D5.1

MOBILITY ASSESSMENT

DATASET2050

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DATASET2050

DATA DRIVEN APPROACH FOR A SEAMLESS EFFICIENT TRAVELLING IN 2050

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Abstract:

This document provides documentation on the mobility assessment metrics and methods for use within DATASET2050. On the one hand it describes what the key performance areas, attributes, indicators and metrics such as seamlessness, cost, duration, punctuality, comfort, resilience, etc. incorporated into the model are. On the other, it gives details about mobility metric computation, modelling methodology, visualisations used etc.

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1. Introduction

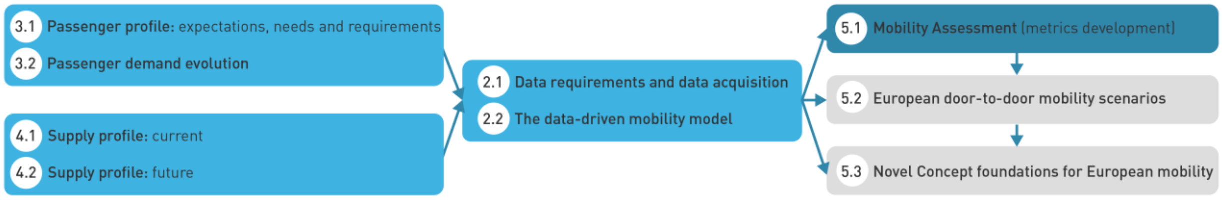
1.1 DATASET2050 introduction

DATASET2050, "DATA-driven Approach for Seamless Efficient Travelling in 2050" is a Coordination and Support Action (CSA) funded by the European Commission, under H2020 Call MG.1.7-2014 "Support to European Aviation Research and Innovation Policy", Grant Agreement no: 640353. The Coordination and Support Action is coordinated by Innaxis, with EUROCONTROL, the University of Westminster and Bauhaus Luftfahrt as partners. DATASET2050 was launched in December 2014, for 36 months. The key highlights of DATASET2050 are the following:

- The objective of DATASET2050 is to provide insights into European door-to-door travel for the current, 2035 and 2050 transport scenarios, through a data-driven methodology.
- DATASET2050 puts the passenger at the centre, paving the way for seamless, efficient door-to-door travel. The main focus is to analyse how the European transport supply profile (capacity, connections, business models, regulations, intermodality, processes, and infrastructure) could adapt to the evolution of the demand profile (customers, demographics, passenger expectations, requirements).
- DATASET2050 addresses one of the main transport mobility goals stated in Flightpath 2050: 90% of travellers within Europe will be able to complete their journey, door-to-door within four hours. Through the application of statistical analyses, multi-modal mobility modelling and predictive analytics, DATASET2050 computes 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 gained will highlight research needs and requirements towards the four-hour door-to-door goal. Due to the multi-dimensionality of the problem, DATASET2050 uses visualisation techniques, to ease the consumption of the results.
- An Advisory Board, formed by European transport stakeholders, supports the DATASET2050 partners.
- The dissemination and communication plans ensure efficient circulation of results among key European transport policy makers and stakeholders. The plans also include incorporating their valuable input and perspectives through the project workshops.

1.2 WP5 and Deliverable 5.1 context

WP2 consolidated the data frame and model to be used in DATASET2050. WP3 was devoted to the mobility demand profile (customers, demographics, passenger profiles etc.), with a deliverable on the current status (D3.1) and one on future scenarios, namely 2035 and 2050 (D3.2). In a symmetric approach, WP4 tackled the current and future European transport supply sides for passenger journeys, with D4.1 looking at the current supply status and D4.2 on the future supply profile.



WP5 is a key outcome of the project: using all the previous deliverables/WPs, the future mobility needs will be assessed. In this context, D5.1 is focused on the mobility as such: what are the metrics that need to be extracted from the model? Are they significant in the context of the door-to-door travelling being assessed? How does the model provide that information? How are the mobility attributes calculated?

The finalisation of the current deliverable (D5.1) enables the delivery of the door-to-door metrics to the different scenarios (D5.2), including the calculation of metrics and with a high quantitative flavour. Consequently both D5.1 and D5.2 are crucial for the final CSA project deliverable on novel concept foundations for European mobility. The last technical deliverable, D5.3 deals with novel concept foundations for European mobility.

1.3 Deliverable structure and contents

This deliverable D5.1 focuses on mobility metrics, indicators and methods. It is composed of three sections, following this introduction.

- Section 2 lists the Key Performance Areas (KPAs), inspired and adapted from the corresponding ICAO ones. Each KPA is broken down into one or several Mobility Focus Areas (MFAs). This section provides the reader with the definition and classification of the KPAs and their associated MFAs. The text intends to have a "scoping approach" and not to be too prescriptive. This is tried via documenting the different meanings a single word can have depending on the stakeholder asked about it. In these cases, all the different definitions, attributes and approaches are documented in the deliverable, for the sake of completion. As an example: the predictability concept (KPA) covers the punctuality, reliability and variability MFAs.

- Section 3 describes the Key Performance Indicators (KPIs) that provide measures of the performance of the system. The KPIs are derived from the corresponding KPAs and MFAs. The current deliverable explains with a noticeably quantitative flavour how these KPIs are/would be measured.
- Section 4 explains how the different KPIs are calculated and consolidates the deliverable's mains conclusions and key remarks.
- Section 5 provides conclusions.
- Section 6 comprises the bibliography and references.
- Section 7 lists acronyms used in the deliverable.

1.4 Terms and definitions

For clarity of reference, we here define or provide definition references (sources: ICAO, SESAR, PRU) of the several terms used throughout the deliverable, .

Term or acronym	Definition(s)
Key Performance Area (KPA)	"KPAs are a way of categorising performance subjects related to high-level ambitions and expectations". [ICAO, 2009]. ICAO defines 11 KPAs in this document: safety, security, environmental impact, cost effectiveness, capacity, flight efficiency, flexibility, predictability, access and equity, participation and collaboration, interoperability. In [SESAR, 2014] these 11 ICAO KPAs plus Human Performance (a proposed addition not yet formally adopted by ICAO) are considered as given. The DATASET2050 consortium, as part of D5.1 and inspired by ICAO's KPA definitions and lists, has selected a number of (key) mobility focus areas within the project scope. These are described in the current deliverable, Section 2
Key Performance Indicator (KPI)	1. [performance indicator] "A quantitative or qualitative measurement, or any other criterion, by which the performance, efficiency, achievement, etc. of a person or organisation can be assessed, often by comparison with an agreed standard or target" [Collins English Dictionary]. 2. [performance indicator] "Current/past performance, expected future performance (estimated as part of forecasting and performance modelling), as well as actual progress in achieving performance objectives is quantitatively expressed by

Term or acronym	Definition(s)
	means of indicators (sometimes called key performance indicators, or KPIs)." [ICAO, 2009]. 3. [key performance indicator] "A clearly defined measurement indicator considered to be of the highest importance for measurement in validation exercises and used for validation assessment." [SESAR, 2014]. Guidance on KPIs and Data Collection Version 1. DATASET2050 consortium, as part of D5.1 and inspired by ICAO's KPI definition and list, has defined a number of (key) mobility focus indicators within project scope. These KPIs are described in the present deliverable: sections 3 (full D2D list), 4 (performance assessment method) and 5 (KPIs within DATASET2050).
Mobility Focus Area (MFA)	ICAO subdivides KPAs into Focus Areas. In a similar way, the current deliverable subdivides some of the KPAs into Mobility Focus Areas (MFAs). MFAs are derived from the air transportation goals, to distinguish them from other focus areas (e.g. ATM focus). Each MFA covers one or several KPIs. For instance the KPA "Access and equity" is divided into 3 MFAs (Affordability; Equity; Reach). Each of those MFAs has different KPIs associated with it. These MFAs have been inspired by the expected future transport properties (e.g. affordable, quick, seamless etc.) given in the "Meeting societal & market needs" section of Flightpath 2050 [EC, 2011]. Some of the MFAs have been also derived/inspired/complemented by the European Commission Aviation Strategy [EC, 2015] which describes several research areas in the context of tackling challenges to growth in air transport.
(Supporting) Metric	"Supporting metrics determine which data need to be collected for calculating values for the performance indicators" [ICAO, 2009].
Utility	"Total utility refers to the total satisfaction derived from consuming a certain good or service. [...] Marginal utility refers to the satisfaction gained from consuming an additional unit (the marginal unit) of the good or service." [Hobday, 1988].

2. Key (mobility) performance areas (KPAs)

Over the next 30 years, EU mobility should progressively evolve from the gate-to-gate focus currently prevalent in the aviation industry towards a seamless and efficient door-to-door-orientated vision, in which the passenger's overall experience is paramount. Air transport is envisaged as being at the heart of an integrated, clean, and efficient transport system, capable of transporting users (freight, and travellers with their luggage) from door to door safely, quickly, seamlessly, predictably, and affordably.

Lord Kelvin said what was later abbreviated to "if you can measure it, you can manage it" and "if you cannot measure it, you cannot manage it". Managing developments towards the DATASET2050 goal require, therefore, that we be able to measure these developments using metrics and that we produce indicators, often composed of combinations of metrics, that enable us to see progress towards the goals. However, there are many dimensions to the problem of attaining a goal, so we define indicators for several Key Performance Areas (KPAs) relevant to the problem. The most relevant indicators are called Key Performance Indicators (KPIs).

The International Civil Aviation Organisation (ICAO) first defined [ICAO, 2005] and later elaborated the context of [ICAO, 2009] 11 KPAs for the improvement of the air traffic management (ATM) system. They are: 1, access and equity; 2, capacity; 3, cost effectiveness; 4, efficiency; 5, environment; 6, flexibility; 7, interoperability; 8, participation and collaboration; 9, predictability; 10, safety; 11, security.

While ICAO's ATM-system objectives differ greatly from the mobility and connectivity objectives of DATASET2050, the nomenclature they have used provides a good basis for our purposes, though certain names and definitions of KPAs have been slightly modified or adapted, in order to expand them to the door-to-door concept. One of the KPAs (Participation and collaboration), as defined by ICAO, has been considered irrelevant to DATASET2050 needs.

ICAO subdivides KPAs into Focus Areas. In a parallel way we subdivide our KPAs into Mobility Focus Areas (MFAs), derived from the air transport goals, to distinguish them from other potential focus areas such as ATM, safety etc. These MFAs have been inspired by the expected future transport properties (affordable, quick, seamless etc.) given in the "Meeting societal (sic) & market needs" section of Flightpath 2050 [EC, 2011]. Some of the MFAs have also been derived/inspired/complemented by the recently published European Commission Aviation Strategy [EC, 2015] which describes several research areas in the context of tackling challenges to growth in air transport.

This section discusses the key mobility focus areas (MFAs) defined within DATASET2050 and to be monitored for assessing the progress of the transport industry towards the mobility/connectivity goal of having 90% of journeys that involve an air segment taking 4 hours or less from door to door (4HD2D). Each MFA is additionally defined and, where it is considered necessary and feasible, metrics are provided for measuring performance in these areas. Evaluating these metrics will therefore show whether we are advancing towards the 4HD2D mobility target or, on the contrary, retreating from it.

The key mobility performance areas (KPAs) have been subdivided into MFAs as follows:

KPA	MFAs
Access and equity	Affordability; Equity; Reach
Cost effectiveness	Beneficiary; Cost; Value for money
Efficiency	Duration; Comfort; Speed
Flexibility	Diversity of destinations; Multimodality; Resilience
Interoperability	Seamlessness
Predictability	Variability; Punctuality; Reliability
Safety	Safety
Security	Security
Sustainability	Environmental aspects;

KPA	MFAs
	Social aspects
Capacity	Capacity

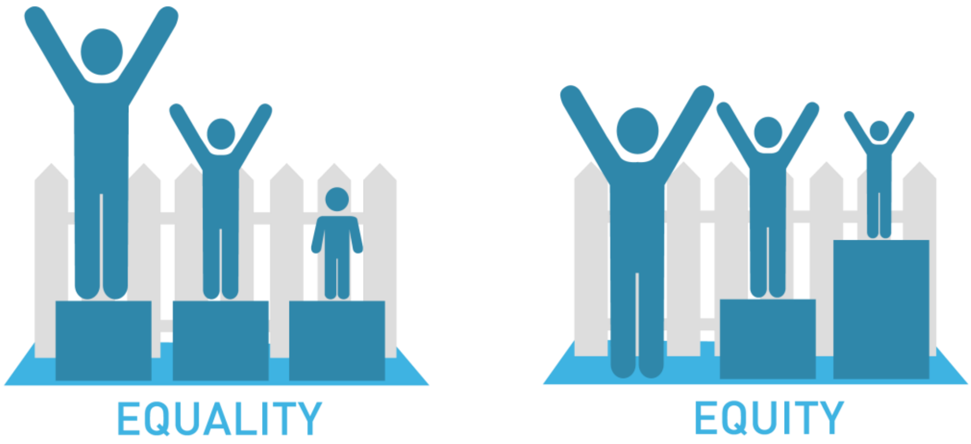
2.1 Access and equity

According to Article 13 of the Universal Declaration of Human Rights "everyone has the right to freedom of movement and residence within the borders of each state". It has been demonstrated that access to affordable and reliable transport widens human opportunities and is essential in addressing poverty, unemployment, and other equal opportunity goals.

In this context, the EU is the only area in the world where citizens are fully protected by a whole set of passenger rights - (http://ec.europa.eu/transport/themes/passengers_en) - whether they travel by air, rail, ship, bus or coach. These rights apply not only in the context of denied boarding, cancellation, delays and accidents, but also in several areas in the context of access and equity: eg under European passenger rights legislation, persons with disabilities or reduced mobility enjoy specific rights and protection at the airport and during air travel throughout the EU.

The concept of "a level playing field" is very important in the context of European mobility. Not everyone lives in major cities within a few minutes or kms of a major hub airport. In a similar fashion, the price of some trips can make them inaccessible in terms of affordability for certain groups of EU travellers. Some mobility solutions can also present a disadvantage for a certain section of the population.

It is very important to remember the difference between equality and equity, as shown by the following meme:

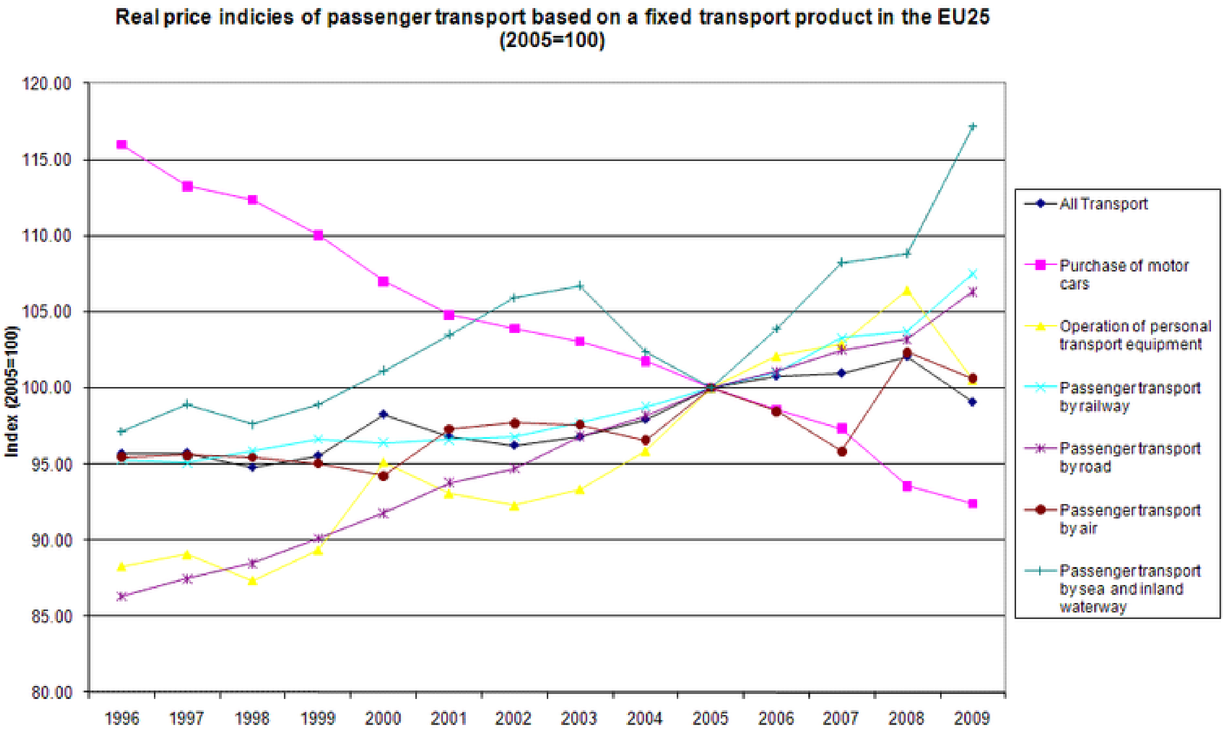


For this reason, the Key Performance Area on "Access and Equity" reports on three mobility focus areas (MFAs): affordability, equity and reach. Further implications of these and how the public institutions (EU and national level) should address these points are considered to be out of the scope of DATASET2050. The only aim is reporting, for each of the three mobility focus areas, the current status, consolidating the indicators, metrics, and pointing out how they are incorporated in DATASET2050 results and metrics.

2.1.1 Affordability

Transport demand is the passengers' desire to purchase trips backed by the ability and willingness to pay the price for these. As seen in DATASET2050's deliverables 3.1 and 3.2, the demand for air transport and income level are strongly linked.

The cost of air travel has remained fairly stable, and even increased, with respect to general prices over the 1995-2010 period, as can be seen in figure 1 [EEA, 2016]. This tendency has been modified with the rise of low cost European airlines in the first decade of the century [ICAO, 2003]. Those airlines nowadays gather close to 50% seat capacity on scheduled services in Europe. [ICAO, 2015]



As efforts are made to speed up travel with better connectivity, and shorter waiting and processing times, it is essential that journeys remain affordable and, preferably, become more so. Failure to achieve this means that fewer people will travel, which is detrimental to the growth of the industry and to EU mobility goals, or that people will not use the improvements offered and thus the goal of 4-hours door-to-door for 90% of journeys will not be attained.

