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datAcron

D6.1 Aviation use case detailed definition

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EXECUTIVE SUMMARY

This is the first deliverable (D6.1) of datAcron work package 6 "Aviation Use Case" which main objective is the validation of datAcron research results in an Aviation Industry use case. D6.1 "Aviation use case detailed definition" is devoted to setup a clear understanding for all datAcron partners about concepts and terminology, business objectives, data involved, events to detect and metrics to obtain.
The first part of the document presents Airlines and Air Traffic Management (ATM) business context. It establish the relation of Airline Revenue with flying "optimal" trajectories, i.e. minimizing main costs: fuel, time/schedule adherence related cost and air traffic services fees. Then it presents the Flight Plan as the "optimal" trajectory (agreed at a given time). Then the relation of Air Navigation Service Providers (ANSP) resource optimization with system uncertainty is explained and how the limits of automation are due to the same uncertainty. This leads to the objective of the use case: Increase predictability (=reducing uncertainty). Big Data approach applied to trajectory prediction can help to this improvement, understanding Big Data as Data-Driven (i.e. learning from historical data).
Two mains scenarios are selected for the use case: Flow Management and Flight Planning. Both scenarios are split in increasingly complex smaller scenarios which are related to datAcron components and technical work packages so the coverage of the different datAcron developments can be easily mapped.
Flow Management scenarios main objective is to allow better planning of the demand and capacity balance which will lead to less delays.
Flight planning scenarios main objective is to enhance the trajectory prediction to avoid plans prone to great deviations the day of operations.
Both scenarios leverage the analysis of historic data related to:

- Flight Plans
- Context ATM data
- Surveillance data
- Weather data
- Flow Management

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TERMS & ABBREVIATIONS

ACC	Area Control Center
ADS-B	Automatic Dependent Surveillance-Broadcast
AIC	Aeronautical Information Circulars
AIP	Aeronautical Information Publication
ALS	Alarm Service
AMDT	AIP Amendments
ANSP	Air Navigation Service Providers
ASM	Air Space Management
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATZ	Aerodrome Traffic Zones
CAS	Calibrated Air Speed
CM	Center of Mass
CNS	Communication, Navigation and Surveillance
CTA	Control Traffic Areas
CTOT	Calculated Take Off Time
CTR	Controlled Traffic Regions
D-ATIS	D-ATIS Digital Automatic Terminal Information Service
DOC	Direct Operational Costs
DSTs	Decision Support Tools
EAS	Equivalent Air Speed
ECAC	European Civil Aviation Conference
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure

ETOT	Estimated Take Off Time
FDPs	Flight Data Processing Systems
FIR	Flight Information Region
FIS	Flight Information Service
FMS	Flight Management System
GS	Ground Speed
IAF	Initial Approach Fix
IAS	Indicated Air Speed
IATA	International Air Transport Association
ICAO	International Civil Air Organization
IFR	Instrumental Flight Rules
IMC	Instrument Meteorological Conditions
IOC	Indirect Operational Costs
MET	Meteorological Information Services
NARI	The Naval Academy Research Institute
NOTAM	Notice to Airmen
QNE	pressure when the altimeter is regulated with standard 1013.25 hPa isobar
QNH	barometric pressure adjusted to sea level – Query: Nautical Height
QoS	Quality of Service
RNAV	Area Navigation
RNP	Required Navigation Performance
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
SUP	AIP Supplements
TAS	True Air Speed
TCAS	Traffic Alert and Collision Avoidance System
TMA	Terminal Manoeuvring Areas
ToC	Top of Climb

ToD	Top of Descent
TP	Trajectory Prediction
UIR	Upper Information Region
UOCs	User Operations Centers
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

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1. INTRODUCTION

1.1 Purpose and Scope

The aviation use case detailed definition is a document intended to the use of all partners of datAcron and not only for subject matter experts. In this sense it explains all needed concepts and terms for understanding the application of datAcron to the scenarios selected but does not try to go deeper than needed for the experiments and validation.
The uses case detailed definition needs to be completed in a way that for all the researches in the project to understand the objectives of applying the technologies developed and the benefits expected in case of success. Success itself need to be defined in terms of measurable and understood metrics.
Data is a key player in datAcron and this document specifies the different data sources relevant to the use cases described. However there is one specific deliverable D6.2 "Aviation data preparation and curation" due in month 6 (M06) for the detailed definition of the datasets to be used. This will contain the detailed specification and definition of the data sources and data sets.

1.2 Approach for the Work package and Relation to other Deliverables

The technological developments in datAcron will be validated and evaluated in user-defined challenges that aim at increasing the safety, efficiency and economy of operations concerning moving entities in the Air-Traffic Management and Maritime domains. The overall objective of work package 6 (WP6) is to validate the research results by means of experiments relevant to an Aviation Industry (ATM) use case. It relates directly to proposal objective 5: **"[O.5] Validation and evaluation of the datAcron system and individual components on the surveillance of moving entities in the ATM and marine domains."**
The aviation use case detailed definition is the first step needed to achieve this objective. This document sets up the foundation and common understanding for the next two steps in WP6:

1. Collect the data needed for the validation (Task 6.2).
2. Specify the experiments to be conducted for the validation (Task 6.3).

1.3 Methodology and Structure of the Deliverable

This deliverable is developed by industry subject matter experts and follows a use case definition for high level understanding of the business and then several detailed scenarios to allow the application of the project technology developments in such business.
Several aspects proposed by NARI were agreed on datAcron Kick off meeting about the use cases:

- Main role of the use cases is to
    - Act as a guide for research and development
    - Exemplify and validate research findings
- Use cases can provide a powerful tool for datAcron to address different aspects of the research problems providing a common story and representative datasets
- They focus on relevant practical challenges and operational questions
- Compared to scenarios, a use case briefly tells stories about specific examples relevant to trajectories surveillance and mobility prediction with fairly limited details
- It is thus expected that use cases will provide an initial conceptual storyline to be further enriched with
    - more detailed scenarios depending on needs expressed for each work package, and
    - relevant datasets or technical aspects as the work progresses.

Five requirements were identified too about use cases:

- UC Req. 1: Addresses a challenging problem deemed of interest, and representative of operational concerns.
- UC Req. 2: Tells the story in a simple way as a kind of "skeleton", flexible enough to allow further evolution and developments all along the project.

- UC Req. 3: Reflects the expected outcomes in terms of data management, trajectory analysis and prediction, event detection and visualization (i.e. should depend on interests of the different work packages).
- UC Req. 4: Acts as an “integrator” for the different aspects to be pursued so that different work packages can illustrate their findings within a common story
- UC Req. 5: Relies on available (unclassified) datasets.

2. BUSINESS NEEDS

Air transportation plays an integral role in our way of life. Commercial airlines allow millions of people to travel around the globe every year for leisure or business needs. Around 30000 flights overfly European skies everyday, representing approximately 11 millions flights and 1600 million passengers per year. The aviation industry is considered a strategic activity, being its economic impact (direct + indirect + induced) of nearly $581 billion (roughly 3.5%) to GDP in Europe and supporting 7 millions jobs (Doganis, 2002).

The aviation industry has evolved during the past 30 years, moving from system composed of public or highly state-participated airlines with almost no competition towards a very competitive global business very sensitive to the global economy. The liberalization of the aviation across the world in the 80's-90's and the high competition have pushed the decrement on the ticket price, also reducing airline's profit to less than 3% of the revenues (Air Transport Action Group (ATAG), 2014). Airline's strategies to increase profit margins to surpass the Cost of Capital (~7%) include boosting the demand and reduction of costs. Roughly, the costs associated to the direct operation of the aircraft corresponds to 60% of the total cost (Air Transport Action Group (ATAG), 2014), and nearly 15% of the total cost are those associated to aircraft and traffic services. From the direct operation cost, 60% corresponds to fuel and labor costs. In summary, the deviations from the most optimal trajectory in terms of fuel, time cost and traffic services greatly impact the overall cost borne by the airlines.

In order to minimize their overall costs, airlines plan well in advance their fleet schedule and assignment, flown routes, maintenance services, crew rotations and ticket prices. Getting close to the day of operation, the final schedule, aircraft and crew are assigned to each flight and the ***flight plan*** is defined. The flight plan (see section 3.12 for the complete and detailed definition) is the best representation of the airlines intention to minimize their direct operating costs with the information available the day it was planned. Adjustments to this flight plan are done until the day of operation, which may include adjustments in the ***Estimated Time of Departure*** (ETD) and ***Arrival*** (ETA) or changes in the planned route. These changes are the result of the coordination between the airlines with the different ***air navigation service providers*** (ANSPs)[1], which are in charge of balancing the navigation services offered in a particular region of the airspace with the amount of aircraft that will require those services ensuring safe and efficient aircraft operations in that region[2]. These adjustments represent an adaptation to events and weather conditions that influence the cost and even the safety of that flight. The ***uncertainty*** associated to the flight plan, which in turn is associated to the uncertainty in the weather, the overall traffic and the air navigation resources available, has an estimated cost of $30 billions just in US (Mueller & Chatterji, 2002). (See also a detailed description in the ***Flight Cost*** section 3.15)

For all the actors involved in the ***air traffic management*** (ATM), i.e., aircraft, airlines, ANSPs and airports, increasing the level of ***predictability*** can help their planning stage and the proper assignments of their resources. One aspect of vital importance for airlines is ensuring that the filed flight plans will comply with all the disrupting events that may affect the air traffic, so at the end all the ATM actors will have a common and realistic picture of the air traffic, minimizing the delays and inefficiencies in the ATM system.

Delay costs are often considered only at the tactical level (day of operations), where they are encountered, and measured against planned activities. However, delay has to be anticipated by airlines at the strategic stage (months or days in advance of operations), when developing schedules which can absorb the unpredictability of day-to-day operations. Airlines deal with these circumstances usually by adding buffers into their schedules, what in practice increases unpredictability. Adding some figures to seize the impact of this issue, according to Performance Review Report 2014 a total amount of 5.87 million minutes of ***en-route*** time occurred in the EUROPEAN CIVIL AVIATION CONFERENCE (ECAC) area, increasing 17.2% respect to the previous year, meaning an average en-route delay per flight of 0.61 minutes, with 1.6% of the overall flights in ECAC

[1] In Europe, regional ANSPs also need to coordinate with the ***Network Manager*** to balance their navigation services among themselves.

[2] ANSPs executes the functions of ***flow management*** and ***air traffic control*** functions, defined in section 3

area delayed more than 15 minutes for flow management reasons. While the situation is significantly better than in past years, the impact is still huge.

