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Vista

MARKET FORCES TRADE-OFFS IMPACTING EUROPEAN ATM PERFORMANCE

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Abstract

Vista assesses primary trade-offs in ATM between key performance areas in the current and future timeframes, including how they are affected by SESAR and non-SESAR factors. The project has examined the effects of market forces (e.g. fuel prices, economic development), technologies and regulatory factors on European performance in ATM, through the evaluation of stakeholder and environmental indicators. The approaches selected for the various layers in the model are described, and the corresponding results of each are presented. The strategic layer implements an agent-based economic model and a schedule mapper to generate demand and capacity for the different stakeholders, flight schedules and passenger flows – it feeds the pre-tactical layer. The pre-tactical layer transforms the output of the strategic layer into individual flight plans, passenger itineraries and ATFM regulations delay – it feeds the tactical layer. The tactical layer runs the day of operations, tracking flights and passengers and reacting to the tactical situation in the system. Trade-offs have been assessed and visualised within and between periods, and between stakeholders. The Final Project Results Report provides a summary of the entire project, from objectives to main conclusions. Lessons learned and recommendations for future research and development activities are reported along with a self-assessment of the project's maturity.

Important note

Whilst the official status of this deliverable according to Grant Agreement No 699390 is "Confidential", the consortium has agreed to release it as "Public".

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1 Executive summary

Vista examines the effects of conflicting market forces on European performance in ATM, through the evaluation of impact metrics on four key stakeholders, and the environment. Vista models the **current, 2035 and 2050 timeframes** based on various factors and their potential evolution. Vista's model covers the three temporal phases of ATM (strategic, pre-tactical and tactical), and represents a typical (busy) day of operations. The model is able to estimate the impact of factors on the different phases independently, allowing us to capture **how indicators change under different scenarios and execution phases**. This report presents a description of the various parts of the model, together with the final results obtained.

The approaches selected for the various layers in the model are described. The strategic layer implements an **agent-based economic model** and a **schedule mapper** to generate demand and capacity for the different stakeholders, flight schedules and passenger flows – it feeds the pre-tactical layer. The pre-tactical layer transforms the output of the strategic layer into **individual flight plans**, **passenger itineraries and ATFM regulations** delay – it feeds the tactical layer. The tactical layer runs the day of operations, **tracking flights and passengers** and reacting to the tactical situation in the system.

The model includes estimates of **door-to-door times**, for example showing the impact of flight delays on door-to-door times, which is an important capability set in the context of assessing the Flightpath 2050 vision of 90% of EU passengers travelling within four hours door-to-door for journeys involving air as one of the modes.

The **cost of uncertainty** is also estimated, in euros, by calculating the difference of the cost of delay in two situations, and included as a new assessment metric under the various scenarios. This is a valuable feature of the model, since SESAR envisions substantial reductions of uncertainty in the future, the impacts of which Vista can quantify economically.

A significant amount of effort has been devoted to calibration activities to ensure that the model is adequate and captures the impact of factors properly.

Vista deploys five background scenarios: 'current', 'L35' (low economic growth and low technological development in 2035), 'H35' (high economic growth and high technological development in 2035), and likewise 'L50' and 'H50' for 2050. The scenarios also include 'supportive' and 'non-supportive' contexts, modelled through five foreground factors: the **price of fuel**; implementation level of **4D trajectories**; level of **passenger reaccommodation** tools; level of **(regulatory) passenger** provision schemes; and, level of **(regulatory) emissions** scheme. Supportive scenarios reflect a strong emphasis on environmental and passenger protection, with a low price of fuel; non-supportive scenarios reflect a poor emphasis on environmental and passenger protection, with a (very) high price of fuel.

The final results are described layer-by-layer, focusing on key metrics. Such metrics investigated include **the cost of delay**. Considering its importance in airline operations, it is surprisingly rare to have an estimation of this cost taking the full distribution of delays into account. The **total delay per flight** shows how much the system will be under stress in the future; if the airports are indeed the main contributors to delay, we show that the ANSPs, in turn, have a high potential for greater delays, since they move close to their maximum capacities. The **total level of emissions in CO_2 equivalents** has an obvious importance, given rapid climate change; the emissions are all too often only measured per flight, which does not show their full impact. The model predicts a **substantial increase in the total emissions** due to the increase in traffic, differences in the emissions per flight expected can be observed across the different layers of the model due to the different assumptions made strategically, pre-tactically and the actual fuel consumptions computed tactically. The key results per layer are indicated below.

Key strategic results.

1. The main drivers for most of the metrics are the demand and the price of fuel.
2. ANSPs may get close to their maximum capacity (set to 120% of current capacity, with technological advancements), depending on the scenarios, and trigger some significant delay for airlines, even with the technological advancements envisioned by SESAR.
3. ANSPs see their **unit rates decrease substantially** in the future. This is due to the joint effect of higher levels of traffic and greatly improved efficiencies.
4. Airports create most of the delay, and the **increase of capacity envisioned by SESAR is not sufficient** on its own to deal with the increase in traffic.
5. The cost of emissions only really has an impact on airlines when **NO_x is taken into account** together with a large increase in the price of allowances. Emissions have otherwise (almost) no impact on the cost structure of the airlines.
6. The average size of aircraft used by airlines is increasing. This has an impact on the average cost of fuel and environmental impact per flight. Other technological improvements related, for instance, to engine efficiency, have not been considered in Vista.
7. Total emissions are expected to very substantially increase in the future. They are mainly driven by the increase in traffic, and, to a lesser extent, by the increase in the average size of aircraft.
8. The reduction of uncertainty on the departure time envisioned by SESAR is expected to a have major impact on the cost of delay to the airlines. The **cost of uncertainty represents roughly half of the total cost of delay in the current scenario**, but its share drops substantially in the future.
9. Passengers usually see a moderate decrease of fare with respect to their income, except when the operational cost of the airlines increases too much, notably because of the price of fuel.

Key pre-tactical results.

1. Fuel consumption per flight is flat over time as the (e.g. technological) benefits obtained by the system are offset by the **use of longer routes with larger aircraft**, with a potential shift to greater fuel efficiencies. The relative importance of the fuel price over time might also favour the selection of trajectories that use less fuel.
2. The selection of larger aircraft over time is related to the increase of passenger demand and route length.
3. There is an **increase in the size of the buffers** per flight: this may contribute to the **reductions in tactical delay costs** and could be used by the strategic layer to tighten the

schedules – the reason for this increment may be linked to having more numerous longer routes, which usually have larger buffers to manage greater uncertainty.

4. The number of passengers connecting increases over time – these effects are also discussed further in the tactical results.

Key tactical results.

1. Most passenger- and flight-centric metrics follow similar trends overall, but there are non-linear differences on how metrics scale, i.e., **no simple, direct translation between passenger and flight metrics**.
2. Reducing delay, either departure or arrival, has a limited effect on the total door-to-door travel times for passengers.
3. Reductions in flight arrival delay with passenger arrival delay map close to a 1 : 1.3 ratio. That is, on average, one minute of flight delay corresponds to 1.3 minutes of delay per passenger. This is due to the fact that the delay experienced by passengers is higher due to missed connections.
4. There is a **diminishing return of the positive effects** (in terms of delay and environmental impact) **of foreground factors** (implementation of 4D trajectories, advanced passenger reaccommodation tools, protective regulatory passenger provision schemes and regulatory emissions schemes) in the long term (e.g. 2050).
5. There is a clear **trade-off between delay performance and cost metrics**: improving system performance is usually expensive; Vista can quantify such trade-offs to find compromise solutions.
6. The results show that an improvement in passenger door-to-door times does not necessarily imply an increase in the average emissions per flight.
7. The average emissions per flight tend to slightly decrease, remaining mostly flat, but the increase in traffic leads to an overall higher impact of aviation on the environment.

The modularity of the development of the model layers allows the enhancement or part replacement of the model seamlessly. Vista is capable of capturing and quantifying the relationship between complex metrics across several stakeholders, reproducing classic KPIs and estimating complex and newly defined metrics.

Vista is unique in the sense that it supports the analysis of how a given metric changes during the temporal evolution of the different ATM phases: from the expected outcomes of the stakeholders' plans defined strategically, to the planned operations pre-tactically, to the actual execution phase, tactically. As future work, the outcome of the downstream layers can be fed back to the previous layers to improve how some decisions are made. This is a typical case of **reinforcement learning, which can be used to make better predictions** and also to optimise the system. If the divergences between layers is too large, stakeholders may be expected to modify their decisions to adapt to opportunities and to reduce costs.

Further scientific questions can be studied by modifying the model. The impact of infrastructure **expansions for airports**, the **way airlines may compete** for new routes, and **new ANSP structures** (including pricing schemes) are but some examples.

2 Project overview

2.1 Operational/technical Context

Vista is a transversal project, which responds to the increasing need to study the likely impact of joint implementations of different operational improvements. Moreover, these implementations are influenced by different external factors, which also need to be assessed.

As set out in Table 1, Vista examines the relationships between, and impacts of, three major regulatory instruments in Europe, (a) – (c), and the goals and targets set out in the European Commission's high-level vision document for aviation in 2050, (d). These instruments are currently not systematically coordinated.

Table 1. Four driving regulatory forces in European air transport and ATM

Instrument	Scope	Main regulation
(a) SES Performance Scheme	Binding targets set in context of Single European Sky	Regulation 390/2013
(b) Regulation 261	Passenger compensation and assistance scheme	Regulation 261/2004
(c) European ETS	Emissions trading system	Regulation 421/2014
(d) Flightpath 2050	High-level vision document	-

Furthermore, current SES targets and instruments also include:

- SES high-level targets for 2020, as set out, for example, in Edition 2 of the European ATM Master Plan [36];
- Complementary 'Strategic Performance Objectives' also put forward in the ATM Master Plan (*ibid*.);
- SESAR's Performance Target [37].

The figure below shows the relationship between the SES high-level goals, Strategic Performance Objectives and the Performance Scheme.

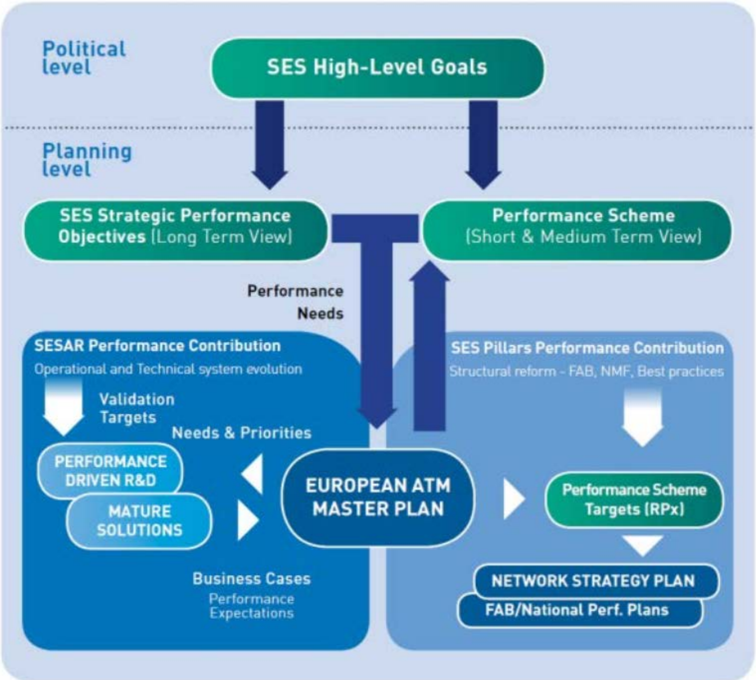


Figure 1. Relationship between political goals and performance objectives/targets

Source: ATM Master Plan (*ibid.*)

These regulatory schemes may impact different business environments depending on when they are implemented. Some regulations can be rendered obsolete or have undesirable effects if the situation is significantly different between the time they are designed and the time they are implemented. As an example, the 2008 crisis decreased traffic so much that the emissions allowances were essentially free for airlines. It is thus important to understand and predict not only the independent and joint effects of regulations, but also to do so in different situations. Several bodies have also cited the need for better mapping of trade-offs in a more empirical manner. For example, in October 2014, the PRB published [38] its assessment report of RP2 Functional Airspace Block (FAB) performance plans. "[...] in all cases, assessment of potential interdependencies between different KPAs was conceptual - rather than evidence based."

