DATASET2050

DATA DRIVEN APPROACH FOR A SEAMLESS EFFICIENT TRAVELLING IN 2050

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D5.2: ASSESMENT EXECUTION

DATASET2050

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Abstract: The current deliverable 5.2 compiles the quantitative results, insights and metrics of current and future door-to-door EU mobility.

DATASET2050

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520. Abstract and executive summary

Over recent years there has been an increasing effort to enhance **European door-to-door mobility**. Several initiatives have focused on improving the seamlessness, effectiveness and predictability of the European transport system through improving the related systems, technologies, concepts or processes. In an effort to establish a concrete methodology for assessing the system's current performance, this document describes a data-driven model centred on the current and future performance of European mobility. Included in this study, but not restricted to, is data and insight related to the Flightpath 2050 goal that states "90% of travellers within Europe [will be] able to complete their journey, door-to-door within four hours" where this journey includes at least one leg by air. In this report, the current door-to-door times and prices are quantified, dis-aggregated by passenger profile, door-to-door phase (door-kerb-gate-gate-kerb-door) and airport considered. In addition, major bottlenecks are identified that are hindering the 4-hour goal.

Under the umbrella of the European Commission's Horizon 2020 programme, the **DATASET2050** Coordination and Support Action (CSA) was conceived as a data-driven approach to European door-to-door mobility involving air transport; or an entire trip each time a journey includes at least one flight segment. DATASET2050 follows a multimodal approach covering all the phases involved in a door-to-door journey including airport access. This broader perspective leverages previous gate-to-gate studies which focused on the air transport segment. The DATASET2050 approach also puts the passenger at the centre of the system, or a "human-centred approach", as air transport should increase passenger mobility (door-to-door) not just aircraft movements (gate-to-gate). Having a passenger-centric approach ensures the sustainability of multimodal recommendations, as passengers or "beneficiaries" continue or increase their usage. DATASET2050 consistently operates with multimodal and passenger centricity in mind, and it is this shift in perspective that enables DATASET2050 to comprehensively recommend efficiency gains in overall mobility.

This advantageous approach is also applied to the data and resources used in DATASET2050. As there is an increasing number of generated **data sources**, isolated data silos will only hinder the ability to produce a holistic and multimodal view of EU door-to-door mobility. Additionally, there are technical, commercial, and legal concerns when sharing certain datasets. Considering this, DATASET2050 research has identified a wide range of datasets, covering both mobility demand (passenger profiles, requirements, transport trends etc.) and passenger supply (modes of transport, time, cost), for present and future EU mobility. These datasets will be integrated, as it enables us to produce the holistic, multimodal view mentioned above. These data sources have been summarised in an interactive web visualisation tool: http://visual.innaxis.org/dataset2050/datasources/

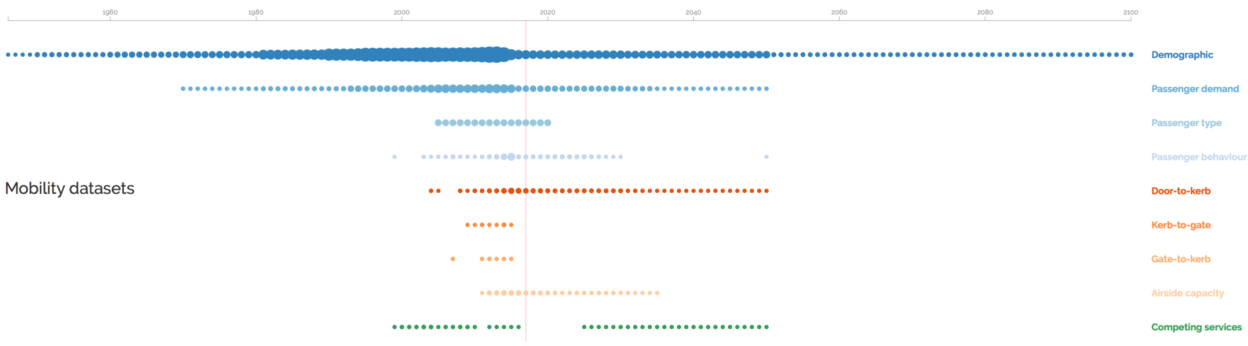


Figure 01: Current data coverage, source http://visual.innaxis.org/dataset2050/datasources/

Available datasets were analysed and it was concluded that demographics and demand data provide vast and relevant insight, both in current data and future prospects. Competing services, air-side capacity, and airport access data have slightly less available data, but still a good coverage. The main limitation is the amount of available data on airport processes, i.e. kerb-to-gate and gate-to-kerb processes. In particular, dwell times are not fully addressed, at least publicly, for most airports. Additionally, all considered studies and available data are local by nature, and therefore too focused on one particular airport, region, route or market. Another factor to consider is that the quality of data sources varies amoung datasets.

In order to move from data to actually measuring European mobility, a **complete set of mobility metrics** has been defined. These metrics have been organised into **ten mobility performance areas** and broken down into mobility performance indicators. Despite **time** being the most relevant metric, a global view of mobility has been adopted to consider other relevant aspects such as **access equity, cost-effectiveness, predictability, sustainability** and more. A framework for indicator evaluation has been defined, including explicit formulas and required input data for metric computation.

A complete door-to-door model has been created for DATASET2050, with the support of the **Mercury mobility modelling tool,** in an effort to quantify the metrics and provide the required holistic and multimodal view of current European mobility. This deliverable reviews the the methodology, results, and conclusions. Some of the most notable insights regarding door-to-door times are the following:

- **Seven and a half hours:** The estimate of current time 90% of the passengers take to cover their door-to-door trip, as estimated by the DATASET2050 mobility model. This is nearly twice the four hour door-to-door goal defined by Flightpath 2050.
- **10%:** The percentage of passengers that presently cover their door-to-door itineraries in four hours or less.
- **Six hours:** The average door-to-door time when all passengers are considered . Of that, around 40% is spent in the air and one third at the departure airport: mainly due to the buffer time passengers allow themselves - most often provoked by the **uncertainty of the processing times and a risk aversion** for the consequences of arriving at the boarding gate late.
- **One hour:** The difference, in average, of overall door-to-door times depending upon the passenger profile. While the gate-to-gate time remains similar for all passenger profiles, most of the differences occur in the ground phases; i.e. door-to-gate and gate-to-door.
- **Double:** Passengers almost double their door-to-door times with at least one flight connection with respect to those flying direct. This is partially due to the longer distances covered, but also due to the waiting time at the connecting terminal(s).

The complete time distribution can be explored using the data visualisation tool cited above.

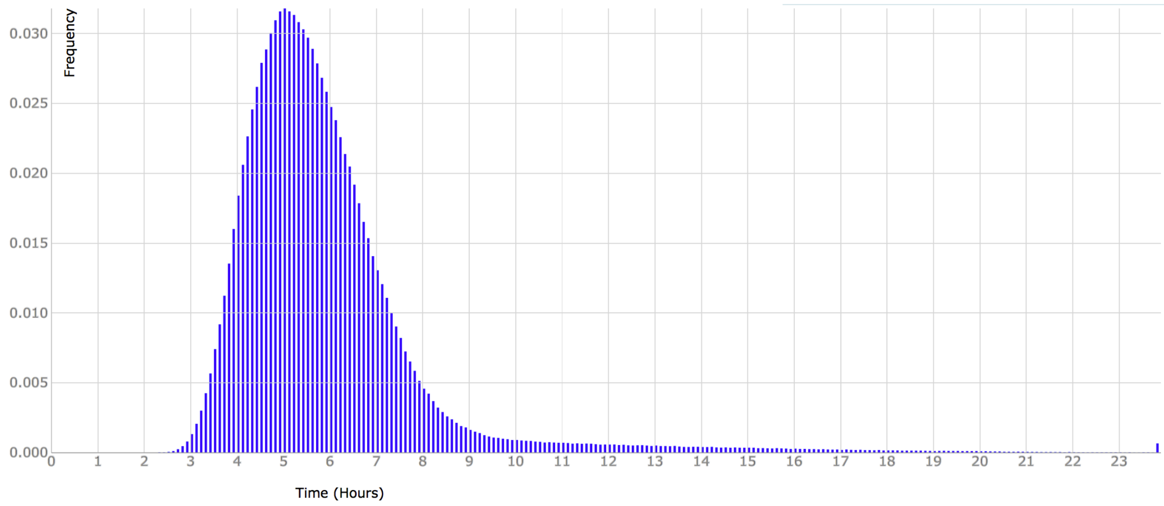


Figure 02: Distribution of DATASET2050 mobility model passenger door-to-door total time in the EU

Using a simplified Mercury (flight-based) data sample, the model also analysed a basic **price distribution** per passenger profile. The concept of reachability, both in time and price for the main 200 airports in Europe has been made available via the following URLs: http://visual.innaxis.org/dataset2050/d2d-time-map and http://visual.innaxis.org/dataset2050/d2d-price-map. These display locations that are accessible from a given origin: either spending X amount of time or using Y budget door-to-door. Both the origin, the X and the Y figures can be adjusted in these dynamic visualisations.

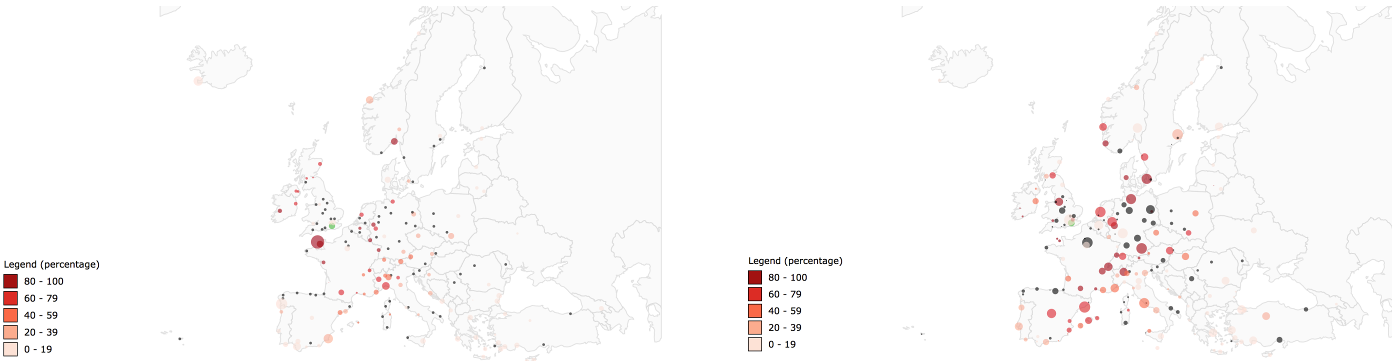


Figure 03: Reachability distribution near Gatwick Airport taking six hours or less (left) and a price of 100€ or less (right), circle colour indicates % of passengers

Lastly, three **future mobility scenarios** have been considered through a literature review of novel mobility concepts forecasted for the future, as well as leveraging the DATASET2050 mobility model. The actual level of future implementation (and real door-to-door "impact") of these novel mobility concepts cannot be accurately predicted. Hence, each of the three scenarios (named weak, intermediate and futuristic) represent the different potential impact levels. Each scenario isolates changes per door-to-door phase and estimates the overall door-to-door impact. This approach also allows for identifying and analysing bottlenecks and determining the largest door-to-door efficiency gains. Section 525 details how the scenarios were constructed and the identified impacts.