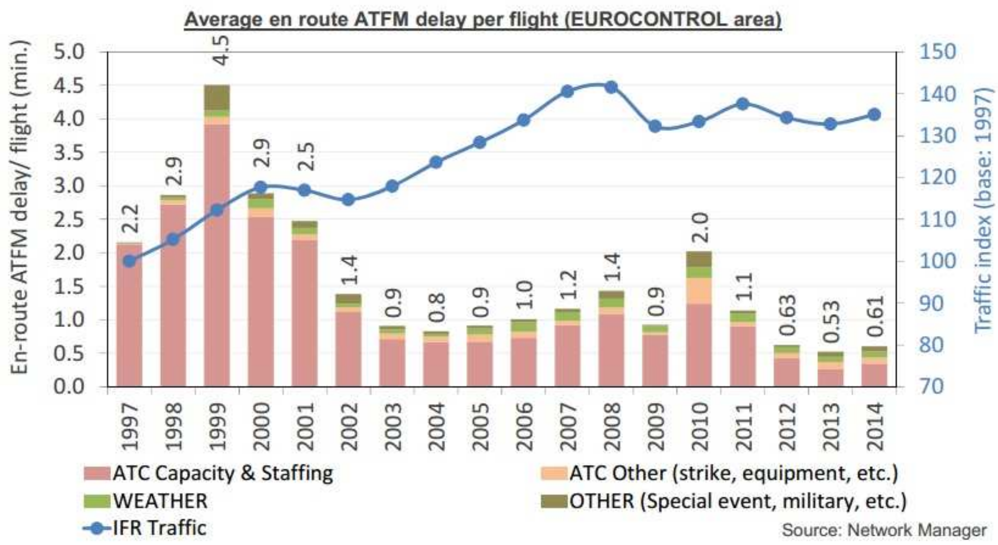


Figure 1 - Average en route ATFM delay per flight (EUROCONTROL area)

A better detection and forecasting of those kinds of imbalances would mean major savings for all the actors in the ATM system. According to (Cook, Tanner, & Anderson, 2004), passenger delay costs incurred by airlines in consideration of both 'hard' and 'soft' costs are estimated as EUR 0.30 per average passenger, per average delay minute, per average delayed flight (considering every delay cause, not only due to flow management causes, but still valid for assessing the cost). An overall range impact of ATFM delay cost for airlines in 2004 was evaluated as 840-1200 million EUR, consequently meaning a cost of 72 EUR per minute of ATFM delay for airlines.
The current state is such that the all the ATM actors must manage aircraft operations under the presence of this high level of uncertainty. Since the automations they use to assist them in their decisions can only exploit the available predictability of certain aspects related to their own operations[3], the remaining uncertainty can only be coped with through the provision of safety margins. The tradeoff between predictability and uncertainty plays a central role in ATM. Thus, e.g. combining all available mechanisms to achieve the highest possible level of predictability may allow the automation to attain the maximum performance in terms of capacity, but at the expense of worsening other aspects such as efficiency, flexibility and/or environmental impact, which may not necessarily/desirably be the case. For instance, the current air traffic flow management (ATFM) system suffers a certain lack of flexibility that does not allow enough pro-activity in the operational day. Because of the high degree of uncertainty in the system, the perceived safest course of action is taken – namely regulation. Often decisions to balance demand and capacity (implementation of regulations) have to be taken two hours and more prior to the time of occurrence of the predicted overload situation in order to ensure the needed effect of these measures.

It is essential to investigate and enable the mechanisms that allow achieving the necessary predictability but, besides that, it also results paramount to understand the influence that such mechanisms exert in the different Quality of Service (QoS) performance aspects of the system. The

[3] For example, aircraft can manage and quantify the uncertainty introduced by their navigation systems (GPS, autopilot), but it cannot cope with the uncertainty of the surrounding traffic or weather hazards. Therefore, safety margins are in place to ensure the proper and safe separation of the aircraft.

current availability to process massive amount of historical and real time data from different sources opens a new paradigm in understanding patterns and correlations between different events that affect the aircraft flight. This can help on the prognosis of the air traffic, therefore, helping on achieving the level of predictability desired at each planning phase. For example, ***flight planning*** and ***flow management*** tools can benefit from a more likely flight plan, since this will allow a more accurate fleet management for the airline and also better balance of sector's capacity which in turns also benefits the likelihood of executing without interventions. A predictable flight allows a better management of the fuel onboard the aircraft, reducing the contingency fuel that pilots need to load, which at the end impacts the total fuel consumed (*'airplane consumes fuel to carry fuel'*). Also, a predictable flight increment the punctuality at all the flight stages, allowing a better management of the airspace and airport resources (e.g., turn around time, slot allocation), and also of end users time.

In conclusion, the evolution towards a more automated and strategic ATM system is closely linked to this system's predictability. Therefore, one of the main objectives in today's ATM is to increase the predictability of the aircraft within the ATM system, and the ATM system with respect to the aircraft, thus reducing instabilities and inefficiencies. To allow a higher automation in airborne and ground based systems, the introduction of accurate ***Decision Support Tools*** (DSTs) are essential. This sophisticated DSTs will require a much higher quality for the predicted flight profiles than available today in the ***Flight Data Processing Systems*** (FDPSs) and flight planning tools. This predictability increase is desirable by both the airspace users and ANSPs. The ANSPs need of reliable information to guarantee that the controlled airspace meets the requirements concerning capacity, efficiency, flexibility, environmental, safety and security. This information is subject of change when the actual conditions, i.e. weather and initial flight conditions, differ from the expected ones. Concerning the airspace users, this differences between the expected and the actual conditions directly affect the duration of the flight (having an impact on fuel burnt, punctuality, etc. and therefore on the cost of the flight) but can also affect the entire flight trajectory due to air traffic controllers' (ATCOs) decisions that may end up in amendments to the flight plan or even its cancellation.

At the cornerstone of all these uncertainty problems is the capacity for an accurate and predictable generation of aircraft ***trajectories***. These trajectories are the basis for flight planning, flow management and traffic control. ***Model-based approach***, as the one defined in 3.9, has been the traditional approach to trajectory prediction. Under this approach, more realistic and accurate models theoretically means better predictions, not being this always the case. The inherent inaccuracies associated to modelling, the coupling of the different error sources and the effect of uncertainty when using these models hamper any great improvement using a model-based approach. Under the **datAcron Aviation Use-Case**, a data-driven approach to trajectory prediction will be explored to enhance flight planning and flow management capabilities. The final objective is to unveil the data management and analytics technologies to reduce the uncertainty associated to the calculation of those trajectories used in the flight planning and flow management DSTs.

3. GENERAL CONCEPTS AND TERMINOLOGY

3.1 Air Navigation (Soler, 2014)

The air navigation is the process of steering an aircraft in flight from an initial position to a final position, following a determined route, and fulfilling certain requirements of safety and efficiency. The navigation is performed by each aircraft independently, using diverse external sources of information and proper on-board equipment.

Air Navigation is based on flight plans and radar information. The established procedure orders that any aircraft before flying must communicate their flight plan (routes which are going to be followed) to all the organizations that have assigned airspace that is going to be crossed. Thus, it is determined an initial estimation of where and when an aircraft pretends to be inside their airspace. At the end of the flight, there will be an initial flight plan and a final/real flight plan as well as the recorded radar track that has to be consistent with the final flight plan.

There are several reference routes which are defined and published by the ANSPs. Those routes are the reference for the flight execution and their characteristics are specified by ICAO for each flight phase.

From an abstract point of view, one route could be specified by means of the projection of their representative points defined by their coordinates (latitude and longitude) over a ground reference surface. With the altitude and the time, the route is defined as 4D.

3.2 Air Navigation Types

According to the meteorology there are two navigation techniques:

- Visual Navigation (VFR):

Visual Navigation is the basic type of navigation and it determines the position of an aircraft by means of direct ground observation. In order to fly using VFR it is needed that the meteorology is good enough to allow good visibility and sufficient separation from clouds, that is to say, there are Visual Meteorological Conditions (VMC). It also requires that aircraft speed and altitude are not too high so as to favor the observation of the Earth's surface.

Note: Visual Navigation is out of the scope of datAcron.

- Instrumental Navigation (IFR):

Instrumental Navigation consists on the determination of an aircraft position without needing to observe the outside since the different aircraft systems provide the required information. IFR permits an aircraft to operate in instrument meteorological conditions (IMC), which is essentially any weather condition less than VMC but in which aircraft can still operate safely.

In controlled airspace, air traffic control (ATC) separates IFR aircraft from obstacles and other aircraft using a flight clearance based on route, time, distance, speed, and altitude. ATC monitors IFR flights on radar, or through aircraft position reports in areas where radar coverage is not available. Aircraft position reports are sent as voice radio transmissions. The pilot must resume position reports after ATC advises that radar contact has been lost, or that radar services are terminated.

IFR flights in controlled airspace require an ATC clearance for each part of the flight. A clearance always specifies a clearance limit, which is the farthest the aircraft can fly without a new clearance. In addition, a clearance typically provides a heading or route to follow, altitude, and communication parameters, such as frequencies and transponder codes.

Within IFR, there are two more ways to navigate through the airspace:

- Conventional navigation: The segments which define the route between the origin and destination are defined by the position of certain air navigation aids.
- RNAV Navigation (ICAO, DOC, 2013): In this case, the route is not defined by any air navigation aid, allowing the flight to fly through any desired route within the system coverage and integrity. The route keeps being defined by the waypoints unequivocally identified by its coordinates. ICAO defines RNP as the required performance for a navigation system (accuracy, integrity, availability and continuity of service) needed to safely navigate within a defined airspace. The bounds of the RNP performance depend on the phase of the

flight, the most stringent ones involving approach and landing within the TMA. One of the advantages of the RNP-RNAV navigation is the high repeatability in the trajectory horizontal path (which is an important contribution to predictability), the implementation of RNP-RNAV procedures is considered in all master plans for the development of the future CNS/ATM system.

It is worthy to highlight that the commercial aviation follows a series of patterns and flight conditions different from the sports and military one where the most of time the flight is using VFR rules and the freedom related to the flight has more weight than the specified route.

3.3 Air Traffic Management (ATM) Services (Soler, 2014)

The Air Navigation Service Providers (ANSPs), i.e., ENAIRE in Spain, FAA in the USA, Eurocontrol in central Europe, must have technical capabilities to develop and support a technical CNS infrastructure, but on the other hand, it is also needed a highly structured organization with high skilled people, forming the operational support needed to provide transit, communication, and surveillance services. This operational infrastructure is referred to as Air traffic Management (ATM).

ICAO defines ATM as “the dynamic, integrated management of air traffic and airspace – safely, economically, and efficiently – through the provision of facilities and seamless services in collaboration with all parties”.

ATM is about the process, procedures, and resources which come into play to make sure that aircraft are safely guided in the skies and on the ground. If we consider the time-horizon between the management activity and the aircraft operation, we can identify three levels of systems:

AirSpace management (ASM). (Strategic level).