Regulation 261/2004 [39] establishes the rules for compensation and assistance to airline passengers in the event of denied boarding, cancellation or delay. Understanding these rules and implementing them properly in the Vista model is vital, since the Regulation has a driving effect on airline behaviour, because the passenger cost of delay is often the most significant delay cost driver for airlines.

The European Parliament's proposals for reform of the Regulation go further than those proposed by the Commission in strengthening air passenger rights [40]. The Commission considers a five hour trigger threshold to be in passengers' best interests, with a longer delay threshold reducing the financial incentive on airlines to cancel delayed flights to avoid paying compensation, and instead make every effort to repair technical problems and operate flights. Herein lies an example of a potential unintended consequence of regulation.

The European Emissions Trading Scheme is another factor to take into account. Several airlines have expressed concerns regarding regulatory changes and the variability of the market, which complicates the estimation of carbon provisions. This has raised concerns regarding operational management and regional competition in aviation [41], [42], [43]. Although the cost of carbon is not currently a driver of airline behaviour with regard to delay recovery, future policy changes and/or significant changes to the price of carbon (and, indeed, potential NO_x charging) may affect airline delay recovery rules, as explored quantitatively in the context of airline punctuality costs [44].

The high-level vision document, "Flightpath 2050", was published by the Commission [45] and establishes Europe's vision for aviation in 2050. It sets a target of 90% of passengers within Europe able to complete their journey, door-to-door, within four hours, for journeys including air as one mode. However, passenger service delivery is currently vitally missing from other target and goal-setting frameworks, and not defined as a specific key performance area (KPA) by ICAO.

In summary, Vista poses several crucial questions, such as: what is the relationship between these targets and to what extent are they reconcilable? How do these relationships change as a function of time, from 2015 to 2050? Does consistency improve or deteriorate as we move closer to Flightpath 2050's timeframe? How do key SESAR and non-SESAR factors modify this picture? Vista sets out to answer these questions through an evidence-driven, holistic model.

2.2 Project scope and objectives

The aims set out in Vista's proposal were to quantify the current and future (2035, 2050) relationships and trends between a currently non-reconciled set of performance targets in Europe, specifically examining the:

- trade-off between, and impacts of, 'regulatory' and 'business' factors;
- vertical metric trade-offs *within* any given period;
- horizontal trade-offs *between* periods, particularly as many targets are not currently mapped from year to year, are discontinuous with other targets, or even entirely missing for given periods (such as, vitally, passenger performance targets);
- alignments between metrics and whether these may be expected to improve or deteriorate as we move closer to Flightpath 2050's timeframe, for example.

Vista has a broad scope. Taking into account several regulatory and business factors, its objective is to compute metrics using ECAC-wide simulations with microscopic details, for long-term horizons (2035 and 2050). As a consequence, Vista's objective is to produce a high-level view. Moreover, Vista cannot realistically predict what will happen in 2035 and 2050. Rather, Vista is a 'what-if' simulator aiming at answering simpler questions such as: "What if factor X and factor Y are implemented at the same time, in different environments?". The result should be a quantitative assessment of the goodness of given decisions, based on a multi-variate objective (the performance indicators).

The perspective of Vista is holistic. Since a complex system such as the air transportation system is more than the sum of its parts, Vista tries to encompass as many mechanisms as possible at the same time. Non-linearities, path-dependencies and stochastic behaviours imply that the response of the system is impossible to predict with studies using only average behaviours and metrics. Vista's perspective is aligned with complexity science, network theory, and, more generally, any framework tackling emergent phenomena.

Vista focuses on identifying how selected indicators for stakeholders evolve under different scenarios in the different considered timeframes. The stakeholders considered are: airlines, air navigation service providers, airports, passengers, plus the environment. The latter is far too often omitted and needs to be balanced against the others in terms of impacts.

2.3 Work performed

The work in Vista has mainly involved four tasks: (i) review of the most important business and regulatory factors; (ii) definition of the scenarios to be modelled; (iii) consultation with stakeholders to validate the premises of the model; (iv) model development. For stakeholder consultation and feedback, see Section 2.4.4. For calibration, see Section 2.4.5.

2.3.1 Business and regulatory factors

Deliverable D2.1 presents the main factors that are likely to affect the evolution and the performance of the air transportation system. These factors are differentiated between regulatory and business factors. The former includes all the legal requirements emanating from national and supranational entities in order to regulate a certain part of the system. These factors are by nature known (for the current situation), and their immediate effects are relatively unambiguous. However, indirect effects due to changes of business models can be present in the medium- to long-term, which could decrease the efficiency of the regulation, have an opposite effect to the expected one, or simply have another effect in another part of the system. Some of these regulatory factors can be seen as enablers of operational and technology modifications in the system, while others have a direct impact on the behaviour of the actors (stakeholders) in the system. The regulatory factors have been grouped based on the phase of the operations (primarily) affected by them. Business factors are more generic and their effects are sometimes less clear. In essence, a business factor is a service, technology, operational concept or commodity which may impact a stakeholder's business model, or the behaviour / customer satisfaction of a passenger, when it is available or changes its price. Obviously, there are a great number of business factors, especially if one considers the heterogeneity of the actors implied. As a consequence, Vista tries to group them into common areas.

Vista first addresses new services and technologies that are likely to be introduced in the future, affecting gate-to-gate performance. For this, Vista looks specifically at major R&D initiatives, and in the first place, SESAR. SESAR has a very clear structure in terms of workpackages and the targets that are likely to be achieved by different dates. These clearly-defined, new solutions can be directly used in the Vista model, either using some heuristic impacting one part of the model, or directly modelling the new mechanism. Regarding socio-economic changes within Europe, several non-independent factors are gathered under the same umbrella to avoid unwanted complexity within the model and inconsistent values for the different factors. Most of the forecasts for these factors are based on economic and social prediction studies such as STATFOR. With respect to commodities, Vista considers fuel as an independent variable from the global economic development of Europe.

2.3.2 Scenarios for Vista

In Deliverable D3.1, the factors previously listed are reviewed and prioritised. Regulatory and business factors have an impact on the stakeholders' behaviour and/or on the system affecting the different KPAs and KPIs that are of interest in Vista. Some of those factors define the background onto which the individual factors are assessed. The regulatory and business factors identified in D2.1 are divided between foreground and background factors. The possible values considered for the foreground factors are identified. The background factors are grouped with their possible values to define the scenarios. The scenarios in Vista are then defined as sets of values over all the factors previously compiled. The scenarios are defined in a hierarchical way. Some regulatory and business factors are grouped together to constitute background factors. Setting the factors to different values then defines different background scenarios. The remaining factors are foreground factors. Setting their values then constitutes a scenario, to be run by the Vista model.

2.3.3 Overview of Vista model

Figure 2 presents an overview of the Vista model as described in D4.1 (Initial framework definition) and used to produce the results reported in D5.1 and D5.2. Vista models the three temporal phases of ATM (strategic, pre-tactical and tactical) for each scenario investigated, with the objective of generating a representative (busy) day of operations for each given scenario. The different factors define the scenario to be modelled.

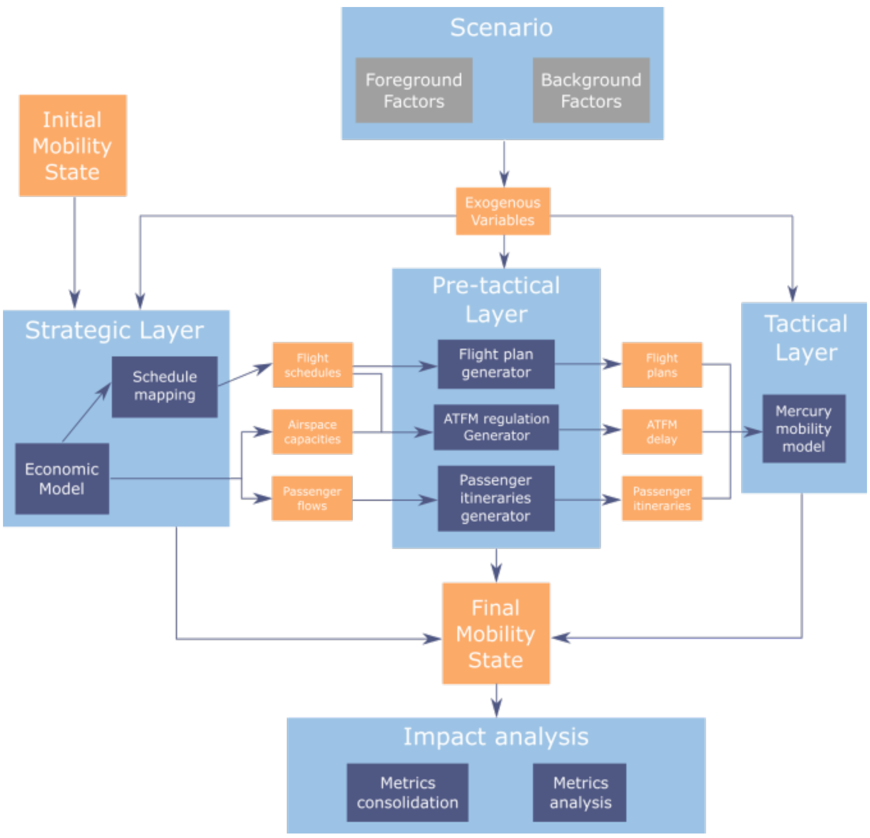


Figure 2. Overview of Vista model

The strategic layer considers the factors and the economic environment to provide the outcome of strategic decisions made by the stakeholders, the capacities provided and demand, flight schedules and passenger flows for a typical day of operations. These flows, schedules and capacities are transformed into individual flight plans, passenger itineraries and air traffic flow management regulations by the pre-tactical layer.

The tactical layer executes the flights and passenger itineraries at a flight and passenger level, tracking the evolution of delay, passenger connections and the tactical decisions carried out by the actors. Among these layers, only the tactical one is based on a prior model, the Mercury engine. Mercury has been reimplemented and enhanced for Vista, but is based on previous models, used in past projects such as POEM and ComplexityCosts. The two other layers are composed of blocks (see Figure 2) which have been written from scratch. One of the capabilities of Vista is to provide metrics for the different stakeholders not only at a model level, but also at the layer level. Therefore, it is possible to obtain an indication of how some metrics evolve as the phases move from strategic to tactical, as presented in D5.2.

