behavioural signs, or deterioration in model performance. Consequently, the final specification retained only these two variables as sources of observed heterogeneity in IAM adoption propensity. The model specification used is:

Canary Islands:

© –2023– SESAR 3 JU

$$V_{IAM} = ASC_{IAM} + \beta_{GC} GC_{IAM}$$
$$V_{Ferry} = ASC_{Ferry} + \beta_{GC} GC_{Ferry}$$
$$V_{Car} = \beta_{GC} GC_{Car}$$
$$V_{Plane} = ASC_{Plane} + \beta_{GC} GC_{Plane}$$

Catalan Pyrenees:

$$V_{Bus} = ASC_{Bus} + \beta_{GC} GC_{Bus}$$
$$V_{IAM} = ASC_{IAM} + \beta_{GC} GC_{IAM} + \gamma_{IAM,inc} income + \gamma_{IAM,purp} purpose$$
$$V_{Car} = \beta_{GC} GC_{Car} + \gamma_{Car,inc} income + \gamma_{Car,purp} purpose$$
$$V_{Train} = ASC_{Train} + \beta_{GC} GC_{Train}$$

Car is used as the reference alternative, with its alternative-specific constant normalised to zero. The IAM utility includes interactions with income and trip purpose in order to capture heterogeneity in IAM adoption propensity. Car also includes income and purpose terms because road-based travel exists in both the SP and MND contexts. This specification reflects the assumption that IAM adoption is not determined only by travel time and cost, but also by user characteristics and trip context. The probability that individual $n$chooses alternative $j$is given by the standard MNL formula:

$$P_{nj} = \frac{exp\,(V_{nj})}{\sum_{k \in C_n} exp\,(V_{nk})}$$

where $C_n$is the available choice set for individual n. The SP model estimates the behavioural parameters that determine how changes in generalised cost, income and trip purpose affect the probability of choosing IAM relative to existing alternatives.

Step 4: MND-based calibration of existing modal shares

Because IAM is not yet operational, it is not directly observed in the MND. Consequently, MND cannot be used to estimate IAM-specific behavioural parameters. Instead, the role of MND in the hybrid framework is to calibrate the baseline modal structure among the existing transport alternatives before introducing IAM into the choice set. The initial SP-based mode choice model was estimated using the survey responses and therefore reproduced the modal shares observed within the SP sample. However, the market shares represented in the SP survey are not necessarily representative of the actual mobility patterns observed in the study region. In particular, SP surveys may overrepresent certain traveller groups, trip purposes, or behavioural preferences, leading to discrepancies between the estimated modal constants and the real-world market shares of the existing modes. To address this issue, a calibration procedure was introduced using the observed market shares derived from the MND. The objective of this calibration step is to adjust the alternative-specific constants (ASCs) of the existing transport modes so that the baseline mode choice model reproduces the actual market shares observed in the large-scale mobility data prior to the introduction of IAM. In other words, the calibration ensures that the mode choice model reflects the real-world modal distribution of the current transport system before evaluating future IAM scenarios. In the implemented workflow, the MND contains observations for the existing transport alternatives (Bus, Car, Train, Ferry, Plane), but naturally does not contain IAM observations. Therefore, the calibration process estimates correction terms for the existing alternatives while preserving the behavioural sensitivities estimated from the SP data. The calibrated utilities are expressed as:

Canary Islands:

© –2023– SESAR 3 JU

Co-funded by the European Union

$$V_{Ferry}^{MND} = (ASC_{Ferry} + \delta_{Ferry}) + \beta_{GC} GC_{Ferry}$$
$$V_{Car}^{MND} = \beta_{GC} GC_{Car}$$
$$V_{Plane}^{MND} = (ASC_{Plane} + \delta_{Plane}) + \beta_{GC} GC_{Plane}$$

Catalan Pyrenees:

$$V_{Bus}^{MND} = (ASC_{Bus} + \delta_{Bus}) + \beta_{GC} GC_{Bus}$$
$$V_{Car}^{MND} = \beta_{GC} GC_{Car} + \gamma_{Car,inc} income_z + \gamma_{Car,purp} purpose$$
$$V_{Train}^{MND} = (ASC_{Train} + \delta_{Train}) + \beta_{GC} GC_{Train}$$

where δ_{Bus}, δ_{Train}, δ_{Ferry} , and δ_{Plane} are calibration parameters estimated using the MND observations. These calibration terms modify the original SP-based constants so that the predicted modal shares of the existing alternatives match the observed market shares derived from the MND. This hybrid calibration strategy provides two important advantages. First, the SP survey supplies the behavioural responses to IAM attributes, including travel time, travel cost, and socio-demographic interactions, which are essential because IAM does not yet exist in the market. Second, the MND provides a realistic representation of the actual large-scale mobility market shares and observed travel demand patterns. By combining both sources, the final framework simultaneously captures (i) travellers' behavioural reactions to IAM and competing modes from the SP survey, and (ii) the real-world modal structure and demand distribution from big-data mobility observations. As a result, the calibrated hybrid model avoids relying solely on the modal shares embedded in the SP sample and instead anchors the future IAM modal shift estimation to the observed baseline transport market. This significantly improves the behavioural realism and policy relevance of the estimated IAM adoption scenarios.

Step 5: Hybrid modal shift estimation

Once the SP-based behavioural model and the MND-based calibration are combined, IAM is introduced into the calibrated baseline choice set as a future transport alternative through a scenario simulation framework. Since IAM is not yet operational, its service characteristics must first be defined through a set of operational and infrastructure assumptions. In particular, the introduction of IAM into the model requires inputs related to vertiport locations, access and egress conditions, IAM travel times, and IAM travel costs for passengers. These assumptions were defined for two reference years: 2035 and 2050. The 2035 scenario represents an earlier stage of IAM deployment, while the 2050 scenario represents a more mature, full implementation scenario in which IAM services are assumed to be more widely available and technologically advanced. This section presents the results of the 2050 scenario, which is considered the full implementation scenario for IAM. However, in other PRIAM deliverables, and particularly in the social cost-benefit analysis, the results of both the 2035 and 2050 scenarios are reported in order to assess the evolution of IAM impacts over time and to compare the implications of different implementation pathways.

For the 2050 scenario, the assumptions related to IAM travel time and travel cost were defined based on a combination of evidence from the literature and inputs collected from stakeholders during the PRIAM workshops. These assumptions are necessary because IAM services are not yet commercially available at scale, and therefore no observed market data exist for passenger fares, operational performance, or user behaviour under real operating conditions.

It is important to clarify that the IAM trip cost used in this analysis refers to the fare paid by passengers. For the 2050 scenario, this value is assumed to be €4 per kilometre. This should not be interpreted as

© –2023– SESAR 3 JU

the full operating cost borne by IAM operators. In reality, the total cost faced by operators is expected to be higher, particularly when vehicle acquisition, maintenance, charging infrastructure, vertiport operations, personnel, insurance, and regulatory compliance are taken into account. Therefore, the assumed passenger fare may only be achievable under specific market or policy conditions, for example through subsidies, public support mechanisms, high fleet utilisation, or significant cost reductions resulting from technological maturity. The assessment of whether such subsidies or financial support mechanisms would be feasible or desirable in the future is outside the scope of this study.

Several IAM fare levels were tested during the demand estimation process. The assumed fare of €4 per kilometre was selected because it provides the most balanced outcome in terms of potential demand and revenue. Lower fares would increase affordability but would reduce revenue per passenger and may not be financially viable. Higher fares, on the other hand, were found to substantially reduce demand, limiting the potential role of IAM in the regional transport system. The selected value should therefore be understood as a modelling assumption that reflects a plausible compromise between user willingness to pay and service revenue potential in a mature IAM market.

The main assumptions regarding IAM and eVTOL operations are summarised in the table below.

Table 40: IAM and eVTOL assumptions

Evtol parameter	2035 scenario	2050 scenario
Maximum wind	45 km/h	45 km/h
Minimum temperature	-5 °C	-5 °C
Maximum temperature	40 °C	40 °C
Seats	4	5
Battery	220 kWh	220 kWh
Cruise speed	160 km/h	270 km/h
Diameter	15 m	
IAM passenger trip cost	4 €/km	

Another key consideration in the implementation of IAM services is the location of vertiports. The attractiveness and feasibility of IAM strongly depend on the spatial distribution of vertiports, since these locations determine access and egress times, the geographical coverage of the service, and the extent to which IAM can be integrated with existing transport modes. To identify suitable vertiport locations in the case studies, a vertiport optimisation algorithm was applied. This optimisation process aimed to identify locations that maximise the potential usefulness of IAM while considering the specific spatial and transport characteristics of each case study area. Further details on the vertiport optimisation methodology and the generation of the selected locations are provided in the relevant section of this document. The figures below present the optimised vertiport locations used in the 2050 IAM implementation scenario.

© –2023– SESAR 3 JU

Co-funded by the European Union



Figure 40: Optimised selected vertiport locations in the Canary Islands

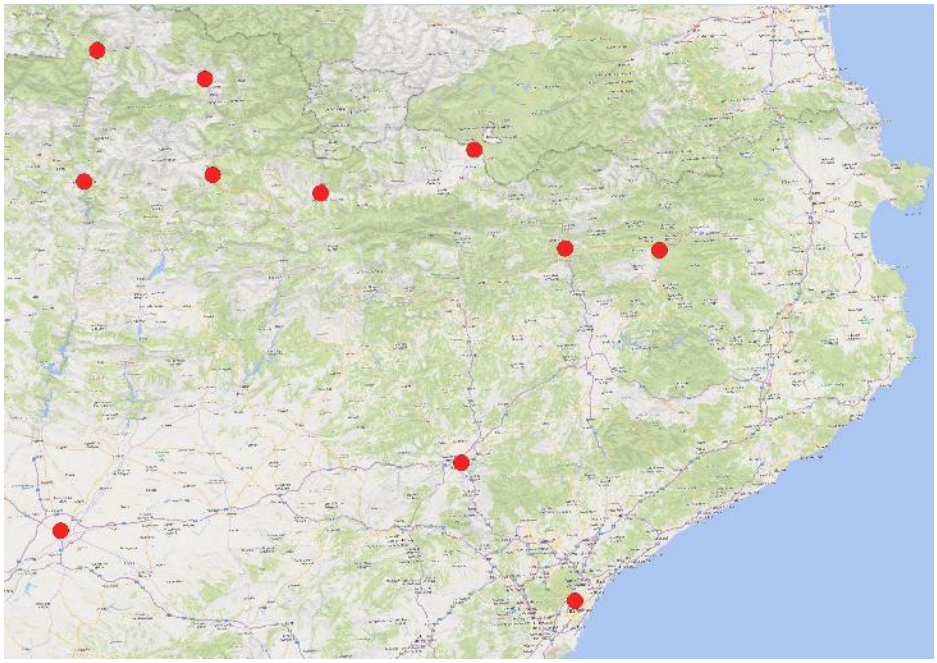


Figure 41: Optimised selected vertiport locations in Catalonia

For a full description of the optimisation method used for vertiport selection, please refer to section E.3.2.1, where the operational characteristics of the proposed IAM system are defined.

Based on these assumptions, the IAM attributes are integrated into the calibrated mode choice model together with the existing alternatives. For each observed MND-derived trip or origin–destination flow, the model computes the utility of IAM and the utilities of the existing modes using the same generalised cost framework. The calibrated model then estimates the probability of choosing each mode under the future IAM scenario. The expected number of trips shifting to IAM is computed by applying the IAM choice probability to the MND-derived demand flows:

$$D_{IAM,od} = P_{IAM,od} \times D_{od}$$

© –2023– SESAR 3 JU

where $D_{od}$is the observed demand between origin o and destination d, and $P_{IAM,od}$is the modelled probability of choosing IAM for that flow. The modal shift from each existing mode can be estimated by comparing baseline probabilities without IAM against future probabilities with IAM. In this way, the model does not simply estimate whether respondents like IAM in a survey; it estimates how much observed regional mobility demand could realistically be captured by IAM under specific service assumptions.

Step 6: Interpretation of modal shift results

The resulting modal shift estimates can be interpreted at several levels. At the individual or trip level, the model estimates the probability that a traveller chooses IAM instead of Bus, Car, Train, Ferry, Plane. At the OD-pair level, it estimates the expected number of trips captured by IAM. At the corridor or regional level, it estimates the change in modal shares caused by the introduction of IAM. This allows the analysis to identify whether IAM mainly attracts users from road transport, public transport, or rail, and under which service configurations IAM becomes competitive. The interpretation of the model should distinguish between behavioural sensitivity and market size. Behavioural sensitivity comes from the SP component and reflects how respondents react to changes in time, cost and user characteristics. Market size comes from the MND component and reflects how many trips currently exist in the relevant corridors. The value of the hybrid method is that modal shift is estimated as the product of these two dimensions: the willingness to switch and the number of trips that could potentially switch.

The main methodological contribution of this study is the integration of behavioural preference modelling with observed large-scale mobility flows. The SP survey provides the behavioural mechanism needed to model adoption of a non-existing IAM service, while MND provides the empirical baseline needed to scale those behavioural probabilities to real regional demand. This makes the approach more informative than using SP data alone, which may overrepresent hypothetical enthusiasm, and more forward-looking than using MND alone, which cannot observe future IAM choices. The hybrid framework is therefore suitable for estimating IAM modal shift in regional case studies where the new service is not yet operational but where detailed baseline mobility flows are available. It also provides a direct link between service design variables, such as travel time and fare, and policy-relevant outputs, such as demand captured by IAM, modal shift from existing modes, and potential induced demand.

4. Induced Demand Model

This section describes the methodology used to estimate induced demand from a MND-based trip distribution model. The purpose of the method is to estimate how many additional trips may be generated when the introduction of IAM reduces the generalised cost of travel between zones. Induced demand refers to new trips that would not have been undertaken in the absence of the new transport option ([30],[31]). In the context of IAM, induced demand captures journeys generated by the availability of a fast, direct, and novel mode of travel, rather than the diversion of trips from existing modes. The underlying assumption is that travel demand is sensitive to changes in generalised cost. When travel becomes faster, cheaper, or otherwise more attractive, some trips that were previously not made may become feasible or worthwhile. These additional trips are interpreted as induced demand. In this methodology, induced demand is not estimated through a full behavioural demand model, but through an aggregate cost-sensitivity relationship derived from observed MND trip patterns.

© –2023– SESAR 3 JU

The methodology follows a sequential approach. First, observed trips from MND are used to construct a relationship between trip frequency and generalised cost. Second, this relationship is estimated using a gravity-style exponential model. Third, the estimated model is applied to calculate the additional trips that may occur when IAM reduces generalised cost.

Step 1: Prepare MND

The analysis is based on MND comprising daily counts of observed trips between origin-destination pairs. Each record in the dataset represents the number of observed trips between an origin zone i and a destination zone j, disaggregated by trip purpose, income level, socio-demographic group, and reported travel mode. For each record, the following information is required: 1- observed number of trips between origin i and destination j, denoted by F_{ij}; 2- travel time between the two zones, denoted by t_{ij}; 3- monetary travel cost between the two zones, denoted by c_{ij}; 4- trip purpose, such as business or leisure; 5- income level, such as low, medium, or high; 6- reported or dominant travel mode in the dataset. This step creates the input dataset needed to estimate the relationship between travel demand and generalised cost.

Step 2: Assign the value of time

The value of time is used to convert travel time into a monetary equivalent. Instead of applying a single value of time to all trips, this methodology uses different values of time according to trip purpose and income level. The values used in the model are shown below. These values are estimated by fitting a discrete choice model on the MND.

Table 41. MND Value of Time

Purpose	Income level	Value of time
Business	low	17.6 €/h
Business	medium	18.2 €/h
Business	high	49.6 €/h
Leisure	all	15.6 €/h

For business trips, different values of time are used for low-, medium-, and high-income travellers. For leisure trips, the same value of time is applied to all income groups. This distinction is important because the same travel time saving does not have the same monetary value for all trip types. For example, a reduction of 30 minutes has a larger impact on generalised cost for high-income business trips than for leisure trips, because the assigned value of time is higher.

Step 3: Calculate the baseline generalised cost

For each record in the MND, a baseline generalised cost is calculated. The generalised cost combines the monetary travel cost and the monetised travel time.

The baseline generalised cost is calculated as:

$$C_{ij}^{p,q} = c_{ij} + VOT^{p,q} \times t_{ij}$$

where: $C_{ij}^{p,q}$ is the generalised cost between origin $i$and destination j for trip purpose p and income level q; c_{ij} is the monetary travel cost, including out-of-pocket costs such as fares or fuel costs; t_{ij} is the travel time between origin $i$and destination j; $VOT^{p,q}$ is the value of time associated with trip

© –2023– SESAR 3 JU

purpose $p$and income level q. This step produces one baseline generalised cost value for each record in the dataset. The result is a dataset in which each observed flow F_{ij} is associated with a corresponding generalised cost $C_{ij}^{p,q}$.

VISSIM transport simulation outputs were used as part of the transport performance input data, particularly for estimating or validating travel-time indicators used in the generalised cost calculation.

Step 4: Group trips into generalised cost bins

After calculating the generalised cost for each record, the records are grouped into generalised cost bins. This is done because individual MND records can be noisy, especially when some origin-destination pairs have small observed trip counts. Binning reduces this noise and allows the model to capture the average relationship between generalised cost and trip frequency. In this methodology, only records with a generalised cost greater than €10 are used for the estimation. This threshold is applied to avoid very short or very low-cost trips, which may follow a different behavioural pattern and could distort the estimation. The remaining records are grouped into €5 generalised cost intervals. For each bin, the observed trip counts are aggregated. A representative generalised cost is then assigned to the bin, for example using the midpoint or average generalised cost of the records within that bin. The output of this step is a binned dataset where each observation represents: 1- a generalised cost range; 2- the representative generalised cost of that range; 3- the total number of observed trips within that range. This binned dataset is then used to estimate the trip distribution model.

Step 5: Estimate the trip distribution model

The relationship between trip frequency and generalised cost is estimated using a gravity-style exponential impedance function:

$$F = \alpha \exp(-\beta C)$$

where: F is the observed trip frequency in a given generalised cost bin; C is the representative generalised cost of that bin; α is a scale parameter; β is the cost-sensitivity parameter. The parameter β is particularly important because it determines how strongly trip demand responds to changes in generalised cost. A larger β indicates that demand decreases more sharply as generalised cost increases. A smaller β indicates that demand is less sensitive to changes in generalised cost.

Step 6: Calculate the post-IAM generalised cost

The next step is to calculate the generalised cost after the introduction of IAM. IAM may reduce the generalised cost between zones by reducing travel time, monetary cost, or both. For each relevant MND record, the post-IAM generalised cost is calculated as:

$$C_{ij}^{\prime p,q} = c_{ij}^{\prime} + VOT^{p,q} \times t_{ij}^{\prime}$$

where: $C_{ij}^{\prime p,q}$ is the post-IAM generalised cost; $c_{ij}^{\prime}$ is the post-IAM monetary travel cost; $t_{ij}^{\prime}$ is the post-IAM travel time; $VOT^{p,q}$ is the same value of time used in the baseline generalised cost calculation. The reduction in generalised cost is then calculated as:

$$\Delta C_{ij}^{p,q} = C_{ij}^{p,q} - C_{ij}^{\prime p,q}$$

© –2023– SESAR 3 JU

Co-funded by the European Union

If $\Delta C_{ij}^{p,q} > 0$, IAM reduces the generalised cost and induced demand may occur. If $\Delta C_{ij}^{p,q} \leq 0$, no induced demand is assumed for that record.

Step 7: Convert the generalised cost reduction into a proportional demand increase

The estimated exponential model is then used to convert the reduction in generalised cost into a proportional increase in trips. The baseline model is:

$$F = \alpha \exp(-\beta C)$$

After IAM is introduced, the new trip frequency becomes:

$$F' = \alpha \exp[-\beta(C - \Delta C)]$$

This can be rearranged as:

$$F' = F \exp(\beta \Delta C)$$

Therefore, the proportional increase in demand is:

$$\%\Delta = \exp(\beta \Delta C) - 1$$

This equation means that the percentage increase in demand depends on the estimated cost-sensitivity parameter $\beta$and the size of the generalised cost reduction ΔC. A larger reduction in generalised cost produces a larger proportional increase in demand. Similarly, if the estimated value of β is higher, demand responds more strongly to the same cost reduction.

Step 8: Calculate induced demand for each record

The proportional increase is then applied to the observed number of trips in each MND record. For each record, induced demand is calculated as:

$$\Delta F_{ij} = F_{ij} \times [\exp(\beta \Delta C_{ij}^{p,q}) - 1]$$

where: ΔF_{ij} is the number of induced trips between origin $i$and destination j; F_{ij} is the observed baseline number of trips; β is the estimated cost-sensitivity parameter; $\Delta C_{ij}^{p,q}$ is the reduction in generalised cost after the introduction of IAM. This step produces an estimate of induced demand for each origin-destination pair and traveller segment in the MND.

Validation results

Survey-Based Results: Willingness to use IAM

We provide an analysis of the mode choice behaviour of respondents based directly on the stated preference survey responses. This preliminary descriptive analysis offers valuable insights into how participants perceive and select between different travel options, including the potential introduction of IAM services. To understand the potential adoption of IAM services, respondents were asked, after a brief explanation about IAM, *"How likely are you to use air taxis in the future?",* with answers recorded on a five-point Likert scale ranging from 1 (*"not likely at all"*) to 5 (*"extremely likely"*). The analysis of these responses provides a preliminary descriptive insight into people's general willingness to use IAM and helps to identify the characteristics of individuals who are more open to adopting this new transport mode.

A feature importance analysis using Random Forest classifier has been done in order to identify the most influential factors associated with respondents' willingness to adopt IAM services. Feature importance analysis quantifies the relative influence of each predictor variable on the model's

© –2023– SESAR 3 JU

predictions. A higher feature importance score indicates that the variable is frequently used in decision splits and contributes substantially to reducing prediction error. Unlike regression coefficients, feature importance does not indicate the direction of the effect (positive or negative), but rather the strength of each feature's predictive power. Random Forest is an ensemble learning method that combines multiple decision trees to improve predictive accuracy and reduce overfitting. Before model training, all categorical variables (e.g. age, gender, income, IAM familiarity, IAM knowledge) were converted into numerical form using label encoding to ensure compatibility with the algorithm. The Random Forest model was trained with 300 decision trees, and feature importance scores were derived based on the mean decrease in Gini impurity criterion, which measures how much each variable reduces prediction uncertainty across the trees. The resulting feature importance values were normalized to sum to one and ranked to show each variable's relative contribution to predicting the willingness to IAM adoption.

The results of the feature importance analysis using a Random Forest model (Figure 42) revealed which variables most strongly contribute to predicting IAM adoption willingness. This method does not indicate the direction (positive or negative) of influence, but it identifies which variables are most useful for prediction. The top three most important features were: 1-Income, 2- Age, 3-IAM familiarity. Other factors, like gender and car ownership were less important prediction of IAM willingness However, because feature importance analysis only ranks the strength of predictors, not how each factor affects adoption, we further analysed and visualized the average IAM willingness across different income groups, age groups, and familiarity levels to interpret the direction and shape of their effects.

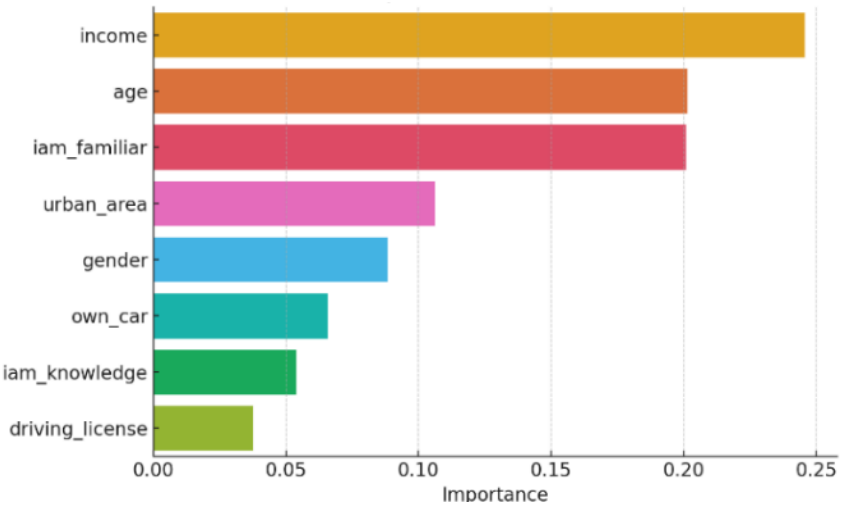


Figure 42. Feature importance for willingness to use IAM

Figure 43 shows how the willingness to adoption IAM across the most relevant socio-demographic characteristic: income (a), age group (b) and familiarity with IAM (c). Figure 43a shows that the willingness to adopt IAM decreases with increasing income. Respondents earning €15–25k reported the highest willingness (3.44), while those earning over €60k had the lowest (2.56). This suggests IAM services may appeal more to lower-income individuals. Regarding age (Figure 43b), the highest willingness to IAM adoption is observed among respondents aged 25–54. Both younger (<25) and, especially, older (55+) groups show slightly lower interest. This indicates a stronger adoption potential among working-age population. Additionally, a strong positive association exists between IAM familiarity and adoption willingness (Figure 43c). Average scores increase from 2.76 among those not

© –2023– SESAR 3 JU

Co-funded by the European Union

familiar at all to 3.85 for the extremely familiar group. This underscores the importance of awareness and information campaigns to boost adoption.

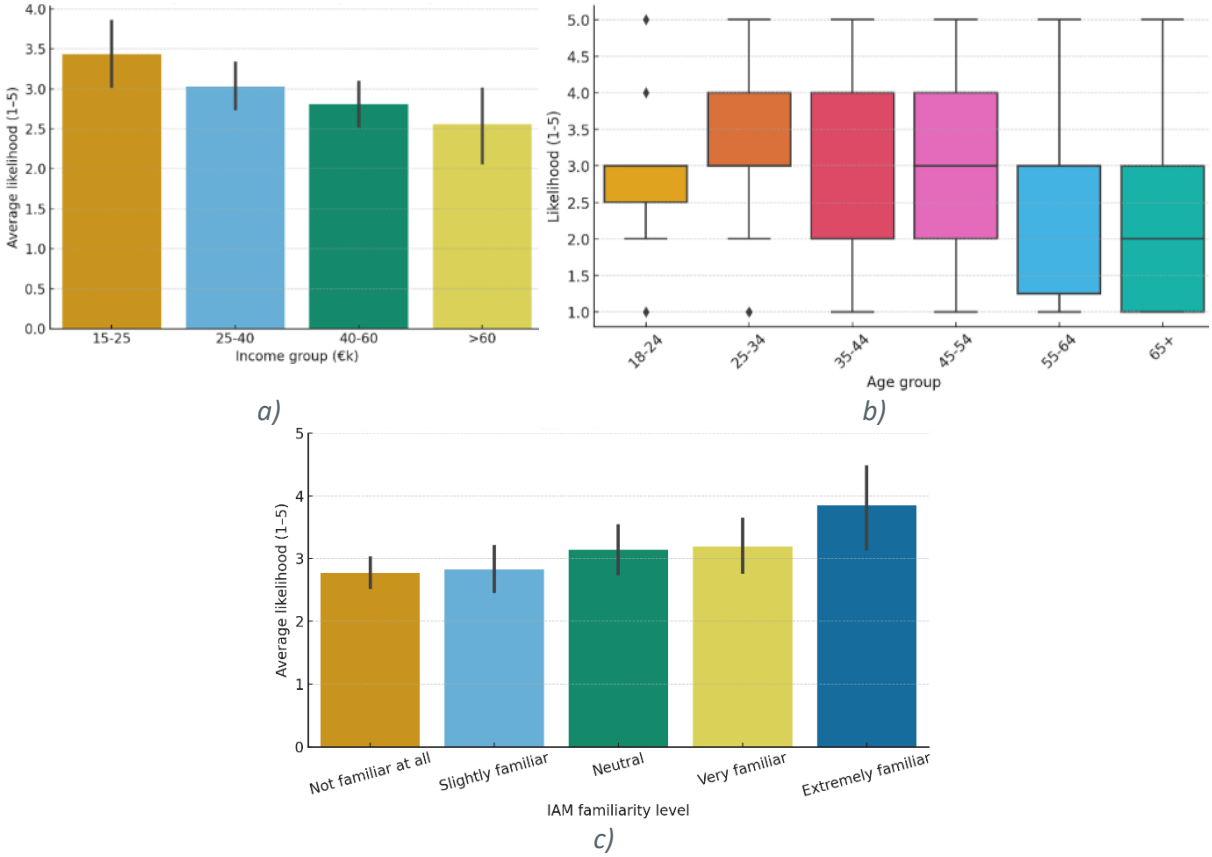


Figure 43. IAM willingness to adopt IAM by income (a), age (b) and IAM familiarity (c)

The analysis of the willingness to adopt IAM per income may initially seem counterintuitive. To further investigate this behaviour, an additional analysis was conducted to examine the correlation between income and other relevant factors. Figure 44 illustrates the correlation between the age of respondents and their income. The results show that higher income levels are more strongly associated with older individuals. In particular, incomes above €60k are predominantly reported by respondents over the age of 45, whereas younger respondents tend to report lower income levels. These patterns suggest a correlation between age and income, which may help to explain the behaviour observed in Figure 43a.

© –2023– SESAR 3 JU

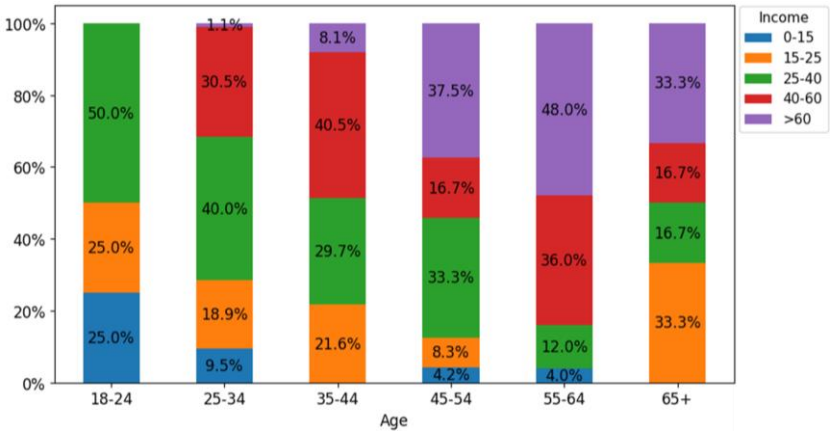


Figure 44. Income per age group

Overall, these results suggest that respondents' economic status, demographic profile, and awareness of IAM services are the strongest correlates of their willingness to adopt these services. Other factors such as living in urban areas, gender, and car ownership contributed less to the prediction and were therefore considered secondary. Hence, informational campaigns and exposure to IAM concepts could significantly increase willingness to adopt these services, potentially more than demographic targeting alone.

These findings are key to the development and validation of the discrete choice model, as they shed light on the importance of different passenger characteristics in explaining passenger behaviour when adopting IAM services.

Survey Based Results: Modal shift

As mentioned, respondents were presented with a set of hypothetical travel scenarios in two case study regions: the Canary Islands and the Catalan Pyrenees. Each scenario described a specific trip, its current travel options along with their travel time and cost, and a new future option including IAM services. For each scenario, respondents first selected their preferred current travel mode, and then indicated their future choice assuming IAM services were available. This design allowed us to examine how mode shares change with the introduction of IAM and to quantify the extent of modal shift from existing transport modes to air taxis. Below, we present the scenarios that were shown to the participants. Following each scenario, we display the results of the survey (current and future mode shares), illustrating how travel behaviour changes when IAM services are available. To illustrate this modal shift, Sankey diagrams are used, where the left side of the Sankey diagram represents the current modal share, while the right side shows the future modal share based on the hypothetical scenarios presented to the respondents. The values are expressed as percentages, so the totals on each side add up to 100.

It should be noted that although this questionnaire, as mentioned in the previous section, includes various IAM travel time and cost scenarios for each origin–destination pair, for the sake of simplicity we present here the aggregated results for the modal shift.

The first scenario considers travel between an unspecified location in southern Tenerife and San Sebastián de La Gomera. Passengers currently have two main options: either travel north to TFN, take a flight to GMZ, and then continue by ground transport to San Sebastián; or travel south to Los Cristianos and take a direct ferry to San Sebastián de La Gomera. The origin and destination for this

© –2023– SESAR 3 JU

scenario are and projected modal shares, based on aggregated survey results, are illustrated in Figure 45.

As presented, most of the projected demand for IAM comes from passengers who initially indicated that they would have travelled by ferry. Although the absolute number of passengers shifting from air travel appears relatively small, the relative effect is significant: 75% of those who originally stated that they would travel by plane opted instead for IAM. Given the limited sample size of air travellers, it is difficult to determine whether these results are consistent or potentially biased. Nevertheless, this behaviour is noteworthy and provides valuable insights for the case study analysis.

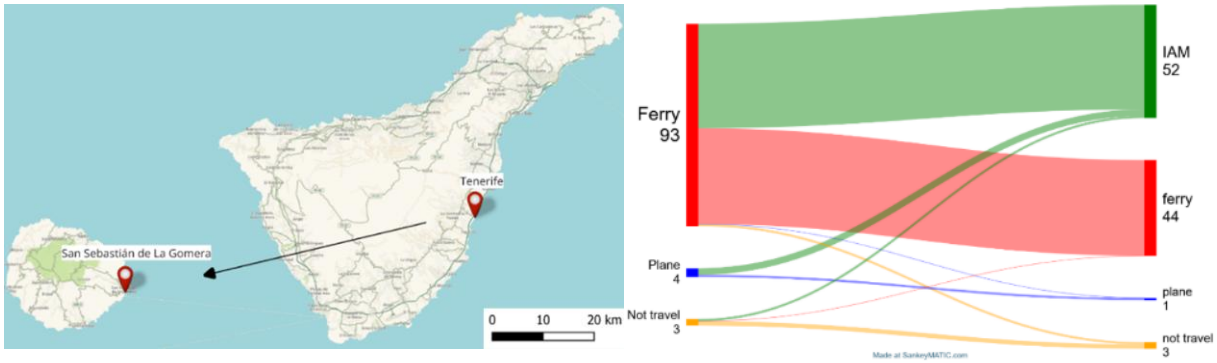


Figure 45. Scenario 1: South of Tenerife to San Sebastián de la Gomera (~70 km)

Scenario 2 considers travel between La Gomera Airport and San Sebastián de La Gomera (Figure 46). Although the straight-line distance is only 12 km, the island's orography makes ground transportation take more than 50 minutes. Passengers currently have two main options: travel directly by taxi to San Sebastián, or reach the coast, either by taxi or on foot, and then take a direct ferry to San Sebastián. As presented, in this scenario most of the demand captured by IAM originates from taxi users, with a smaller share coming from ferry passengers. This suggests that IAM could become a competitive alternative to taxis in this scenario.

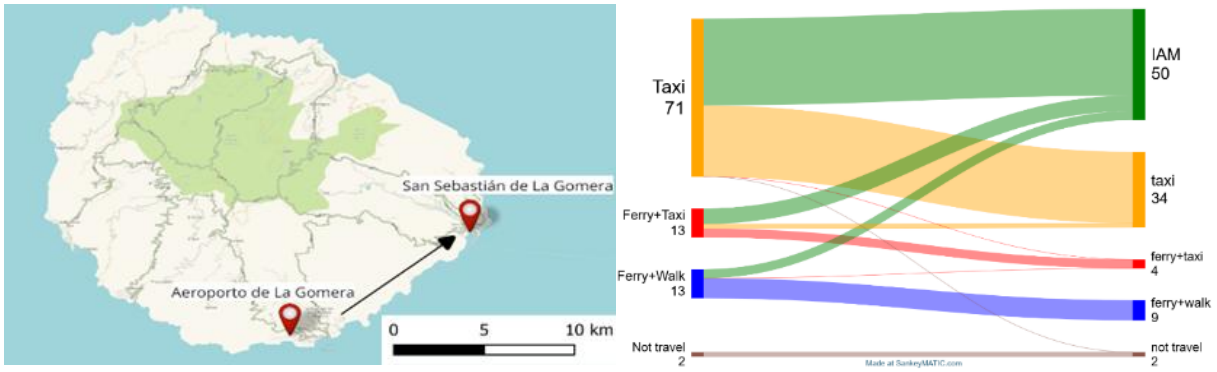


Figure 46. Scenario 2: Intra-Gomera

Scenario 3 analyses travel between La Seu d'Urgell Airport and Andorra (Figure 47) where the available options are limited to ground transportation either by bus or taxi. As presented, most of the potential IAM demand originates from taxi users. However, in relative terms the difference is less pronounced, with 31% of taxi users and 27% of bus users shifting to IAM.

© –2023– SESAR 3 JU

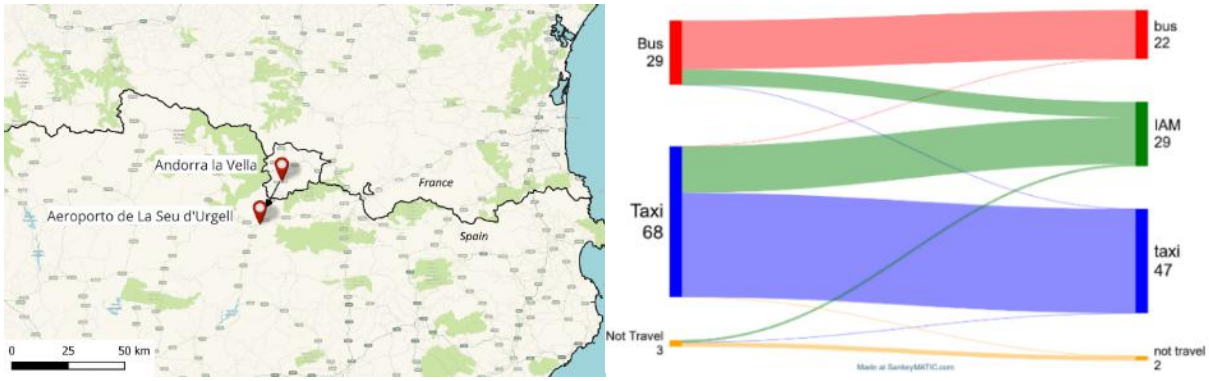


Figure 47. Scenario 3: Andorra la Vella to the airport of La Seu d'Urgell (22 km)

Scenario 4 involves long-distance travel from Puigcerdà to Barcelona (Figure 48), where the available options are limited to ground transportation either by bus, train or taxi. Travel times range from about 2 hours by car to around 3 hours by bus or train. As illustrated, initially, most travellers choose the train (76%) as their mode of transport. However, with the introduction of IAM, it is expected to decrease to 59%. Most future IAM users are likely to come from current train users, probably because IAM offers a shorter travel time at a reasonably higher price compared with the train.

It is interesting to remark that, unlike in the rest of scenarios, this case shows a substantial amount of induced demand, as almost half of respondents who initially declared they would not make the trip indicated they would do so if IAM services were available.