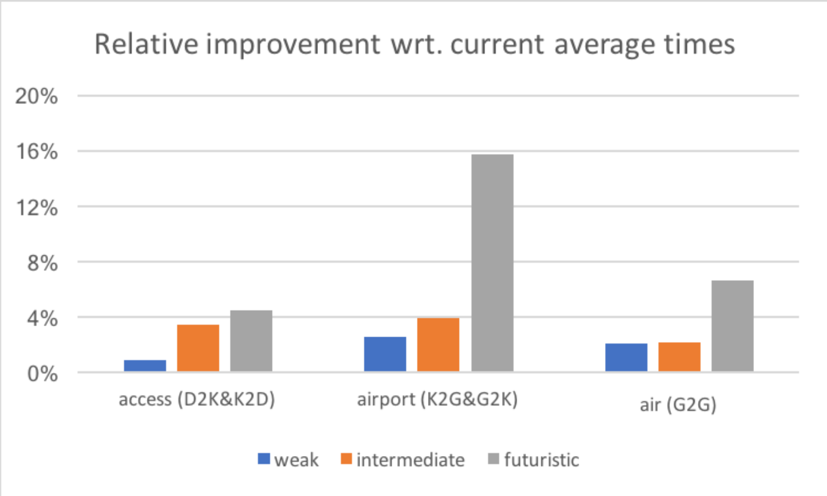


Figure 04: Relative average door-to-door time reduction in % on scenarios considered

The scenarios revealed a series of trade-offs. Notable trade-offs ones include:

- **10% reduction:** If the current hub-and-spoke network structure is abandoned, and most connections become direct, a reduction in average travel duration of **30 minutes** door-to-door would be feasible. This is equivalent to an overall 10% reduction in kerb-to-gate times.
- **1 hour reduction:** If overall dwell time was reduced by 65%, then the average door-door time would decrease by more than **1 hour.**
- **40 minute reduction:** An improvement in flights and ATM procedures during the gate-gate segment will allow a maximum reduction of **40 minutes**.
- **30 minute reduction:** A reduction in access and egress times (future scenario) brings results similar to the loss of the hub structure (a total reduction of **30 minutes** including potential access and egress improvements).

Overall, the **kerb-to-gate** part of the journey provides the largest room for improvement. The time taken for this includes the sum of all the airport processes plus the buffer time planned in advance by passengers - usually much more than expected because of the uncertainty of door-to-gate processes, and sometimes imposed by airlines and airports.

In addition to the quantitative results presented in this document, DATASET2050 has also reviewed other qualitative studies. These include an analysis of upcoming **novel transport concepts** such as autonomous multimodal transportation, ridesharing on demand, innovative chauffeur services or piloted flying urban mobility. The DATASET2050 CSA has taken a holistic approach, both researching the future evolution and characterisation of demand (passenger profiling, growth, trends) as well as assessing how future developments in the transport supply chain may impact European mobility involving air transport. Section 531 presents a description of additional material generated by DATASET2050. Finally, a blog has been maintained throughout the project in order to reach a wider audience. This contains reader-friendly posts on European mobility-related topics: www.innaxis.org/category/dataset2050.

Further research beyond DATASET2050 will continue in CAMERA, a CSA funded by the Horizon 2020 programme launched in November 2017. CAMERA includes all DATASET2050 partners and broadens the scope of addressing mobility to future concepts and their impacts on the door-to-door mobility of European passengers. More information is available at www.h2020camera.eu.

521 DATASET2050 introduction

DATASET2050, "DATA-driven Approach for Seamless Efficient Travelling in 2050" is a Coordination and Support Action (CSA) funded by the European Commission, under Horizon 2020 Call MG.1.7-2014 "Support to European Aviation Research and Innovation Policy", Grant Agreement no: 640353. It is coordinated by Innaxis, with EUROCONTROL, the University of Westminster and Bauhaus Luftfahrt as partners. DATASET2050 was launched in December 2014 for 36 Months. Key highlights are as follows:

- The objective of DATASET2050 is to provide **insights into European door-to-door** travel for current and future transport scenarios, through a data-driven methodology;
- DATASET2050 uses a **passenger-centric approach**, paving the way for seamless, efficient door-to-door travel. The main focus has been to analyse how the **European transport supply profile** (capacity, connections, business models, regulations, intermodality, processes, infrastructure) could adapt to the **evolution of the demand profile** (customers, demographics, passenger expectations, requirements);
- DATASET2050 addresses the **main transport mobility goal,** stated in the Flightpath 2050: "90% of travellers within Europe [will be] able to complete their journey, door-to-door within four hours", through statistical analyses, multi-modal mobility modelling and predictive analytics. Through this, DATASET2050 has determined the **current status** of air transport mobility across Europe;
- These analyses enable the identification of **transport bottlenecks** in the current scenario and across different future scenarios. These findings serve as a basis for the development of **intermodal transport concepts**; identifying possible solutions for current and predicted shortcomings. The insights highlight **research needs and requirements towards the four-hour door-to-door goal** formulated in Flightpath 2050. Due to the multi-dimensionality of the challenge, DATASET2050 has implemented various visualisation techniques to facilitate understanding of results.

521.1 WP5 and Deliverable 5.2 context

The aim of this section is to set and clarify the deliverables/work-packages/project context, in order to make the deliverable as self-contained as possible.

- WP2, at the beginning of the project, listed the data requirements and data acquisition (**D2.1**) and provided details on the data-driven mobility model (**D2.2**)
- WP3 was devoted to the mobility demand profile (customers, demographics, passenger profiles, etc.), with a deliverable on current status **D3.1** and one on the future scenarios/future passenger profiles, both in 2035 and 2050 (**D3.2**).
- Through a symmetric approach, WP4 tackled the current and future European transport supply side (airports, means of transport available, connection times, metrics) for passenger journeys. WP4 was also divided into **D4.1** on the current supply status and **D4.2** that considers the future supply profile (in 2035 and 2050).

The aim of WP5, is to **merge, consolidate, and document** the project outcomes at all levels, leveraging the previously completed work-packages. WP5 entails providing:

- Qualitative insight into the main project outcomes, at the different time frames. This includes defining and documenting the mobility assessment metrics / KPAs / KPIs (**D5.1**), and novel concept foundations for EU mobility (**D5.3**)
- Quantitative information and results regarding the transport processes involved in door-to-door trips, both currently and in the future scenarios. In brief, this means presenting the results of the computation/simulation of the door-to-door metrics. The relationship between the current deliverable (D5.2) with the remaining WPs/deliverables is outlined below.

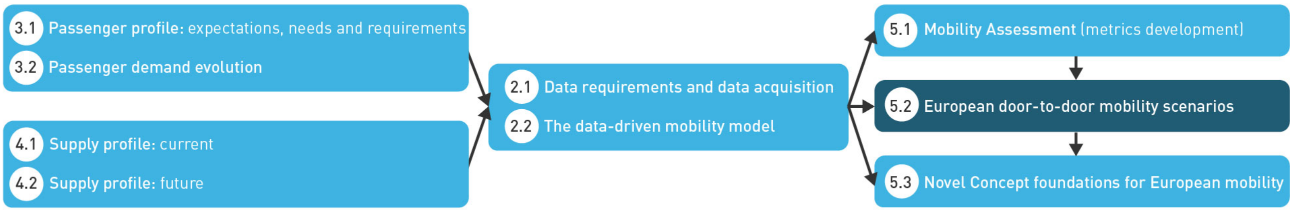


Figure 05: Relationship between DATASET2050 deliverables and D5.2

521.2 Deliverable structure and content :

Section	Title	Description
(52)0 (52)1	Abstract, executive summary and introduction	Current section, DATASET2050 context
(52)2	Modelling baseline	Model scope, data used, the journey, modelling steps
(52)3	Modelling execution	Technical details on model, algorithms and their execution
(52)4	The metrics on current mobility	Metrics and results achieved (current scenario)
(52)5	Future scenarios quantitative assessment	Metrics and results achieved (future scenarios, "what if" approach)

522 Modelling baseline

This section introduces and lists the main features, highlights, overall scope and steps of the **whole door-to-door model**. For more technical guidelines of the modelling and the underlying data-driven architecture please see the following section (5.2.3) and WP2 "Data driven architecture" deliverables, specifically D2.2 "Data-driven model".

522.1 Geographical coverage and scope.

Passenger journeys within the model are those with at least one air segment departing, arriving (and potentially also connecting) to/from/via one of the top 200 busiest EU airports (2015 data). For the context of DATASET2050, "EU" is understood to be the following 32 countries: 28 EU member states (EU-28) plus Iceland, Liechtenstein, Norway and Switzerland (EFTA). Trips involving a non-EU origin/destination/connection have been considered out of scope.

522.2 Is it a data-driven simulation?

It is important to highlight that many of the models used in the simulator were data-driven, using real information about the door-to-door phases. Most datasets (see http://visual.innaxis.org/mobilityDataSETs/) came from countries/airports/cities/countries that represent the bulk of EU mobility, with less data available for the door-kerb-door processes and/or their surface connections at secondary airports. When data were not available (for instance security queuing time at a seasonal mid-size airport), the processes were approximated using suggestions from consortium and advisory board experts: fitting different mathematical models to either archetypes, queue models or even qualitative survey data sets in order to ensure that results were as realistic as possible.

522.3 Who are the passengers?

The model includes any type of air traveller within Europe, covering all journeys for which air transport has a contribution in the door-to-door segment. This includes cases where the air segment is shorter in time or distance than the other surface transport segment (e.g. passengers requiring 2 hours to get to an airport for a 1 hour flight). Door-to-door trips with no air segment at all are not considered. Passengers transported via military aircraft, helicopters, freight flights or any other non-commercial passenger flight are also excluded.

A whole work package (WP3 "Demand profile") has been devoted to documenting and describing different passenger profiles. (Refer to D3.1 for current transport demand and D3.2 for the future forecasted demand.) The model replicates the behaviour of six of these passenger profiles. (These six profiles represent six "cluster" profiles of the more than 30 profiles initially described).

- **Family and Holiday Travellers:** "Family": This particular profile consists of larger groups of more than three people, travelling for leisure purposes and staying away for more than 7 nights, which requires them to take several pieces of luggage.
- **Best Agers:** Passengers within this category are mainly over 65 years old, thus usually retired and more flexible with regard to journey times than other groups, conducting short-stay trips with access to the airport by private car, either driving themselves or being dropped off by friends and relatives.
- **Executives:** This group of passengers travel for business purposes, which requires them to reduce journey time, leading to only hand luggage being taken and using private cars or taxi as airport access modes.
- **Exclusive Experience Travellers**: "Exclusive": This passenger group travels for private reasons and is characterised by rather frequent travellers who are interested in short-stay trips and use public transport as a means of accessing the airport.
- **Price-conscious business travellers:** "Conscious": Travellers within this group travel for business purposes but are subject to budget constraints. This influences their choice of transport mode to the airport as well as the amount spent during the journey, cost savings are often more important than time savings.