2.3.4 Strategic layer

2.3.4.1 Economic model

The economic model is the first block of the strategic layer. It has the ambitious task of creating appropriate levels of supply and demand in Europe based on different scenarios. The model provides high-level views of the number of flights, passengers, etc., for each origin-destination pair. The main requirements of the model are that it should capture: (i) the main business drivers in terms of cost and revenues, for the airlines in particular; (ii) complex, non-linear economic feedback; (iii) highly heterogeneous behaviours in terms of agents – airlines, airports, etc.; (iv) network effects due to alliances, code sharing, connecting passengers, etc.; (v) main stakeholder behaviours – airports, airlines, passengers, and ANSPs. In addition, it should not be computationally over-demanding. For all these reasons, we chose to use a deterministic, turn-based agent-based model, underpinned by a network structure. Agent-based models are particularly well suited to represent different competing agents with heterogeneous behaviours. The agents can have arbitrary complex rules and interact heavily with each other, which allows potential strong feedback between them. We chose a deterministic model to avoid multiple runs as an output, which would require more runs performed by the downstream blocks. Turn-based models are also easier to build and control, even if some scientific issues can arise. For instance, the sequence of 'play', even for the same types of players, sometimes changes the model outcomes. The model is based on a common environment, called 'world', in which different agents evolve. The following types of agents are implemented in the model: alliance, airline, flight, ANSP, passenger. See Deliverable D5.2 for details. There are no hard-coded archetypes of agents within each type. What defines the different behaviours of the agents is their cost structure and their initial conditions (initial network for airlines for instance). The supply and demand interact in this network in an intricate way. On the one hand, the supply is leg-based. To compare the supply and demand, the latter is aggregated based on all the passengers going through this leg for this airline, for whatever itinerary. (An "itinerary" is a distinct permutation of legs between a given OD pair, operated by a given alliance.) The supply for the leg for this airline is simply given by the corresponding flight agent. A price variable attached to this leg plays its adjusting role. On the other hand, the demand reacts only to prices of itineraries. These prices are thus aggregated from each leg in the corresponding itinerary.

2.3.4.2 Schedule mapper

The schedule mapper converts the high-level flows of the economic model into individual schedules, to be used by the flight plan generator. Planning schedules based on expected demand is a highly demanding task, even at a single airline level, which in general have a dedicated tool for this. The complexity of assigning schedules is due to the high number of possibilities and the multiple constraints. These constraints include hard constraints such as crew, aircraft, and airport slots and soft constraints such as the cost of operating an OD pair.

It is out of scope for Vista to reassign completely from scratch all the schedules created by the economic model. In particular, this would imply capturing very complicated slot management behaviours from the airlines (including 'irrational' behaviour such as endowment). Moreover, the number of flights in play is simply too large to hope for a quick, stable solution. As a consequence, Vista simplified the problem by relying heavily on an initial state, set to be 12SEP14, as for the rest of the model. This is however, in keeping with airlines operations: their schedules are expected to evolve from the current state and not completely abruptly change in the future.

The schedule mapper compares, for each airline, the new flow to the old one for each OD. If the new flows are high enough compared to the old ones, each airline tries to add new aircraft and optimise its route so that most of the new flow is served. If the new flows are small, it removes some of its aircraft to avoid wasted capacity. The airline takes crew and airport slots into account only indirectly through the possible patterns (routes) available to the new aircraft and the corresponding likely turnaround times. The schedule mapper is based on machine learning techniques, aiming at keeping the current features of the system when replicating the schedules. It uses in particular a pattern analyser, and with the support of a greedy algorithm and a decision tree, produces schedules that meet, on average, most of the constraints identified. Details are provided in D5.2.

2.3.5 Pre-tactical layer

2.3.5.1 Flight plan generator

The flight plan generator transforms origin-destination schedules into defined possible flight plans. The schedule mapper provides to the flight plan generator the origin and destination airports and the SOBT and SIBT and the aircraft type for each flight. With this information, and using historical flight plan data analysis and aircraft performance models (BADA), the flight plan generator computes a set of possible flight plans (i.e., trajectories) per flight. The possible routes available between a given origin-destination pair are based on a clustering of historically used routes between those airports. The length of these routes might, however, be adjusted depending on the factors in the modelled scenario. The route generator is able to create new routes between new origin-destination pairs. The flight plan generator also uses historical analysis of wind between ANSPs to assign realistic expected cruise winds for each flight plan. Considering historical flight plan performances (flight plan and cruising speed selected, climb and descend time, and distance) and aircraft performances, it estimates the direct operating cost of each trajectory option for each flight. This includes the computation of fuel, CRCO and emissions costs. These operating costs are taken into consideration when prioritising the different flight plans for each flight done by the flight plan selector.

2.3.5.2 ATFM regulation generator

The ATFM regulation generator estimates the probability of being affected by ATFM regulations and the amount of delay due to those regulations. The input of the ATFM regulation generator is the capacity of the ANSPs and the traffic. The ATFM regulation generator thus requires the outcome of the flight plan generator (and flight plan selector) and the 2014 demand and capacity to be able to compute the variation of demand and capacity with respect to the 2014 case, which is used as reference. ATFM regulations are divided between regulations due to capacity issues (i.e., regulations flagged as “C” as their reason to be implemented by the FMP) and all the other regulations. It is assumed that regulations due to capacity are affected by the demand in the ANSP while the regulations that are not due to capacity remain homogeneous across the ECAC region. This assumption allows us to modify the probability of having ATFM delay due to the demand expected at different ANSPs and their expected capacity, while maintaining delay, which is not directly linked with a capacity/demand imbalance (e.g., regulations due to weather).

2.3.5.3 Passenger itineraries generator

One of the outputs of the strategic layer is the passenger flows, for example, passengers wishing to fly with Lufthansa from EGLL to EDDF. The strategic layer also reports the schedules that the airlines are providing with their aircraft types assigned for each flight leg and the number of seats available on the aircraft. The objective of the pre-tactical layer is to transform the flows of passengers into individual itineraries, i.e., assign the passengers to specific flights. This is done in a three-stage process: computing the possible options available for the passengers in each flow, then optimising the assignment of passengers among their options, and finally creating additional passengers’ itineraries to ensure that the load factors of the aircraft are realistic and indicating which passengers are ‘premium’ and which are ‘standard’. Details are provided in D5.2.

2.3.6 Tactical layer

The tactical layer analyses the delay propagation between flights and the adaptability of the system during disruption (cancellations, background and foreground delay) and with limited resources (e.g., airports and en-route capacity). The analysis is performed both per flight and per passenger to allow us to measure the trade-offs between passenger and flight performance. This layer is integrated in the Vista platform making use of the data and metrics generated in previous layers to simulate the selected scenarios and their underlying factors. However, when provided with the necessary inputs, the tactical layer is independent from the other Vista layers. It is thus possible to replace other layers or to use historical data from other sources. The tactical layer simulation is a sequence of two processes, the gate-to-gate simulation and the door-to-door simulation. One of the characteristics of the tactical model is its door-to-door approach. This layer reproduces the whole passenger journey including the transport choices of the passenger to reach the airport from their origin to their destination. This model was validated during the last ten years across several research projects and it is an evolution of the Mercury simulator, further developed for Vista. Conversely, the improvements made during the project will be integrated into Mercury.

There are various feedback loops considered in this layer. One example is the arrival delay of flights, which is updated several times during the simulation. Airline operators are affected by such delay because a connecting flight is notified in order to adapt its behaviour to the current status of the system. Several costs are considered during the simulation, such as fuel costs, crew costs, ANSP costs and passenger delay costs. Those costs have an impact on the behaviour of the system such as when selecting the flight plan. This model also updates the cost metrics considering the last state of the system (i.e. when the simulation ends). Environmental emission costs are also considered, in particular the CO_2 emission costs, as the NO_X emission costs are already modelled in the strategic layer.

2.3.6.1 Gate-to-gate simulation

The gate-to-gate simulator models each flight and passenger itinerary capturing flight and passenger metrics (e.g., delay, costs, number of missed connections) while modelling pre-tactical and tactical disruptions in the system (i.e., delay due to ATFM regulations and due to other reasons, such as tactical capacity limitations at runway occupancy, and uncertainty in the different flight phases). Instead of simulating the whole temporal continuous domain between the first flight that departs and the last flight that arrives, we have discretised continuous intervals in several discrete events. The time between these events is not fixed: the simulator only evaluates those events that are important for coordination, such as those related to system capacity (runway occupancy, TMA control, en-route control). Once a flight event is processed, it adds the next event to be simulated in the events queue. The event scheduler is responsible for maintaining the event list accessible during the whole simulation and ensuring that all events are processed in order (synchronised). This simulator considers four processes: flight plan submission, previous aircraft ready, push-back-ready, arrival. Details are provided in D5.2.

2.3.6.2 Door-to-door simulation

The door-to-door simulator transforms gate-to-gate passenger itineraries into door-to-door itineraries and calculates several passenger metrics for those itineraries. Firstly, the model calculates gate-to-gate metrics for each passenger itinerary, in this case the gate-to-gate time and the delay costs associated if the passenger experiences any type of delay. Next, the model assigns an archetype for each passenger type randomly. There are six different passenger archetypes in the door-to-door module and two type of tickets considered in the gate-to-gate phase. The mapping between the two gate-to-gate ticket types and the six passengers' archetypes is detailed in D5.2. As soon as all passengers have an assigned archetype, passengers are grouped and then counted per origin/destination and archetype. This information defines the number of distributions that have to be modelled in order to assign door-to-door times for each passenger. This approach reduces the number of distributions pre-calculated and thus the performance is improved.

2.4 Key project results

The Vista model is organised in layers; we present the key results obtained for each of them in the following subsections.

2.4.1 Strategic layer

2.4.1.1 Key metrics

In order to summarise the main results of the model, we present a set of key metrics that concern all stakeholders (airports, airlines, ANSPs, passengers, plus the environment). These metrics have been chosen for their relevance and/or for their originality with respect to similar studies:

- the cost of delay has been chosen for its importance in airline operations; it is very rare to have an estimation of this cost taking the full distribution of delays into account;
- the cost of uncertainty, part of the above cost, is even more rarely measured; the fact that SESAR envisions substantial reductions of uncertainty in the future, calls for a proper estimation of the associated benefits;
- the total level of emissions in CO_2 equivalents has an obvious importance, given rapid climate change; the emissions are all too often measured per flight, which does not show their full impact; note that not only does the model predict a massive increase in the total emissions, but also an increase in emissions per flight, since heavier flights are expected to fly in the future;
- the fare-to-income ratio is important to properly estimate whether the system is more efficient economically or not; this metric is probably underestimated in the model; however, it is interesting to see that it still decreases in some cases, even without strong competition between airlines;
- the total delay per flight shows how much the system will be under stress in the future; if the airports are indeed the main contributors to the delay, we show that the ANSPs have a high potential for greater delays, since they move close to their maximum capacities, even with the technological advancements envisioned by SESAR.