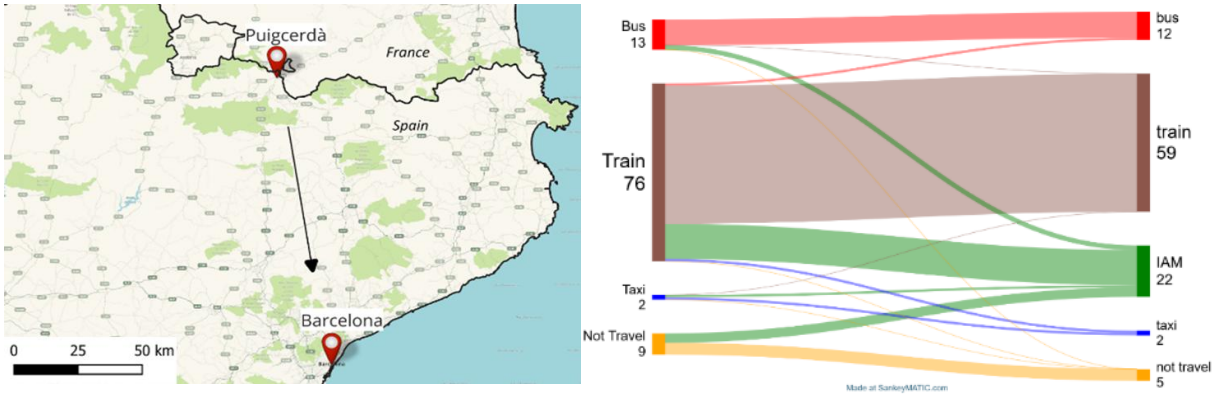


Figure 48. Scenario 4: Puigcerdà to Barcelona (118km)

Finally, Scenario 5 considers travelling from Lleida to Andorra (Figure 49), where the available options are limited to ground transportation either by bus or taxi. As presented in Figure 15, most demand originates from bus passengers, while taxi use is almost negligible due to the high cost of long-distance travel. In relative terms, all taxi users shifted to IAM, likely due to similar or lower prices and significantly reduced travel times. Additionally, also some induced demand seems to emerge in this scenario.

© –2023– SESAR 3 JU

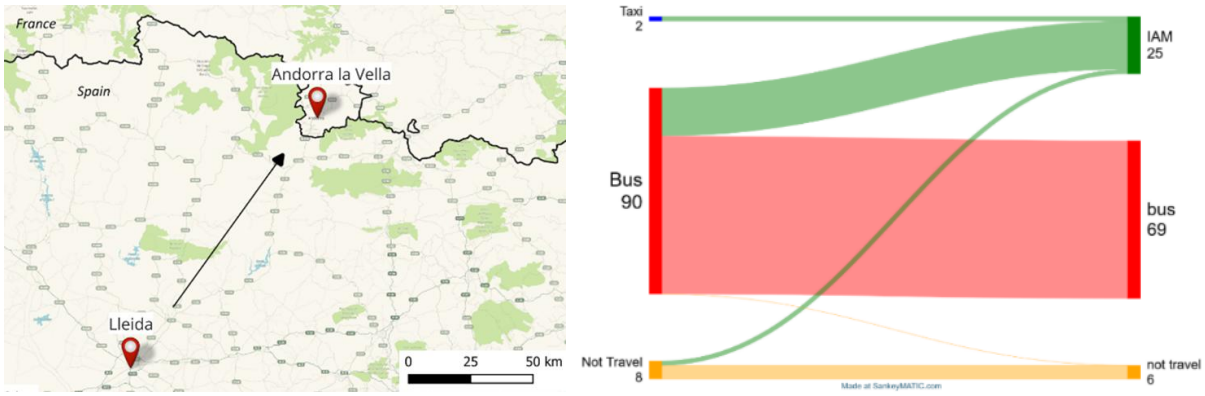


Figure 49. Scenario 5: Lleida to Andorra la Vella (124km)

This study provides valuable insights into the potential adoption and modal shift behaviour associated with IAM services in two European case study regions. By combining revealed and stated preference data, the survey captured both current travel behaviours and future choices under hypothetical IAM scenarios.

The modal shift results highlight the competing modes for IAM, the potential market share of air taxis in each scenario, and the degree to which IAM might reshape regional travel behaviour. It also provides valuable input for later model development to estimate behavioural parameters and evaluate IAM's impact on transport systems. The results revealed that IAM has significant potential to attract users from existing modes, particularly ferries and taxis in the Canary Islands scenarios and trains in the Catalan Pyrenees scenario. For instance, Figure 45 and Figure 46, illustrate that ferry and taxi users are the most likely to switch to IAM, indicating that IAM could serve as a competitive alternative to these modes, especially in regions with limited connectivity. In longer-distance scenarios such as Puigcerdà to Barcelona (Figure 48), IAM is expected to draw a considerable share from current train users, highlighting the importance of travel time savings in influencing mode choice. Similarly, Figure 49 shows that IAM can capture a substantial share of bus users in certain routes and replace taxis almost entirely. This finding is environmentally relevant, as it seems that IAM could replace most taxi trips (the mode contributing most to emissions and congestion) in certain scenarios, although the small sample of taxi users limits the certainty of this conclusion.

Discrete Choice Model Results

In this section, the results of the discrete choice model estimations, together with their validation results, are presented. The model is validated using both statistical and behavioural checks. For the SP component, the signs and magnitudes of the estimated parameters should be checked against theoretical expectations. Travel time and travel cost coefficients are expected to be negative, indicating that longer and more expensive trips reduce utility. The model fit can be assessed using the final log-likelihood, likelihood ratio statistics, rho-square and information criteria. The results of the validation indicators are provided below.

Canary Islands: After estimating behavioural parameters from the survey and recalibrating alternative-specific constants using MND training dataset, the final utility functions are:

$$V_{IAM} = 1.668 - 0.0336 \cdot GC_{IAM}$$
$$V_{Ferry} = -0.670 - 0.0336 \cdot GC_{Ferry}$$
$$V_{Car} = -0.0336 \cdot GC_{Car}$$
$$V_{Plane} = -3.538 - 0.0336 \cdot GC_{Plane}$$

© –2023– SESAR 3 JU

where:

$$GC_{IAM} = TC_{IAM} + 163.73 \cdot TT_{IAM}$$
$$GC_{other} = TC + 39.11 \cdot TT$$

Table 42 presents the final calibrated parameter estimates with robust standard errors.

Table 42. Discrete Choice model results for Canary Islands

Parameter	Estimate	Robust SE	t-stat	p-value
ASC_IAM	1.668	0.227	7.36	0.000
ASC_Ferry	-0.851	0.144	-5.89	0.000
ASC_Plane	-2.10	0.394	-5.345	0.000
β_GC	-0.0336	0.0036	-9.42	0.000
δ_Ferry	0.181	0.168	1.08	0.281
δ_Plane	-1.431	0.428	-3.34	0.000
Log-likelihood (final): −2,911.04 Log-likelihood (null): −7,703.20 McFadden ρ^2= 0.622 Adjusted ρ^2= 0.621 AIC = 5,834.07 BIC = 5,869.23				

The relatively high ρ^2 indicates strong explanatory performance for a discrete choice model combining behavioural and large-scale OD data. The negative and highly significant generalised cost coefficient confirms robust sensitivity to time–cost trade-offs. The calibration step primarily adjusts the attractiveness of Plane, while Ferry requires only minor correction.

After calibrating the discrete choice model, the calibrated model was applied to the full OD matrix using MND test dataset for simulation. Figure 50 and Figure 51 compares observed and predicted weighted modal shares for different O-D pairs in Canary Islands case.

© –2023– SESAR 3 JU

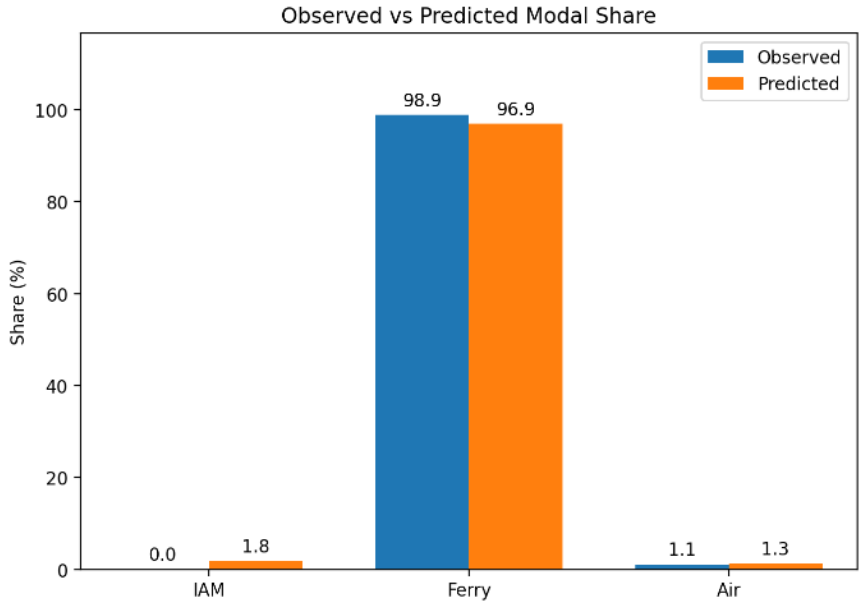


Figure 50. Observed vs Predicted Modal share: Tenerife to San Sebastián de la Gomera

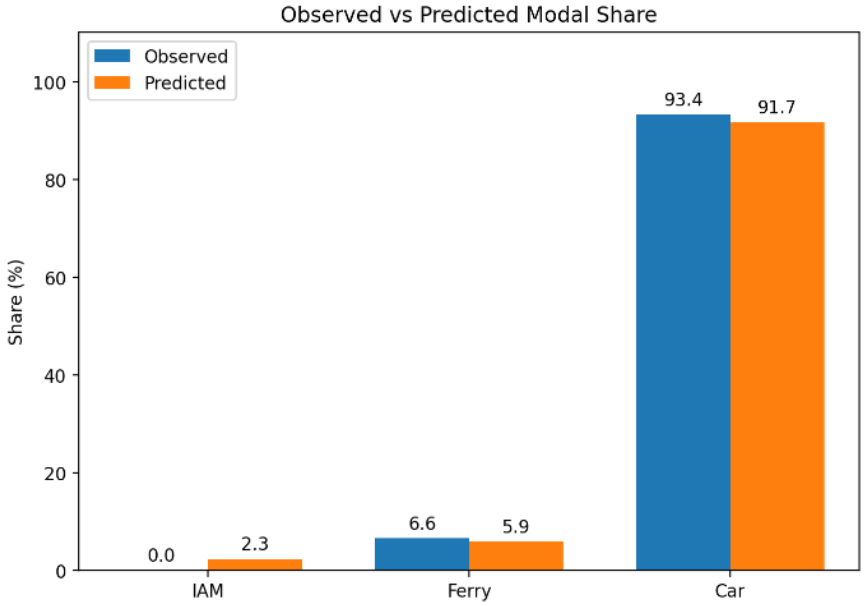


Figure 51. Observed vs Predicted Modal share: Intra-Gomera

In the IAM implementation scenario, IAM captures approximately 1.8% of total demand between Tenerife and La Gomera and 2.3% of trips within Gomera, across all OD flows. The largest reduction occurs in car usage, followed by a modest redistribution from ferry. Plane demand remains relatively small but increases slightly in some corridors due to network-wide rebalancing effects. To illustrate this, it is important to identify the original modes of transport used by potential IAM users. Therefore, the figures below present a Sankey diagram showing the source modes from which travellers switch to IAM when the service is available.

© –2023– SESAR 3 JU



Figure 52. Sources of Predicted IAM Users by Original Mode (Tenerife to San Sebastián de la Gomera)

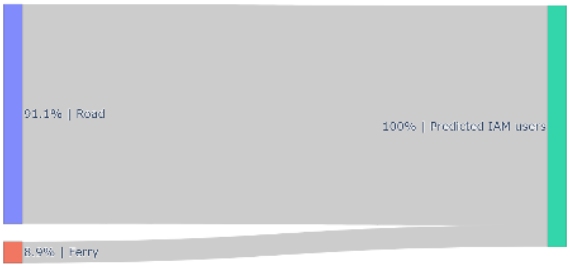


Figure 53. Sources of Predicted IAM Users by Original Mode (Intra-Gomera)

In addition, OD-level trips were visualised for the 70% most frequent trips in both observed and predicted records in order to see the spatial impacts of the presence of IAM.

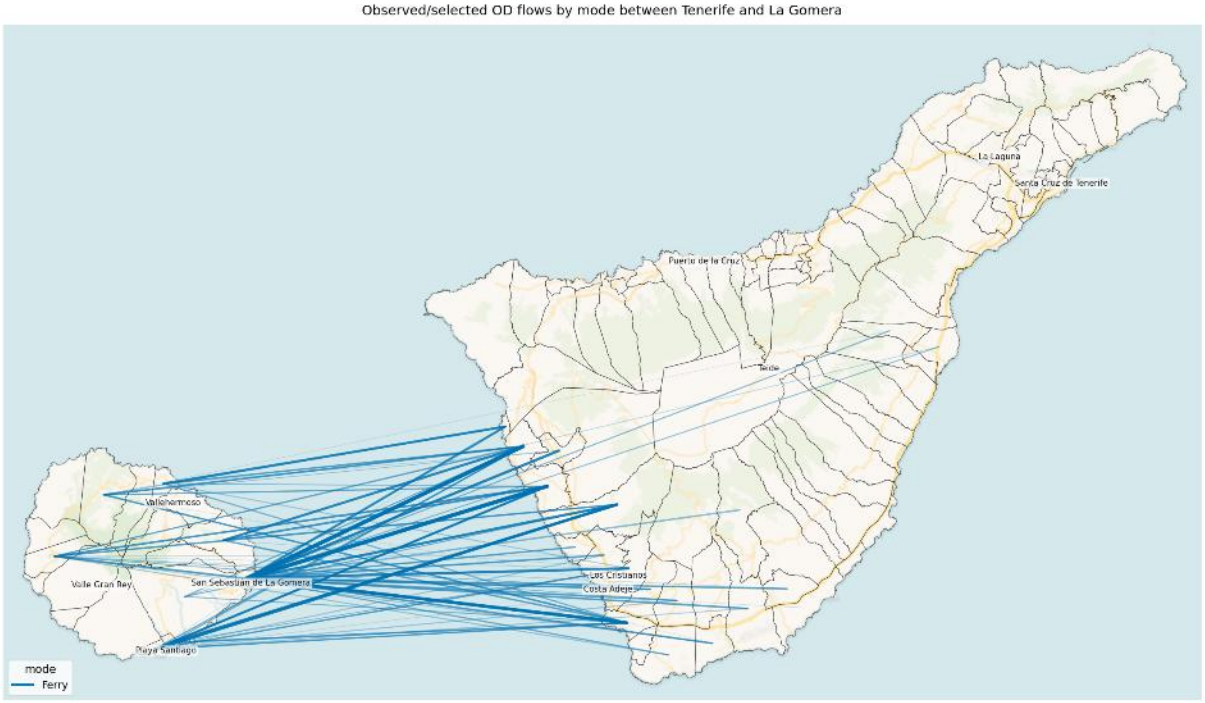


Figure 54. OD flows (observation) for Tenerife to San Sebastián de la Gomera

© –2023– SESAR 3 JU

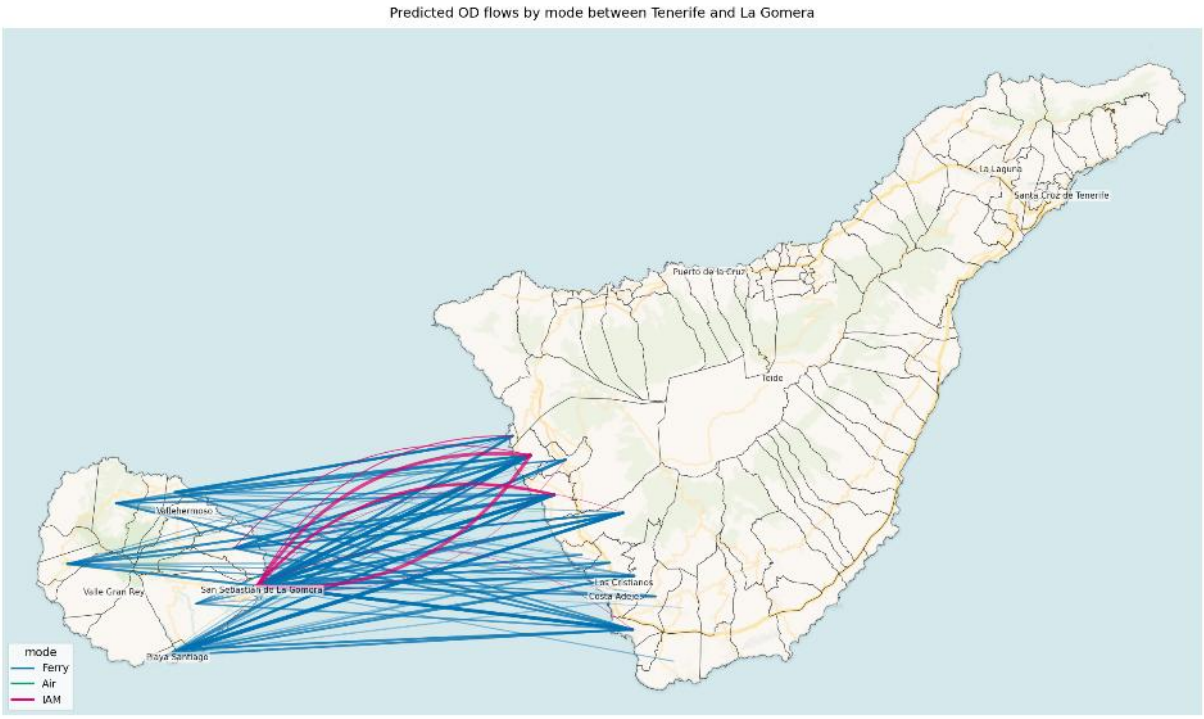


Figure 55. OD flows (prediction) for Tenerife to San Sebastián de la Gomera

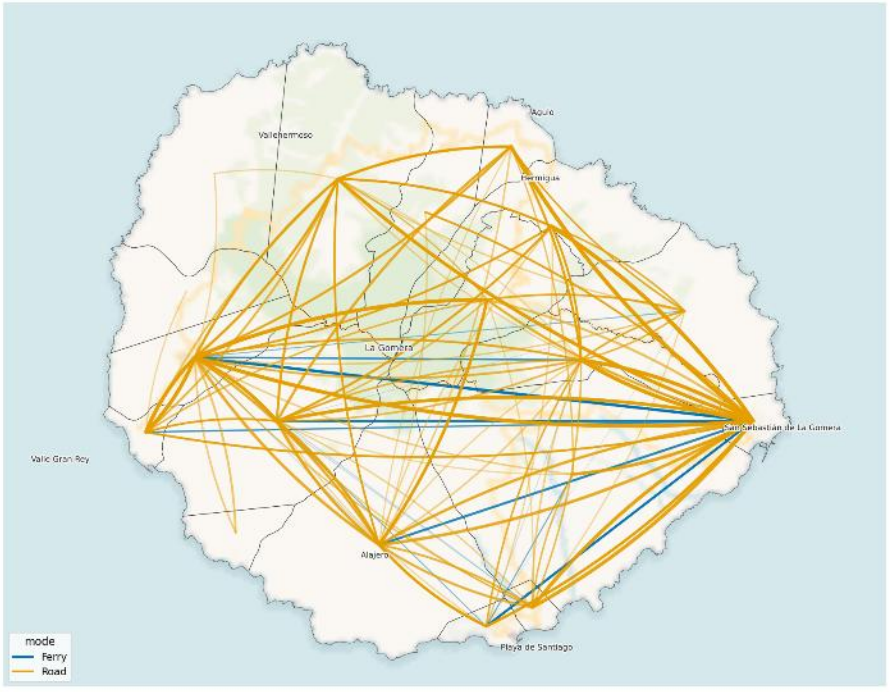


Figure 56. OD flows (observation) for La Gomera airport to San Sebastián de la Gomera

© –2023– SESAR 3 JU

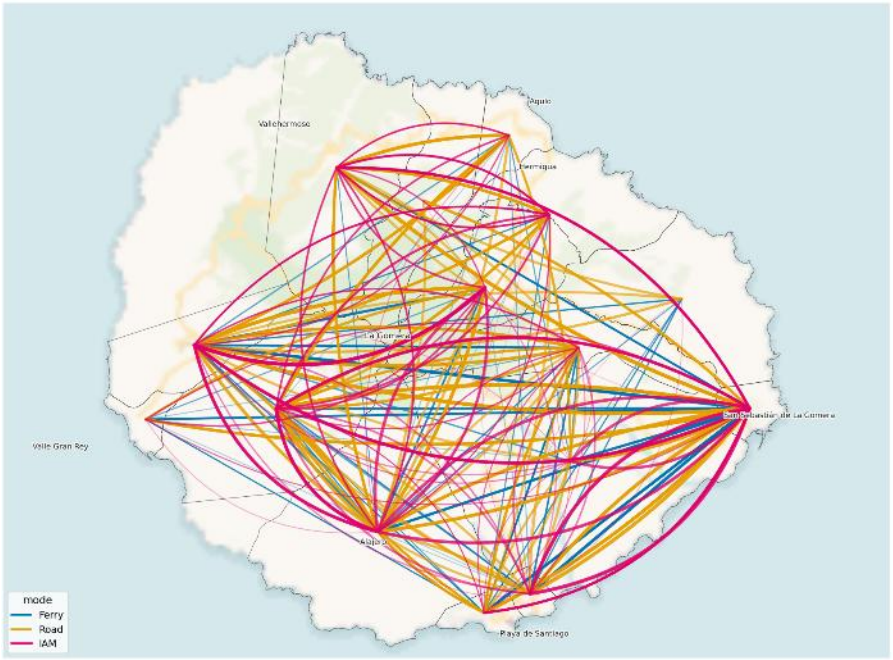


Figure 57. OD flows (prediction) for La Gomera airport to San Sebastián de la Gomera

Catalan Pyrenees:

The results of the parameter estimation for the discrete choice model for the Catalan Pyrenees, together with the goodness-of-fit indicators and the p-values of the estimated parameters, are presented below. As can be observed, the rho-squared (ρ^2) value of the model is relatively high, indicating that the model provides a good representation of the survey and MND data. In addition, all estimated variables are statistically significant, and both the magnitude and the sign of the parameters are consistent with theoretical expectations.

$$V_{Bus} = -1.18 - 0.014GC_{Bus}$$

$$V_{IAM} = -0.35 - 0.014GC_{IAM} + 0.3\ income - 0.7\ purpose$$
$$V_{Car} = -0.014GC_{Car} + 0.2\ income - 0.6\ purpose$$

$$V_{Train} = 0.64 - 0.014GC_{Train}$$

Table 43. Discrete Choice model results for Catalan Pyrenees

Parameter	Estimate	Robust SE	t-stat	p-value
ASC_IAM	-0.353	0.170	-2.075	0.038
ASC_Bus	1.355	0.199	6.814	0.000
ASC_Train	3.169	0.238	13.335	0.000
$\gamma_{IAM\ Income}$	0.300	0.106	2.826	0.005
$\gamma_{IAM\ Purpose}$	-0.762	0.218	-3.497	0.000
$\gamma_{Car\ Income}$	0.272	0.115	2.362	0.018
$\gamma_{Car\ Purpose}$	-0.694	0.228	-3.041	0.002

© –2023– SESAR 3 JU

Parameter	Estimate	Robust SE	t-stat	p-value
β_GC	-0.014	0.001	-15.458	0.000
δ_Bus	-2.540	0.084	-30.139	0.000
δ_Train	-2.520	0.042	-59.741	0.000
Log-likelihood (final): -12102.559 Log-likelihood (null): -34410.626 McFadden ρ^2= 0.648 Adjusted ρ^2= 0.648 AIC = 24225.118 BIC = 24298.104				

Similar to the Canary Islands case, for the Catalan Pyrenees case, the calibrated discrete choice model was applied to the full OD matrix using the MND test dataset for simulation purposes. The objective was to compare the observed modal shares with the shares predicted by the calibrated model under the baseline scenario.

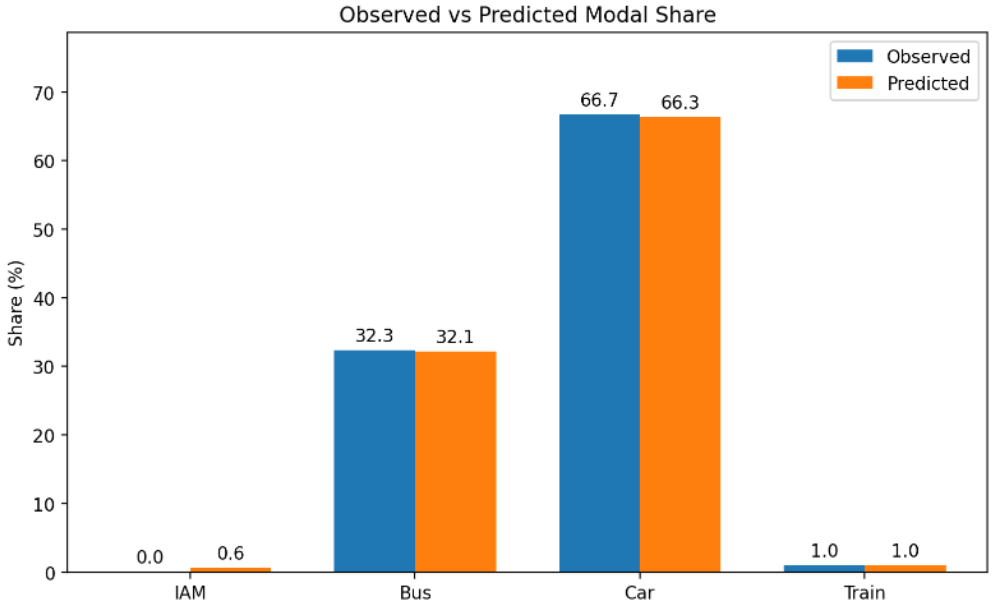


Figure 58. Observed vs Predicted Modal share: intra-Pyrenees

© –2023– SESAR 3 JU

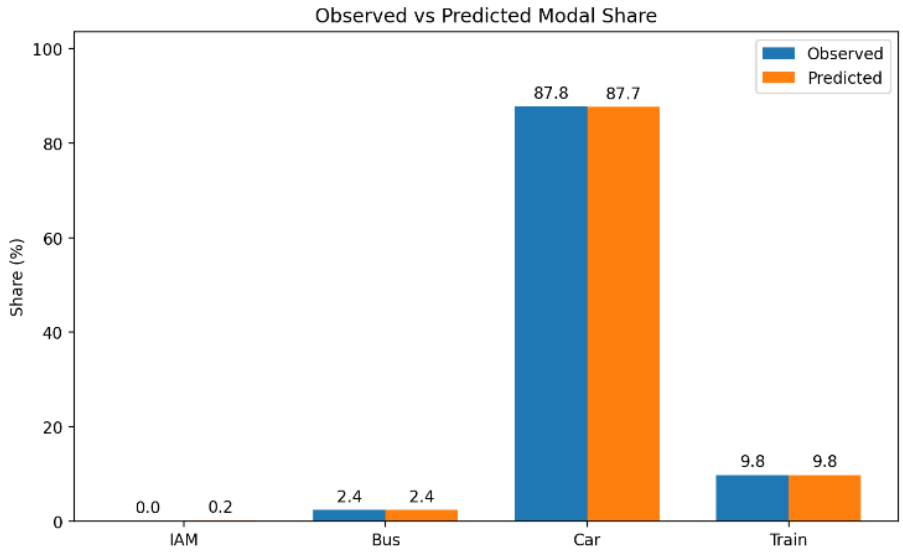


Figure 59. Observed vs Predicted Modal share: Puigcerdà to Barcelona

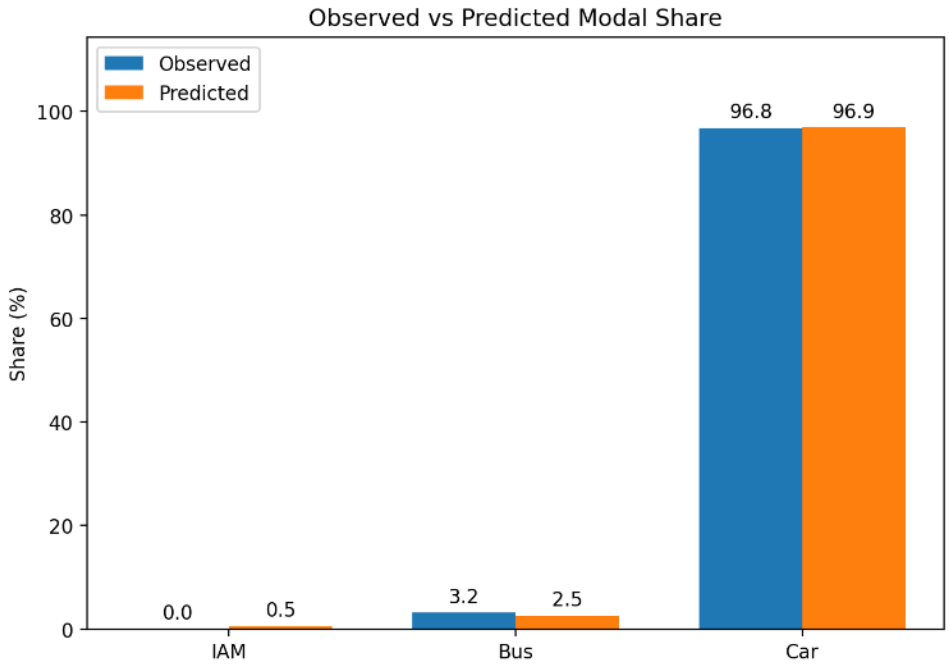


Figure 60. Observed vs Predicted Modal share: Lleida to Pyrenees

Another objective was to estimate the potential future share of IAM under IAM implementation scenario. Figure 58 to Figure 60 presents the comparison between observed and predicted weighted modal shares for different OD-pares in Catalan Pyrenees case.

In the IAM implementation scenario, IAM is estimated to capture approximately 0.6%, 0.2%, and 0.5% of the total travel demand in the Intra-Pyrenees, Puigcerdà–Barcelona, and Lleida–Pyrenees case studies, respectively. These results are based on the optimised vertiport locations identified within the study, together with the assumptions adopted regarding IAM travel times, access and egress times, waiting times, and travel costs. The results indicate that, under the analysed conditions, IAM captures

© –2023– SESAR 3 JU

between 0.2% and 0.6% of the overall travel demand. In other words, the total travel demand for IAM, across all OD pairs, is estimated at 140,300 IAM trips, out of a total of 29,236,142 trips in the Catalonia case study area. This relatively limited market share suggests that IAM is unlikely to function as a mass transportation mode in these regions. Instead, it is more likely to serve as a complementary or supplementary transport option, targeting specific market segments that place a high value on travel time savings and service quality. A comparison of the three case studies also reveals that IAM tends to be more attractive for shorter regional trips than for longer-distance journeys. The Intra-Pyrenees case study, which is characterised by shorter travel distances and more constrained ground transport connections, exhibits the highest IAM market share (0.6%). In contrast, the longer-distance corridors between Puigcerdà and Barcelona and between Lleida and the Pyrenees show lower levels of IAM adoption. This finding suggests that the relative competitiveness of IAM is influenced not only by travel time savings but also by factors such as access and egress requirements, service costs, and the characteristics of the existing transport network.

Beyond estimating the total demand captured by IAM, it is equally important to understand from which existing transport modes IAM users are expected to originate. To investigate this aspect, Sankey diagrams were developed to visualise the modal shifts associated with IAM adoption. These diagrams illustrate the distribution of travellers who switch from their current mode of transport to IAM.

As shown in the figures below, the majority of IAM users are former car users. This indicates that private car and road-based travel constitute the primary source of demand for IAM services. The observed modal shift can largely be explained by the substantial travel time savings offered by IAM compared with conventional road transport, particularly in areas where mountainous terrain, congestion, or limited transport infrastructure result in longer journey times. Consequently, IAM appears to be most attractive to travellers who are willing to pay a premium in exchange for faster and more direct connections.

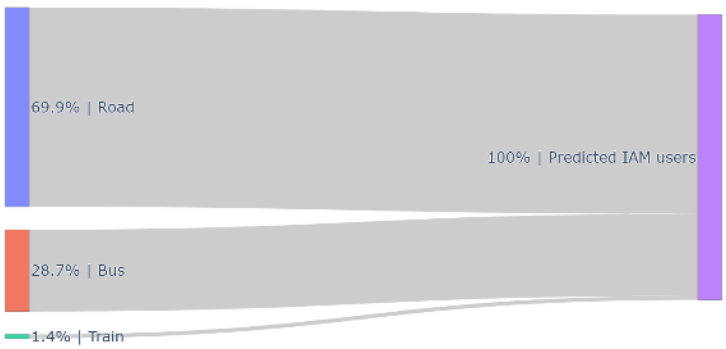


Figure 61. Sources of Predicted IAM Users by Original Mode (intra-Pyrenees)

© –2023– SESAR 3 JU

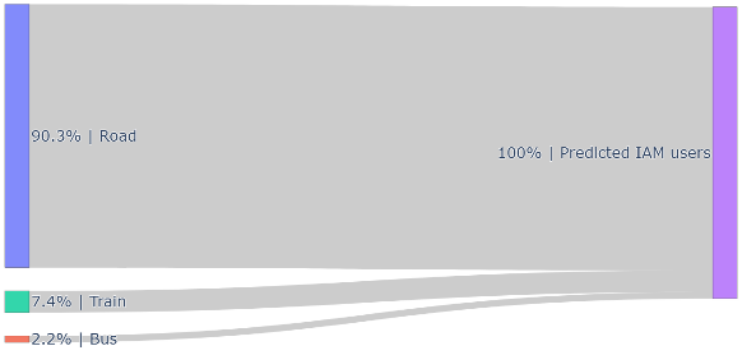


Figure 62. Sources of Predicted IAM Users by Original Mode (Puigcerdà to Barcelona**)**

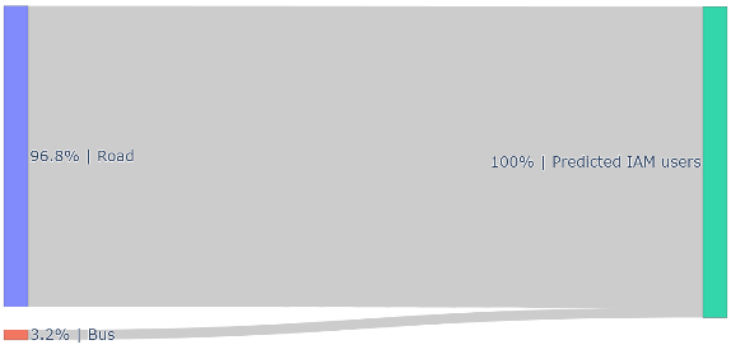


Figure 63. Sources of Predicted IAM Users by Original Mode (Lleida to Pyrenees)

To provide a clearer understanding of the main OD flows for each transport mode, the figures below present the observed and predicted flows for each OD pair. These visualisations make it possible to identify which transport modes are used for each OD flow and to determine the OD pairs where IAM is most frequently selected. This information can support policymakers in making decisions on vertiport location selection and in better understanding passenger behaviour, particularly where and for which types of trips passengers are most likely to choose IAM.

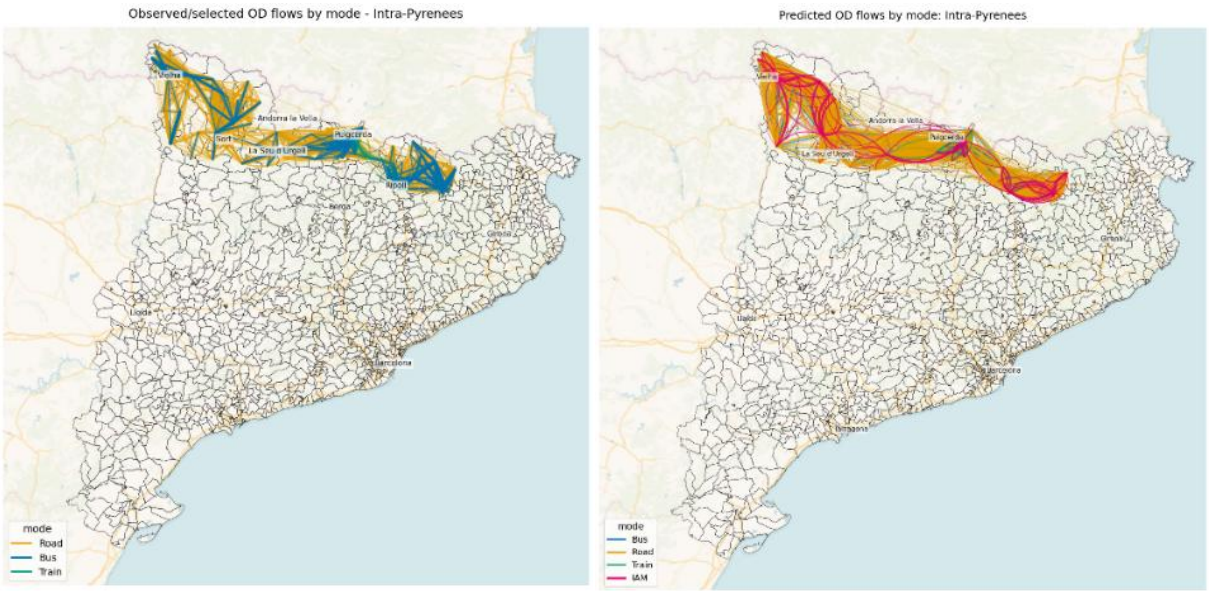


Figure 64. OD flows observed (left) and predicted (right) for intra-Pyrenees

© –2023– SESAR 3 JU

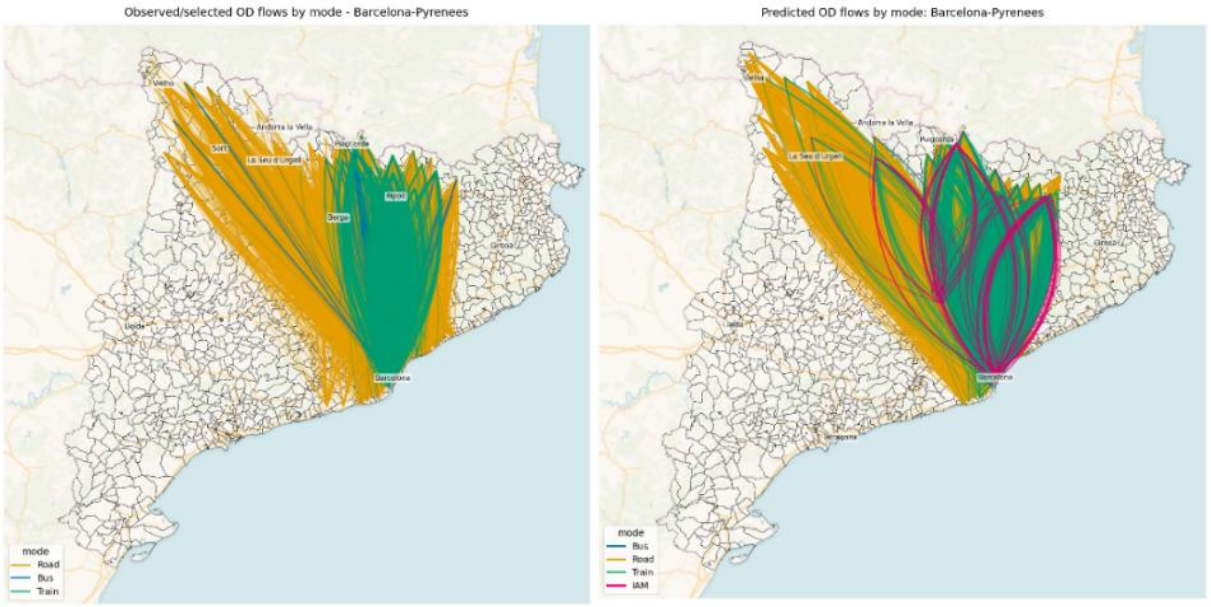


Figure 65. OD flows observed (left) and predicted (right) for Puigcerdà to Barcelona

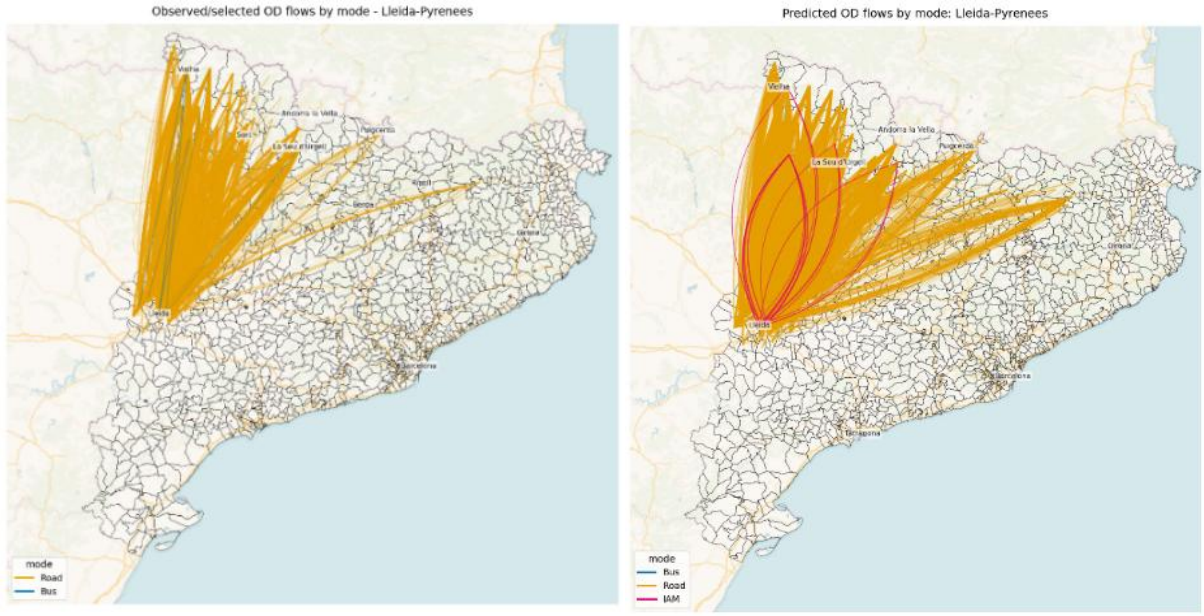


Figure 66. OD flows observed (left) and predicted (right) for Lleida to Pyrenees

Induced Demand Model Results

The induced demand model has been fitted to the two case study datasets. The trip distribution model is estimated using the binned observations. After fitting the gravity-style distribution model $F_{ij} = \alpha exp(-\beta C_{ij})$ the following estimations has been calculated.