As an example: The UK government has recently proposed selling fast-track access through baggage screening and passport control. How much would this help in attaining the goal if the price is high enough to make it worthwhile, in terms of time saved, for the rich few to purchase it? Is it "affordable"?

An affordable trip is considered to be one within the passenger's financial means. To enable such affordability to be measured, therefore, a metric is required that includes not just the price of a ticket, but the cost of a journey, and the disposable income of the prospective passenger. This depends on the passenger profile, assessed in detail both for current passengers (see D3.1) and future ones (D3.2).

An estimation of the price of every trip will be incorporated as a metric in DATASET2050, through taking into account the passenger profile, means of transport chosen, trip duration and distance.

2.1.2 Reach

The land mass of the EU stretches from the Algarve to the north of Finland and from the Greek islands to the Hebrides of Scotland. It is much easier and economically more viable to provide services to the major population centres than to these far-flung rural areas. People in these areas must not, however, be left behind in moves towards connectivity, and transport options must be available to those who live on the periphery of Europe, often a long way from major cities and their airports.

Similarly, people in certain areas must not be penalised in their options of destination. Limiting the 4HD2D options of someone who lives in the north of Scotland, say, to London and Oslo is not equitable when someone from Manchester can reach anywhere in Europe. This is partly supported in Europe through the provision of public service obligations, as commented upon by [ACI EUROPE, 2017a]: "Given that many smaller regional airports and their communities have come to depend on public service obligations for their connectivity, ACI EUROPE is reassured that the Commission recognises the continuous need for this system – which acts as an essential tool of economic and social cohesion". Working with SEO Amsterdam Economics, ACI EUROPE has defined and quantified four types of airport connectivity per se [ACI EUROPE, 2017b], as defined in the table below.

Type of connectivity	Definition
Direct connectivity	These are the direct air services available from the airport – measured not just in terms of destinations, but also in terms of frequency (so for example, an airport with 5 daily flights to another airport, will register a higher score than one with only 4)
Indirect connectivity	This measures the number of places people can fly to, through connecting flights at hub airports from a particular airport. For example, if there is a flight to Amsterdam-Schiphol, Istanbul or Dubai – the large number of available onward connections from these airports expands the range of destinations available from the airport of origin. Indirect connections are weighted according to their quality, based on connecting time and detour involved with the indirect routing. For example, a flight from Manchester to Johannesburg via Paris-Charles de Gaulle will register a higher score than an alternative routing via Doha.
Airport con-	As the name suggests, this is the most comprehensive metric for airport connectivity – taking into account both direct and indirect connectivity from the airport in question.

Type of connectivity	Definition
nectivity	Airport connectivity is defined as the sum of direct and indirect connectivity – thus measuring the overall level to which an airport is connected to the rest of the World, either by direct flights or indirect connections via other airports.
Hub connectivity	This is the key metric for any hub airport big (such as London Heathrow) or smaller (such as Keflavik). Essentially, it measures the number of connecting flights that can be facilitated by the hub airport in question – taking into account a minimum and maximum connecting times, and weighting the quality of the connections by the detour involved and connecting times.

Broader than these airport-specific metrics, but drawing on similar definitions, a metric of reach, embracing, for example, the ability of people in remote areas to access (at least) the heart of Europe, will be vital for this KPA.

2.1.3 Equity

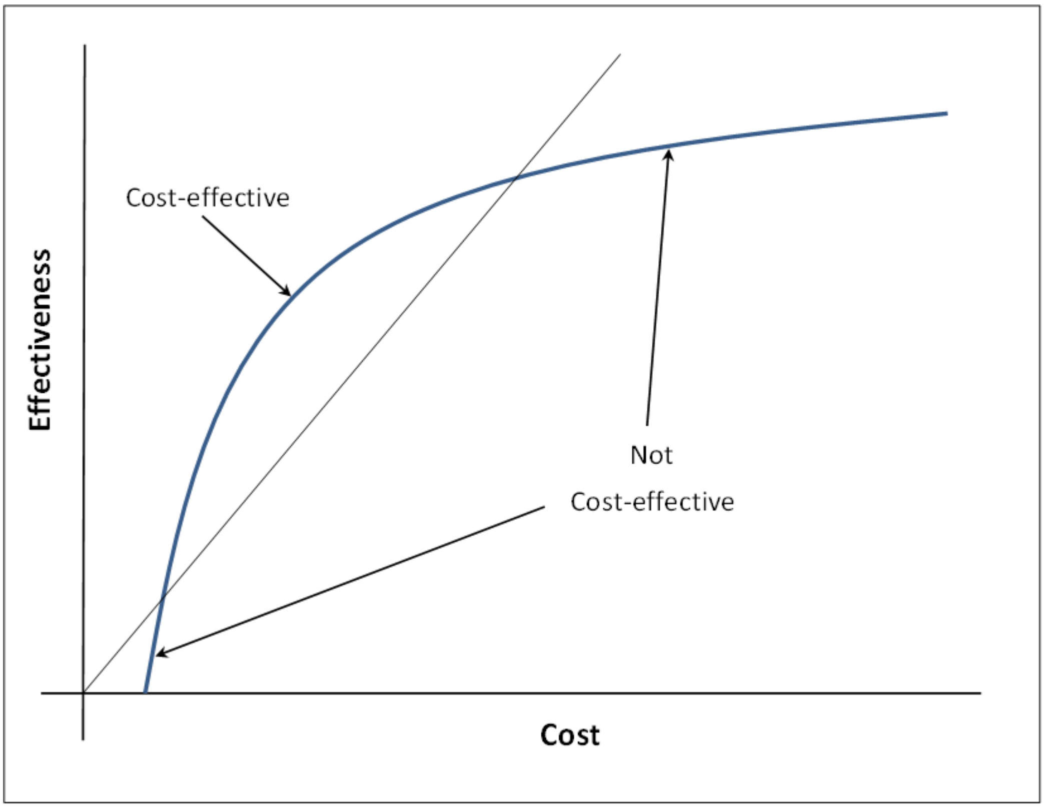
Whereas the affordability MFA (section 2.1.1) aims to ensure that not only the rich can take advantage of improvements in connectivity; the Reach MFA (section 2.1.2) looks at the accessibility gains of outlying areas. The underlying common idea is that any improvements in D2D time towards the 4HD2D objective should not just benefit one sector of society (e.g. just the rich or just those who live within 20km of a major hub). Following this same approach there are other social sectors or aspects that must not be overlooked:

- people with disabilities must be able to perform their journey with as little inconvenience - which often equates to time and will therefore affect the 4-hour door-to-door goal - as possible;
- people from different social backgrounds often have different travel needs and it is important that these be available to them all equally;
- surface links often prioritise city dwellers whereas people who live in the countryside are generally required to take their car to the airport. A major difference in cost between surface transport from the city and airport car park charges, is inequitable;
- any other gender, health, sexuality, lifestyle, ethnicity, political opinion, religious or philosophical conviction that would prevent passengers from fulfilling 4HD2D trips
- etc.

The equity MFA exists to monitor the extent to which connectivity/mobility solutions disadvantage such sections of the population.

2.2 Cost-effectiveness

The general concept of cost-effectiveness compares the relative costs and outcomes (effects) of different services. In other words it is a concept that considers to what point the service rendered is worth the cost. Is it value-for-money? And how do we define "value"? Can something be considered cost-effective if it only serves a small part of its potential market and brings no benefit to anyone else? The real measure of effectiveness is how well the service achieves its objective. The cost-effectiveness of an improvement would be measured along a Pareto front as shown below:



The shape of the curve and the angle of the cost-effectiveness line are context dependent.

The cost-effectiveness KPA has been divided into 3 mobility focus areas (MFAs) - beneficiary, cost, and value for money - to better express the overlapping elements involved.

2.2.1 Beneficiary

A beneficiary is someone who benefits from the existence of a service, but is not necessarily someone who uses that service. In the case of transport, the beneficiaries of a link in the transport mobility chain include the hotelier whose establishment the traveller will be staying in thanks to the existence of that link. Beneficiaries are even potential travellers that do not use the transport service but would have the benefits of enjoying it, if willing to do so.

In theory, for the DATASET2050 context, it is not sufficient to just look at getting 90% of passengers into a 4-hour door-to-door time-frame, but optimising this 90% such that European citizens and the European economy as a whole benefit. For two options that have the same number of 'users', the one that provides the most 'benefit' (often, but not always, the one with the more 'beneficiaries'), is the better one. Building railway A in northern Europe or railway B in central Europe may have the same cost, and may bring the same number of passengers within our 4-hour door-to-door time-frame, but one might also increase local tourism possibilities whereas the other may create much more noise impact without helping the economy at all.

However, defining such a metric, and more importantly calculating one, is well beyond the scope of the DATASET2050 project. The concept is mentioned here merely in the hope that it will be taken into account in further work and research exercises towards the 4-hour door-to-door goal.

2.2.2 Cost

In order to know whether something is cost-effective, it is necessary to know what it costs.

The cost of something is the amount required in payment for its provision. This is not necessarily a monetary amount, but in the modern context it usually is, and for the purposes of this project it will be considered as such. Cost is also the amount the supplier has to spend in order to be able to provide the product/service in question. This again will be considered to be monetary.

These two values are linked in that the cost to the purchaser is equal to the cost to the supplier minus any subsidy the supplier receives plus the supplier's pre-tax profit on the supplied product/service. If the supplier receives a subsidy, it is likely that either their profit or the selling price (cost to the purchaser) will be restricted by the subsidy provider.

Another element of "cost" is the cost of providing infrastructure, for example a new road, rail track, or runway, so that the goals can be met. It is to be assumed that this cost will be recuperated through fares, or will be included in the subsidies referred to above.

In DATASET2050, the interest is in the total cost for each trip, including all segments door-to-door, based on the different means of transport selected.

2.2.3 Value for money

The concept of value for money comes from two statements:

- A given person can have different preferences concerning two similar journeys at the same price,
- Two persons can have very different preferences concerning the exact same journey.

In other words, the quality of the journey is a subjective measure that depends on the individual and its environment. The exact value put over a given journey is difficult to measure, therefore. To do so, there are two main techniques called "Revealed Preference (RP)" and "Stated Preference (SP)".

RP allows inferences to be made from the actual behaviour of people. Standard economic theory tells us that in a perfect competition situation with perfect information, perfectly rational agents will choose the option whose price equates its inner, subjective value. This approach is powerful because prices are easily observable and thus data are easily acquired. However, it has many flaws, in particular regarding the hypotheses, which are never actually verified in reality. Moreover, one only has access to a restricted set of such data since it is hard to know, for instance, the level of income of passengers and thus how this enters the equation. Finally, it requires a substantial volume of data and heavy data analysis to forecast future behaviours of people in new situations. By definition, this technique allows the current values of trip to be determined.

To resolve these problems, another way of evaluating the intrinsic value of a trip has been developed over the years: asking the passengers directly. This is usually done by using SP surveys where different options are presented to the traveller, a longer journey, more legroom, etc., together with financial options (e.g. a €10 saving, an increased fare), and the subject is asked to rank the options by preference. After analysis, one is able to conclude the value that the subjects give to a particular element (e.g. punctuality, a better seat, journey time). This approach is powerful because the analysis has a direct access to the decision-making process (at least the conscious one), is able to acquire all supplementary information of interest (income, age, etc.) and can probe the behaviours of people facing completely new situations. However, it also has its downsides:

- firstly, one asks the opinion of passengers (a conscious process), which can be significantly different from their attitude (a largely unconscious process);
- secondly, compared with other techniques this data acquisition process is very slow and costly, which limits post-analysis and the conclusions one can draw from the data;
- finally, there are many non-trivial parameters in people's decision-making process in general - interactions between parameters, positive or negative, non-linearity, etc. This means that questions have to be tailored very carefully and focus only of a few parameters (e.g. delay or comfort), and that the results usually have a high degree of variability.

2.3 Efficiency

Efficiency is the extent to which time or other resources are well used for the intended task. However, having time or resources well used doesn't imply that the shortest possible time and the lowest number of resources have been taken. In travel, we have to take into account the passengers and employees and ensure that they are not inconvenienced by the efficiency we are striving to achieve. So in our context the passenger should not be made to feel is if they have to hurry. On the other hand, if they have to wait or queue as a result of efficiencies inherent in the system, they must not be made uncomfortable by this.

The efficiency KPA has been divided into the following three MFAs: comfort, unproductive time and speed.

2.3.1 Comfort

Ease or comfort is directly linked with the lack of difficulty/effort the passenger experiences along their door-to-door trip. There is a close-to-endless list of quantitative and qualitative factors that somehow measure the trip's comfort. The non-exclusive list includes:

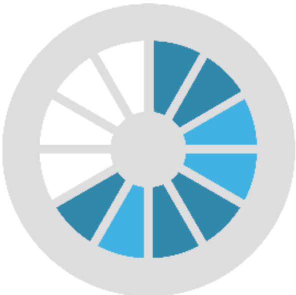
- time and distance for which a passenger has to carry their luggage in the different door-to-door phases;
- number of separate reservations required to purchase the trip: single ticketing vs multi-ticketing;

- provision (or not) of food, drink and entertainment /amenities (internet connection, media), whether during the actual journey phases or while waiting;
- number and features of facilities - toilets, prayer room, smoking area, rest room etc. - available to the traveller;
- proportion of the journey where the traveller is self-transported - walking, cycling, driving - rather than being transported;
- use of private, tailored "VIP" means of transport vs public transport that often offers less comfort.

Some of these criteria are merely scoped in the present deliverable, and we could only evaluate a small fraction of them in DATASET2050, taking into account the project scope. Other H2020 projects such as PASSME (http://www.passme.eu/) are currently researching this topic. An extensive highly detailed exercise would include market research such as that routinely undertaken by airlines and airports.

Therefore, the chosen DATASET2050 metric for the ease and comfort experienced by passengers will be calculated based on the passenger profiles and the different means of transport chosen, taking as many of the above criteria as possible, and relevant, into account.

2.3.2 Unproductive time



Time spent queuing is time that a passenger considers to be unproductive or, colloquially speaking, "wasted". Queues do, on the other hand, perform an important function as far as the efficiency of a system is concerned, smoothing out peaks and troughs in demand and thus enabling resources to be more precisely planned. A balance must therefore be found between the amount of queuing that a passenger finds acceptable or not, and the amount of queuing an operator requires for the optimal smooth execution of their business.

There is also quite often a certain amount of time wasted due to uncertainties. This means that most of the passengers leave "buffer time" just in case of potential traffic jams, overlong queues at check-in/bag-drop/security etc. Quite often, this buffer is imposed by the airline - check-in closes 45 minutes, say, before the gate does. The amount of buffer time varies significantly depending on the passenger profile (e.g. frequent travellers with hands-on experience of same trip)

In comparison with other transport mode infrastructures, airports are notorious for the amount of time passengers have to spend walking from one point to another. This is generally imposed by the spacing between gates necessary to park an 80m-wingspan airplane at each gate. This fact nevertheless contributes greatly to the inefficiency of the process and to the overall journey time for the passenger, who most of the time considers it both wasted time and wasted effort.

Unproductive time MFA is measured in passenger minutes.

2.3.3 Speed

Speed is generally defined as the distance travelled per unit of time and by extension the rate at which something is done with respect to time e.g. typing speed in words per minute.

A fast door-to-door process is one accomplished in relatively little time. However, a door-to-door journey will use several forms of transport of wildly different speeds - from walking at a few km/h to flying at several hundreds of km/h. The longer the journey, the higher the average speed, therefore, since this increased length will generally have been flown. Conversely, the further from the airport the origin or destination doors are, the slower the average speed will be. It is, therefore, important to define a speed metric that will be useful in showing the improvements in mobility and connectivity without being biased by performance on shorter routes.

Additionally, as the value of time differs among traveller profiles, the speed/time spent has a subjective component from the passenger's perspective. This subjective impression of the speed of the trip will be estimated based on the time spent, trip distance and the passenger profile.

The distance travelled per segment divided by the speeds for that segment gives the duration of the segment. The sum of these is the overall duration of a journey, the raison d'être of DATASET2050.

DATASET2050 measures the time spent (and therefore speed) in the different transport phases and of the major sections of the door-to-door journey: door-kerb; kerb-gate; gate-gate; gate-kerb; kerb-door, for all passengers.

2.4 Flexibility

Flexibility has two principal dimensions in a passenger journey:

- flexibility in the choices offered to the passenger;
- and flexibility in both the providers' reactions to disruption and the passengers' ability to continue their journey if they miss a connection, for example.

The first of these may be broken down into the number of destinations possible from a given starting point and the number of ways of getting from that starting point to the chosen destination, both in terms of means of transport available and in terms of frequency of connection.

The second is a function of the resilience in the system and, again, the means available and frequency.

2.4.1 Diversity of Destinations

There is an interesting geographical dimension in the 4HD2D challenge: the variety of destinations that can be achieved from a departure point, meeting the 4HD2D criteria. Now diversity is a strange concept: "a range of different things or people", "the fact of many different types of things or people being included in something" [Cambridge Dictionary].

DATASET2050 incorporates a metric on the diversity of destinations that can be achieved from a departure point. It should look at all the airports a given passenger can get to from their door, which destinations are served by those airports, and where the passenger can get to once they've landed at the destination airport, all within 4 hours.

But is being able to get to the whole of one large country (however diverse that country may be) as diverse as being able to get to small parts of a lot of different countries, where the total accessible area is the same? In other words, if you can fly to Athens, Madrid, Bucharest, Helsinki and Edinburgh, but only get to within 15 minutes of these airports in four hours, do you have more or less diversity than if you can only fly to Berlin, but have two and a half hours of drive time available from there. Even though the latter will have a greater area of possible destinations, the former is more diverse.

