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Airports: Spanish initiative for "Airport Improvement Research on Processes & Operations of Runway, TMA and Surface"

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Abstract

AIRPORTS (Airport Improvement Research on Processes & Operations of Runway, TMA & Surface) is a research and development initiative aimed at developing technologies and capabilities to enable the implementation of TBO (*Trajectory-Based Operations*) and PBO (*Performance-Based Operations*) in the airport context, considering operations and processes affecting both aircraft and ground vehicles. AIRPORTS is a multidisciplinary and integrated effort that tackles highly complex scientific and technological challenges with important repercussions for the global air transportation system. The project tackles the development of technology solutions that contribute to modernize and improve the air transportation system from a multidisciplinary perspective, considering both air and ground operations. The project embraces a holistic approach, considering both analysis and experimentation and culminating in proofs of concept and integrated use case scenarios that demonstrate advanced technology solutions that enhance airport operations.

Keywords: Airport, TMA; TBO; PBO.
TMA (Total Airport Management).

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Nomenclature

TMA	Total Airport Management
TBO	Trajectory-Based Operations
PBO	Performance-Based Operations
AV	Automated Vehicle
GV	Ground Vehicle

1. Introduction

AIRPORTS (Airport Improvement Research on Processes & Operations of Runway, TMA & Surface) is a research and development initiative which **main goal** is to develop technologies and capabilities in order to enable the implementation of TBO (Trajectory-Based Operations) and PBO (Performance-Based Operations) in the airport context, considering operations and processes affecting both aircraft and ground vehicles. AIRPORTS is a multidisciplinary and integrated effort that tackles highly complex scientific and technological challenges with important repercussions for the global air transportation system.

So, based on the main objective mentioned above, the scientific and technologic **objectives** of the AIRPORTS project are the following:

- **Objective A1**: Develop key enabling technologies to facilitate the implementation of trajectory-based operational concepts in the airport context (TBO), with a view to managing the trajectories/operations of air and ground vehicles safely and efficiently with high levels of automation and autonomy.
- **Objective A2**: Develop advanced analytics to understand and quantitatively assess the performance of airport operations, with a view to facilitating the introduction of new processes aimed at improving operational performance (PBO).
- **Objective A3**: Develop advanced solutions to existing challenges in the fields of communications, autonomous navigation, sensors and information management that limit the predictability of aircraft and ground vehicle operations in the airport context and hinder the introduction of new automation solutions to manage those operations more effectively. The focus is on aircraft operations both within the Terminal Maneuvering Area around the airport and on the ground as well as the operations of ground vehicles within the airport (airside operations).
- **Objectives A4 and A5**: Design and conduct experimental proofs of concept in the context of integrated use case scenarios to demonstrate and validate those technology solutions developed within the project with the highest potential to improve airport operations.

The project tackles the development of technology solutions that contribute to modernize and improve the air transportation system from a multidisciplinary perspective, considering both air and ground operations. The project embraces a holistic approach, considering both analysis and experimentation and culminating in proofs of concept and integrated use case scenarios that demonstrate advanced technology solutions that enhance airport operations.

The global transportation system is under intense pressure to increase its efficiency and reduce its environmental footprint. Governments, industry and institutional stakeholders have begun to question the sustainability of the current system and, as a result, modernization initiatives have emerged in different parts of the world, proposing new legislative and economic models, concepts of operation and enabling technologies. In the context of air transport, two large-scale modernization initiatives, SESAR in Europe and NextGen in the United States, are already underway and have begun to bring about transformational changes in legislation, standards, technology and operations. These two initiatives are set to invest tens of billions of Euros over the next 15-20 years.

Besides, the growing pressure to unlock the enormous business potential of civilian commercial applications of unmanned autonomous systems, both aerial and ground-based, is crystalizing in a variety of initiatives that aim at tapping at a global market that is estimated to reach 100,000 M$ during the next decade.