Table 44. Induced Demand Model Estimation

© –2023– SESAR 3 JU

Parameter	Estimate	Robust SE	t-stat	p-value
α	45031	1301.7	34.593	< 0.001
β	0.077355	0.0041185	-18.782	< 0.001
$R^2 = 0.94$				

These parameters define the baseline relationship between observed trip frequency and generalised cost. The relationship between trip frequency and generalised travel cost is shown in the figures below.

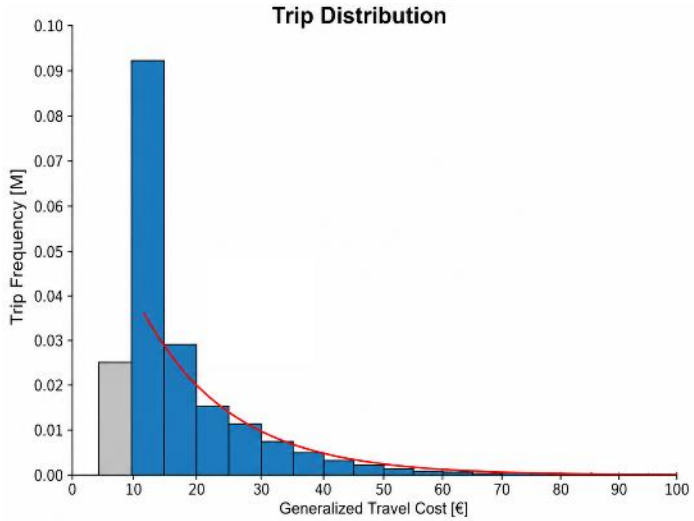


Figure 67. Trip Distribution Model

Therefore, as mentioned in the previous sections, using these models, it is possible to calculate the raw number of induced demand for each OD-air pair. We have done this exercise using different fare-per-km scenarios for IAM. However, as mentioned in the previous section, the optimised fare for IAM is €4 per km. The results of the induced demand model are presented in the tables below. In each table, for each case study, the percentage of the induced trips that would be added to the initial number of trips due to the presence of IAM in the mode choice set are presented.

Table 45. Induced Demand Model Results (Tenerife)

# trips in dataset = 1792700		Fare per km		
		5€/km	4€/km	3€/km
Business	low	0.0%	0.0%	0.0%
	medium	0.0%	0.01%	0.01%
	high	0.0%	0.0%	0.0%
Leisure	all	0.02%	0.04%	0.22%
Total		0.02%	0.05%	0.26%

Table 46. Induced Demand Model Results (Catalonia)

# trips in dataset = 1120619	Fare per km

© –2023– SESAR 3 JU

		5€/km	4€/km	3€/km
Business	low	0.0%	0.0%	0.0%
	medium	0.0%	0.0%	0.0%
	high	0.0%	0.0%	0.0%
Leisure	all	0.0%	0.0%	0.0%
Total		0.0%	0.0%	0.0%

The induced demand results indicate that IAM generates only a very limited amount of additional travel demand in the analysed scenarios. In the Tenerife case study, induced demand ranges from 0.02% to 0.26% of the total annual demand, depending on the assumed IAM fare. A clear relationship can be observed between fare levels and induced demand: lower fares lead to higher levels of induced travel, as the reduction in generalised travel cost makes some trips more attractive. However, even under the most optimistic scenario of 3 €/km, induced demand remains below 0.3% of total trips. Furthermore, the generated demand is almost entirely associated with leisure travellers, while business travellers show virtually no induced demand across all income groups. This suggests that IAM is more likely to stimulate discretionary leisure trips than essential business travel, which would generally take place regardless of the availability of IAM. The results also indicate that induced demand mainly occurs for relatively short-distance trips, where the total cost of IAM remains affordable for potential users.

In contrast, no induced demand is observed in any of the Catalonia scenarios, regardless of the fare level. This indicates that, under the assumptions adopted in this study, IAM does not reduce the generalised cost of travel sufficiently to generate new trips beyond those already captured through modal shift from existing transport modes. However, this does not necessarily imply that IAM could never generate induced demand in the Catalan Pyrenees, but rather that, within the tested service configurations, IAM does not reduce generalised cost sufficiently to create additional trips beyond modal shift. A likely explanation is that the longer travel distances in the Catalonia case study result in higher total IAM travel costs, reducing its attractiveness as a means of generating entirely new travel demand. Overall, the findings suggest that IAM is unlikely to act as a mass transport solution that creates substantial additional travel demand. Instead, its primary impact is through modal shift from existing modes, while induced demand remains limited and is mainly concentrated among leisure travellers in scenarios where IAM fares are sufficiently low.

D.3.3 Unexpected behaviours/results

No unexpected behaviours or unexpected results were identified during Validation Exercise #04. The results were consistent with the methodological assumptions and confirm that IAM mainly acts as a complementary transport option, with limited induced demand.

D.3.4 Confidence in results of validation exercise #04

D.3.4.1. Level of significance/limitations of validation exercise results

The validation exercise results should be interpreted in light of the assumptions and limitations of the methodology. First, all modal shift and induced demand results are conditional on the assumptions

© –2023– SESAR 3 JU

adopted for IAM travel time, travel cost, access and egress conditions, waiting time, and vertiport locations. Since IAM is not yet commercially available at scale, these inputs are scenario-based and may change as the technology, operational models, and market conditions evolve.

The induced demand methodology also relies on the assumption that a reduction in generalised cost leads to an increase in travel demand, and that this relationship can be represented using an exponential impedance function. Although this provides a transparent and practical modelling approach, it remains an aggregate approximation of travel behaviour. The model estimates induced demand from changes in generalised cost, but it does not explicitly represent full mode choice, destination choice, or activity generation behaviour.

In addition, the current generalised cost formulation does not include all possible components that may influence the attractiveness of IAM. Elements such as parking costs, waiting time, transfer time, schedule-delay penalties, service reliability, and other service-quality factors are not explicitly included. These factors may be relevant for IAM, particularly where access and egress conditions or transfer penalties affect the total door-to-door experience. Finally, although the stated preference survey sample represents the best achievable data collection within the project constraints, the sample size remains limited and may not fully capture the diversity of future IAM users.

D.3.4.2. Quality of validation exercises results

The quality of the validation exercise results is considered satisfactory because the methodology combines two complementary data sources. The stated preference survey provides behavioural evidence on how respondents may react to a future IAM service, while the MND provide large-scale information on observed origin–destination flows, baseline modal shares, and population-level travel patterns. This combination improves the reliability of the results compared with using survey data or MND in isolation.

The quality of the modal shift results is further strengthened by the calibration process applied to the discrete choice models. The models were first estimated using stated preference data and were then recalibrated using MND to align the predicted baseline modal shares with observed travel behaviour. This ensures that the scenario simulations are not only based on hypothetical stated choices, but are also anchored to real mobility patterns in the case study regions.

The induced demand results are also based on a structured and transparent modelling process. Observed MND were used to estimate the relationship between trip frequency and generalised cost, after which the model was applied to assess the additional trips that may be generated by IAM. This provides a consistent basis for comparing different IAM fare scenarios and identifying where induced demand may occur.

D.3.4.3. Significance of validation exercises results

The validation exercise results are significant because the statistical indicators show that the developed models provide a robust representation of travel behaviour within the scope of the exercise. For the discrete choice models, the McFadden’s rho-squared values are 0.622 for the Canary Islands and 0.648 for the Catalan Pyrenees, indicating strong model performance for this type of transport demand model. The final log-likelihood values also show a substantial improvement compared with the null models, confirming that the explanatory variables improve the representation of observed choices.

© –2023– SESAR 3 JU

The estimated parameters further support the significance of the results. In both case studies, the generalised cost coefficient is negative and statistically significant, which is consistent with transport demand theory: as travel time and cost increase, the utility of a transport option decreases. The other retained variables are also statistically significant and behaviourally meaningful, which supports the validity of the final model specifications.

The induced demand model also provides statistically significant results. The estimated relationship between trip frequency and generalised cost achieves an R-squared value of 0.94, indicating that the model explains a high share of the observed variation in travel demand. The cost-sensitivity parameter is statistically significant, confirming that generalised cost is an important explanatory factor in the trip distribution model. These indicators show that the validation exercise provides a credible basis for estimating IAM modal shift and induced demand at this stage of the PRIAM Solution development.

D.4 Conclusions

D.4.1 Conclusions on concept clarification

Validation Exercise #04 clarified the role that IAM may play within regional multimodal transport systems. The results confirm that IAM should not be interpreted as a mass transport mode, but rather as a complementary mobility option that can improve connectivity in specific corridors where existing ground or maritime connections are relatively slow, indirect, or constrained by geography. This is particularly relevant for island and mountainous regions, where travel time savings may be more substantial and where IAM can provide more direct links between selected origin–destination pairs.

The exercise also clarified the distinction between IAM captured demand through modal shift and IAM induced demand. The largest share of IAM demand is generated by modal shift from existing transport modes, while induced demand remains limited. This means that IAM mainly redistributes part of the existing travel demand rather than creating large volumes of new trips. This finding is important for the interpretation of IAM impacts, especially in relation to environmental assessment, infrastructure planning, and social cost-benefit analysis.

The final results are summarised below.

Table 47. IAM total demand in case studies

Case study	Total annual trips	IAM modal shift	IAM induced	Total IAM trips
Canary Islands	4,677,023	100,993 (2.15%)	2,381 (0.05%)	103,374 (2.21%)
Catalan Pyrenees	29,236,142	140,299 (0.47%)	0.00	140,299 (0.47%)

These results show that IAM captures a higher relative share of demand in the Canary Islands than in the Catalan Pyrenees. In absolute terms, the Catalan Pyrenees case study generates more IAM trips because the total underlying demand is much larger. However, in both case studies, the IAM share remains relatively limited, supporting the conclusion that IAM is most relevant as a targeted regional connectivity solution rather than a large-scale replacement for existing transport systems.

The difference between the two case studies suggests that IAM-induced demand is more likely to appear in short-distance or geographically constrained contexts, where IAM can provide substantial travel time savings without generating excessive total travel costs. This explains why induced demand

© –2023– SESAR 3 JU

appears in the Canary Islands, especially for leisure trips, but not in the Catalan Pyrenees, where longer distances and higher total IAM costs limit the ability of IAM to generate additional trips.

From a planning perspective, the results indicate that IAM should not be justified primarily on the basis of large induced demand. Instead, its potential value lies in targeted modal shift, accessibility improvement, and travel time savings in corridors where existing connections are slow, indirect, or geographically constrained. This is important for infrastructure planning because vertiport investment should be prioritised in corridors where IAM can capture meaningful demand from existing modes without relying on unrealistic assumptions about newly generated travel.

D.4.2 Conclusions on technical feasibility

The validation exercise demonstrates that the proposed modelling framework is technically feasible within the scope of the PRIAM Solution. The methodology successfully combines stated preference survey data with MND to estimate IAM modal shift and induced demand. This confirms that the hybrid approach can be implemented in practice, even though IAM is not yet available in the real transport market and no revealed preference data exist for this mode.

The discrete choice modelling component was able to estimate behavioural sensitivities to travel time and cost, while the MND provided a large-scale empirical basis for observed origin–destination flows and baseline modal shares. The calibration of the alternative-specific constants using MND was a key technical step, as it allowed the model to move beyond survey-only results and align the baseline predictions with observed mobility patterns.

The induced demand model was also technically feasible, as it used observed trip patterns and generalised cost values to estimate a cost-sensitivity relationship. This relationship was then applied to assess whether IAM could generate additional trips by reducing the generalised cost of travel. The method is transparent, reproducible, and suitable for exploratory validation. However, further technical refinement would be needed in future versions, particularly to include additional generalised cost components such as waiting time, transfer time, parking costs, service reliability, and schedule-delay penalties.

D.4.3 Conclusions on performance assessments

The performance assessment indicates that the developed models provide a strong basis for estimating IAM demand at the exploratory research stage. The discrete choice models achieved strong goodness-of-fit values, with McFadden's rho-squared values of 0.622 for the Canary Islands and 0.648 for the Catalan Pyrenees. These values indicate that the models provide a good representation of observed and stated travel behaviour within the case study datasets. The estimated model parameters are also behaviourally consistent. The induced demand model also performed well, achieving an R-squared value of 0.94, which indicates a strong relationship between generalised cost and observed trip frequency.

From a performance perspective, the results show that IAM has a measurable but limited effect on total travel demand. In the Canary Islands, IAM accounts for 2.21% of total annual trips when both modal shift and induced demand are considered. In the Catalan Pyrenees, IAM accounts for 0.47% of total annual trips, entirely through modal shift. These results suggest that IAM can contribute to improved regional accessibility, but its overall transport-system impact remains concentrated in specific corridors and user segments.

© –2023– SESAR 3 JU

D.5 Recommendations

Based on the validation results, IAM should be considered as a complementary regional transport service rather than as a mass transport solution. Future planning and policy work should therefore focus on corridors where IAM can provide clear added value, such as island connections, mountainous areas, areas with poor road accessibility, or origin–destination pairs where existing public transport options are slow or indirect.

The results also show that IAM demand is highly dependent on assumptions related to travel time, fare levels, vertiport locations, access and egress times, and waiting times. Future analyses should therefore test a wider range of operational scenarios, including different fare levels, service frequencies, vertiport network configurations, and integration levels with existing transport services. This would help identify the conditions under which IAM becomes more attractive and financially or socially viable.

Further refinement of the generalised cost formulation is also recommended. Future versions of the model should include additional cost and service-quality components, such as parking costs, waiting time, transfer time, schedule-delay penalties, reliability, and comfort. These variables are likely to influence IAM adoption, especially because IAM competitiveness depends not only on in-vehicle travel time, but also on the full door-to-door travel experience.

Future work should conduct a more extensive sensitivity analysis of induced demand and modal shift by testing a wider range of IAM fares, access and egress times, waiting times, service frequencies, vertiport locations, and values of time. This is particularly important because the current results show that induced demand remains very low and is highly dependent on whether IAM produces a sufficient reduction in generalised cost.

Also, future studies should compare modal shift and induced demand results with external benchmarks from comparable regional air mobility, ferry replacement, high-speed rail opening, bridge/tunnel opening, or major accessibility-improvement studies. This would help assess whether the estimated elasticity of demand to generalised cost is plausible beyond the two PRIAM case studies.

Finally, future validation should benefit from larger and more geographically targeted stated preference surveys. Although the survey sample used in this exercise was sufficient for exploratory model development, a larger sample would improve the representation of different user groups, trip purposes, income levels, and regional travel contexts. This would strengthen the behavioural robustness of the discrete choice models and support more detailed policy conclusions on IAM adoption, modal shift, and induced demand.

© –2023– SESAR 3 JU

Co-funded by the European Union

Appendix E Validation exercise #05 report

E.1 Summary of the validation exercise #05 plan

As defined in the ERP SESAR Solution 0515

E.2 Deviation from the planned activities

There are no deviations from the planned activities.

E.3 Validation exercise #05 results

E.3.1 Summary of validation exercise #05 results

Exercise #05 validation objective ID	Exercise #05 validation objective title	Exercise #05 success criterion ID	Exercise #05 success criterion	Exercise #05 validation results	Exercise #05 validation objective status
OBJ-0515-ERP-005	Validation of algorithms for vertiport location optimisation	CRT-0515-TRL1-ERP-005.001	The results of the multicriteria evaluation methods for the optimisation of IAM infrastructure networks are consistent with the expected behaviour. The achieved results have been validated through expert reviews conducted by external stakeholders as part of the project's planned engagement activities.	The results of the IAM network optimisation are consistent with the expected behaviour. Across the two case studies, the tool produced coherent and explainable vertiport configurations, with demand, cost, and revenue outputs aligning with the MND-derived mobility patterns. The consistency between the IAM demand, the vertiport profitability, and the location of the selected vertiports confirms the tool behaves as intended. Additionally, these results have been validated through expert reviews conducted with external stakeholders as part of the project's planned engagement activities. A workshop session, complemented by individual meetings, was used to validate the key modelling assumptions and the preliminary results, confirming that the assumptions and outputs were reasonable and plausible, and provided feedback that informed the refinement of the tool. Taken together, the consistency of the results with expected behaviour and their validation by external experts demonstrate that the objective of this val exercise has been successfully achieved.	OK

Table 48. Validation exercise #05 results

© –2023– SESAR 3 JU

E.3.2 Analysis of validation exercise #05 results per validation objective

E.3.2.1. OBJ-0515-TRL1-ERP-005 Results

The purpose of this validation activity is to ensure the robustness, accuracy, and applicability of the multicriteria evaluation tool developed for the optimisation of IAM infrastructure networks.

To support the future validation process, several coordination meetings have been conducted with the leaders of other PRIAM components in order to define the required interfaces, data exchange mechanisms, and specific algorithmic needs. These discussions are essential to guarantee full interoperability between the IAM optimisation tool and the broader PRIAM components.

In parallel, collaborative meetings have been held with representatives of the Engage 2 project Vertiport Location, which developed tools and methodologies closely aligned with the objectives of PRIAM. The insights and experiences gathered from Engage 2 are being used to inform and strengthen the design of the PRIAM optimisation tool, ensuring methodological consistency and avoiding duplication of effort.

Furthermore, a comprehensive literature review has been carried out on the outcomes of the MAIA project [32], which developed a vertiport location optimisation tool tailored for Madrid Airport. The methodologies and modelling approaches identified in MAIA are being carefully analysed to extract lessons learned and identify potential synergies with the ongoing work in PRIAM.

Methodology

The vertiport location tool developed in the PRIAM project follows the architecture depicted in Figure 68.

© –2023– SESAR 3 JU

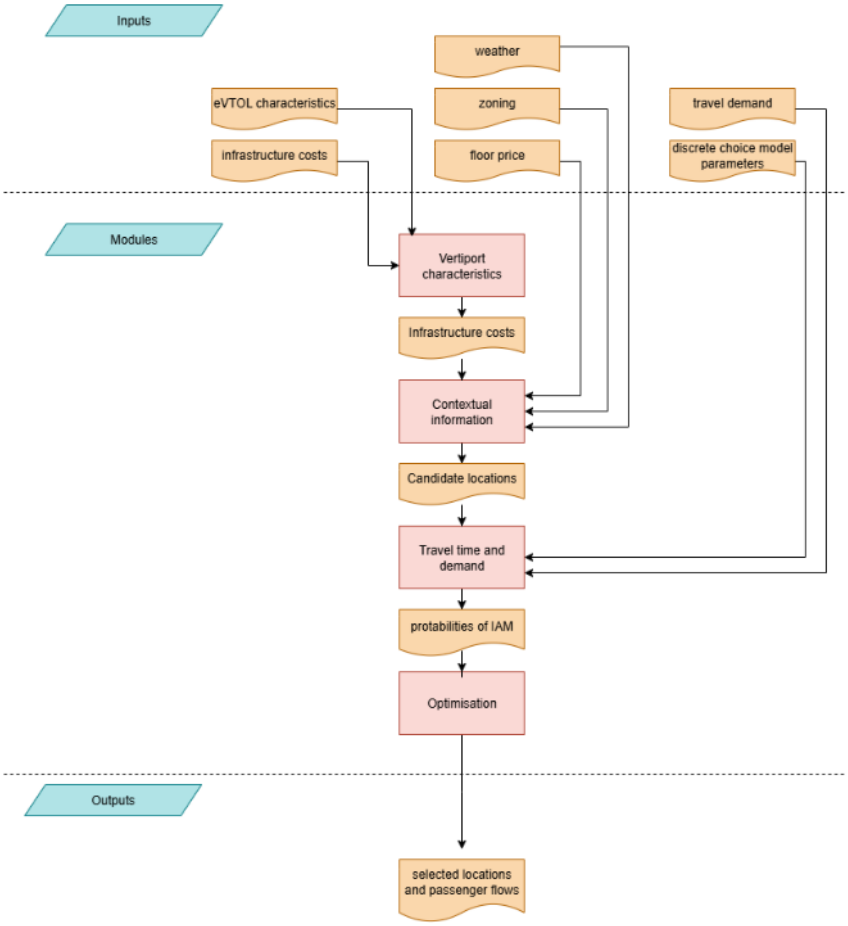


Figure 68: Vertiport location tool high-level architecture diagram

In summary, the tool operates in four steps. First, it calculates infrastructure costs based on vertiport and eVTOL characteristics. Second, it identifies candidate micro-locations for vertiport construction and estimates their associated costs, including infrastructure, connection, and weather. Third, it computes travel times and mode-specific disaggregated demand for each candidate location. Finally, it uses all this information to optimise the IAM network. The final output of the tool is the optimal location of the vertiports (or vertihubs) along with their associated costs, revenues, profits, and the captured demand. Below, we summarise all the steps for the optimisation.

Vertiport characteristics

This module calculates the infrastructure costs associated to vertiport/vertihub construction. For the categories of “vertiport” and “vertihub”, the user can specify

- The layout between satellite, multi-functional FATO, pier 1 FATO, pier 2 FATO, linear 2 FATO, and LEIDT. The different layouts are presented in Figure 69: Possible vertiport/vertihub layouts. The different layouts have different associated areas. The different layouts areas are calculated using the MAIA VSC tool.
- The number of gates.

© –2023– SESAR 3 JU

- The proportion of gates with charger and the price of charger.
- The average construction price per meter square.

The distinction between vertiports and vertihubs is determined by the user, but vertihubs are expected to have more gates and more chargers. The tool can decide to upgrade a vertiport to a vertihub if due to the increased capacity, the location is able to accommodate more demand, thus compensating for the increased costs.

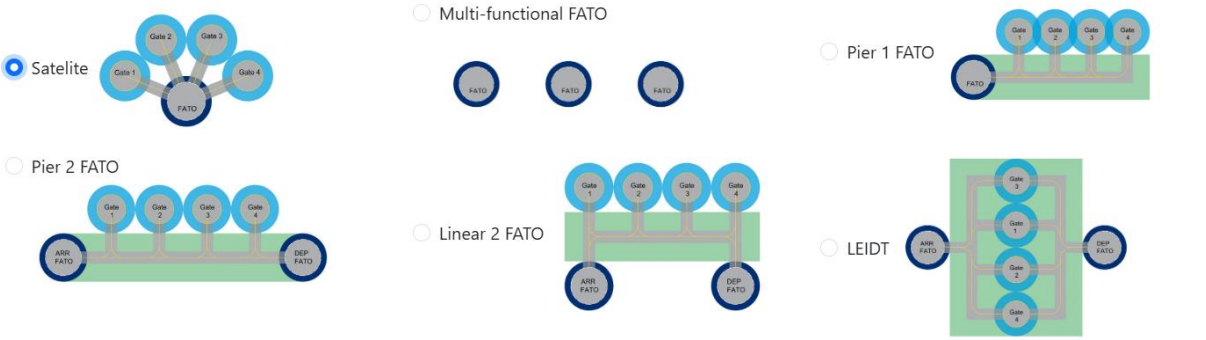


Figure 69: Possible vertiport/vertihub layouts

Contextual information

After calculating the infrastructure costs, the tool generates the "candidate locations", i.e., the micro-locations where vertiports or vertihubs can be built. The process for candidate generation is the following:

1. Demographic information (population and population density) is added to the initial zoning.
2. Optionally, locations with population and population density lower than a given threshold are filtered out. The remaining locations are the candidate locations.
3. Floor price is added to the candidate locations.
4. Weather information is added to the candidate locations.

In order to obtain the most precise locations possible, the initial zoning of the case studies was generated using floor use information. Thus, instead of potentially geographically extensive municipalities or districts, the starting point for the PRIAM project is a collection of population centres. The tailored zonings for the case studies are presented in Figure 70.

© –2023– SESAR 3 JU

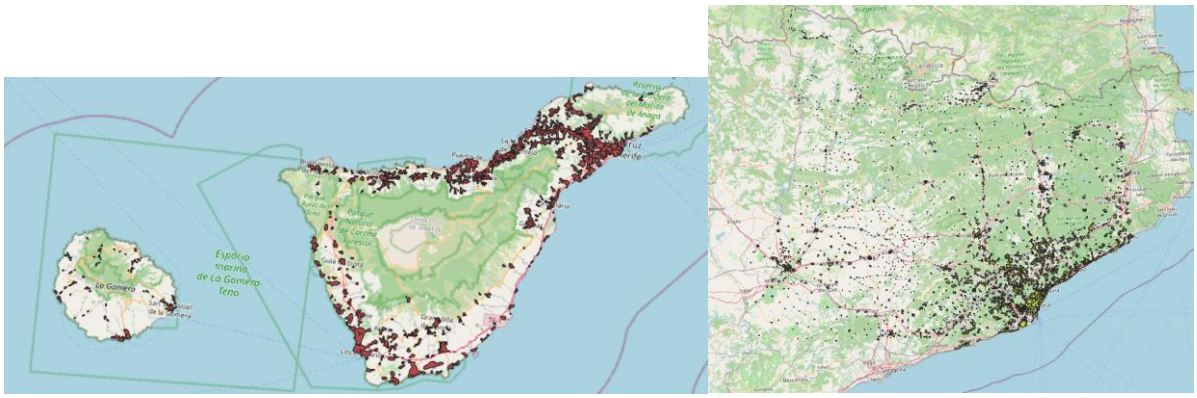


Figure 70: PRIAM case study initial zonings.

As the analysis of IAM mobility from a social perspective is core to the PRIAM project, no locations were filtered out.

Floor price can vary extensively from region to region. Additionally, detailed and actualised floor price information is not always easy to obtain. Floor prices for Catalonia and the Canary Islands were obtained using information publicly available in the Spanish Institute of Statistics (INE). Floor price estimations at municipality level are presented in Figure 71.

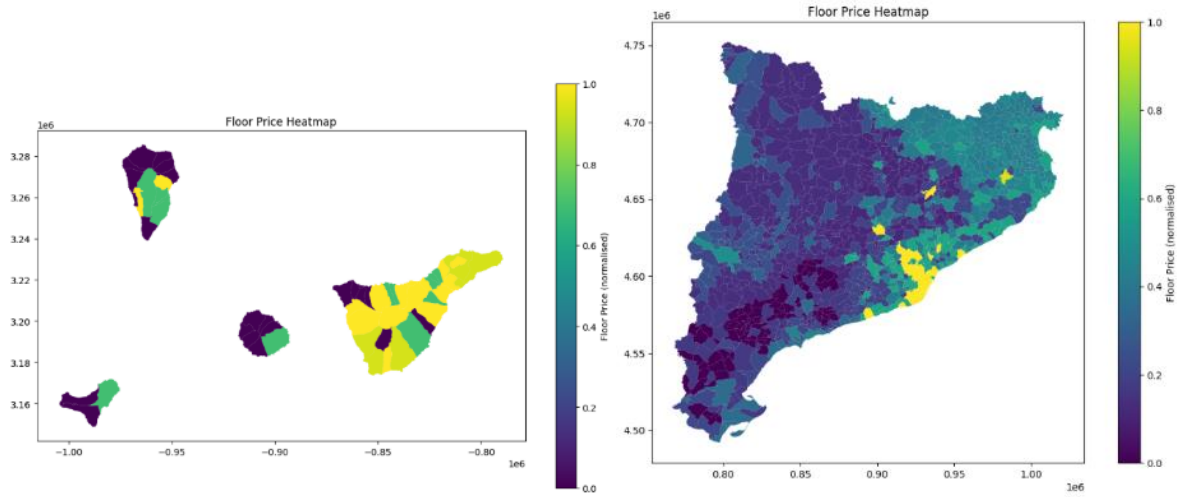


Figure 71: PRIAM case study floor prices.

As expected, floor price varies widely between different municipalities. Floor price is used to estimate the associated costs of buying the required land to build the vertiport infrastructure.

Lastly, the tool adds the weather information of each candidate location. Weather can vary substantially in mountainous areas and archipelagos; it is therefore of the upmost importance to monitor and predict how many operations can actually take place in a given area. This allows to accurately predict the demand captured by a given vertiport. Using historical data from weather stations and the chosen eVTOL maximum temperature, minimum temperature, maximum wind speed and the minimum visibility necessary to operate, the tool calculates the proportion of days per year for which the eVTOL would be cleared for take-off/landing. We refer to this proportion as the "usable

© –2023– SESAR 3 JU

days". They give a proxy of how many operations could be eventually carried on in a given location. The heatmap of usable days of the case study areas is presented in Figure 72.

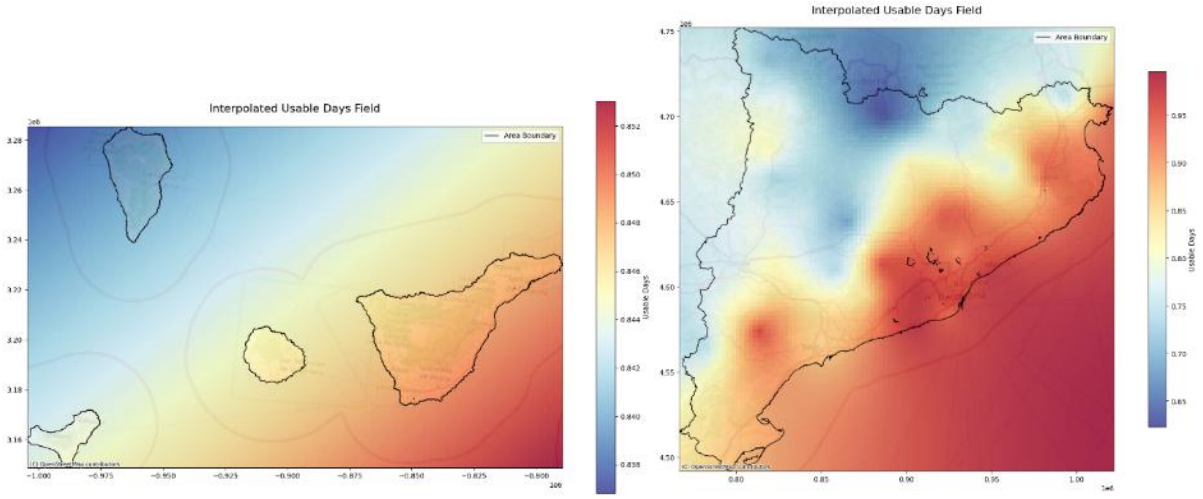


Figure 72: Usable days in the two PRIAM case studies

Infrastructure costs, floor purchase costs, and usable days proportion are the main costs taken into account to find vertiports optimal locations.

Travel time and demand

This module is responsible for calculating the IAM travel time and applying the logit model developed in Component 3 of the Solution (see Section 4.2.4 and Appendix E).

The main challenge in calculating the IAM travel time is that it depends on the final selected location of the vertiports, since this location determines both the in-vehicle travel time of the IAM vehicle and the access and egress times to and from the vertiports. For this reason, the travel time is computed for all potential combinations of vertiports.

The calculation follows the same logic used for the other modes, with the IAM travel time obtained as the sum of the following components:

- Access time: Driving time between the trip origin and the origin vertiport, computed using OSM.
- Processing + dwell time: It is assumed to be 15 minutes. This value is intended to reflect the processing time is more similar to the one at a bus or train station rather than the considerably longer dwell time associated with an airport.
- In-vehicle time: the sum of the take-off and landing times plus the cruise time, calculated as the route distance divided by the cruise speed
- Egress time: Driving time between the destination vertiport and the final trip destination, computed using OSM

The IAM travel cost is calculated by assuming a cost per kilometre and multiplying it by the distance of the IAM route.

© –2023– SESAR 3 JU

Once the travel time and cost have been determined, the logit model is applied to estimate the probability that a trip shifts from its current mode to IAM. As noted above, this probability depends on the specific pair of vertiports used, and is therefore computed for all potential vertiport pairs.

The output of this component is a matrix specifying, for each trip detected from MND and each potential pair of vertiports, the probability that the trip is performed using IAM. This matrix constitutes the input to the subsequent optimisation algorithm, which uses this information to identify the optimal set of vertiport locations.

Optimisation

Once all the information about candidate locations and demand patterns is generated, the tool uses Mixed-Integer Programming (MIP) solvers to identify the optimal locations for vertiports or vertihubs. The optimisation was performed using the HiGHS solver.

The objective function is formulated from the perspective of the vertiport operator, meaning that only costs and revenues directly associated with the operator are considered.

The cost components include personnel costs, maintenance costs, infrastructure investment costs (including the floor cost and the cost of building the vertiport), and loan costs. Revenues are derived from passenger service fees, operation fees, and income generated from providing eVTOL charging services. The optimisation process determines the network configuration that maximises the operator's economic performance while satisfying the relevant operational and demand constraints. More information about the considered costs are presented in Table 49.

Results

Stakeholder validation

The tool has been developed in coordination with the Advisory board and external stakeholders. The main stakeholder validation activity took place during PRIAM second stakeholder workshop. The tool, the methodology and preliminary results were presented to the stakeholders. Following the presentation, the members of the workshop were divided in smaller groups for an interactive session. The interactive session was key refining the technical details regarding the case studies, scenarios, and functionalities of the tool. Some of the main take-away from the interactive session are:

- Connection costs should be different in the two case studies to reflect the different reality of La Gomera Tenerife and Catalonia. The maintenance and adaptation of the electrical substations should be taken care of by the relevant authority and therefore should not present an extra cost for the vertiport operator.
- The 2035 scenario should focus on IFR and piloted operations and the 2050 scenario should focus on IFR and non-piloted operations.
- In future scenarios CNS could be considered as SaaS.
- Number of gates, FATOs and number of employees should be determined in an iterative manner and be adapted to the different potential demand of each case study.
- In the first version of the tool floor prices have been calibrated using urban land use data. For future implementations other land uses such as industrial land use should be considered.

© –2023– SESAR 3 JU

- Despite current trends of technology getting cheaper with time, the price of chargers might not follow that trend due to potentially stricter standards in 2050 than in 2035.
- Weather monitoring should be taken into account for maintenance costs.
- Global instability, while hard to model, should be taken into account whenever possible.
- Different models for floor acquisition such as leasing should be considered.

Additionally, the consortium held bilateral meetings with regional authorities and Bluenest, a consortium member, and specifically requested eVTOL operators' guidance towards the choice of eVTOL for the case studies. The validation activities resulted in the final selection of all the free parameters and the final differentiation between the 2035 and the 2050 scenarios.

Simulations results.

We present in Table 49 the common parameters used for the two timeframes (2035 and 2050). Some parameters have different values depending on whether the infrastructure considered is a vertiport (vp) or a vertihub (vh).

Table 49: common parameters across simulations.

Category	Parameter	Value
Vertiport layout	Vertiport general layout	Satellite
	Number of gates	3 (vp) 6 (vh)
	Proportion of gates with charger	100%
Infrastructure costs	Unit construction price	80 €/m^2
	Charger price	80,000 €
Employee costs	Number of employees	5 (vp) 7.5 (vh)
	Gross monthly salary	3,000 €
	Operating hours	12
Maintenance costs	General maintenance	20,000 € (vp) 40,000 € (vh)
	Software maintenance	12,000 €
eVTOL flight assumptions	Take-off time	6 min
	Landing time	6 min
	Passenger processing time	15 min
	% Of battery used in take-off and landing phases	8%
	Horizontal distance travelled during take-off and landing phases	1.25 km

© –2023– SESAR 3 JU

Others	Payback time	40 years
Benefits for eVTOL operators	Benefit for charging	150%

The eVTOL characteristics used for the two case studies are presented in Table 50.

Table 50: eVTOL characteristics.

eVTOL parameter	2035 scenario	2050 scenario
Maximum wind	45 km/h	45 km/h
Minimum temperature	-5 °C	-5 °C
Maximum temperature	40 °C	40 °C
Seats	4	5
Battery	220 kWh	220 kWh
Cruise speed	160 km/h	270 km/h
Diameter	15 m	15 m
Maximum range	25 km	200 km

These characteristics have been decided in collaboration with experts and eVTOL manufacturers and building from the initial work of WP2. The range of the eVTOLs effectively limits the 2035 scenarios to only la Gomera or trips inside the Pyrenees, while for the 2050 scenario a wide network of vertiports can be established. In the following, we summarise the main results of the two case studies, starting from the 2050 scenario.