Therefore, the diversity of destinations metric could therefore measure the number of doors or the number of NUTS3, NUTS2 and NUTS1 regions that can be reached from a given point.

2.4.2 Multimodality

The terms multimodal and intermodal transport are used almost interchangeably nowadays, to mean that more than one mode of transport is, or may be, used.

In some transport contexts, intermodal refers to journeys in which there are different transport providers/entities responsible, whereas multimodal is understood as the use of a single carrier, despite the multiple means of transport used, for the entire journey.

In other contexts, intermodal is the adjective used for the transport infrastructure (stations etc.) that cover different transport modes e.g. airports which are also significant rail/coach/bus hubs and multimodal can mean that there is the possibility of using any one or several of different available transport modes.

In common with previous DATSET2050 deliverables, this document uses multimodality in its widest sense, covering the two meanings:

- the capacity of travellers to use alternative transport modes to perform the same trip;
- the consecutive use of different means of transport for the same trip.

As described in D4.1 and in WP2, DATASET2050 metrics will only focus on the trips that involve at least one air phase. Any metric for multimodality must, therefore, take into account the number of alternatives both in parallel and in series.

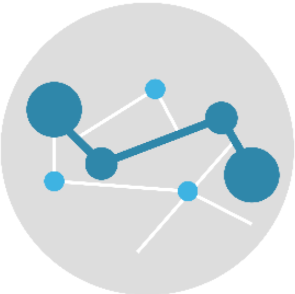
2.4.3 Resilience

The resilience of the transport system is its capacity to recover from unexpected circumstances (see FP7 project www.resilience2050.eu). Or in other words: is the system flexible enough to cope with disturbances? The resilience definition also includes an element of time used to recover, the reactivity to the circumstances; how quickly an alternative solution, or a rectification of the original problem, can be found.

Resilience would involve, for example, a carrier re-booking a passenger onto another operator's flight, with minimum delay and impact on the passenger, if the original flight was cancelled. So resilience can also be a part of the interoperability KPA, though really it is dependent on it, rather than the other way around. In parallel, passengers usually experience the consequences of the system resilience (or the lack of it) as part of other MFAs such as Comfort or Time spent. Nevertheless, taking into account the scoping approach of the deliverable, resilience has also been included as an MFA within the flexibility KPA.

DATASET2050 models the resilience of journeys by counting the number of disruptions and perturbations faced by passengers - from a strike causing cancellations, to a problem on any transport segment provoking a disruption and delay - and the delay in the passenger's journey induced by this and its resolution.

2.5 Interoperability



Interoperability is the ability of different mobility services to work together to provide a continuous journey to the passenger without apparent transitions or interruptions between its 'phases'.

A holder of a typical city travel pass (such as an Oyster card in London) that allows freedom of travel on different modes of transport does not have to think about buying a ticket for the next leg of the journey ("Do I have a ticket already?"/"Do I have enough cash to buy a ticket?"/"Where do I have to go to get a ticket?"/"Will I miss my train by queuing to buy a ticket?"), they simply catch the bus/train. Similarly, they are (usually) not limited in their choice of service provider, even though different service providers may provide a city's transportation system. This integration of services thus much reduces both the cognitive load and the transition time, thereby increasing interoperability. This can also add resilience. If a train is cancelled, it might be possible to take a bus in its place, or another operator's train using the same ticket. (Before the de-regulation of the 1980s, a plane ticket from London to Paris was valid on both British European Airways and Air France; if you missed your flight, you could re-book on the next one, whichever the airline).

It should be noted that this integration and resilience are also parts of the concept of "flexibility" and can influence "efficiency" (q.v.).

Interoperability is considered a crucial KPA at the European mobility level for the move towards complete integration of all mobility services and an EC consultation (https://ec.europa.eu/transport/themes/its/consultations/2017-evaluation-its-directive_en) was run from May through July 2017 on the Intelligent Transport Systems Directive [EC, 2010], which has legally binding specifications for interoperability, .

There are two major aspects of interoperability:

- seamlessness of operation, in which the passenger is oblivious to a change of operator;
- resilience, as described under the flexibility KPA (and not discussed further here).

The seamlessness of a trip is related to the number of specific phases (steps, stages) involved in reaching the destination. One thus needs to first define exactly what a 'phase' is and what its boundaries are. The UK 'National Travel Survey' [DfT, 2016] defines a trip as a succession of "stages" where passengers change their mode of transport or their vehicles (for instance a change of bus). Small walked segments (<50 metres) are excluded from the definition. After this, the ease with which the passengers go through the different transitions between such phases must be estimated. For example, when a passenger at the departure airport checks in baggage through several connections to the final destination airport, despite several changes of airline, this adds to the seamlessness of the journey (from a passenger perspective) - they do not have to collect their bags after one flight and re-check them on the next. Seamlessness can be also understood as a lack of unproductive time, for instance time spent waiting or queuing, when there is no transport activity as such.

We consider a trip to be made up of a succession of 'phases' separated by 'transitions'. We define the former as the parts of the trip that are cognitively and physically easy for the passenger to undertake, whereas the latter are associated with higher cognitive and/or physical loads. Typically, the transitions are much shorter than the phases themselves, which nevertheless can have various loads. For example, being on a train or in a taxi – in a particular phase – is cognitively easier than making a connection at a train station – a transition. Note that transitions are sometimes only slightly more cognitively demanding than phases. For instance, changing to a new bus at a given bus stop is very easy, but still slightly more difficult than just staying on one bus for the whole trip.

Phases are times during which one can perform activities not (strictly) related to the journey, because their cognitive load is (otherwise) quite low. Transitions, on the other hand, involve activities which require fuller attention, even for a brief moment. As explained further in Section 3, this allows us to build very simple metrics (number of transitions) or more advanced ones (actual cognitive loads), since not all phases are equivalent (e.g. waiting in a queue is slightly more demanding, physically and cognitively, than sitting in a train).

2.6 Predictability

Predictability is a key transport feature, from the passengers' perspective. In the end, passengers travel for a specific reason: tourism, meetings, etc., with a specific goal to be achieved once they have arrived at their destination. Predicting the time spent travelling - or the true arrival time at their destination, with advance knowledge of any transport disruption, is crucial in allowing them to do this.

Predictability differs a lot depending on the transport chosen: from the over 95% predictability of German trains [Deutsche Bahn AG, 2017] to the almost total lack of road transport predictability in major cities due to traffic jams caused by potential accidents, road works or simply rush hour. Lack of predictability in one leg of a journey can have a major impact on the rest of that journey. At the very least, it requires the passenger to incorporate large quantities of buffer time into their planning which therefore increases the overall D2D time.

Some basic predictability metrics will be incorporated into DATASET2050, based on the means of transport used, the length of the trip and the countries involved.

Predictability is composed of three factors, or MFA: punctuality, variability, and reliability.

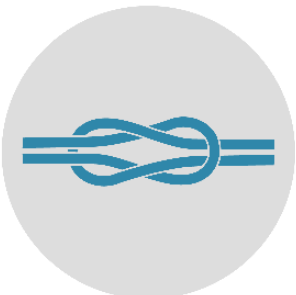
2.6.1 Punctuality

In mobility, punctuality is the characteristic of being able to complete a required trip by, or before, a previously defined time. Punctuality stands on top of the "time/duration" metric, providing a comparison between that figure and the expected duration of the trip.

Punctuality differs from variability in that a measure of punctuality would be a percentage of journeys completed within a given number of minutes of the required time, whereas variability measures the spread of arrival times irrespective of the required time. Journeys that are consistently 10 minutes late have 0% punctuality and no variability.

In the context of a multi-modal journey, punctuality of arrival time is of extreme importance since the lateness of the mode of transport used for one leg could imply being too late to be able to take the next leg. This, combined with uncertainties in variability, causes passengers to factor large buffers into their timing which reduces, therefore, the possibility of completing the journey in under 4 hours.

2.6.2 Reliability



Reliability is the second aspect of predictability. Can we be sure that the bus we want to take to the airport will run at all? What is the chance that the plane I want will be overbooked and that I'll be dragged screaming and bloodied from my seat, back into the departure lounge?

There is also the possibility that a bus, train, or car will break down mid-journey, that an air-traffic controllers' strike will prevent all planes from flying for the next three days, or that track repair work means that the train won't stop at my station.

Published details of reliability should be used to enable a measure of the chances of being able to successfully undertake a given journey to its destination

2.6.3 Variability

Variability is a measure of the spread of departure or arrival times, or process durations, compared with the mean. A passenger would generally prefer a route that usually involves variations of +/- 5 minutes in its departure or arrival timings over a totally unpredictable one with uncertainties of the order of +/- an hour.

It is important to note that variability is independent of any published or expected times; it simply covers how variable the trip times are compared with the mean. In mathematical concepts, variability is measured with the variance or standard deviation of the distribution. Variability should not be confused with punctuality or with any other KPA/KPI associated with the value of the mean. For instance:

- Case 1: A specific trip segment (e.g. the security check in a crowded airport on a busy day) takes 20 minutes on average, with a variability of +/-5 minutes depending on the day/time.
- Case 2: Another process (e.g. taxiing at complex airports like Madrid Barajas) takes 15 minutes on average, with a variability of +/- 10 minutes depending on the final gate.

While passengers spend more time on average in the first case than in the second (20 minutes vs 15 minutes), the second case has greater variability (+/-10 minutes rather than 5). The time expected for completing the first segment is more predictable than for the second one, despite being linked with a longer process time.

Unlike most other focus areas defined in this document, which are positive factors - the more they increase, the better - variability is a negative factor - it is best when variability is zero. The closer the variability is to zero, the better passengers can plan their journeys.

2.7 Safety

Safety and security often go hand-in-hand; indeed, in many languages the same word is used for both. In DATASET2050, the English distinction that safety is protection against accidental events whereas security is concerned with protection against intentional damage is made.

In transport, safety encompasses the theory, investigation, and categorisation of transport failures that can or could cause death, injury or damage to life, property or resources, and the prevention of such failures through regulation, education, and training. When studying the question of mobility, the question of the probability of death or major injury is uppermost. A metric is required that will describe the safety of each trip, that takes into account all of the different means of transport used, and the country or countries in which they were used.

[Savage, 2013] shows that public transport is responsible for many fewer deaths (in the USA) than private transport.

Average annual fatalities in the United States, 2000-2009

	Private Transportation			Commercial Transportation		
	Crashes solely involving private users	Crashes with commercial highway carriers	Crashes with commercial non-highway carriers	Passengers	Employees	Bystanders
			Highway Modes			
Cars and light trucks	26,678	3,766	245	7	9	n.a
Pedestrians & bicycles	4,930	545	592	n.a	n.a	n.a
Motorcycles	3,989	156	2	n.a	n.a	n.a
Large Trucks	n.a	n.a	n.a	n.a	724	n.a
Buses	n.a	n.a	n.a	30	9	n.a
			Non-Highway Modes			
Maritime	704	0	1	42	85	1
Aviation [d]	548	0	1	74	21	2
Railroads	n.a	n.a	n.a	7	27	4
Rail Transit	n.a	n.a	n.a	22	3	0
Pipeline	n.a	n.a	n.a	n.a	5	12
			Totals			
Total	**36,849**	**4,467**	**839**	**182**	**883**	**19**
U.S. Total			**43,239**			

"Comparing the Fatality Risks in United States Transportation Across Modes and Over Time," 2013

It states that a person who was in a motor vehicle for 30 miles (48km) every day for a year faced a fatality risk of about 1 in 12,500, and that this risk was 17, 67, and 112 times greater, respectively, compared with that of mainline trains, buses and commercial aviation.

It follows then that the greater the use of a multi-modal public transport system, the fewer the transport-related deaths that will occur.

DATASET2050 will determine a metric based on EUROSTAT transport statistics, that will highlight the increase in safety that greater multi-modality can bring.

2.8 Security

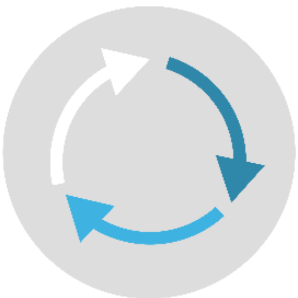
Whereas safety concerns protection against accidental events, transport security refers to the techniques and methods used in protecting passengers, staff, planes, systems and data from malicious harm, crime and other threats.

Security is a function of two opposing forces - those who would try to cause damage or harm, and the means put in place to stop them. The administrations responsible for public security try to balance the latter to the perceived threat from the former.

Security goes beyond the 'physical' security (passengers, planes, staff, and hardware) and incorporates the cybersecurity concept (information, systems, and data). Cybersecurity, also known as computer security, or IT security, is the protection of computer systems from the theft or damage to their hardware, software or information, as well as from disruption or misdirection of the services they provide. Since future multimodal concepts will be fully predicated on digitisation, appropriate cybersecurity should be ensured at all levels (technical, legislative etc.) in the future 4HD2D context.

DATASET2050's security metric measures the security of each trip, based on the different transport means used, and the country, calculated using EUROSTAT transport statistics.

2.9 Sustainability



Sustainability addresses the ability of a certain magnitude of quality or service to be maintained at a certain rate or level. In the air transport context, measures taken to improve connectivity and to achieve the 4HD2D objective have different impacts on pollution (CO_2, NO_X, particulate matter, O_3, etc.), noise, risk, quality of life, GDP, gross national happiness (GNH), etc. Care must be taken regarding the trade-off between D2D journey times (for example) and a number of other variables. The concept of sustainability is often broken down into three components, the "Triple Bottom Line": "people, profit, planet" [Elkington, 1997]. For a product, technology or procedure to be sustainable it must meet all three of the following conditions. It must not:

- be detrimental to human living and social cohesion;

- harm the future well-being of our environment by creating pollution, or destroying or over-exploiting natural resources;
- inhibit businesses from making a return on their investments.

For instance, adding a third or fourth runway to London Heathrow may help progress towards the 90%/4-hour goal, but average life quality could possibly decrease for the neighbourhood (noise, pollution). DATASET2050 will produce initial metrics on the impact of connectivity solutions on sustainability criteria by assessing 2 MFAs: environmental and social aspects.

2.9.1 Environment

After being ignored for most of the period since the industrial revolution, questions revolving around the impact of human activities on the environment are now taking an important place both in public discourse and in decision making. There are several facets to these questions.

- **Climate change** has become the main focus of discussion globally, starting with the first World Climate Conference in 1979, leading to the signature of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 [UN, 1992] and its entering into force in 1994. This was followed by annual Conference of the Parties (COP) meetings, with the Kyoto protocol being agreed at the third COP (COP3) in 1997, and culminating in the Paris Agreement, adopted in Paris on 12th December 2015 at the COP21. [UN, 2015] This agreement entered into force on 4th November 2016, requiring all nations to undertake efforts to combat climate change and adapt to its effects. Enhanced support was promised to developing countries to assist them in this. The goal of the the Paris Agreements is to limit global warming this century to 2°C above pre-industrial levels, and to pursue efforts to limit it to 1.5°C. The main cause of climate change is the emission of greenhouse gases into the atmosphere, the main one of these being carbon dioxide (CO_2). The transport sector is responsible for 26% of global anthropogenic CO_2 [Chapman, 2007]. It is evident that an indication of how efforts to reach the DATASET2050 goals affect this is required.
- **Air quality** deterioration, especially that due to ozone (O_3), nitrogen oxides (NO_X), volatile organic compounds (VOCs) and particulate matter (PM), is responsible for a number of health-related problems from minor throat irritation to asthma, heart disease, and lung cancer [Kampa et al., 2008]. These pollutants are produced in large quantities by different means of transport, and will vary if the number of car journeys increases, or if they are replaced by electric train journeys; if more or fewer aircraft journeys are made etc. They

should, therefore, be analysed by DATASET2050. However, such an analysis is complicated and could not include pollutant dispersion - a major part of the calculation of air quality - within this project.

- **Noise** is not, per se, an environmental problem. It has no impact on the planet and disappears within a second or so. If there is no-one around to hear it, it is not a problem at all. However, noise is a major social problem that is generally included in the list of environmental effects of transport. If efforts towards attaining the 4HD2D goals greatly increase, for example, the air traffic at what is currently a small regional airport, it is clear that DATASET2050 must include the increased noise impact in its indicators. However, see 2.9.2. about other factors involved in noise annoyance.
- **Water quality** is affected by the entry into water courses and water tables of harmful pollutants. This can be caused by run-off from polluted land - agricultural pesticides, unmanaged glycol from de-icing aircraft, etc. - infiltration into water tables from agricultural or industrial processes, including fracking, or through wilful pollution of rivers and streams, or the sea, whether legal or illegal from industry, sewage works, etc. DATASET2050 will not examine the impact of the four-hour door-to-door goal on water quality.
- **Rubbish**, and in particular non-biodegradable rubbish, is one of the longer lasting environmental problems associated with the modern era. It is highly unlikely, however, that the amount of rubbish produced will be impacted by 4HD2D so this will not be taken into account in the present project.
- **Land-use** change can have serious consequences for the environment. From the destruction of forests or the covering of previously absorbent land with concrete and asphalt to the implications for bio-diversity and complex ecosystems, changing the way a given area of land is used can cause major disruptions to wildlife or the global climate, and be responsible for flooding, drought etc. Efforts to attain 4HD2D could require the building of new runways, railways or roads, and the expansion of airports. An indicator is therefore needed to reflect this.

2.9.2 Social Aspects

Many of the impacts associated with transport noise and emissions, especially concerning aircraft activity, on people who live and work near them are often related to many factors that have nothing to do with the noise and emissions themselves. For example: people might understand the long-term health problems associated with a lowering of local air quality, but it is a difficult subject for complaint – how do you complain about a 0.000n% increase in your chances of contracting lung cancer or asthma? Similarly, you might be scared that a plane flying overhead will one day crash onto your house or your children's school, but you cannot complain about fear. So most annoyance expressed by people living near airports is about noise.