In Figure 3, we show the evolution of these key metrics. The total cost of delay includes the compound effects of the mean delay and the uncertainty (shown second, alone). The total emissions in CO_2 equivalents is for the entire system, taking into account CO_2, NO_x, H_2O and contrails (the latter two not being charged in any scenarios). The last plot is the sum of the delay produced by ANSPs and the delay produced by airports, per flight.

The cost of delay and the cost of uncertainty decrease substantially in both the supportive and non-supportive scenarios, significantly more than the baseline for the cost of delay. On the other hand, we can see that the total CO_2 equivalent emissions increase substantially, and that total delay increases, especially in the supportive scenario. The fare to income ratio decreases slightly in the supportive case, as well as in the baseline.

Figure 3. Key metrics evolution

Note that the emissions in the figure are the total equivalent emissions with respect to long-term climate impact, summing the CO_2, NO_x, H_2O, and contrail effects, but it is interesting also to see which type of emissions has the bigger impact. We show in Figure 4 that the biggest greenhouse effects are not due to CO_2, but rather to NO_x, which is not yet charged by any scheme. According to the model provided by DLR, contrails also have a very substantial impact. Water has a lower impact. Note that this partition does not change much across scenarios.

This result, together with the high increase in the total emissions, means that charging for the CO_2 only is not enough and that it is urgent to consider all types of emissions at the same time when devising an environmental scheme.

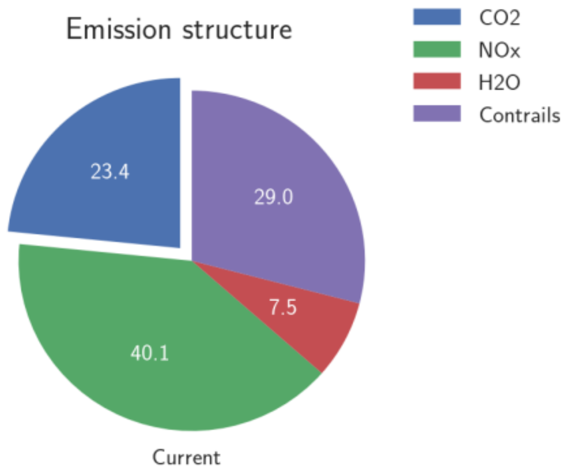


Figure 4. Emissions structure

2.4.1.2 Key results

The main points that emerge from the strategic results are as follows.

1. The main drivers for most of the metrics are:
    a. the demand (set in the model by the average income of passengers);
    b. the price of fuel (as shown also more in detail in D5.1).
2. ANSPs may get close to their maximum capacity (set to 120% of current capacity, with technological advancements), depending on the scenarios, and trigger some significant delay for airlines, even with the technological advancements envisioned by SESAR.
3. ANSPs see their unit rates decrease substantially in the future. This is due to the joint effect of higher levels of traffic and greatly improved efficiencies.
4. Airports create most of the delay, and the increase of capacity envisioned by SESAR is not sufficient on its own to deal with the increase in traffic.
5. The cost of emissions only really has an impact on airlines when **NO_x is taken into account** together with a large increase in the price of allowances. Emissions have otherwise (almost) no impact on the cost structure of the airlines.
6. The average size of aircraft used by airlines is increasing. This has an impact on the average cost of fuel and environmental impact per flight. Other technological improvements related, for instance, to engine efficiency, have not been considered in Vista.
7. Total emissions are expected to very substantially increase in the future. They are mainly driven by the increase in traffic, and, to a lesser extent, by the increase in the average size of aircraft.
8. The reduction of uncertainty on the departure time envisioned by SESAR is expected to a have major impact on the cost of delay to the airlines. The cost of uncertainty represents roughly half of the total cost of delay in the current scenario, but its share drops substantially in the future.
9. Passengers usually see a moderate decrease of fare with respect to their income, except when the operational cost of the airlines increases too much, notably because of the price of fuel.

Among these qualitative main results, #6 is important to note as there are some conflicting studies about the increase of the size of aircraft in the future. It is interesting to see that we obtained this result without actually changing the size of the aircraft anywhere, but just by allowing the most profitable flights to grow faster than the others, which leads naturally to a higher average for the size.

The impact of uncertainty (#8) on the ATM system is also an open question. In the model, we have only used unpredictability to compute real expectations of costs as opposed to costs of average delay, as is often the case. With this simple set-up, we obtain the important result that the uncertainty counts for around 50% of the cost of delay in the current scenario. As a result, any changes to uncertainty substantially impacts the cost of delay and thus the total operational cost of the airline (note however that the cost of delay is not the major contributor to the operational cost of the airline). The changes envisioned by SESAR – although optimistic – thus will have a great impact on the operations. Note also that we did not take into account other phenomena linked to uncertainty: change of buffers, suboptimal human decisions due to time constraints, etc.

The model also answers an important question regarding the ANSPs (#2, #3). Keeping the current scheme, and provided that the SESAR innovations are implemented, we find that the system is able to cope with the increase of traffic in most scenarios, at least in the long run, but is dangerously close to its limit. Moreover, the gains in efficiency and the gains in capacity mean that the ANSPs are able to reduce their unit rates very significantly, driving the ATC costs down for the airlines. The validity of this result is also subject to whether the maximum capacity of the ANSPs is actually currently around 120% of their capacity on average. Moreover, the fact that ANSPs are currently differently close to their limits could have an impact on the results.

Airports are not able to cope with the increase of traffic with the SESAR improvements alone. They already produce a large share of the delay currently, and are likely to produce most of it in the future. Several other factors mentioned in D3.1 could help them (e.g. better passenger processing) but have not been implemented. Infrastructure expansions seem, however, to be the best option for many of them.

The main trade-off highlighted by this study is the environment *versus* the increase in traffic. It has been known for years that economic development is prejudicial towards climate impact, in the short and medium term. We find this to be the case in aviation also. Even taking into account the fact that we did not include increased efficiency of aircraft engines, it is crucial to note that the overall efficiency of the system is nowhere near enough to offset the potential increase in traffic, let alone decrease the emissions. Even more important, we highlight the fact that gains in efficiency in the model turn into increased profits, and thus into the expansion of operations, which negate the gains *in fine* from an environmental point of view.

2.4.2 Pre-tactical layer

2.4.2.1 Key metrics

In the pre-tactical layer, the key metrics presented capture the main characteristics of the flight plans, the ANSPs and the passengers, as shown below.

For fight plan characteristics, to describe how the flight plans change due to the different scenarios:

- average fuel per flight (kg);
- average distance flown (NM);
- average flight time (minutes);
- buffer time per flight plan (minutes).

Wider ATM system status: in order to identify how the system in general is evolving, the amount and characteristics of the traffic and passengers, and the impact on ANSPs' operations:

- number of flights (count);

- average MTOW of the aircraft used (tonnes);
- number of passengers (count);
- connecting passengers (percentage);
- ANSPs' revenues (euros).

In Figure 5, we present the evolution of these key metrics for the flight plan characteristics. The average fuel burn per flight in 2050 is slightly lower than for the current scenario, and lower for the non-supportive scenario. The total amount of CO_2 emissions is proportional to the fuel consumption and hence follows the same trend. The flight plan distance increases for 2035 and 2050, being larger for the supportive scenarios. This indicates the selection of longer routes and the operation of longer origin-destination routes, as demand increases. Note that for both the supportive and non-supportive cases, the increase is lower than in the (low) baseline. The average flight plan time evolves proportionally to the increment in flight plan distance. However, buffer times (time allocated for taxi in, taxi out and buffer for the flight plan) increase over time and are higher for supportive scenarios. This is important, as it might have an impact on the amount of delay actually incurred by the flights tactically. Whilst longer routes are being used with longer flight times, fuel consumption is flat. Initial investigation of this effect suggests that it may be due to the assignment of more fuel-efficient aircraft types to the routes.

Figure 5. Key flight plan metrics evolution

If we consider the evolution of the system metrics in Figure 6, we see that the number of flights increases over time, even if lower for the supportive and non-supportive scenarios than for the low baseline. This is in accordance with the increment in the number of passengers. The average MTOW of the aircraft increases over time, with no difference between the supportive and non-supportive cases. An increment in the percentage of passengers making connections points towards more operations on longer routes. From an ANSP perspective, the revenues obtained due to en-route airspace charges of the supportive case are similar to the baseline case, which increase in 2035 with respect to the current value, and then decrease. In the non-supportive case, the revenues decrease as the capacity that needs to be provided is offset by the increment in flights.

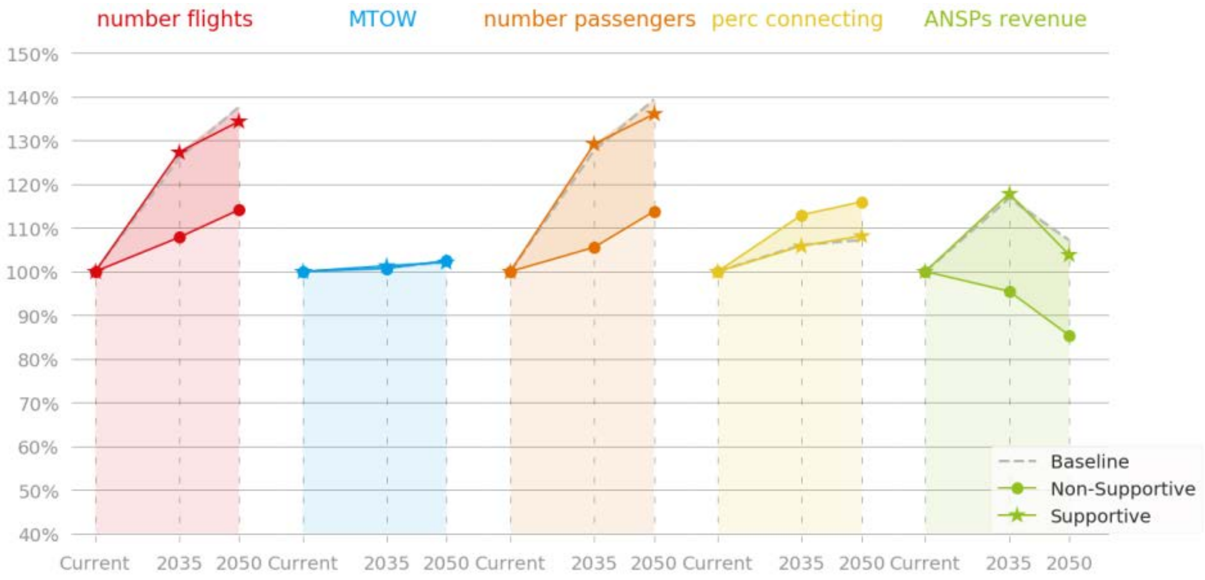


Figure 6. Key system metrics pre-tactical

2.4.2.2 Key results

The main points that emerge from the pre-tactical results are as follows. These results obtained are in accordance with the outcome of the strategic layer.