Catalonia case study

As previously discussed, two scenarios have been considered within the project, one for 2035 and one for 2050, and the selection of vertiport locations has been approached jointly for both. The approach followed is top-down, the optimal vertiport locations are first selected for the 2050 scenario, representing the final objective of a mature IAM network operating under mature technology assumptions; the 2035 scenario is then solved considering the locations selected for 2050. This most likely leads to a smaller network for 2035, but one whose selected locations fall within the 2050 subset. The rationale is to avoid selecting locations that are optimal for 2035 in isolation but that, once the technology matures and the 2050 conditions apply, would become underused or suboptimal, ensuring instead a coherent deployment path between the two horizons.

2050 Scenario

The following figures present the results for the **2050 scenario**. The figures show how IAM network demand (annual passengers) and annual profit evolve as the network grows from 2 to 11 vertiports, under four IAM price levels. Figure XX shows that demand behaves as expected. Demand is strongly price-sensitive, and it also increases with the number of vertiports, but with clearly diminishing returns: the curves rise quickly up to around 7–8 vertiports and then start to flatten. This reflects the

© –2023– SESAR 3 JU

fact that the most relevant origin–destination pairs are served first, so each additional vertiport captures progressively less incremental demand.

Figure XX shows that demand and profitability do not necessarily follow the same trend. At higher IAM prices, the resulting drop in demand prevents the system from being profitable, although the revenue per trip is higher, the lower number of trips is not sufficient to offset the annual costs of the network. At 6 €/km, the network is unprofitable for any number of vertiports, while at 5 €/km it becomes viable only for certain network sizes. From 4 €/km downwards, the higher demand allows the IAM service to be financially self-sustaining and to generate profit.

These results highlight a strong interaction between pricing and network size, with direct implications for network planning. The optimal number of vertiports depends entirely on the assumed fare: under low fares, larger networks remain advantageous, with profit still increasing at 11 vertiports; under intermediate fares, an interior optimum emerges at around 8 vertiports; and under high fares, network expansion becomes unprofitable. Importantly, in this scenario the objectives of maximising demand and maximising profitability are aligned, both favouring a low-fare, high-volume strategy. This reinforces the conclusion that affordable pricing is a prerequisite for both the adoption and the financial viability of the IAM service, and is consistent with the broader finding that public support or subsidies may be required to sustain this type of service.

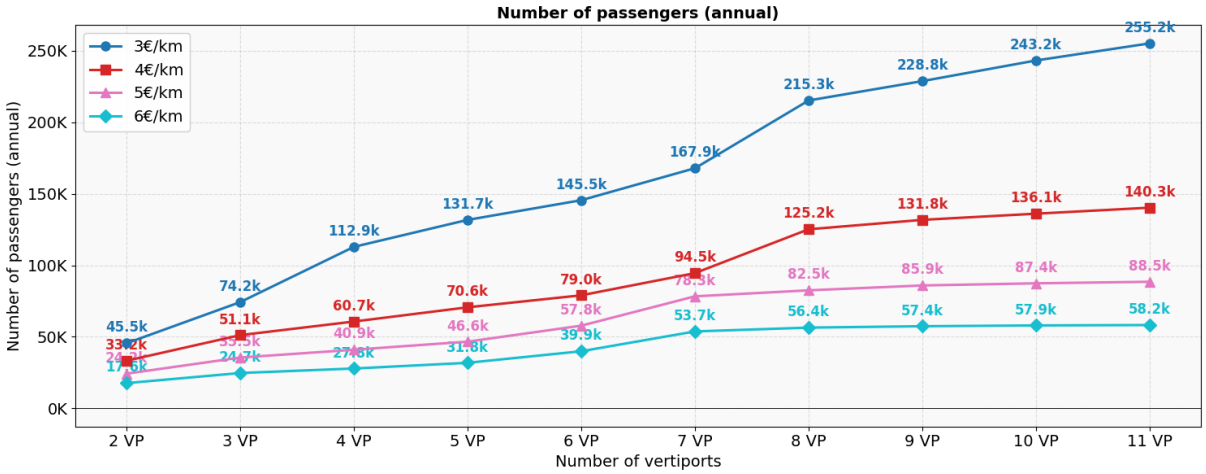


Figure 73. Vertiport network demand with respect to IAM price and number of vertiports. Scenarios for 2050

© –2023– SESAR 3 JU

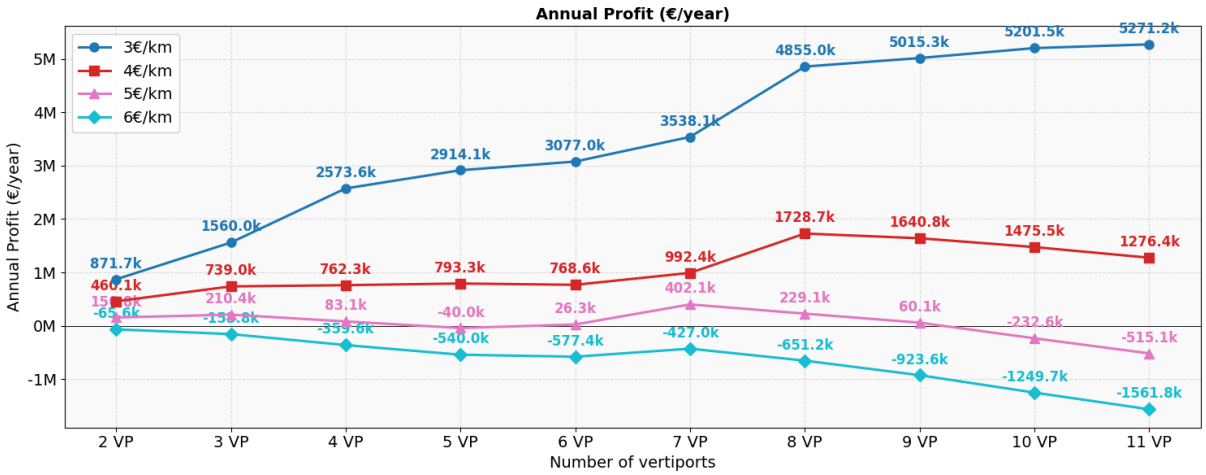


Figure 74. Vertiport network profits with respect to IAM price and number of vertiports. Scenarios for 2050

In the following images, the results for the 4€/km scenario are detailed, which represents the threshold fare at which the IAM network becomes financially self-sustaining. As shown in Figure 75, demand increases steadily with the number of vertiports but with diminishing marginal gains. The network grows from approximately 33,200 passengers per year with 2 vertiports to around 140,300 with 11. The relative increments are largest in the early stages of expansion, exceeding 50% when moving from 2 to 3 vertiports, and progressively diminish to only around 3% per additional vertiport beyond 9, confirming that the most valuable connections are captured first and that later vertiports add comparatively little demand.

Figure 76 shows that both revenues and costs grow with the size of the network, but at different rates, which shapes the profit trajectory. Annual profit rises from approximately €460k with 2 vertiports to a maximum of around €1,729k at 8 vertiports, and then declines to about €1,276k at 11 vertiports. This behaviour is the direct consequence of the interaction between the two figures: as demand growth slows (Figure 75) while infrastructure and operating costs continue to increase with each additional vertiport (Figure 76), the marginal cost of expanding the network eventually exceeds the marginal revenue it generates. The network therefore reaches an economic optimum at 8 vertiports under this fare, beyond which further expansion, although still profitable in absolute terms, progressively erodes the annual profit.

© –2023– SESAR 3 JU

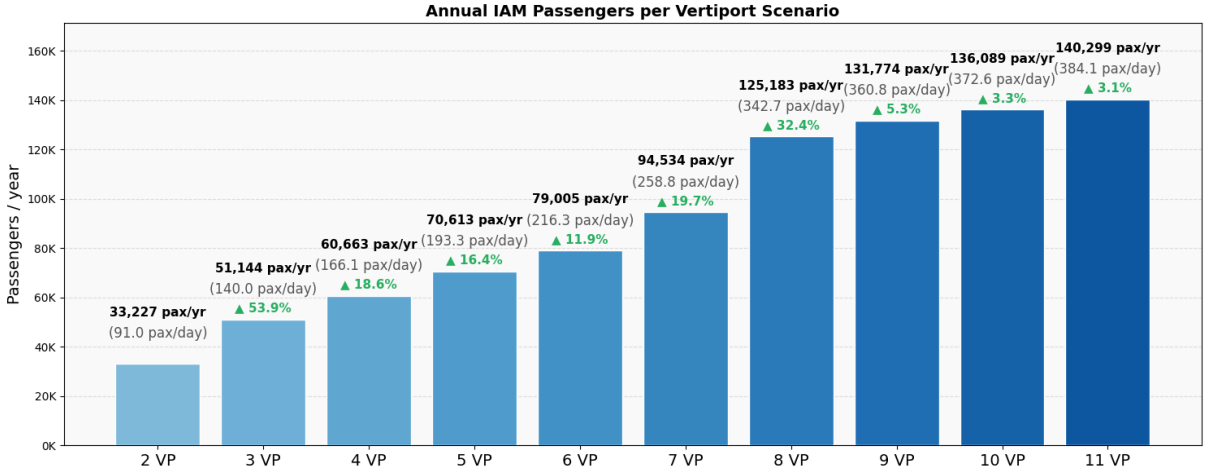


Figure 75. Annual demand of the vertiport network with respect to the number of vertiports for the 4€/km scenario for 2050.

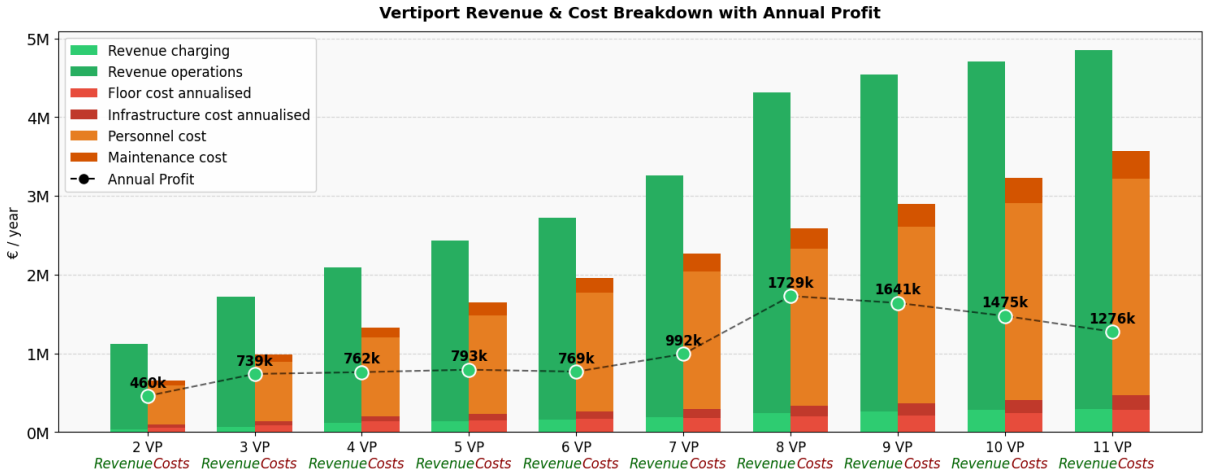


Figure 76. Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports for the 4€/km scenario for 2050.

The following image shows the location of the selected vertiports, indicating the step at which each is added. As shown, the corridor between Ripoll (1714702_0) and Olot (1711405_0) is served first, followed by Puigcerdà (1714101_0) and Barcelona (0801906_0) in the eastern part of Catalonia. The network is then progressively expanded to the west with vertiports in La Seu d'Urgell (2520301_0), Sort (2520901_2), and Esterri d'Aneu (2808601_1), reaching seven vertiports while demand and profit continue to grow steadily, as shown in Figure 76 and Figure 31. The addition of Vielha (2524301_0) brings the network to its optimal size of eight vertiports. The three vertiports added last, Pont de Suert (2517301_1), Lleida (2512006_0), and Manresa (0811304_0), are those that reduce the overall profit due to the limited demand they capture.

© –2023– SESAR 3 JU

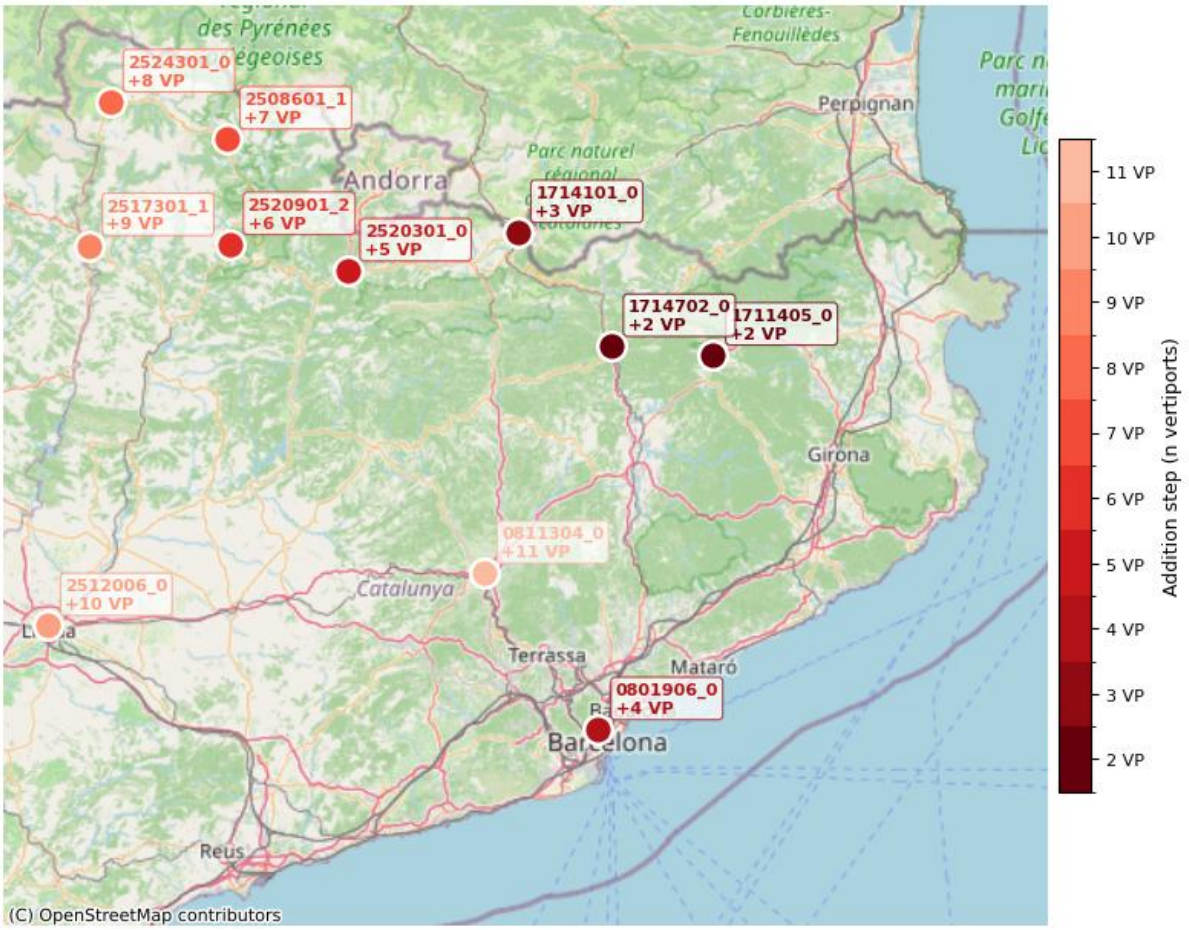


Figure 77. Location of the selected vertiports

The selected vertiport locations can be grouped into three categories according to their territorial role, which helps interpret the vertiport location results.

A first group corresponds to the major urban and metropolitan nodes. Barcelona (1.7M inhab) is the largest city in Catalonia and the main origin of trips towards the Pyrenees, whether for leisure, second-home, or business purposes. Lleida (147K inhab) is the main urban centre of western Catalonia and the natural gateway to the western Pyrenees, while Manresa (80K inhab), in central Catalonia, acts as an intermediate node between the Barcelona metropolitan area and the mountain corridor. These nodes provide the large population base underpinning the network's potential demand.

The second group consists of the consolidated tourist and service centres of the eastern and central Pyrenees, combining resident population with year-round tourism: Ripoll and Olot (gateways to the eastern Pyrenees and the Garrotxa volcanic park, whose connecting route concentrates the highest demand in the network), Puigcerdà (a major tourist hub in the Cerdanya with a strong second-home and cross-border component), and La Seu d'Urgell (gateway to Andorra). Their higher and more stable demand is reflected in their positive contribution to the network.

The third group consists of the high-mountain locations of the western Pyrenees, whose demand is strongly tourism-driven and markedly seasonal. Vielha, capital of the Val d'Aran, is the clearest example: a small town of around 4,000 inhabitants that fills with tourists in winter to practise winter sports at the nearby and renowned Baqueira Beret resort, while also attracting nature-based tourism

© –2023– SESAR 3 JU

(hiking, mountain biking) in summer. Vielha holds around 40% of the Val d'Aran population and sits at a genuine crossroads of roads, which reinforces its role as the access point to the valley. Sort, Esterri d'Aneu, and Pont de Suert are smaller mountain towns, associated with adventure tourism, natural parks (Aigüestortes) but with a limited permanent population.

Figure XX presents a per-vertiport breakdown of the 4 €/km scenario, showing the marginal revenues, costs, and profit of each vertiport in the order it is added to the network, together with the annual IAM passengers it captures (upper graph) and its fraction of operational days (lower graph), representing the fractions of days the vertiport will be available based on weather conditions.

The vertiport with a higher demand and, therefore, a higher profit, are the ones located in Ripoll (1714702_0) and in Esterri d'Aneu (2808601_1) with a demand of 27,183 and 23,261 passengers, and a profit of 604K and 487K, respectively. Followed closely by the vertiports in Olot (1711405_0), Vielha (2524301_0), Puigcerdá (1714101_0) and Sort (2520901_2), with a demand between 20-15 thousand passengers yearly and a profit of around 450-180K € yearly. The rest of vertiports, including La Seu d'Urgell (2520301_0), Barcelona (0801906_0), Pont de Suert (2517301_1), Lleida (2512006_0), and Manresa (0811304_0), present negative profits due to limited demand.

Operational availability also plays an important role, with some of the vertiports located in the Pyrenees with a fraction of operational days below 80%. Particularly interesting is the case of the vertiport located in Pont de Suert, where the fraction of operational days is limited to just the 55% of the days, which is probably also impacting its low potential for capturing demand.

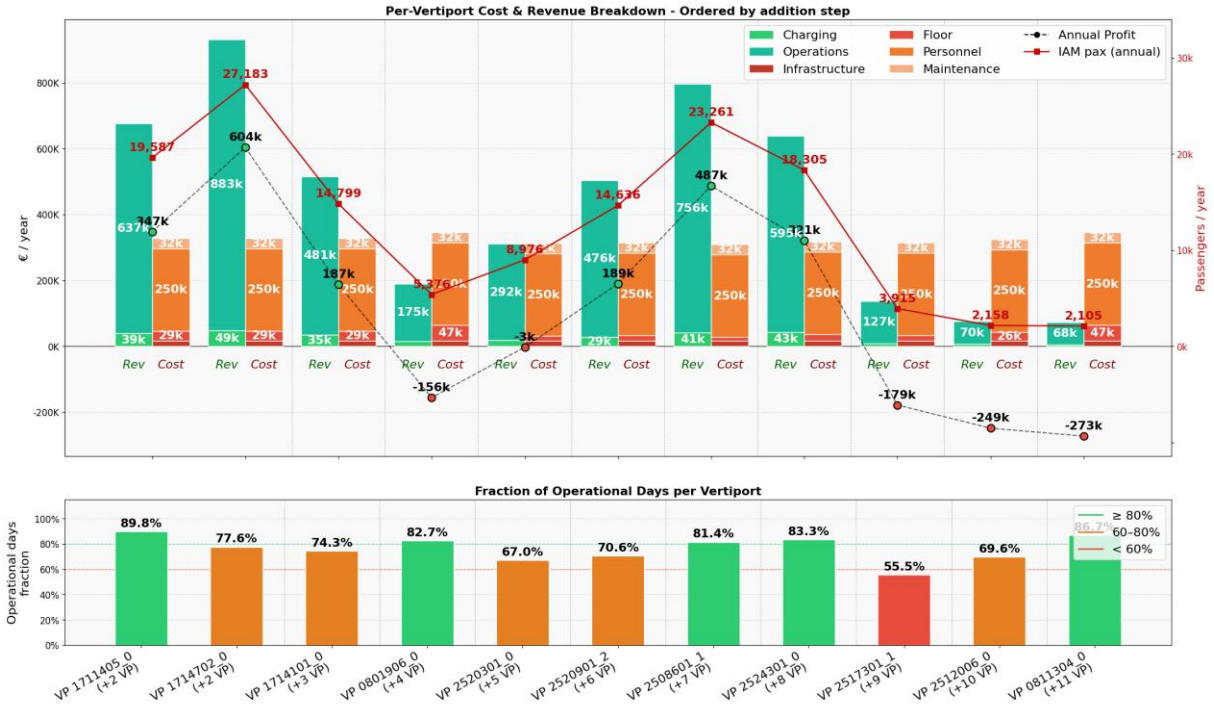


Figure 78. Cost & Revenue (top) and Operational days (bottom) analysis per vertiport for the 4€/km scenario for 2050

The figure below shows the yearly IAM demand across the routes connecting the selected vertiports. Demand is highly concentrated on a small number of routes, while the majority of connections carry

© –2023– SESAR 3 JU

only marginal volumes; for readability, only routes with a demand higher than 50 passengers are labelled with their demand value.

The dominant route is the connection between Ripoll (1714702_0) and Olot (1711405_0), which carries around 1,274 trips and stands out as the highest-demand link in the network, which is consistent with these being the first two vertiports added. A second high-demand route connects Vielha (2524301_0) and Esterri d'Aneu (2508601_1), with 1,081 passengers. Together with these, a set of routes along the Pyrenean axis forms the backbone articulating the main flows between the mountain nodes and the central part of the network: Ripoll (1714702_0)–Puigcerdà (1714101_0), with 662 passengers; Esterri d'Aneu (2508601_1)–Sort (2520901_2), with 657; and, to a lesser extent, Puigcerdà (1714101_0)–La Seu d'Urgell (2520301_0), with 307, and La Seu d'Urgell–Sort (2520901_2), with 266. The remaining routes carry substantially lower demand, confirming that, although the vertiports are interconnected, only a limited subset of routes sustains meaningful traffic.

Of particular interest are the connections to the more peripheral vertiports such as Lleida (2512006_0) to the south-west, and Barcelona (0801906_0) and Manresa (0811304_0) to the south, which show only minor volumes. Among these, only a few links exceed 50 passengers per year: Barcelona (0801906_0) with Olot (1711405_0), Ripoll (1714702_0), and Puigcerdà (1714101_0), carrying 175, 108, and 82 passengers respectively.

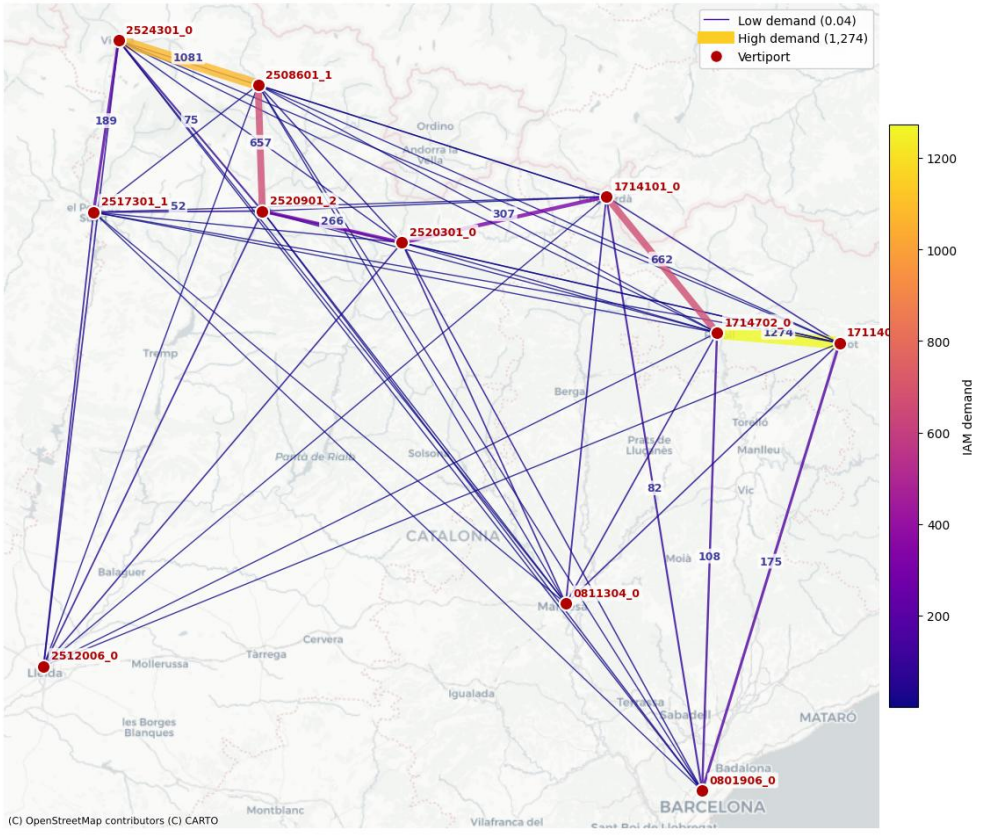


Figure 79. Yearly IAM demand across the routes connecting the selected vertiports

This demand pattern can be explained by two complementary factors. First, mobility demand is inherently higher between nearby zones, so the routes connecting closer vertiports start from a larger base of potential trips. Second, the relatively high cost of IAM makes it more competitive on short

© –2023– SESAR 3 JU

routes: in the Pyrenean area, even short distances can entail long road travel times due to the mountainous terrain and winding road network, so IAM offers a substantial time saving that justifies its higher fare. On longer routes, by contrast, the IAM cost increases considerably, reducing its competitiveness; this effect compounds with the fact that the more distant vertiports also generate less demand per se due to their peripheral location. The combination of these two factors — higher underlying demand at short distances and the greater attractiveness of IAM where it saves significant time at an affordable cost — concentrates demand on the shorter routes between the central and Pyrenean nodes, while the longer connections to peripheral vertiports remain marginal.

2035 Scenario

As stated above, for the 2035 scenario the locations already selected for 2050 are pre-selected, in order to assess the performance of the 2035 network using the optimal 2050 locations. Due to the assumed shorter range of the aircraft in 2035, the network does not include connections to the more peripheral areas, such as Lleida or Barcelona, where distances typically exceed 100 km. The maximum number of locations is therefore reduced to eight.

The figures below present, as in the 2050 case, the annual profit and IAM demand for different IAM pricing scenarios. Comparing these results with their 2050 counterparts reveals a notable effect: for the same IAM price, profit is higher in 2035 despite the lower demand. Although counterintuitive, this follows directly from the structure of the model. The vertiport operator's revenue derives from charging the vehicles, a per-passenger fee, and a per-operation fee. Since operations in 2035 are assumed not to be unmanned, the number of seats per vehicle is lower than in 2050 (4 versus 5). A smaller seat capacity requires a larger number of operations to accommodate a given demand, so that even with lower overall demand the number of operations (and therefore the per-operation revenue collected by the vertiport operator) increases, resulting in higher profit. It should be noted that this effect would not necessarily hold for the aircraft operator, who would require more vehicles and operations to serve a lower demand and would therefore incur higher operating costs. As explained previously, however, the current approach adopts the perspective of the vertiport operator; extending the analysis to the aircraft operator is identified as a task for future R&D phases.

For the present analysis, the 5 €/km scenario is considered, consistent with the higher expected cost of IAM in its early stages.

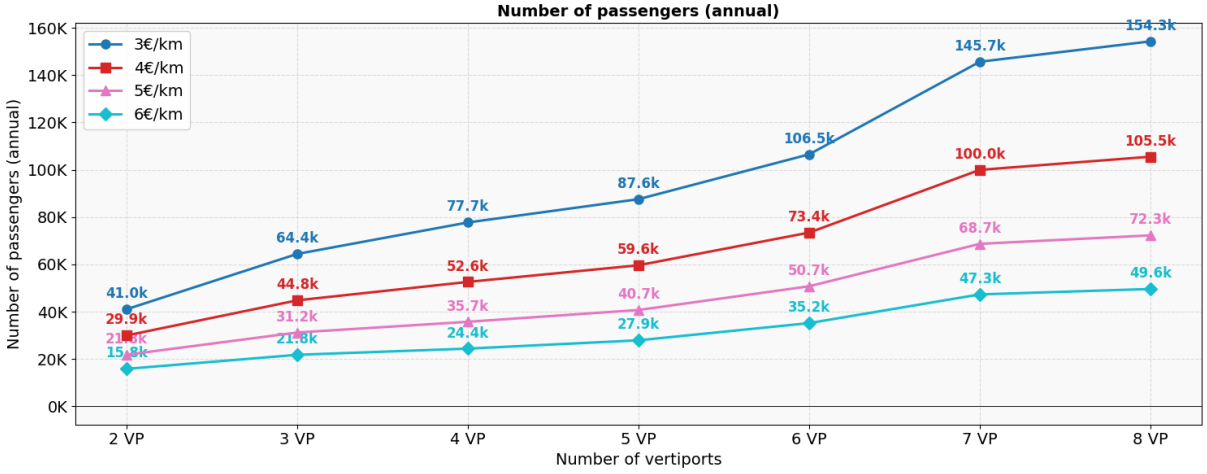


Figure 80. Vertiport network demand with respect to IAM price and number of vertiports. Scenarios for 2035

© –2023– SESAR 3 JU

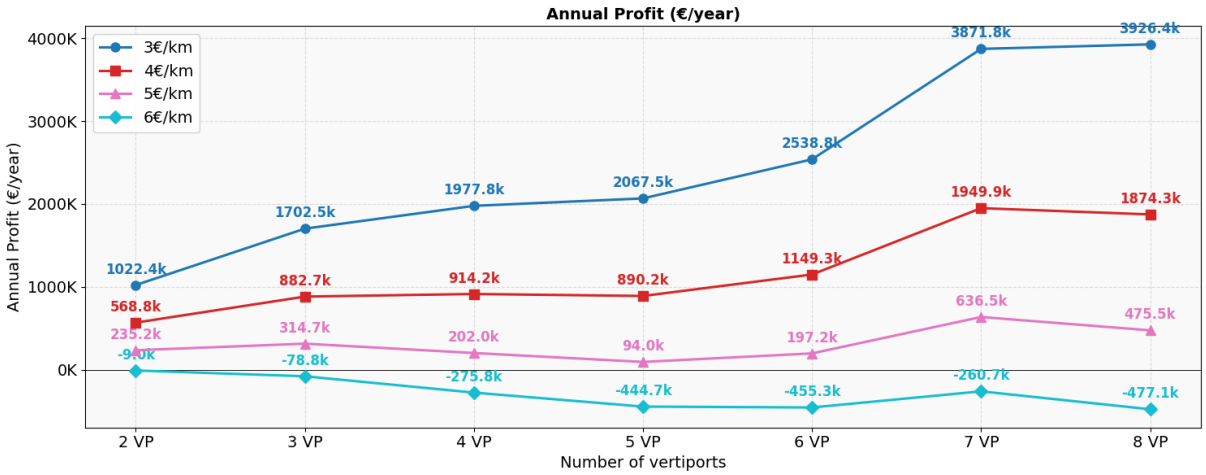


Figure 81. Vertiport network profits with respect to IAM price and number of vertiports. Scenarios for 2035.

As shown in Figure 82 and Figure 83, the behaviour regarding the optimal number of vertiports is similar to that of the 2050 scenario: an optimum of seven vertiports is reached, while adding the eighth contributes only marginal demand (around 5%) and therefore reduces profit. The optimum lies at the seventh rather than the eighth vertiport because the Barcelona vertiport (the fourth in the 2050 scenario) is excluded from this study; consequently, the optimum is again reached with the addition of Vielha (the eighth vertiport in the 2050 study), as shown in Figure 84.

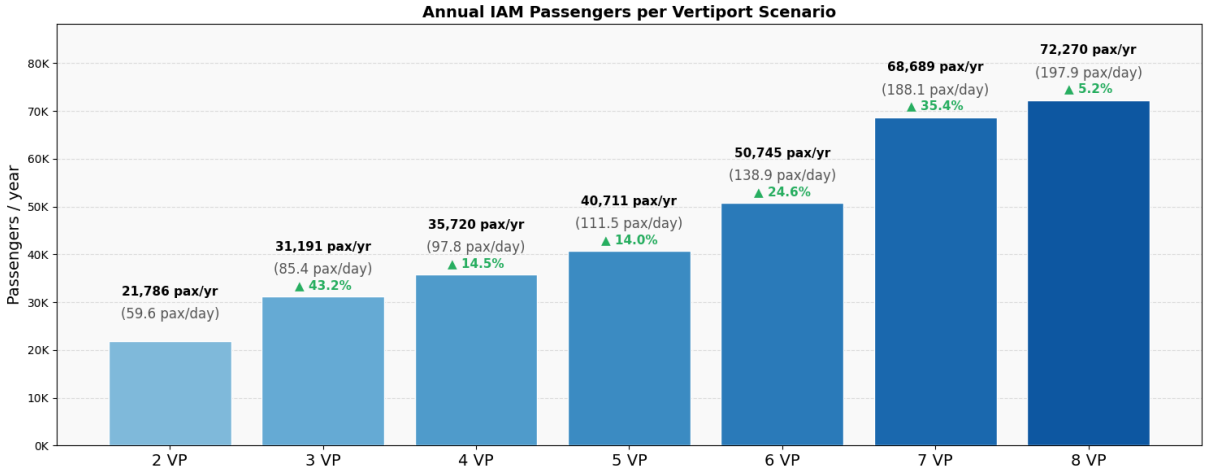


Figure 82. Annual demand of the vertiport network with respect to the number of vertiports for the 5€/km scenario for 2050

© –2023– SESAR 3 JU

Co-funded by the European Union

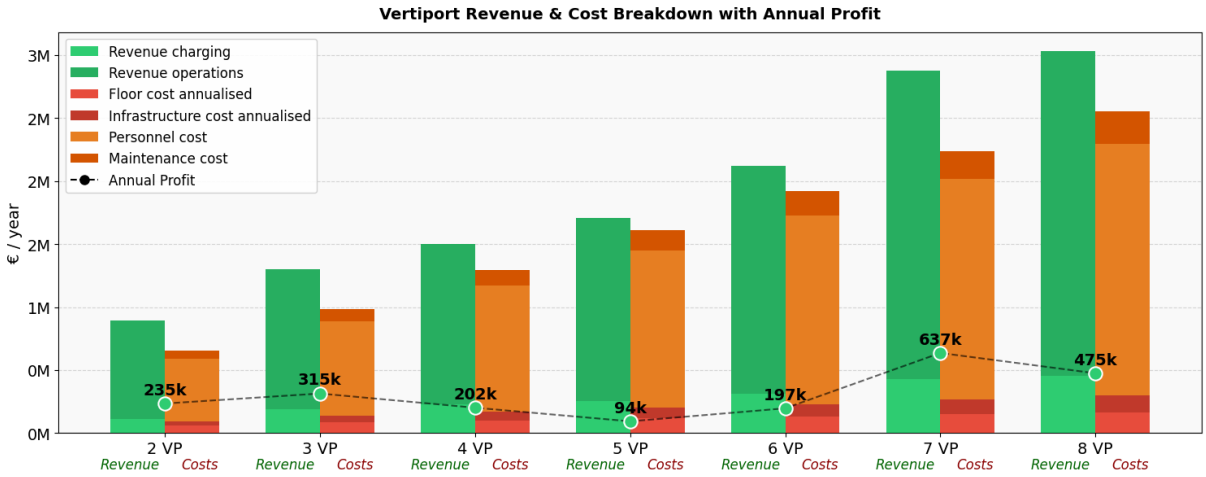


Figure 83. Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports for the 5€/km scenario for 2050



Figure 84. Location of selected vertiports for the 5€/km scenario for 2035

The figure below show the demand for the different IAM routes between the selected vertiports. The behaviour again mirrors the 2050 scenario, with the main difference that there are no longer routes due to the IAM vehicle range reduction for the simulaiton, however this demand was marginal as presented in the 2050 scenario. The main routes are Ripoll (1714702_0)–Olot (1711405_0), with 835 passengers, and Vielha (2524301_0)–Esterri d'Aneu (2508601_1), with 652 passengers. These are followed by Ripoll (1714702_0)–Puigcerdà (1714101_0), with 360 passengers; Esterri d'Aneu (2508601_1)–Sort (2520901_2), with 428; and, to a lesser extent, Puigcerdà (1714101_0)–La Seu d'Urgell (2520301_0), with 150, and La Seu d'Urgell–Sort (2520901_2), with 163. The remaining routes carry substantially lower demand.

© –2023– SESAR 3 JU



Figure 85. Yearly IAM demand across the routes connecting the selected vertiports

Finally, the figure below shows the demand, cost, and revenue breakdown for each selected vertiport. As in the 2050 scenario, the most profitable vertiports and those capturing the highest demand are Ripoll (1714702_0) and Esterri d'Aneu (2508601_1), while the vertiports at Puigcerdà (1714101_0), La Seu d'Urgell (2520301_0), and Pont de Suert (2517301_1) yield negative profits.