The main obstacles to the success of the above initiatives are in many cases related to the lack of maturity of key technological enablers. To tackle these challenges, which are considered critical to the future of the global air transportation system, some of the countries with the most advanced industrial fabric are investing heavily on research and development, placing them in a position of advantage to seize emerging business opportunities.

With an overall budget close to 12,5 M€, the AIRPORTS initiative addresses some the most important challenges referred to above and is expected to make a significant impact in the field. To that aim, AIRPORTS is backed by a consortium made up of 7 leading companies in relevant technology sectors not only in Spain but internationally (Boeing, IKUSI, CRIDA, Maser Mic, Skylife, Carbures Systems and Ixion), including three Small and Medium Enterprises (SMEs) with a recognized capability for innovation (Skylife, Maser Mic and Ixion) and supported by ten public research organizations from five different Spanish regions.

The AIRPORTS initiative has already attracted the interest of many relevant stakeholders, including institutions and companies in the air and ground transportation sectors both at the national and European level, such as EUROCONTROL, the SESAR Programme through its network for innovative research in advanced automation for Air Traffic Management (HALA!), Aena, Air Europa, Iberia Express, DHL, AZKAR and ERTICO.

Besides contributing to the improvement of the safety, efficiency and environmental impact of airside airport operations6, the results of AIRPORTS will contribute to foster the technology maturation process required to exploit unmanned autonomous systems in civilian commercial applications, thereby contributing to accelerate the creation of new business opportunities associated with the exploitation of these applications.

It is anticipated that the scientific and technological results of the AIRPORTS project will allow the partners involved to consolidate a collaborative network of reference for research and development on enabling technologies for higher transport efficiency in Spain, as well as to attain a leading role in ongoing initiatives to modernize the air transportation system in Europe and beyond. These initiatives will continue to mobilize research investment and open the way to new business opportunities for the next two decades.