However, [Meidema and Oudshoorn, 2001] have found that only 25-30% of the variance in expressed annoyance can be accounted for by noise exposure and the physical characteristics of noise, and [Leverton, 2009] stated that virtual noise (non-acoustic reactions to, in this case, helicopter noise) is "of equal or even greater importance than the maximum noise level observed during a particular flyover…". [Maris, 2006] showed that just being nice to people reduced their annoyance to aircraft noise!

Focus groups organised as part of the EUROCONTROL-sponsored Attitudes to Aircraft Annoyance Around Airports (5A) project, also identified fear as a major factor: not just of accidents and health problems, but of lower house or land prices, of increased development and increased road traffic [Heaver, 2002]. Factors such as fear have been found to have a greater influence on levels of annoyance than demographic variables such as age or wealth [Miedema and Vos, 1999]. Still, the same study found that higher levels of education and occupational status are likely to be associated with higher reported annoyance and that owner occupiers were also found to report higher levels of annoyance than those who rent. They would also be willing to pay more to reduce noise levels [Fietelson et al, 1996].

The [Miedema and Vos, 1999] study found that confounding factors such as employment at the airport or high levels of use were found to reduce annoyance levels and [Brooker et al 1985] found dependency on the airport to be a major confounding factor. The 5A project's focus groups in Manchester and Bucharest identified jobs and economic development to be important beneficial effects of the airport. In fact [Tomkins et al 1998] found that, for residential properties around Manchester Airport, the benefits often outweighed the impact of noise on house prices. Perhaps it could be advantageous to site an airport near a town whose residents who will work there rather than in the countryside among villagers who won't. The 5A project found that urban Manchester residents were less annoyed than rural Lyon residents. ([Fields, 1998] found that levels of background noise are not a contributing factor.)

On a macro scale, however, it must not be forgotten that, as [Lu, 2011] showed, the macro-economic benefits of an airport far outweigh the environmental cost. The challenge is to ensure that those who bear the cost share in the benefit and, as we strive to ensure that passengers can travel from door to door in under four hours, we must make sure that we don't do so at the expense of those left behind.

2.10 Capacity

Capacity is a fundamental indicator in transport and communication systems. It refers to maximum possible output or performance. In air transport, it may relate to an aggregate measure such as the available seat kilometres operated by an airline in a given season or year (a standard airline capacity metric), or the number of seats in a specific aircraft operated with a given class configuration. In air traffic management, it may relate to the hourly aircraft capacity of a runway or en-route sector.

Trade-offs with capacity and other KPAs are particularly pronounced and well-known: "To respond to future growth, capacity must increase, along with corresponding increases in efficiency, flexibility, and predictability while ensuring that there are no adverse impacts to safety giving due consideration to the environment. The air navigation system must be resilient to service disruption and the resulting temporary loss of capacity." [ICAO, 2009]. There are also typical capacity trade-offs between different times of the day (peak and off-peak), geographical locations (heavily congested and relatively uncongested) and service users (often with an associated price differential). Increased capacity also often leads to less stable operations, with greater unpredictability regarding congestion and delays.

Capacity should also not be considered as a strict maximum. In reality, the transportation system often operates at a higher throughput than the declared one. The upshot consists often in unwanted consequences, like longer travelling times than normal and/or scheduled. Since small delays are usually acceptable, this means that the system naturally operates slightly above its theoretical capacity. In fact, from this point of view capacity is more a relationship between throughput and actual travelling times than a number per se.

Introducing the European aviation vision for 2050 and its corresponding goals, Flightpath 2050 [European Commission, 2011], with regard to serving society's needs, cites: "Meeting social and market needs for affordable, sustainable, reliable and seamless connectivity for passengers and freight with sufficient capacity".

In DATASET2050, capacity needs to be defined as a door-to-door mobility indicator.

3. Key (mobility) performance indicators (KPIs)

Measurement of mobility/connectivity performance relies on key performance indicators (KPIs). While many indicators can be developed for each mobility focus area (MFA) and key performance area (KPA), having too many may obscure the focus of the analysis and fail to show the true progress. On the other hand, it is necessary to be able to see which MFAs are providing the most progress and which are hindering that progress and thus require more effort. This section describes the development of KPIs for mobility/connectivity that will resolve this dilemma.

3.1 Access and equity

Three FAs have been described for the Access and Equity KPA: Affordability, Equity, and Reach. KPIs for this area need, therefore, to ensure that improvements to the overall journey times do not benefit just the rich, just the able-bodied, just those who live close to a major airport, etc.

Concerning equity, we suggest several KPIs that take the different facets of equity into account. The first metrics capture equity over income by examining the difference between the number of trips taken by the populations in different income bands, similarly to what is done with inequality of income or wealth. (We ignore trips by people in the "executive" and "price-conscious business traveller" categories in these metrics.) If the number of trips were equally distributed among the total population, each sub-part of the population would make a number of private trips, proportional to their size. The discrepancy between the number of trips and the size of the population is thus an indication of inequity. We suggest the three following indicators:

Low-income access = Number of private trips on average in the bottom 50 percent/Number of private trips on average in the total population

Medium-income access = Number of private trips on average between the 50th-90th percentiles/Number of private trips on average in the total population

High-income access = Number of private trips on average in the 10 top percent/Number of private trips on average in the total population

If an indicator is less than 1, it means that the corresponding population gets a smaller share of the total number of trips than would be expected with perfect equity.

Similarly calculated indicators may be used for showing other inequities by simply looking at different groups of the population: physical disability; genetic background; age; etc.

Equity is also linked to the affordability of a trip for a given person. In order to capture this, we use another well-known indicator in the economic field: the Gini coefficient. The basic assumption for equity here is that the price of a given trip should be roughly proportional to the disposable income of the person, regardless of other factors like the purpose of the trip or the specific profile of the passenger. The Gini coefficient can be computed graphically using the cumulative distribution of the ratios price/income or via the formula:

$$e_{gini} = \frac{\sum_i \sum_j |p_i/i_i - p_j/i_j|}{2N \sum_i p_i/i_i}$$

which is the average absolute difference of price/income over all the pairs of people in the population. The Gini coefficient is equal to 0 when the ratios are the same among the population.

The inequalities of affordability are not the only interesting part of this area however. It is also important to keep the general, average cost of the trip per passenger at a low level. In addition, a measure of the average cost of a trip is deeply linked to the cost-efficiency KPA. The difference lies in the point of view taken: the cost-efficiency KPA relates more to operator concerns – the supply – whereas affordability is linked to the passenger – the demand. In perfect competition situations (including perfect information and unbounded rationality), both areas are supposed to measure the same thing: the company offers the exact price which covers its costs, including return on investment.

The problem of defining an average affordability measure is that the offer is not constant in time: the price can increase for instance, but so does the quality of the trip – because it is faster for instance. However, these considerations bring us back to the issue of efficiency, which measures the quality of the output given an input. Here instead, we focus only on the price itself, and so we simply suggest using the average ratio between the price of a trip and the income of the passengers.

Finally, the idea behind the Reach MFA is at the heart of the 4HD2D target. The problem of reaching any destination from any point in Europe in a reasonable time is an open challenge that relates to the issue of population distribution and infrastructure development. Measuring the time of travel between any two points in Europe is indeed the simplest way of defining a metric for this MFA.

Reach is a measure of how far one can get from their door of origin, in our case in less than 4 hours. For any given point in Europe there will be a maximum distance that can be travelled in 4 hours. This is a function of the distance from that door to one or more airports, the time taken to transit the airport, the number of destinations available at the airport(s) and how long it takes to fly to them, including connections, and how long it takes to transit the arrival airport. The time taken for surface egress from the arrival airport is relatively unimportant in this indicator, since it doesn't much alter the total distance travelled, while the access time to the nearest airport will have a large impact on it. But the major qualifier will be the offer from local airports.

It can be imagined that this indicator can be shown as a colour-map of Europe, where the colour indicates the distance that can be travelled in 4 hours. To convert this into an indicator, we take the 10th percentile value of this metric; people starting from 10% of doors cannot travel this distance in four hours.

3.1.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
ACEQ1	Y	4-hour reach	The distance that can be attained, within Europe, from 90% of European doors of origin in exactly 4 hours	Percentage	Seasonal
ACEQ2		Low-income access	Number of private trips on average in the bottom 50% by income / Number of private trips on average in the total population	Unitless	Yearly
ACEQ3		Medium-income access	Number of private trips on average between the 50th-90th percentiles by income / Number of private trips on average in the total population	Unitless	Yearly
ACEQ4		High-income access	Number of private trips on average in the 10% by income / Number of private trips on average in the total population	Unitless	Yearly

Code	Key?	Name	Definition	Unit(s)	Scope
ACEQ5	Y	Income access disparity	Number of private trips on average in the top 50% by income / Number of private trips on average in the bottom 50% by income	Unitless	Yearly
ACEQ6		Carless access	Number of private trips on average by people in households without a car / Number of private trips on average in the total population	Unitless	Yearly
ACEQ7	Y	Disabled access	Number of private trips on average by disabled people / Number of private trips on average in the total population	Unitless	Yearly
ACEQ8		Affordability	Average ratio between the price of a passenger's trip and their income	Unitless	Seasonal
ACEQ9		Unaffordability	Percentage of passengers whose trip-price to income ratio value exceeds the average	Percentage	Seasonal

3.2 Cost-effectiveness

Cost-effectiveness involves comparing a given output of a system with how much it costs to produce it. In the area of services, the output is not always easy to define since a system can be considered as producing several distinct outputs at the same time, all of them given different importance by different individuals. So in order to define a cost-efficiency indicator for mobility, we must turn to the question of what the primary goals of the transport system are.

The basic idea of transport is to take people or goods from point A to point B. In this regard, a first metric one could define is the total throughput of the transport system divided by the total cost incurred. However, DATASET2050 is only interested in journeys with an air leg, so we would have to separate out all of the costs not associated with these journeys, including their share of the infrastructure. Instead, one could measure the total number of kilometres of passenger trips that include an air leg divided by the cost of undertaking them. This has of course the down-side that artificially longer trips are more cost-efficient, which is why this KPI should be used in conjunction with the efficiency KPIs presented in section 3.3.

Measuring the cost is not an obvious matter either, because the cost to the consumer is distinct from the cost to the companies and to society as a whole. This can be because of subsidies from the state for instance, or because of dividends given to shareholders. As a result, two distinct measures of cost efficiency should be considered:

- The total distance travelled divided by the total price paid by consumers,
- The total distance travelled divided by the total cost to the different companies involved in the transport system.

The first KPI is probably easier to measure to some extent, and can easily be used locally (e.g. for a given type of trip). Computing the second requires having access to the financial data of all the actors involved and is only computable on a very large scale (because companies are typically involved at different location at the same time).

More generally, since cost-effectiveness is the ratio between an output of the system and an input, many different definitions of cost-effectiveness can be given. The following table shows the possible inputs (denominator) and outputs (numerator) leading to the ratios that could be useful in this KPA.

i₩O	Number of passengers	Total number of passengers-kms	Total number of passenger-kms / Total travel time	Number of tonne-kms (for freight)	Total subjective value for passengers
Price for passengers	Inverse of average price	pax-kms per euro spent by pax	pax-speed per euro spent by pax	tonne-kms per euro spent by client	value per euro spent by client
Cost for airline	pax per euro of operational airline cost	pax-kms per euro of operational airline cost	pax-speed per euro of operational airline cost	tonne-kms per euro of operational airline cost	value per euro of operational airline cost
Cost for all stakeholders: airports, airlines, ANSPs,	pax per euro of total operational cost	pax-kms per euro of total operational cost	pax-speed per euro of total operational cost	tonne-kms per euro of total operational cost	value per euro of total operational cost

i₩O	Number of passengers	Total number of passengers-kms	Total number of passenger-kms / Total travel time	Number of tonne-kms (for freight)	Total subjective value for passengers
etc					
Number of hours of crew duty for airline	pax per hour of duty	pax-kms per hour of duty	pax-speed per hour of duty	tonne-kms per hour of duty	value per hour of duty

As highlighted in the table above and in section 2, another aspect of cost-effectiveness is the subjective value that travellers put on their journeys - "was it good value for money?" This value is usually expressed in a common currency, since the whole concept of value of time can be expressed as "what is my time worth when it is spent this way?" or "how much am I willing to spend to pass my time this way rather than that way?". As explained in section 2, this is estimated through different means, including surveys. After evaluating the value of time for different kinds of travel and different types of passenger, this can be extrapolated for the whole transport system and can be considered one of its outputs (the most important one, one could argue). This output can be compared to different inputs of the system, as shown in the previous table.

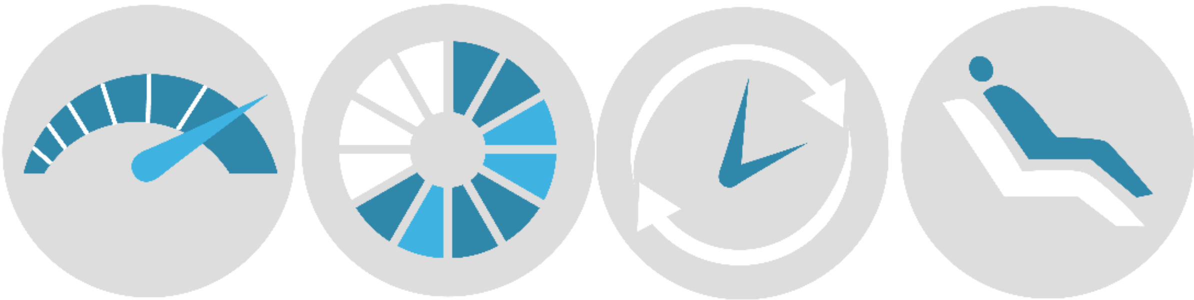
A further area of interest was added section 2, namely the number of beneficiaries - can something be considered cost-effective if, despite being value for money, it only serves a small part of its potential market and brings no benefit to anyone else. On the other hand, if it does bring benefit to other parts of society than just those who buy the ticket, shouldn't they pay towards the cost? Evaluating a metric for this is, however, an incredibly complex task and this will not figure in the indicators used in DATASET2050. It should nevertheless be taken into consideration at some point in the future.

3.2.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
COST1	Y	Passenger distance per euro spent	The total passenger distance travelled divided by the total travel price paid by consumers	pax.km/euro	Seasonal
COST2		Passenger distance per euro airline	The total passenger distance travelled divided by the total operational airline	pax.km/euro	Seasonal

Code	Key?	Name	Definition	Unit(s)	Scope
		cost	cost		

3.3 Efficiency



Efficiency is associated with the 'performance' of a given trip with respect to some baseline. For instance, SESAR uses the geometric length of the trajectory with respect to the great circle distance to define the efficiency of the flight trajectory. In the context of mobility, we are more interested in the time dimension, and so our measures of efficiency are related to duration.

To define efficiency, one needs a baseline, and this is not a trivial issue. It is related to some expectations of the 'best' one could do under some constraints. In the mobility case, there are two reasonable levels of expectation: what the trip could be under optimal conditions with the current processes and technology, and what it could be after improving the technology and processes. The first level of expectation can reasonably be measured and compared. To do this, the table below gives the definition of each of the best times achievable in the different legs and under which conditions they can be reached.

Phase	Basic assumptions	Conditions
D2K	Fastest possible mode or combination of modes is selected	No congestion or disruption during the (intermodal) surface access journey(s)
K2G	Shortest possible time, (a) with, (b) without, bags*, allowing for arrival at gate within minimum (boarding process) time specified by the carrier^	No queues for check-in, baggage drop, security, passport control, or customs**; no elective wait, buffer or retail time for the passenger
G2G	Shortest terminal, taxi-out, *available* routing (not GCD) and taxi-in configurations	No ATFM delay or other disruption; no flight buffer time; MCTs^ observed for connections

Phase	Basic assumptions	Conditions
G2K	Shortest possible time, (a) with, (b) without, baggage reclaim*	No queues for baggage reclaim, security, passport control, or customs**; no elective wait, (onward mode) buffer or retail time for the passenger
K2D	As per D2K	As per D2K

* We thus assume that even in future timeframes airport processes for passengers may be quicker without bags. This may not be the case, e.g. with remote check-in and baggage delivery, in which case (a) = (b).

^ These times are thus considered incompressible for the purposes of this measurement. In future timeframes they become less, but not zero.

** Alternatively, the 10th percentile of such queue times could be used.

The efficiency is then simply computed by dividing the best time with actual time of travel. Note that SESAR defines the total efficiency of trajectories ECAC-wide by computing the sum of the best lengths divided by the sum of the actual lengths. However, SESAR only deals with en-route trajectories here, and in this case distance is a proxy for fuel consumption, the real efficiency gain aimed for. We consider that the average of the ratios of times for each trip is more in line with what the DATASET2050n efficiency KPI is trying to capture.

The second level of expectation is obviously more complicated to compute since it cannot be based on actual data but needs to be the result of projections. The best time is then estimated by modifying the durations measured for the current baseline. By using this second baseline (for instance corresponding to 2050), one can quantitatively measure the gap between the current situation and the policy-makers' ambitions.

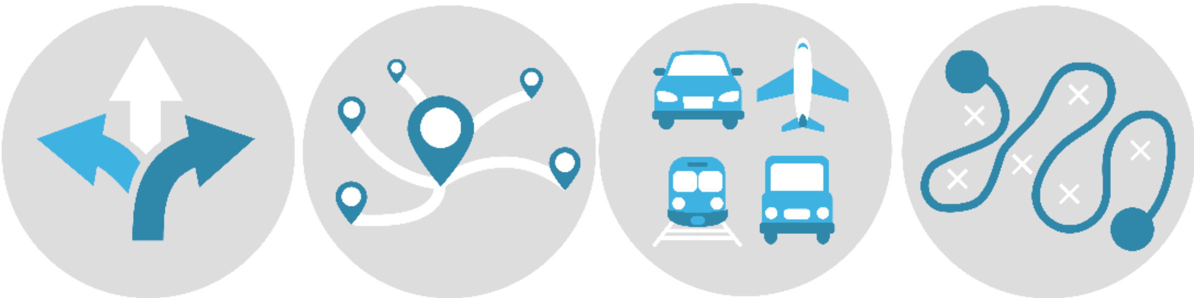
3.3.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
EFFI1		Pax time efficiency	Best possible journey time[1]/actual time of travel	Unitless	Seasonal
EFFI2		Average time efficiency	Average of EFFI1 for all passengers	Unitless	Seasonal
EFFI3	Y	Time efficiency per-	Percentage of journeys for which EFFI1 ex-	Percentage	Seasonal

Code	Key?	Name	Definition	Unit(s)	Scope
		formance	ceeds 0.8		

[1]without bags, no queuing, minimum connection times

3.4 Flexibility



The flexibility KPA is made of three FAs: diversity of destinations, multimodality, and resilience.