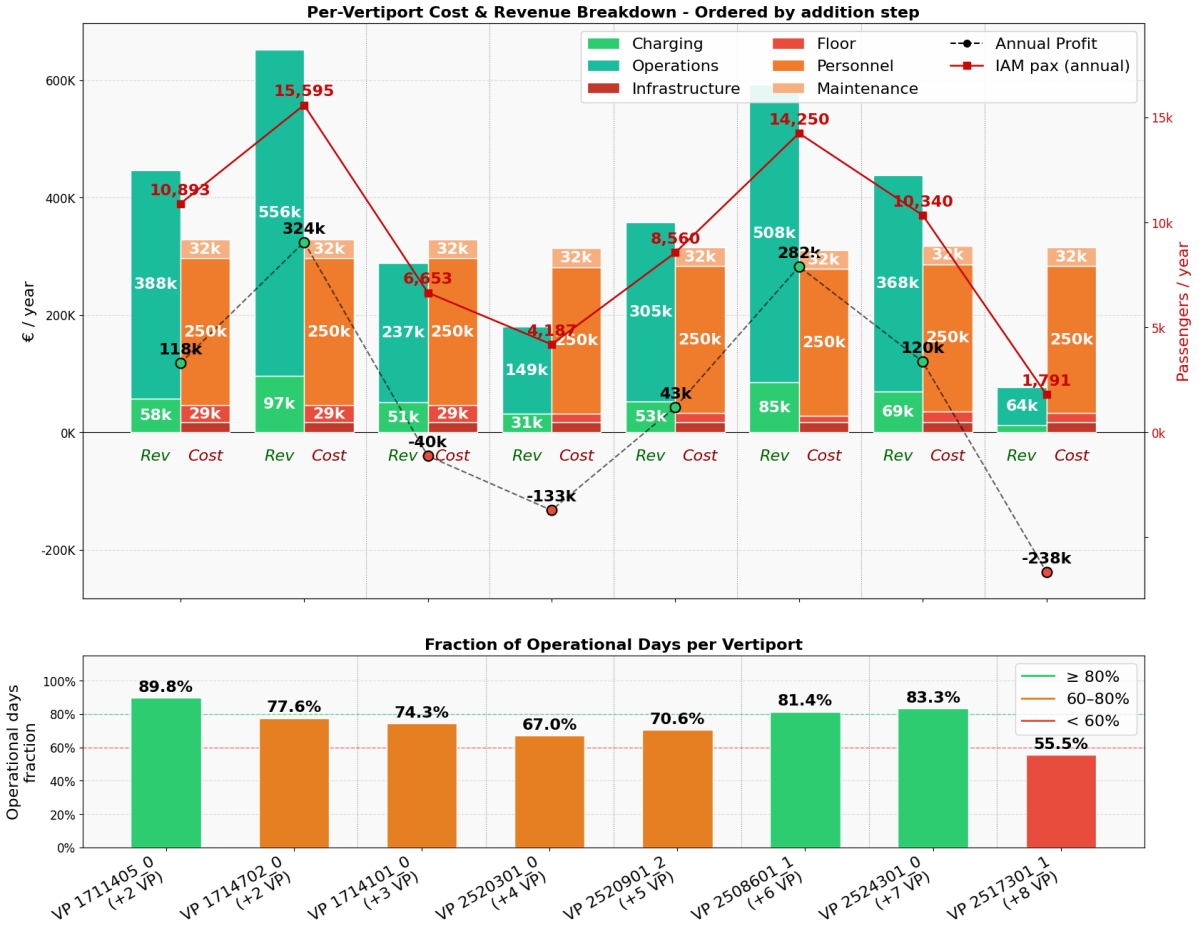


Figure 86. Cost & Revenue (top) and Operational days (bottom) analysis per vertiport for the 5€/km scenario for 2035

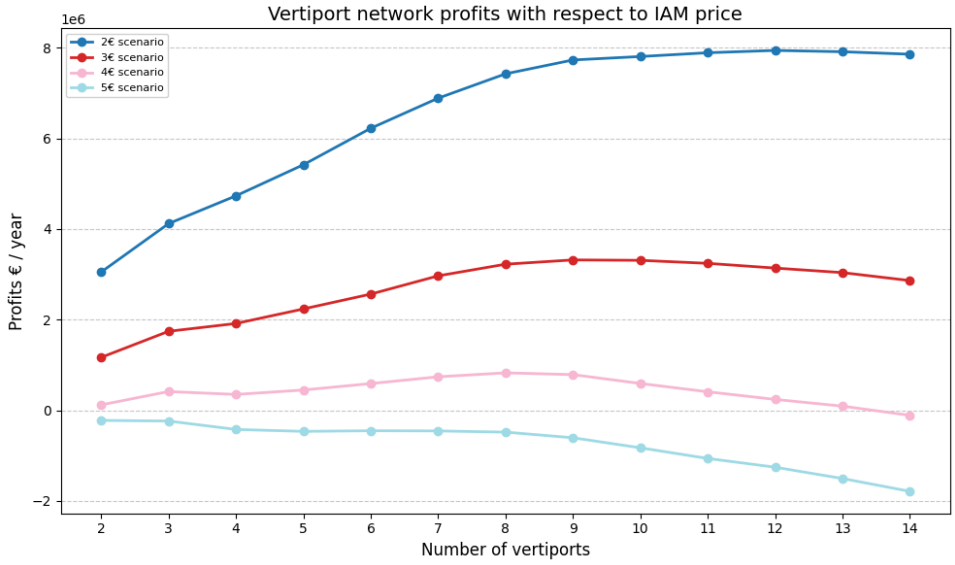
© –2023– SESAR 3 JU

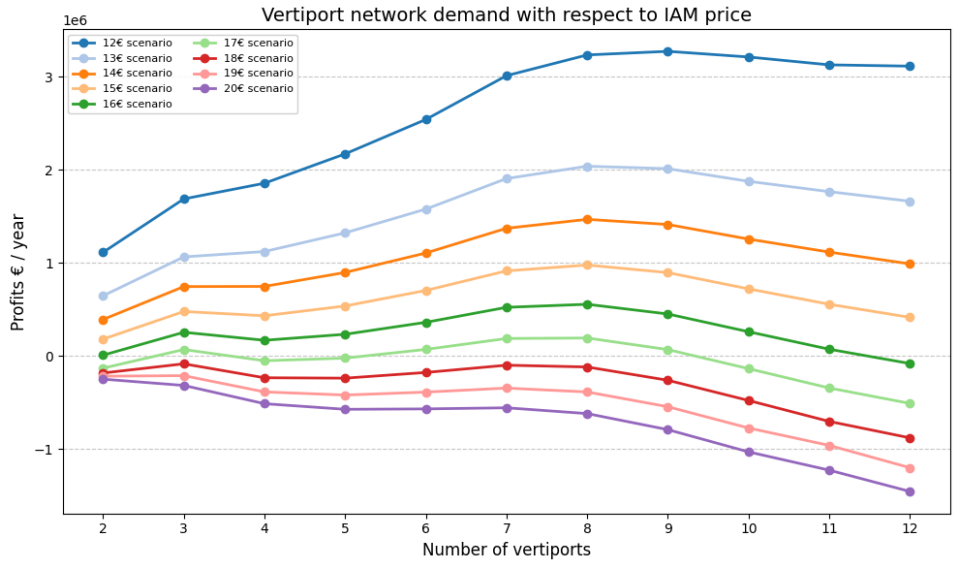
La Gomera – Tenerife case study

Residents of the Canary Islands benefit from a 75% discount in all modes of transport, including commercial aviation. The islands, however, receive a considerable number of tourists who do not benefit from the discount during the year. MND allows the distinction between residents and non-residents. Therefore, several simulations with different prices per km for IAM and different attitudes towards the discount for Canary Island residents. For the two time-frames (2050 and 2035) the following prices for IAM were considered:

- 2 to 5 euros per km for everyone (no discount)
- 12 to 20 euros per km for non-residents (meaning 3 to 5 euros for residents)

These prices represent what the passengers are paying when using the eVTOL services. The simulation is agnostic to any subsidies that might be included in these prices. We present in the following the results for the 2050 scenario.





© –2023– SESAR 3 JU

Figure 87: Vertiport network profits with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2050

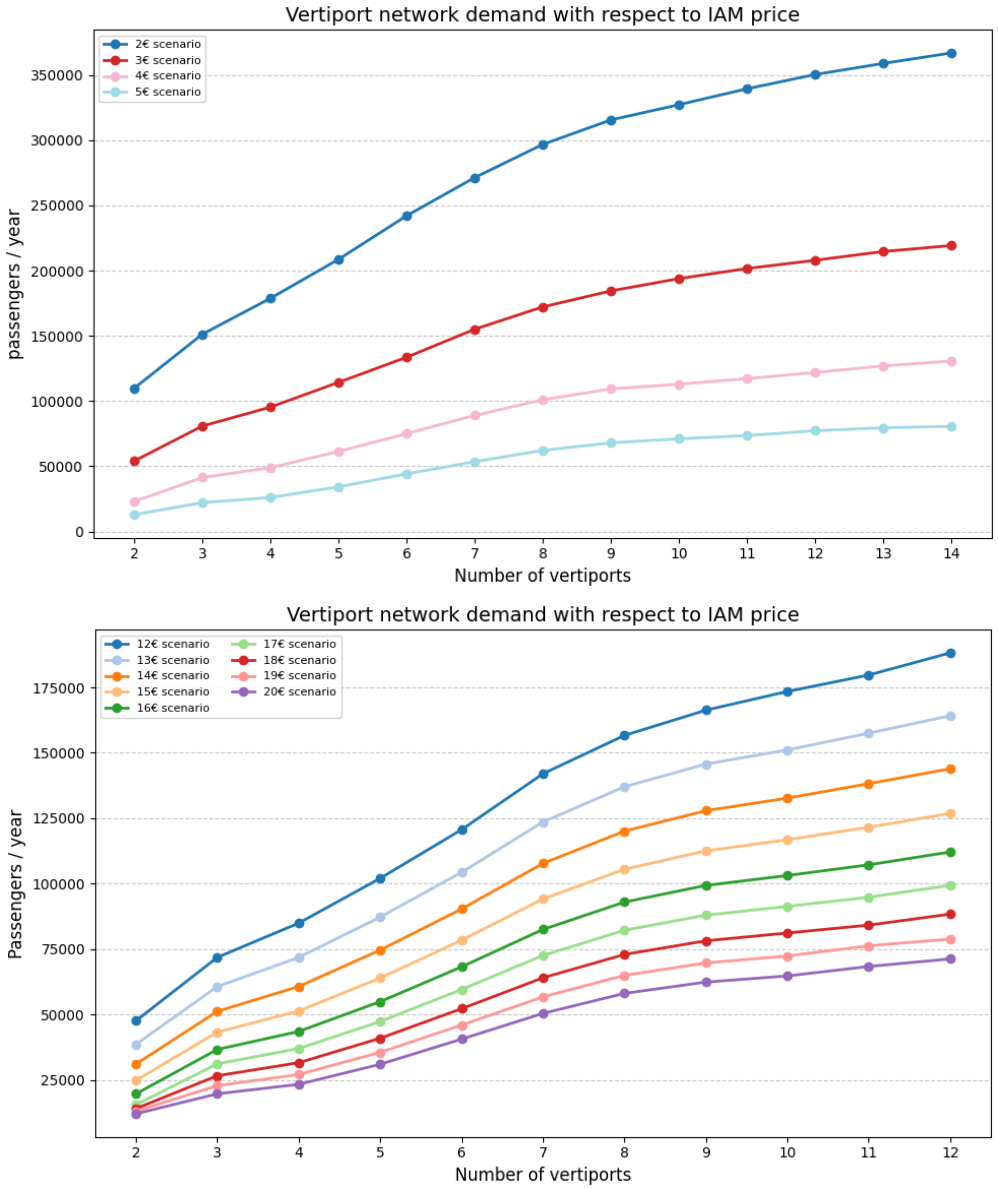


Figure 88: Vertiport network demand served with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2050

As we can see in both scenarios (with and without discount) two tendencies are visible. Before roughly 8 vertiports demand and profits grow significantly. After 8 vertiports, demand starts to grow lower and profits either decrease or also grow slower. Therefore, we consider that in this case study, the optimal number of vertiports is 8. Interestingly, not all prices for IAM considered yield profits. Figure 89 and Figure 90 show the revenue vs costs comparisons for simulations done assuming an IAM price per km of 4-5€ (without discount) and an IAM price per km of 16-20€ (with discount). We can conclude that for IAM to be economically viable in the La Gomera Tenerife region, passengers should not pay more than 5€ or 20€ per km. If IAM is more expensive to operate, the price difference could be provided by

© –2023– SESAR 3 JU

subsidies for example. We also notice that IAM uptake is slightly higher in the non-discounted simulations. This makes sense as otherwise the price difference between residents and non-residents strongly discourages the use of IAM from non-residents.

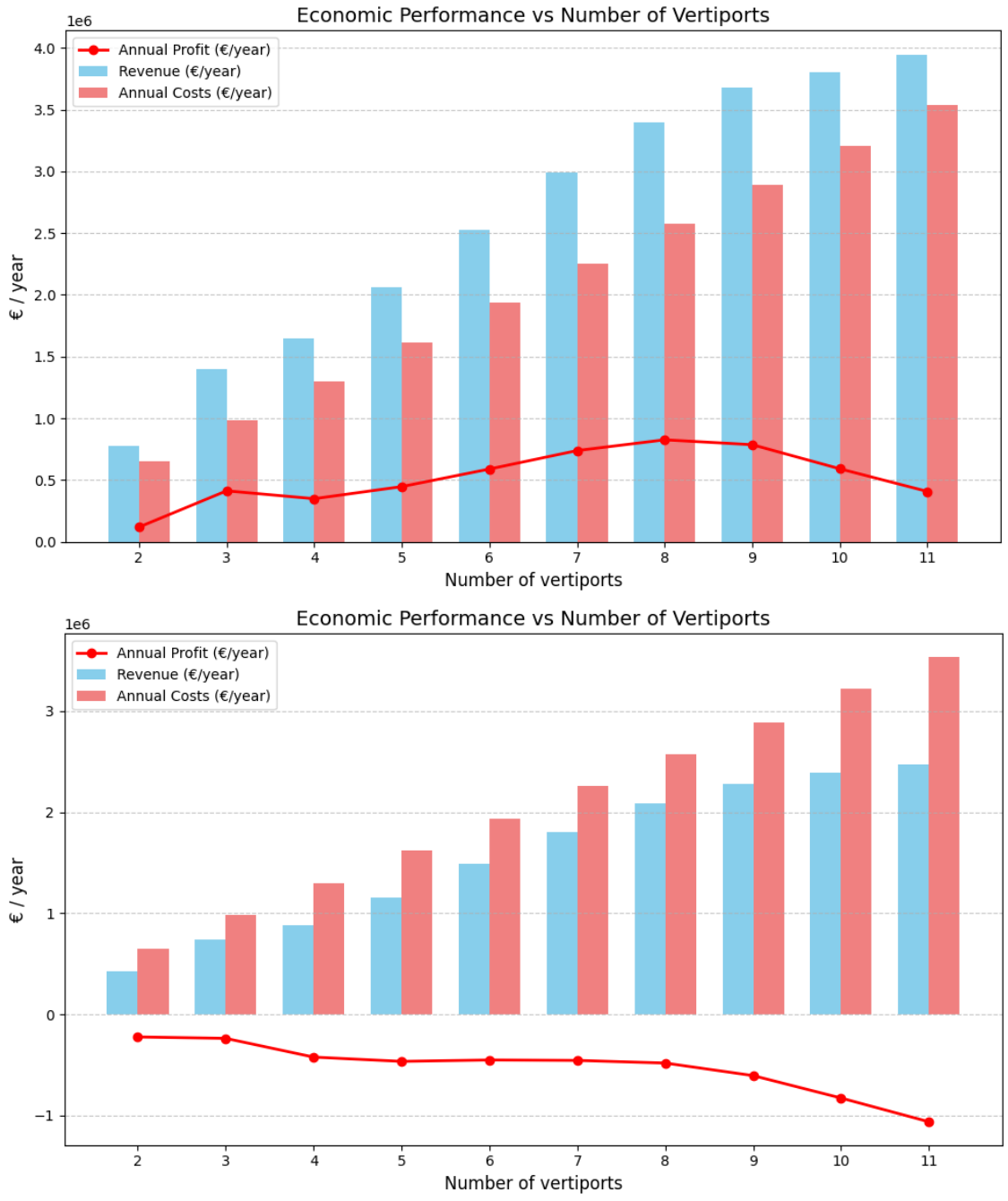


Figure 89: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario without discount for 2050. Above figure 4€ per km and below figure 5€ per km

© –2023– SESAR 3 JU

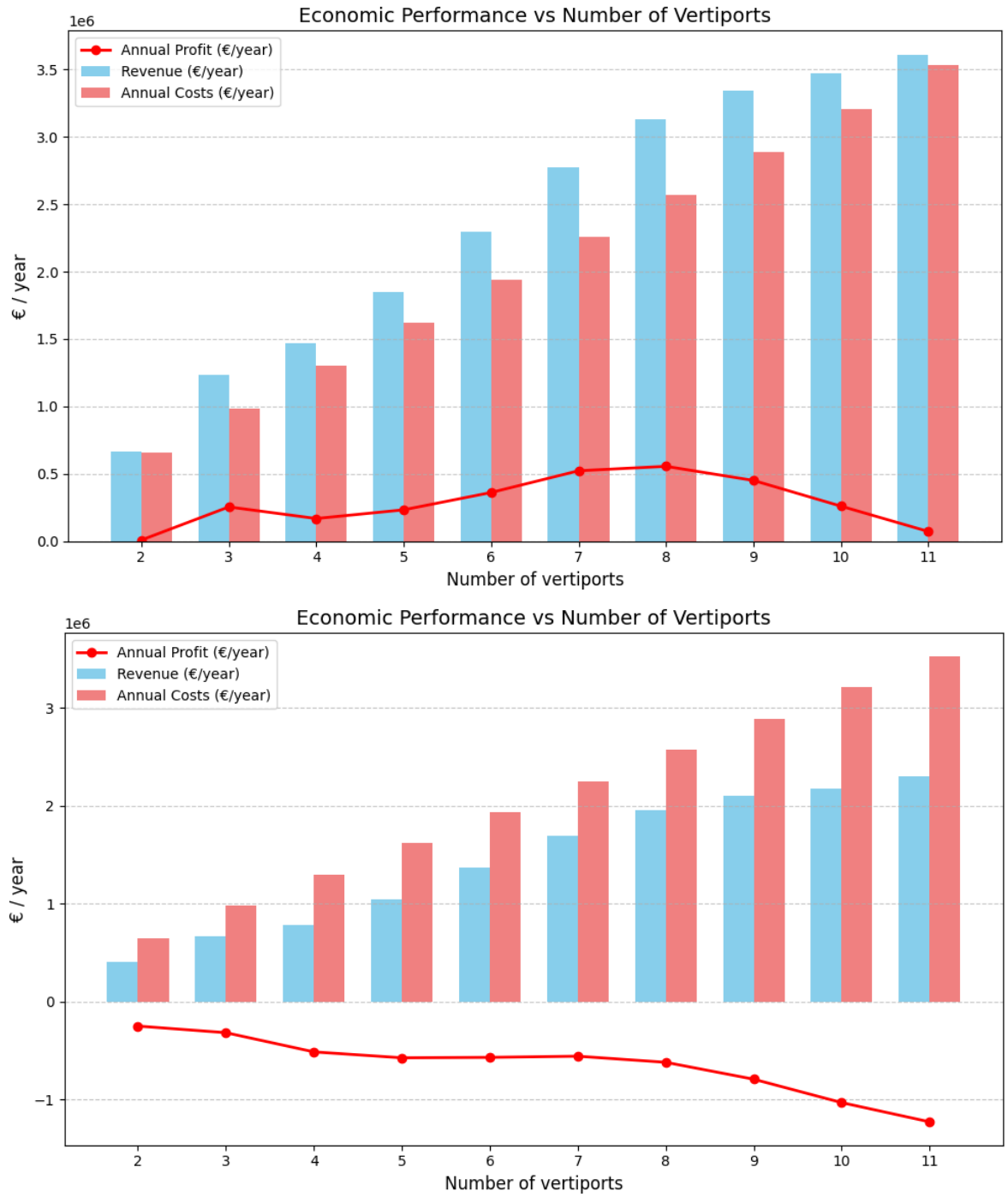


Figure 90: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario with discount for 2050. Above figure 16€ per km and below figure 20€ per km

Depending on the IAM price per km, the optimal location of vertiports may vary, but for most of the simulations performed, the optimal locations remained stable. The vertiport locations can be found in Figure 91. The first pairs to be placed (and hence the ones that generate the most amount of trips) are the vertiport in San Sebastián de la Gomera along with the vertiport in Tenerife. This vertiport is located in a zone close to Guía de Isora. The third vertiport to be placed is in Playa Santiago, close to

© –2023– SESAR 3 JU

la Gomera's main airport. Additionally and in no specific order, the remaining 5 vertiports are located in the areas of las Tajaras, Chipude, the north of la Calera, Vallehermoso and Hermiga.

We can see that most of the vertiports except one, are placed in la Gomera. This can be due to the combination of different factors.

- From the start, there is more mobility intra Gomera than between the islands of la Gomera and Tenerife. More concretely there are 2.2 times more trips intra Gomera than from la Gomera to Tenerife.
- The ferry between Los Cristianos in Tenerife and San Sebastián de la Gomera is a very competitive option. There is an internal ferry service in la Gomera, linking San Sebastián de la Gomera, Playa Santiago and Valle Gran Rey, however, this service only runs three times a day and does not offer a significant advantage with respect to other modes. As a matter of fact, other additional simulations with even lower IAM prices were implemented a posteriori to test this hypothesis. With very low prices (for example 1€ per km without discount), IAM becomes competitive with the ferry link between San Sebastián de la Gomera and with the air link between Santa Cruz de Tenerife and San Sebastián de la Gomera, placing vertiports in Los Cristianos and near the Tenerife north airport. However, these vertiports are still not the most profitable, and IAM still fails to capture significant amount of demand.

The Tenerife vertiport (Guía de Isora) is conveniently placed far away from the main port of los Cristianos, but very close to where the distance to the to islands is at its minimum. In this situation, the ferry is not as competitive because of the long access and egress time, and IAM is very competitive, due to the reduced flight distance.

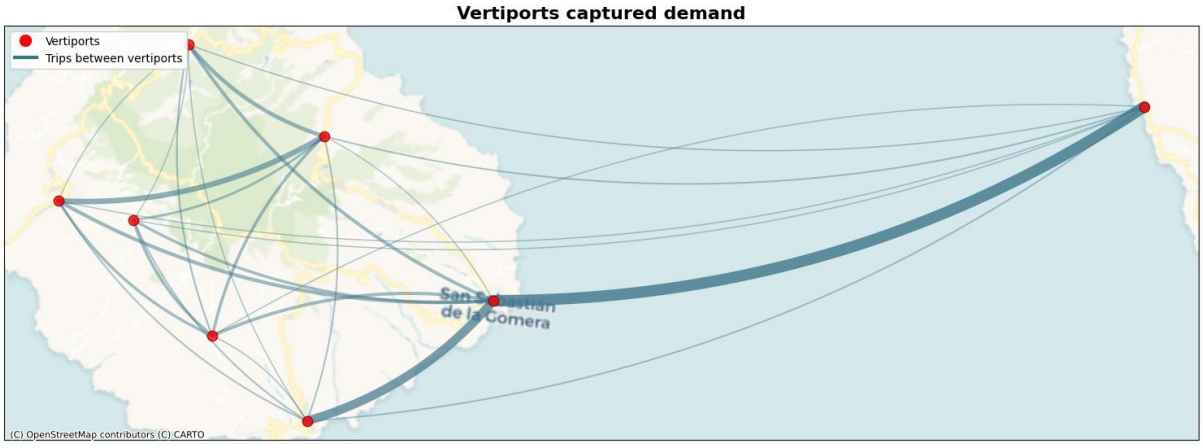


Figure 91: The 8 most profitable vertiports between la Gomera and Tenerife and the respective demand between pairs for 2050.

To simulate the 2035 scenario, we used an eVTOL with reduced range (Table 50). This effectively nullifies the possibility of inter-island travel. The results of regarding profits and demand served are presented in Figure 92 and Figure 93.

© –2023– SESAR 3 JU

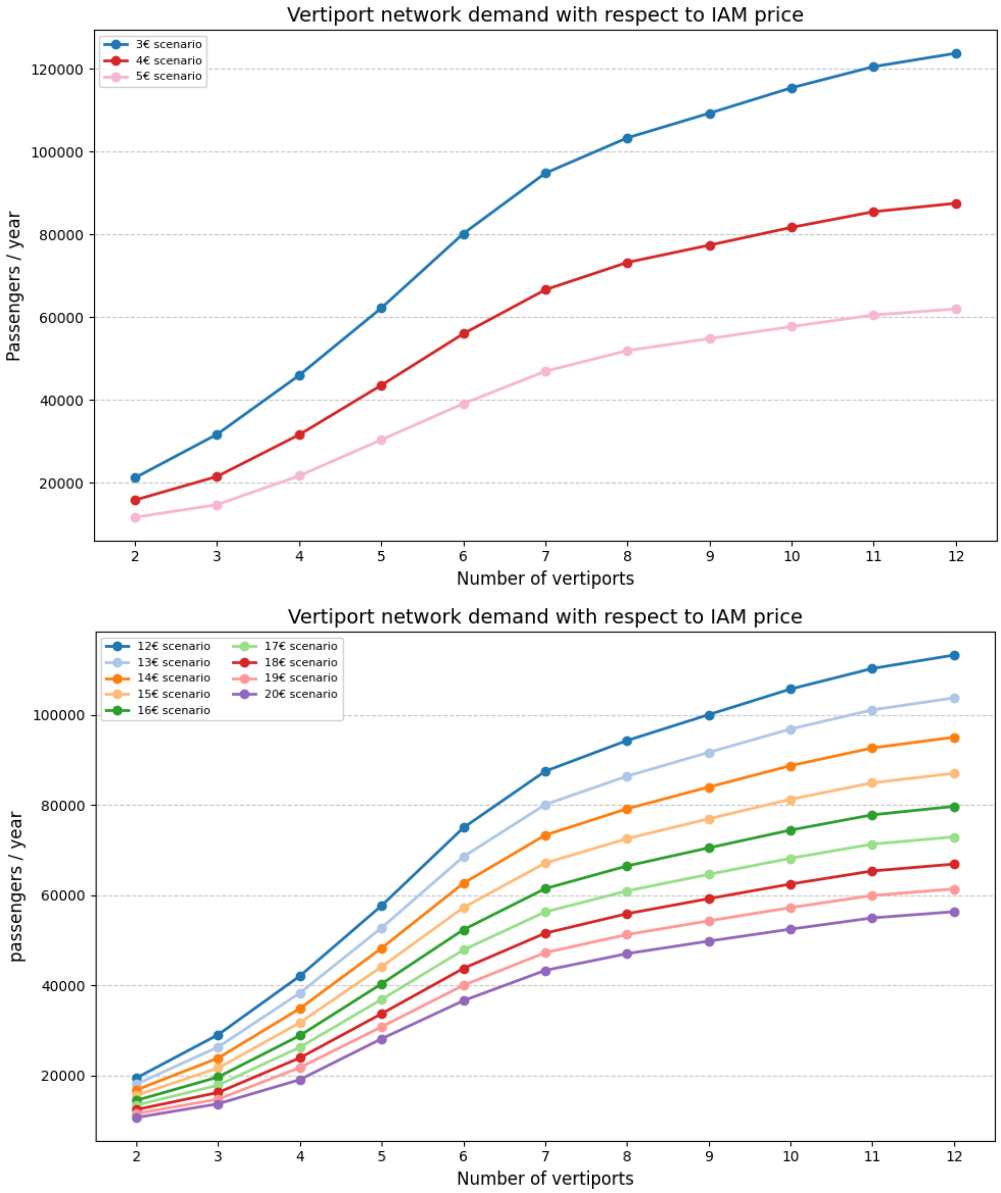


Figure 92: Vertiport network demand served with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2035

© –2023– SESAR 3 JU

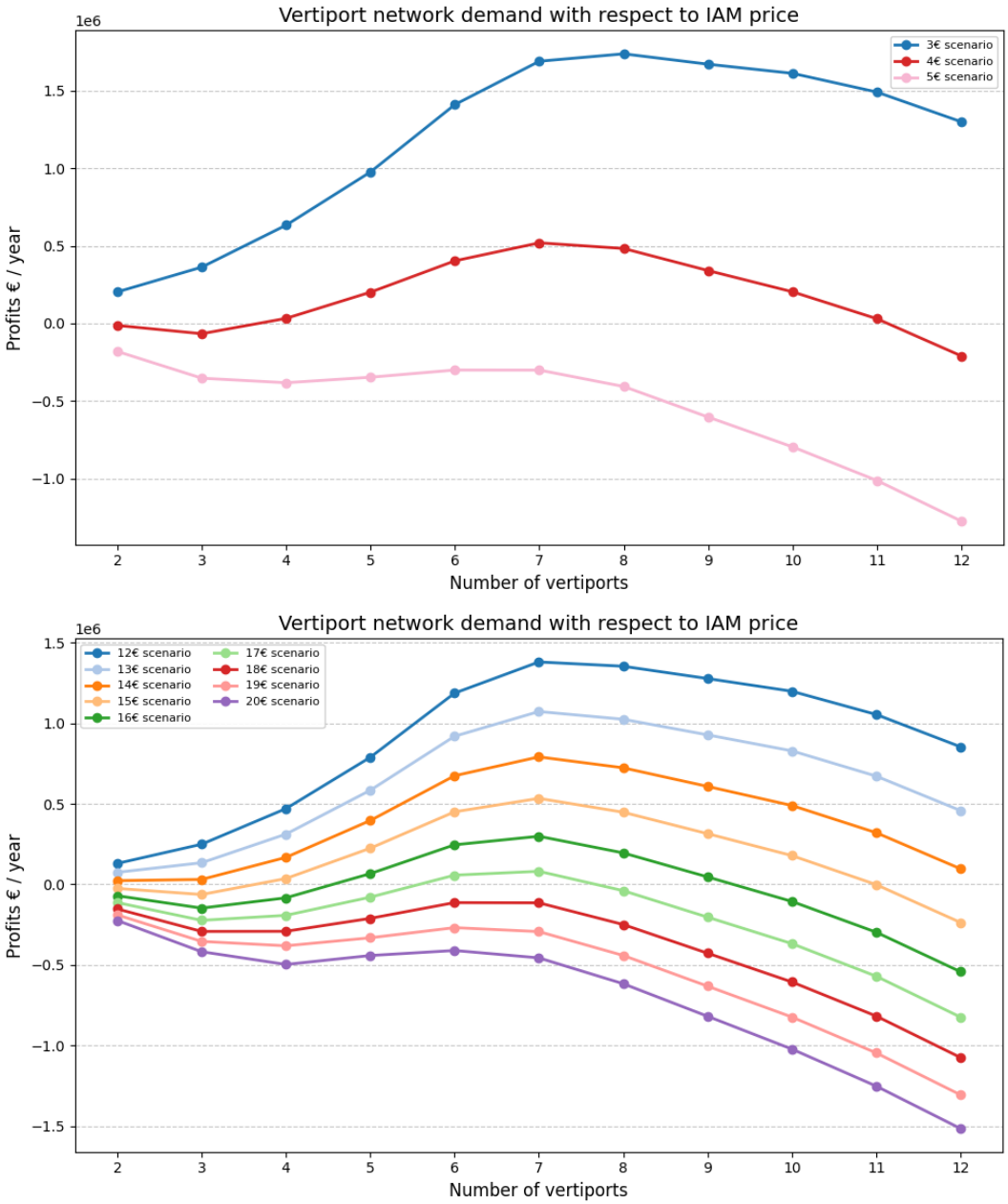


Figure 93: Vertiport network profits with respect to IAM price and number of vertiports. Scenarios without discount (above) and scenarios with discount (below) for 2035

We see a clear change of tendency at 7 vertiports. After 7 vertiports profits start to decline and captured demand grows much slower. Therefore, we consider that the optimal number of vertiports in this network is 7. This makes sense as trips between the two islands are not possible but the rest of the demand dynamics have not varied significantly. Figure 94 and Figure 95 show the revenues, costs and profits for scenarios assuming 4€ and 5€ IAM price (no discount) and 16€ and 20€ (discount). We observe that, despite reduced range, cruise speed and seats, the vertiport network can still be profitable for 4€ and 16€, albeit with less profits than in the 2050 scenario. Thus, the conclusion regarding how much passengers should pay IAM remains the same, even if most likely in 2050 IAM subsidies would be higher due to a higher technology cost.

© –2023– SESAR 3 JU

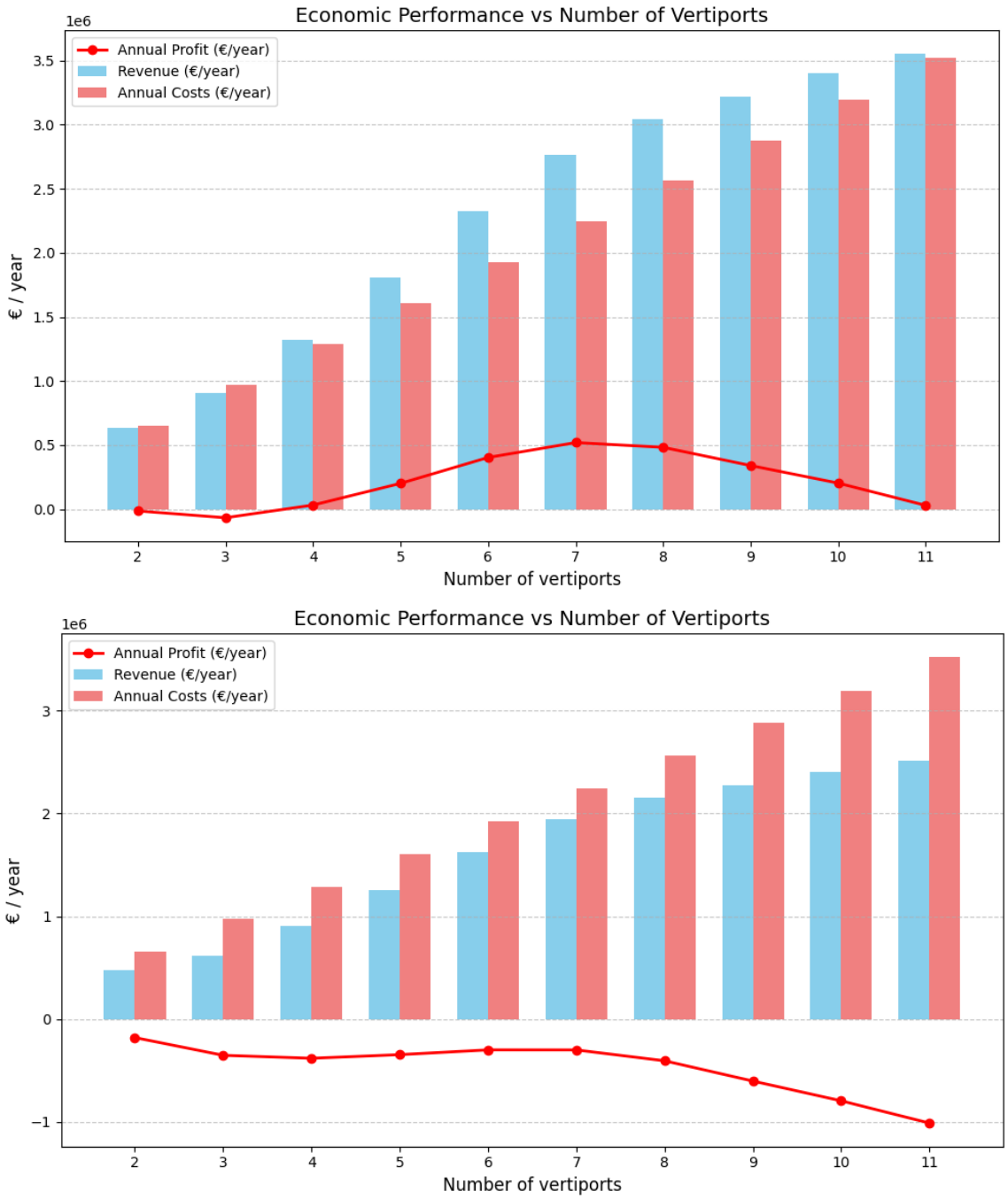


Figure 94: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario without discount for 2035. Above figure 4€ per km and below figure 5€ per km

© –2023– SESAR 3 JU

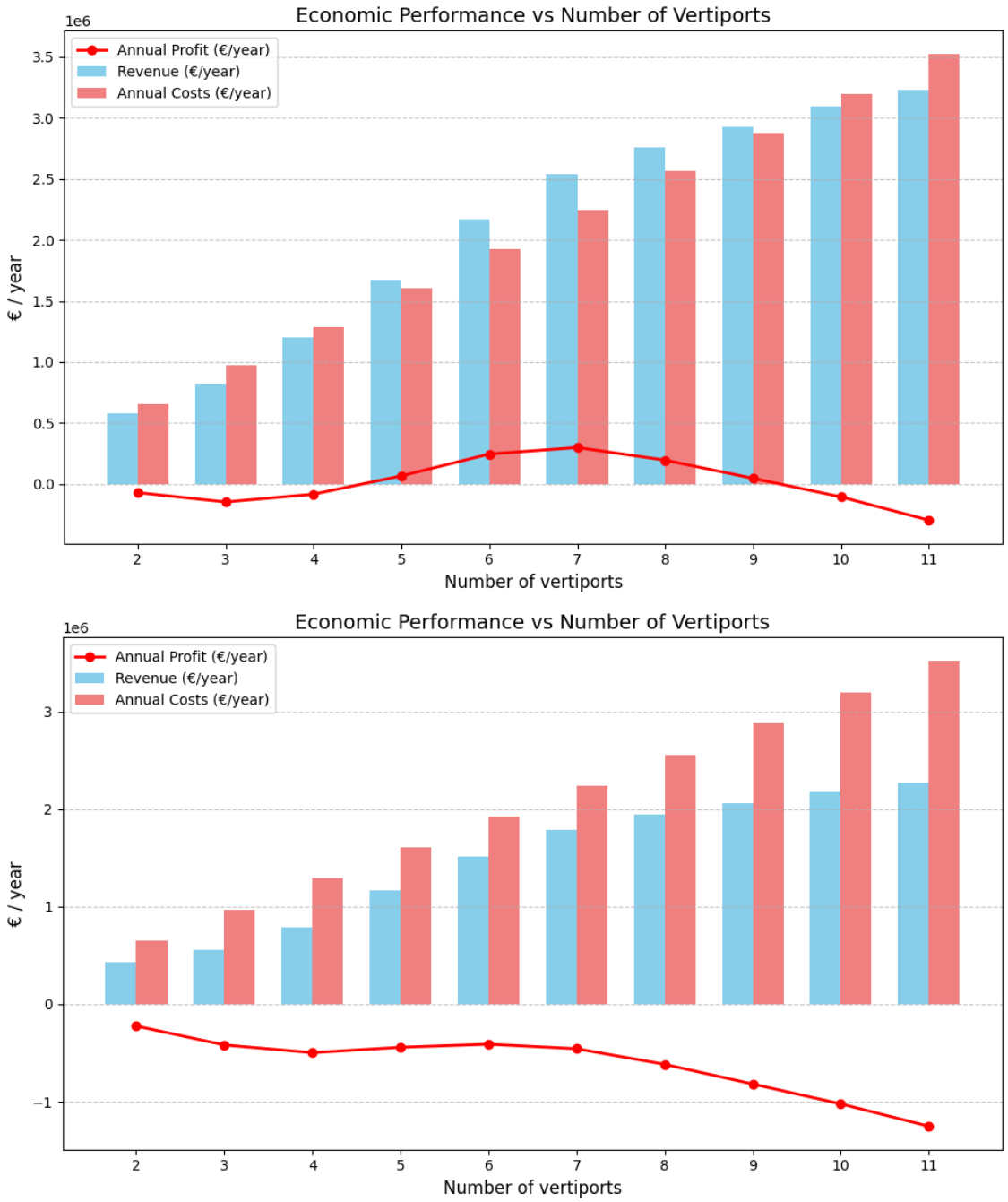


Figure 95: Annual profit, annual revenues and annual costs of the vertiport network with respect to the number of vertiports scenario with discount for 2035. Above figure 16€ per km and below figure 20€ per km.

The 7 most profitable vertiports are the same as for the 2050 scenario and the vertiport pair that captures the most trips is again the pair between San Sebastián de la Gomera and Playa Santiago (close to la Gomera airport). Figure 96 presents the different flows between vertiports.