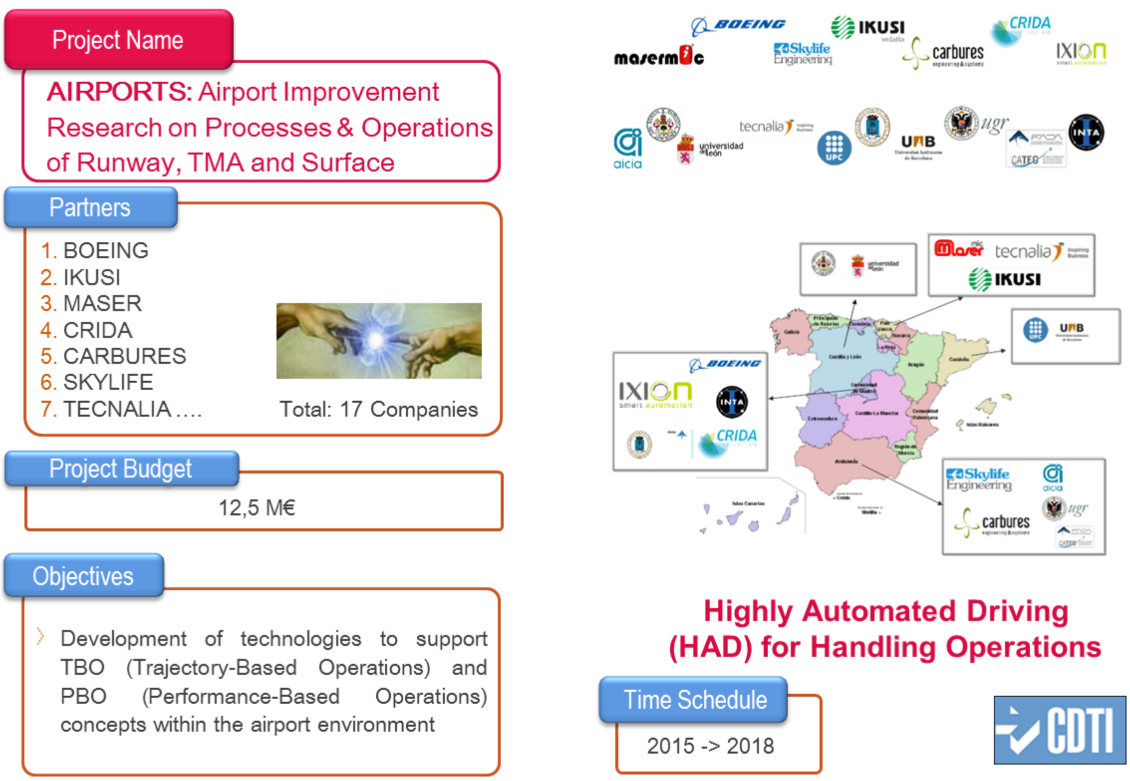

Fig. 1 Project summary

2. Technical project description

This section describes the technical approach of the project on line along with the scientific and technical objectives previously given following a top-down methodology based on its most general and abstract aspects, to target specific R+D activities affecting a set of significant challenges existing in the state of the art. Discussion is organized around **five complementary R+D activity blocks** that comprise an integrated initiative on the idea of developing technological advances in the conduct of operational concepts in TBO and PBO and their validation in a representative environment.

2.1 Enabling trajectory management technologies (A1)

From this viewpoint, taking advantage of the know-how and experience separately accumulated by BR&TE (BOEING) and IKUSI in their respective application environments and the existing potential of technology transfer, the AIRPORTS initiative proposes an R+D thrust geared towards the development of enabling technologies for mixed vehicle trajectory management. The thrust specifically revolves around two aspects:

- The development of a Domain-Specific Language (DSL) along with a tool environment based on this that will allow for enabling the advanced computational processing of modelling, prediction and control problems entailed by mixed vehicle trajectories. The proposal seeks to develop and expand AIDL (Aircraft Intent Description Language), originally conceived for ATM (Air Traffic Management) contexts, extending its capacities, addressing some of the inconveniences identified, and spreading it to adapt it to all the flight phases for aircraft and ground vehicles, whether or not manned (which would enable, among other things, the coverage of AV ground operations).

- The development of advanced technologies for managing the Trajectory-based Operations (TBOs) of a set of mixed ground vehicles, which would enable validating the expansion of the AIDL concept to the entire life cycle of AV trajectories in all phases and operating contexts, as well as extending its applicability as an enabling technology for automation in the context of land transport (GVs).

On the other hand, it is also necessary to ensure that the vehicles rigorously execute the operating prescription captured through the language proposed. To further the state of the art with regard to computational representation and the consequent capacity to predict these features, there is evident need for R+D efforts geared towards such purpose:

- The development of a general model for vehicle action extending throughout the trajectory; i.e., to all AV flight phases, including take-off and landing as well as taxi operations, and encompassing GV activities. The major challenge here consists of predicting AV action during take-off and landing due to the complexity associated with accounting for the aerodynamic effects caused by proximity to the ground (ground effect) as well as interaction with the ground during acceleration/braking.

- The development of a predictive model for weather conditions in a space-time domain (4D) that will include the layers of atmosphere close to the ground. One fundamental challenge in this case consists of improving the predictability of wind, temperature and pressure within the boundary layer of the terrain and its area of influence, which, on another front, is essential to the predictability of UAS/RPAS (Unmanned Aerial System/Remotely Piloted Aircraft System) operations. Apart from improving the accuracy of predictions, the other challenge relates to the need to somehow limit the uncertainty associated to these. In this sense, recent advances in the application of probabilistic techniques to weather forecasting open a horizon of rather promising possibilities in terms of the problem described.