Airspace Management (ASM), is performed at strategic level before aircraft departure, within months/years look-ahead time. The ASM is an activity which includes airspace modeling and design. As aircraft fly in the sky, they follow pre-planned routes defined by waypoints, airways, departure and arrival procedures, etc. The route followed by an aircraft is selected by the company before departure based on the airspace design previously made by the ASM. The ASM activity includes, among others, the definition of the network or routes, the organization of the airspace in regions and control sectors, the classification (determined airspace is only flyable by aircraft fulfilling determined conditions) and the delimitation (some regions of the airspace might be limited/restricted/prohibited for civil traffic) of the airspace. All this information is in turn published in the AIP.

Air Traffic Flow and capacity Management (ATFM). (Pre tactical level).

Air Traffic Flow and Capacity Management (ATFM) is performed at pre-tactical level before aircraft departure, within weeks up to three hours look ahead time. The idea is the following: Once the flight plan has been determined by the company according to its individual preferences and fulfilling the ASM airspace design and organization, the next step is to match the flight plan with all flights to be operating at the same time windows in the same areas in order to check whether the available capacity is exceeded. This is an important step as only a certain number of flights can be safely handled at the same time by each air traffic controller in the designated volumes of airspace under his/her responsibility. All flight plans for flights into, out of, and around a region, e.g., Europe, must be submitted to an air traffic flow and capacity management unit (for example the Eurocontrol’s Network Manager in Europe), where they are analyzed and processed. Matching the requested fights against available capacity is first done far in advance for planning purposes, then on the day before the flight, and finally, in real-time, on the day of the flight itself. If the available capacity is exceeded, the flight plans are modified, resulting in reroutings, ground delays, airborne delays, etc.

To reach a better air traffic flow management, the airspace is divided in Flight Information Regions (FIRs), within which flight information service and alerting service are provided. The upper space of a FIR is called Upper Information Region or UIR (from FL245 to FL460). The lower space of a FIR includes the Terminal Maneuvering Areas (TMA), Control Traffic Areas (CTA), Controlled Traffic Regions (CTR) and Aerodrome Traffic Zones (ATZ).

Air Traffic Control (ATC). (Tactical level)

Air Traffic Control (ATC) is performed at tactical level, typically during the operation of the aircraft or instants before departure. The idea is the following: once the flight plan has been approved by ATFM, it has to be flown. Unfortunately, there are many elements that introduce uncertainty in the system (atmospheric conditions, measurement errors, piloting errors, modeling errors, etc.) and the flight intentions, i.e., the flight plan, is rarely fully fulfilled. Thus, there must be a unit to ensure that all flight evolve safely, detecting and avoiding any potential hazard, e.g., a potential conflict, adverse meteorological conditions, by modifying the routes. This task is fulfilled by ATC. ATC is executed over different volumes of airspace (route, approximation, surface) in different dependences (Area Control Centers (ACC) and Control Tower) by different types of controllers. Controllers use communication services to advice pilots. Also, pilots are aided by the FIS and ALS. All these systems together increase the situational awareness of the pilot to circumvent any potential danger.

3.4 Flow management

A service complementary to Air Traffic Control (ATC), the objective of which is to ensure an optimum flow of air traffic to or through areas within which traffic demand at times exceeds the available capacity of the ATC system.

Once the operation day begins, this monitoring process is performed to continuously analyze the expected demand versus the reported capacity of the system and detect potential imbalances between them. If a specific imbalance is detected, a regulation is applied to adjust the demand values to the available capacity by means of a new calculated take off time (CTOT) for all the aircraft which want to cross the affected area and they have not yet departed. This new time usually supposes a delay in the departure time of the affected aircraft that airlines may comply with by adjusting to a new departure slot of, by default, 5 minutes before to 10 minutes after the designed CTOT, thereby introducing a new factor of unpredictability by this slot window.

In Europe, ANSPs together with the Network Manager are in charge of this task and they decide the regulations that should apply to a particular imbalance.

Therefore, a regulation is a measure that a flow manager takes to solve an excess of demand (although the reason to apply a regulation could be also bad weather conditions, strikes, etc. we will focus on those ones applied due to an excess of demand) in a punctual moment in a certain ATC sector. The main consequence of a regulation is the re-schedule of the ETOT (Estimated take off time) by a CTOT (Calculated take off time) that is a new time to take off after the first one that cause a delay. Those ETOTs that are replaced by the CTOTs correspond to those flights that were going to fly in the affected region during a punctual moment.

Below, in Figure 2, there is a diagram which outlines the flow management process previously described:

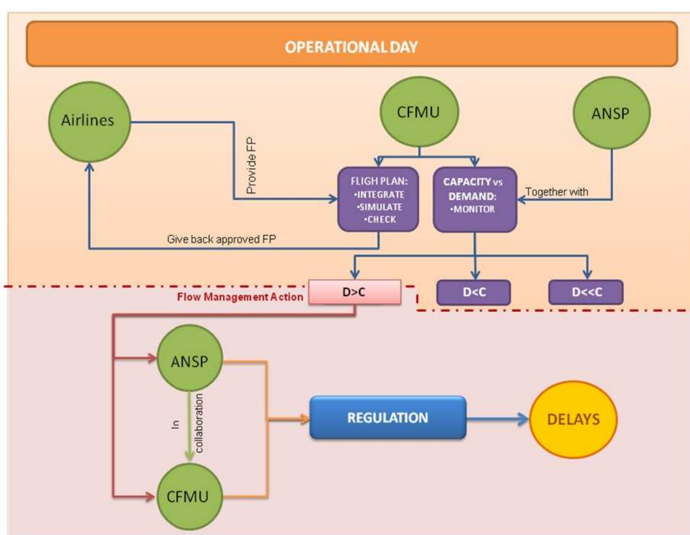


Figure 2 - Flow Management Process

3.5 Communication, Navigation and Surveillance (CNS)

Communications, navigation, and surveillance are essential technological systems for pilots in the air and air traffic controllers on the ground. They facilitate the process of establishing where the aircraft is and when and how it plans to arrive at its destination. It also facilitates the process of identifying and avoiding potential threats, e.g., potential conflicts with other aircraft or incoming storms.

Communication

The communications are utilized to issue aeronautical information and provide flying aircraft with air transit services. The air transit services are provided from the different control centers (in which air traffic controllers operate), which communicate with aircraft to give instructions, or simply to inform about potential danger. On the other hand, aircraft must use the proper communication equipment (radios, data-link) to receive this service (by receiving this service it is meant to maintain bidirectional communication with control centers). Besides the communication aircraft-control center (the so-called mobile communications), there must be a communication network between ground stations, i.e., control centers, flight plan dispatchers, meteorological centers, etc.

Navigation

The navigation services refer to ground or orbital (satellites) infrastructures aimed at providing aircraft in flight with information to determine their positions and be able to navigate to the desired destination in the airspace. The aircraft will have the required on-board equipment (navigation instruments and displays) to receive this service.

Surveillance

The action of tracking and identifying an aircraft throughout its trajectory to maintain the safety of air traffic is known as surveillance. Nowadays, surveillance is done through radar (primary and secondary). Civil aviation operates mainly the secondary radar, which uses transponders installed on aircraft so, when the ground station interrogated the aircraft, it responds and from its reply can be determined the position, altitude and identification (surveillance cooperative) (Doganis, 2002). In the future, Automatic Dependent Surveillance-Broadcast (ADS-B) will be replacing radar as the primary surveillance method for controlling aircraft worldwide. There are also airborne systems that fulfill a surveillance function. That is the case of the Traffic Collision Avoidance System or Traffic alert and Collision Avoidance System (both abbreviated as TCAS).

3.6 Aeronautical Information Services (AIS) (Soler, 2014)

The AIS provides the necessary information to ensure aeronautical operations develop with safety, regularity, economy and efficiency. All the information is made public and distributed by air navigation central services.
The information included in the AIS is composed of:

- Aeronautical Information Publication (AIP).
- AIP Amendments (AMDT) and Supplements (SUP).
- Aeronautical Information Circulars (AIC).
- Notice to Airmen (NOTAM)-SNOWTAMs.

3.7 Meteorological Information Services (MET)

With the aim to contribute to the safety, regularity and efficiency of the aircraft operations, ICAO's Annex 3 (Annex, ICAO, 2010) defines the need to provide *Meteorological Information Services* (MET). Such services involve the dissemination of observed operational parameters related to meteorology, reports on relevant meteorological phenomena, and weather forecasts to the different actors involved, such as ATFM and ATC services, user operations centers (UOCs) and the aircraft itself. Likewise, ICAO's Annex 3 specifies the procedures to obtain, generate and distribute the relevant meteorological information, so far it is expected that the introduction of air-ground communications will enable:

i) the aircraft as being one of the main sources of observation and

ii) the replacement of voice meteorological reports by digital communications D-MET (already in use in ground-ground communications).

So far the meteorological information is extensively exploited in order to optimize safety and efficiency of the operations, but mainly at strategic and pre-tactical phases. Such is the case of the well known optimized wind trajectories in use in oceanic navigation (North Atlantic, and Asia-Pacific), in which the short term forecast is exploited (within 48 hours previous to operation), and the jet-streams that involve important benefits in both fuel saving and operation time.

The challenge within the TMA is to exploit the big amount of atmospheric conditions observations available through ADS-B-out services coming from all the aircraft operating in the TMA, in order to reduce the uncertainty in the trajectory prediction that supports the tactical phase of the flight.

Those services have been established on the prevailing state-of-the-art available in the 1960's, and consist mainly in coded information, which is composed of:

- METAR/TAF: Aerodrome MET conditions/forecast;
- SIGMET: En-route significant weather advisory;
- AIRMET/GAMET: En-route concise description of weather phenomena (less signification).
- Warnings.

3.8 Trajectory

Representation in time of the 3D position of the aircraft. A trajectory, additionally, might include other aircraft state information, such as the evolution with time of the speed or mass. Generically, any aspect included in the aircraft state is subject to be included in a trajectory.

Common points of interest in a trajectory are the following [8]:

- Top of Climb (ToC): The point where the trajectory arrives at the cruise flight level. There will be one top-of-climb for each cruise flight level (step climbs).
- Top of Descent (ToD): The point where the trajectory begins a descent from the cruise flight level.
- Crossover Altitude: The point in climb or descent where the aircraft change its speed indicators transitioning from Mach number to IAS (Indicated Air Speed) control.
- Transition Altitude: It is the point below which the airplane will use QNH reference to establish its altitude. Furthermore, when the airplane is climbing it should transition from QNH to QNE and vice versa when the airplane is descending.
    - QNH: This is the value of the pressure at sea level corresponding to that in which the altimeter marks the topographic altitude at the aerodrome when the aircraft is on it. If the altimeter use QNH reference, it will mark the aerodrome elevation when the aircraft is on the runway. It's communicated from the Air Traffic Controller to the pilot (using voice or D-ATIS) in order to be set on an aircraft's altimeter. It can be obtained from weather information at the airport.
    - QNE: Is the pressure when the altimeter is regulated with standard 1013.25 hPa isobar. All aircraft in its route phase should take the altimeter regulated with standard pressure and altimeter reading will indicate the level of flight. Thus, any change in atmospheric conditions equally affect all aircraft, ensuring the safety height between them.
- Cruise Altitude changes (Step Climb): Those points in cruise where the aircraft transition to a different cruise flight level.
- Cruise Speed change: Those points in cruise where the aircraft transition to a different cruise speed.