© –2023– SESAR 3 JU

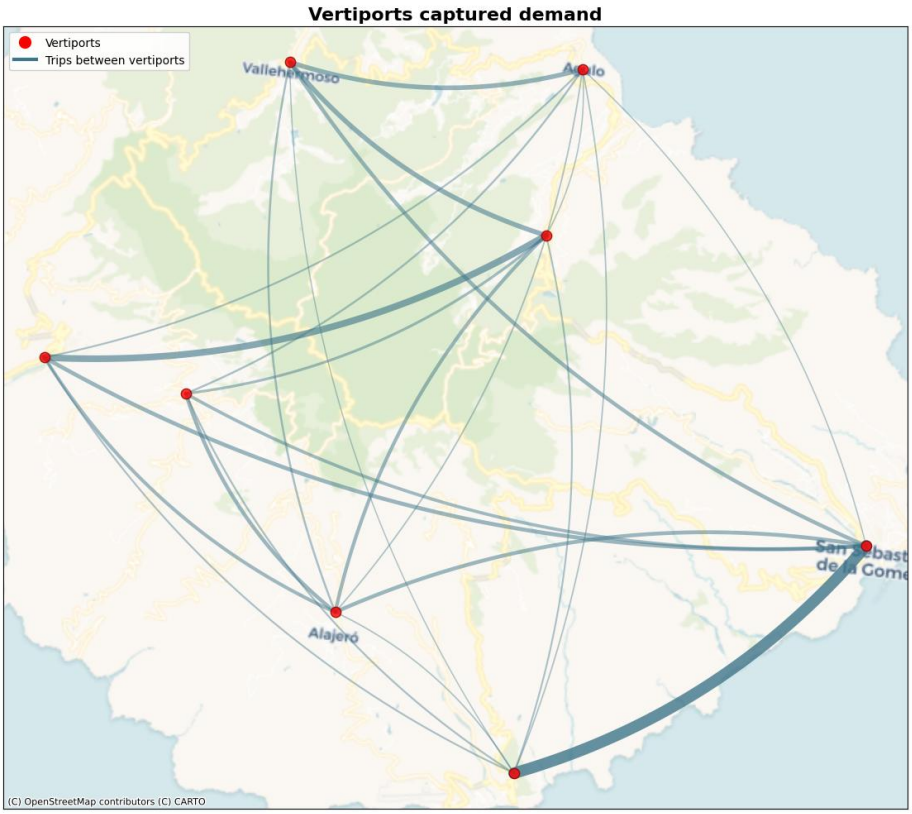


Figure 96: The 7 most profitable vertiports between la Gomera and Tenerife and the respective demand between pairs for 2035.

As an additional exercise, we simulated the 7-vertiport network of the 2035 scenario, but using the eVTOL characteristics from 2050 and estimated the difference with captured demand and profits. The results of this analysis are summarised in Figure 97. We see that with the 2050 eVTOL characteristics, the demand uptake is higher, however the network generates more profits in 2035 with the same demand. This is due to the fact that reducing the number of seats increases the total number of operations and since the operators charge for passengers and for operations this ultimately leads to an increased revenue, compensating for the lower passenger intake. This effect is interesting; however, it highlights one of the current limitations of the tool. Currently the tool is not capable to microsimulate each flight and assumes a fixed occupancy for each flight. It's likely that the difference in profits will be less severe.

© –2023– SESAR 3 JU

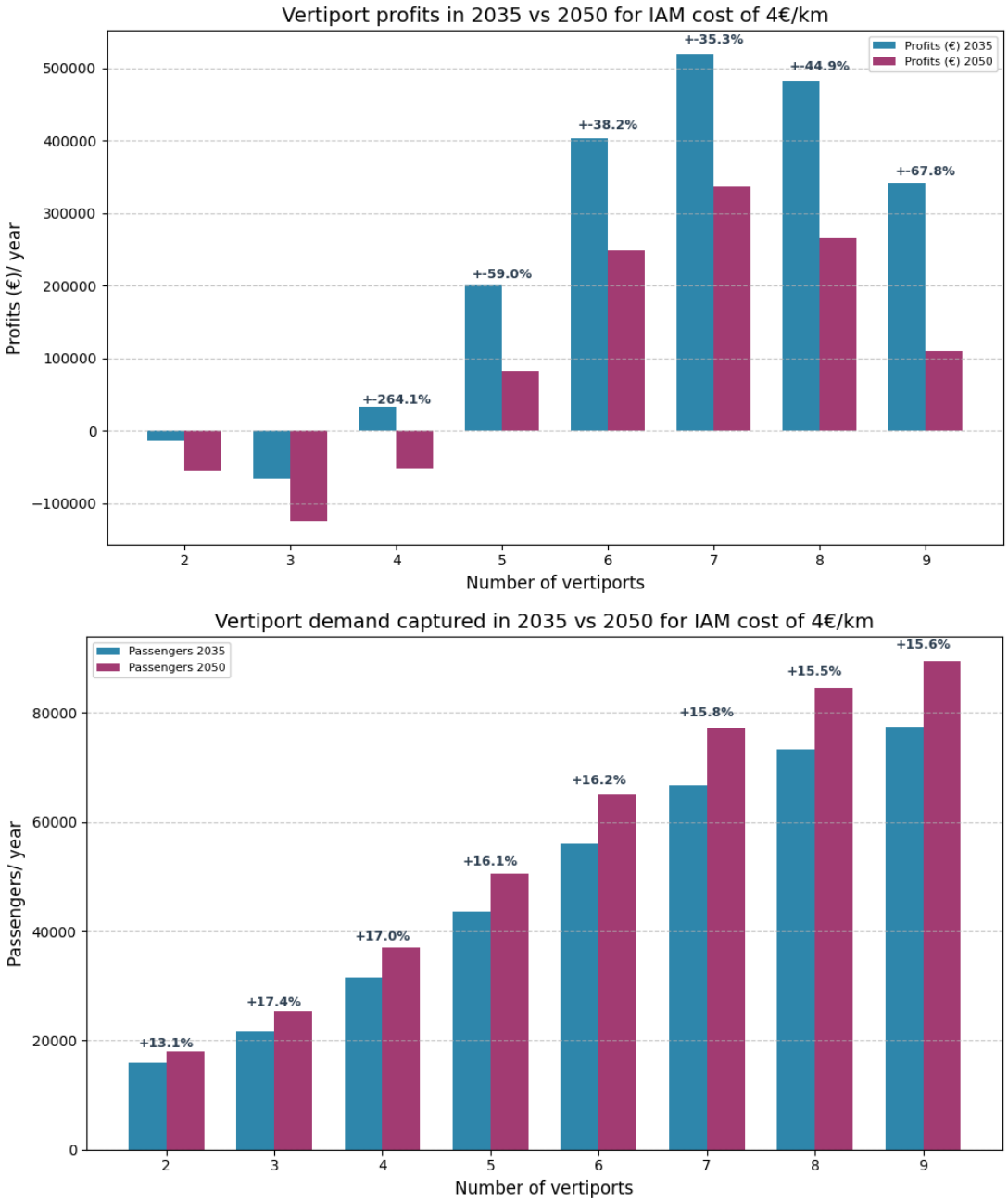


Figure 97: Profits (upper) and demand (bottom) difference with respect to the same vertiport network assuming the eVTOL characteristics of 2035 and 2050.

As a general comment, we note that no vertihub is built in any of the simulations performed since the demand is not high enough to justify the extra costs.

E.3.3 Unexpected behaviours/results

No unexpected behaviours or results were identified during the validation exercise. The outputs of the vertiport optimisation tool (the selected vertiport locations, demand, and the cost–benefit results) were consistent with prior expectations and with the underlying mobility patterns derived from MND.

© –2023– SESAR 3 JU

The only result that initially appeared counterintuitive was the higher profit obtained in the 2035 scenario despite its lower demand, which was fully explained by the structure of the revenue model (the lower seat capacity of the 2035 aircraft increases the number of operations required and therefore the per-operation revenue accruing to the vertiport operator) and does not constitute an anomalous behaviour of the tool.

E.3.4 Confidence in results of validation exercise #05

E.3.4.1. Level of significance/limitations of validation exercise results

The level of significance of the results is adequate for a TRL1 tool. The vertiport optimisation tool is able to select the most optimal vertiport and vertihub locations and allows high-level Cost Benefit Analysis and sensitivity analyses across different scenarios, pricing assumptions, and time horizons. he results should therefore be interpreted as a sound proof of concept that demonstrates the validity of the approach.

The main limitations of the current version of the tool are the following:

- The land purchase price was gathered using prices in urban land, but most likely vertiports could be cleared to be built in other land uses (for example industrial land uses). Additionally, in very dense urban areas the roof of already built buildings could be used to build such infrastructure. Taking into account these effects require an even more precise location finding.
- Visibility was an important factor in the usable days' calculation. However, only the weather stations located directly in airports and aerodromes directly measure visibility. As a first approximation, the visibility in all remaining stations was extrapolated using the closest station with visibility data. This methodology has clear limitation since visibility can vary substantially from place to place. In future versions of the tool, visibility could be implemented using ML techniques and exploiting the relation between visibility and other weather factors.
- The demand estimation is based on the current demand and mobility patterns and does not take into account potential behavioural changes or demand growth.
- Potential new trips that could be generated by the introduction of the new service are not considered. The reason for that is that the induced demand analysis showcased that induced demand was not significant unless IAM prices were significantly lower than the simulations realised for this validation exercise; however, this behaviour can be different in other areas of implementation, so would be interesting to include this on the tool in further research phases.
- The tool currently uses a fixed eVTOL occupancy to calculate the required number of operations. In future versions of the tool occupancy could be interpolated using occupancy data from related mode (taxi, shared vehicles etc).
- The running time of some simulations can be quite long, since the optimisation problem is NP-hard. To mitigate this limitation, several filters to the demand and the candidate locations were applied. In future versions of the tool other solvers will be explored as well as heuristic techniques to improve scalability.
- The expert validation was conducted in a workshop session, which have some limitations. It can lead some individuals to participate less than others or to converge towards a dominant

© –2023– SESAR 3 JU

view, the assessment is qualitative and confirms the plausibility of the results rather than their numerical accuracy; and its conclusions depend on the size and composition of the expert panel. To mitigate this, the panel was composed of experts specifically selected for their relevance to the topic and representing different points of view, and individual meetings with relevant stakeholders were performed afterwards.

- The current tool adopts the perspective of the vertiport operator. The objective function maximises the profit (or demand) of the vertiport operator and does not explicitly represent the economics of the aircraft operator, whose cost structure may respond differently to the same scenarios. Incorporating the aircraft operator into the analysis is identified as a key direction for future development. Doing so would enable a more complete economic assessment, including the financial viability of specific routes and more refined insights into IAM pricing.

E.3.4.2. Quality of validation exercises results

The quality of the validation results is in line with expectations for a tool at this level of maturity. The validation was approached along two complementary lines: an internal assessment of the consistency and plausibility of the results, and an external validation of the assumptions and preliminary results with relevant stakeholders.

The internal assessment analysed that the outputs of the tool were coherent both internally and with the underlying data. The optimisation produced coherent and explainable vertiport configurations across the two case studies, with demand, cost, and revenue figures behaving consistently with the MND-derived mobility patterns and the economic logic of the model. In the Catalan Pyrenees, demand concentrates on the central and eastern corridors, while the peripheral locations show lower demand due to higher costs. In the Canary Islands, the intra-Gomera demand is predominant, due to its higher underlying demand and the limited IAM cost combined with significant time savings on these short but road-constrained routes. In both cases, the different views of the results (IAM route demand, per-vertiport profitability, and the spatial distribution of the selected locations) are consistent and align with the demand.

The external validation was carried out with experts and stakeholders relevant to the IAM and mobility domains, with the aim of validating the key modelling assumptions and the preliminary results rather than only the final figures. This process confirmed that the assumptions adopted, regarding demand, costs, operational constraints, and the modal-shift mechanism, were reasonable and representative of the problem, and that the preliminary results were plausible and consistent with expert expectations. The feedback gathered also helped to refine the assumptions and to identify the limitations and priorities for future development documented in this section. The qualitative nature of this validation and its associated limitations are discussed above; however, the convergence between the experts' judgement and the internal consistency of the results strengthens the overall confidence in the quality of the tool's outputs.

E.3.4.3. Significance of validation exercises results

The validation results clearly demonstrate the capability of the tool to identify the optimal placement of vertiports for the case studies. Beyond the specific locations obtained, the exercise establishes a more fundamental result: that the overall methodolofy (from MND-derived demand, through the logit-based modal-shift model that estimates the probability of each trip shifting to IAM for every candidate

© –2023– SESAR 3 JU

pair of vertiports, to the optimisation of the vertiport network) is coherent, operational, and able to be applied end to end to realistic case studies.

Methodologically, it confirms that MND, when combined with a calibrated modal-choice model and an optimisation framework, can be turned into an operational decision-support instrument for IAM infrastructure planning. From an application point of view, the tool provides a quantitative, evidence-based basis for early strategic decisions on where to deploy IAM infrastructure, for assessing the financial viability of candidate networks, and for exploring their sensitivity to key parameters such as IAM pricing and the time horizon. The fact that these analyses can be performed consistently across different territorial contexts and time frames reinforces the general applicability of the approach. As with any tool at this level of maturity, the value of the results lies primarily in their relative and comparative insights rather than in the precision of the absolute figures, which remain conditioned by the input-data assumptions and limitations identified above.

E.4 Conclusions

E.4.1 Conclusions on concept clarification

The validation exercise has clarified and demonstrated the concept of an integrated, data-driven methodology for optimising IAM vertiport networks. The concept combines three elements that were shown to operate together coherently: the estimation of mobility demand from MND; the calibration of a logit modal-choice model using both MND and survey data to estimate, for each trip and each candidate pair of vertiports, the probability of shifting to IAM; and an optimisation algorithm that selects the vertiport locations maximising the operator's profit or the captured demand. The exercise confirms that this concept is well defined and internally consistent, and that it can be applied end to end to realistic case studies, producing interpretable results that connect demand, network configuration, and economic performance.

E.4.2 Conclusions on technical feasibility

The exercise confirms the technical feasibility of the proposed approach. The full pipeline was successfully implemented and executed in the two case studies, demonstrating that the methods are transferable across different territorial and temporal contexts. The optimisation, although based on an NP-hard problem, was successfully applied and produced stable and reproducible results. The integration of the heterogeneous data sources required (MND-derived demand, the calibrated logit model, weather, travel-time and cost calculations, etc) was shown to function as a coherent whole. The principal feasibility constraints, namely computational time and the granularity of certain input data (land prices, visibility, occupancy), are understood and bounded, and do not prevent the tool from fulfilling its intended purpose.

E.4.3 Conclusions on performance assessments

The performance assessment indicates that the tool meets the requirements of its intended application at the current level of maturity. The tool consistently identifies optimal locations for the vertiports and provides insights about its captured demand, costs, revenues, etc. It also captures the sensitivity of demand and profitability to the IAM price, identifying the fare ranges under which the service is financially viable. These capabilities allow the tool to support high-level cost–benefit and sensitivity analyses, which is the performance level expected for a TRL1 proof of concept. The accuracy

© –2023– SESAR 3 JU

of the absolute figures remains conditioned by the input-data limitations noted above, and should be refined as the tool matures.

E.5 Recommendations

The recommendations are organised into two groups: those aimed at raising the TRL of the tool, and those concerning future research and development of the underlying methodology.

To increase the technical maturity and usability of the tool:

- Integrate the tool with a user interface, enabling stakeholders to configure scenarios, launch simulations, and explore results interactively without direct access to the underlying code.
- Improve computational performance and scalability by, for example, exploring heuristic optimisation techniques that reduce simulation times for the NP-hard problem.

From a research and development perspective:

- Incorporate the aircraft operator point of view into the objective function. This is considered a key extension, since the current vertiport-operator perspective does not capture the aircraft operator's cost structure. A model accounting for both actors would provide a more complete and balanced economic assessment.
- Apply the tool to further contexts and case studies, to test its transferability and to consolidate its validity across a wider range of territorial and demand conditions.
- Introduce machine-learning techniques to improve key inputs such as the estimation of the visibility (and hence usable days) from related meteorological variables
- Adopt more dynamic representations of the competing modes, incorporating dynamic (e.g. dependent of the day of week or season) and travel times (e.g. reflecting congestion), so that the modal-shift estimation better reflects real-world variability.

Explore a two-stage, hierarchical approach to the problem. A first stage focused on demand, using a simplified, aggregated view of the data and rough cost–benefit estimates to identify the main areas that generate and attract trips. And a second stage zooming in on those selected areas to fine-tune the exact vertiport locations and work out the detailed costs (land, access and connection, etc.). As well as reflecting more closely how infrastructure decisions are made in practice, this approach would make the tool faster and easier to scale.

© –2023– SESAR 3 JU

Appendix F Validation exercise #06 report

F.1 Summary of the validation exercise #06 plan

As defined in the ERP SESAR Solution 0515

F.2 Deviation from the planned activities

There are no deviations from the planned activities.

F.3 Validation exercise #06 results

F.3.1 Summary of validation exercise #06 results

Exercise #06 validation objective ID	Exercise #06 validation objective title	Exercise #06 success criterion ID	Exercise #06 success criterion	Exercise #06 validation results	Exercise #06 validation objective status
OBJ-0515-ERP-006	Validation of algorithms for IAM and ground transport services optimisation	CRT-0515-TRL1-ERP-006.001	The optimisation algorithms for IAM service coordination with other modes are assessed in terms of computational efficiency, robustness under varying operational conditions, and scalability within a European regional scope. Validation has been carried out through simulation-based testing, ensuring that the results are aligned with operational feasibility, technical feasibility, and performance requirements. Additionally, the results have been validated through expert reviews conducted by external	This validation objective successfully demonstrated the optimisation algorithms for IAM and ground transport service coordination. The developed framework, including both heuristic and exact optimisation methods, was implemented and evaluated in two case studies. Comprehensive multimodal transport network graphs were generated from GTFS data and integrated with IAM operational constraints to support realistic simulation and assessment. The validation results confirmed the capability of the proposed methods to coordinate passenger routing and IAM vehicle dispatch while complementing existing public transport services. Comparative analyses highlighted the trade-off between computational efficiency and solution quality, with the heuristic approach providing faster solutions and the exact method achieving higher optimality. The assessment further demonstrated the applicability of the framework	*OK*

© –2023– SESAR 3 JU

Exercise #06 validation objective ID	Exercise #06 validation objective title	Exercise #06 success criterion ID	Exercise #06 success criterion	Exercise #06 validation results	Exercise #06 validation objective status
			stakeholders as part of the project's planned engagement activities.	across different regional transport contexts and network structures. These results provide a validated basis for analysing multimodal IAM operations, supporting transport planning and decision-making, and facilitating the future deployment of IAM services within European regional mobility systems. The findings were reviewed by stakeholders and experts, whose feedback confirmed the relevance and practical value of the proposed approach.	

Table 51. Validation exercise #06 results

F.3.2 Analysis of validation exercise #06 results per validation objective

F.3.2.1. OBJ-0515-TRL1-ERP-006 Results

This sub-subsection presents the design, implementation and validation of optimisation algorithms for IAM and ground transport services optimisation. The developed methodology addresses the coordination of multimodal transport services within a European regional context, with a focus on improving operational efficiency, robustness, and scalability under realistic constraints.

The overall workflow of the proposed approach follows a structured pipeline that links algorithm design, simulation environment development, and performance assessment. This ensures traceability between methodological development and validation outcomes, and allows a consistent comparison of different optimisation strategies under identical testing conditions.

A high-level overview of the workflow is illustrated in Figure 98, outlining the full evaluation process from algorithm development and simulation scenario design to execution and comparative performance analysis.

© –2023– SESAR 3 JU

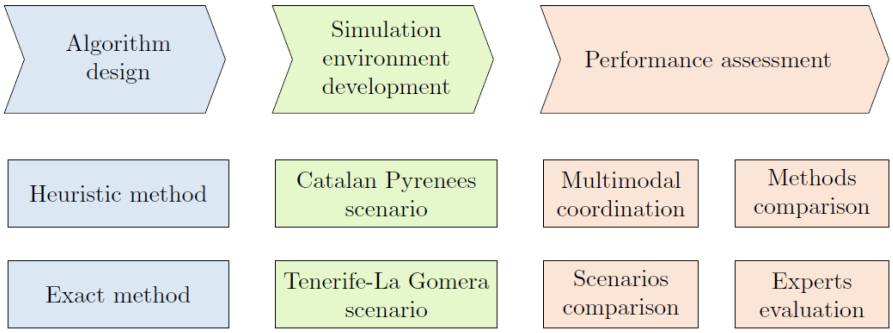


Figure 98. Workflow of the validation exercise #06.

The following paragraphs describe each component of the workflow in detail.

Algorithm design

Heuristic method

The heuristic method designed to optimise regional-scale multi-modal services for IAM. Given a set of travel demands and a fixed fleet of IAM vehicles stationed at designated vertiports, the study focuses on determining optimal dispatch strategies to ensure IAM operations complement the existing public transport network, which is considered static and provided as input data. Moreover, to enable practical cooperation between IAM and traditional transport modes, passenger journeys must also be optimised, as multi-modal integration is fundamentally human-centred and built upon the efficient movement of people. Hence, there are two interrelated sub-problems to be solved in the heuristic method:

- Firstly, IAM trajectory optimisation is NP-hard. In the single-vehicle scenario, where one IAM vehicle connects multiple OD pairs, representing the network as a directed graph reduces the task to finding a minimum-cost tree spanning all service nodes, equivalent to the Directed Steiner Tree problem, which is NP-hard. In the multi-vehicle scenario, coordinating trajectories across multiple vehicles further generalises the problem, thereby preserving its computational hardness.
- Secondly, passenger journey optimisation is also NP-hard. Since passengers have distinct OD pairs, the problem can be formulated as a Multi-Commodity Flow Problem, where each passenger represents a separate commodity whose flow through the network is optimised to minimise overall travel time or cost while satisfying vehicle capacity and routing constraints. Solving it requires routing multiple flows simultaneously through a shared network under capacity and demand constraints, making it computationally intractable in the general case.

Both sub-problems are inherently NP-hard, posing significant computational challenges even when addressed separately. Attempting to integrate trajectory and passenger journey optimisation into a unified framework, with the goal of improving overall performance, further amplifies the complexity.

In practice, there is only a little time allowed for addressing such a complex problem. To this end, a staggered rolling time horizon strategy is employed, which can not only reduce the computational burden but also mitigate the impact of uncertainty over long time horizons. As shown in Figure 99, each optimisation cycle consists of two phases: a 5-minute travel requests collection phase followed by a five-minute optimisation phase. While the current optimisation is in progress, the system concurrently gathers demand data for the upcoming time window, which covers the trips to be

© –2023– SESAR 3 JU

planned in the next scheduling cycle. This pipelined structure ensures continuous operation with minimal idle time and reduced latency. During each optimisation phase, the IAM vehicles' scheduling established in previous iterations must remain unchanged. This ensures that once a passenger's travel request is accepted, it will neither be delayed nor cancelled.

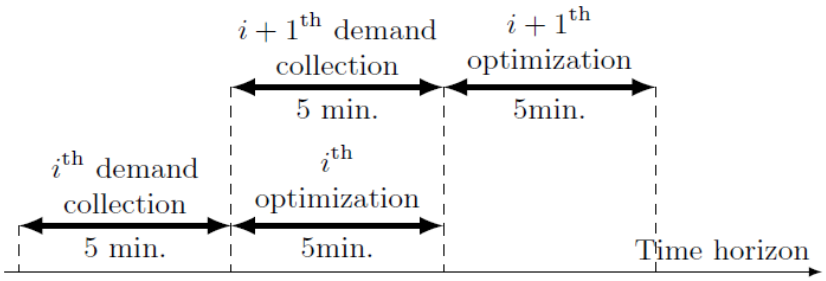


Figure 99. Optimisation cycle.

To accelerate the optimisation process, an approximate optimisation approach is employed, which strikes a balance between solution quality and computational efficiency. Figure 100 illustrates the framework of this approximate approach. A* and Dynamic Programming are used within the framework, both of which have polynomial-time complexity. Consequently, although the original problem is NP-hard, this framework provides a polynomial-time method that generates feasible, high-quality approximate solutions.

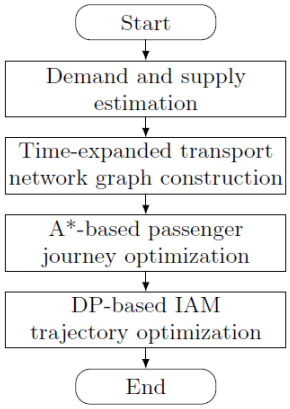


Figure 100. The framework of the heuristic method.

The first step in Figure 100 is demand and supply estimation, which serves as an initialisation step. Since this estimation can be completed prior to the following processes, it is treated as an offline step.

The second step in Figure 100 is the construction of a time-expanded transport network graph, which incorporates both the existing public transport network and the IAM service network to facilitate cooperation between IAM vehicles and public transport. This step serves as the problem formulation stage, generating the graph on which the subsequent optimisation algorithms (A* and Dynamic Programming) operate.

The third step in Figure 100 is the A*-based passenger journey optimisation. In this step, passenger journeys are optimised under the assumption of unlimited vehicle availability, meaning that passengers can move freely between nodes in the graph without constraints imposed by specific transportation modes. The decision variables correspond to the selection of edges included in each

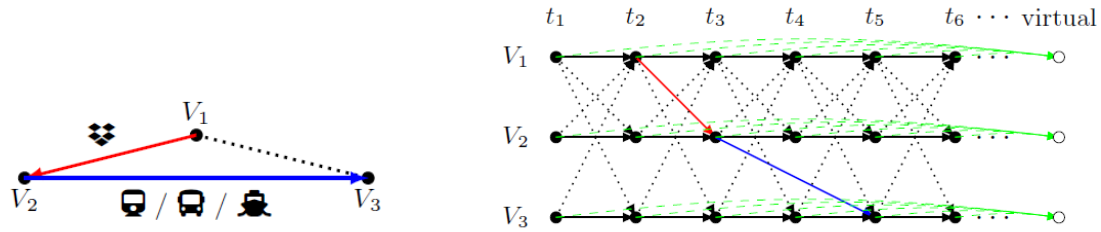
© –2023– SESAR 3 JU

passenger's path, and the constraints ensure that each path forms a continuous connection from the origin to the destination. The objective is to minimise the total cost along the selected paths. As a by-product of this process, each edge is assigned a passenger-demand-related reward reflecting its relative popularity, which serves as input for the subsequent Dynamic Programming-based vehicle dispatch optimisation.

The fourth step in Figure 100 is the Dynamic Programming-based IAM trajectory optimisation. In this step, the dispatching strategy for IAM vehicles is optimised to meet passenger demand on each edge of the graph. The optimisation determines the routes of each vehicle and their departure times, while ensuring that each IAM performs only one task at a time, routes form continuous feasible paths, and the existing transport dispatching strategy is maintained. The objective is to maximise the total passenger-demand-related reward obtained from the previous model, efficiently fulfilling passenger travel requests.

It is worth noting that iteratively optimising the passenger journey (third step) and IAM dispatching (fourth step) may yield better results. This is because the fourth step updates the supply, causing the edge costs to change accordingly. As a result, the fourth-step outcomes influence the third step. However, for the sake of computational efficiency, we do not perform this iteration.

It is clear that this framework may not achieve a global optimum, as passengers' journeys and the IAM dispatching strategy are difficult to optimise simultaneously. This situation is analogous to air traffic flow optimisation in air traffic management, where traffic flows (corresponding to passenger journeys) and sector configurations (corresponding to IAM dispatching) are challenging to optimise at the same time and are typically addressed through iterative approaches. Nevertheless, the framework provides a practical way to obtain an acceptable solution within a reasonable time frame.



(a) Public transport network. (b) Time-expanded transport network graph.

Figure 101. Time-expanded transport network graph construction.

The time-expanded transport network graph construction process is outlined in Figure 101. As shown in Figure 101 (a), a simple transportation network comprises three vertices: V_1, V_2, and V_3. The links between V_1–V_2 and V_1–V_3 are bidirectional and served by IAM vehicles, whereas the connection from V_2 to V_3 is unidirectional and operated by a bus. Based on the schedule illustrated in Table 52, an IAM is scheduled to depart from V_1 to V_2 at time t_2, and a bus is scheduled to depart from V_2 to V_3 at time t_3.

Figure 101 (b) presents the corresponding time-expanded network graph, which incorporates both the spatial structure from Figure 101 (a) and the temporal information from Table 52.

In the time-expanded graph, each column represents the set of vertices at a particular time step, while each row corresponds to a specific physical location across multiple time steps. Solid directed edges between two nodes indicate confirmed travel arcs based on the given transport schedules, whereas dotted directed edges represent candidate travel arcs that may be available but are not yet confirmed.

© –2023– SESAR 3 JU

In addition, the final column contains white vertices representing virtual destination nodes. Each black vertex in the last time step is connected to the corresponding white vertex in the same row by a zero-cost directed edge, allowing an immediate transition to the virtual node once the physical destination is reached, thereby marking the completion of the optimisation process.

Table 52. Temporal information in transportation

	O	D	T_{dep}	Duration
	V_1	V_2	t_2	$\tau_{(V_1,V_2)}$
/ /	V_2	V_3	t_3	$\tau_{(V_2,V_3)}$

A*-based passenger journey optimisation algorithm is outlined in Algorithm 1, which assigns OD pairs based on edge costs and annotates the edges with demand-related rewards, providing the basis for subsequent Dynamic Programming-based optimisation.

Algorithm 1 OD Pair Assignment with A* Path Planning.

```
Initialise the priority score of each edge to zero.
while unassigned OD pairs remain do
    Select OD pair (V_i, V_j) with highest priority
    Update network graph based on demand and residual supply
    Find lowest-cost path from V_i to V_j using A*
    if no reachable path is found then
        Remove the OD pair from travel demand table
        continue
    end if
    if lowest-cost path has non-zero residual supply then
        Assign as many passengers as possible to the path
        Update network supply by reducing assigned path capacity
        Update travel demand by subtracting assigned volume
        if remaining demand volume for (V_i, V_j) is 0 then
            Remove the OD pair from travel demand table
        end if
    else
        for all edges with no supply on the shortest path do
            Add the OD pair's demand to the edge's reward
        end for
        Remove the OD pair from travel demand table
    end if
end while
```

The cost for each edge $(V_i \rightarrow V_j)$ at time t_k can be calculated via Equation (1) , which considers multiple factors such as the time-dependent attenuation, mobility requirements, supply-demand balance, pricing adjustments, and the actual travel time between the vertices and is defined as a generalised cost function tailored for heuristic optimisation rather than the MND-provided OD travel cost. This formulation allows the model to dynamically capture both temporal and spatial variations in travel cost.

$$c_{i,j,k} = \lambda_k \cdot \eta_{i,j} \cdot \xi_{i,j,k} \cdot \zeta_{i,j} \cdot \tau_{(V_i,V_j)} \quad (1)$$

where factor λ_k denotes the attenuation coefficient which can be calculated via Equation (2), factor $\eta_{i,j}$ denotes the mobility requirement coefficient, which can be calculated via Equation (3), factor $\xi_{i,j,k}$

© –2023– SESAR 3 JU

describes the supply and demand coefficient which can be calculated via Equation (4), factor $\zeta_{i,j}$ denotes the price coefficient, which can be calculated via Equation (5), factor $\tau_{(V_i,V_j)}$ denotes the travel time from V_i to V_j.

The factor λ_k reduces the edge cost over time, making it more likely that the edge used in this time window will serve future travel demands.

$$\lambda_k = \alpha + \beta^k \tag{2}$$

where $\alpha + \beta = 1, k \in \mathbb{Z}^+, \alpha \in (0,1)$, and $\beta \in (0,1)$. When k increases from 1 to ∞, λ_k decreases from 1 to α. In this method, α and β are set to be 0.9 and 0.1, respectively, based on preliminary tests and operational considerations. These values serve as a baseline, and future work will explore alternative settings and conduct a systematic sensitivity analysis.

The factor $\eta_{i,j}$ lowers the cost of edges where passengers remain at the same location and only need to wait briefly, without requiring any mobility.

$$\eta_{i,j} = \begin{cases} 1 & i \neq j \\ 0.5 & i = j \end{cases} \tag{3}$$

where $i \neq j$ means that V_i and V_j are vertices with different physical locations, $i = j$ means that V_i and V_j are vertices with the same physical location but different in time step. If $i = j$, then passengers just need to wait at the same place for a while to transfer from V_i to V_j; otherwise, passengers need to take transportation to transfer from V_i to V_j.

The factor $\xi_{i,j,k}$ reduces the cost of edges with residual supply, with greater reductions applied to edges that have higher residuals.

$$\xi_{i,j,k} = (1-\kappa) + \frac{\kappa \cdot (d + d^*)^2}{s_{i,j,k}^2 + (d + d^*)^2} \tag{4}$$

where $s_{i,j,k}$ describes the remaining supply from vertex V_i to vertex V_j at time t, d describes the demand of an OD pair, d^* denotes the residual demand of the preceding OD pairs carried over from previous iterations. When $s_{i,j,k}$ increases from 0 to $(d + d^*)$, $\xi_{i,j,k}$ decreases from 1 to $1 - \frac{\kappa}{2}$. When $s_{i,j,k}$ increases from $(d + d^*)$ to ∞, $\xi_{i,j,k}$ decreases from $1 - \frac{\kappa}{2}$ to $1 - \kappa$. In this method, κ is set to be 0.8. While it provides a reasonable baseline, future research will further examine its effect on system performance.

The factor $\zeta_{i,j}$ is the cost ratio, which determines the relative expense of IAM travel compared to conventional modes: a ratio of 1 means IAM costs are equivalent to those of rail or bus transport, while a ratio of 20 indicates that IAM costs are twenty times higher.

$$\zeta_{i,j} = \begin{cases} \Upsilon & \text{from } V_i \text{ to } V_j \text{ requires IAM} \\ 1 & \text{other} \end{cases} \tag{5}$$

where $\zeta_{i,j}$ increases the travel cost from vertex V_i to vertex V_j if IAM is required, since Υ is always larger than 1.

Dynamic Programming-based IAM vehicle dispatching optimisation is based on the edge rewards (the edge priorities defined above). It plans IAM vehicles sequentially (one-by-one), with each trajectory

© –2023– SESAR 3 JU

obtained via a single Dynamic Programming step on the time-expanded transport network, which is a directed acyclic graph. Each Dynamic Programming step solves a single-source maximum-reward problem. Since edges only connect to later time layers, the topological order is naturally given by the temporal structure, allowing Dynamic Programming to proceed directly in chronological order. For a single run, each node is visited once and each edge relaxed once, resulting in relatively low computational complexity.

Although the Dynamic Programming formulation is inherently suited for single-source, single-sink problems, some IAM vehicles do not have fixed destinations. To accommodate these cases, as shown in Figure 102, a virtual sink node is introduced manually, enabling the DP to handle trajectories without predetermined endpoints.

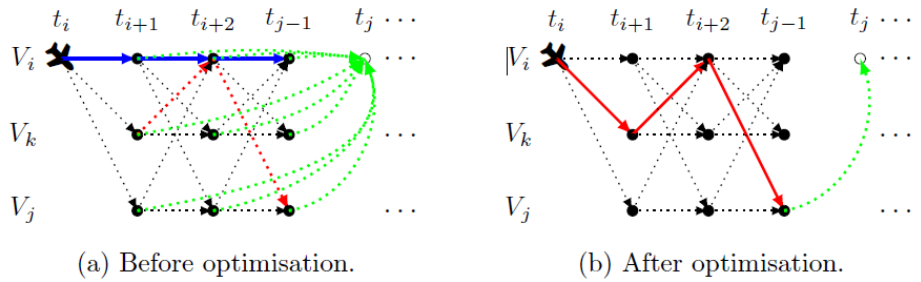


Figure 102. Single IAM vehicle routing with departure constraints. The blue solid edges represent the original route of the IAM vehicle. The black dotted edges denote candidate edges that the vehicle may traverse. The red dotted edges indicate high-priority edges. The red solid edges represent the optimised route of the IAM vehicle. The green dotted edges represent the auxiliary edges directed to a virtual vertex.

Exact method

Although the heuristic method provides an approximate solution, passenger journeys and IAM dispatch decisions are highly coupled. Treating them separately fails to fully capture their mutual dependencies, which may lead to suboptimal system-level performance.

Motivated by this limitation, an exact method that explicitly models the interaction between passenger routing and IAM dispatch is developed by formulating the problem as a Mixed-Integer Linear Programming model.

For a clearer understanding of the problem studied, the superscripts, indices, sets, parameters, variables are summarized in Table 53.

It worth noting that $\mathbf{n}_{v,t}$, $\dot{\mathbf{n}}^{\text{air}}_{v,t}$, $\dot{\mathbf{n}}^{\text{ground}}_{v,t}$, $\mathbf{z}_{i,a,t}$, and $\mathbf{z}_g$ denote passenger-related vectors of dimension equal to the total number of stations, where the kth element of each vector corresponds to the number of passengers with destination station k. Moreover, since the ground transit leg g already includes the time information, the index t is omitted whenever g is specified.

Table 53. Notations

Sets	$\mathcal{A}$	set of vertiport connections
	$\mathcal{G}$	set of ground transit legs
	$\mathcal{I}$	set of IAMs
	$\mathcal{T}$	set of timestamps
	$\mathcal{V}$	set of all the stations

© –2023– SESAR 3 JU

	$\mathcal{V}^{\text{air}} \subset \mathcal{V}$	set of vertiports
	$\mathcal{V}^{\text{ground}} \subset \mathcal{V}$	set of ground stations
	$\{s\}$	set of virtual sink
Indices	$a \in \mathcal{A}$	indices of valid air connections
	$g \in \mathcal{G}$	indices of ground transit legs
	$i \in \mathcal{I}$	indices of IAMs
	$t \in \mathcal{T}$	indices of timestamps
	$v, u \in \mathcal{V}$	indices of vertices
Parameters	Δ	time interval
	$\tau_{v,u}$	travel time between vertiports
	τ_a	travel time of air connection a
	τ_g	travel time of transit leg g
	Υ	air/ground unit distance cost ratio
	ω	time-cost weight ratio
	$c_{i,t}^{\text{air}}$	capacity of IAM i at t
	c_g^{ground}	capacity of transit leg g
	g	ground transit leg
	l	locality threshold
	N_{v,t^0}	initial passengers at v
	r	endurance of IAM i at t
	t^0	first timestamp
	t^*	last timestamp
	f	fulfillment rate
Functions	$arr(a, v, t)$	whether a arrive at v at t
	$dep(a, v, t)$	whether a departure from v at t
	$arr(g, v, t)$	whether g arrive at v at t
	$dep(g, v, t)$	whether g departure from v at t
	$V^{\text{source}}(i)$	spatial origin (vertex) of i
	$V^{\text{sink}}(i)$	spatial destination (vertex) of i
	$T^{\text{source}}(i)$	temporal origin (time) of i
	$T^{\text{sink}}(i)$	temporal destination (time) of i
Variables	$\mathbf{n}_{v,t}$	total passengers at v at t
	$\dot{\mathbf{n}}_{v,t}^{\text{air}}$	passengers change via air
	$\dot{\mathbf{n}}_{v,t}^{\text{ground}}$	passengers change via ground
	$x_{i,v,t}$	existence of IAM i at v at t
	$y_{i,(v,u),t}$	IAM i from v to u at t
	$y_{i,a,t}$	IAM i start flying a at t
	$\mathbf{z}_{i,(v,u),t}$	passengers on i from v to u at t
	$\mathbf{z}_{i,a,t}$	passengers on i start flying a at t
	$\mathbf{z}_g$	passengers on ground leg g

© –2023– SESAR 3 JU

The optimisation problem integrates two objectives into a single scalar function. The first component seeks to maximise the share of travellers completing their trips within four hours, in line with Flightpath 2050 . The second term minimises total travel costs, encompassing both air and ground transportation, representing a general efficiency objective. The combined objective function is expressed as follows:

$$min \sum_{\forall v \in V} \sum_{\substack{\forall u \in V \\ u \neq v}} \mathbf{n}_{v,t*\{u\}} + \omega \Upsilon \sum_{\forall t \in T} \sum_{\forall i \in I} \sum_{\forall v \in V} \sum_{\forall u \in V} \tau_{v,u} ||\mathbf{z}_{i,(v,u),t}|| + \omega \sum_{\forall t \in T} \sum_{\forall g \in G} \tau_g ||\mathbf{z}_g|| \quad (6)$$

where $\omega > 0$ denotes the time-cost weight ratio, balancing the relative importance of timely arrivals and total travel costs; Υ denotes the air/ground unit distance cost ratio. For example, a value of $\Upsilon = 1$ indicates that travelling by IAM incurs the same cost per unit distance as ground transportation modes. Since IAMs are generally faster than existing transport options, this method sets Υ greater than 1; otherwise, many passengers would prefer travelling by IAM, creating direct competition between IAM services and public transport.