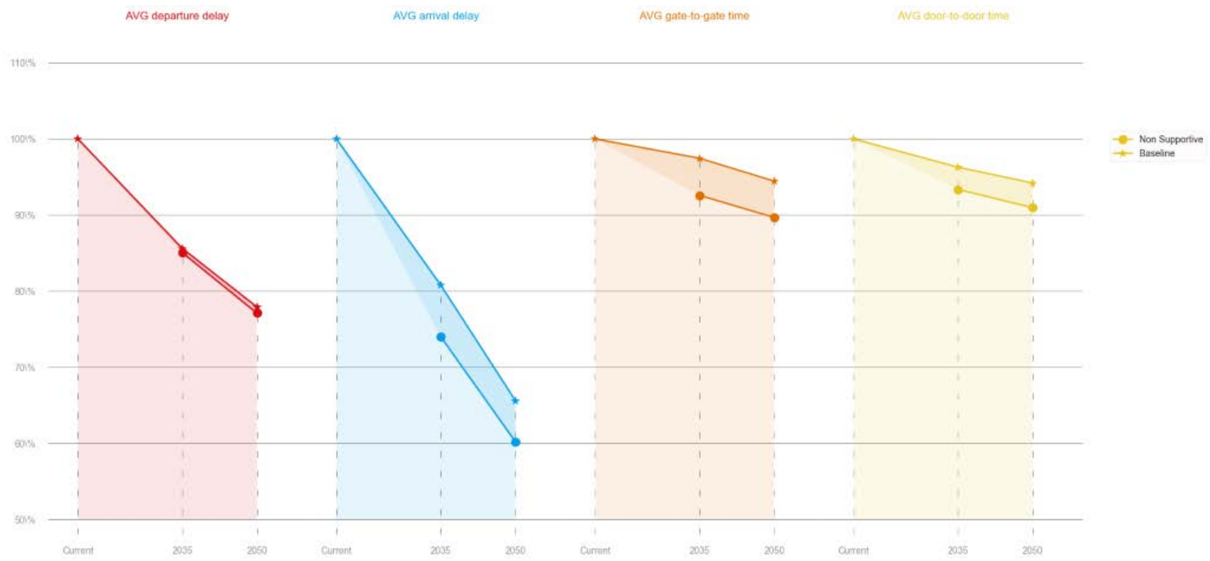
1. Fuel consumption per flight is flat over time as the (e.g. technological) benefits obtained by the system are offset by the use of longer routes with larger aircraft, with a potential shift to greater fuel efficiencies. The relative importance of the fuel price over time might also favour the selection of trajectories that use less fuel.
2. The selection of larger aircraft over time is related to the increase of passenger demand and route length.
3. There is an increase in the size of the buffers per flight: this may contribute to the reductions in tactical delay costs and could be used by the strategic layer to tighten the schedules – the reason for this increment may be linked to having more numerous longer routes, which usually have larger buffers to manage greater uncertainty.
4. The number of passengers connecting increases over time – these effects are also discussed further in the tactical results.

2.4.3 Tactical layer

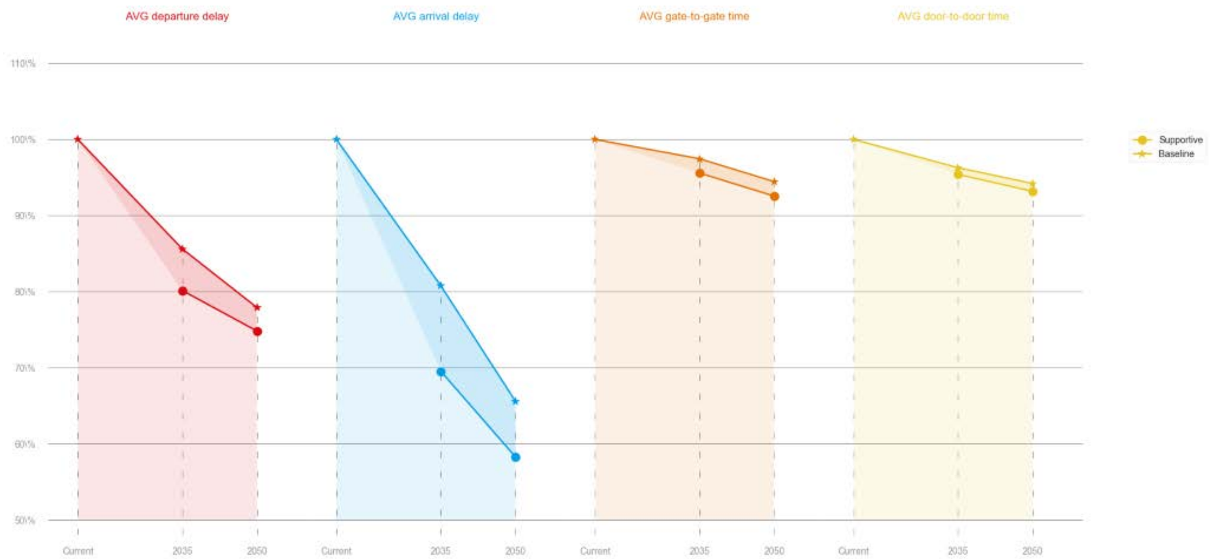
2.4.3.1 Key metrics

When comparing the passenger metrics with the flight metrics, there are clearly similar trends in both departure and arrival delay. Whilst the relationship is clear, the metrics do not scale the same way. This result is repeated across all scenarios and simulations. The reduction in arrival delay on average is quite substantial: close to 50%. There are several rationales for this phenomenon, with the increasing buffers and the reduction of reactionary delay the main factors.

It is also striking to observe that even if gate-to-gate times increase for flights in the mid- and long-term scenarios, it is in fact reduced from the passenger perspective. Despite gate-to-gate times for passengers being composed of one or more flight and gate-to-gate sequences, there are also the layovers for connecting passengers. Reducing passenger waiting times at the airport makes the overall trip length shorter. However, lower connecting times could lead to reduced passenger spend, which in turn could increase airport charges and ultimately passenger ticket prices.

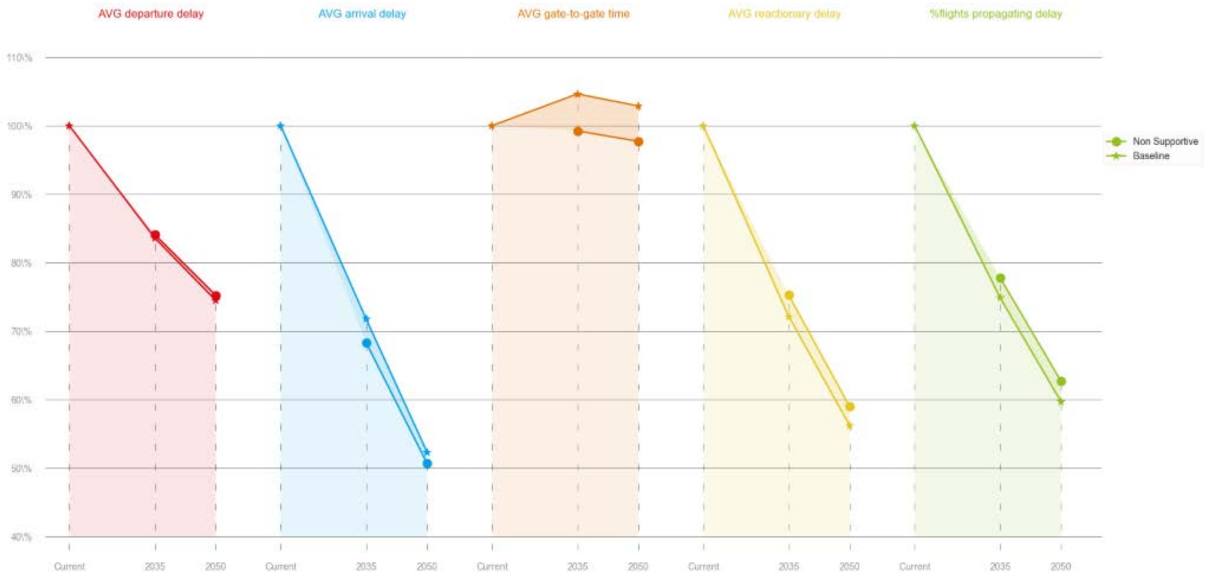


(a) non-supportive

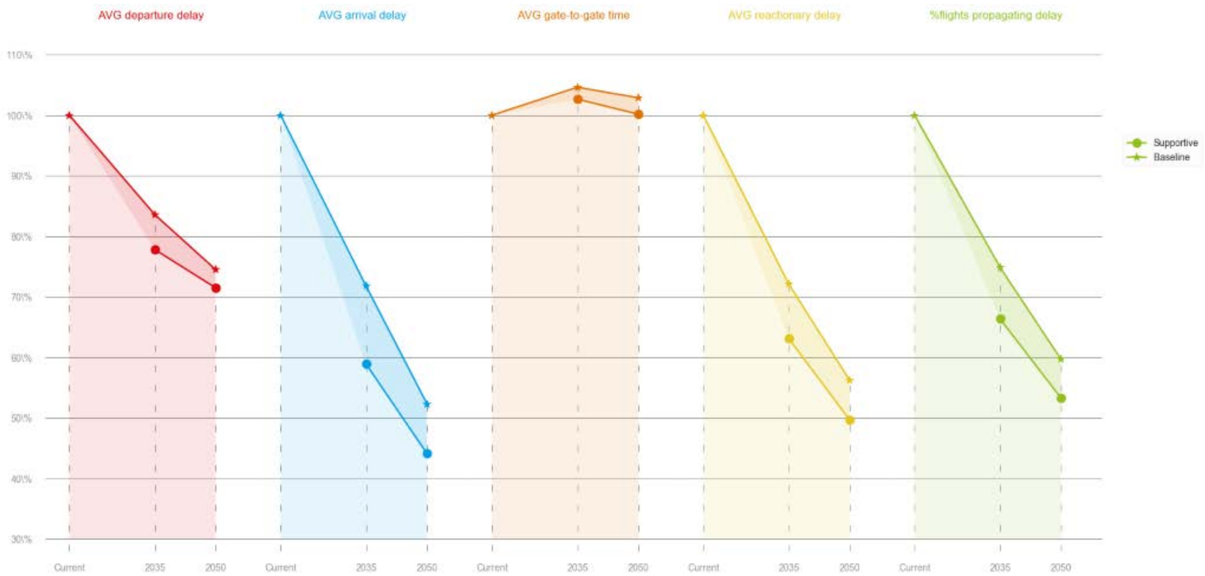


(b) supportive

Figure 7. Evolution of passenger delay metrics in supportive and non-supportive scenarios



(a) non-supportive



(b) supportive

Figure 8. Evolution of flight metrics in supportive and non-supportive scenarios

2.4.3.2 Key results

The main points that emerge from the tactical results are as follows.

1. Most passenger- and flight-centric metrics follow similar trends overall, but there are non-linear differences on how metrics scale, i.e., no simple, direct translation between passenger and flight metrics.
2. Reducing delay, either departure or arrival, has a limited effect on the total door-to-door travel times for passengers.
3. Reductions in flight arrival delay with passenger arrival delay map close to a 1 : 1.3 ratio.
4. There is a diminishing return of the positive effects of supportive factors (mechanisms) in the long-term (e.g. 2050).
5. There is a clear trade-off between delay performance and cost metrics: improving system performance is usually expensive; Vista can quantify such trade-offs to find compromise solutions.
6. The results show that an improvement in passenger door-to-door times does not necessarily imply an increase in the average emissions per flight.
7. The average emissions per flight tend to decrease over time but the increase in traffic leads to an overall higher impact of aviation on the environment.