Additionally to these points, the following list represents those points of the trajectory which identification requires their association to the Operational Context Data:

- Holding pattern: Predefine maneuver which keeps an aircraft within a specified airspace while awaiting further clearance. The holding procedure has a holding fix which is a geographical location that serves as a reference and are defined in the AIP.
- FlyOver / FlyBy on Waypoints and Navaids: Those waypoints associated to the route included in the flight plan.
- SID: Departure procedure associated to the origin airport, defined in the AIP.
- STAR : Arrival procedure associated to the destination airport, defined in the AIP.
- Takeoff Runway: Runway used by the aircraft in the origin airport, defined in the AIP.
- Destination Runway: Runway used by the aircraft in the destination airport, defined in the AIP.
- FIR/Sector crossing points: Those geographical waypoints in where the aircraft crosses from one FIR/sector to another one. An accurate time and altitude at these points are critical for an efficient coordination among different ANSPs/ATCos.

3.9 Introduction to Model based trajectory prediction

From an abstract viewpoint, every TP infrastructure (including the intuitive mental capacity of pilots and controllers) predicts trajectories based in two essential processes, represented in Figure 3, regardless of its purpose or whether it is ground based or airborne, as it was concluded in the COURAGE project (BR&TE, DFS, and Avtech, 2005).

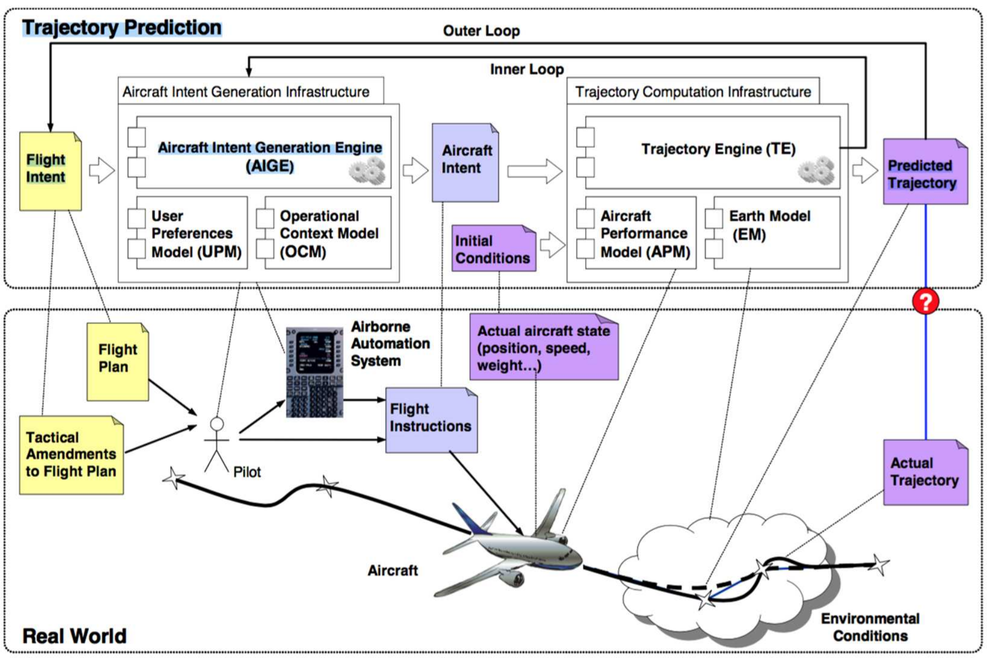


Figure 3 - Abstraction of the TP technology elements

- *Aircraft Intent Generation*. This process is an abstraction of the way in which the pilot, either himself or by the use of the flight management automation system generates the aircraft intent, that is, the specific way to guide the aircraft with the aim to execute a trajectory according to the provided flight intent, i.e. with the constraints imposed by the flight plan and/or ATC tactical amendments to it. The adopted aircraft intent shall result in the trajectory being compliant with current general restrictions associated to the operational context, and to the extent possible, optimal (according to user's preferences). The intent generation infrastructure which is responsible to carry out this process, shall be able to evaluate the trajectories that result from different aircraft intents into consideration in order to make the appropriate decisions, for which it is necessary to perform iterative trajectory prediction processes. In current context, this intent generation process takes place within pilots' and controllers' minds on a regular basis, replacing computations for mental estimations of aircraft performances, atmospheric conditions and experience.

- *Trajectory Computation.* This process relies on physics and mathematical models as well as numerical algorithms in order to determine the resulting trajectory from the flight intent mentioned in previous process. Basically such models are i) the aircraft performance model, which predicts the aircraft's response to the provided instructions, as well as the aerodynamic, propulsive and gravitational forces (the latter require the prediction of the aircraft's fuel consumption) that affect the aircraft's motion, and ii) the predictive atmosphere model , which affects the aircraft's response (through temperature and pressure) and it is also involved in the equations that rule the aircraft's motion (through the wind).

3.10 Operational Context Information

The Operational Context Information is the set of ATM constraints that may limit the trajectory followed by an aircraft in one or more dimensions. This information gathers those elements limiting or conditioning the range of potential operational strategies (flight interventions) that an Air Navigation Service Provider (ANSP) can adopt to ensure safe air traffic operations. They include strategic restrictions applied during the complete flight or tactical constraints imposed by the air traffic controllers (ATCo) on a case by case basis. In general, the strategic constraints are associated to a specific flight volume (typically a sector), or a route (typically the waypoints defining the route), whereas tactical constraints are applied during a certain period of time (e.g., until an ATCo new intervention, when crossing a new sector). Some of the most common constraints that can be found in a navigation chart are briefly described below:

- Altitude Constraints, representing an altitude restriction at which the aircraft is cleared to perform the flight. For example:

  - Fixed Altitude. Restriction in altitude which imposes to fly at a specified altitude between two defined 2D points;

  - Altitude Range. Definition of an interval of cleared altitudes (Max; min) where the aircraft is able to operate;

- Speed Constraints, representing the speed at which the airborne is cleared to perform the flight.

  - Maximum Speed. Definition of ceiling speed at which the aircraft is cleared to fly;

  - Hold Speed Constraint. This constraint represents a constraint on a flight to follow a speed holding pattern during a period of time;

  - Speed Range: Definition of an interval of cleared speeds (Max; min) where the aircraft is able to operate;

  - Climb/Descent Rate. This describes the range of admissible speed profiles during the climb or descent maneuvers.

- Heading/Vectoring/Route, representing a constraint in the heading angle given to the aircraft. The aircraft will leave its current route assuming the new specified heading.

- Standard Procedures. The standard operating procedure is a set of constraints which have to be followed by all aircrafts when they are flying in a specific route. These standard procedures contain a combination of the constraints aforementioned.

  - Route Structures. Fixed routes defined by waypoints which will be followed by flights within the designated airspace sector.

- SID. The Standard Instrument Departure consists of a number of waypoints and a climb profile, instructing the aircraft to cross certain points at or above a certain altitude. The SID procedure ends at a waypoint lying on an airway which the aircraft will follow from there. The SID procedures are defined by the local authorities (governments, airports and air traffic control organizations) to ensure safety and expedite handling of departing traffic and - when possible - to minimize the amount of noise over inhabited areas such as cities.

- STAR. The Standard Terminal Arrival Route usually covers the phase of a flight that lies between the top of descent from cruise or en-route flight and the final approach to a runway for landing. It consists of a set of points, called transitions, and a description of routes (typically via waypoints) from each of these transitions to a point near a destination airport, upon reaching which the aircraft can join an instrumental approach (IAP) or be vectored for a final approach by terminal air traffic control.

- Coordination & Transfer. This kind of constraint represents the speed and altitude ranges and the location of entrance and exit points which should be respected by any flight when it is moving from one sector to the next one.

3.11 Flight Phases (Team, C. A. S., 2013)

Trajectories are divided in different flight phases or stages which could be classified in: standing, pushback, taxiing, take-off, initial climb, en route, approach and landing.

Standing: Prior to pushback or taxi, or after arrival, at the gate, ramp, or parking area, while the aircraft is stationary.

Pushback/Towing: Aircraft is moving in the gate, ramp, or parking area, assisted by a tow vehicle (tug).

Taxiing: The aircraft is moving on the aerodrome surface under its own power prior to takeoff or after landing.

Take-off: From the application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation.

Initial climb: From the end of the Takeoff phase to the first prescribed power reduction, or until reaching 1,000 feet above runway elevation.

En Route:

It is the flight phase in where the aircraft spend more time. This flight phase is subdivided into *climb* (from the end of initial climb to the Top of Climb), *cruise* (from Top of Climb to Top of Descent) and *descent* (from Top of descent until initialization of the Approach phase)

The cruise level/s correspond to those altitudes in where the aircraft is more fuel efficient so the majority of the flight should occur at this level/s.

Approach:

Defined from the Initial Approach Fix (IAF) to the beginning of the landing flare.

Landing:

From the beginning of the landing flare until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in the case of a touch-and-go landing

3.12 Flight Plan (Soler, 2014)

A flight plan is an aviation term defined by the International Civil Aviation Organization (ICAO) as:

Specified information provided to air traffic services units, relative to an intended flight or portion of a flight of an aircraft.