The first one is linked to the possibility of reaching a large number of destinations from a given origin. Moreover, we want to emphasise the fact that reaching very different destinations is more important for this KPA than reaching similar destinations. As an example, a passenger from a city A could reach several cities in different countries but then have little transportation means to the surrounding areas, whereas a passenger from a city B could reach only another city C and have efficient transportation from there to continue the journey, but to destinations quite similar to C.

We start by considering a maximum travelling time of 4 hours,. We consider an origin O for the trip, somewhere in Europe and not necessarily an airport itself. We consider all the possible destinations D_j reachable in 4 hours from O. From O, it takes m_x minutes to get to K_x^O (Kerb of origin airport x). There is then a list of destination airports, whose kerbs are signified as K_y^D (Kerb of destination airport y), that can be reached from each K_x^O such that the journey time f_{xy} from K_x^O to K_y^D < 4h - m_x). Finally, each D_j is a destination door that can be reached from each K_y^D in (4h - m_x - f_{xy}). The physical distance (e.g. great circle distance) between O and D_j is d_{ODj}.

The following metric reflects the diversity of destinations from O:

$$\delta_O = (1/\sum_j d_{ODj}) \sum_i (d_{ODi} \sum_{j \neq i} d_{DiDj}/d_{ODj})$$

For a given number of destinations, the measure increases with the distance between destinations. For a fixed distances between destinations, the measure increases with the number of destinations. As it is above, the metric is normalised properly against the absolute distances involved during the trips. This can be modified if needed, to give a greater weight to further destinations. The metric is designed to be computed based on a single origin. It can then be averaged over all possible origins in a given area or Europe-wide.

If enough computing power and data access is available, it a map of Europe with each point coloured according to the size of the (not necessarily contiguous) area that can be reached within 4 hours from that point could be envisaged. A single metric can be produced by taking the integral of these area values divided by the total area of the EU.

One can also consider diversity in a cultural context, which in Europe most frequently means its countries, each of which has been coloured by centuries of tradition, annexation, separation etc. The countries, or "member states" are, however, of vastly different sizes and there are often major cultural variations within each of them (Prussians vs. Bavarians in Germany, for example). Eurostat's *nomenclature d'unités territoriales statistiques* (NUTS) (Classification of Territorial Units for Statistics - http://ec.europa.eu/eurostat/web/nuts/overview) subdivides each of the EU's 28 member states into several high-level regions (NUTS 1), generally the states' own highest administrative subdivisions. In total, there are 98 NUTS 1 regions which, though not identical in size, are more closely aligned in terms of population while still generally representing specific cultural traits. The number of NUTS 1 regions per country is given in the table below.

Country	NUTS1s	Country	NUTS1s	Country	NUTS1s	Country	NUTS1s
AT	3	BE	3	BG	2	CY	1
CZ	1	DE	16	DK	1	EE	1
EL	4	ES	7	FI	2	FR	9
HR	1	HU	3	IE	1	IT	5
LT	1	LU	1	LV	1	MT	1
NL	4	PL	6	PT	3	RO	4
SE	3	SI	1	SK	1	UK	12

These NUTS 1 regions are further sub-divided into NUTS 2 areas and then further into NUTS 3 areas. Although in some cases NUTS 2 sub-regions can have very strong cultural identities - Catalonia is a NUTS 2, for example -

A good measure of diversity of destinations then would be an association of the number of countries and the number of NUTS 1 regions that can be reached in 4 hours from a given destination. It is important, however, that the indicator show greater diversity if a single NUTS 1 region can be reached in each of 8 states than if 8 NUTS 1 regions, all from a single state, can be reached. An indicator formed from both the number of countries and the number of NUTS 1 regions accessible must, therefore, be created. Such an indicator could be:

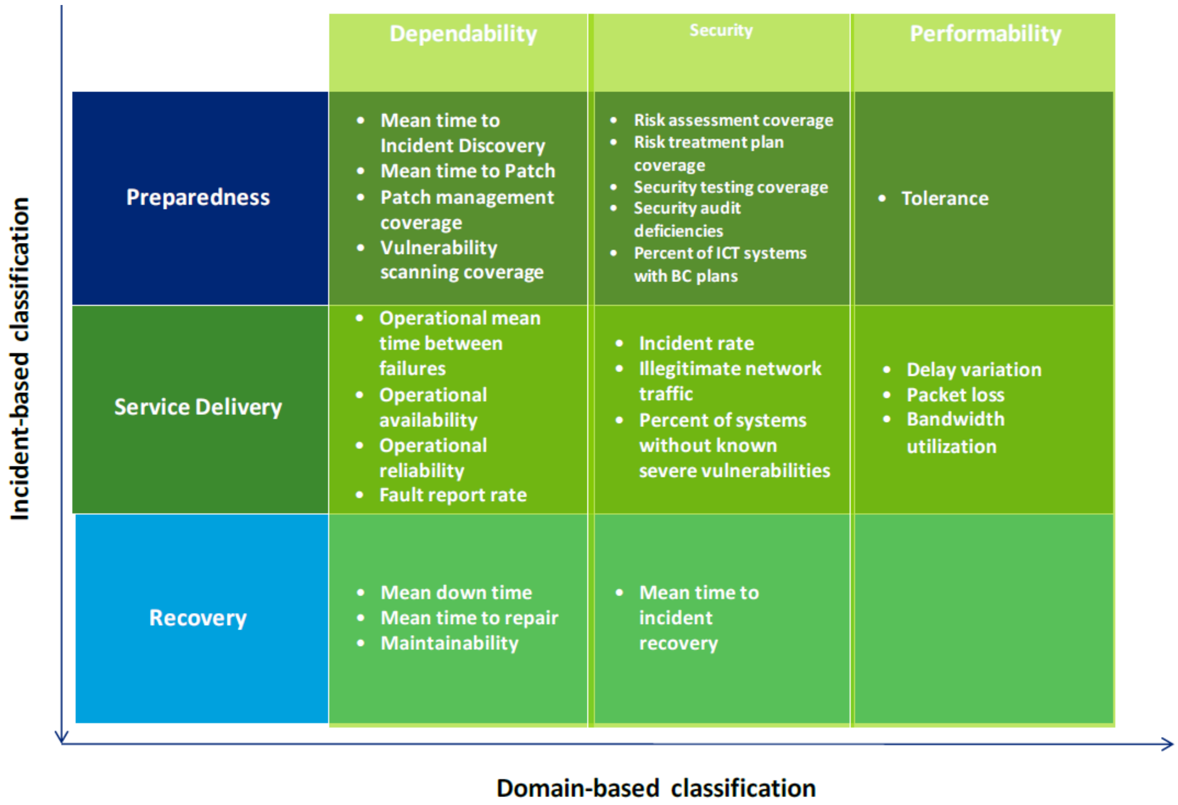
Cultural diversity score = number_of_NUTS1 x number_of_countries reachable

in this case reaching 8 NUTS 1 regions in 8 countries would give a score of 64, whereas 8 NUTS 1 regions in just one country would produce a score of 8 as would reaching 2 NUTS 1 regions in each of 2 countries. The minimum value of the index is 1 (the home NUTS 1 region in the home country) and the maximum is 98 x 28 = 2744. A KPI based on this indicator could be:

The number of origins giving rise to a cultural diversity score greater than 1372 (equivalent to $^{2}/_{3}$*98 * $^{3}/_{4}$*28 or half of the maximum). This figure can be refined from current data.

A graphic representation of this measure diversity can be produced similar to the one described above.

A traveller needs to know that if a plane, train, bus or coach is cancelled, there will be an alternative available to help them onward with their journey in time to not miss their next connection. This is rarely the case at present! However, if we are to achieve the Flightpath2050 goal by 2050, such measures will need to be put in place. For an analysis of this resilience, we can take our cue from work performed on IT network resilience by ENISA, the European Union Agency for Network and Information Security [ENISA, 2011]. They have categorised resilience metrics into incident-based and domain-based classifications as follows:



Obviously, many elements here are irrelevant to our needs, but since transport is a network there are many others, especially in the "Dependability" domain, that, "mutatis mutandi", can be taken on-board. In DATASET2050, we are mostly concerned with time; it is reasonable, therefore, that metrics relating to time should be considered as most important to our requirements:

- Mean time to patch (i.e. to implement a workaround solution);
- Patch management coverage (i.e. availability of workaround solutions);
- Mean time to repair (i.e. to have standard service again).

The service-delivery metrics in the dependability domain are more concerned with reliability than resilience and therefore should be taken into consideration for the "predictability" indicator.

In general, for the 4-hour door-to-door objective, it is the "mean to patch" indicator that is the most pertinent; how long before our traveller is back on their way? It is quite possible that a workaround could be implemented during the buffer time the passenger allowed themself, so the effect of the failure could be nil.

3.4.1 List of proposed indicators

Code	Key ?	Name	Definition	Unit(s)	Scope	Com-ments

Code	Key ?	Name	Definition	Unit(s)	Scope	Comments
FLEX 1	Y	Distance diversity of destinations	$\delta_O = (1/\sum_j d_{ODj}) \sum_i d_{ODi} \sum_{j \neq i} d_{DiDj}/d_{ODj}$	Unitless	Seasonal	
FLEX 2		Cultural diversity of destinations	Number of NUTS1 regions reachable * number of countries reachable, for a given origin.	Count		
FLEX 3		Cultural diversity performance	Percentage of population whose FLEX2 indicator exceeds 1372	Population percent		1372 is $^{2}/_{3}$*98 (NUTS1 regions) * $^{3}/_{4}$*28 (EU countries) (i.e. 0.5*98*28)
FLEX 4		Mean time to fix	Average time necessary for a replacement service to be available to replace a cancelled one	Minutes		

3.5 Interoperability

The key to analysing interoperability performance is the relationship between the "transitions" and the "phases" that make up the journey.

The most simple measure of (non-)interoperability is the number of transitions in a trip, or the number of transitions in a trip per unit of time. This can be considered a good proxy for the cognitive load of the passenger when across different, vaguely similar travel options. It is very easy to measure in reality and does not require any 'subjective' data. Unfortunately, it fails in particular when one tries to introduce new concepts. For instance, smart travel card does not change the number of transitions, but reduces their cognitive load greatly.

To go further, one has to tackle the issue of the intensity of the cognitive load associated with the transitions, and even the phases. This is much more difficult to measure since it is difficult to observe. One possibility is to consider the extreme case where the passenger always uses their maximum cognitive capacity to make the transition and no cognitive capacity during actual phases. This is quite unrealistic for normal transitions – when everything is going well and the passenger just needs basic orientation capacities for instance – but might be a fairly good approach in times of heavy disruption – for instance when the passenger has to find alternative itineraries in a short time. Under this assumption, the total time spent during the transition can be considered to be the total cognitive load 'spent' for it. A second measure of interoperability could therefore be the ratio of the time spent during phases to the total travel time. The higher the ratio, the less time the passengers spend in transition and the easier it is for them to undertake the journey. This ratio will be quite easy to compute in practice because of the relative ease in measuring the different times involved.

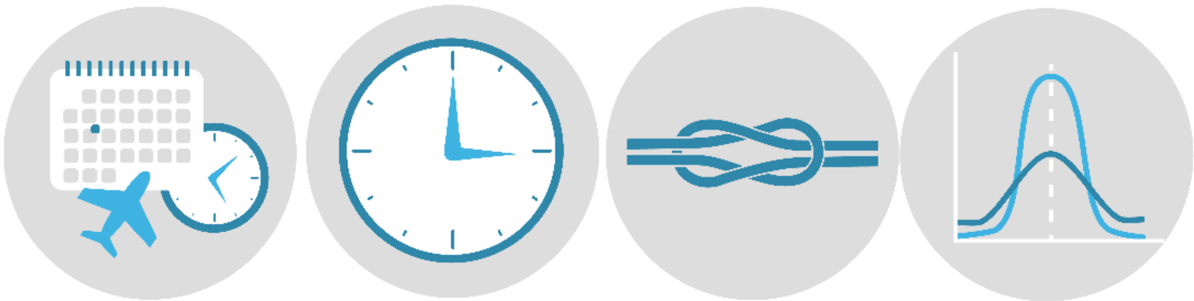
An even more advanced measure would take into account the real cognitive load on the passenger. This is of course impossible to do extensively, but some targeted questionnaires could help in estimating it since people typically associate cognitive load with a feeling of discomfort. The use of what neuro-economics sometimes calls 'system 2' – the 'conscious' part of the brain – is demanding, whereas 'system 1' – the intuitive part – is easy to use [Kahneman, 2011]. As a result, one could ask passengers to rate the comfort they experienced just after the transition, e.g. on arriving at the gate. These measures could then be used to weight the transitions differently with respect to their ease of processing. Thus a third measure for (non-)interoperability could be the sum (over the transitions) of the measures of discomfort throughout the trip. Finally, one could combine these last two indicators by taking the sum of the transition times, each weighted by the measure of discomfort, divided by the total (un-weighted) travel time. One could even extend this procedure to the phases of travel, when cognitive loads are sometimes non negligible (waiting times for instance).

3.5.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
INOP1		Journey transition time	Total time spent in transitions during a journey	Minutes	Journey

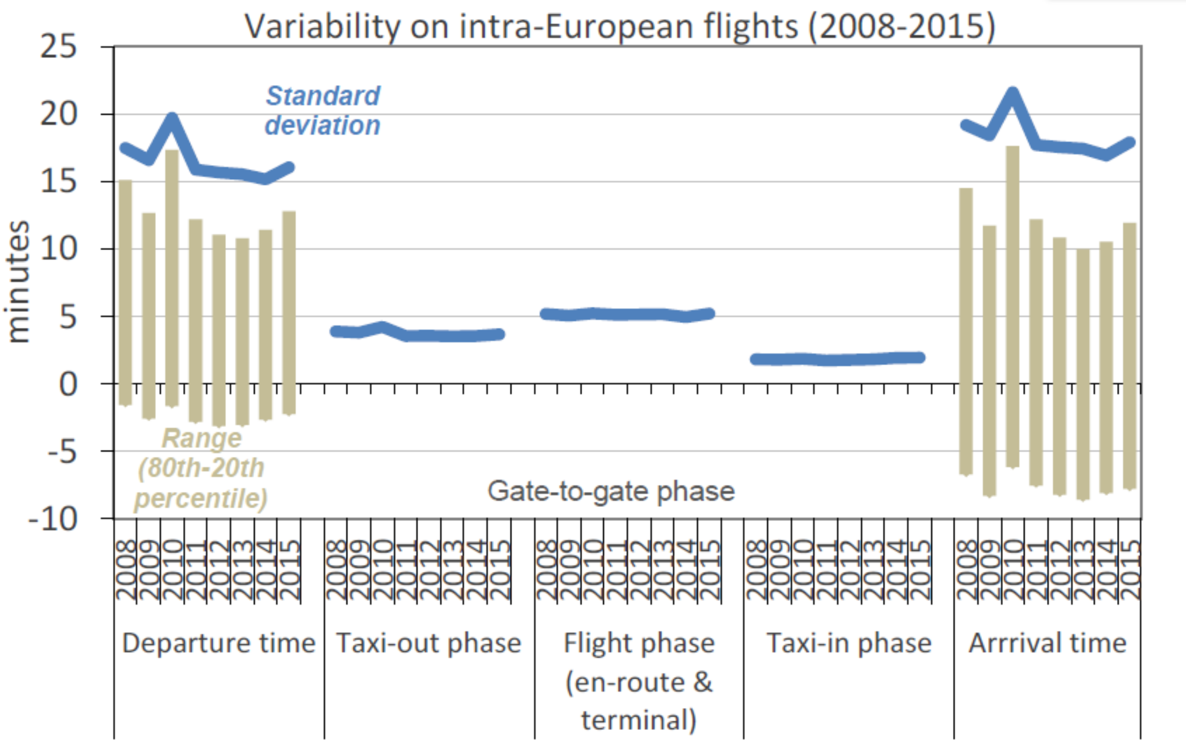
Code	Key?	Name	Definition	Unit(s)	Scope
INOP2		Number of phases	Number of phases required to complete a journey	Number of phases	Day
INOP3	Y	Transition-journey ratio	Average of (Time spent during transitions / total travel time for the journey)	Unitless	Day
INOP4		Average time per transition	Average of time spent per transition	Minutes	Day

3.6 Predictability



When looking at the requirements of DATASET2050, the variability, punctuality and reliability, not just of the air leg, but especially of the ground access modes is vitally important. Punctuality needs to be known and taken into account in planning (and preferably corrected). Variability gives rise to large buffer times that the passenger has to build into the time allowed for the different stages of the journey. Variability will also be a major factor in buffer times left for airport processes.

Variability is a function of the spread of (e.g.) arrival times, independent of the published arrival time. Predictability is a function of the variability in a large number of factors including departure delays, weather conditions, congestion, and route availability [PRR, 2016]. It can be seen that, for aviation, en-route performance helps to reduce the delay at arrival compared with the delay on departure, thus punctuality is improved; however, the spread of delays at arrival is greater than those at departure, thus predictability deteriorates over the flight.