2.4.4 Stakeholder consultation and feedback

Three main consultation exercises were performed in Vista. A first questionnaire was sent to several targeted experts, asking them to comment on the design and scope of the factors and scenarios. This was reported in D6.2. In order to complement the consultation experts' view, it was decided to organise a workshop ([26] – [29]). The output of the workshop was directly integrated into the relevant deliverables. The modelling team also spent some time talking with the Vista airline partners and Belgocontrol, in particular, to collect useful feedback on the hypotheses of the model. Once the first results of the model were produced and reported in D5.1, Vista carried out a further consultation with the original targeted experts to help with the prioritisation of the final scenarios and metrics to analyse. This third consultation activity was reported in D6.3, and also included the Vista industry partners. Final feedback from the latter on D5.2 will be reported upon in the final close-out presentation (being prepared in parallel with this document), which will include potential next steps for the Vista model, in addition to those already identified in Section 4.3.2 with other interested parties from industry (that can be publicly reported).

2.4.5 Model calibration

The model calibration is discussed extensively in Deliverable D5.2, at various points through Section 2, and in a dedicated, detailed Section 3. An indicative summary is presented below.

2.4.5.1 Strategic layer

The calibration of the economic model is done on multiple sources of data which are far from consistent or aligned. The initial state of the model is set to be as close as possible to 12SEP14. Input data for the airports, itineraries and legs, passenger economic data, airlines, flight plans and ANSP data are described in turn. Post-calibration checks are also summarised.

The calibration of the schedule mapper relies heavily on historical information. In input, the schedule mapper needs four types of information: airport data: standard airport data, also used in the economic model and elsewhere; historical schedules: the schedules that were already planned for 12SEP14; strategic input: the flows from the economic model; and, pattern and taxon data: the historical taxons and patterns. All data except the third category come from a prior analysis of historical data. Deliverable D5.2 focuses on the pattern and taxon analysis. All this analysis in based on DDR data, and includes the departure and turnaround times pre-analysis, and decision tree for turnarounds analysis.

2.4.5.2 Pre-tactical layer

For the pre-tactical layer, calibration for the flight plan generator also relies on the analysis of historical data. This historical data analysis is used to generate a pool of flight routes between origins and destinations and to generate distributions that are used to model flight trajectories (climb, descent and cruise phases characteristics) and weather factors (cruise wind). The data analysed is primarily sourced from DDR and BADA performance models.

Input data for the flight plan generator is detailed in terms of historical flight plan routes, historical flight plan requests, historical flight plan trajectories and aircraft performance models. The objective of the post-calibration of the flight plan generator is to analyse and ensure that the flight plans that are generated are as close as possible to historical flight plans when the scenario is set to the current scenario. Ensuring that the results are close to current operations gives us confidence in the model results. For the flight plan generator there are different metrics that can are analysed: flight plan distance; buffers; fuel usage and en-route costs; route preference between origin and destinations; and, demand at the different NASs. We calibrate the model to ensure that these metrics are as close to historical values as possible obtaining in this manner routes that are realistic.

Regarding the calibration principles for the ATFM regulation generator, this is based on information on historical ATFM regulations and on the demand produced by the flight plan generator. An analysis of historical regulations and delay is needed to adjust the probability of being delayed and the intensity of this delay based on the historical data. The data analysed is primary sourced from DDR. Input data for ATFM regulation generator post-calibration are discussed.

The objective of the passengers itineraries generator is to transform flows into individual passenger itineraries. The assigned itineraries use information from different data sources to ensure that the minimum connecting times are respected at the airports. It is also important to validate that the percentage of connecting passengers at the different hubs is as expected from historical data and that the load factors on the flights are also aligned with industry reported values. Input data and post-calibration are discussed.

2.4.5.3 Tactical layer

The calibration of the tactical model is done using some of the data sources identified in D2.1. Those data sources relate to 12SEP14. Most of the calibrations were already performed in the previous iteration (as reported in D5.1). However, the model had to be calibrated again to include the new sub-models added in this final iteration.

Calibration for the gate-to-gate simulation is described for: flight cancellations; minimum turnaround times; primary delay unrelated to ATFM; flight plan selection; primary delay due to ATFM; minimum connecting time; additional delay for waiting connecting passengers; taxi times; AMAN and DMAN capacity; passenger re-accommodation policy; climb uncertainty; cruise uncertainty; delay recovery model; passenger delay costs (to the airline); APU fuel burn; and, crew and maintenance costs.

The door-to-door simulation model has two different data types that have to be calibrated: passenger archetypes and airport archetypes, in order to validate the model for 12SEP14. The model was calibrated previously as part of the Horizon 2020 DATASET2050 project. The model includes 200 airports and has assessed granular information about the different internal process times (e.g. check-in, security) of the top ten airports (LFPG, EGLL, EDDF, EHAM, LFPO, EDDM, LEMD, LIRF, LEBL, EGKK). The rest of the airports have been aggregated. We have also plotted average walking distances within airports, therefore clustering them into two archetypes (large and small). These two types of airports are themselves clustered into two groups depending on their seasonality (i.e. if the traffic is higher in summer or winter due to some touristic location for example). These characteristics determine the passenger archetype dwell times at the airports.

2.5 Technical deliverables

Table 2. Project deliverables

Reference	Title	Delivery Date[1]	Dissemination Level[2]
	Description		
D1.1	Project Management Plan	02/11/2016	Confidential
The Project Management Plan (PMP) documents the management plan and procedures, complementing the project information provided in the Grant Agreement Description of Action with additional detail and including refinements agreed at the Kick-off Meeting. The PMP follows the SESAR 2020 Project Execution Guidelines, which are the requirements that are applicable to all Exploratory Research projects, complying with processes defined in the Annotated Model Grant Agreement.			

[1] Delivery date of latest edition.
[2] Public or confidential.

Reference	Title	Delivery Date[1]	Dissemination Level[2]
Description			
D1.2	Final Project Results Report	09/11/2018	Confidential *Note: GA status is "Confidential", however released as "Public"*
The Final Project Results Report (this deliverable) summarises the entire project, covering the scope and objectives, scientific work performed (with associated deliverables) and the main conclusions. It includes a self-assessment of the TRL achieved at the end of the project. The main purpose of D1.2 is as an input to the project's Close-out Meeting, assisting the discussion relating to the transition to subsequent development stages. Some of the content can also be reused for the H2020 publishable summary.			
D2.1	Supporting Data for Business and Regulatory Scenarios Report	28/02/2017	Public
This deliverable reports the work done early in the project on the review of the business and regulatory factors which could potentially be included in Vista's model for the current, 2035 and 2050 scenarios. It presents an inclusive review of potential regulations, technologies, services and operational changes which could impact the ATM system. The scoped factors are divided into two categories: regulations and business factors.			
D3.1	Business and Regulatory Scenarios Report	28/02/2017	Public
This deliverable presents work regarding the market forces to be considered in the model as well as the construction of the scenarios to be run. While D2.1 presents an exhaustive list of business and regulatory factors potentially affecting the future air transport system, this deliverable focuses on how to handle them with respect to the model. The main objective of Vista is not to find the most likely scenario for the future, but rather to test the impact of the decisions of the different actors. The project thus takes an empirical approach of 'test and assess', aiming at finding the effect of several foreground factors, on a constant background canvas composed of all the remaining (background) factors. These factors and the justification of the choices are given.			
D4.1	Define Initial Framework	22/12/2016	Public
The initial evaluation framework definition of the Vista project is presented. The framework is software code of an extended air traffic management model. The primary objective of Vista is to quantify the current and future relationships between a currently non-reconciled set of performance targets in Europe. Specifically, it examines the trade-offs between, and impacts of, regulatory and business factors and whether future alignment between these may be expected to improve or deteriorate. A preliminary selection of the business and regulatory factors, and metrics, to be modelled is presented. Various modelling approaches are considered and an appropriate method selected.			
D5.1	Initial Assessment Report	07/04/2018	Public
This deliverable presents Vista's model and its calibration. The features of each of the model layers (strategic, pre-tactical and tactical) are described in detail along with their calibration. Over 50 scenarios with four foreground factors are modelled. The results of the layers are produced independently to present the capabilities of the system. The first main batch of results obtained from the model are presented.			
D5.2	Final Assessment Report	09/11/2018	Public
This deliverable presents the final results obtained from the Vista model, together with a detailed description of the various parts of the model, the analyses performed to prepare the data, and the model calibration. In total, 67 scenarios and around 20 factors are simulated.			

Reference	Title	Delivery Date[1]	Dissemination Level[2]
Description			
D6.1	Dissemination plan and project identity	07/10/2016	Public
This document describes the dissemination plan, dissemination policy and initial dissemination products of the project, taking into account its specifications and the target audience. Project branding is presented along with a list of events and journals potentially suitable for project dissemination.			
D6.2	Stakeholder Consultation on Business and Regulatory Scenarios	27/05/2017	Public
This deliverable presents the results from the consultation with stakeholders on business and regulatory factors, scenarios and metrics. With Vista examining the effect of factors on the current and future framework, the aim of this consultation is to help identify which factors and scenarios should be prioritised and to ensure we are capturing all relevant parameters within the model.			
D6.3	Stakeholder Consultation on Initial Assessment	29/03/2018	Public
This deliverable contains the summary of consultation activities carried out by Vista to validate and obtain feedback on the first results obtained from the model. Consultation activities have been conducted in different forums (workshop/conferences) and with a dedicated consultation to targeted experts and stakeholders. D6.3 contains the main findings from these consultation activities and the next steps to finalise the development of Vista's model and the production of the final results considering the feedback obtained.			
D7.1	POPD - Requirement No. 2	30/07/2016	Confidential
This is one of the ethics deliverables and relates to the provision of informed consent procedures and the protection of personal data by the project.			
D7.2	NEC - Requirement No. 3	30/07/2016	Confidential
This is one of the ethics deliverables and relates to the involvement of non-EU countries.			
D7.3	H - Requirement No. 1	30/07/2016	Confidential
This is one of the ethics deliverables and relates to the provision of informed consent procedures when human participants are involved in the project.			
D7.4	POPD - Requirement No. 4	30/07/2016	Confidential
This is one of the ethics deliverables and relates to the data management aspects of protecting personal data by the project.			
D7.5	H - Requirement No. 5	30/07/2016	Confidential
This is one of the ethics deliverables and relates to the recruitment procedures when human participants are involved in the project.			

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

This section reports on the contribution to the ATM Master Plan, following the guidelines requested and noted here for clarity and completeness, *viz*.: "Describe the progress the project has made in increasing the level of maturity (V-level or TRL for technical enablers) of all the OI Steps and Enablers that the project has worked on. If the project did not work on OI Steps and Enablers captured in the ATM Masterplan already, please suggest new OI Steps or Enablers to be added."