A flight plan is prepared on the ground and specified in three different manners: as a document carried by the flight crew, as a digital document to be uploaded into the Flight Management System (FMS), and as a summary plan provided to the Air Transit Services (ATS). It gives information on route, flight levels, speeds, times, and fuel for various flight segments, alternative airports, and other relevant data for the flight, so that the aircraft properly receives support from ATS in order to execute safe operations. Two safety critical aspects must be fulfilled: fuel calculation, to ensure that the

aircraft can safely reach the destination, and compliance with Air Traffic Control (ATC) requirements, to minimize the risk of collision.
An effective flight plan can reduce fuel costs, time-based costs, overflight costs, and lost revenue from payload that cannot be carried, simply by efficiently modifying the route and altitudes, speeds, or the amount of departure fuel.
Flight plan includes the following required information:

- Message Type
- Aircraft Identification
- Flight Rules
- Type of Flight
- Type of Aircraft
- Wake Turbulence Category
- Radio Communication, Navigation and Approach Aid Equipment and Capabilities
- Surveillance Equipment
- Departure Aerodrome / Destination Aerodrome
- Departure Time (also Estimated Time of Departure (ETD))
- Expected Cruise Speed and Altitude
- Route
- Estimated Elapsed Time (EET)

Notice that the ETD and the EET allows the obtention of the Estimated Time of Arrival (ETA)
A flight plan is developed taking into account weather forecasts and predetermined routes. Traditional Airline Flight Planning tools try to provide an optimized Flight Plan based on schedule, fuel burn, operational costs and/or CO2 emissions considering the following information:

- Weather Information
- NOTAM information
- Route Availability
  - Time restricted routes
  - Conditional Route Availability
  - Free route airspace
- Customized user databases
  - Enroute charges
  - Aircraft fleet performance
  - Airport Information
  - High/Low Altitude Airway Information
  - SID/STAR Information
  - SID/STAR Details
  - SID/STAR Preferences
  - Waypoint Information
  - Currency Exchange Rates
  - FIR Traversal Information
  - Enroute Charges Information
- Navigation Database

3.13 Aircraft state

It describes geometric (aircraft center of mass (CM) position and body attitude), kinematical (CM and body angular velocity) and kinetic (forces and moments acting on the aircraft as well as the flight controls influencing the value of those forces and the time evolution of the aircraft mass) aspects of the aircraft motion. Since the angular dynamics is not relevant in the context of ATM to calculate the aircraft's CM motion, the aircraft state at a given time, will be defined by the following variables: CM position, CM velocity, aircraft body attitude, aircraft mass, the resultant of the forces acting on the aircraft assumed applied at the centre of mass, and the aircraft aerodynamic configuration.

3.14 Aircraft Speed

Airspeed is the speed of an aircraft relative to the air. The most common conventions for qualifying airspeed are:

IAS: indicated airspeed (IAS or KIAS) means the speed of an aircraft as shown on its pitot static airspeed indicator, calibrated to reflect standard atmosphere adiabatic compressible flow at sea level, uncorrected for airspeed system errors. The static pressure measurement is subject to error due to the inability to place the static ports at positions where the pressure is true static pressure at all airspeeds and attitudes.
CAS: calibrated airspeed is indicated airspeed corrected for instrument errors, position errors (due to incorrect pressure at the static port) and installation errors.
TAS: true airspeed is the speed of the aircraft relative to the atmosphere. The true airspeed and heading of an aircraft constitute its velocity relative to the atmosphere. This is the speed listed on the flight plan, also used in flight planning, before considering the effects of wind.
EAS: equivalent air speed is the airspeed at sea level in the International Standard Atmosphere at which the dynamic pressure is the same as the dynamic pressure at the true airspeed (TAS) and altitude at which the aircraft is flying.
GS: Ground speed is the speed of the aircraft relative to the ground. This speed is the combination of the true airspeed vector of the aircraft and the speed vector of wind at aircraft altitude. This speed is measured by air traffic controller radar.
Mach number (M) is a ratio of the speed of a body (aircraft) to the speed of sound in the undisturbed medium through which the body is traveling. It is said that the aircraft is flying at Mach 1 if its speed is equal to the speed of sound in air (which is 332 m/s or 1195 km/hr or 717 miles/hour.)
Calculation:
$GS = TAS + V_w$
$TAS = a_0 \times M \times \text{sqrt}(T/T0)$
A_0 = Speed of sound at standard sea level = 661.478 KT
M = Mach number
T= Temperature in Kelvin
T_0= Standard sea level temperature (288.15 Kelvins)

3.15 Flight Operation Costs

In order to understand the potential of higher predictability in the ATM industry we introduce the airline's cost structure (Doganis, 2002). Following ICAO, most airlines adopted this approach which divides costs into operational and non-operational.

- Non-operational costs: are typically financial costs not related to the airline's own air services.
- Operational costs: are associated with administering a business on a daily basis. These are the best descriptors of an airline's performance and they are subdivided into Direct Operational Costs (DOC) and Indirect Operational Costs (IOC).

The traditionally used categorization made by ICAO divides the direct operational costs (DOC) into: flight operations (flight crew salaries, fuel, airport and en-route charges, aircraft insurance and rental/lease of flight equipment), maintenance and overhaul, depreciation and amortization; and the indirect operational costs into: station and ground expenses, passenger services, ticketing, sales and promotion, general and administration, and other.

The cost of flight operations is the largest single element of operating costs which is aircraft-dependent and is the one that could be affected due to a flight plan change. Data collected from US Department of Transportation (US DOT, 2012) estimates that the flight operations cost contributes near 50% (20% of this DOC being the flight crew cost, 32 % being fuel and 10% due to landing fees and en-route charges).

Moreover, IATA estimate that the delays caused by inefficient airspace management in Europe alone cost the industry $3.8 billion during 2014, in addition to generating unnecessary CO_2 emissions

(IATA). The FAA estimated the annual costs of delays in just over $3.2 billion in 1999 (Mueller & Chatterji, 2002), raising to near $8 billion in 2007 (Ball, et al., 2010).

Studies have identified that 84% of all delay occur on the ground and that surface movement inefficiencies are not the only reason for delays on the ground. Ground delay programs, en-route capacity/constraints, aircraft/maintenance/issues, ground services, customer service issues, late aircraft crew arrival, and poor weather conditions elsewhere all contribute to surface delays. The following figure shows how different factors affect delay.

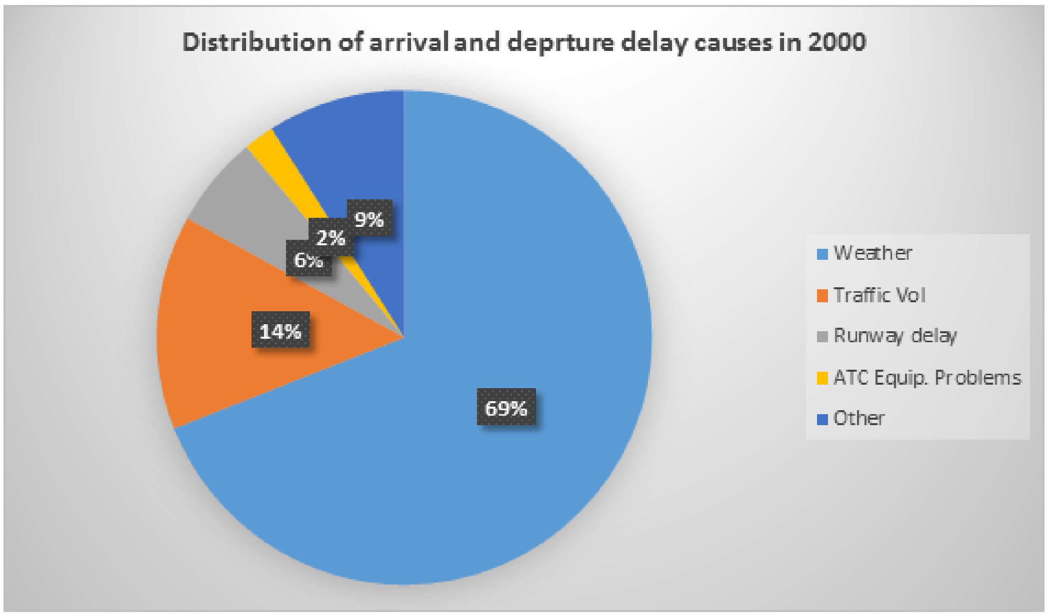


Figure 4 - Distribution of arrival and departure delay causes in 2000

A better predictability in the ATM industry could reduce the weight of flight operations in the airline’s costs structure while also improving delay causes since 83% of those are predictability dependent.

4. Matrix Scenarios-datAcron project

This matrix shows the relationship of each Scenario with the different objectives, components and work packages of datAcron project:

datAcron objective	**[O.1] Scalable integration and management of data from disparate and heterogeneous sources**	**[O.2] Real-time detection and forecasting of trajectories**	**[O.3] Real-time event recognition and forecasting**	**[O.4] Real-time interactive analytics**
Main datAcron Component	Data Management and Query	Trajectory Detection and Forecasting	Complex Event Recognition	Visual Analytics
Main datAcron WP	WP1	WP2	WP3	WP4
FM01- Flow Management – Regulation prediction	X		X	
FM02 - Flow Management – Demand & Capacity prediction	X		X	X
FM03- Flow Management – Resilience assessment	X	X	X	X
FP01 - Flight Planning - Real Trajectory Reconstruction		X		X
FP02 - Flight Planning - Real Trajectory Enrichment	X			X
FP03 - Flight Planning - Event Recognition in trajectories	X	X	X	X
FP04 - Flight Planning - Event Forecasting in trajectories			X	
FP05 - Flight Planning - Data Set preparation	X			X
FP06 - Flight Planning - Trajectory Clustering		X		X
FP07- Flight Planning - Trajectory prediction - preflight		X		X
FP08- Flight Planning - Trajectory prediction - preflight schedule based		X		X
FP09- Flight Planning - Trajectory prediction - real time		X		
FP10- Flight Planning - Trajectory comparison	X	X		X

Table 1 - Matrix Scenarios / Objectives / Components / WP’s.

5. Flow Management Scenarios

Scenarios related to Flow Management have been designed with focus on two different approaches. The first one takes into account regulations imposed by the main flow management actors based on different indicators collected by means of data sets. The second one aims at analyzing demand and capacity indicators of air traffic without regulation measures, it means, the real scenario that the flow manager had had in front of him to apply the regulation.

Combining both scenarios it is reached the Resilience one, as the difference between the D-C imbalances detected and regulations applied. In theory, when a D-C imbalance happens, the flow manager imposes a regulation, it means, a ground delay, but actually, this decision can not be directly quantified as it seems. That process involves human experience that allows to exist, for instance, certain D-C imbalance without any measure to cover them due to the consciousness that system will be able to stand it.

Thus, the final goal is an effective characterization of the flow management process throughout its study. This one is carried out isolating human decisions and technical indicators to finally detect and predict the behavior of the whole system and its capacity to work in nominal conditions.

5.1 Scenario FM01 – Flow Management – Regulations detection and prediction

Objectives

This scenario objective is to demonstrate how datAcron regulations detection and prediction capability is useful for reproducing Flow Management Behaviour. This behaviour is mainly represented by the applied regulations as well as the delay produced as consequence. Regulation is a measure that a flow manager takes to solve an excess of demand in a punctual moment in a certain sector and it is applied over those flights that have not yet took off. The main consequence of a regulation is the re-schedule of a ETOTs (Estimated take off time) by a CTOT (Calculated take off time) that is a new time to take off after the first one that cause a delay. As it has been said before, those ETOTs that are replaced by the CTOTs correspond to those flights that were going to fly in the affected sector during a punctual moment.

These delays are calculated as the difference between the estimated take off time and the calculated take off time of those flights affected by a regulation. If a flight is affected by more than one regulation, the delay corresponds with the most restrictive measure. Finally the indicator delay of the evaluated sector is the average of every flight delay for this sector.

$$Delay\ per\ sector = \frac{\Sigma(CTOT - ETOT)(min)}{Number\ of\ flights}$$

In order to reproduce future regulations behavior, datAcron should be able to learn and identify patterns that allows to detect and predict these terms.