Source: CODA; PRC Analysis

Punctuality - what percentage of flights finish within n minutes of the advertised time - is a major indicator used by transport providers to show their level of service to passengers. Obviously, DATASET2050 is looking at passenger journeys so we have to examine the flight punctuality for each passenger on that flight. The table below gives flight punctuality by EMEA airline with respect to published arrival times [OAG, 2017]

Europe, Middle East & Africa (EMEA)

Table 5: Top EMEA airlines by OTP*

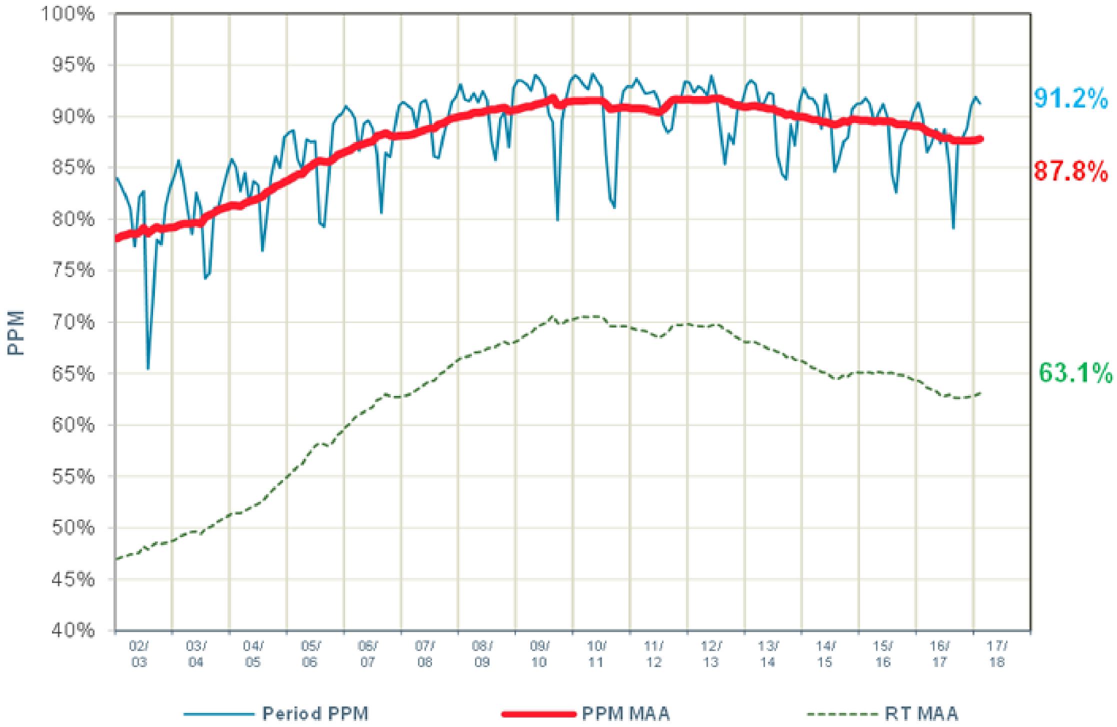
Rank	Coverage	Airline Name	Airline Code	OTP 2016
1	99.5%	KLM	KL	87.89%
2	80.0%	Flybe	BE	86.62%
3	97.2%	Iberia	IB	85.67%
4	82.7%	Monarch Airlines	ZB	85.67%
5	99.1%	Austrian Airlines	OS	84.89%
6	98.8%	Finnair	AY	84.12%
7	86.8%	Transavia	HV	83.98%
8	90.5%	Aer Lingus	EI	83.97%
9	99.0%	Gulf Air	GF	82.70%
10	89.4%	Jet2.com	LS	82.64%

* Regions are defined by IATA and OAG must have received data for at least 80% of scheduled flights operated by an airline. Airlines must also have operated a minimum of 18,000 flights in 2016 to quality for regional ranking.

A problem associated with punctuality is that it includes operators' contingencies for unpredictability already built into their schedules in the form of schedule buffer.

The two concepts may be combined by considering arrival time as a normalised probability function ($\int f dt = 1$) of mean t_μ and standard deviation σ. The smaller σ, the lower the variability. The greater the area of the distribution within the limits $t_p \pm n$ minutes (where t_p is the published arrival time), the higher the punctuality.

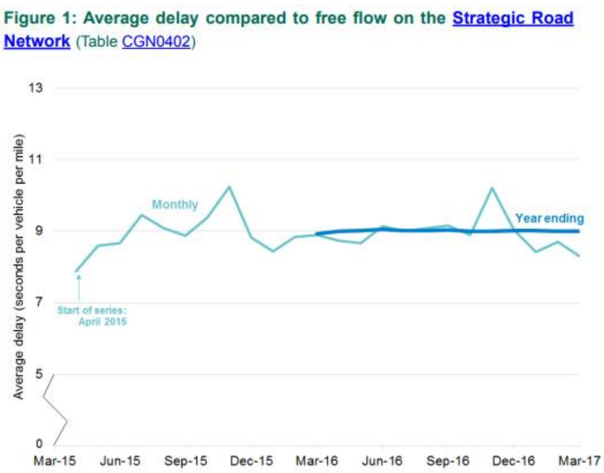
For European railways, the rail industry has a standard measurement of performance called the Public Performance Measure (PPM) that, in the UK at least, includes all trains and all factors (including weather, suicides, etc.) causing delay or disruption. It shows the percentage of trains that arrive at their terminating station on time, defined as less than 5 minutes from the scheduled time for commuter services and less than 10 minutes for long distance services. UK railway PPM from 2002 to 2017, including moving annual averages (MAAs), are given below [Network Rail, 2017]

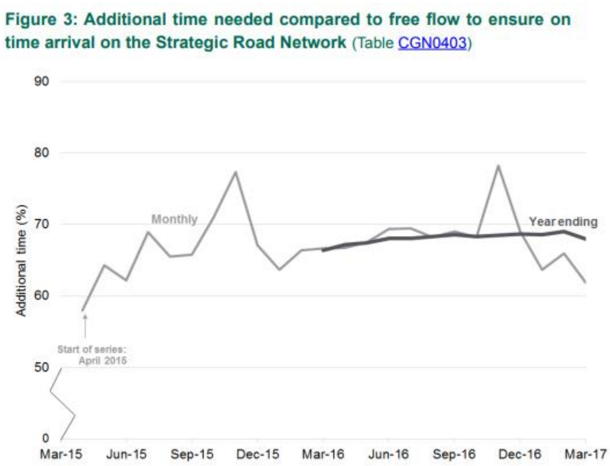


As well as the PPM, UK Network Rail also produces indicators for average lateness of passengers and for right-time performance - the percentage of trains arriving before or within 59 seconds of their scheduled time - see RT MAA on the above chart. Finally, they also publish details of cancelled and significantly late trains (CaSL), which is a measure of reliability.

The UK Department for Transport produces performance statistics for the average excess waiting time for frequent bus services [DfT, 2017a]. It is noticeable that, as opposed to trains and planes where arrival time is considered to be the most important, with buses it is departure time (the time when the bus picks up its passengers) that is analysed. However, since this is also the set-down time for alighting passengers, it is a perfectly good proxy for arrival time.

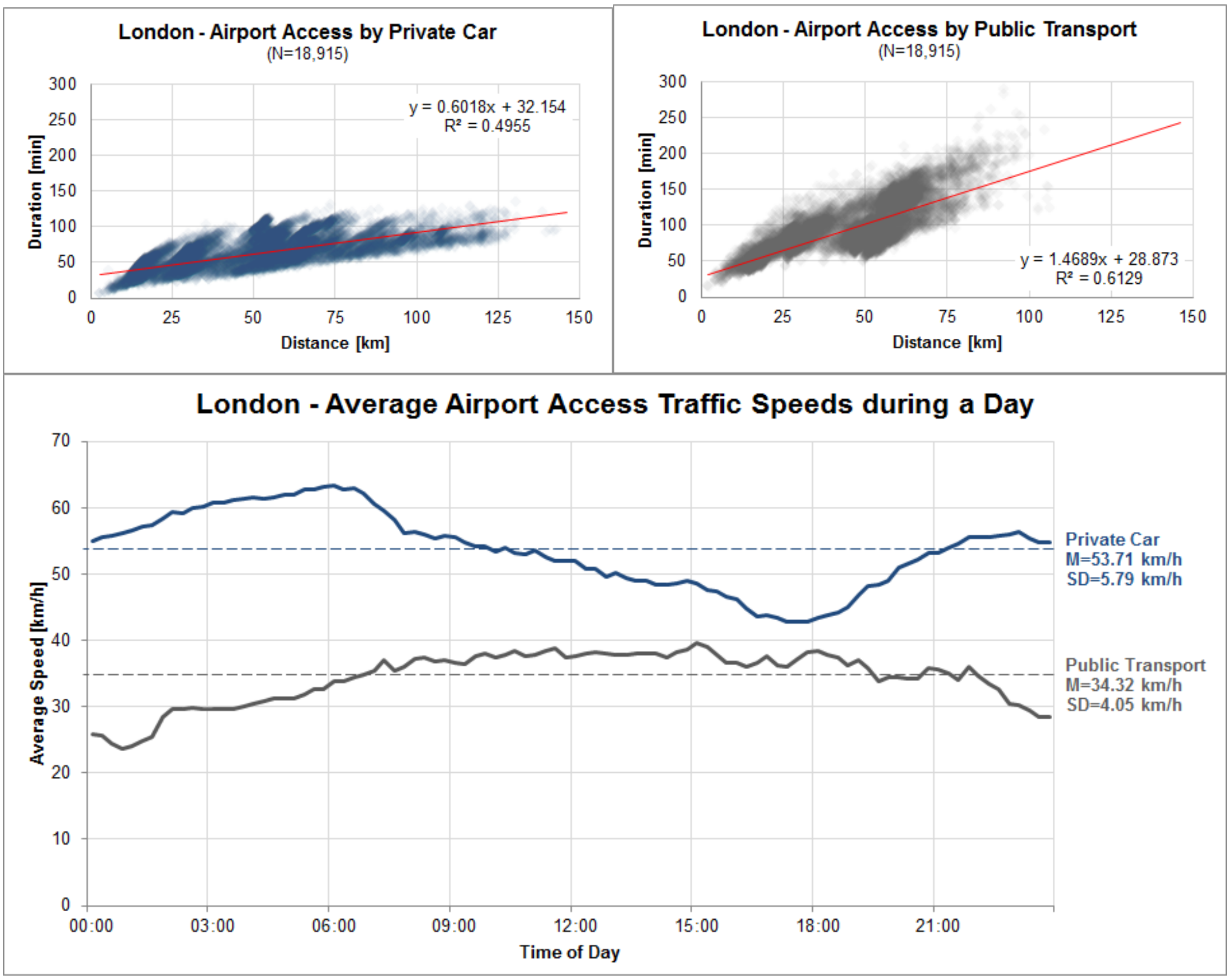
For roads, there are many factors that can affect the delay in a journey by car or taxi. These are generally brought together under the term "congestion". In the UK, the Department for Transport publishes annual "Travel time measures" [DfT, 2017b] which give average delay values in terms of seconds per mile travelled and in terms of percentage overhead required compared with free-flow:





These charts show the evolution of delays for the UK's Strategic Road Network (SRN) - mainly motorways and dual carriageways - compared with the free-flow time (the speed limit is generally 70mph, 112km/h). They show a 9 second delay per vehicle mile (s/veh.mile) (5.625 s/veh.km), or 17.5%. On local "A" roads (national class roads other than those in the SRN), this delay varies between 12 s/veh.mile (7.5 s/veh.km) on rural roads (speed limit 60mph, 96km/h) - 20% - and 60 spvpm (37.5 s/veh.km) on urban roads (speed limit 30mph, 48km/h) - 50%.

Deliverable 4.1 of this project showed that road traffic access speeds vary considerably during the day:



Reliability is a game changer: a bus or train not showing up or breaking down can mean a missed plane and a cancelled business trip or holiday. It is not likely to affect the door-to-door journey time as much as it will cancel the journey, unless the contingency measures that are part of the resilience discussed in the context of the flexibility KPI can kick in and enable the traveller to continue their journey in time.

Indicators for predictability will help understand how efforts to improve this can help towards reducing buffer times and improving the chances that a passenger will be able to complete their journey within 4 hours. Such indicators will include metrics on the variability (standard deviation in arrival time), punctuality (percentage of trips arriving within n minutes of their scheduled time) and reliability (percentage of trips cancelled or delayed excessively) not just of flights, but especially of the public transport services that will enable the passenger to accomplish the D2K and K2G phases of their journey. These metrics will build up into more specific indicators such as:

- the probability that delays in the D2K and K2G segments of the journey will result in the passenger's not being able to board their plane including being too late to be able to accomplish bag-drop etc. A standard minimum buffer time will be allowed.

- the probability that individual delays in each leg of a journey will result in a final delay greater than 15 minutes. This basically assumes that the D2K and K2G phases allowed the flight(s) to be caught, so we are concerned here with delay in take-off of the flight, and during the G2G, G2K and K2D phases.

A journey can be affected by many events throughout its duration and these events have different implications for the journey as a whole depending on the mode of transport or airport process concerned. These are summarised below.

Phase	Mode/Process	Event	Probable implication for journey
D2K	Walking/cycling	Crowds	Delay
	Car/taxi/minicab/car-hire	Traffic jam	Delay
		Breakdown	Cancellation
	Local public transport (bus/metro/tram)	Late leaving	Delay
		Missed	Delay
		Cancellation	Delay
	Fixed-timetable train/coach	Late leaving	Delay (but may be absorbed)
		Delayed arrival	Delay
		Missed	Delay or Cancellation (depending on service frequency)
		Cancellation	Delay or Cancellation (depending on service frequency)
	Airport shuttle (car-park/hotel/car-hire)	Traffic jam	Delay
		Breakdown	Cancellation
		Missed	Delay
		Cancellation	Delay
		Late leaving	Delay

Phase	Mode/Process	Event	Probable implication for journey
K2G	Check-in	Queues	Delay/Cancellation
		Missed	Cancellation
	Bag-drop	Queues	Delay/Cancellation
		Missed	Cancellation
	Border control	Queues	Delay/Cancellation
	Security	Queues	Delay/Cancellation
G2G	Boarding	Missed	Cancellation
	Flight	Technical failure	Major delay/Cancellation
		Cancellation	Cancellation
G2K	All processes	Queues	Delay
K2D	All legs	All causes	Delay

NB: In this table, Kerb (K) refers to the point of entry/exit of the terminal, not the airport.

The traveller will generally allow for a certain buffer time in their journey. This time is intended to cover, in the mind of the traveller, the delays they might face on the different transport modes they will use, as well as the possible queuing for airport processes. Its value may be large (even allowing for missed connections) or small, depending on the traveller's degree of pessimism and may be more or less an accurate reflection of the buffer required, depending on their knowledge of the general delay situation on their route, and of the specific one for that occasion. This buffer will have a bearing on the probabilities mentioned above.

It is important to note that just adding n minutes to the journey time does not necessarily improve the chances of getting to the airport on time. There's no advantage to getting to the bus stop outside your house 25 minutes before the bus goes rather than 5 minutes before. However, if busses leave every 10 minutes, there is an advantage to being there 20 minutes earlier, but then only if getting an earlier bus improves your chances of getting the next transport leg. It follows, therefore, that buffers need to be calculated in reverse order:

- What time do I need to be at the airport terminal by?
- Which transport mode selections will get me there most predictably and, preferably, fastest?
- What departure time of the last leg L_n should I take to be sure of getting there in time?
- What departure time of leg L_{n-1} should I take to be sure of catching leg L_n?
- etc.
- When do I have to leave the house to be sure of catching leg L_1?

In fact, this concept applies to the entire journey, every leg of which is determined, in reverse order, by the time the traveller needs to be at the door of their destination.

It follows that it is possible to calculate what minimum buffer time would required at the door of origin to ensure a, say, 95% chance of arriving at destination within 15 minutes of the planned arrival time.

3.6.1 List of proposed indicators

The following metrics and indicators are proposed for the Predictability Key Performance Area.