Table 3. Project Maturity

Code	Name	Project contribution	Maturity at project start	Maturity at project end
N/A[3]	*System-wide, Performance-Based Analysis & Trade-offs*	*The Vista model is a 'what-if' tool designed to assess the impact of economic and technological changes on the air transportation system. This assessment is system-wide, encompassing a large geographical and operational scope. It is designed to produce high-level views of performance, simultaneously capturing several stakeholders' perspectives. In particular, it can be used to assess the balance of a change between stakeholders, and also within stakeholders of the same type. Issues such as trade-offs, equity, and system efficiency can thus be taken into account, at the same time as supporting more informed decision-making and policy development.*	*TRL0*	*TRL1*

3.2 Maturity assessment

The following table is an extract from the Maturity Assessment Tool.

[3] New OI Step / Enabler added.

Table 4. ER Fund / AO Research Maturity Assessment

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	**Achieved**	The model is able to run 'what-if' scenarios for the evolution of a range of KPIs related to all key stakeholders. Tools for the analysis of KPIs, their alignment and their trade-off have been developed. See D5.1 and D5.2.
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	**Achieved**	The model is able to quantitatively estimate the degree of alignment and trade-off of KPIs across multiple stakeholders, ATM phases and timeframes.
TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others.	**Not Applicable**	N/A
TRL-1.4	Has the concept/technology under research defined, described, analysed and reported?	**Achieved**	The concept of a holistic model for trade-off analysis has been defined in D3.1 and D4.1. It has been fully described, analysed and reported in D5.2.

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	**Achieved**	Vista is able to quantify the achievement of numerous SESAR performance ambitions (e.g., departure delay, flight time, fuel burn per flight, gate-to-gate ANS cost) in the different scenarios, and may readily evaluate new performance indicators. It makes a contribution to the system analysis required for setting strategic objectives. Vista contributes to the understanding of trade-offs between different indicators across time and stakeholders.
TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	**Achieved**	Vista provides a new capability for the analysis of the system as a whole. It uses and combines innovative techniques (agent-based models, machine learning) to make (very) long-term, scenario-based predictions and trade-offs. Vista's model has been implemented during the project and runs on medium-range machines. It can easily be expanded and reimplemented in commercial/regulatory environments.
TRL-1.7	Are physical laws and assumptions used in the innovative concept/technology defined?	**Achieved**	The assumptions used as scenarios and the associated calibrations are defined in detailed, dedicated sections of D5.2.

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.8	Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified? - Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.	**Achieved**	The strengths of the approach have been documented in D3.1 and explained more in detail in D4.1 and D5.2. The limitations of the approach have been flagged during the description of the model as strong hypotheses, and during the post-calibration and results analysis whereby some results required further investigation. Vista shows the possibility of performing long-term multi-stakeholders' KPIs trade-offs analysis with a holistic modelling of SESAR solutions.
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	**Partial - Non Blocking**	Detailed observations have been reported in D5.1 and D5.2. More observations will be disseminated as journal papers and conference presentations.
TRL-1.10	Have the research hypothesis been formulated and documented?	**Achieved**	All the research hypotheses have been compiled and discussed in D5.2 (in particular, as the formulation of model scenarios).
TRL-1.11	Is there further scientific research possible and necessary in the future?	**Achieved**	Further scientific research is possible and necessary in the future. Several hypotheses of the model should be tested more in depth, more sensitivity analyses should be performed and more data should be included in the model. These opportunities are flagged in D5.2

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.12	Are stakeholder's interested about the technology (customer, funding source, etc.)?	**Achieved**	Please see Section 2.4.4 (stakeholder consultation and feedback) and Section 4.3.2 (next steps), of D1.2, for full details.

4 Conclusion and lessons learned

4.1 Conclusions

Vista aimed at demonstrating the feasibility of building a tool able to capture high-level alignments and trade-offs in terms of key performance indicators, in particular for long-term horizons. This has been achieved through the implementation of a highly detailed model and machine-learning techniques capturing non-linear feedback and cascade effects in the system.

The model is heavily based on historical data. It is a holistic, heterogeneous model, featuring key stakeholders and measuring ECAC-wide impacts, capturing important effects while remaining a 'white box' whose results can be explored in more detail at each step, or ATM phase.

The results of the model have highlighted several interesting effects, which are summarised in Section 2.4. Among them, the impact of uncertainty, supporting forecasts that airlines will use heavier aircraft in the future, the non-linear impact of flight delay on passenger delay, the potential increment of buffers in the future are particularly noteworthy.

The model has been run on a number of scenarios built on a prioritisation of the factors listed earlier in the project. These scenarios have been used both to generate knowledge of the system and to demonstrate the capabilities of the model. In this regard, the model can be seen as a successful proof-of-concept that such approaches could be used more systematically and be included in high-level decision-making processes, both in technological contexts (SESAR in particular) and regulatory / policy-setting environments.

4.2 Technical lessons learned

The following points summarise those technical lessons learned that may be of benefit to other projects. (Numerous, more general, e.g. administrative and managerial lessons, are reported in the close-out presentation).

1. With increasing pressure on experts' time, and GDPR constraints, obtaining expert feedback to consultation exercises may be very demanding, and organising alternative procedures, such as workshops, may delay project development significantly, also to the detriment of consortium effort deficits and travel budgets (which is a particularly an issue due to the difficulty of securing project extensions). It is therefore preferable to build consultation functionality into the Advisory Board of the project, or through the projects' partners: even if giving some partners a limited role mainly for this purpose, to avoid having to request free effort from Advisory Board members, which can become problematic over multiple projects.

2. Implementing Amazon's DynamoDB to share the data between the layers of the model, and among the project partners, resulted in structural requirement incompatibilities. Project data storage and access was thus migrated to a MySQL database hosted on a virtual machine, which required significant additional effort. Furthermore, supplying secure access to the database for external partners triggered significant delays, due to additional, protracted

security procedures. The solutions to these problems will enable future research activities to be carried out more smoothly, but it is inevitable that new issues arise in a changing technological and legal/operational research framework.

3. Identifying detailed data needs at the proposal stage and incorporating the appropriate external partners to supply such data (in this case, airlines and ANSPs) was vital. Nevertheless, there remain on-going data access issues, e.g. regarding DDR data download restrictions from EUROCONTROL and to airport expansion planning data (see Deliverable D5.2).

4. Limited aspects of the proposal were not fully implemented (e.g. the outcome of the downstream layers feeding back to the previous layers to improve how some decisions are made), due in part to the ambition level of the project in the proposal, other delays incurred, and numerous additional features incorporated into the model over and above the specification of the proposal. This remains a perennial problem in a highly competitive research proposal environment and with very short project lifecycles: effectively well under two years in duration, e.g. allowing for warm-up and close-out requirements.

4.3 Recommendations for future R&D activities (next steps)

4.3.1 Future R&D activities

Vista is more than a simple model. It is an integrated set of three models: strategic, pre-tactical and tactical. Each is composed of different blocks and can be executed independently or jointly, the outcome of one layer being the potential input to another. This allows us to perform analyses not only such as those presented in detail in Deliverable D5.2, but also targeted case studies such as those described in D5.1 (where the impact of a given variable is analysed more finely by each of the layers, independently).

The modularity of the development of the model layers allows the enhancement or part replacement of the model seamlessly. Vista is capable of capturing and quantifying the relationship between complex metrics across several stakeholders, reproducing classic KPIs and estimating complex and newly defined ones (such as the cost of uncertainty, or door-to-door travel times for passengers).

This modularity allows for different parts of the model to be adapted and reused in other situations. The strategic and pre-tactical layers will, for instance, be used in current and future projects to produce synthetic data to be used by other models, such as Domino and ADAPT in SESAR ER3.

The simulations already performed in Vista have created a large database, which contains many metrics that can be analysed more in depth, e.g., regarding in detail the ATFM delay generated per ANSP for different scenarios, or variations in specific flows of passengers through Europe. This includes deeper analyses of the behaviour of the model in different situations and with different parameters, furnishing further insights into future scenarios and trade-offs.

Vista is also unique in the sense that it supports the analysis of how a given metric changes during the temporal evolution of the different ATM phases: from the expected outcomes of the stakeholders' plans defined strategically, to the planned operations pre-tactically, to the actual execution phase, tactically. As future work, the outcome of the downstream layers can be fed back to the previous layers to improve how some decisions are made. This is a typical case of reinforcement learning, which can be used to make better predictions and also to optimise the system.

Further scientific questions can be studied by modifying the model. The impact of infrastructure expansions for airports, the way airlines may compete for new routes, and new ANSP structures (including pricing schemes) are but some examples. Further internal mechanisms (new behaviours) and external factors could be added. Concerning the latter, a comprehensive list was compiled in Deliverable D3.1. Some of them would require little effort and only moderate changes to the model. Others would need more dedicated research and development, for instance concerning the impact of drones on the ATM system.

Vista has developed several subroutines for an automated analysis of the results, including statistical tests and graphical representations. Given the amount of information produced by the model, a more interactive interface would be very useful to explore the data. This is a common issue in this kind of project, where the effort is mainly focused on the development and production of results, and cannot expend effort on producing interfaces for non-experts.

Finally, as part of the validation of the model, in-depth review of the models and their assumptions will be carried out by experts via peer-reviewed publication of the models and their results. See Section 4.3.3 for more details.

4.3.2 Next steps

Note: in order to make this deliverable public, confidential content has been removed from this section.

The specific next steps (which can be reported publicly, several others having been removed) regarding potential further development and wider application of the Vista tool in research and development contexts include the following discussions, at different stages, with:

- SESAR PJ.19, facilitated by the SJU, regarding the trade-off capabilities of Vista. (The Vista team is at the disposal of the SJU to contribute to follow-up work planned for October 2018.)
- The airline and ANSP members of the Vista consortium, regarding how the model could help to assess the impacts of strategic decision-making, as flagged in Section 2.4.4.

4.3.3 Dissemination

It is also planned that the members of the consortium will submit several articles to peer-reviewed journals (e.g. Journal of Air Transport Management; Journal of Transport Economics and Policy; Transportation Research (due to the broad scope of Vista, all of the following parts could be appropriate – Part A: Policy and Practice; Part B: Methodological; Part C: Emerging Technologies; Part D: Transport and Environment)) and participate in conferences and workshops where Vista's approach and/or results are apposite (see Table 5). This will be subject to the availability of alternative funds for these activities, after the project closure. Vista may also present at selected

Engage (SESAR KTN) thematic challenge workshops, but *only* if this is deemed appropriate by the KTN consortium members and if such a presentation would be specifically aligned with the objectives of the thematic challenges and corresponding workshop(s).