Data

The data involved in this scenario are:

- Flight Plan data: Used in order to know the flight intentions and predict based on that, the regulations needed to be imposed. Flow management is a process that try to anticipate critical events as imbalances between demand and capacity. Considering that, flight plan is the required data by the flow manager in order to applied measures over them.
- Sector configuration: Actual configurations detailed in the ATC Watch Log, where the controllers and unit manager detail significant events and operational information, as well as the division of airspace in sectors in which the provision air traffic services is decomposed.
- Radar tracks: That is surveillance data, used in order to draw useful information from flights flying together with those ones which pretend to fly.
- Metar Information: Report of weather information used in order to assist in weather forecasting.

· Flow Management Information: This one provides regulation data, that is, regulation id, time (day and duration of the measure), affected sector and traffic volume, the caused delay (max, min, total), regulated flights and their modified schedules due to the regulation in each case. Although there are some types of regulations according to the reason that has caused it (D-C imbalance, weather, strikes, etc), it has been studied those ones related only with the Demand and Capacity Imbalance.

Querying the data
From end user point of view the queries will be:

- Flights affected by a regulation will be linked by an aircraft unique identifier with its flight plan and real radar track.
- Duration of the flight regulation is linked with the time window of metar info (last meteorological observation) and the current sector configuration.

Visualizations
Regulations visualization would represent the number of decisions taken by the flow manager by means of a heat map that shows affected sectors by regulations, as well as the severity of those measures. The severity would be represented by the total delay produce due to a certain regulation.

Events
Regulations

Metrics
Accuracy of the predicted regulations: Number and Duration compared with the real applied regulations. Also the impact of those regulations should be compared that is assessed by means of the total delay produced by each regulation.

5.2 Scenario FM02– Flow Management – Demand and capacity imbalance detection and prediction

Objectives
This scenario objective is to demonstrate how datAcron imbalance detection and prediction capability is useful for detecting demand and capacity imbalance by means of indicators monitoring. Those indicators are based on real demand (Hourly Entry Count: for a given sector is defined as the number of flights entering in this sector during one hour) and declared capacity (Maximum number of flights allowed to enter in a sector during one hour) of the current configuration of airspace, by calculating them from the initial flight plan (deregulated traffic) instead of the real flight plan. The main reason for that, rests on the fact that if a flight has been regulated, its flight plan is modified to take off later and avoid the previously detected excess of demand. Thus if the real flight plan were used in that scenario, it would not be possible detect the imbalance because this one would be avoided thanks to the regulation.
Although in theory an imbalance could be produced by an excess of capacity compared with the demand, it should be an unusual situation that is out of our scope. datAcron will be focus on the excess of demand vs capacity.
Once the first imbalance is detected, if no measure were applied, the imbalance would cause a divergence in the system and a no realistic scenario would be obtained. In order to continue detecting real imbalance it has to be used a recurrent method:

1. To use the initial flight plan (without any regulation applied) to detect real imbalance that would not be detected if a regulation were applied.
2. After the previous detection, the excess of demand is stored.
3. It is necessary to check comparing with the first scenario if a regulation was applied at the same time that the imbalance happened.
4. If the answer is positive, it will be applied this regulation changing those initial flight plans (affected by the regulation) by the new (regulated) ones. The rest of the flight plans will continue being the initial ones
5. This process will be repeat it each time that an imbalance was detected.

Finally, it would be obtained a scenario based on the stored imbalance detected in the previous process. datAcron learns and identifies patterns useful to detect those real imbalance. As it has been noted in the previous scenario, regulations considered are those ones related to D-C imbalance.

Data

The data involved in this scenario are:

· Post- processed Flight Plan data (deregulated traffic, post-processed in order to get the initial flight plan before regulation)
· Flight Plan data
· Sector configuration.
· Radar tracks
· Metar Information
· Flow Management Information:

Querying the data

From end user point of view the queries will be:

- Flights affected by a regulation will be linked by an aircraft unique identifier with its flight plan and real radar track. In this scenario the flight plans of the flights affected by a regulation will be substituted by the initial ones and then will be calculated the new hypothetic demand (the hourly entry count) with this new traffic configuration.
- Declared capacity of the sector is obtained by linking Sector Configuration Information with start/end time of the flight plan.
- Duration of the flight regulation is linked with the time window of metar info (last meteorological observation).

Visualizations

Demand and capacity evolution, as well as the moment when any of them exceed a particular established limit should be visualized to better monitor its development and the event detection. A heat map would be useful to show the difference between the assessed values.

Events

Demand and Capacity evolution and imbalance monitoring.

Metrics

Precision of the demand and capacity predicted indicator compared with those ones detected from deregulated flight plans.

5.3 Scenario FM03 – Flow Management – Resilience assessment

Objectives

This scenario objective is to demonstrate how datAcron resilience assessment and prediction capability is useful for **evaluating** and **forecasting** the system capacity to assume imbalance under nominal conditions. For that purpose, it will be necessary to compare each detected imbalance (from the scenario 02) with the decision taken by the flow manager assessed by means of the scenario 01 (It could be found real imbalance with a regulation application to solve it but also it is possible to find an imbalance without any regulation because the flow manager considered that the system was able to absorb it). Once these situations are characterized, datAcron will establish patterns of those which get a better system behaviour characterization.

Data

The data involved in this scenario are:

· Flight Plan data
· Sector configuration
· Radar tracks
· Metar Information
· Flow Management Information

Querying the data
From end user point of view the queries in this scenario will be linear combination from scenario 1 and 2 ones previously calculated in order to obtain, through heat maps, the excess of demand that the system is able to manage without any regulations applied.

Visualizations
Resilience characterization as the amount of demand that the system is able to manage without regulation measures should be represented by means of heat maps supported by geographical maps. It would be interesting to show, in a visual way, the difference between the excess of demand that system could assume and the real decision taken in each case.

Events
Inconsistency between imbalance and regulation measure recognition: Time, Duration, Intensity

Metrics
Same as the Scenario 02 and 01

6. Flight Planning Scenarios

Scenarios related to Flight Planning have been defined in a stepped approach, increasing complexity. Last scenarios, which are the final goals, will require to solve previous ones (more simple ones). This approach allows to relate the more simple scenarios to specific components and objectives in datAcron project.

6.1 Scenario FP01 - Flight Planning - Real Trajectory Reconstruction

Objectives

This scenario objective is to demonstrate how datAcron trajectory reconstruction capability is useful for building the real trajectories of aircraft both off-line and real-time. The trajectories need to be reconstructed from the surveillance data (ADS-B messages and/or radar data). Additional information needed to assign departure and/or destination to each trajectory will be the airport coordinates. When available, additional information about the aircraft can be added to the trajectory, i.e. Model, Owner… The trajectories reconstructed are expected to be spatio-temporal objects.

Data

The data involved in this scenario is:

- Surveillance data (stored)
- Surveillance data (streaming)
- Airports Database
- Aircrafts Database

Steps for ADSB data source

1. Filter ADSB messages, retain the ones with location and/or flight identification
2. Group messages for the same aircraft
3. Group messages in continuous sequences from take-off to landing (interruptions may arise, use a maximum time gap to cut)
4. Build Spatio Temporal object
5. Assign Flight identification if known
6. Assign departure and destination airports (base on distance)
7. Assign Aircraft relevant data

Steps for Radar Track data source

1. Build Spatio Temporal object
2. Assign already present data (Flight id, dept/dest, Aircraft data)

Querying the data

It is expected WP2 components will query:

- the surveillance data based on available aircraft unique identifier (i.e. ads-b messages with hex_id code = ‘xxx’) or a combination of identifiers that create an unique identifier (i.e. Aircraft address + date/time).
- the nearest airport to a lat/lon to assign the departure and/or destination

From end user point of view the queries will be:

- trajectories starting/ending at an airport
- trajectories starting/ending at a given day/hour
- trajectories from airline and model of aircraft
- incomplete trajectories (i.e. not starting or ending at an airport)
- original messages generating a reconstructed trajectory

Visualizations
One visualization helpful to validate this capability will be a geographical representation of the trajectories reconstructed with the option to switch to visualize the original surveillance messages used for each trajectory reconstructed.

Metrics

Valid Messages unassigned to a trajectory. Should tend to zero.

6.2 Scenario FP02 - Flight Planning - Real Trajectory Enrichment

Objectives
This scenario objective is to demonstrate how datAcron data management capability can help for adding (linking) new data to real trajectories. The trajectories reconstructed from the surveillance data (ADS-B messages and/or radar tracks) need to be enriched with data from the aircraft (when known), data from the weather and operational context data, including Flight Plans. This step will create spatio-temporal objects with more data associated to them that may be key data in later scenarios like event detection, trajectory clustering and/or trajectory prediction.

Data
The data involved in this scenario is:

- real trajectories (stored and/or in streaming)
- weather data
- context data
- Flight Plan Database

Steps

1. For each 4d point in the trajectory, find weather data variables available (typically wind speed, temperature and geopotential height). This may require interpolation among 16 4d points. Link it to the spatio-temporal object.
2. For each trajectory find the relevant flight plan. Using the ICAO ID and/or the AircraftID and the date of the flight and the time and/or the origin and destination look in Flight Plan database.
3. Find intersection of the trajectory with relevant context geo-spatial objects (i.e. sectors). Associate them for later queries.

Querying the data
From end user point of view the queries will be:

- for every 4d point of the real trajectories include the available weather variables at that point. It may require interpolation. These may include several version of each variable, one for each available forecast time.
- for every 4d point of the real trajectories include the available ATC variables at that point (i.e. sector, enforced regulation…)
- for a trajectory, which is the corresponding flight plan

Visualizations
One visualization helpful to validate this capability will be a geographical representation of the trajectories reconstructed with the option to visualize the available variables for a selected point of the trajectory.

Metrics
#trajectories with complete information: i.e. whether data, aircraft type, Flight Plan, sectors crossed...
Query performance: Time needed to generate the enriched trajectory

6.3 Scenario FP03 - Flight Planning - Event Recognition in trajectories

Objectives

This scenario objective is to demonstrate how datAcron complex event recognition capability can help for detecting relevant events in trajectories. The events are added to the trajectories and, like in previous scenario, this new data can be relevant for next scenarios like trajectory clustering or trajectory prediction.

Data

The data involved in this scenario is:

- real or synthetic trajectories

Steps

1. For each trajectory scan the 4d points sequence and identify the events from the list. Querying the Flight plan will be necessary for certain events.
2. For mandatory events (details in Annex 1) missing mark the trajectory as incomplete.

Querying the data

From end user point of view the queries will be:

- For a given trajectory, events detected and time of occurrence
- Group of trajectories with certain events at specific time or speed or altitude

Visualizations

One visualization helpful to validate this capability will be a geographical representation of the trajectories with visual labels attached to the point when event is detected.