2.2 Quantitative performance analysis capacities (A2)

Given the scenario of complexity described in the preceding section, another of the big challenges facing the introduction of greater levels of automation in future transport systems consists of developing advanced capacities that will enable understanding and modelling of the complex relations and interactions between the multiple processes involved and the influence that individual performances will have on the aggregate behaviour of the system.

In this sense, there are problems on two closely associated fronts: on the one hand, the vehicle trajectory life cycle process, and on the other, the implication of the human factor within it. In effect, the vehicle trajectory life cycle may be seen as an extraordinarily complex succession of diverse processes and events, as a result of which the vehicle carries out a mission of certain merit. Although the fundamental thrust of this process is the progress of the vehicle from an initial to a final state (known as the trajectory), the entire universe surrounding this progression covers an enormously broader horizon in which said trajectory is only an example within a multitude of trajectories interacting with one another.

2.3 Critical CNS+I infrastructures (A3)

The features and capacities of infrastructures for communication, navigation, surveillance, integration and the management of available data play an essential role in defining an operational concept that should enable the exploitation of such capacities while adjusting to their limitations. Four more major challenges relating to the new capacities that these infrastructures should offer in their diverse fields of application may be underscored with a view to the near future:

- As regards communications, the essential challenges are associated, on the one hand, with the standardized ground-air data connections that commercial aircraft will be required to have to facilitate their connectivity to a data distribution system (System-Wide Information Management, SWIM) oriented towards services and based on network architecture, which will provide support for the large data volumes expected from the implementation of the numerous service concepts proposed for the conduct of the operational concepts defined. On the other hand, there is the ground-air data connection required for UAS/RPAS command and control, as their operation is particularly critical, at least until greater levels of autonomy are achieved.

  Finally, another challenge related to communications, of special interest to the AIRPORTS initiative due to its novelty and potential in terms of applications, is the development of data communication solutions between ground vehicles, between these and taxing aircraft, and with other infrastructures such as the pertinent GV control centre. Such capacity is new in the ATM domain and indeed critical to accurately geo-locate the different GVs and manage their operations optimally with a high degree of automation.

- As regards navigation, the essential challenges identified to date are associated to the increasing use of GNSS (Global Navigation Satellite System) systems, which depend on spatial signals vulnerable to interferences (whether or not deliberate), the integrity of which, to date, does not allow for their use as the sole medium for certifiable navigation. This poses one of the main obstacles to UAS/RPAS inclusion, due to their critical dependence on GPS signals. In view of the situation, Skylife, based on know-how and experience in multi-sensor hybridization technologies, proposes an initiative focusing on the study of UAS/RPAS navigation improvements in non-operative GPS environments and GNSS geolocation for GVs in airport contexts characterized by an innovative approach and a cutting-edge technological component.

- As regards surveillance, the fundamental challenge from the viewpoint of operation safety in a context characterized by a high degree of autonomy lies in endowing vehicles (RPASs and GVs) with perceptive capabilities as well as the capacity to interpret perceptions, recognizing their immediate surroundings and the objects (or traffic) in these in order to provide useful information for decision-making. This capability is critical, for instance, to develop an acceptable solution to "detect and avoid" (D&A) problems, which is required in all autonomous mobile system environments. To such an end, Ixion proposes an R+D thrust focused on researching an advanced solution for autonomous GV environment perception and recognition based on latest-generation sensor technology and artificial intelligence.

- With regard to data integration and management, the basic challenge lies in extending application of the service-oriented network-based architecture paradigm represented by the SWIM concept – to date, developed fundamentally in the aircraft (ATC/ATFM) operations environment – to the complex heterogeneous operating environment of airports as a whole, considering all interrelated processes holistically beyond the mere aircraft-process model (i.e., including passenger, luggage/merchandise and infrastructure processes). To this end, based on its know-how and vast experience in the domain of airport operations, IKUSI proposes to investigate the creation of a SWIM infrastructure for airport environments based on the TAM (Total Airport Model) philosophy and on technologies for massive data management and exchange that can enable efficient integration of the different systems for providing service to these operations.