522.4 The journey phases and means of transport

The complete door-to-door model is composed of five segments:

- **Door-to-Kerb (D2K):** for which multimodal, public/private transport means are included. Potential connections (using different transport modes: bus and train etc.) are also covered. The time and distance involved in the door-to-kerb segment is sometimes longer than the gate-to-gate part; for instance passengers travelling to another city via car, coach, train, etc. to take their flights, because there are no direct flights from the airport closer to their "door". Other door-to-kerb times may only take a matter of minutes, such as passengers staying at hotels attached to the airport terminal (e.g. Sheraton Brussels, 10 metres away from the airport kerb).
- **Kerb-to-Gate (K2G):** includes all the airport departure processes: moving within the terminal(s), check-in, baggage drop-off, security, immigration, boarding and the amount of "buffer/dwell time" planned in advance by the passenger. The time it takes from kerb to gate differs significantly depending on the passenger profile (luggage etc.) and the airport geometry and services.
- **Gate-to-Gate (G2G):** from boarding to alighting (with connections included), including off-block, taxiing-out, take-off, route, landing, taxiing-in and on-block. In terms of time, all the passengers on the same aircraft share the same experience. In contrast, the price paid for tickets varies.
- **Gate-to-Kerb (G2K):** alighting, luggage reclaim, immigration and customs.
- **Kerb-to-Door (K2D):** including multimodal, public/private means of transport. These processes are similar to the kerb-to-gate processes, with some underlying differences such as the availability of some means of transport (e.g. taxi stop at airport, whereas there might not be one at the "door") and also with passenger behaviour.

The model results provide insights and metrics, per segment (e.g. gate-to-kerb etc.) and at an aggregated door-to-door level, as documented in the next sections.

522.5 Modelling steps

Step	Rationale	Further info
1	As there has to be an air segment phase, we have used the **flight segment(s)** as the model starting point. The flight segment can involve one or more flights (connections).	
2	From the flight segments, we have access to the departing/arrival airports and some basic passenger profile information (passenger itinerary data which indicates passengers' "time flexibility"), ticket cost of each passenger and the category of their tickets (flexible or not). Also, using the Mercury tool, the gate-to-gate duration of the segment is easily computed, including connections.	
3	A more **advanced passenger profile** is built in step 3. This is based on the previously extracted basic passenger profile (step 2). The two basic categories (flexible/not flexible) are then split into 6 passenger profile clusters. The proportion of passengers from each category has been determined from the conclusions of D3.1 (air transport demand statistics per country). Hence, each passenger is linked to one of the 6 categories. Each category has specific characteristics: income level, ICT usage, luggage patterns, preferred means of transport etc.	D3.1 D3.2
4	From the origin/destination of the flight segment, each passenger profile type can be cross-referenced with the different **kerb-to-gate and gate-to-kerb** processes for **origin** and **destination airport** respectively**.** This is done taking the passenger profile type into account: e.g. fast track mostly used by executive/exclusive passengers, families tend to have luggage checked in, best agers require more time to move within the terminal etc**.** This type of information (that depends both on the airport and the passenger profile) is derived for every passenger and airport (see D4.1: Section 3.1 Airport connections and Airport archetypes) for the top 20 airports. Data ranges from security processes duration or the time required to walk around airports. In the case of average values, they have then been extrapolated to distributions as a function of the nature of the process (e.g. simple random distribution for luggage arrivals) according to state-of-the-art modelling functions for these types of process. The average duration values for the same processes at airports with no *a priori* data available have been approximated through different mathematical models that take both the airport size and their seasonality component into account.	D4.1 D4.2
5	The fifth stage is parallel to the fourth stage, as it focuses on the **door-to-kerb and kerb-to-door processes** for the origin and departure airports. In this case also, the information will depend on the airport (e.g. what means of transport are available or what is the price of each transport mode) and the passenger profile type: e.g. executives will tend to prefer fast modes regardless of price while the inverse is probably true for young travellers, etc. Data available about the access/egress times and prices for the top 10 EU airports is very granular. These averages have also been transformed into distributions as a function of the nature of the process (e.g. queuing process for bus/trains) according to state-of-the-art modelling functions for these types of process, taking into account the different modes of transport frequency/waiting times. When such information about price or time was not available, it has been approximated through different mathematical models that take into account both the airport/city size and the seasonality component of that precise airport.	D4.1 D4.2
6	At this step all the door-kerb-gate-gate-kerb-door processes are known. Hence, the model is able to **replicate the full itinerary of every passenger**, paving the way for the calculation of the mobility metrics previously defined (see D5.1).	D5.1
7	The previous 6 steps are repeated for all the passengers. The full mobility metrics for an "average" day in EU (now taking all the passengers into account) are **calculated, aggregated and visualised** in the dynamic tool.	D2.1 D2.2 D5.1

523 Modelling execution

This section describes the technical, programming and computation details of the modelling execution, the algorithm pipeline and the data/results visualisation tools used.

523.1 Technical model details:

Programming language: The simulator was coded in Python 3.6 and requires several additional libraries. The simulator has been partitioned into three modules.

The first module reads and processes 20 databases using the Mercury tool to extract and pre-process all the data available for DATASET2050 (i.e. that includes the simulated flight duration of each flight and their ticket price, the granular information about the top 10 airports for door-to-gate processes). The module needs three open source libraries ('Numpy', 'Pandas', and 'random') and is run as a single-command line that executes the 260 line script to return all the pre-processed information for the simulator.

The second module of the code is a command line that executes the actual simulation/model. This 660 line long script combines the data and information available about the system (prices, schedules) with the mathematical model that experts, the consortium and advisory board have created to approximate the behaviour of passengers or the duration of the processes where there was no information available. It returns a list of passengers and flights with an extended list of metadata (time of flight, type of passenger, origin, destination, price paid, distance flown, surface transport, waiting times, final destination (door) etc.).

Finally, the last module, a 400 line script, extracts from the simulator output information about the system and process it into manageable formats that fits the style of representation desired for the information, the deliverable and visualisations (plot, bar plot, map, etc.).

Computational power: The code has been optimised with the multiprocessing Python library to run on parallel on different cores (computer or cloud). This is possible because the process of simulation, although complex for each flight/passenger trajectory, is linear, in the sense that the information is created for each trajectory independently (see later, algorithm pipeline for more details) which allows the partitioning of trajectories into several clusters and execution on each of the clusters by the simulator, before data aggregation. In our case, the simulation (second module only) of a full day lasted around 15 minutes in a Mac Book Pro (edition 2015) with 4 computational cores. However, a more powerful configuration (more cores) would further speed up the processing.

Results visualisation: In order to overcome the complexity/multi-dimensionality of the project and represent multiple variables, a dynamic / interactive representation was required to facilitate understanding. D3.js have been chosen as a tool/language to improve the quantity and quality of the information displayed. D3.js is a JavaScript library for producing dynamic, interactive data visualisations in web browsers. It makes use of the widely implemented SVG, HTML5, and CSS standards. We have created three interactive graphics/maps focusing on the topics of door-to-door time, price and time reachability taking into account the three dimensions of the system (i.e. the door-to-door segment, the profile type of the passenger and the number of connections of the flight segment). The three of them are accessible here:
(a) http://visual.innaxis.org/dataset2050/d2d-time-distribution
(b) http://visual.innaxis.org/dataset2050/d2d-time-map
(c) http://visual.innaxis.org/dataset2050/d2d-price-map

523.2 Algorithm pipeline:

1. Flight segments are considered. We define a flight segment or trajectory as an ensemble of flights taken by the same group of people. It can be a single direct trajectory, or two consecutive flights. Notice that a flight ID can appear in various trajectories as the portion of the passenger of a flight X that will take flight Y afterwards are going to be processed separately.
2. Each segment/trajectory is complemented by metadata. Metadata contain:
   a. The ID of each flight composing the trajectory;
   b. The number of passengers taking this trajectory;
   c. The number of passengers paying for flexible fares;
   d. The number of connections executed during the trajectory, i.e. the number of direct flights;
   e. The origin and destination.
3. G2G travel time is then calculated as the sum of the individual G2G of all direct flight contained in the trajectory.
   a. If the trajectory is a unique direct flight, then G2G is extracted from the Mercury database (the flight duration, take-off and landing times have been previously randomly selected from 200 iteration of Mercury in the first module of the simulator).
   b. If the trajectory is composed of multiple flights, then G2G of the first flight is extracted, then the effective Landing Time of the first flight and effective Take-Off Time of the next flight are compared. If sufficient time (superior to an airport-dependent buffer) is allowed for passengers to make the connection then G2G is completed adding the connecting time and the G2G of the next flight. Otherwise, the flight database is scanned looking for the next direct flight leaving passengers at the correct destination. If no posterior flight is encountered for that day, passengers are reallocated on the first flight of the following day. The same step is repeated if a third flight is taken within the trajectory.
4. The passengers holding flexible tickets (i.e. "flex" passenger itineraries) are then partitioned in two passenger profiles (executive and exclusive) according to a determined passenger profile distribution. The rest of the passengers are split in four categories (i.e. best agers, youngsters, families and conscious) according to D3.2 distributions.
5. Given the profile type of each passenger and the origin and destination of each segment/trajectory, door-to-gate segments are computed cross-referencing the simulated data of our passengers with their expected behaviour extracted from data or mathematical mode.
   a. Door-to-kerb segments are determined the same way going to or returning from the airport. The information about the transport ways (time and money wise) are synthesised for the top 10 airports and modelled for the remaining airports by a function of their size and seasonality behaviour. We have thus average values T(k) and M(k) that are the average time duration and price of a transport mode depending on the airport type k. (Note that each one of the top 10 airports has been considered as an individual type here). T(k) and M(k) have afterwards been transformed into distributions using a bi-variate log-normal distribution to modelling the bus/train behaviour (i.e. the bi-variate model has been proven as a better way of modelling the travel length in case of missing the first train for example) or simpler models as a truncated log-normal distribution for car trips.
   b. On the other hand, each passenger profile has been allocated with a set of preferences for the transport mode that is represented as a distribution of use: P(i,j) = probability of a passenger of profile type i uses the transport mode j. Further details and data about passenger preferences in D3.1 and D3.2.

c. Each passenger is then allocated a door-to-kerb duration randomly sampling a value from the duration distribution corresponding the selected transport mode (selected randomly according to the probability P). Also, the price of this transport mode is added to the price of the flight extracted from the in-house database of passenger itineraries.

6. Kerb-to-gate processes have been modelled the following way: each process has been allocated an average value, which might be obtained from real data, or by mathematical model. So for each kind of airport, D(k,l,j) is the average time spent on process l in airport k for the passenger profile j. These processes have been transformed into distributions using basic exponential distributions that represent the output of a queuing model at each process of the airport. The actual value spend by the passenger for this segment is then sampled randomly in the resulting distribution, and added to the total door-to-door value.

524 The metrics on current mobility

This section presents different calculated metrics for current EU door-to-door mobility, along with some of the most significant results and highlights. To facilitate understanding, the DATASET2050 project has also developed several dynamic interfaces and visualisations; links to these are provided within the text.

524.1 Trip segment time metric / distribution

One key outcome of DATASET2050 is the time calculation for the passenger door-to-door journey. The figure for current EU mobility is the following, disregarding filters for passenger profile, number of connections, etc.:

- **6 hours** is the approximate mean;
- 90th percentile (90% of passengers are able to do it in less time) of around **7 hours 40 minutes**;
- **5 hours** is the distribution peak (mode); and
- around **10% of passengers** spend less than 4 hours door-to-door;

Please note that given the stochastic nature of the simulation and datasets, all results are given with an estimated acceptable error of 5 minutes. The distribution is shown below.