Events

Some relevant events in a trajectory from a spatial point of view are:

- Climb to Cruise transition (Top of Climb)
- Cruise to Descent transition (Top of Descent)
- Surface to Terminal / Terminal to Surface transitions
- Terminal to Enroute / Enroute to Terminal transitions
- Turnings (radius and direction) vs straight flight (great circle)
- Cruise Altitude change
- Cruise Speed change
- Crossover Altitude
- Transition Altitude
- Holding pattern
- Hold on ground
- FlyOver / FlyBy on Waypoints and Navaids
- SID
- STAR
- Takeoff Runway
- Destination Runway
- FIR/Sector crossing points
- Flight Phases

There is a more in-deep event analysis in Annex 1. Some events should be detectable only with geometry data, others may need context data, and the more complex will require data not available (unless aircraft recorded data available). Only the first two groups of events are expected to be detected.

Metrics

Some events are always present in a trajectory so number of undetected events of this class can be a good metric (the lower the best).

Some groups of trajectories with special events (i.e. holding pattern) can be prepared in an specific dataset and again number of undetected events can be used as a metric for the event recognition.

6.4 Scenario FP04 - Flight Planning - Event Forecasting in trajectories

Objectives

This scenario objective is to demonstrate how datAcron predictive analytics capability in complex event forecasting can help for predicting relevant events in trajectories on flight. After many runs of previous scenarios (event recognition) a baseline for learning will be available.

Data

The data involved in this scenario is:

- surveillance data real time streaming
- Context data
- flight plan may be used

Steps

1. For a stream of a trajectory, gather as much information as possible… when this information is enough for forecasting an event fire the process.
2. Review forecasted events as new updated information is gathered from the stream

Querying the data

From end user point of view the queries will be:

- For a given trajectory, list of forecasted events and forecasted time of occurrence

Visualizations

Same than scenario FP03.

Events

Some relevant events in a trajectory from a spatial point of view are:

- Climb to Cruise transition (Top of Climb)
- Cruise to Descent transition (Top of Descent)
- Surface to Terminal / Terminal to Surface transitions
- Terminal to Enroute / Enroute to Terminal transitions
- Turnings (radius and direction) vs straight flight (great circle)
- Cruise Altitude change
- Cruise Speed change
- Crossover Altitude
- Transition Altitude
- Holding pattern
- Hold on ground
- FlyOver / FlyBy on Waypoints and Navaids
- SID
- STAR
- Takeoff Runway
- Destination Runway
- FIR/Sector crossing points
- Flight Phases

There is a more in-deep event analysis in Annex 1. Some events should be detectable only with geometry data, others may need context data, and the more complex will require data not available (unless aircraft recorded data available). Only the first two groups of events are expected to be detected.

Metrics
Same than FP03.

6.5 Scenario FP05 - Flight Planning - Data Set preparation

Objectives
This scenario objective is to demonstrate how datAcron data management capability (querying of integrated spatio-temporal data) for all the data needed can help to prepare a dataset for subsequent scenarios. The trajectories and context data need to be grouped according to spatio temporal boundaries.

Data
The data involved in this scenario is:

- real and synthetic trajectories
- flight plan data
- weather data
- context data

Steps

1. Collect all parameters for the data set query restrictions
2. Scan dataACRON storage and collect objects matching the query criteria

Querying the data
From end user point of view the queries will be:

- All trajectories for a particular time interval and geographical region
- All flight plans for a particular time interval and geographical region
- All weather data for a particular time interval and geographical region
- All static and dynamic context data for a particular time interval and geographical region

Visualizations
A helpful visualization in order to validate this capability, would be a geographical representation of all the trajectories, flight plans, weather and context with the option of filtering using a sliding time window.

Metrics
Performance in querying the data (time to respond).

6.6 Scenario FP06 - Flight Planning - Trajectory Clustering

Objectives
This scenario objective is to demonstrate how datAcron trajectory clustering capability can work for both real and synthetic trajectories of aircrafts. The trajectories with common departure and destination may be clustered based on flight path / aircraft type / time / events...

Data
The data involved in this scenario is:

- Real Trajectories
- Synthetic Trajectories
- Context data

Steps

1. For all trajectories in a set (i.e. from previous scenario) identify clusters
2. Show clusters and some (if available) common characteristics of the clusters

Querying the data
It is expected WP2 components will query:

- trajectories starting/ending at an airport
- trajectories following a SID/STAR

From end user point of view the queries will be:

- clusters for a pair of airport (departure-destination)
- detail of trajectories forming a detected cluster

Visualizations
One visualization helpful to validate this capability will be a geographical representation of the clustered trajectories with the option to switch to visualize the original trajectories included in each cluster.
When several cluster are visualized, the relative size of the clusters (in term of number of original trajectories included in the cluster) should be perceived visually.
Visual pattern recognition may be used to validate the identified clusters.

Metrics
trajectories unassigned to a cluster. Should be marginal (outliers) for frequent routes (i.e. daily routes)

6.7 Scenario FP07- Flight Planning - Trajectory prediction - preflight

Objectives
This scenario objective is to demonstrate how datAcron predictive analytics capability can help in trajectory forecasting. For a given flight plan a forecasted trajectory will be obtained and compared with the real one finally flown (Historical).

Data
The data involved in this scenario is:

- Real Trajectories
- Weather forecasts
- Context data
- Flight Plans

Steps

1. For a given Flight Plan generate a spatio temporal object representing the most probable trajectory.

Querying the data
From end user point of view the queries will be:

- For each Flight Plan, a single predicted trajectory.

Visualizations
The comparison between the predicted trajectory and the final trajectory flown can be visualized in a geographical representation.
Historical real trajectories in a timeframe for the same flight visualization may be useful.

Metrics
Performance of the prediction (time needed for a single trajectory)
Precision of the predicted trajectory. (i.e. Compared with the real trajectory flown).
Precision compared to the precision of the model based trajectory prediction (the synthetic one).

6.8 Scenario FP08- Flight Planning - Trajectory prediction - preflight schedule based

Objectives

This scenario objective is to demonstrate how datAcron predictive analytics capability can help in trajectory forecasting. For a given set of flight plan fields, the airline schedule, a forecasted trajectory will be obtained and compared with the real one finally flown (Historical). The main difference with previous scenario is that in this case there is still not flight plan available, just the schedule, destination and departure.

Data

The data involved in this scenario is:

- Real Trajectories
- Weather forecasts
- Context data
- Flight Plans (historical)
- Airline Schedule
    - Aircraft Identification
    - Aerodrome of departure
    - Aerodrome of destination
    - Date/time of departure

Steps

1. For a pair of airports (Departure/Destination) and schedule data find related representative Flight Plans.
2. Apply previous scenario algorithm to propose a predicted trajectory.

Querying the data

From end user point of view the queries will be:

- For a single flight (Aerodrome of departure, Aerodrome of arrival, time, Aircraft Identifier) a single predicted trajectory

Visualizations

The comparison between the predicted trajectory and the final trajectory flown can be visualized in a geographical representation.
Historical real trajectories in a timeframe for the same flight visualization may be useful.

Metrics

Performance of the prediction (time needed for a single trajectory)
Precision of the predicted trajectory. (i.e. Compared with the real trajectory flown).

6.9 Scenario FP09- Flight Planning - Trajectory prediction - real time

Objectives

This scenario objective is to demonstrate how datAcron predictive analytics capability can help in trajectory forecasting in real time. For a given flight plan and the current surveillance data arriving to the platform a forecasted trajectory will be obtained and updated continuously.

Data

The data involved in this scenario is:

- surveillance data real time streaming
- Weather forecasts
- Context data

- Flight Plans

Steps

1. For a trajectory streaming, find the Flight Plan, and use current flight past data to feed previous scenario algorithm in the prediction.
2. Maintain an updated trajectory prediction updated each X seconds.

Querying the data

From end user point of view the queries will be:

- For a live flight, obtain a single predicted trajectory.

Visualizations

Predicted vs real trajectory. Real trajectory, and maybe prediction, will be updated in real time as more information about the live flight is received in datAcron. Visualization of all predictions for the real time flight (even preflight forecasted trajectory) is desirable.

Events

Events in a trajectory have a specific scenario.

Metrics

Performance of the prediction (time needed for a single trajectory)
Precision of the predicted trajectory. (i.e. Compared with the real trajectory flown).

6.10 Scenario FP10- Flight Planning - Trajectory comparison

Objectives

This scenario objective is to demonstrate how datAcron data management capability (querying of integrated spatio-temporal data) for all the data needed can help to calculate similarity metrics for trajectories generated in previous scenarios. The validation experiments will need this capability to measure the success of the trajectory prediction algorithms and the trajectory clustering algorithms.

Data

The data involved in this scenario is:

- trajectories

Steps

1. For a couple of trajectories a set of metrics will be calculated:
    a. Lateral deviation
    b. Vertical profile deviation
    c. ETA deviation
    d. Cross sector ETA deviation
    e. Cross sector position deviation
    f. Events deviation

Querying the data

From end user point of view the queries will be:

- Selecting matching trajectories (surveillance and/or synthetic and/or datAcron generated). Usually will be trajectories associated to the same flight plan.
- Similarity of trajectories in a cluster.

Visualizations

Previous visualizations can be applied to the trajectories compared, the metrics of similarity can be shown attached to both trajectories.

Metrics

Performance of the similarity calculation (time used).