2.4 Proofs of concept (A4)

The research proposal made by the AIRPORTS initiative would not be complete without the experimental component that the nature proper to many of the technologies involved in such research requires to advance beyond mere concept formulation or model simulation. Thus, the experimental component of the project revolves around four concept tests that cover the aspects of the technologies under study depending more critically on experimentation for their proofing and validation, or for performance evaluation. It may be underscored that the experimental side of the AIRPORTS project builds on the experience and a large part of the experimental media developed in the course of previous initiatives such as ATLANTIDA, ADAM and others, which will be reused where formulations so allow, in combination with the new experimental prototypes that are being investigated.

2.5 Analysis of results (A5)

Lastly, the approach adopted for the analytical component of the project is to combine the efforts related to the formulation of the studies, the simulation and/or experimental tests and the validation tests corresponding to the integrated analysis thrusts (i.e., combining several project lines, the technological products of which are to interact), along with the discussion, evaluation and documentation of the results attained throughout the different research lines, considering them as a single cross-cutting activity involving previous efforts, in which all the consortium members will participate. This is expected to facilitate efforts at integration, comparison and the exchange of approaches and analytical methods, as well as the integrated analysis of solutions involving technological products from multiple research lines.

3. Work plan

3.1 Activities

The technical approach described in the preceding section reflects a complete cycle of scientific and technical research structured into five blocks. The first two relate to the development of enabling technologies and analysis capacities considered critical to modernize air and ground transport systems along the lines of the demand for those technological advances marking the roadmaps set by the principal European initiatives in these spheres (operational concepts in TBO and PBO). The three blocks following supplement the thrust along the experimental and analytical component, facilitating the critical communication, navigation, surveillance and information management infrastructures necessary for the creation of the technological concepts proposed, and, in particular, a set of tests for these concepts revolving around use cases for the technologies being researched in the airport context. In line with this approach, the working structure adopted is laid out along **five activities** that correspond to the activity blocks described, to wit:

- **A1**. Enabling Trajectory Management (ETM) technologies. This includes the L11, L12, L13 and L14 research lines (see section 3.2), all of which are related to the design and development of technologies essential to enable robust solutions to automate vehicle trajectory management broadly applicable to the fields of air and ground transport, and, in particular, to unmanned transport systems for these areas.
- **A2**. Quantitative Performance Analysis (QPA) capabilities. This includes the L21, L22 and L23 research lines, all of which relate to the design and development of analytical capacities for highly complex transport system performance evaluation, as in the case of the ATM system, in particular, based on high-fidelity models of two of the aspects essential to system performance: vehicle (AV and GV) trajectories and the cognitive workload of the operators involved in the control processes entailed.
- **A3**. Critical CNS+I infrastructures (CNS+I – Communications, Navigation, Surveillance & Integration). This includes the L31, L32, L33 and L34 research lines, along with those lines related to developing technologically advanced solutions for the requirements posed by advanced capacities of automation/autonomy with regard to date communication, navigation/geolocation, perception/recognition of the environment and data management, integration and distribution.
- **A4**. Proofs of Concept (POC). This includes the L41, L42, L43 and L44 research lines, all of them related to experimental proofs of concept relevant to the airport context, integrated on the basis of the technological solutions developed in activities A1, A2 and A3.
- **A5**. Analysis of results (AR). This includes the single research line L5, which combines the formulation and analysis of results and efforts for their publication.