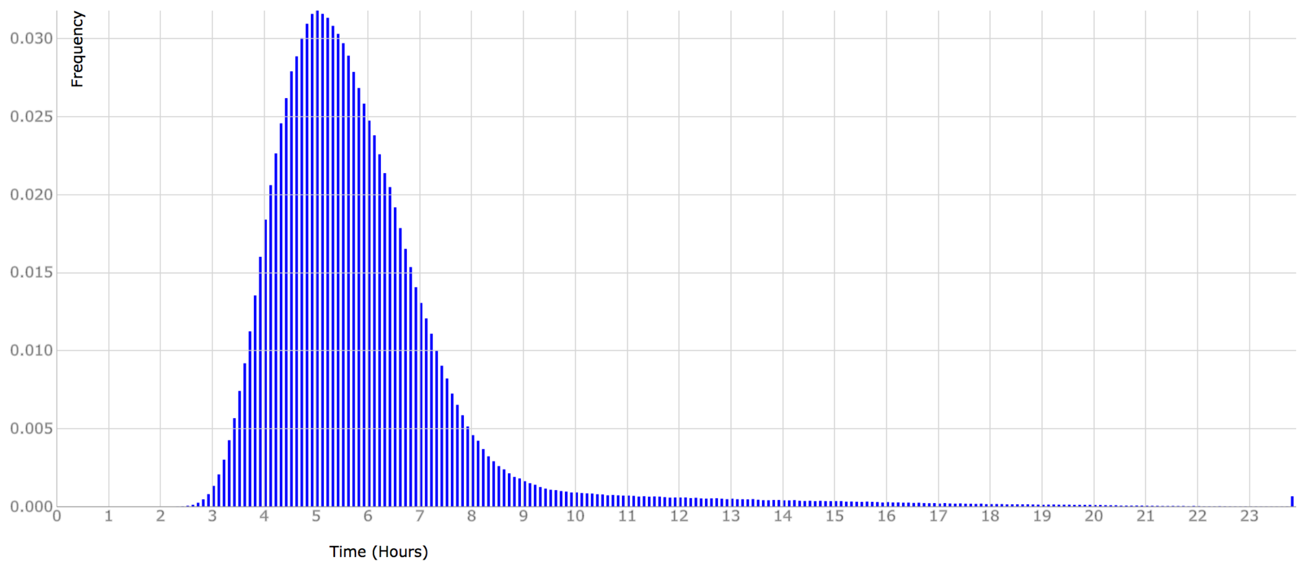


Figure 06

This graph is also available and can be easily generated by selecting "door-to-door" segment and "all category" passengers in the dynamic tool at http://visual.innaxis.org/dataset2050/d2d-time-distribution

The overall door-to-door (D2D) journey is composed of door-to-kerb (D2K), kerb-to-gate (K2G), gate-to-gate (G2G), gate-to-kerb (G2K), kerb-to-gate (K2G) and gate-to-door (G2D) sub-segments. The table below summarises the duration distribution of each segment. Please note that the information given in the table has been extracted from the interactive graphic, in order to plot the time (duration) distribution of each trip segment.

Segment	Mean time
D2K	33 minutes
K2G	1 hour 54 minutes
G2G	2 hours 30 minutes
G2K	31 minutes
K2D	28 minutes
D2D	6 hours

The table above outlining mean time per segment shows:

- Asymmetric K2G and G2K processes.
- 2 hour 30 minute average gate-to-gate duration (as already noted by the SESAR-POEM project).

This analysis unveiled some surprising results: around **35 minutes** are spent door-to-kerb, which seems to be shorter than most passengers experience, especially within big cities. At the same time, kerb-to-gate time (**almost 2 hours**) seems too long. After some consideration, these results can be explained as follows:

- All of the top 200 airports are included in the model and assessment. This includes the top 20 major airports (typically requiring up to 1 hour door-to-kerb) and a greater number of mid-size and small-size airports (10-15 minutes away from their city-centres), which significantly decrease the overall mean. The following figure shows the fraction of passengers departing from a growing number of sampled airports ranked according to passenger departures. As 25 airports are considered in the figure below, we are considering the 25 busiest airports in terms of passenger departures. It can be seen that the top 20 airports include 38% of the passengers (blue curve) and that the average D2K time measured decreases continuously as increasingly smaller airports are sampled.

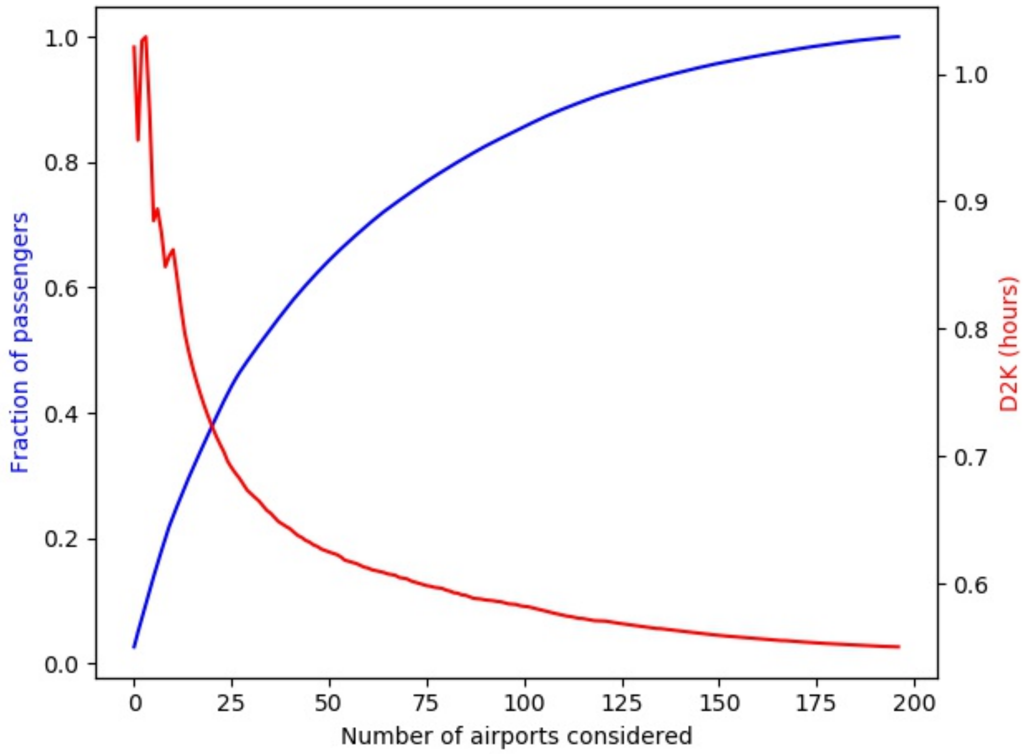


Figure 07

- The **buffer time planned for the door-to-kerb segment**, if not "used", is translated into "kerb-to-gate" time. This is a consequence of how our model was built, as the assumption is that most passengers, when planning buffer time, cover both potential traffic jams (or other variables) in D2K, as well as long queues in K2G. Hence, D2K values are actual travelling times, while K2G times include processes at the airport and waiting (buffer) times. This causes a bias both in the D2K (too low) and in the K2G (too high) in a passenger's mind. The following table differentiates between the K2G process time and the buffer time. It shows the average time for both segments (i.e. in processes within the airport and waiting because of the non-intentional buffer resulting from surface-access time and the intentional buffer at the airport planned by the passenger). The durations are then given per airport archetype (see D4.1). We can see that the buffer time actually accounts for 70 to 80% of the K2G time. Note that the proportions of the buffer time resulting from an over-estimation of the surface-access time and from being over-cautious in planning the airport process duration is hard to assess with the available data.

Archetype	Process Time	Buffer Time	Overall K2G
1	28 min	1h 47min	2h 15min
2	28 min	1h 30min	1h 58min
3	27 min	1h 29min	1h 57min
4	25 min	1h 17min	1h 43min

From the distributions in the interactive plots, one can observe that surface access and airports segments (D2K-K2D and K2G-G2K) have less variability in comparison to flight segment (G2G). This variability is mainly due the different physical distances that the flights have to travel, whereas the surface segment travel times are closer to each other, even across different airports. Indeed, flight travel times typically range from 30 minutes up to 4h, even without a connection, whereas D2K-K2D times range from 10min to 1h, and K2G (respectively G2K) times typically range from 1h (resp. 10min) to 2h30 (resp. 50min). Note, however, that for a given origin-destination pair, the variability over time, i.e. over the day, is probably higher for the surface access segments than for the G2G; in absolute terms or with respect to their mean. Indeed, the surface access travel times are quite unpredictable, whereas nowadays flights have a very good predictability record on average.

Also, it is interesting to note that some K2G processes are longer than G2G segments. This means that some passengers spend more time at the airport (i.e. to pass through security, check in their luggage and use their remaining buffer time to wander through the airport prior to the departure of their flight) than other passengers spend on the actual G2G segment.

Summarising the distribution information into partitioned boxes (one for passengers who used direct flights, and another for those who had one connection, all pairs of airports considered) shows how considerably different the D2D metrics are. There is a significant difference between a D2D time of **5 hours 30 min** for direct flights and a total of **11 hours 30 min** when one connection is taken. There are also some 2 or 3 connection flights in EU but they are not presented here because of their limited number.

The model did not implement any variations in the D2K, K2G, G2K or K2D processes for either category (i.e. the process and waiting time for the connection between two flights does not count as a segment per se, but is included within the G2G segment). Also explored was the possibility of having an additional buffer, due to passengers being overly cautious with flights that have connections because of higher prices. It was concluded that there would be little effect on the overall results if such assumption were correct. As such, there are only differences in the G2G segment, which is directly included in the total D2D duration.