Code	Key?	Name	Definition	Unit(s)	Scope	Comments
PRED1		Variability on intra-European flights	Standard deviation in arrival time of scheduled flights at their destination airport around the mean arrival time of that flight	minutes	Seasonal	This could be yearly if there is no seasonal effect.
PRED2		Variability on airport public transport	Standard deviation in arrival time of public transport surface access modes at the airport around the mean arrival time of their journey	minutes	Yearly, by access mode	
PRED3		Punctuality of intra-European flights	Percentage of scheduled flights that arrive within 10 minutes of their scheduled arrival time (irrespective of their departure time)	percentage	Seasonal	This could be yearly if there is no seasonal effect.
PRED4		Punctuality of airport public	Percentage of scheduled public transport journeys that arrive at	percentage	Yearly, by access	

Code	Key?	Name	Definition	Unit(s)	Scope	Comments
		transport	the airport within 5 minutes of their scheduled arrival time		mode	
PRED5		Reliability of intra-European flights	Percentage of scheduled flights that are cancelled or delayed by more than two hours	percentage	Yearly	Two hours is a parameter that can be changes if necessary
PRED6		Reliability of airport public transport	Percentage of scheduled public transport journeys that are cancelled or delayed by more than 30 minutes	percentage	Yearly, by access mode	The value 30 can be changed if necessary
PRED7		Likelihood of missing a flight	Probability that delays in the D2K and K2G segments of the journey will result in the passenger's not being able to board their plane. (Includes being too late for check-in etc.)	percentage	Per journey	
PRED8	Y	Likelihood of arriving more than 15 minutes late at destination	Probability that individual delays in each leg of a journey will result in a final delay greater than 15 minutes, including total cancellation of the journey	percentage	Per journey	The value 15 can be changed if necessary
PRED9	Y	Minimum buffer time required	Average minimum buffer time required at the door of origin to ensure a 95% chance of arriving at destination within 15 minutes of the planned arrival time	minutes	Seasonal	The values 95% and 15 minutes can be changed if necessary

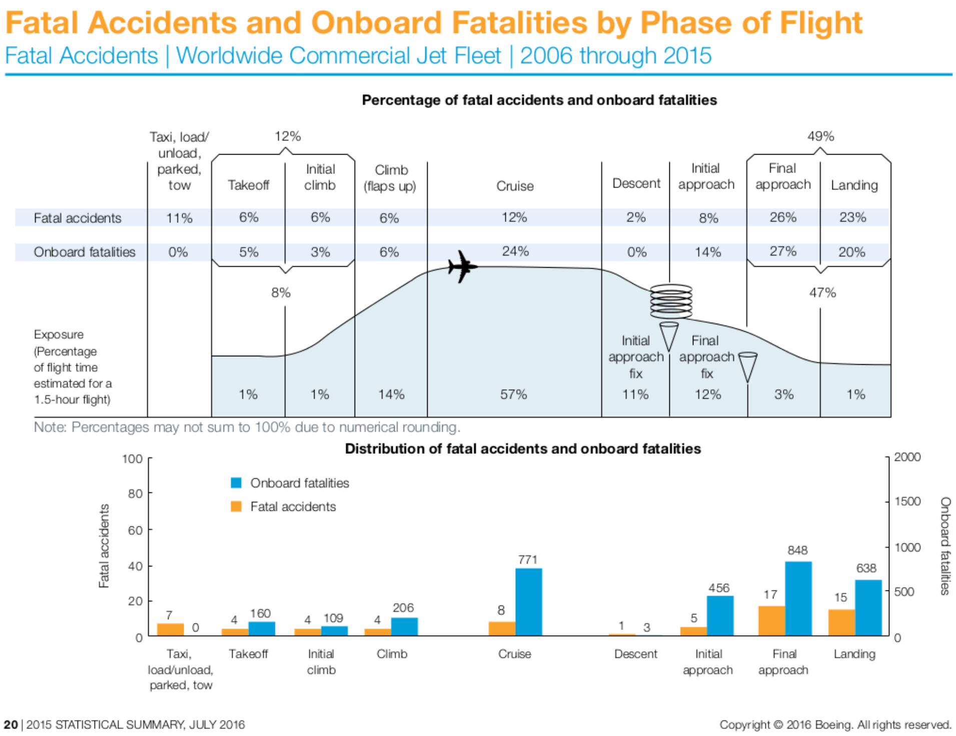
3.7 Safety

There are many ways to measure transport safety. From the passenger's point of view, safety can be summarised as: 'I want to still be alive and not have suffered a life-changing accident when my trip ends'. Unfortunately, this is not always the result. The job of a safety indicator is, therefore, to measure how often an undesired result occurs.

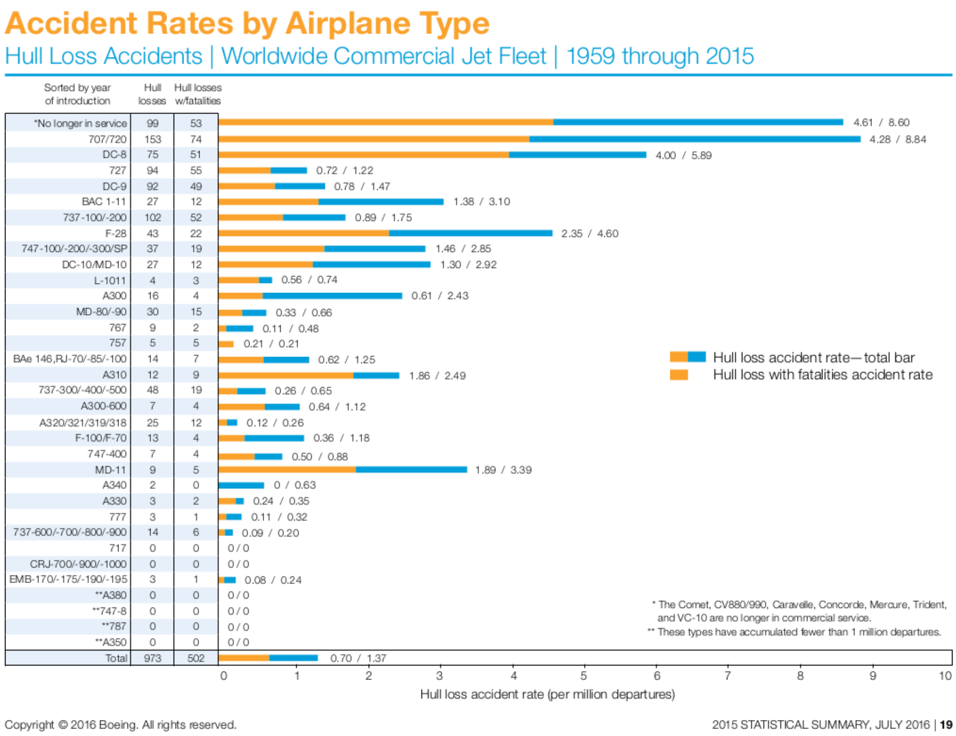
Indicators can range from the number of accidents involving death or life-changing injury for every n journeys to the number of deaths or life-changing injuries per passenger-km. The results of using these can vary considerably. Additionally, different sectors of the transport system have their own specific ways to measure safety that depend upon that sector. For example, in Air Traffic Management, the Risk Analysis Tool (RAT) method [EUROCONTROL, 2015] is used to produce indicators on the effectiveness of safety management.

It is not considered that complicated indicators such as the RAT method are required for our purposes. On the other hand, in a door-to-door journey, it is necessary to take every segment of the journey into account and it is essential that the safety indicator used be capable of showing the safety difference between several mobility options: ground access by train or car; flight between two hubs with its associated ground access, compared with a point-to-point flight from smaller local airports with much shorter ground access; etc.

An initial indicator could be the number of deaths or life-changing injuries per million passenger journeys. This responds exactly to the passenger viewpoint given above. It doesn't, however, take the length of the journey into account; the longer a journey is, the more opportunity there is for an accident. So the above indicator could be modified to include the number of deaths or life-changing injuries per million passenger kms. While this is logical for trips by road (whatever the form of transport used) it is not the case for air journeys, where the length of the flight is generally unrelated to safety - the main risk of accident is during take-off and especially landing [Boeing, 2016].



However, flight safety statistics vary according to airplane model [Boeing, 2016]



and according to airline [JACDEC, 2017].

RANK	AIRLINE	CODECS	COUNTRY	INDEX 2016
1	Cathay Pacific Airways	CX, CPA	China,Hong-Kong	0,005
2	Air New Zealand	NZ, ANZ	New Zealand	0,007
3	Hainan Airlines	HU, CHH	China	0,009
4	Qatar Airways	QR, QTR	Qatar	0,009
5	K L M	KL, KLM	Netherlands	0,011
6	EVA Air	BR, EVA	Taiwan	0,012
7	Emirates	EK, UAE	United Arab Emirates	0,013
8	Etihad Airways	EY, ETD	United Arab Emirates	0,014
9	QANTAS	QF, QFA	Australia	0,015
10	Japan Airlines	JL, JAL	Japan	0,015
11	All Nippon Airways	NH, ANA	Japan	0,016
12	Lufthansa	LH, DLH	Germany	0,016
13	TAP Portugal	TP, TAP	Portugal	0,017
14	Virgin Atlantic Airways	VS, VIR	United Kingdom	0,017
15	Delta Air Lines	DL, DAL	USA	0,018
16	Air Canada	AC, ACA	Canada	0,020
17	jetBlue Airways	B6, JBU	USA	0,020
18	Virgin Australia	VA, VOZ	Australia	0,020
19	British Airways	BA, BAW	United Kingdom	0,023
20	Air Berlin	AB, BER	Germany	0,023

It follows, therefore, that our initial indicator should be the average of a metric for the probability of a given passenger dying on their journey (life-changing injury is not often an available statistic) over a given period, expressed as the number of deaths per million passenger journeys, where the per-journey metric would be calculated as a mix of km-based and journey-based statistics, taking modes of transport, the airline(s) used, the plane(s) used, and the country or countries involved in each leg of the journey into account.

$$M = 1 - \prod_{i=1}^{n}(1 - m_i d_i)$$

where m_i is the fatality rate per km of the i^{th} transport mode in the journey and d_i is the length of the i^{th} journey in km. For rail and air legs, whose fatality rates are given per journey, $d_i = 1$.

Eurostat data on passenger traffic and fatalities is given in the appendix. It gives an analysis of recently reported traffic and deaths for different reported transport modes (pedestrian, bicycle, motorcycle, car, local public transport, rail and air) in the 28 EU and 4 EFTA countries.

These data show that aviation accident rates are incredibly small nowadays. There were two major air crashes in Europe in the 10 years from 2006-2015 - Spanair Flight 5022 in 2008, GermanWings Flight 9525 in 2015 (Eurostat). These accounted for 304 of the total of 434 air fatalities (including crew) in those years. For the years 2011 to 2015, there were 37.6 fatalities/year on average, for over 556 million intra-EU passenger journeys in 2015, or one death per 14.8 million passenger journeys.

Train safety has also improved over the last few decades and there were 45 rail passenger deaths per year on average in Eu28+4 between 2011 and 2015. The fatality rate is 1 death for 209 million passenger journeys and 1 per 9,721 million passenger kilometres.

For car journeys to and from the airport, data from those countries that report to Eurostat show a fatality rate of 1 for every 228 million passenger kilometres. The rate for motorcycles (including mopeds) is 1 to 12 million passenger kilometres, and that for buses and coaches is 1 to 2,515.

Norway is the only country that reports bicycle use to Eurostat; they recorded 10 fatalities on average over the 5 years from 2011 to 2015 for 1,114 million passenger kilometres of bicycle use per year: or a ratio of 1 to 111. There were 2093 bicycle deaths on average per year in EU28+4 and 5,661 pedestrians were killed in road accidents.

These values are summarised below:

Transport Mode	Deaths		1 death per	
Bicycle	8.977E-09	/pax.km	111.40	Mpkm
Motorcycle	8.375E-08	/pax.km	11.94	Mpkm
Car	6.030E-09	/pax.km	165.83	Mpkm
Local public transport (LPT)	3.976E-10	/pax.km	2,515.35	Mpkm
Rail	1.029E-10	/pax.km	9,721.04	Mpkm
	4.782E-09	/pax	209.11	Mpax
Air	6.758E-08	/pax	14.80	Mpax

As has been stated above, the fatality-rate values used should preferably be those for the country in which a leg of the journey took place. Care should be taken, however, with international legs. The two major air crashes mentioned above took place in Spain and France, but should they be considered as increasing the risk to passengers who fly over those countries? The Spanair crash was caused by a mix of pilot-error, a faulty warning light and a bad technical workaround for the faulty light. Given that the pilot, the airline, the technician, and the airport - Madrid Barajas - were all Spanish, there is a reasonable argument for saying that this should count towards the safety of Spanish air travel. The GermanWings flight started, as did the Spanair one, at Barcelona airport. The airline and pilots were German. The crash, however, was caused by the co-pilot's committing suicide. Had his flight that day taken him over the Italian Alps rather than the French ones, the crash would therefore have happened in Italy, not France. Such a flight cannot meaningfully be attributed to a single country's accident statistics.

In the light of this, it is recommended that air travel be considered as a single risk of 1 fatality per 14.8 million passenger trips.

3.7.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
SAFE1	Y	Number of deaths per million passenger journeys	$\frac{\sum_{j=1}^{N}(1-\prod_{i=1}^{n_j}(1-m_{ij}d_{ij}))}{N} \times 1,000,000$ where: N is the number of journeys j in the reference period; n_j is the number of legs i in the j^{th} journey m_{ij} is the fatality rate per km of the i^{th} leg of the j^{th} journey d_{ij} is the distance travelled in the i^{th} leg of the j^{th} journey; $d_{ij} = 1$ in the case of rail and air legs whose fatality rate is given per passenger journey.	Fatalities per million passenger journeys	Yearly

3.8 Security

It is considered that nothing in the 4HD2D concept is going to change a passenger's security to any measurable extent. It has been decided, therefore, to not include a KPI for security.

However, as with all other aspects of modern life, transport is heavily reliant on modern information infrastructure and with this comes the necessity for strong cyber-security. We therefore propose a metric on this, though we do not consider this to be a key indicator. This indicator is simply the number of cyber-security "events" on in the transport system per year.

3.8.1 List of proposed indicators

Code	Name	Definition	Unit(s)	Scope
SECU1	Number of cyber-security events	Number of cyber-security "events" on in the transport system per year	No. of events	Yearly

3.9 Sustainability

KPIs related to environmental sustainability are usually proxies aiming at giving an idea of how much a process is irreversible in terms of environmental impact. By 'irreversible', we mean that the natural recovery time is much longer that the typical span of human civilisation, or that artificial means of recovery are beyond our reach for now.

The typical impact of our industrial processes is borne by the environment, with the most important consequence being global warming. In order to measure the impact of the transport system towards this (undesirable) consequence, it is customary to focus on the production of greenhouse-effect gases such as methane or carbon dioxide. These gases are not toxic per se for human beings in such small concentrations, but greatly participate to global warming, according to climate models. A list of KPIs covering the global warming effect could thus be:

- Volume of CO_2 produced per kilometre travelled by each passenger;
- Volume of CH_4 produced per kilometre travelled by each passenger;
- Total volume of CO_2 and CH_4 produced.

However, many other gases such as nitrogen oxides (NOx) are responsible for global warming, as are cirrus clouds induced by aircraft contrails. Moreover, the different gases impact the global climate in different ways, due to complex positive and negative feedback loops. Finally, they have different impacts on the climate due to their various electromagnetic absorption properties. For these reasons, we suggest using a global measure of the impact of all these gases combined. We propose the 'Global Warming Potential' (GWP) index used by the Kyoto protocol that gives the radiative forcing capacity of each pollutant with respect to CO_2. In its definition, the GWP takes into account the feedback from other parts of the climatic systems, like the 'sinks' that can absorb vast quantities of gases (the oceans, for instance). As a consequence, it takes into account the likely decay of the gas's concentration after its release into the atmosphere, which implies that the GWP measure is given for a specific time horizon. Here we consider the time horizon of 20 years, which is one of the time horizons used in the Kyoto protocol (along with 100 years and 500 years). For a single trip, we suggest the following two measures:

- $g = \frac{\sum_i v_i GWP_i}{d}$
- $g_a = \sum_i v_i GWP_i$

where v_i is the volume of pollutant i produced during the journey, GWP_i is the corresponding GWP of the pollutant, and d is the total distance travelled (possibly great circle instead of real distance). The first of these gives the CO_2 equivalent produced per kilometre travelled, whereas the second is simply the absolute version in order to measure the real impact of the transport system on the environment. These measures can then be averaged or summed over the different passengers and journeys performed in Europe. It is important to note that these measures are only approximations, since the impact of a gas on the climate is usually non-linear with its volume in the atmosphere.

Equivalent indicators can be produced using values of the Global Temperature change Potential metric (GTP) instead of GWP. GTP is the ratio of change in global mean surface temperature at a chosen point in time from the substance of interest relative to that from CO_2. Similarly, AGWP and AGTP, that give the absolute value of the warming and temperature-change potentials, may also be used. Rather than being relative to CO_2, these give the total warming effect in W/m^2 and the total temperature change in pK respectively, at the given time horizon.

Another important aspect of environmentally sustainable development is the total environmental impact when all the processes and objects needed to transport a passenger from A to B are taken into account. Among them, the gas emissions due to the construction of the aircraft, the heating and electricity needed at the airport, the commuting trips of the ground staff and aircrew to operate the flights, etc. This is of course harder to measure but given that the information is available, one can use the above formulas to have a more complete description of the transport system.

Most greenhouse gases are not actually toxic to human beings in weak concentrations. More problematic on a short time scale are the micro-particles emitted during travel that degrade air quality and thus people's health. Many measures of these pollutants exist in different reports, in particular categorising them into different types according to their typical size. The present work does not see any relevant and simple measure which could be added to this list. For the same reason, issues related to noise are not tackled here due to the existence of very good metrics in the literature.

No industry can survive without being economically viable and a final factor in sustainability is its economic aspect. A sustainable operation should be economically competitive with other solutions, or at least competitive enough so that it can be subsidised within reasonable ranges. Ensuring that an operation is environmentally sustainable must not produce an economic impact that would make that operation nonviable. However, in many cases, the internal costs of pollution mitigation - what an industry pays to avoid producing that pollutant - far outweigh the costs of that pollutant to the industry since these costs are external - society and the environment pay the price. In order to reduce the relative cost of mitigation, it is necessary to (partially) internalise these external costs.

If an alternative is more expensive than its non-sustainable counterpart, one can put a price on a volume of a pollutant which is avoided in the first alternative. The smaller the price, the more competitive the sustainable alternative is, and the more likely it is to be widely adopted and actually make a difference in terms of the environment.

The main issue with this concept is that it assumes that there is an alternative, more sustainable path for every journey. This could be something that already exists as an option for the traveller or something that has yet to be deployed. From here, it is clear that this kind of concept can only be applied to specific cases but can hardly be generalised to the whole transport system. Moreover, some of these alternatives are actually linked to different conditions of travel, not just to the price itself. In fact, some alternatives nowadays are actually cheaper (car sharing for instance). With such considerations, we begin to step into the field of the value of time, i.e. what preferences people have for spending their time. This is a complex subject which needs more study but is out of the scope of the present definition of sustainability KPIs.

Here we use a simple definition available for some specific cases where a clear, 'greener' alternative to a given journey exists. The supplementary cost of the green alternative (i.e. the price of avoiding a unit of GWP) can be computed as follows:

$$\Delta_g = \frac{p_g - p_{ng}}{g_{ng} - g_g}$$

3.9.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
SUST1		CO_2 per passenger km	Sum of CO_2 produced per passenger.km for each mode of travel used times kms spent in that mode	kg	Passenger journey
SUST2		NO_x per passenger km	Sum of NOx produced per passenger.km for each mode of travel used times kms spent in that mode	kg	Passenger journey
SUST3		Global Warming Potential per km of air journey	Average of $\frac{\sum_i v_i GWP_i}{d}$ over all journeys i	kg CO_2e	All intra-European flights
SUST4		Global Warming Potential of intra-European air travel	Average of $\sum_i v_i GWP_i$ over all journeys i	kg CO_2e	All intra-European flights
SUST5	Y	Total Global Warming Potential of intra-European travel	$\sum_i \sum_j v_{ij} GWP_{ij}$ for each pollutant i for each leg j of a journey	kg CO_2e	All intra-European journeys, door-to-door

3.10 Capacity

We have previously remarked that capacity is a fundamental indicator in transport and communication systems. Trade-offs between capacity and other KPAs are particularly pronounced - notably that increased capacity cannot be offered at the expense of safety. There are also trade-offs between peak and off-peak service provision, in that in order to satisfy peak demand (or the demand of certain users), there may be unused capacity during off-peak times (or negative consequences for other others).