The following figure shows the structure of AIRPORTS project activities in diagram:

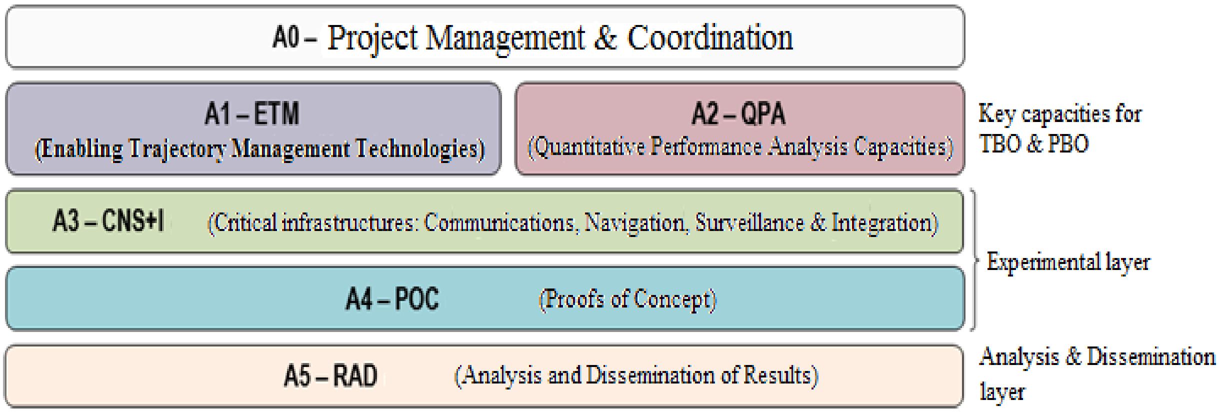

Fig. 2 Structure of activities

3.2 Research lines

In line with the approach described in the preceding section, the five general scientific and technological objectives are in turn broken down into **16 research lines**, each of them dealing with the pertinent technological challenge identified in the said section, as described below.

Objective A1 – Development of technologies enabling automated trajectory management support

- **L11 (VIDL):** Development of a technologically advanced solution for the end-to-end computational processing of mixed-vehicle movement (trajectory) design, calculation and control suited to air vehicles (AVs) and land vehicles (GVs), responding to the multiple and generally highly demanding requirements specified in the field of future transport systems.
- **L12 (APM):** A predictive model for vehicle response to the direction and control requirements that should cover activity in flight, take-off and landing (for AVs) as well as on the ground (taxiing AVs and GVs).
- **L13 (PAM):** A predictive model for atmospheric features influencing vehicle movement that should improve the accuracy of predictions in atmospheric layers close to the ground and provide as well a reliable measurement for the uncertainty inherent in such predictions.
- **L14 (AOPM):** Based on the foregoing capabilities, the development of a technologically advanced solution for the integrated management of airport processes, including automated support for the collaborative management of movement in a set of mixed land vehicles (GVs and/or taxiing AVs) capable of responding to the requirements set in the field of future transport systems. Specifically, such solution must holistically integrate ground operations with TMA, runway and terminal processes, in addition to considering network effects.

Objective A2 – Development of quantitative performance analysis capacities

- **L21 (TBOEA):** Development of advanced quantitative merit or performance analysis capacities for vehicle trajectories, whether individual or aggregate, based on reverse engineering techniques for the observable aspects of vehicle movement facilitated by the L11 and L12 solutions.
- **L22 (OWLM):** Development of automated decision-making assistance capacities for executive controller workload evaluation, prediction and planning at the airport terminal area (TMA) as a tool for evaluating the complexity of the TMA air space within the process of NOP/AOP (Network Operations Plan/Air Operations Plan) integration and modification.
- **L23 (HAPM):** Based on the foregoing L21 and L22 capacities, and with the assistance of technologies for massive data treatment, the development of an integrated model of key performance indicators that will enable quantitative analysis of the multiple aspects of merit in the entire complexity of airport operations. Performance monitoring in the planning, execution and post-operation phases will facilitate improved knowledge of the system, efficient prediction of the impact of decisions, and an objective tool for evaluating the effects of measures taken on the global system.