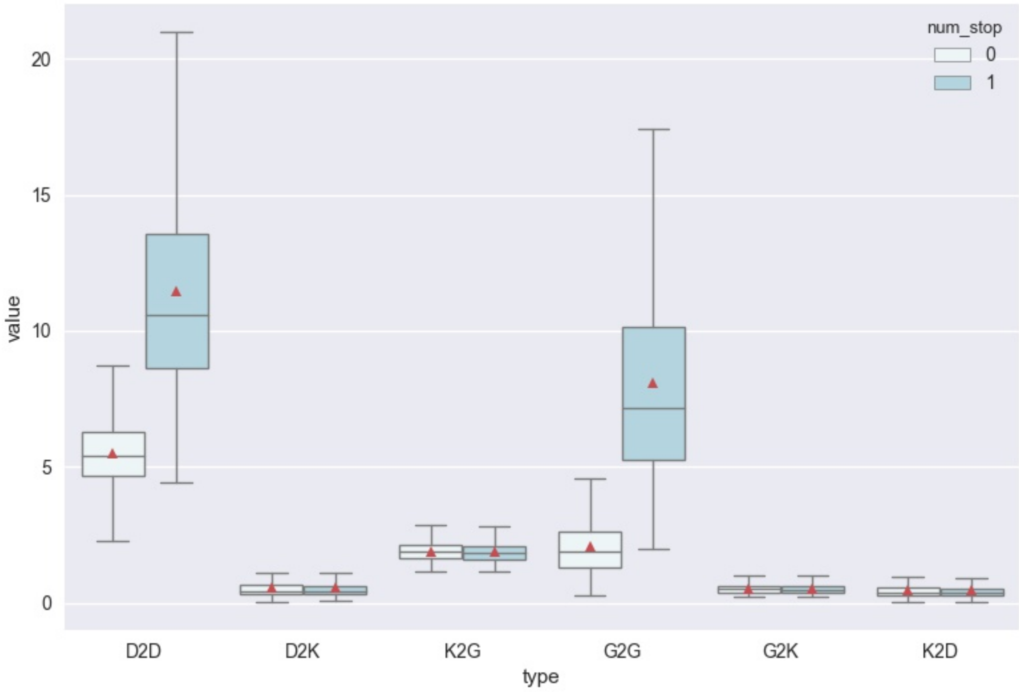
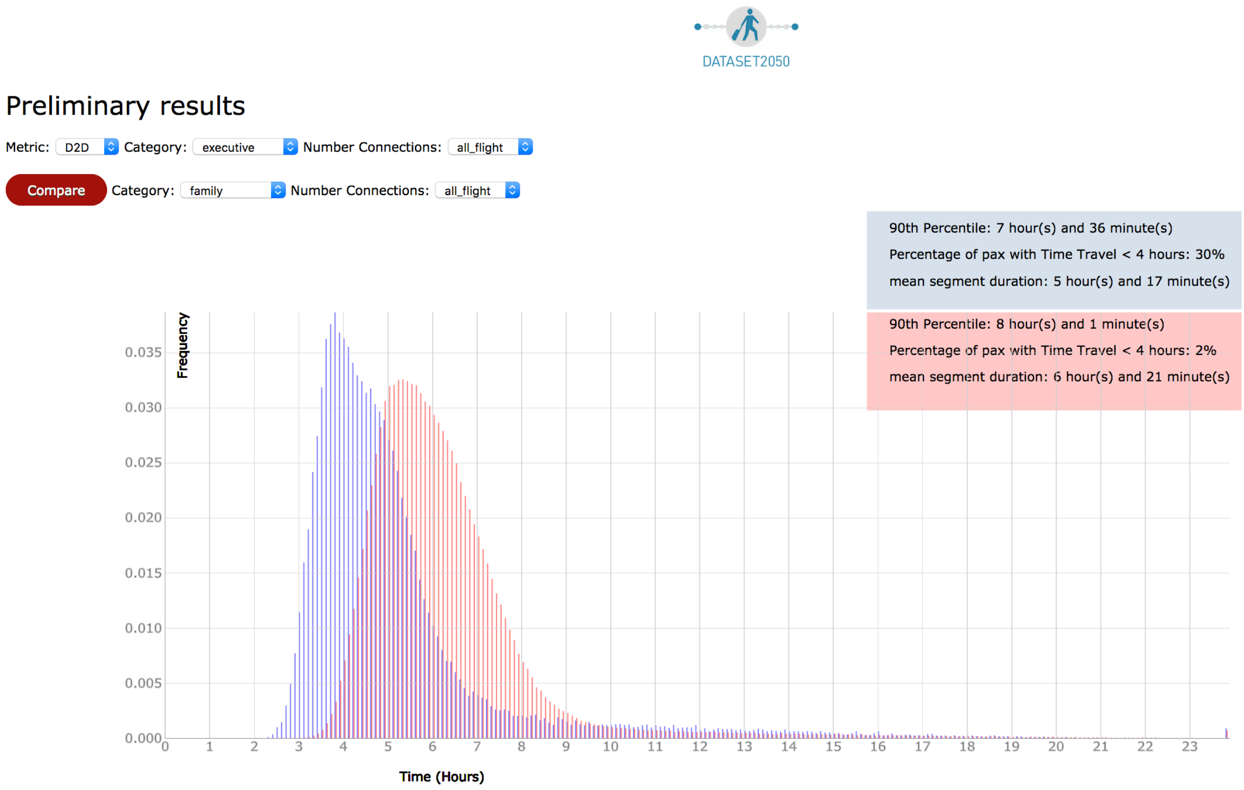


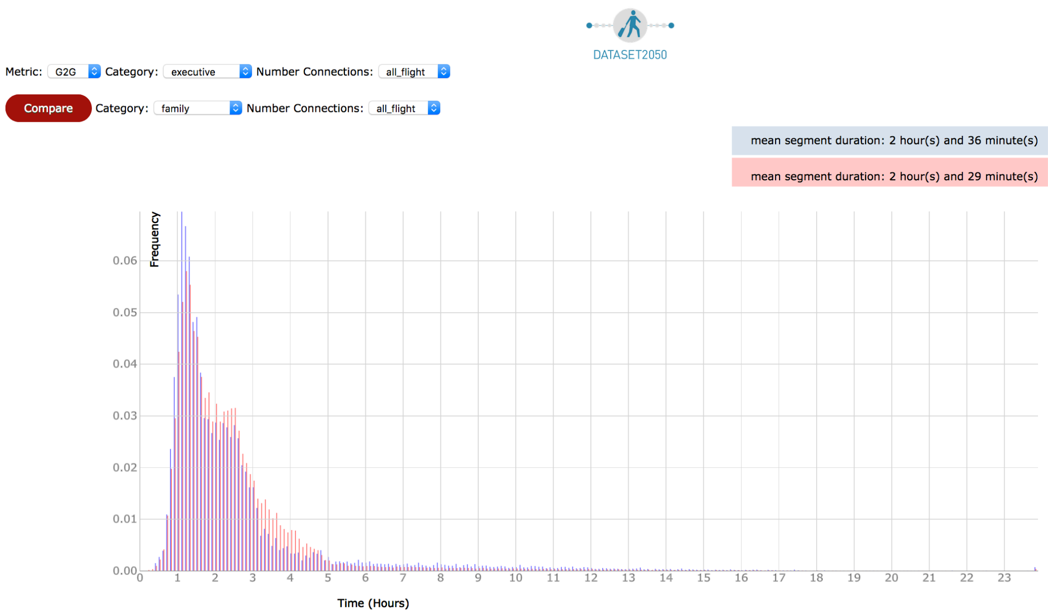
Figure 08

524.2 Advanced interactive characterisations of different travel segments per passenger profile and number of connections

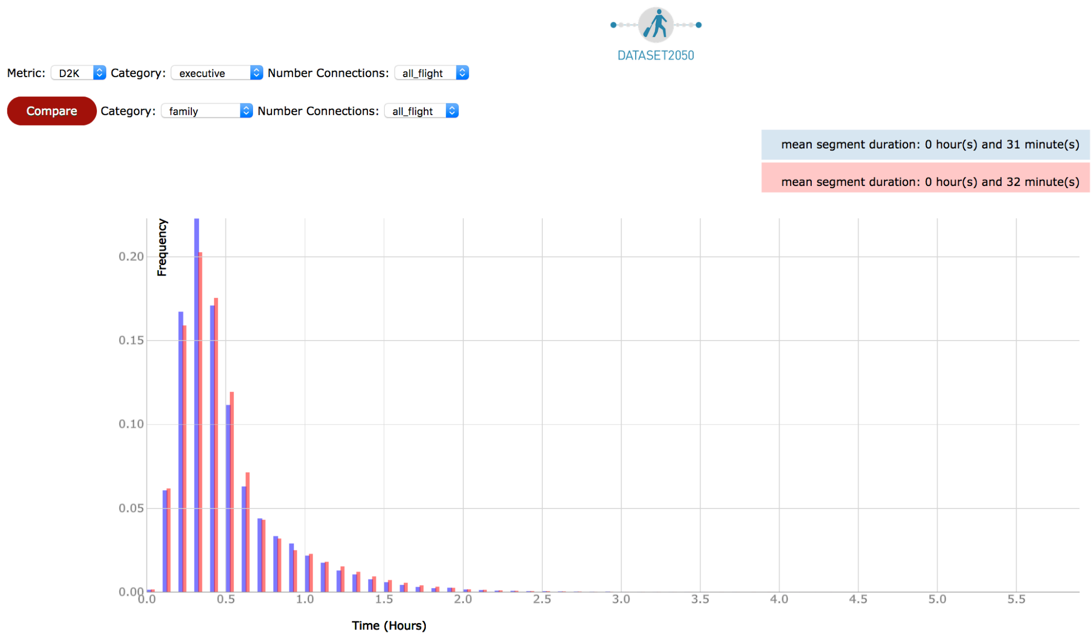
The DATASET2050 outcomes also provide a much more granular description of travel segment duration by plotting the entire distribution along three dimensions: passenger profile, door-to-door segment, and number of connections. This interactive plot also allows two distributions compared for a more in-depth analysis. The following diagrams show screenshots taken directly from the interactive tool.



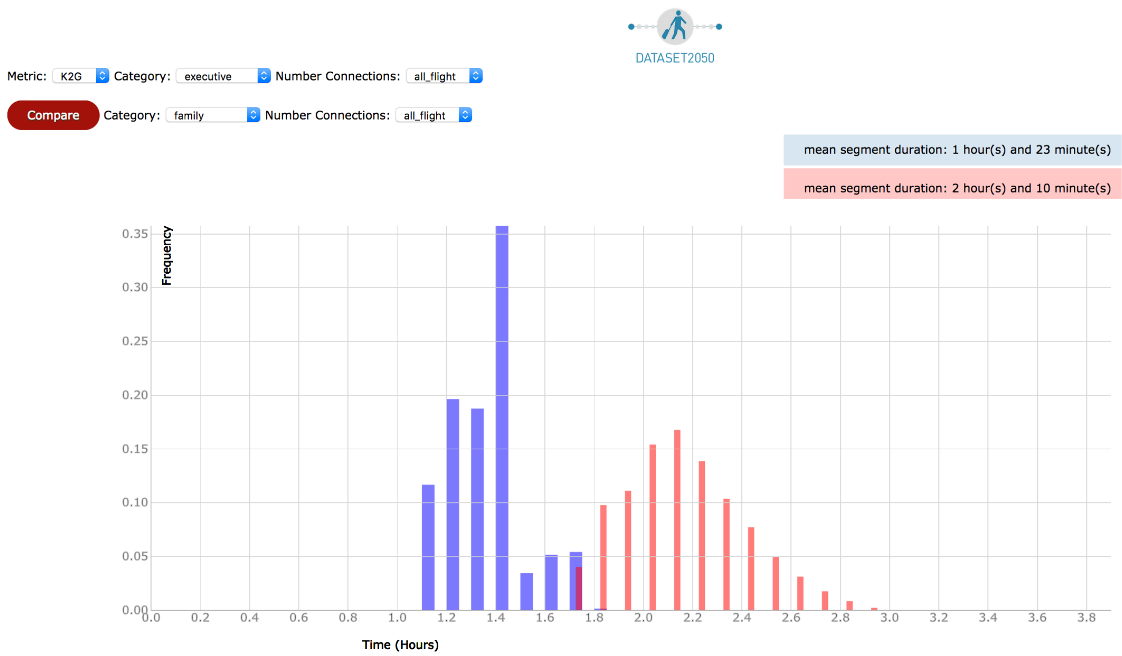
A



B



C



D

Figure 09

Figure A is a screen-shot of the distribution of D2D segments for business passengers (executive) compared to families. The purpose of this interactive plot is to present the very granular information implemented within the simulator in an intuitive manner. For example, the D2D distribution of the two categories are distinct in Figure A, while the G2G (Figure B) and D2K (Figure C) plots are similar, showing the main difference between these two type of passenger profiles occurs specifically within the K2G segment (check-in, buffer times, etc. See Figure D).