Since ω, Υ, $\tau_{v,u}$, and τ_g are constant parameters, the objective function in Equation (6) is a linear combination of the decision variables. Therefore, the objective function proposed in this method is linear.

The first term in Equation (6) represents the total number of passengers who have not reached their destination within four hours. Minimising this term increases the fulfilment rate f, defined as the proportion of passenger demand that is satisfied, as shown in Equation (7).

$$f = \frac{\sum_{\forall v \in \mathcal{V}} \sum_{\forall u \in \mathcal{V}} \| \mathbf{n}_{v,t^*} \|_1 - \sum_{\forall v \in \mathcal{V}} \sum_{\substack{\forall u \in \mathcal{V} \\ u \neq v}} \mathbf{n}_{v,t^*}[u]}{\sum_{\forall v \in \mathcal{V}} \sum_{\forall u \in \mathcal{V}} \| \mathbf{n}_{v,t^*} \|_1} \quad (7)$$

where $\sum_{\forall v \in \mathcal{V}} \sum_{\forall u \in \mathcal{V}} \| \mathbf{n}_{v,t^*} \|_1$ is a constant representing the total number of passengers.

The second term in Equation (6) represents the total cost incurred by passengers travelling with IAMs. The longer a passenger travels with an IAM, the higher the associated cost.

The third term in Equation (6) represents the total cost incurred by passengers travelling via ground transport modes, such as trains and buses. Due to the air-to-ground unit distance cost ratio Υ, travelling by ground transport is always less expensive than travelling with IAMs.

Passengers whose demand cannot be fully satisfied by the end of the planning horizon are rejected at the time of request submission and are therefore prevented from entering the transport network and consuming resources unnecessarily. This mechanism is automatically enforced by the objective function: for any passenger, if the optimiser determines that allowing the passenger to travel in the transport network—thereby increasing the second and third terms of the objective function—does not reduce the first term by satisfying their demand, then no travel is assigned to that passenger.

The constraints considered in this method can be divided into five categories: existence constraints, dispatching constraints, reachability constraints, flow constraints, and capacity constraints.

$$\sum_{v \in V^{air} \cup \{s\}} x_{i,v,t} \leq 1, \forall i \in I, \forall t \in T \quad (8a)$$

$$x_{i,s,t} \leq x_{i,s,t+\Delta}, \forall i \in I, \forall t \in T \quad (8b)$$

© –2023– SESAR 3 JU

Co-funded by the European Union

$$x_{i,V^{\text{source}}(i),T^{\text{source}}(i)} + x_{i,V^{\text{sink}}(i),T^{\text{sink}}(i)} = 2, \forall i \in I \quad (8c)$$

$$y_{i,(v,u),t} = 0, \forall i \in I, \forall v, u \in V^{\text{air}}, \forall t \in \{t | t + \tau_{v,u} > t^*\} \quad (8d)$$

$$\sum_{u \in V^{air}} y_{i,(v,u),t} \leq x_{i,v,t}, \forall i \in I, \forall v \in V^{\text{air}}, \forall t \in T \quad (8e)$$

$$\sum_{u \in V^{air}} y_{i,(v,u),t-\tau_{v,u}} - y_{i,(v,u),t} = x_{i,v,t+\Delta} - x_{i,v,t}, \forall i \in I, \forall v \in V^{\text{air}}, \forall t \in T \quad (8f)$$

$$y_{i,(v,u),t}\tau_{v,u} \leq r, \forall i \in I, \forall v, u \in V^{\text{air}}, \forall t \in T \quad (8g)$$

$$\mathbf{n}_{v,t^0} = \mathbf{N}_{v,t^0}, \forall v \in V \quad (8h)$$

$$\dot{\mathbf{n}}_{v,t}^{\text{air}} = \sum_{u \in V^{air}} z_{i,(u,v),t-\tau_{u,v}} - z_{i,(v,u),t}, \forall v \in V^{\text{air}}, \forall t \in T \quad (8i)$$

$$\dot{\mathbf{n}}_{v,t}^{\text{ground}} = \sum_{arr(g,v,t)=1} z_g - \sum_{dep(g,v,t)=1} z_g, \forall v \in V, \forall t \in T \quad (8j)$$

$$\mathbf{n}_{v,t+\Delta} = \mathbf{n}_{v,t} + \dot{\mathbf{n}}_{v,t}^{\text{air}} + \dot{\mathbf{n}}_{v,t}^{\text{ground}}, \forall v \in V, \forall t \in T \quad (8k)$$

$$\left|z_{i,(v,u),t}\right| \leq c_{i,t}^{\text{air}} y_{i,(v,u),t}, \forall i \in I, \forall v, u \in V^{\text{air}}, \forall t \in T \quad (8l)$$

$$\left|z_g\right| \leq c_g^{\text{ground}}, \forall g \in G \quad (8m)$$

The **existence** constraints for IAMs are defined in constraints (8a)-(8c). Constraints (8a) ensure that each IAM can be located at most at one vertiport (including a virtual sink s) or in flight at any given time. If an IAM does not have a specified destination, the virtual sink s is assigned as its destination. Constraints (8b) ensures that once an IAM reaches the virtual sink s, it remains stationary. Constraints (8c) specifies the origin and destination for each IAM.

The **dispatching** constraints for IAMs are defined in constraints (8d) - (8f). Constraints (8d) ensures that all IAMs arrive at their destinations by the final timestamp. In other words, no IAM remains in flight at the end of the horizon. Constraints (8e) require that an IAM may be dispatched from vertiport v to any other vertiport only if it is present at vertiport v at that time. In this method, charging time is not explicitly modelled as a separate component. For simplicity, it is incorporated into the in-flight time of IAM operations, thereby being implicitly accounted for within the overall travel time estimation. Constraint (8f) captures the relationship between the existence of an IAM and its dispatch.

The **reachability** constraints for IAMs are specified in constraint (8g). These constraints require that, if an IAM is dispatched from vertiport v to vertiport u at time t, the corresponding flight time $\tau_{v,u}$ does not exceed the endurance of the IAM.

The **flow** constraints for passengers are provided in constraints (8h) - (8k). Constraints (8h) define the initial passenger distribution across all vertices. Constraints (8i) and (8j) specify the net changes in passenger flow at vertex v and time t resulting from IAMs and ground transportation modes, respectively. Constraint (8k) enforces passenger conservation by accounting for these flow changes.

The **capacity** constraints are specified in constraints (8l) and (8m). Those constraints require the number of passengers on those vehicles must not exceed their capacity.

© –2023– SESAR 3 JU

Besides, as shown in Equation (8), all sub-constraints considered in this method are linear with respect to the decision variables. Each sub-constraints consist solely of linear combinations of decision variables and constant parameters, without introducing any non-linear terms.

As both the objective function and the constraints considered in this method are linear. Therefore, the problem formulated in this method is a Mixed-Integer, which has the potential to be solved using commercial solvers such as CPLEX to obtain globally optimal solutions for small- to medium-scale instances.

Table 54 summaries how the number of decision variables grows with problem size, providing insight into whether the proposed formulation can be solved using CPLEX. Given $|\mathcal{T}| \approx 50$, $|\mathcal{V}| \approx 150$, $|\mathcal{V}|^{\text{air}} \approx 50$, $|\mathcal{I}| \approx 30$, and $|\mathcal{G}| \approx 25\,000$, the total number of decision variables reaches 572 700 000. Although the problem is formally defined, it quickly becomes intractable due to its enormous size—reflecting the NP-hard nature of the formulation—and often exceeds the memory limits of standard solvers.

Table 54. Scalability of decision variables. ($|\mathcal{T}| \approx 50$, $|\mathcal{V}| \approx 150$, $|\mathcal{V}|^{\text{air}} \approx 50$, $|\mathcal{I}| \approx 30$, and $|\mathcal{G}| \approx 25\,000$)

Variables	Size	Expectation
$\mathbf{n}_{v,t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^2$	125 000
$\dot{\mathbf{n}}_{v,t}^{\text{air}}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert \cdot \lvert\mathcal{V}\rvert^{\text{air}}$	375 000
$\dot{\mathbf{n}}_{v,t}^{\text{ground}}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^2$	1 125 000
$x_{i,v,t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^{\text{air}} \cdot \lvert\mathcal{I}\rvert$	75 000
$y_{i,(v,u),t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^{\text{air}^2} \cdot \lvert\mathcal{I}\rvert$	3 750 000
$\mathbf{z}_{i,(v,u),t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert \cdot \lvert\mathcal{V}\rvert^{\text{air}^2} \cdot \lvert\mathcal{I}\rvert$	562 500 000
$\mathbf{z}_g$	$\lvert\mathcal{V}\rvert \cdot \lvert\mathcal{G}\rvert$	3 750 000
Total		572 700 000

The main culprit is the combinatorial growth of $\mathbf{z}_{i,(v,u),t}$, which represents connections between pairs of vertiports. Its size scales as $|\mathcal{T}| \cdot |\mathcal{V}| \cdot |\mathcal{V}|^{\text{air}^2} \cdot |\mathcal{I}|$, explaining the explosive increase in the total number of variables.

To make the problem tractable with CPLEX, developing a more efficient representation of vertiport connections is essential. In this regard, sparse the connections between vertiports, making the formulated Mix-Integer Linear Programming tractable is necessary. Specifically, a locality-based nearest neighbour approach is used to reconstruct the vertiport network, ensuring that closely located vertiports have dense connections, while distant vertiports have sparse connections. This sparsification reflects real-world patterns: transport demand is high within regions, but relatively low between regions.

The pseudo code of the locality-based nearest neighbour approach is given in Algorithm 2. For each vertiport $v \in \mathcal{V}^{\text{air}}$, the algorithm iterates over all other vertiports $u \in \mathcal{V}^{\text{air}}$ and computes the pairwise distance $dist(v,u)$. If the distance is smaller than the specified locality threshold l, an edge (v,u) is added to the connection set $\mathcal{A}$, thereby establishing dense local connectivity. Simultaneously, the nearest vertiport v^* and its corresponding distance d^* are recorded for v. After examining all vertiports, if the closest vertiport lies beyond the threshold l, a connection (v,v^*) is added to ensure that every vertiport maintains at least one connection, preventing isolated nodes. This procedure results in a sparse vertiport network that preserves local clusters.

© –2023– SESAR 3 JU

Co-funded by the European Union

Algorithm 2 Locality-based nearest neighbour.

Require: Vertiports set $\mathcal{V}^{air}$, locality threshold l
Ensure: Set of connections $\mathcal{A}$

```
A ← ∅
for v ∈ V^air do
    d* ← ∞
    v* ← null
    for u ∈ V^air do
        d ← dist(v, u)
        if d < l then
            A ← A ∪ {(v, u)}
        end if
        if d < d* then
            d* ← d
            v* ← u
        end if
    end for
    if d* > l then
        A ← A ∪ {(v, v*)}
    end if
end for
```

Using this method, the number of connections between vertiports is reduced from quadratic to approximately linear in the number of vertiports, substantially improving scalability and computational efficiency for large-scale networks. Consequently, the original Mixed-Integer Linear Programming formulation is reformulated to ensure tractability when solved with CPLEX.

The reformulated Mixed-Integer Linear Programming is as follows:

$$min \sum_{\forall v \in V} \sum_{\substack{\forall u \in V \\ u \neq v}} \mathbf{n}_{v,t*\{u\}} + \omega \Upsilon \sum_{\forall t \in T} \sum_{\forall i \in I} \sum_{\forall a \in A} \tau_a ||\mathbf{z}_{i,a,t}|| + \omega \sum_{\forall t \in T} \sum_{\forall g \in G} \tau_g ||\mathbf{z}_g|| \tag{9}$$

Subject to:

$$\sum_{v \in V^{air} \cup \{s\}} x_{i,v,t} \leq 1, \forall i \in I, \forall t \in T \tag{10a}$$

$$x_{i,s,t} \leq x_{i,s,t+\Delta}, \forall i \in I, \forall t \in T \tag{10b}$$

$$x_{i,V^{\text{source}}(i),T^{\text{source}}(i)} + x_{i,V^{\text{sink}}(i),T^{\text{sink}}(i)} = 2, \forall i \in I \tag{10c}$$

$$y_{i,a,t} = 0, \forall i \in I, \forall a \in A, \forall t \in \{t | t + \tau_a > t^*\} \tag{10d}$$

$$\sum_{dep(a,v,t)=1} y_{i,a,t} \leq x_{i,v,t}, \forall i \in I, \forall v \in V^{\text{air}}, \forall t \in T \tag{10e}$$

$$\sum_{arr(a,v,t)=1} y_{i,a,t} - \sum_{dep(a,v,t)=1} y_{i,a,t} = x_{i,v,t+\Delta} - x_{i,v,t}, \forall i \in I, \forall v \in V^{\text{air}}, \forall t \in T \tag{10f}$$

$$\mathbf{n}_{v,t^0} = \mathbf{N}_{v,t^0}, \forall v \in V \tag{10g}$$

© –2023– SESAR 3 JU

$$\dot{\mathbf{n}}_{v,t}^{\text{air}} = \sum_{u \in V^{air}} z_{i,(u,v),t-\tau_{u,v}} - z_{i,(v,u),t}, \forall v \in V^{\text{air}}, \forall t \in T \quad (10h)$$

$$\dot{\mathbf{n}}_{v,t}^{\text{ground}} = \sum_{arr(g,v,t)=1} z_g - \sum_{dep(g,v,t)=1} z_g, \forall v \in V, \forall t \in T \quad (10i)$$

$$\mathbf{n}_{v,t+\Delta} = \mathbf{n}_{v,t} + \dot{\mathbf{n}}_{v,t}^{\text{air}} + \dot{\mathbf{n}}_{v,t}^{\text{ground}}, \forall v \in V, \forall t \in T \quad (10j)$$

$$\left|z_{i,a,t}\right| \leq c_{i,t}^{\text{air}} y_{i,a,t}, \forall i \in I, \forall a \in A, \forall t \in T \quad (10k)$$

$$\left|z_g\right| \leq c_g^{\text{ground}}, \forall g \in G \quad (10l)$$

Compared with the original formulation, two modifications are made. First, the air connections previously denoted by the subscripts (v,u) and (u,v) are replaced by a unified index $a \in \mathcal{A}$. Accordingly, the parameters and variables $\tau_{u,v}$, $\tau_{v,u}$, $y_{i,(v,u),t}$, and $\mathbf{z}_{i,(v,u),t}$ are reformulated as τ_a, $y_{i,a,t}$, and $\mathbf{z}_{i,a,t}$, respectively. Second, constraint (8g) is removed, since all unreachable air connections have already been eliminated during the sparsification process, and the remaining air connections inherently satisfy this constraint.

The scalability of the decision variables after sparsification is reported in Table 55. Compared with the results in Table 54, the total number of decision variables is reduced to 110 640 000, indicating that only 20% of the original variables are retained. This reduction results in a substantially smaller Mixed-Integer Linear Programming model and significantly improves its tractability when solved using CPLEX.

Table 55. Scalability of decision variables after sparsification. ($|\mathcal{T}| \approx 50$, $|\mathcal{V}| \approx 150$, $|\mathcal{V}|^{\text{air}} \approx 50$, $|\mathcal{I}| \approx 30$, $|\mathcal{G}| \approx 25\,000$, and $|\mathcal{A}| \approx 460$)

Variables	Size	Expectation
$\mathbf{n}_{v,t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^2$	125 000
$\dot{\mathbf{n}}_{v,t}^{\text{air}}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert \cdot \lvert\mathcal{V}\rvert^{\text{air}}$	375 000
$\dot{\mathbf{n}}_{v,t}^{\text{ground}}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^2$	1 125 000
$x_{i,v,t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert^{\text{air}} \cdot \lvert\mathcal{I}\rvert$	75 000
$y_{i,a,t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{A}\rvert \cdot \lvert\mathcal{I}\rvert$	690 000
$\mathbf{z}_{i,a,t}$	$\lvert\mathcal{T}\rvert \cdot \lvert\mathcal{V}\rvert \cdot \lvert\mathcal{A}\rvert \cdot \lvert\mathcal{I}\rvert$	103 500 000
$\mathbf{z}_g$	$\lvert\mathcal{V}\rvert \cdot \lvert\mathcal{G}\rvert$	3 750 000
Total		110 640 000

Simulation environment development

Catalan Pyrenees scenario

To obtain the public transport supply information, the General Transit Feed Specification (GTFS) data was download from the Spain's official National Transport Data Access Point [https://nap.transportes.gob.es/]. GTFS is a standardised data format used to represent public transportation schedules, routes, stops, and related geographic information. Originally developed by Google and transit agencies, GTFS enables consistent sharing and integration of transit data, supporting applications like trip planning, service optimisation, and real-time tracking.

© –2023– SESAR 3 JU

The public transport supply in the Catalan Pyrenees is visualized in Figure 103. Although there are 8,742 stations within this region, they are unevenly distributed, which diminishes overall accessibility. Specifically, most stations are concentrated around Barcelona, with only a few located in the rural areas.

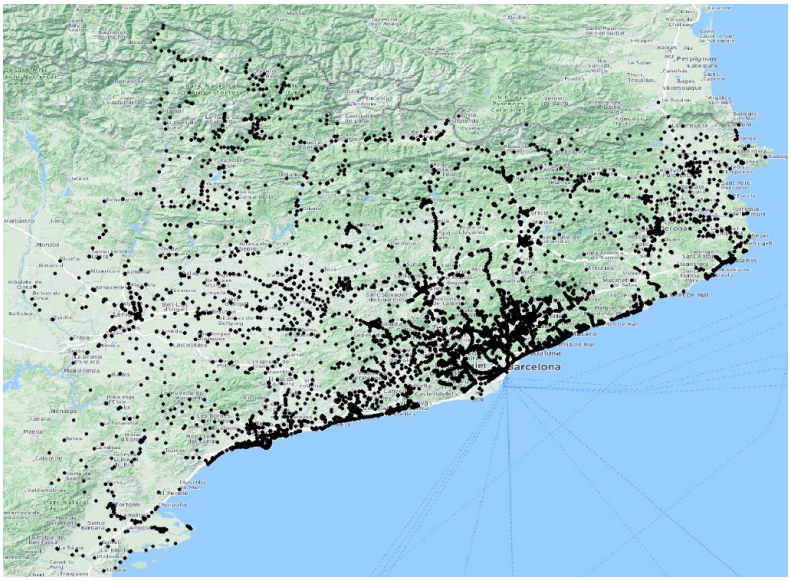


Figure 103. The public transport stations within Catalan Pyrenees. Each black dot denotes a bus station. There are totally 8742 stations.

Before constructing the public transport network graph with the collected 8742 stations, it is necessary to perform node compression. The main advantage of this step is that it reduces the size of the graph, which in turn accelerates the process of solving the optimal scheduling or routing problem later on. Node compression helps to:

- Reduce computational complexity. With fewer nodes, the graph scale becomes smaller, significantly lowering the time and space complexity of subsequent algorithms such as path-finding and optimization.
- Save storage resources. A smaller graph requires less memory to store nodes and edges, which is especially beneficial for large-scale graph processing.
- Improve solving efficiency. A reduced graph scale leads to faster computation of shortest paths, maximum flows, or optimal schedules, resulting in quicker system responses.
- Eliminate redundancy and noise. By compressing nodes, redundant or less important nodes can be merged or abstracted, resulting in a more concise and clearer graph structure, which facilitates further analysis and optimization.

Common methods for node compression include node merging (combining closely related or functionally similar nodes), abstract node substitution (replacing groups of nodes with representative nodes), and pruning (removing nodes deemed less important).

However, since this project focuses on ensuring accessibility in rural and remote areas by deploying IAM vehicles, pruning cannot be directly applied. Removing nodes indiscriminately might compromise coverage and accessibility, which contradicts our core objectives.

© –2023– SESAR 3 JU

The node merging process is illustrated in Figure 104. Functionally similar nodes, as defined in Definition 1, are merged together to reduce the number of nodes. This is because such nodes usually represent intermediate stations on a continuous line without transfers. Merging them is equivalent to combining consecutive non-transfer stations into a "virtual station" or "segment," thereby reducing the number of nodes. As shown in Figure 104 (a), nodes V_4 and V_5 both have a degree of 2 and are adjacent, so they are functionally similar and can be merged. The result of this merging is shown in Figure 104 (b), where nodes V_4 and V_5 are combined into a single node labeled V_m. As shown in Figure 105, there are 6,204 nodes remaining after the merging process.

Definition 1 (Functionally Similar Nodes). *Two adjacent nodes are considered functionally similar if both nodes have a degree of 2.*



(a) Before node merging. (b) After node merging.

Figure 104. Node merging by combining functionally similar nodes.

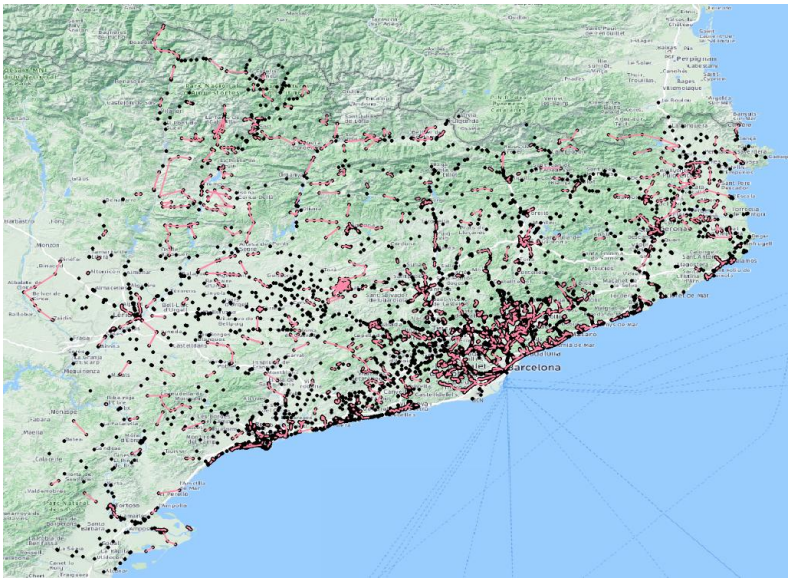


Figure 105. The results of node merging process. Nodes connected by the same line are considered functionally similar and are merged together. After the merging process, there remain 6,204 nodes.

To further reduce the number of nodes in the transport network graph, abstract node substitution is required. Since this method involves replacing groups of nodes with representative nodes, the Leiden algorithm was adopted for community detection and node aggregation.

Resolution is the most influential parameter in Leiden, as it controls the scale of community structure detected. Tuning it carefully is essential for obtaining meaningful and interpretable results depending on the specific network and task. To determine the optimal resolution value, we conducted a series of experiments.

© –2023– SESAR 3 JU

Co-funded by the European Union

As shown in Figure 106, when the resolution value increases from 0 to 10^{-3}, the number of clusters rises from 8 to 436, while the quality decreases from 0.98 to 0.66. To increase the number of clusters without sacrificing too much quality, the resolution for the Catalan Pyrenees case is set to 10^{-4}.

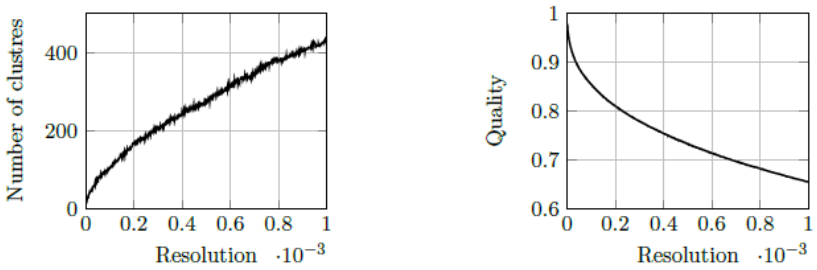


Figure 106. Performance variation with different resolution values.

The clustering results is shown in Figure 107. The nodes are clustered into 105 clusters. The resulting clusters are reasonably balanced in size, with the number of nodes in each cluster falling within a relatively narrow range. This suggests that the clustering process avoided dominance by any single group and achieved a well-proportioned partitioning of the data.

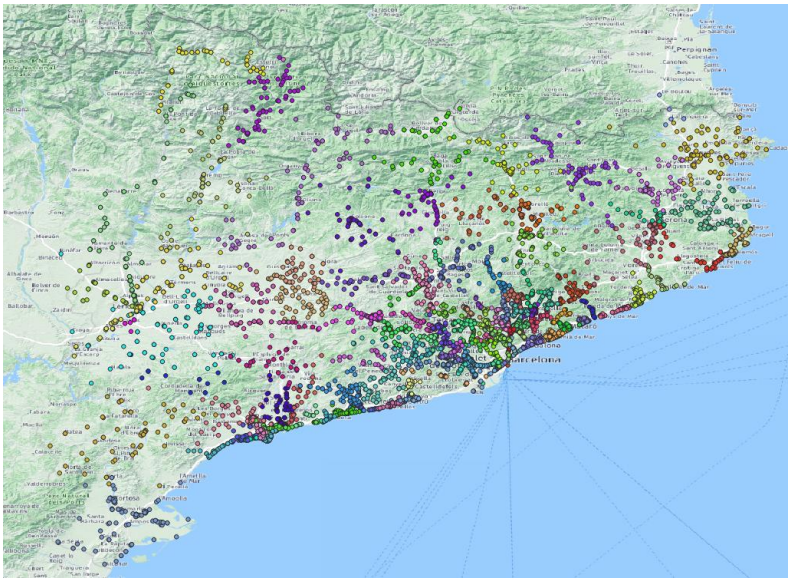


Figure 107. The results of node clustering based on Leiden algorithm. Different colours denote distinct clusters.

Moreover, the clusters exhibit distinct strong spatial coherence and a high degree of alignment with the underlying road network. Nodes within the same cluster are generally located along the same road segment or within closely connected paths, suggesting that the algorithm successfully captured the local structure of the transportation network. Rather than forming arbitrary groups, the clusters reflect meaningful topological and spatial continuity—stations grouped together tend to lie along contiguous roadways.

These characteristics indicate that the clustering not only achieved good modularity and intra-cluster cohesion but also respected the real-world layout of the network, making the results both interpretable and practically relevant.

© –2023– SESAR 3 JU

Finally, as shown in Figure 108, a public transport network graph is constructed using the identified abstract nodes. The black dots represent the abstract nodes obtained through the Leiden algorithm, while the pink lines indicate the edges connecting these nodes.

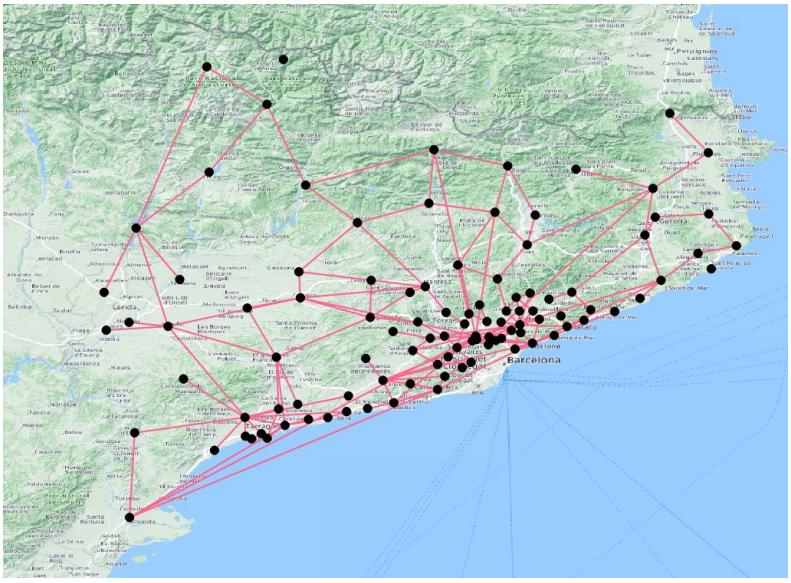


Figure 108. The public transport network graph of Catalan Pyrenees. Each black dot denotes an abstract node, and each pink edge denotes an edge. The graph has 105 nodes and 152 edges.

Given that this project is a prospective study focused on the future deployment of IAM at the regional scale, it is not feasible to obtain concrete information on operational vertiports during the project duration, as such IAM services have not yet been implemented at this level. Accordingly, an estimation of the potential supply of vertiport stations is required to support forward planning.

Since a dedicated vertiport siting tool is outside the scope of this validation exercise and was under development in parallel, a simplified proxy set of potential vertiport locations was used to define the network nodes required for the IAM service optimisation model. These locations are not the result of a location optimisation process, but serve solely as exogenous inputs to support algorithm development and validation. The proxy node set is constructed to represent the main regional mobility structure of the study area and to ensure connectivity across key demand centres. It includes major functional origin–destination pairs such as links between the Barcelona metropolitan area and its international airport, connections between the Catalan Pyrenees and Lleida-Alguaire Airport and/or Lleida HSR station, access between La Seu d'Urgell Airport and surrounding regional centres (e.g., Andorra, hospitals, and ski resorts), as well as connectivity between major towns within the Catalan Pyrenees.

The geographic locations corresponding to these use cases are summarised in Table 56.

Table 56. Geographic location data of key areas

Index	Type	Name	Location
K01	Airport	JT Barcelona Airport	41.2970, 2.0783
K02	Airport	Reus Airport	41.1475, 1.1672
K03	Airport	Girona Airport	41.9008, 2.7605

© –2023– SESAR 3 JU

K04	Airport	La Seu D'Urgell Airport	42.3462, 1.4147
K05	Airport	Lleida–Alguaire Airport	41.7280, 0.5353
K06	Station	Lleida HSR station	41.6208, 0.6328
K07	Hospital	Nostra Senyora de Meritxell Hospital	42.5117, 1.5336
K08	Hospital	Fundació Hospital de Puigcerdà	42.4325, 1.9261
K09	Ski resort	Ordino Arcalís estación de esquí	42.6317, 1.4997
K10	Ski resort	Grandvalira	42.5783, 1.6453
K11	Ski resort	Pal Arinsal Ski Resort	42.5728, 1.4711
K12	Ski resort	Estació Vallter 2000	42.4261, 2.2653

In addition to these points of interest, information on existing civil heliports was obtained from OpenAIP [https://www.openaip.net/], an open-access platform offering aeronautical data for pilots, developers, and aviation professionals. The geographic locations of these heliports are presented in Table 57.

Table 57. The existing civil heliport data

Index	Ctry	Name	Code	Location
H01	FR	CERBERE		42.4589, 3.1600
H02	ES	AUTORIDAD PORTUARIA DE BARCELONA	LEPB	41.3640, 2.1830
H03	ES	BERGA HELIPORT	LERG	42.1060, 1.8530
H04	ES	CIUDAD SANITARIA Y UNIVERSITARIA DE BELL	LEHB	41.3450, 2.1070
H05	ES	COSTA BRAVA-CENTRO HELIPORT	LEBC	41.8080, 3.0370
H06	ES	EL PORTINYOL HELIPORT	LEPY	41.5840, 2.5610
H07	ES	FIRA M2 HELIPORT	LEFR	41.3540, 2.1290
H08	ES	GARIDELLS	LEGD	41.2139, 1.2414
H09	ES	HELI MONTSIÁ - AMPOSTA	LEMN	40.6652, 0.5639
H10	ES	HOSPITAL DOCTOR JOSEP TRUETA HELIPORT	LEJT	41.9980, 2.8210
H11	ES	HOSPITAL GENERAL DE MANRESA HELIPORT	LEHM	41.7200, 1.8410
H12	ES	HOSPITAL UNIVERSITARIO JOAN XXIII	LEHJ	41.1256, 1.2381
H13	ES	HOTEL REY JUAN CARLOS I	LEJC	41.3808, 2.1083
H14	ES	HOSPITAL GENERAL DE CATALUNYA HELIPORT	LEHG	41.4740, 2.0420
H15	ES	HOSPITAL SAN PAU HELIPORT	LESP	41.4140, 2.1720
H16	ES	MAS PASSAMANER	LEPS	41.1858, 1.1600
H17	ES	NOU HOSPITAL DE MATARÓ HELIPORT	LENH	41.5610, 2.4300
H18	ES	OLIANA		42.0687, 1.2779
H19	ES	PARQUE DE GARRAF-SITGES HELIPORT	LEGS	41.2740, 1.9150

© –2023– SESAR 3 JU

H20	ES	PARQUE DE BOMBEROS DE ORRIOLS HELIPORT	LEOR	42.1320, 2.9040
H21	ES	R.A.C.C. BARCELONA	LERA	41.3814, 2.1072
H22	ES	SANT MARTÍ DE SESCORTS HELIPORT	LETM	42.0160, 2.3190
H23	ES	SERVEI D EVACUACIÓ DEL CIRCUIT DE CATALU	LERV	41.5720, 2.2620
H24	ES	SERVEIS GENERALS DEL CIRCUIT DE CATALUNYA	LETA	41.5740, 2.2570
H25	ES	TIRVIÁ HELIPORT	LETV	42.5190, 1.2420
H26	ES	TREMP HELIPORT	LETR	42.1690, 0.8930
H27	ES	ULLASTRELL-TERESA VILÁ HELIPORT	LEUL	41.5240, 1.9720
H28	ES	VIELHA HELIPORT	LEVH	42.7040, 0.7970
H29	ES	VILALLER HELIPORT	LEVR	42.3050, 0.7130
H30	ES	GERMANS TRIAS I PUJOL HOSP	LEJL	41.4796, 2.2385

Those potential vertiports are shown in Figure 109.

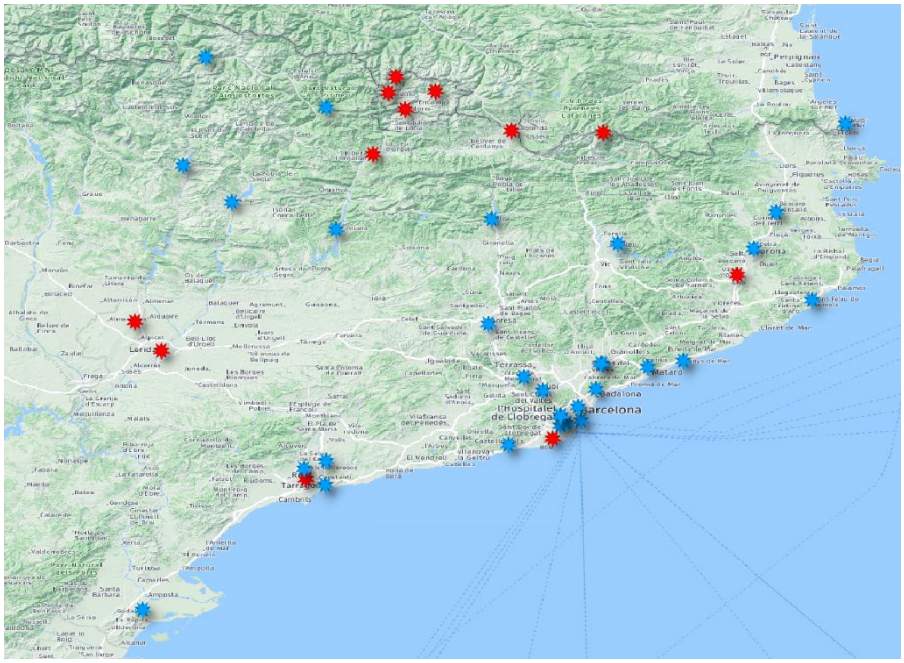


Figure 109. The potential vertiports of Catalan Pyrenees. Each red star denotes a key area, and each blue star denotes a civil heliport. There are totally 42 potential vertiports in Catalan Pyrenees.

The mobility flow estimation of Catalan Pyrenees is conducted with existing trip distribution laws and models. Following information is needed to implement trip distribution models: the population in each region, the out-commuter in each region, and the in-commuter in each region. Firstly, the population distribution data is collected; secondly, a Voronoi-based service area delimitation is conducted to determine the population corresponding to each abstract node; thirdly, the inter-node commuting flows is estimated with trip distribution laws and models.

Although the MND dataset is of high quality, it was not available at the time of this case study due to the parallel development of the data processing pipeline; therefore, a standard modelling approach

© –2023– SESAR 3 JU

was used for algorithm validation, while MND data were applied in the Tenerife case where they were available.

To obtain the population distribution data, the gridded population dataset of Spain is downloaded from the WorldPop Hub [https://hub.worldpop.org/], which provides open access spatial demographic datasets built using transparent approaches.

The downloaded dataset provides an estimate of the total number of people per grid cell, disaggregated from census/projection-based population estimates for the year 2020. The data is available in GeoTIFF format at a spatial resolution of 3 arc-seconds (approximately 100 meters at the equator) and is projected using the Geographic Coordinate System WGS84. The units represent the number of people per pixel. Population disaggregation was performed using a Random Forests-based dasymetric mapping approach. The modelling was carried out by Maksym Bondarenko and David Kerr at WorldPop, using the wpgpRFPMS R scripts, under the supervision of Alessandro Sorichetta.

The dataset incorporates multiple input sources, including:

1. National census or projection-based population estimates for 2020;
2. Outputs from the Built-Settlement Growth Model;
3. A suite of geospatial covariates from the Global High Resolution Population Denominators Project (OPP1134076).

The population distribution of Catalan Pyrenees is visualised in Figure 110.