Objective A3 – Development of technology for critical communication, navigation, surveillance and integration (CNS+I) and data management infrastructures

- **L31 (COM):** Development of a solution for mobile communications between ground vehicles (V2V) as well as between these vehicles and the infrastructure executing the L14 solution (V2I) that will respond to the critical needs and requirements posed by future smart transport systems, and which in particular will support the conduct of the concept tests formulated in points L42, L43 and L44.
- **L32 (NAV):** Development of a navigation solution for mixed autonomous vehicles (AVs and GVs) with advanced features of integrity and accuracy that will make it possible, on the one hand, to address the inconveniences related to the critical dependence of these systems with regard to GPS, and on the other hand, provide support for the needs in precision trajectory mapping formulated in the proof of concept for L41. Said solution must consider the problems relating to occlusion, possible interference and the multiple trajectories of navigation signals in environments with obstacles and buildings (e.g., airport surroundings) and, in particular, must provide support for the geolocation needs of ground vehicles formulated in the proofs of concept for L42, L43 and L44.
- **L33 (SUR)**. Development of an integrated solution in ground vehicle (GV) environment perception, recognition and surveillance based on latest-generation sensor technology, which should enable both safe vehicle movement by avoiding collisions with other vehicles or obstacles, and controlled approach and coupling with other vehicles or fixed installations, as their applications require. In particular, such a solution should provide support for the requirements related to the proofs of concept formulated for L42, L43 and L44.
- **L34 (SWIM)**. Development of a solution for the integration, management and exchange of information that will provide the central infrastructure around which the data exchange between the different subsystems providing services to the advanced airport operations dealt with by L11 to L32 will be structured, in line with modern specifications for network-based service-oriented system architecture. Such infrastructure is to be an implementation of the SWIM concept in airport surroundings, based on a holistic data model of the operational airport environment (TAM, a Total Airport Model) and network technologies for massive data management and exchange.

Objective A4 – Proofs of concept with applicability to airport environments

- **L41 (AV-RNP):** Based on the foregoing L11, L12 and L32 capacities, the development of a proof of concept or use case consisting of an RPAS application equipped with trajectory mapping instrumentation and SDR (Software-Defined Radio) technology signal reception to conduct automatic calibration flights and air navigation radio assistance monitoring, such as ILS (Instrument Landing System) and VOR/DME (VHF Omni-Range/Distance Measurement Equipment).
- **L42 (GV-FM):** Based on the foregoing L11, L12, L14, and L31 to L34 capacities, the development of a proof of concept or use case consisting of automating an electric ground vehicle to guide taxiing aircraft (follow-me) under conditions of low visibility, which may be extended to the concept of aircraft towing during procedures of noise and emission abatement in airport environments.
- **L43 (GV-PAX):** Based on the foregoing L11, L12, L14, and L31to L34 capacities, the development of a proof of concept consisting of automating an electric passenger transport microbus for autonomous operation, with decision-making capacities regarding the possible obstacles that can interfere with the route.
- **L44 (GV-BAG):** Based on the foregoing L11, L12, L14, and L31 to L34 capacities, the development of a proof of concept or use case consisting of automating a baggage and other merchandise transport vehicle to autonomously shuttle between the terminal building and the aircraft parking slot.

Objective A5 – Analysis of results

L5 (AR): Based on the formulation of all the foregoing lines, the identification of integrated analysis use cases (i.e., involving the interaction of several project lines), formulation and methodology of the analytical process and the preparation, discussion and documentation of results.

Table 1. Lines of research comprising the AIRPORTS initiative.