7. Annex 1. Event Description

Events will always be expressed at a significant point belonging to the 4D trajectory, the change must be "planned to commence" at that significant point. Events may have an impact in lateral path, vertical path or both in every trajectory. For example, in the following picture there is a fly-by event on the lateral path and a level change in the vertical path:

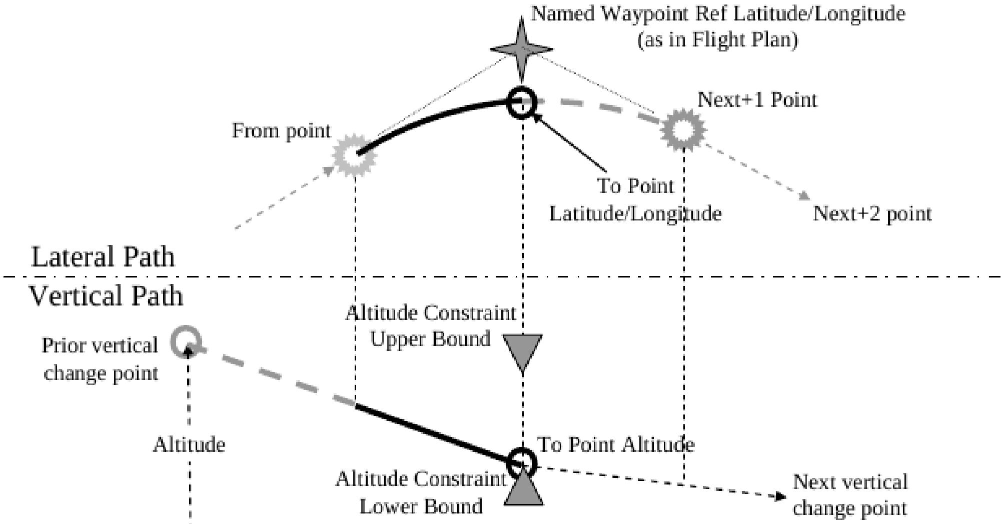
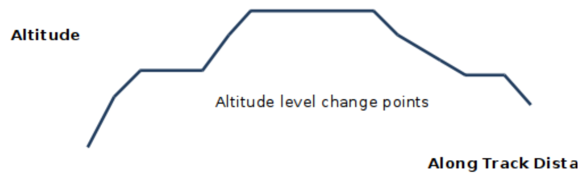
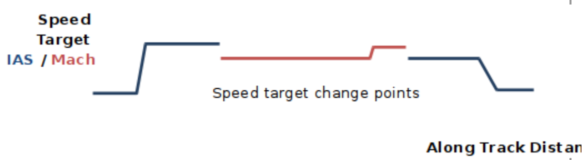


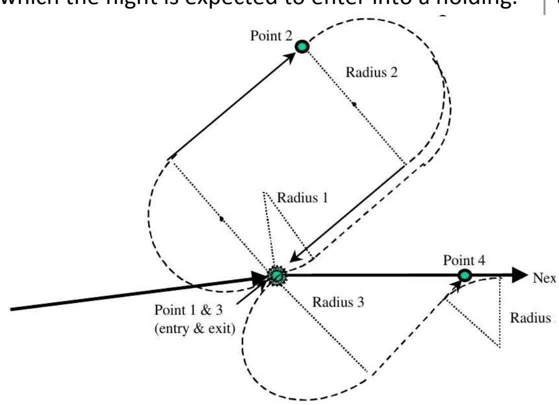
Figure 5 - Lateral vs. Vertical Path

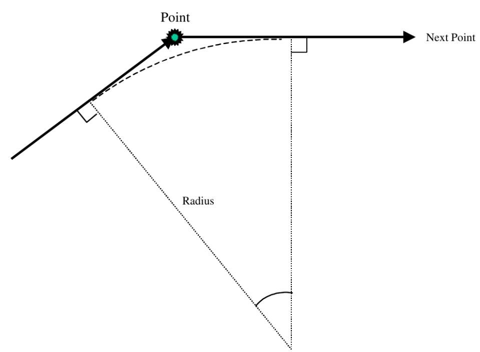
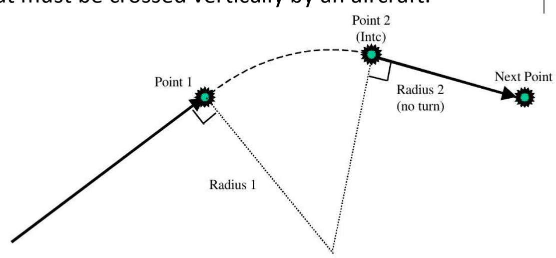
Regarding thresholds for event detection, most are defined in the PANS-ATM, Document 4444, and ARINC 702A-3, anyway, that reference values may be or not input to the complex event recognition module. For example, for speed and level event detection, margins are defined in the PANS-ATM, Document 4444, Item 15c allows the specification of a planned change in speed or level as follows: *The point* at which a change of speed (5% TAS or 0.01 Mach or more) or a change of level is planned to commence, expressed exactly as in (2) above, followed by an *oblique stroke and both the cruising speed and the cruising level*, expressed exactly as in (a) and (b) above, without a space between them, *even when only one of these quantities will be changed*."

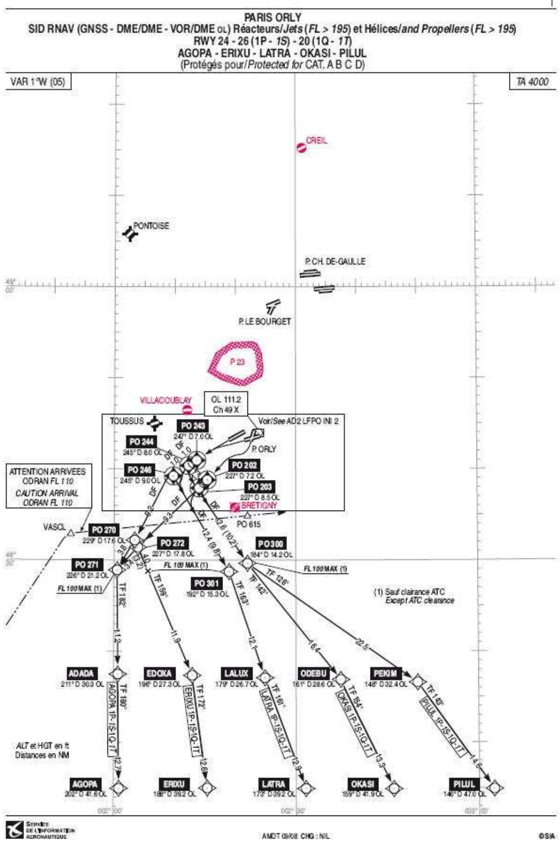
Table 2 - Events in a trajectroy

Event Name	Event Description	Data needed for detection	Present in every trajectory	Mandatory Detection
Top of Climb	(From ARINC 702A-3) The point where the trajectory arrives at the cruise flight level. There will be one top-of-climb for each cruise flight level (step climbs)	Surveillance	Yes	Yes

Top of Descent	(From ARINC 702A-3) The point where the trajectory begins a descent from the cruise flight level.	Surveillance	Yes	Yes
FIR / Terminal Boundary Crossing Point	Indicates the point at which the trajectory crosses from one FIR into another. A named reference to the FIR being entered may also be identified.	Surveillance Context	No	Yes
TCP – Altitude	Indicates that the associated trajectory change point (TCP) is one at which an altitude level-off will be initiated or terminated. 	Surveillance	yes	Yes
TCP – Speed	The point where the airplane will begin accelerating or decelerating as a result of speed constraint or limit, or reaches the target speed (ARINC 702A) 	Surveillance	Yes	Yes
TCP – Heading	Indicates that the associated trajectory change point (TCP) is one at which the course, track or heading is expected to change.	Surveillance	Yes	No
Crossover Altitude	The point in climb or descent where the airplane will transition between Mach and IAS control. (ARINC 702A)	Surveillance + inference	Yes	No
Transition Altitude or Level	Indicates that the associated trajectory point is the point at which the trajectory reaches the transition altitude (in climb) or level (in descent).	Surveillance + inference	Yes	No
Runway Threshold	This point is the threshold (which may be displaced) at the center of the runway at the arrival end when arriving. See ICAO Annex 14.	Surveillance and Context	Yes	No
Start of takeoff roll	Indicates that the associated trajectory point corresponds to the point at the start of takeoff roll (used for departures only)	Surveillance and Context	Yes	No

Landing gear off	Indicates that the associated trajectory point corresponds to the point at which the aircraft is predicted to be wheels off the runway on departure.	Surveillance	Yes	No
Landing gear on	Indicates that the associated trajectory point corresponds to the point at which the aircraft is predicted to be wheels on the runway for arrival.	Surveillance	yes	No
End of landing roll	Indicates that the associated trajectory point corresponds to the point at which the aircraft is predicted to come to a full stop on the arrival runway. (A prediction only, the flight will likely exit the runway without coming to a full stop).	Surveillance and Context	Yes	No
Hold Entry	Indicates that the associated trajectory point is a point at which the flight is expected to enter into a holding. 	Surveillance and Context	No	Yes
Hold Exit	Indicates that the associated trajectory point is a point at which the flight is expected to exit from planned holding.	Surveillance and Context	No	Yes
Hold on ground	Indicates that the aircraft after push-back, when taxiing on ground holds on ground, normally because of airport traffic.	Surveillance and Context	No	Yes
Start of Expect Vectors	When procedures specify “Expect Vectors”, the associated point identifies the starting point of the vectoring.	Surveillance and Context	No	No
Fly-by	The majority of the waypoints in your GPS flight plan are called fly-by waypoints, usually depicted on charts	Surveillance and Context	No	Yes

	as a four-pointed star. As the name implies, you don't have to fly directly over these waypoints. Since the GPS knows your groundspeed, current track, and the number of degrees of change between the current DTK and the upcoming DTK, it can provide turn anticipation for fly-by waypoints.  			
Fly-over	As the name implies, a fly-over waypoint is a waypoint that must be crossed vertically by an aircraft.  	Surveillance and Context	No	Yes
STAR entry	Standard terminal arrival. A Standard Arrival Route (STAR) is a standard ATS identified in an approach procedure by which aircraft should proceed from the enroute phase to an initial approach fix.	Surveillance and Context	No	Yes
SID entry	Standard instrument departure. A Standard Instrument Departure Route (SID) is a standard ATS route identified in an instrument departure procedure by which aircraft should proceed from take-off phase to the en-route phase. SIDs and STARs aim to deconflict potentially conflicting traffic by the use of specific routings, levels and checkpoints. This deconfliction is not active, it's just airport design in order to maximize throughput. Typically, each runway will have a number of SIDs and STARs to ensure that air traffic is not unnecessarily delayed by deviation from the direct route from or to the aerodrome.	Surveillance and Context	No	Yes

	Aircraft can follow or not SID and STARS depending on Air Traffic Controller instructions. datACRON must detect for each trajectory which SID/STAR is being used (in case it is) and if the SID and STAR are the ones that were initially planned. 			
Aircraft not following planned route	Partial or full lateral path change according to the initial flight plan. The typical reason of rerouting will be ATC or weather, and normally it's followed by a flight plan update containing the route. 	Surveillance Context Flight Plan	No	Yes

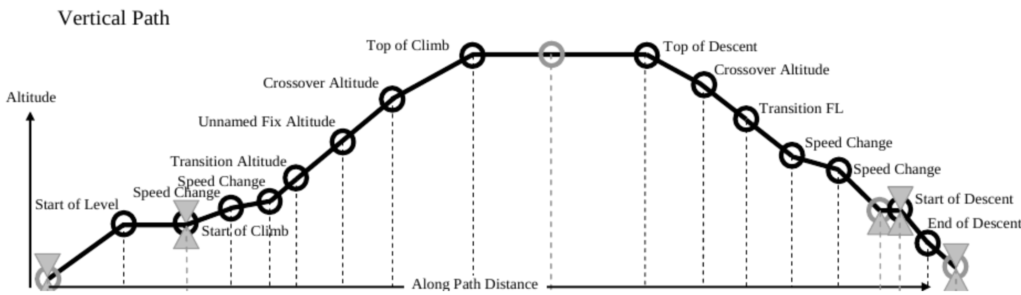


Figure 6 - Possible event sequence along the flight path

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