Table 5. Potential events for future Vista dissemination

Event	Date	Location	Description	Comments
KDD 2018 - 24th ACM SIGKDD Conference on Knowledge Discovery and Data Mining	*19-23AUG18*	*London, UK*	*Leading conference on data mining*	
ART - Agency Research Team Machine Learning workshop	*24SEP18*	*Brussels, Belgium*	*Regular EUROCONTROL advisory body workshop*	
AGIFORS Annual Symposium - 58th Airline Group of the International Federation of Operational Research Societies Annual Symposium	*08-12OCT18*	*Tokyo, Japan*	*Airline operations research and analytics conference*	*Target event for Vista, but corresponding edition in 2019, if in Europe*
INAIR 2018 - 7th International Conference on Air Transport	*20-21NOV18*	*Hainburg an der Donau, Austria*	*Forum for industry and academia*	
SIDs - 8th SESAR Innovation Days	*04-06DEC18*	*Salzburg, Austria*	*Forum for ATM exploratory research*	*Target event for Vista*
NM User Forum - Network Manager User Forum 2019	*JAN19 (TBC)*	*Brussels, Belgium*	*ATM event aimed at the operational community*	
ART - Agency Research Team Economics in ATM workshop	*MAR/APR19 (TBC)*	*Europe (TBC)*	*Regular EUROCONTROL advisory body workshop*	
WAC 2019 - World ATM Congress	*12-14MAR19*	*Madrid, Spain*	*Forum for ATM industry*	
ATM Seminar - 13th USA/Europe Air Traffic Management (ATM) Research and Development (R&D) Seminar	*17-21JUN19*	*Vienna, Austria*	*FAA/EUROCONTROL jointly organised event, alternating with ICRAT*	*Target event for Vista*
SIGMOD/PODS - ACM SIGMOD/PODS International Conference on Management of Data	*30JUN-05JUL19*	*Amsterdam, The Netherlands*	*Leading conference on data management*	*Target event for Vista*
AAAT-PAAMS - Workshop on Agent based Applications for Air Transport	*JUN19 (TBC)*	*Europe (TBC)*	*Forum on Agents and Multi-Agent Systems for multi-disciplinary experts, academics and practitioners*	*Target event for Vista*
ATRS - 23rd Air Transport Research Society World Conference	*02-05JUL19*	*Amsterdam, The Netherlands*	*Forum for the aviation industry*	*Target event for Vista*
ICRAT - 9th International Conference on Research in Air Transportation	*JUN20 (TBC)*	*USA (TBC)*	*FAA/EUROCONTROL jointly organised event, alternating with ATM Seminar*	

5 References

5.1 Project deliverables

Please note that public deliverables are available from the project website (http://vista-eu.com/) and the University of Westminster's on-line repository of research outputs (https://westminsterresearch.westminster.ac.uk/).

[1] Vista Project, Deliverable 1.1, "Project Management Plan", Edition 01.01.00, 02 November 2016.

[2] Vista Project, Deliverable 1.2, "Final Project Results Report", Edition 01.02.00, 09 November 2018. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D1.2-Final-Project-Results-Report.pdf

[3] Vista Project, Deliverable 2.1, "Supporting Data for Business and Regulatory Scenarios Report", Edition 01.00.00, 28 February 2017. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D2.1-Supporting-Data-for-Business-and-Regulatory-Scenarios-Report.pdf

[4] Vista Project, Deliverable 3.1, "Business and Regulatory Scenarios Report", Edition 01.00.00, 28 February 2017. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D3.1-Business-and-Regulatory-Scenarios-Report.pdf

[5] Vista Project, Deliverable 4.1, "Define Initial Framework", Edition 01.00.00, 22 December 2016. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D4.1-Initial-Framework-Definition.pdf

[6] Vista Project, Deliverable 5.1, "Initial Assessment Report", Edition 01.01.00, 07 April 2018. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D5.1-Initial-Assessment-Report.pdf

[7] Vista Project, Deliverable 5.2, "Final Assessment Report", Edition 01.02.00, 09 November 2018. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D5.2-Final-Assessment-Report.pdf

[8] Vista Project, Deliverable 6.1, "Dissemination plan and project identity", Edition 01.01.00, 07 October 2016. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D6.1-Dissemination-Plan-and-Project-Identity.pdf

[9] Vista Project, Deliverable 6.2, "Stakeholder Consultation on Business and Regulatory Scenarios", Edition 01.00.00, 27 May 2017. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D6.2-Stakeholder-Consultation-on-Business-and-Regulatory-Scenarios.pdf

[10] Vista Project, Deliverable 6.3, "Stakeholder Consultation on Initial Assessment", Edition 01.00.00, 29 March 2018. https://s3.eu-central-1.amazonaws.com/innaxis-comm/VISTA/Deliverables/Vista-D6.3-Stakeholder-Consultation-on-Initial-Assessment.pdf

[11] Vista Project, Deliverable 7.1, "POPD - Requirement No. 2", Edition 01.00.00, 30 July 2016.

[12] Vista Project, Deliverable 7.2, "NEC - Requirement No. 3", Edition 01.00.00, 30 July 2016.

[13] Vista Project, Deliverable 7.3, "H - Requirement No. 1", Edition 01.00.00, 30 July 2016.

[14] Vista Project, Deliverable 7.4, "POPD - Requirement No. 4", Edition 01.00.00, 30 July 2016.

[15] Vista Project, Deliverable 7.5, "H - Requirement No. 5", Edition 01.00.00, 30 July 2016.

5.2 Project publications

[16] Vista Project, 2016. Vista – Market forces trade-offs impacting European ATM. Poster at the 6th SESAR Innovation Days, 08-10 November 2016, Delft.

[17] Gurtner, G., Delgado, L., Cook, A.J., Martín, J., Cristóbal, S. and Plets, H., 2017. Building a Holistic ATM Model for Future KPI Trade-Offs. In proceedings of the 7th SESAR Innovation Days, 28-30 November 2017, Belgrade. http://ww.sesarju.eu/sites/default/files/documents/sid/2017/SIDs_2017_paper_53.pdf

[18] Vista Project website: http://vista-eu.com/

[19] Cook, A.J., 2016. The challenge of ATM performance measurement. Presentation at Global Workshop on Aviation System Performance 2016, 21-23 July 2016, Tianjin.

[20] Cook, A.J. and Pérez, D., 2016. Assessing European mobility. Presentation at ACARE Implementation Review Group, 13 December 2016, Brussels.

[21] Gurtner, G., 2017. Vista – Market forces trade-offs impacting European ATM performance. Presentation at 1st COMPAIR Workshop, 07 March 2017, Madrid. http://www.compair-project.eu/files/madrid_workshop_02_-_vista_market_forces_trade-offs_impacting_european_atm_performance.pdf

[22] Cook, A.J. and Gurtner, G., 2017. Performance measurement in a world of targets and trade-offs. Presentation at 11th Agency Research Team Meeting, 26 April 2017, London.

[23] Delgado, L., 2017. Vista – Market forces trade-offs impacting European ATM performance. Presentation at COCTA Workshop, 27 September 2017, Frankfurt.

[24] Gurtner, G. and Cook, A.J., 2017. Understanding KPI trade-offs – key challenges of modelling architectures and data acquisition. Presentation at Data Science in Aviation 2017 Workshop, 29 September 2017, Cologne. http://datascience.aero/2017-workshop/

[25] Cook, A.J., 2017. Modelling strategic trade-offs – Insights into the SESAR Vista project. Presentation at AGIFORS 57th Annual Symposium, 02-06 October 2017, London.

[26] Gurtner, G., 2017. The Vista model: the challenges of building a holistic model across the strategic, pre-tactical and tactical phases of ATM. Presentation at Vista Consultation Workshop, 23 October 2017, Vienna. http://vista-eu.com/

[27] Delgado, L., 2017. Modelling the 2035 and 2050 timeframes: key business and regulatory factors to be considered. Presentation at Vista Consultation Workshop, 23 October 2017, Vienna. http://vista-eu.com/

[28] Cook, A.J., 2017. Indicator development: how could we improve existing indicators and which new ones do we need? Presentation at Vista Consultation Workshop, 23 October 2017, Vienna. http://vista-eu.com/

[29] Cristóbal, S., 2017. Trade-off analyses: what are the best methods and how do we satisfy stakeholder needs? Presentation at Vista Consultation Workshop, 23 October 2017, Vienna. http://vista-eu.com/

[30] Gurtner, G., Delgado, L. and Cook, A.J., 2018. Vista – Building a holistic ATM model for future KPI trade-offs. Presentation at Performance Work Forum, 07 February 2018, Brussels.

[31] Delgado, L., Gurtner, G. and Cook, A.J., 2018. Vista – Building a holistic ATM model for future KPI trade-offs. Presentation at PJ19 WP04 Progress Meeting 5, 06 March 2018, Madrid.

[32] Delgado, L., 2018. Door-to-door perspective. Tutorial session at 8th International Conference on Research in Air Transportation, 26-29 June 2018, Barcelona.

[33] Belkoura, S. and Cristóbal, S., 2018. New insights on non-linear delay causation network for passengers and flights in Europe. Presentation at 8th International Conference on Research in Air Transportation, 26-29 June 2018, Barcelona.

5.3 Other

[34] Vista Project, 2016. Grant Agreement number 699390, 31 May 2016.

[35] SESAR Joint Undertaking, 2016. Project Execution Guidelines for SESAR 2020 Exploratory Research, Edition 01.00.00, 08 February 2016.

[36] SESAR Joint Undertaking, 2012. European ATM Master Plan, Ed. 2, October 2012.

[37] SESAR Consortium, 2006. SESAR Definition Phase: Milestone Deliverable 2, Air Transport Framework – The Performance Target.

[38] EUROCONTROL, 2014. PRB Assessment Report of RP2 FAB Performance Plans, Volume 1 - Union-wide view assessment report, Oct. 2014.

[39] European Commission, 2004. Regulation (EC) No 261/2004 of the European Parliament and of the Council of 11 February 2004 establishing common rules on compensation and assistance to passengers in the event of 11 February 2004 establishing common rules on compensation and assistance to passengers in the event of denied boarding and of cancellation or long delay of flights, and repealing Regulation (EEC) No 295/91, 17 February 2004, 1-7.

[40] European Commission, 2014a. European Parliament votes on air passenger rights, Press Release IP/14/119, Brussels, 5 February 2014, 1-4.

[41] Lufthansa Group, 2014. Annual Report 2013.

[42] Ryanair, 2014. Ryanair annual report 2014.

[43] Finnair, 2014. Finnair annual report 2013.

[44] Cook, A, Tanner, G, Lawes, A, 2012. The hidden cost of airline unpunctuality. Journal of Transport Economics and Policy, 46 (2), 157-173.

[45] European Commission, 2011. Flightpath 2050 – Europe's Vision for Aviation (Report of the High Level Group on Aviation Research), ISBN 978-92-79-19724-6, DOI 10.2777/50266.

Appendix A

A.1 Acronyms and terminology

Table 6. Acronyms and terminology

Term	Definition
AMAN	Arrival Manager
ANS	Air navigation service
ANSP	Air Navigation Service Provider
APOC	Airport Operations Centre
APU	Auxiliary Power Unit
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
BADA	Base of Aircraft Data
CRCO	Central Route Charges Office
DDR	Data Demand Repository
DMAN	Departure Manager
ECAC	European Civil Aviation Conference
ER	Exploratory Research
FAA	Federal Aviation Administration
FAB	Functional Airspace Block
FMP	Flow Management Position
GDS	Global Distribution System
H2020	Horizon 2020 Research and Innovation programme
ICAO	International Civil Aviation Organization
KPA	Key performance area
KPI	Key performance indicator
KTN	Knowledge transfer network
MTOW	Maximum take-off weight

Term	Definition
NAS	National Airspace System
OD	Origin-destination
PMP	Project Management Plan
PRB	Performance Review Body
R&D	Research and Development
SES	Single European Sky
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
STATFOR	EUROCONTROL Statistics and Forecast Service
TMA	Terminal Manoeuvring Area
TRL	Technology Readiness Level
UDPP	User-Driven Prioritisation Process

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