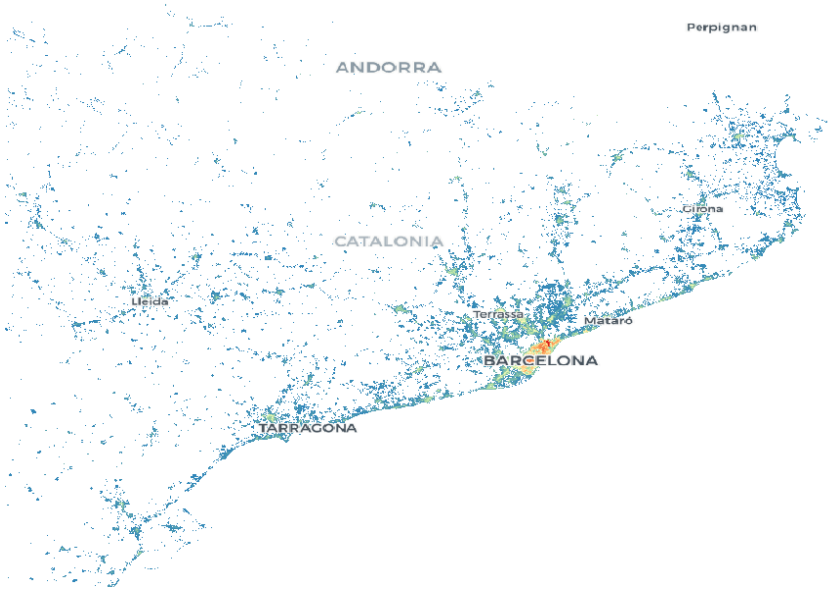
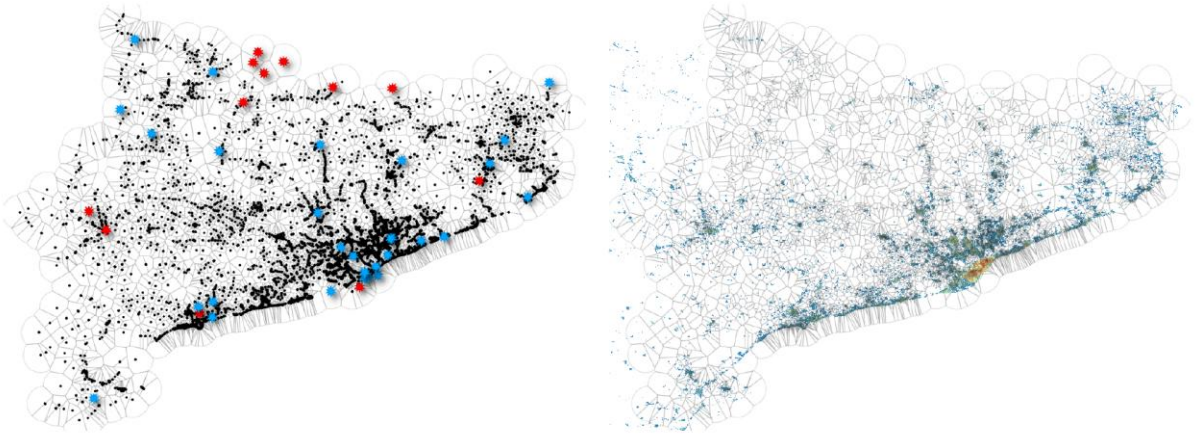


Figure 110. The population distribution of Catalan Pyrenees. White pixels indicate areas classified as unsettled, while coloured pixels represent settled areas. The intensity of red corresponds to population density — the deeper the red, the higher the number of people settled.

To assign population values to each node, a Voronoi diagram is used. As shown in Figure 111 (a), each node (representing either a public station or a potential vertiport) is treated as a seed, generating a corresponding Voronoi cell. Based on this diagram, the population associated with each node is estimated by overlaying the Voronoi partition with the population distribution map. As shown in Figure 111 (b), if a pixel in the population map falls within the Voronoi cell of a particular node, the population

© –2023– SESAR 3 JU

of that pixel is assigned to the corresponding node, indicating that the node serves the people located in that pixel.



(a) Voronoi diagram (b) Population assignment

Figure 111. Population assignment for each node using the Voronoi diagram.

According to the abstract node substitution results, Voronoi cells whose seeds correspond to the same abstract node can be merged to form a unified service area. As illustrated in Figure 112, this process groups together the original coverage areas of individual nodes into larger regions, each representing the influence zone of a single abstract node.

During this merging process, the population values associated with each original Voronoi cell are summed together, so that the total population assigned to an abstract node reflects the cumulative population within its merged region. This ensures that the abstracted spatial structure still preserves accurate demand estimation, enabling more efficient regional planning and analysis in the following modelling steps.

© –2023– SESAR 3 JU

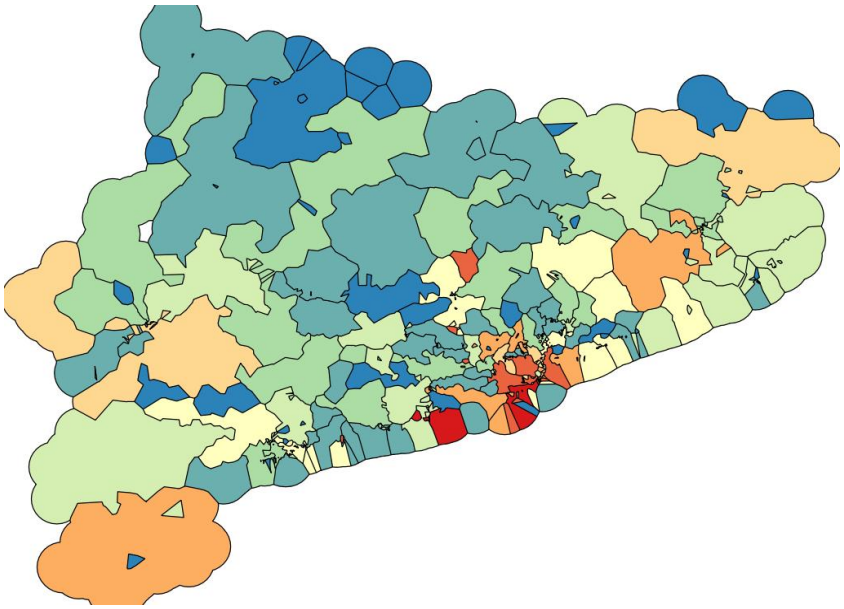


Figure 112. Aggregated Voronoi regions after abstract node substitution. Each merged region corresponds to an abstract node composed of multiple original nodes. The colour gradient reflects the total population within each region — the warmer the colour (e.g., red or orange), the higher the accumulated population.

The estimation of inter-node commuting flows is divided into two main components: trip distribution laws and constrained flow models.

The purpose of trip distribution laws is to model the probability p_{ij} that a trip will occur from origin i to destination j, based on underlying geographic, demographic, and spatial interaction factors. These probabilities form the foundation for estimating mobility flows between regions. Trip distribution laws rely on three main factors: m_i - the population in region i, m_j - the population in region j, and d_{ij} - the travel distance between regions i and j.

The general form of the trip probability function can be written as:

$$p_{ij} = \propto f(m_i, m_j, d_{ij}) \qquad (11)$$

where the population data m_i and m_j can be obtained in Figure 112, and the travel distance d_{ij} can be obtained based on Google Maps API , which provides accurate travel distances based on real-world road networks.

The eight trip distribution laws can be grouped based on how they treat distance decay and opportunity structures:

1. Gravity-based Models – assume that interactions between regions decrease with distance, similar to Newton's law of gravity.
   - GravExp: Gravity law with exponential decay of distance
   - GravPow: Gravity law with power-law decay of distance
   - NGravExp: Normalised version of GravExp ensuring probabilities sum to 1
   - NGravPow: Normalised version of GravPow

© –2023– SESAR 3 JU

Co-funded by the European Union

2. Intervening Opportunities Models – assume the probability of choosing a destination depends not on distance per se, but on the number of opportunities encountered before reaching it.
   - Schneider: Classical intervening opportunities model
   - Rad: Radiation model (parameter-free, based on intervening opportunities)
   - RadExt: Extended radiation model with a tunable parameter to account for scaling effects
3. Random Model – assumes equal probability of choosing any destination, regardless of distance or population.
   - Rand: Uniform distribution across destinations

Once the trip probabilities p_{ij} are computed, the second step converts them into actual flow estimates using different constraint-based models. These models ensure that the generated flows conform to observed marginal totals such as total outflows O_i and/or inflows D_j. The four standard models are:

- Unconstrained Model – no constraints on row or column sums
- Production Constrained Model – constrains the total outflow from each origin
- Attraction Constrained Model – constrains the total inflow to each destination
- Doubly Constrained Model – constrains both origin outflows and destination inflows

Tenerife-La Gomera scenario

According to the GTFS data, as shown in Figure 113, there are totally five transport service providers providing public transport service on Tenerife and La Gomera: Ferry Balearia (maritime), Fred. Olsen Express (maritime), AECFA (air), Metrotenerife (rail), TITSA (road), and GUAGUA (road). The small island on the left represents La Gomera, while the larger island on the right represents Tenerife. La Gomera does not have intra-island public transport services; its connections with Tenerife are provided by air and maritime transport (i.e., flights and ferry services). In contrast, Tenerife has intra-island public transport services, including metro and bus systems. Besides, Tenerife is connected to other Canary Islands and mainland Spain through air and maritime transport; however, these connections are outside the scope of this study

© –2023– SESAR 3 JU

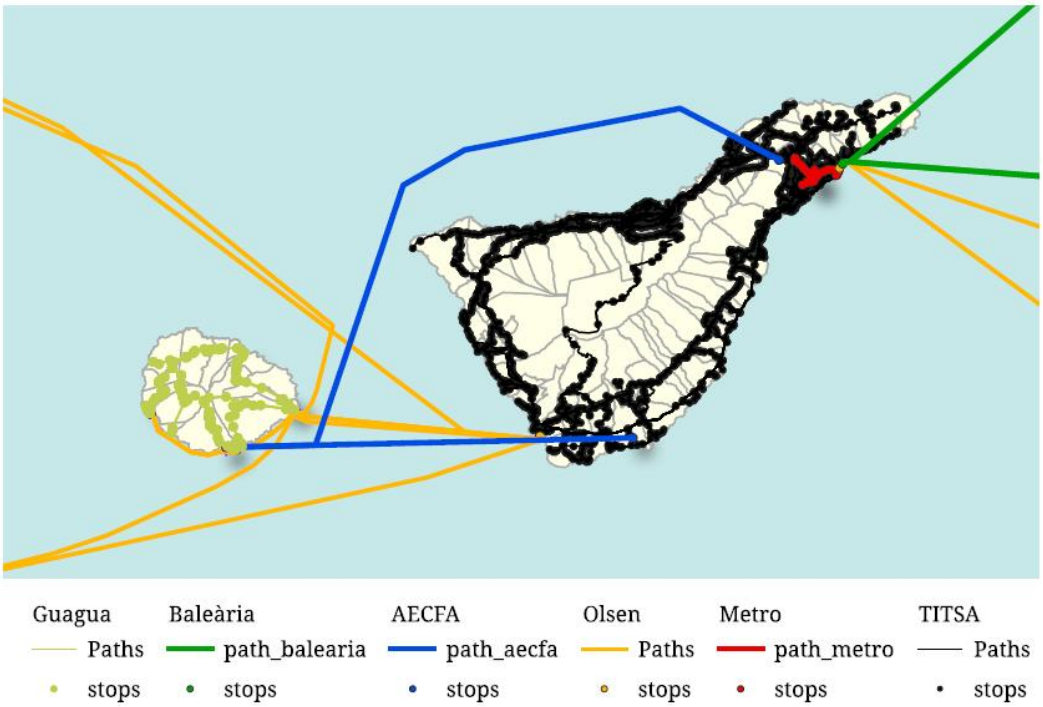


Figure 113. Key public transport services in Tenerife.

As this study focuses on the connections between Tenerife and La Gomera, Baleària (maritime) is excluded from the analysis because it only provides ferry services between Tenerife, other Canary Islands, and mainland Spain, which fall outside the scope of this study. Fred. Olsen (maritime) and AECFA (air) provide the ferry and air transport services between Tenerife and La Gomera, respectively. Within Tenerife, Metrotenerife (rail) and TITSA (road) operate the tram and bus public transport systems, respectively. Within La Gomera, GUAGUA (road) provides ground public transport services.

Since a dedicated vertiport siting tool is outside the scope of this validation exercise and was under development in parallel, a simplified proxy set of potential vertiport locations was used to define the network nodes required for the IAM service optimisation model. These locations are not the result of a location optimisation process, but serve solely as exogenous inputs to support algorithm development and validation. The proxy node set is constructed to represent the main regional mobility structure of the study area and to ensure connectivity across key demand centres. It is designed to capture representative synthetic demand flows, including medical logistics flows between Gomera Hospital and local health centres, passenger flows between La Gomera Airport and the island capital, and inter-island passenger flows between La Gomera and Tenerife.

Accordingly, the locations listed in 58 are identified as potential vertiports in this study. As shown in Figure 114, they are primarily situated in areas with high population density, including the capital, airport, hospitals, clinics, and heliports.

Table 58. The potential vertiport data

Index	Type	Name	Location
K01	Capital	San Sebastián de La Gomera	28.0922, -17.1100
K02	Airport	Tenerife North Airport (TFN)	28.4827, -16.3415

© –2023– SESAR 3 JU

K03	Airport	Tenerife South Airport (TFS)	28.0445, -16.5725
K04	Airport	La Gomera Airport (GMZ)	28.0297, -17.2147
K05	Hospital	Hospital de La Gomera	28.1042, -17.1295
K06	Clinic	Centro de Salud	28.1004, -17.3303
K07	Clinic	Hermigua health centers	28.1709, -17.1906
K08	Heliport	Adeje Heliport	28.1242, -16.7429
K09	Heliport	IES La Guancha Heliport	28.3774, -16.6493
K10	Heliport	Canarias Hospital Heliport	28.4561,-16.2919
K11	Heliport	Candelaria Helipad	28.4487,-16.2846

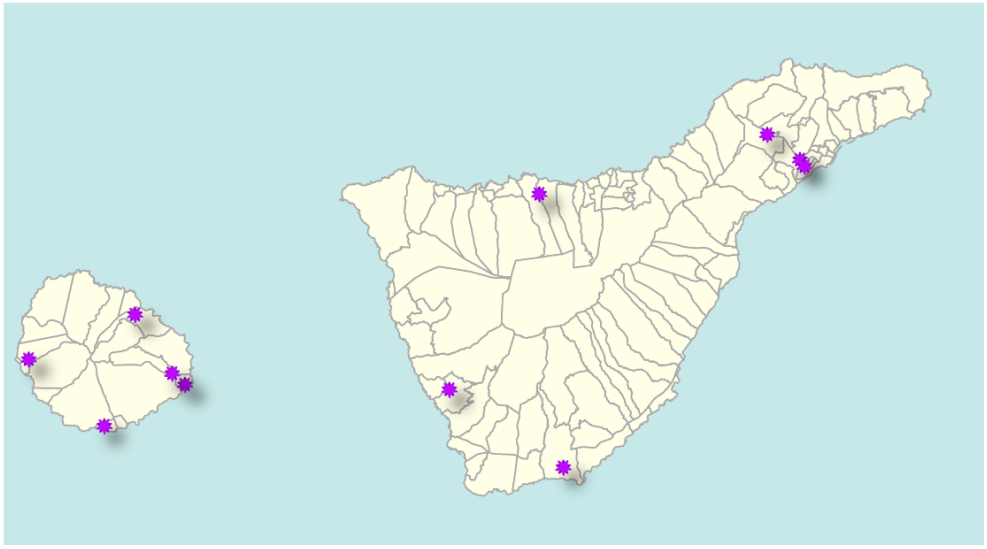


Figure 114. The potential vertiports of Tenerife and La Gomera. Each purple star denotes a potential vertiport.

Due to the highly developed tourism industry in La Gomera and Tenerife, transport demand in the study area is influenced not only by the spatial distribution of residents but also by substantial tourist mobility flows. Consequently, approaches such as those applied in the Catalan Pyrenees case study, where transport demand is estimated primarily based on resident distribution, are less suitable for accurately capturing mobility patterns in this context, particularly for inter-island travel. To improve the accuracy of demand estimation, this study utilizes MND to obtain more reliable and dynamic mobility information, enabling a more accurate representation of actual travel demand between Tenerife and La Gomera.

Performance assessment

Multimodal coordination

In assessing multimodal coordination, the simulation focuses on the Catalan Pyrenees to examine traffic operations during the morning peak period. The analysis considers a one-hour time window from 08:00 to 09:00, which corresponds to typical commuting hours when a large number of residents and visitors generate travel demand for commuting, schooling, and short-distance trips within the

© –2023– SESAR 3 JU

region. This period provides a representative snapshot of the transport system under high-demand conditions.

To capture the dynamic nature of travel demand, this study assumes that approximately 250 passengers submit new travel requests every five minutes. The five-minute temporal window is required to model the continuous arrival of travel requests, thereby enabling a dynamic rather than static evaluation of the IAM optimisation framework. In addition, the discrete choice model developed by TML in this project was not used, as both developments were conducted in parallel and the model was not available at the time of implementing the simulation. Over the course of the one-hour simulation, this results in a total of 3,000 travel demands that need to be accommodated. Firstly, this paper assumes that the capacity of each IAM is 10 passengers and that the unit distance cost ratio relative to ground transportation is 20 (the specific setting is discussed later). The IAM fleet size is then gradually increased from 0 to 50. The results are summarised in Table 59.

Table 59. 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 (%)
0	1 550	0	51.7%
10	1 546	291	61.2%
20	1 542	360	63.4%
30	1 542	380	64.1%
40	1 542	386	64.3%
50	1 542	405	64.9%

Following are the key findings:

- The IAM service is able to improve multimodal coordination significantly. The introduction of IAM services enables a larger share of passenger demand to be satisfied. The benefits are particularly pronounced when the first 10 IAM vehicles are introduced, as the proportion of satisfied demand increases by nearly 10%. This improvement is mainly attributable to the enhanced connectivity of the public transport network. As shown in Figure 115 (a), accessibility in remote areas is relatively low without IAM services, and many locations remain isolated. After the introduction of 50 IAM vehicles, multimodal coordination substantially improves accessibility in remote areas, enabling previously isolated locations to become better connected with one another.
- IAM services do not appear to directly compete with existing transport modes. As the IAM fleet size increases from 0 to 50 vehicles, passenger demand for conventional public transport modes remains relatively stable, whereas the number of passengers using IAM services increases steadily. These results indicate that IAM services can complement existing transport systems and highlight the potential for effective multimodal integration. Further analysis on IAM pricing strategies also supports this conclusion. As shown in Figure 116, when IAM travel costs are set at the same level as ground transportation, a substantial shift of passengers toward IAM can be observed due to its shorter travel time, potentially reducing the utilisation of existing transport resources. This finding suggests that appropriate pricing strategies are essential to maintain the complementary role of IAM services within the multimodal transport network.

© –2023– SESAR 3 JU

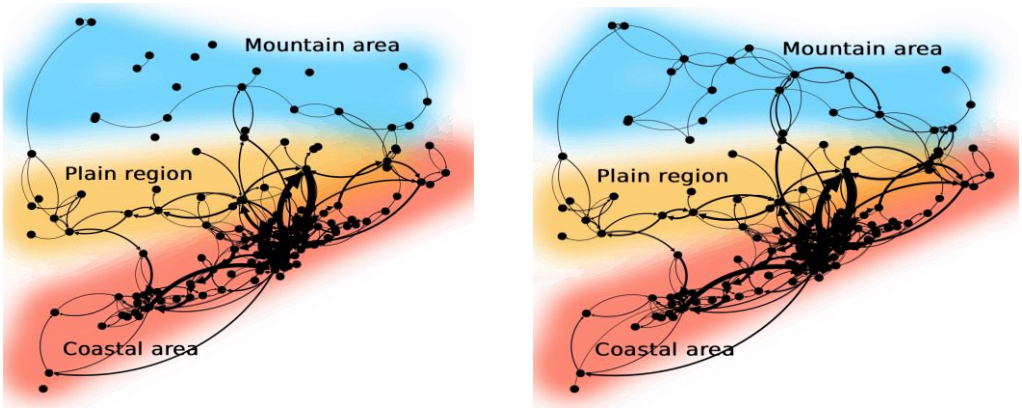


Figure 115. Accessibility improvement after adopting IAM service. While coastal and plain areas experience only modest gains, mountainous areas—benefit substantially, highlighting the IAM service's pronounced impact where accessibility was previously limited.

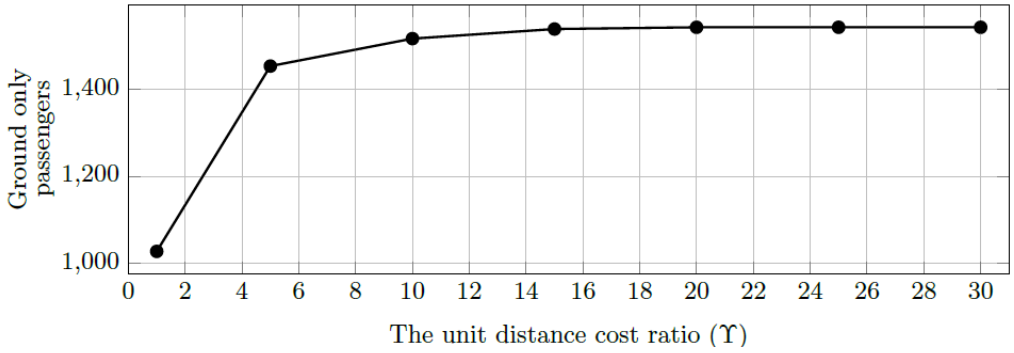


Figure 116. Impact of unit distance cost ratio on demand met rate.

Methods comparison

The comparison between the two methods primarily focuses on computational efficiency and solution optimality. A method with higher computational efficiency requires less computational time, enabling faster re-initialisation and adaptation to dynamic operational environments. This capability enhances the robustness of the system under varying operational conditions and improves its scalability for applications at a European regional scale. Meanwhile, a method with higher optimality is more likely to produce high-quality solutions.

The comparative analysis is conducted using the Catalan Pyrenees scenarios, as they are considerably more complex and larger in scale than the La Gomera–Tenerife scenarios. Consequently, they provide a more suitable benchmark for evaluating both the scalability and computational performance of the proposed methods.

The computational time consumption of the two methods under identical scenarios is presented in Figure 117. The simulation focuses on the Catalan Pyrenees region to investigate traffic operations during the morning peak period. A one-hour time window from 08:00 AM to 09:00 AM is considered, corresponding to typical commuting hours when a large number of residents and visitors generate travel demand for commuting, schooling, and short-distance trips within the region. This period therefore provides a representative snapshot of the traffic system under high-demand conditions.

© –2023– SESAR 3 JU

In terms of computational performance, the heuristic method requires less than 2 seconds for a single optimisation run, whereas the exact method requires approximately 300 seconds under the same scenario. This indicates a substantial reduction in computational time, with the heuristic approach being roughly two orders of magnitude faster. Such efficiency enables rapid re-optimisation and makes the heuristic method more suitable for real-time or large-scale applications where frequent updates are required.

Besides, as shown in Figure 117, compared with the exact method, which exhibits high variance in computational performance across instances, the heuristic method is considerably more stable, showing lower variance in solution time. This improved consistency further enhances its practical applicability, particularly in real-time or large-scale operational settings where predictable computational behaviour is essential.

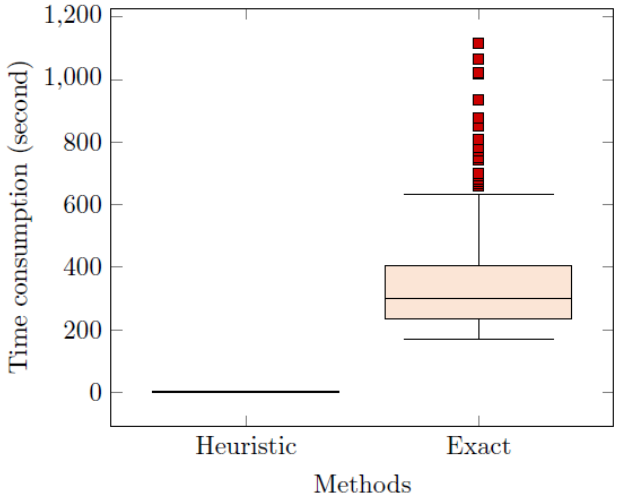


Figure 117. Time consumption of the two methods under the same scenario.

In terms of solution optimality, the results are presented in Figure 118. Although the exact method achieves a higher average passenger satisfaction rate, it also exhibits significantly greater variance compared to the heuristic method. In other words, its performance is less stable across different instances, and in certain cases it can even underperform the heuristic approach. One possible explanation is the sensitivity of the proposed model to hyper-parameter settings. Specifically, the exact method simultaneously maximises the fulfilment rate and minimises travel cost, and balancing these competing objectives through a single fixed weighting parameter ω is inherently challenging. A parameter value that performs well under all operating conditions may not exist. Consequently, the fulfilment rate of the exact method fluctuates more than that of the heuristic method, which optimises passenger journeys and IAM dispatching separately and does not require a weighting parameter to balance multiple objectives.

Moreover, both methods demonstrate a gradual decline in performance over time. This trend can be attributed to the inherently myopic nature of the decision-making process, where both approaches optimise only the current system state without explicitly accounting for long-term system-wide consequences. From a longer time-horizon perspective, the resulting decisions are therefore locally optimal rather than globally optimal, which may induce adverse downstream effects. For instance, IAM resources may be heavily utilised or even depleted in the early stages, leading to insufficient capacity to satisfy passenger demand in later periods.

© –2023– SESAR 3 JU

Consequently, although the exact method initially provides a higher fulfilment rate than the heuristic approach, this advantage diminishes progressively as time evolves. Overall, the heuristic method does not exhibit clear disadvantages in long-term performance, while offering more stable behaviour across scenarios.

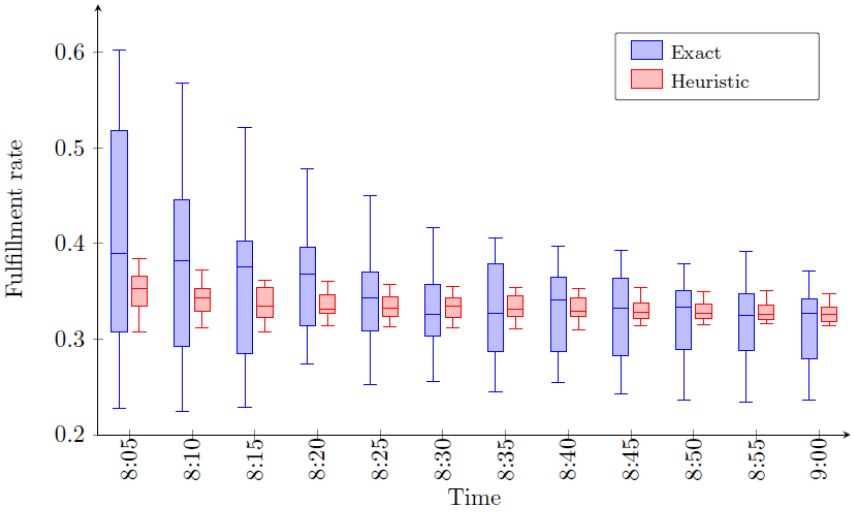


Figure 118. Evolution of the optimisation performance over time.

Through a comprehensive comparison between the exact and heuristic methods in terms of computational efficiency and solution quality, a clear trade-off between optimality and scalability has been identified. The exact method is capable of achieving slightly higher passenger satisfaction rates; however, this advantage comes at the cost of significantly higher computational time and noticeably greater variability in performance across different instances. In contrast, the heuristic method demonstrates substantially improved computational efficiency, requiring only a fraction of the time needed by the exact approach, while maintaining consistently stable performance.

From a system-level perspective, the heuristic method also exhibits competitive solution quality. Although its average passenger satisfaction rate is marginally lower than that of the exact method, the difference is limited, and importantly, the heuristic approach shows significantly lower variance, ensuring more predictable and robust performance under varying operational conditions. This stability is particularly valuable for real-time or large-scale applications, where consistent response time and reliability are critical.

Considering both computational efficiency and solution quality jointly, the heuristic method offers a more balanced and scalable solution. Its fast execution enables frequent re-optimisation and adaptability to dynamic environments, while its stable performance ensures dependable operational outcomes over time. Therefore, despite the theoretical optimality advantage of the exact method, the heuristic method is selected as the preferred approach for this study due to its superior practicality, robustness, and scalability in realistic deployment scenarios.

Scenario comparison

The comparison between the two scenarios is conducted in a qualitative manner rather than a quantitative one, as the Catalan Pyrenees scenario and the La Gomera–Tenerife scenario differ significantly in scale, network structure, and demand characteristics. These inherent differences in spatial extent and system complexity make direct numerical comparisons potentially misleading.

© –2023– SESAR 3 JU

Instead, the analysis focuses on identifying consistent behavioural patterns and relative performance trends across the two settings, thereby providing a more robust and meaningful evaluation of the proposed methods.

The passenger demand satisfaction rates for both scenarios are presented in Figure 119. It can be observed that the proportion of unserved passengers remains identical across the two cases. However, the role of IAM differs significantly between them. In the Tenerife–La Gomera scenario, a larger share of passengers relies on IAM to complete their trips, and without its availability, these journeys would not be feasible. In contrast, in the Pyrenees scenario, a considerable proportion of passengers can still reach their destinations using existing transport modes even in the absence of IAM support.

This difference is mainly driven by the availability of existing transport options in the two regions. The Tenerife–La Gomera islands have a more limited conventional transport network, particularly on La Gomera, where only the Guagua provides a small number of public bus services. This constraint leads to a higher reliance on IAM. In contrast, the Pyrenees region offers a relatively richer set of existing mobility alternatives, which reduces its dependency on IAM.

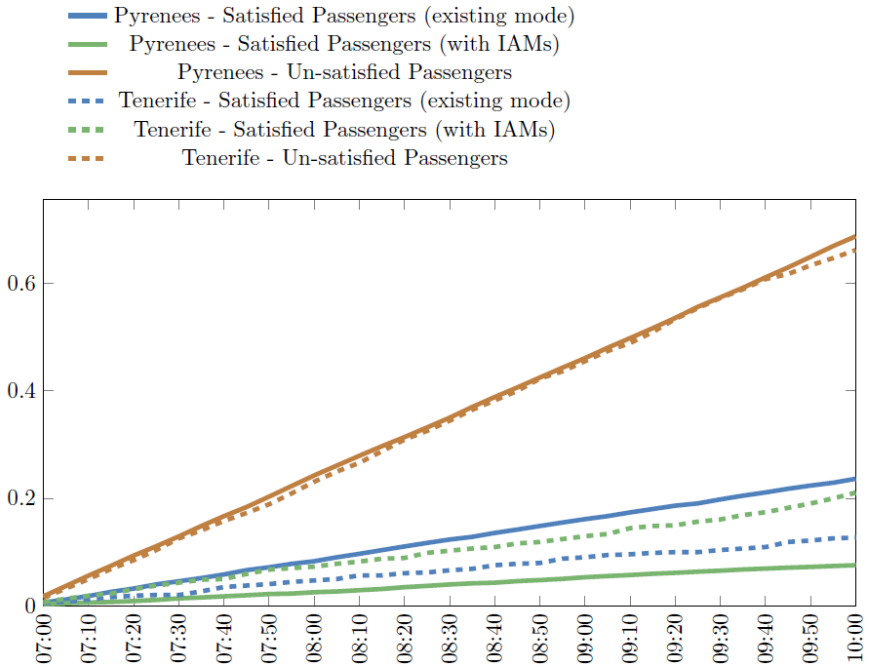


Figure 119. Passenger satisfaction rates across different scenarios. The denominator is the total number of passengers within three hours.

Experts' evaluation

During the 2nd Stakeholder Workshop, participating experts were invited to evaluate the results, and their feedback is summarised below.

1 - How would you evaluate the effectiveness of the proposed model in real-world operational conditions? (The proposed method has high effectiveness in real-world.)

Agreement Level	Score	Responses
Strongly disagree	1	1

© –2023– SESAR 3 JU

Disagree	2	0
Neutral	3	6
Agree	4	6
Strongly agree	5	0

The first question examined how stakeholders would evaluate the effectiveness of the proposed model under real-world operational conditions. A total of 13 responses were collected: 12 were positive and only one was negative, resulting in an average score of 3.3. This result suggests that stakeholders, including vertiport operators and municipal representatives, generally acknowledge the effectiveness of the proposed model in real-world operational settings, although the moderate average score indicates some reservations.

2 - To what extent can the optimisation approach handle demand uncertainty? (The proposed approach can handle demand uncertainty.)

Agreement Level	Score	Responses
Strongly disagree	1	0
Disagree	2	1
Neutral	3	4
Agree	4	5
Strongly agree	5	0

The second question examined stakeholders' opinions on the optimisation approach's ability to handle demand uncertainty. A total of 11 responses were collected: 9 were positive and only one was negative, resulting in an average score of 3.4. This indicates that stakeholders generally view the approach as capable of addressing demand uncertainty, although the moderate score suggests there is still room for improvement or further validation.

3 - How would you rate the component's ability to balance passenger waiting time and vehicle utilisation? (The component can balance passenger waiting time and vehicle utilisation.)

Agreement Level	Score	Responses
Strongly disagree	1	0
Disagree	2	1
Neutral	3	2
Agree	4	7
Strongly agree	5	2

The third question asked stakeholders to rate the component's ability to balance passenger waiting time and vehicle utilisation. A total of 12 responses were collected: 11 were positive and only one was negative, resulting in an average score of 3.8. This result indicates that most stakeholders believe the approach is capable of effectively balancing passenger waiting time and vehicle utilisation.

© –2023– SESAR 3 JU

The fourth question asked stakeholders for their opinions on how the outputs of this component could support operational decision-making. Three options were provided: vehicle dispatching, passenger routing, and resource allocation. The ratings for these three options did not differ significantly. This result indicates that the outputs can be applied across multiple use cases—not only for vehicle dispatching, but also for passenger routing and resource allocation.

The fifth question asked stakeholders how this component should be integrated with existing mobility platforms or traffic management systems. The responses indicate a clear preference for API-based integration, with the majority supporting the exposure of the component as a REST/HTTP API. Other approaches received more balanced support, including edge deployment on passengers' mobile devices, cloud-based integration for scalable access, and event-driven architectures using message brokers for real-time asynchronous processing. Overall, these results suggest that while API-based integration is seen as the most practical and preferred option, stakeholders recognise the value of multiple integration strategies to ensure flexibility, scalability, and adaptability across different operational contexts

F.3.3 Unexpected behaviours/results

No unexpected behaviours were observed during the execution of the validation exercise. All obtained results remained within the expected operational boundaries .

F.3.4 Confidence in results of validation exercise #06

F.3.4.1. Level of significance/limitations of validation exercise results

The validation exercise provides indicative evidence on the performance of the proposed methods under the selected scenarios; however, the results should be interpreted in light of the modelling assumptions and experimental settings.

First, the analysis is based on a limited number of representative scenarios (Pyrenees and Tenerife–La Gomera), which differ in scale, network structure, and demand patterns. While these scenarios enable meaningful comparative insights, they do not fully reflect the diversity of potential operational environments.

Second, the simulation framework relies on predefined system parameters, including cost ratios, vehicle capacity, and operational speed. These factors have a direct influence on system behaviour and final performance outcomes, and therefore variations in these parameters may lead to different results.

Third, demand is assumed to follow fixed or scenario-specific distributions, and stochastic variability is only partially captured. This may affect the generalisability of the observed performance, particularly under highly uncertain or disrupted conditions.

Fourth, greater coordination with other PRIAM tools would have mitigated some of the modelling limitations by improving consistency across system inputs and assumptions. However, such coordination was not possible during this phase, as the different components of the PRIAM framework were designed and developed in parallel.

Despite these limitations, the results consistently highlight the relative trends between the methods, especially in terms of computational efficiency, and overall performance stability. Consequently, the

© –2023– SESAR 3 JU

findings provide a robust qualitative indication of the comparative behaviour of the proposed methods, while absolute performance values should be interpreted as scenario-dependent.

F.3.4.2. Quality of validation exercises results

The validation exercise provides consistent and interpretable results that support the comparative assessment of the proposed methods. The simulation outputs demonstrate stable behavioural patterns across scenarios, particularly in terms of computational efficiency and relative performance trends.

The use of two structurally different case studies enhances the credibility of the analysis by testing the methods under heterogeneous operational conditions. In addition, multiple performance indicators are considered, including computational time, and passenger satisfaction rate, which together provide a comprehensive evaluation framework.

However, the quality of the results is inherently influenced by modelling assumptions, including predefined cost structures, vehicle capacity, and operational speed. These parameters may affect the absolute values of the outcomes, although the relative comparisons between methods remain consistent.

Overall, the validation results are considered of sufficient quality to support the conclusions of the study, while recognising that they are scenario-dependent and should be interpreted within the defined modelling boundaries.

F.3.4.3. Significance of validation exercises results

The validation exercise provides meaningful insights into the performance and applicability of the proposed methods under realistic operational scenarios. The results demonstrate clear and consistent trends across different case studies, supporting the robustness of the comparative analysis.

In particular, the observed differences in computational efficiency and system behaviour highlight the practical advantages of the heuristic approach, especially in terms of scalability and real-time applicability. At the same time, the results show that solution quality remains competitive compared to the exact method, indicating that efficiency gains are achieved without a substantial loss in performance.

Furthermore, the validation results help to better understand the influence of network structure and transport availability on IAM dependency, providing additional insights into system-level interactions in different regional contexts.

Overall, the validation exercise confirms the relevance of the proposed methodology and supports its potential applicability in operational planning and decision-support environments, while acknowledging that the results are scenario-dependent and should be interpreted accordingly.

F.4 Conclusions

F.4.1 Conclusions on concept clarification

The concept underlying the proposed IAM integration framework and its interaction with existing transport modes has been clearly defined throughout the study. The modelling assumptions, system boundaries, and operational logic have been consistently specified, enabling a coherent interpretation of the optimisation problem. In particular, the distinction between IAM-supported trips and trips served by existing transport modes has been explicitly formalised. This ensures that individual

© –2023– SESAR 3 JU

travel decisions and system-level allocation processes are fully traceable within the modelling framework. The proposed tool can be applied as a standalone framework, using demand forecasting methods without relying on the vertiport location tool, or as part of an integrated PRIAM toolset when coupled with the broader suite of modules. Overall, the conceptual framework provides a solid and unambiguous basis for both implementation and subsequent analysis.

F.4.2 Conclusions on technical feasibility

The exact and heuristic methods have been implemented and tested within the proposed optimisation framework, enabling a comparative assessment of their computational characteristics. The exact method serves as a benchmark, providing optimal solutions at the expense of significantly higher computational effort.

In contrast, the heuristic method demonstrates clear advantages in terms of technical performance. It consistently achieves substantially lower computation times while maintaining stable and reliable behaviour across all tested scenarios. This stability is particularly relevant for practical applications, where predictable execution and responsiveness are required under varying operational conditions.

Overall, the results indicate that the heuristic approach offers a more efficient and robust solution strategy, while the exact method primarily serves as a reference for optimality assessment rather than a practical deployment option.

F.4.3 Conclusions on performance assessments

The performance evaluation highlights clear differences between the exact and heuristic approaches. While the exact method generally achieves slightly higher passenger satisfaction rates, it is associated with higher computational cost and greater variability in performance across instances. The heuristic method, on the other hand, demonstrates significantly improved computational efficiency and more stable behaviour, while maintaining competitive solution quality. Both methods show similar overall trends across scenarios, although performance decreases over time due to the myopic nature of the decision-making process. From a system perspective, the heuristic approach provides a more balanced trade-off between solution quality and computational efficiency, making it more suitable for practical and real-time applications.

F.5 Recommendations

Based on the results of the validation exercises, several recommendations can be drawn for future development and potential operational deployment.

First, the heuristic method is recommended as the primary solution approach for practical applications, due to its significantly lower computational time and consistently stable performance across different scenarios. These characteristics make it particularly suitable for real-time or large-scale operational environments where rapid decision-making is required.

Second, the exact method should be retained as a benchmark tool for performance evaluation and model validation. Although it is not suitable for operational deployment due to its computational burden, it provides valuable reference solutions that support the assessment of solution quality and system behaviour.

Third, further work is recommended to extend the testing to additional and more diverse scenarios, in order to strengthen the robustness and generalisability of the findings. In particular, stress-testing

© –2023– SESAR 3 JU

under higher demand uncertainty, disrupted network conditions, and different cost and capacity configurations would provide deeper insights into system performance.

Finally, future developments could focus on improving the heuristic design, particularly in terms of enhancing solution quality while preserving its computational efficiency. This includes exploring adaptive or hybrid approaches that combine the strengths of both exact and heuristic methods.

© –2023– SESAR 3 JU