We can summarise the preliminary results for each passenger profile to assess the respective performances. Using the visualisation tool, and extracting values for the D2D segment to include the 90th percentile, the mean and percentage of passengers completing the D2D trip in less than 4 hours is as follows:

From this table, three sub-categories can be extracted:

PROFILE	MEAN	90TH PERCENTILE	% IN LESS THAN 4 HOURS
EXECUTIVE	5 hours 20 minutes	7 hours 10 minutes	30%
EXCLUSIVE	5 hours 45 minutes	8 hours 5 minutes	14%
FAMILY	6 hours 20 minutes	8 hours	2%
PRICE-CONSCIOUS	5 hours 25 minutes	7 hours	17%
BEST AGERS	6 hours	7 hours 40 minutes	4%
YOUNGSTERS	5 hours 35 minutes	7 hours 15 minutes	13%

HIGHER MEAN — LOWER MEAN

Figure 10

The "fastest" profile D2D is **executive travellers.** Almost a third (30%) of executive travellers are able to accomplish their D2D trip in less than 4 hours. This is caused by a lack of checked-in luggage, taking the fastest (and usually most expensive) D2K and K2D modes, use of fast tracks at airports, not having to coordinate with other travllers including children or elderly people, and general efficiency (potentially due to familiarity with business trips). Also, this passenger profiles is more likely to travel shorter routes (see further below).

The second sub-category groups together exclusive, price-conscious and young passengers "youngster". Around 15% of these passengers achieve a D2D trip within 4 hours, although their mean and 90th percentile are higher than for the executives. (Note: This is disregarding price-conscious passengers who compete with executive passengers in terms of mean D2D value, but for whom distribution is shifted to the right but with less of a tail - see Figure 6). Lack of luggage and efficient trips are both potential explanations for their increased performance, however the gap between this passenger profile and executive travellers is certainly exacerbated by different travel choices on the ground (taxi versus cheaper modes such as the metro).

Finally, the last sub-category groups best agers and families, who seldom manage a trip in less than 4 hours. They usually have checked-in luggage, require more time moving/walking within the terminal, are less familiar with airport processes, etc.

Visually, the performance difference between **executive travellers** (blue) and **families** (red) profiles is very noticeable as they exhibit the most divergent distributions, both in terms of mean (executives taking significantly less time) and overall shape (the standard deviation is significantly smaller for executives: "peaky" like distribution) when examining the door-to-door journey.

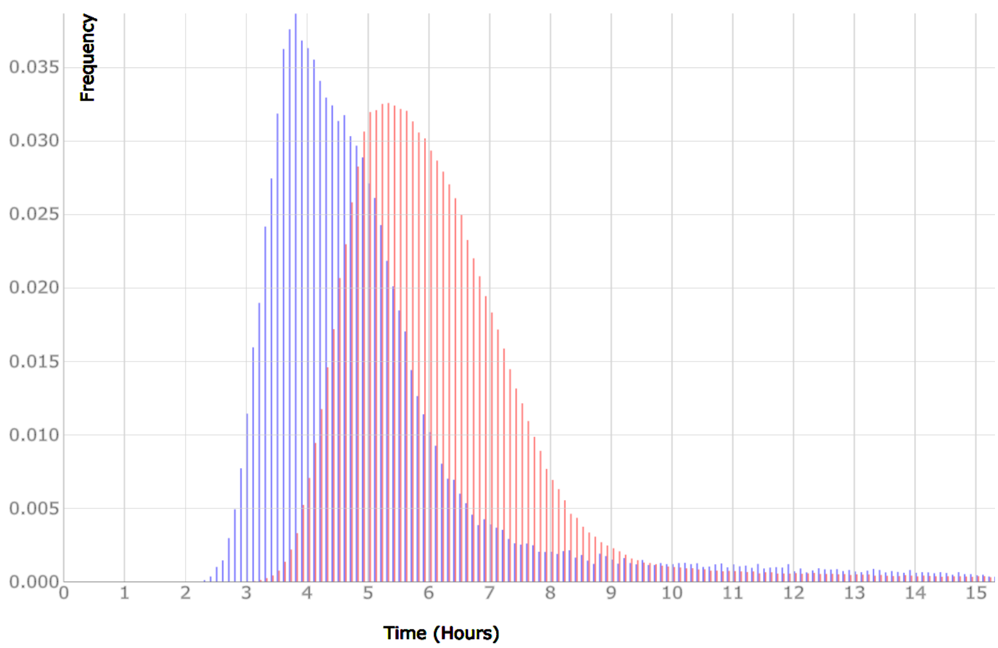
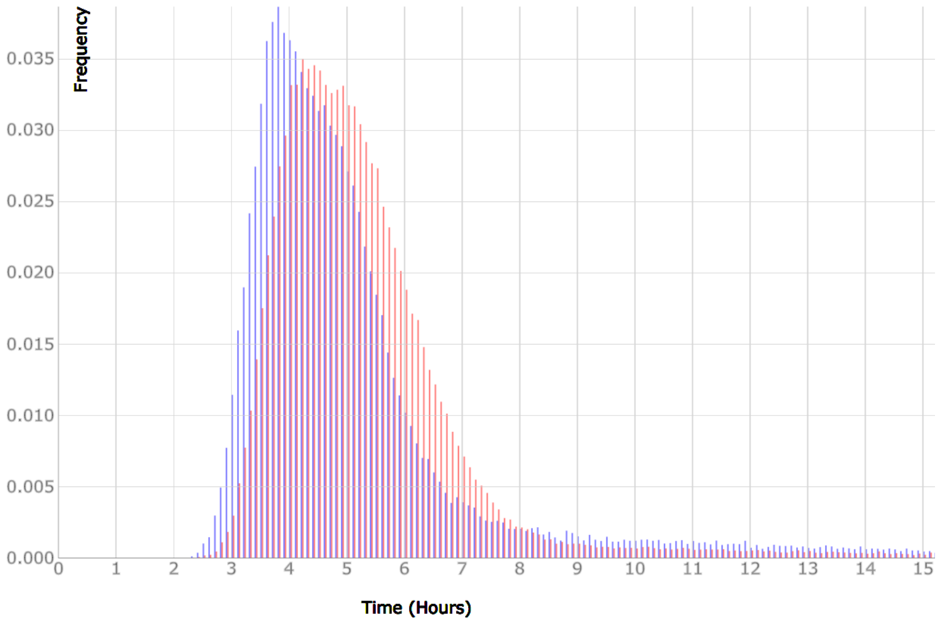


Figure 11



The distributions of the exclusive (blue) vs price-conscious (red) travellers are less divergent. As stated above, they have the same mean and a comparable 90th percentile, but this is due to their distribution shapes. It is clear how fewer price-conscious passengers are able to perform their door-to-door journey in less than 4 hours. However, it seems that they are more constant, in the sense that they have fewer outliers in their distribution.

Figure 12

524.3 Characterisation per gate -to-gate distance

Category	Distance flown on average (km)
Best agers	1214
Price conscious	1220
Exclusive	1060
Executive	1061
Family	1215
Youngster	1217

Each passenger profile has a certain travel behaviour (D3.1, D3.2). Using the Mercury model allows passengers to be characterised in terms of the distance flown in the G2G segment. The results show that the different profiles differ not only due to D2K-K2G and G2K-K2D behaviour models, but also G2G. The results show that executive and exclusive passengers are the travellers using air transport for shorter distances (smaller average), while other profiles travel greater average distances. There are two potential explanations for this:

- Some profiles (non-executive, non-exclusive passengers) use **non-aviation means of transport** for short distances. Those passengers, out of scope of the model, bias the aviation door-to-door results.
- There is an **heterogeneous distribution** of airport-pairs depending on the passenger profiles. E.g. executives mostly fly certain central EU routes such as London-Frankfurt, whereas families

usually fly to more distant places for their holidays such as northern Europe to southern Europe trips and *vice versa*.

524.4 Characterisation per price (one-way door-to-door trips)

The model outcomes allow the system to be characterised on price. This has been a challenging task, considering the following constraints:

- The G2G price information is based on passenger "groups". Mercury (airline-based) data is not available individually per passenger and only at an aggregated level.
- The information is the price at the time of booking the ticket. This does not include potential upgrades (extra/heavy luggage, fast track, business class, early check-in, seat selection).
- There is a total lack of information regarding other costs typically associated to "travelling" that are not recorded in our model: food, drink, wifi access, inflight entertainment & products, airport VIP services, snacks, newspapers, luggage protection, souvenirs/airport shops, etc.
- Cost of some surface transport modes (prices of buses, coaches, trains etc.) were simply estimated using archetypes for the airports where unstructured data was found (typically small airports).

Given the above-mentioned constraints, the differences shown here are only significant between executive and exclusive compared to the other profiles. It is probable that additional differences really exists between best agers, price conscious, youngsters and families.

All in all, the data points to a mean price of **€140 for a one way door-to-door journey**. The passengers that pay more are, as expected, the **exclusive/executive passengers (€184).** On the other hand, **youngsters** are the cheapest travellers spending **€130** on average for their one-way D2D journeys. The cost of transport to the city centre has been modelled according to each passenger profile; youngsters preferring slow but cheap transport modes end up paying a lower price overall. However, as previously mentioned, the difference is mitigated with the magnitude of prices for transport modes being much lower than for flights per se. A future study of passenger price tags may facilitate identifying each price per category, therefore delimiting each category's price behaviour more clearly.

Passenger profile	Mean price paid (D2D) one way
Best agers	€138
Price conscious	€139
Exclusive	€184
Executive	€183
Family	€139
Youngster	€131
Mean	€140

524.5 Basic characterisation (time) of the Top 10 airports:

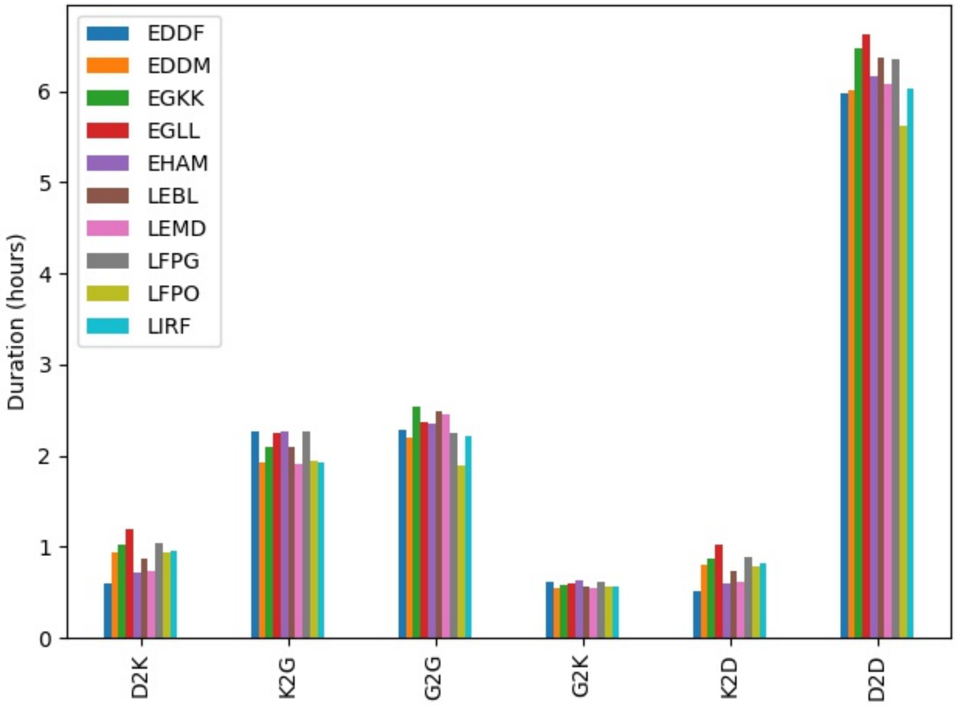


Figure 13

In this subsection we show the durations of the different segments for **the top 10 EU airports** (the segments for which granular information was available to better fit the model). To better observe the differences between them, each segment duration was plotted in log-scale in the first figure.