Activity	Line	Description	Acronym
A1	L11	Design, calculation and control suited to heterogeneous vehicles.	VIDL
	L12	Actuation model for AVs extensible to gate-to-gate.	APM
	L13	Predictive model for atmospheric conditions.	PAM
	L14	Collaborative management of movement in a set of mixed land vehicles.	GTM

A2	L21	Performance analysis capacities for vehicle trajectories.	TBOEA
	L22	Cognitive model of automated decision-making assistance capacities for executive controller workload evaluation, prediction and planning.	OWLM
	L23	Holistic model to monitor the airport performance based on big-data.	HAPM
A3	L31	Infrastructure of communications for automated vehicles.	COM
	L32	Infrastructure of navigation solution for mixed autonomous vehicles.	NAV
	L33	Environment perception, recognition and surveillance for automated vehicles.	SUR
	L34	Infrastructure for the management and exchange of information in airport.	SWIM
A4	L41	RPAS for automatic calibration flights and air navigation radio assistance.	AV-RNP
	L42	AGV to guide taxiing aircraft.	GV-FM
	L43	AGV for passenger transport microbus.	GV-PAX
	L44	AGV for baggage and other merchandise transport.	GV-BAG
A5	L5	Analysis and dissemination of results.	ADR

Lastly, the following figure illustrates the network-based, service-oriented concept of software architecture adopted by the AIRPORTS initiative. Indeed, in line with the approaches accepted among ATM system modernization initiatives and IT advances in highly complex distributed systems, the technological solutions dealt with by the lines corresponding to A1, A2 and A3 activities are presented as interrelated infrastructures and services, distributed and connected to a delocalized infrastructure for data integration and management, which is none other than the SWIM concept extended into the airport environment. On their side, the products of the A4 and A5 activity lines (respectively, experimental proofs of concept and integrated analytical studies) correspond to specific use cases executed as sequences of interactions between infrastructures and services routed through SWIM.

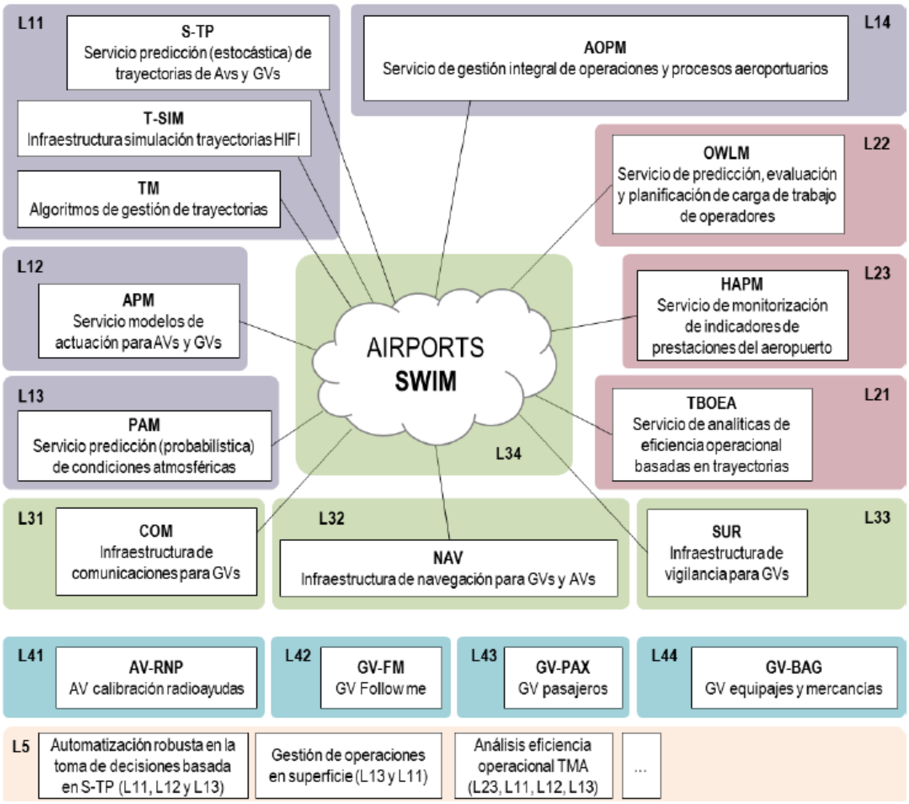

Fig. 3 Diagram of the lines of research comprising the AIRPORTS initiative

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