Surface access to the airport is the principal source of variation between the top 10 airports (and also the egress time, K2D, that has been implemented within the model as 85% of the access time, based on the assumption that passengers are more likely to use opportunistic public transport options and connections (e.g. the first train or bus that turns up) rather than making conservative (lower-risk) choices (e.g. with longer connection times) for the access journey.

Furthermore, we may expect some bias in that access trips are more likely, on average, to take place during peak traffic conditions, than egress trips following the return journey or at the destination airport. More research needs to be carried out as quantitative data are not available.

While the mean K2G segment across all airports is approximately 30 minutes, it appears that this duration expands greatly for large airports, where passengers spend almost as much time in the airport (great uncertainty of traffic leading to large buffers, etc.) than actually flying. The log-scale is better suited to see where the variation occurs between airports, but is less intuitive when it comes to the actual quantitative values. To complement this information, the table below provides a summary of the actual duration of each segment for all top 10 airports. Note that: (a) the D2K and K2G segments have been measured as an average for all passengers departing from the selected airport; (b) G2K and K2D have been measured over all passengers arriving at the selected airport; and finally (c) G2G values have been computed over all passengers, whether departing or arriving at the airport.

Airport	D2K	K2G	G2G	G2K	K2D	D2D
EDDF (Frankfurt)	0H36	2H15	2H17	0H37	0H30	5H58
EDDM (Munich)	0H56	1H55	2H11	0H33	0H48	6H00
EGKK (London Gatwick)	1H00	2H05	2H31	0H34	0H52	6H28
EGLL (London Heathrow)	1H10	2H15	2H21	0H36	1H00	6H37
EHAM (Amsterdam)	0H40	2H15	2H21	0H37	0H36	6H10
LEBL (Barcelona)	0H50	2H05	2H29	0H33	0H44	6H21
LEMD (Madrid)	0H45	1H54	2H27	0H32	0H37	6H04
LFPG (Paris CDG)	1H00	2H15	2H15	0H37	0H53	6H21
LFPO (Paris Orly)	0H55	1H56	1H53	0H33	0H47	5H37
LIRF (Rome)	0H57	1H55	2H12	0H32	0H49	6H02

We can see that by summing the segment process averages (D2K + K2G + G2G + G2K + K2D) results in an overestimation of the actual D2D time from 3% (LEMD - Madrid) up to 12% (EGLL- Heathrow). However, this is perfectly normal as the averages are computed over different passenger samples. D2K and K2G only consider passengers flying from a selected airport. Conversely, K2D and D2D only consider passengers arriving at a selected airport. Finally G2G and D2D covers both arriving and departing passengers. In fact, by computing (D2K + K2G + G2G + G2K + K2D) and comparing it to the actual D2D of airports, we can easily assess how much travel from airports have strayed from the norm, and for example, leaving Heathrow is a clear outlier.

The same approach can be made looking at the prices for passengers coming from/going to these airports. The following figure confirms that executive and exclusive prices are somewhat separated from those of the other profile passengers; it also highlights that this separation is modulated by the origin/destination airport. For instance, the price for all categories seems to be almost identical in Madrid, while there is an almost two-to-one ratio between executive/exclusive and the other categories at Heathrow and Charles de Gaulle. The magnitude of the differences in both these airports suggests that they are due to the ticket prices and not to the transportation modes to the city, while the differences in Madrid might be only due to transportation modes.

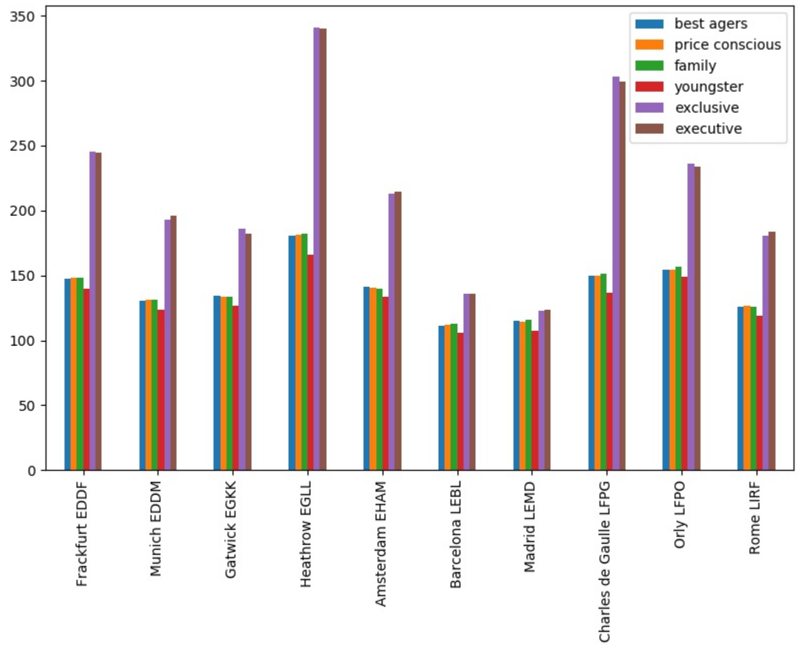


Figure 14

524.6 Advanced interactive map of reachability in Europe:

Two interactive maps have been added to illustrate some reachability metrics for the European air transport system. They are available at the following addresses:

- (a) http://visual.innaxis.org/dataset2050/d2d-time-map plots the percentage of passengers that reach a destination (given a selected origin) in less than a chosen duration;
- (b) http://visual.innaxis.org/dataset2050/d2d-price-map shows the percentage of passengers that paid less than a chosen amount of money for their travel given a selected origin airport.

It is interesting to note that in the first graph, the size of the airport is proportional to the average K2D segment duration (and to the average D2K duration for the selected origin airport), while in the second graph all airports are proportional to the number of passengers they handle.

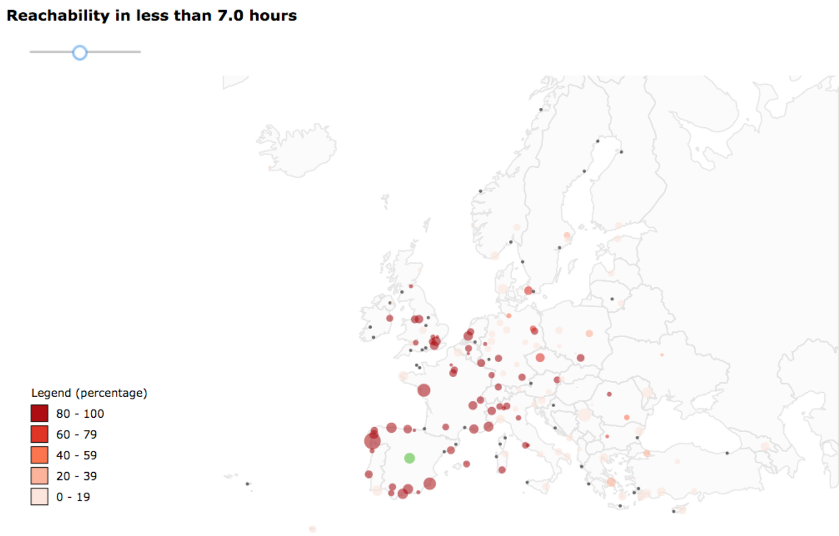


Figure 15Ñ Reachability from Madrid (time)

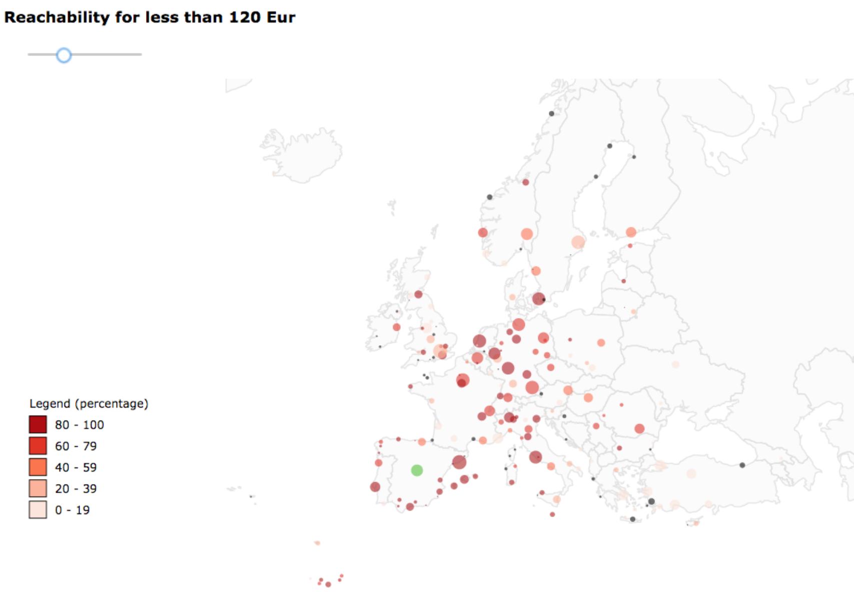


Figure 16Ñ Reachability from Madrid (price)

525 Quantitative assessment of future scenarios

Future EU transport scenarios (2035 and 2050) are described in three different deliverables:

- D3.2: Mobility **demand**: future passenger profiles, future passenger requirements, characteristics, expectations, etc.
- D4.2: Mobility **supply**: future market forces, future technologies, future air traffic forecasts, etc.
- D5.3: Novel, unconventional **future concepts**: urban flying, autonomous mobility, shared-intermodal mobility etc.

This section outlines the differences between the basic current mobility metric (time) and the equivalent D2D metric in future scenarios (2035/2050/other). The differences are calculated by **evaluating different levels of implementation** of the expected changes/enhancements/novelties in the door-to-door mobility segments. This quantitative evaluation is applied in the context of future mobility demand requirements and in the frame of future concepts/supply, available following the outcomes of D3.2, D4.2 and D5.3.

It is impossible to precisely predict the implementation level in the future for every mobility novel concept. Hence, the insights are provided by means of "what if X level of implementation is achieved" scenarios, per door-to-door segment. What would happen in the future to the overall door-to-door mobility **if only that element** is changed/improved? This allows easy analysis of the individual impact on different door-to-door segments, avoiding cross-impacts which would be difficult to assess.

This section has been split into the familiar door-to-door sub-segments used by the DATASET2050 project: door-kerb-gate-gate-kerb-door. For mid-term scenarios (2030s) this is expected to be still valid. However, longer term scenarios (2050s) will perhaps incorporate radically-new mobility approaches (e.g. flying personal vehicles directly to airport aprons, avoiding the kerb-to-gate processes). This means that the assessment tool is likely to be less applicable to very long term scenarios. On the other hand, the results are potentially applicable to future timeframes in addition to the two considered: any future time in which the same implementation level is achieved by that date: 2020s, 2030s or 2040s.

All in all, the following are the **initial European insights** incorporating quantitative **future EU door-to-door metrics**. More specifically, we estimate which indicators would be accomplished if mobility changes are applied in X level of implementation, describing different scenarios. We also compare this to the Flightpath 2050 goal.

Note: all the tables display data corresponding to the **90th percentiles** (i.e. not medians or averages). This eases the comparison with the Flightpath 2050 objective of 90% of passengers achieving the 4-hour door-to-door target, included in the last section.

525.1 Door-to-kerb

Changes are expected by 2035 in the field of fully autonomous driving, car-sharing on demand, surface access improvements etc. It is also expected to have improvements in coordination/links between different transport modes (e.g. long distance trains and airports) that would decrease door-to-kerb times. In contrast, increased environmental restrictions, increased urbanisation, an ageing population and population growth will hinder door-to-kerb metrics. Please refer to D4.2 for more details on the specific impact of every expected change in the future.

For 2050, more disruptive concepts such as autonomous flying, personal aerial vehicles, etc. are expected. This would mean that current door-kerb-gate segments are no longer valid, so it would no longer be feasible to measure them using the current mobility model. Three future scenarios are considered:

- (a) weak implementation (5% reduced D2K or K2D times);
- (b) likely-intermediate scenario (25% reduction D2K or K2D);
- and (c) strong supporting changes (50% D2K or K2D).

525.2 Kerb-to-gate

It is very likely that K2G processes will be negatively impacted by the ageing population or families. However, improvements in self (and/or remote) check-in, self (and/or remote) bag-drop and self boarding, token-based identification (where a passenger is uniquely identified once, e.g. using a biometric identifier, and does not need to be identified again), digital wayfinding (e.g. with mobile tracking/proximity sensing), geofencing, and smart (single) ticketing are expected by 2035. Please refer to D4.2 for more details on the specific impact of such expected changes in the future, including (anonymised) facial/biometric recognition and robot/virtual assistants and other wider contexts. The effect should nevertheless be limited since the process time, shown in D.5.2.4, only counts for 20-30% of the global kerb-to-gate segment. The margin for reducing this segment duration is therefore more centred on passengers' actual conservative behaviour. A more opportunistic behaviour from passengers driven by more confidence in public transport or a less biased prediction of access time and process time would significantly decrease the buffer time (i.e. time actually spent waiting at the airport). Such scenario goes hand-in-hand with the improvement of access time variability; as reliable communication between the airport and the centre will decrease the part of the buffer resulting from access time over-prediction. At the same time, more confidence in the smooth airport processes can help passengers be less cautious and plan less buffer time at the airport.

In 2050, radically smoother and faster kerb-to-gate processes are expected. Here we differentiate between the K2G buffer time (walking, shopping, waiting, etc.) and the K2G process time (check-in, security, etc.) as their compressibility is dependent on different improvements. Three future scenarios are considered:

- (a) weak change implementation (10% reduced K2G buffer times and 5% reduction of process times);
- (b) intermediate change implementation (25% reduced K2G times and 10% reduction of process times);
- and (c) strong changes (optimistic / highly futuristic) (75% reduced K2G times and 15% reduction in process times).

525.3 Gate-to-gate

In parallel to future forecasted traffic based on mobility demand (see D3.2), there are several novelties coming from the supply side: gate-to-gate changes expected in the future include an efficient Single European Sky implementation and increased ATC efficiency (4D trajectories, TBO, free routing, SESAR Operational Packages 01, 04, 05, ENB02) enhanced connection times at airports (for connecting passengers), more efficient runway and approximate procedures. On the other hand, it is expected increased environmental awareness (such as airport noise and physical pollution), and potential solutions not fully developed and/or not efficient enough (electric air mobility currently vs. current fuel-based technologies). Additionally there is a major constraint: the incompressibility of the cruise speed due to the proximity of current aircraft to the speed of sound (Mach 0.9) and the major inefficiencies and environmental impact of transonic and supersonic flights.

As all the different passenger profiles fly in the same aircraft, no differences per profile are expected. The three implementation scenarios considered are:

- (a) Weak novelties implementation (5% reduced G2G times);
- (b) Intermediate scenario (10% reduction G2G);
- and (c) Very optimistic / futuristic (25% G2G).

525.4 Gate-to-kerb

Again, the primary negative effect on future G2K times is the ageing population. Several improvements (similar to the K2G situation) are expected, including token-based identification and improved / remote baggage delivery. Please refer to D4.2 for more details on the specific impacts of expected future changes. In 2050, radically smoother and quicker gate-to-kerb processes are expected. Three future scenarios are considered:

- (a) weak change implementation (10% reduced G2K times);
- (b) intermediate change implementation (25% reduced G2K times);
- and (c) strong changes/ (optimistic / highly futuristic) (75% reduced G2K times).

525.5 Outcomes and results

The results are shown in the following figures.

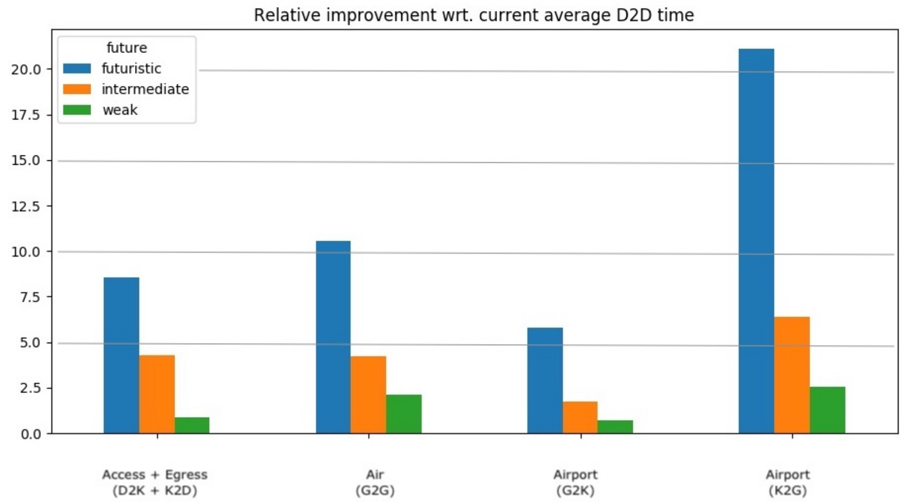
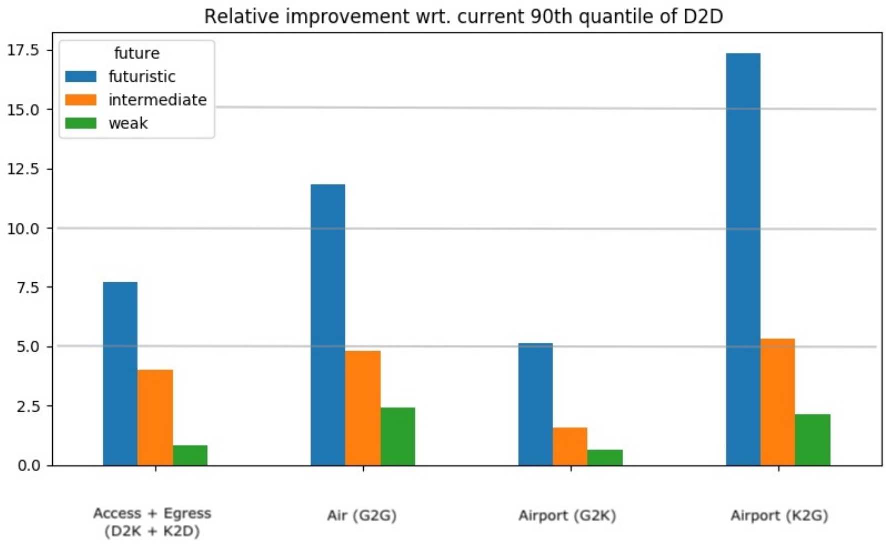


Figure 17



As displayed, the greatest scope for improving the door-to-door time is associated with the **kerb-to-gate** segment. The passenger 'dwell' times are substantially driven by additional buffer due to passenger loss aversion regarding missing a flight, and the significant associated (rebooking) cost penalties. These are also related to access times and buffers therein (earlier-than-planned arrivals turn into additional dwell time). Such effects may be impacted in future by regulatory change (e.g. with regard to rebooking fees and airline capacities) and/or better integrated surface access (e.g. with flight connection insurance/guarantees).

525.6 System with no connections

How would the system behave (time-wise) if all flights were direct? To implement such condition a first proxy would be to only consider the direct flights present within the system and conclude that the passenger's overall D2D duration will decrease from an average of 6 hours to an average of 5 hours and 30 minutes (this was extracted from the interactive visualisation selecting all flights' D2D distribution, then only direct flights).

However, a flight with connections might also involve flying a larger distance. As such, there would be a bias from using the first proxy.

Because of the dependency of the time flown, aircraft type, and distance flown, we propose the following:

- (1) take the origin-destination airports (with indirect connection only, e.g. BHX-BEG), noting their total passenger volumes and great circle distance (GCD);
- (2) find the the closest existing match for passenger volumes and GCD with a direct flight (given a threshold difference of 20 km and 20 passengers);
- (3) apply an average (if more than one flight has been found.

Ultimately we conclude with a slightly higher average D2D duration than that obtained with the first proxy: an average of 5 hours and 30 minutes**. A reduction in the average travel duration of 30 minutes would be feasible if all connections where direct**.

This result must be compared with the previous. A reduction of 30 minutes through losing the hub structure of the system has to be compared with the other possible improvements:

- (a) It allows a better improvement than most of the weak or intermediate future scenarios (e.g. 10% reduction in K2G times);

- (b) However, a 75% reduction in buffer times (equivalent to a 64% reduction in the overall dwell time K2G) reduces the average door-to-door time of more than 1 hour. Also, a reduction in the access and egress times (D2K/futuristic) segment brings similar results as the loss of the hub structure (reduction of 30 minutes). Finally, an acceleration of the flights during the gate-to-gate segment of only 25% will allow a reduction of 40 minutes.

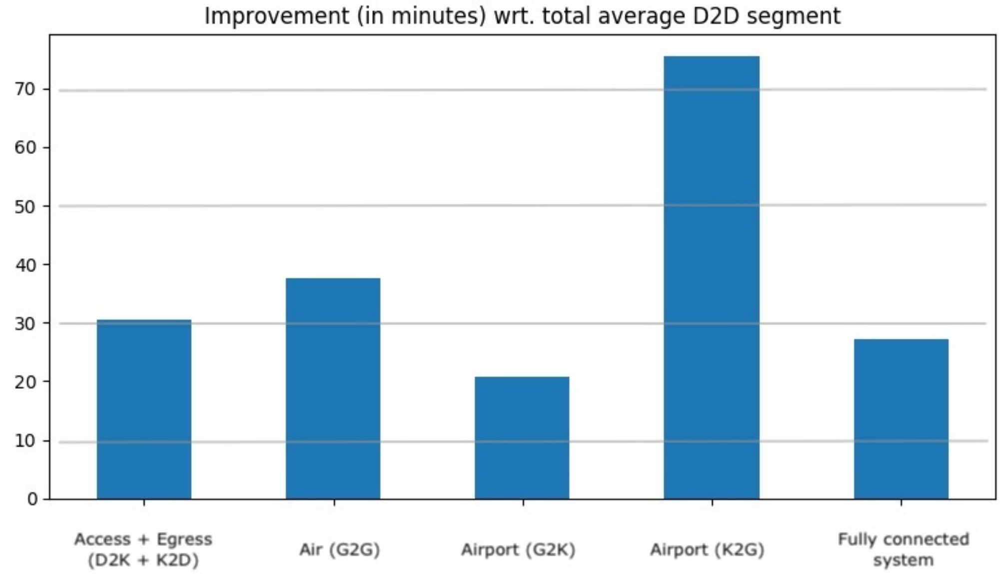


Figure 18

This brings new additional research questions worth considering: Which strategy is most affordable? Should we envisage a trade-off between them? In that case, what would the considered metrics and perspectives? Unfortunately, these questions fall outside the scope of DATASET2050. The answers may be addressed in the successor, CAMERA, officially launched in November 2017.