Capacity strictly refers to the maximum possible output or performance. In practice, however, it is often necessary to use a proxy measure in the public transport / mobility context, since the maximum possible is often undesirable due to conflicts with other indicators (notably safety, flexibility and comfort).

In DATASET2050, capacity is defined as a door-to-door mobility indicator and uses a relative, proxy measure - the percentage of trips falling with certain time durations - rather than the absolute number of such (possible) trips. We note that this does not include any measure of the desirability or demand for such trips.

Following the discussion in Section 2, we also consider the capacity as the potential to transport passengers with minimal disruption. CAP5 in the table below is a suggestion for a metric following this point of view.

3.10.1 List of proposed indicators

Code	Key?	Name	Definition	Unit(s)	Scope
CAPA1		Total journeys	Total number of journeys per year (regardless of travel time)	Number of trips	Passenger journeys
CAPA2	Y	Journeys under 4 hours	Percentage of door-to-door journeys using a public service air carrier in one leg of the journey, made within 4 hours	Percentage	Passenger journeys

Code	Key?	Name	Definition	Unit(s)	Scope
CAPA3		Journeys under 6 hours	Percentage of door-to-door journeys using a public service air carrier in one leg of the journey, made in over 4 hours but within 6 hours	Percentage	Passenger journeys
CAPA4*		Journeys over 6 hours	Percentage of door-to-door journeys using a public service air carrier in one leg of the journey, made in over 6 hours	Percentage	Passenger journeys
CAPA5**	Y	Delay elasticity with respect to throughput	Average number of additional minutes of travelling time triggered by an additional passenger in the system	Minute per passenger	Passenger journeys

* Useful in its own right as an indicator of the tail of the passenger journey distribution, but actually equal to 1 - (CAP2 + CAP3).

** In contrast to most of the other metrics, this should be as small as possible.

4. Mobility performance assessment method

Calculating values of indicators can be complicated, with exceptions and pitfalls to be accommodated. Indicators are often based on several metrics pertaining to different focus areas. The methods for calculating these indicators are described below.

The goal of the assessment methodology is to define the process needed to describe mobility in Europe. This methodology should build upon the theoretical approachhttps://research.innaxis.org/display/H2020TBD/22.4+Theoretical+approach (D22) to mobility and detail all those process that need to be measured to describe the different focus areas of mobility. Concretely, this means showing the level to which journeys are:

- seamless;
- inter-modal / multi-modal;
- frequent;
- resilient;
- fast;
- predictable;
- safe and secure;
- affordable;
- comfortable;
- diverse in their potential destinations.

The mobility assessment will cover the following:

- a procedure to measure mobility, following the general theoretical approach. The procedure will detail the processes to be measured;
- explicit traffic and passenger itinerary data that would need to be measured (e.g. top 10 hubs, or top 15 hubs plus 30% of secondary airports, or at least top 5 airports in every country, etc.);
- processes that need to measured;
- data expected to support the measurements for each of the processes.

The methodology should clarify what the main attributes of mobility are and how these are to be modelled.

The output of this task will be used for measuring with data where possible, or for modelling & simulating those processes for which data is incomplete. Therefore this task will:

- support the simulations;
- help to evolve the architecture of the models to ensure they support the methodology;
- provide credibility to the process and guarantee that results are reproducible.

4.1 Assessment methods

Indicators can be evaluated in different ways, based on the way of collecting the data and the type of data needed. Two main types of data collection are usually considered: prospective and retrospective. The former is designed to provide data to answer a specific question by measuring some specific indicators. The latter uses pre-compiled data to evaluate new indicators. This distinction is sometimes important because some data are very specific and need tailored acquisition techniques such as surveys, as described below.

Data acquisition comes in several forms. The first of these is existing databases that have been compiled for general purposes and come from multiple sources: from information directly taken from smartphones (geolocation, communication) to credit cards transactions; from the Internet of Things (IoT) to the ubiquitous sensors (beacons, GIS) located everywhere nowadays. Data from these types of database, which can be open or closed, are usually very voluminous, and can be more or less extensive and of greatly differing quality. In any case, they usually compile measures of easily observables variables, such as traffic, cost, etc. Besides the sometimes prohibitive cost of obtaining them, the main issues in using them in a European mobility assessment usually relate to their scope or their level of detail. Having a consistent database for the whole of Europe is usually a problem, as well as having measures at too high a level; for instance the revenues of airlines may be aggregated per airport and per year. Another problem often encountered with these datasets is the difficulty in cross-referencing or combining data from one dataset with that of another; for instance, schedule data for flights might have different flight identifiers than trajectory data.

Surveys represent another possibility for obtaining data. As opposed to automatic data acquisition procedures, surveys sometimes allow a deeper look into people's decision-making processes. If answers to some questions could in principle be acquired automatically through other means, others are linked to the declared preferences of passengers and difficult to obtain otherwise. Surveys represent a good opportunity for obtaining tailored answers to complex questions, but their downside is that the volume of data obtained is usually small and barely sufficient for statistical analysis. Surveys are not usually needed when the data are easily obtainable through automatic means.

A variant of the surveying is the use of focus groups. Instead of individuals, focus groups typically involve a group of different kinds of people, who are supposed to represent a vast section of society. Focus groups are usually used in politics and market research and give qualitative feedback on a person, product, etc. They are interesting with respect to surveys because they allow a consensus to be formed quickly, and more generally the open discussion they foster gives precious insight into how people's opinion is formed. In the context of mobility assessment, they can be important in determining the levels of passenger satisfaction in several situations, potentially hypothetical.

A final kind of data can also be used to some extent to provide information that is otherwise difficult or impossible to obtain. Sometimes one wants to compute an indicator for a situation that has not yet arisen, perhaps because the event is highly unlikely or perhaps because it refers to a new operational environment under study. In these cases, the output of a model can complement or replace the data observed in reality. Provided that it is validated, a model can be a powerful data generator, since a vast spectrum of situations can be explored by testing situations that could never be studied in reality. Depending on the type of model and its level of detail, it is also possible to acquire some microscopic, hidden details that are almost impossible to measure in reality. The downside of this kind of data is that, by definition, a model is a simplification of reality and one needs a certain amount of trust in the model to reach a reliable conclusion. This is usually obtained through the use of validation techniques, including expert feedback and calibration of existing databases.

4.2 Summary of indicators recommended for DATASET2050 analysis

The previous discussions have defined many indicators within each MFA that can be useful for analysing the impact of research and developments towards the 4-hour door-to-door objective undertaken between now and 2050. These are detailed in tables at the end of each sub-section of Section 3.

However, calculating the full list of metrics and indicators for current, 2035 and 2050 is beyond the scope of the DATASET2050 project. Some of the concepts are mentioned merely in the hope that they will be taken into account in further work and research exercises towards the 4-hour door-to-door goal. The table below identifies the specific subset that will be calculated, computed and reported in D5.2. These are all within the scope, budget and planning of DATASET2050 activities.

The DATASET2050 project's main objective is that 90% of journeys be achievable in less than 4 hours, door-to-door. For this, there is one primary indicator:

The percentage of intra-European journeys with a publicly scheduled air leg achieved in less than 4 hours, door-to-door.

This can be considered to be a measure of the capacity of the system to enable the goal to be attained. As such, it is defined as indicator CAPA2 in section 3.10.1 (see also below).

Key Performance Area	Key Performance Indicators	Other Indicators
Access and equity	ACEQ1 4-hour reach	ACEQ2 Low-income access
		ACEQ3 Medium-income access
	ACEQ5 Income access disparity	ACEQ4 High-income access
		ACEQ6 Carless access
	ACEQ7 Disabled access	ACEQ8 Affordability
		ACEQ9 Unaffordability
Cost-effectiveness	COST1 Passenger distance per euro spent	COST2 Passenger distance per euro airline cost
Efficiency	EFFI3 Time efficiency performance	EFFI1 Pax time efficiency
		EFFI2 Average time efficiency
Flexibility	FLEX1 Distance diversity of destinations	FLEX2 Cultural diversity of destinations
		FLEX3 Cultural diversity performance
		FLEX4 Mean time to fix
Interoperability	INOP3 Transition-journey ratio	INOP1 Total time spent in transitions during a journey
		INOP2 Number of phases required to complete a journey
		INOP4 Average of time spent per transition

Key Performance Area	Key Performance Indicators		Other Indicators	
Predictability	PRED8	Likelihood of arriving more than 15 minutes late at destination	PRED1	Variability on intra-European flights
			PRED2	Variability on airport public transport
			PRED3	Punctuality of intra-European flights
	PRED9	Minimum buffer time required to ensure arriving less than 15 minutes late	PRED4	Punctuality of airport public transport
			PRED5	Reliability of intra-European flights
			PRED6	Reliability of airport public transport
			PRED7	Likelihood of missing a flight
Safety	SAFE1	Number of deaths per million passenger journeys		
Security			SECU1	Number of cyber-security events
Sustainability	SUST5	Total Global Warming Potential of intra-European air travel	SUST1	CO_2 per passenger km
			SUST2	NO_x per passenger km
			SUST3	Global Warming Potential per km of air journeys
			SUST4	Global Warming Potential of intra-European air travel
Capacity	CAPA2	Journeys within 4 hours	CAPA1	Total journeys
	CAPA5	Delay elasticity with respect to	CAPA3	Journeys under 6 hours

Key Performance Area	Key Performance Indicators	Other Indicators
	throughput	CAPA4 Journeys over 6 hours

4.3 Calculation of Key Performance Indicators for DATASET2050

KPA: Access and equity

4-hour reach is the distance that can be travelled, within Europe, from 90% of European doors of origin in exactly 4 hours. This is defined as the lower 10th percentile of the distribution of the maximum attainable distance, within Europe, from each European door, in exactly 4 hours. For this it is understood that the furthest distance may be reached by taking the shortest possible time in each phase of that journey. So it is assumed that the passenger has no luggage, therefore spends no time at bag-drop or baggage reclaim, and has checked in via internet. For intra-Schengen flights there is no passport control either, while flights involving at least one non-Schengen country will require this. We also assume that the immigration process is the same for all EU citizens at any given airport, inside or outside the Schengen zone.

For our calculations, we modify our standard door-to-door (D2D) breakdown into D2K, K2G, G2G, G2K, and K2D slightly; we consider the airport kerb to be the point of entry to the departure terminal or the point of departure from the arrival terminal, such that D2K and K2D include all consequences, inside and outside the airport, of the choice of surface access/egress to/from the airport. Similarly, K2G and G2K are independent of this choice, give or take the difference in walking time between arrival points metro station, physical kerb, taxi rank etc. D2K and K2D may, on the other hand, vary according to the flight taken, since flights to/from different destinations/origins or using different carriers may depart from/arrive at different terminals.

Note however that the time taken for the K2G phase, t_{K2G}, and that taken for K2G, t_{G2K}, will depend on whether the flight involves a non-Schengen country and therefore involves passport control. These times also depend on which terminal or which zone of a terminal the respective flight flies from/to. There are also different gate-closing requirements according to carriers and whether the flight involves transfer to the plane by bus etc. However, this is included in the G2G time t_{G2G} for the flight. It follows, therefore, that for a given passenger (in our case pre-checked-in, without disability, without luggage), t_{K2G}, t_{G2G}, and t_{G2K} depend on the flight taken and can be considered fixed. We call the minimal duration from kerb to kerb (K2K) t_{K2K}. (This K2K may, of course involve flight connections, especially in the case of a very small local airport.)

It can be considered that, in the minimum case, the destination door is an office at the destination terminal with K2D=0. It follows, therefore, that from each door of origin i, a certain number of local airport terminals j can be reached such that there is at least one flight from that terminal for which

$$t_{K2K} < 4hrs - t_{D2K_{ij}}$$

where $t_{D2K_{ij}}$ is the minimum time required to get from door i to terminal j .

Now for every flight k from terminal j for which $t_{K2K_k} < 4hrs - t_{D2K_ij}$, $\max t_{K2D} = 4hrs - t_{D2K_{ij}} - t_{K2K_k}$. This provides the limit on how far can be travelled d_{K2D}, by any surface egress method, from the destination terminal. The reach from door i is therefore

$$\max(\forall j : distance(D2K_{ij}) + (\forall k : distance(K2K_{jk}) + \max(d_{K2D})))$$

To calculate the value of the "Reach" indicator, we evaluate this maximum distance for each door i and find the 10th percentile.

4.3.2 Income access disparity

The 4-hour door-to-door objective should benefit all travellers, not just one section of society. It is possible that in some circumstances, it might be easier or cheaper to put measures in place to attain the 4HD2D goal that make it easier for a particular section of society to access air travel than it does for another section. The advantaged section could well be those who are better off. The "Income access disparity" indicator is designed to show whether this is the case and to enable an understanding of the impact of 4HD2D measures on income equity.

The idea behind this indicator is to show the disparity in access to airline flights between the more and less well-off parts of society. This does not specifically take into account confounding factors such surface modes available to a traveller, where they live or where the flights they took were to. Nor does it look at differentiating factors such as the length of the journey, the cost, etc.

This indicator is evaluated as:

$$\frac{journeys_h}{journeys_l}$$

where $journeys_h$ is the number of private journeys involving an air leg by people in the top 50% of the population by income and $journeys_l$ is the number of private journeys involving an air leg by people in the bottom 50% of the population by income. These values will be the result of surveys of representative samples of the population and will cover a given year.

A value of 1 indicates perfect equity. It is assumed that this indicator will initially have a value greater than this.

4.3.3 Disabled access

As with the "Income access disparity" indicator, this indicator is designed to show the disparity in access to airline flights between people with and without disabilities. As with the previous indicator, this ignores any other factors such surface modes available and thus allows a true indication of discrimination against people with disabilities in the (air) transport system.

The data used for this indicator will be the taken from population surveys. It is evaluated as:

$$\frac{N-n}{n} \times \frac{\sum_{i}^{n} journeys_i}{\sum_{j}^{(N-n)} journeys_j}$$

where n is the number of people with disabilities in the total population N; $journeys_x$ is the number of journeys involving an air leg taken by person x in the reporting period, in this case a given year.

A value of 1 indicates perfect equity, but it is most likely that the value calculated will be much lower than this.

4.3.4 Passenger distance per euro spent

When looking at the cost of air travel, it is important to include the whole cost, not just the ticket price. This means that if a car is used for accessing the airport of origin, not only the cost of fuel (and possibly depreciation of the car itself) should be taken into account, but also the cost of parking the car. If the passenger was taken to the airport by a friend or relation, the cost of the return trip by that person should also be considered as should their trip to the airport to pick a returning passenger up. Similarly, bus, train, metro and taxi fares should all be taken into account. A difficulty arises with the cost of a hire car, since it is quite probable that that hire will be used for other purposes than simply travelling between the airport and the destination door.

The rise of low-fare airlines, and the increasing corresponding habit among previously full-service carriers to charge for everything, means that the reported cost of an airfare must include charges for extra baggage, booking and "administration" fees, etc. On the other hand, optional items such as insurance, or food and drink should be excluded.

The "passenger distance per euro spent" indicator is given as:

$$\frac{1}{n}\sum\frac{distance}{cost}$$

where $distance$ is the total journey distance; $cost$ is the total cost of the journey to the passenger; and n is the number of passengers in the population.

As a cost-efficiency indicator, the population used will be all passengers on intra-European flights for a season. It could, however, be extended to being an indicator of equity by evaluating it separately for populations originating in the 98 different NUTS1 regions and comparing the resulting values.

4.3.5 Time efficiency performance

Efficiency is a measure of the performance of a system with respect to a baseline. In the case of "time efficiency" here, the baseline is how efficient a passenger's journey could have been (i.e. how long it would have taken) if there had been no delays or queues, and no need for buffer times - the "just in time" scenario. Our indicator is therefore a measure of how long the $actual$ journey took, compared with the $best$ possible journey time.

$$Efficiency = \frac{best}{actual}$$

To calculate this best possible journey time we specify specific criteria for each of the 5 phases of the D2D breakdown:

- D2K - The fastest possible mode or combination of modes is selected. There is no congestion or disruption during the surface access trip(s).
- K2G - The shortest possible time that allows for arrival at the gate within minimum boarding process time specified by the carrier. There are no queues for check-in, baggage drop, security, passport control, or customs and the passenger has not provided for any elective wait, buffer or retail time.

- G2G - The fastest terminal, taxi-out, available routing (though not great-circle distance) and taxi-in configurations are selected. There is no ATFM delay or other disruption and no flight buffer time. MCTs are observed for connections.
- G2K - There are no queues for baggage reclaim, passport control, or customs and the passenger has not provided for any elective wait or retail time.
- K2D - The fastest possible mode or combination of modes is selected. There is no congestion or disruption during the surface egress trip(s).

If the passenger has luggage, the best possible journey is calculated taking bag drop and luggage reclaim (first bag off) into account, otherwise no time is allowed for these.

The "time efficiency performance" indicator is the percentage of journeys in the reporting season for which $Efficiency$ exceeds 0.8.

4.3.6 Distance diversity of destinations

The indicator for "Diversity in destinations" is intended to test whether a passenger from a given origin has the possibility of reaching a large number of disparate destinations as opposed to reaching many similar destinations, within our 4-hour time frame. The more destinations, and the more widespread these destinations, the higher the value of the indicator should be.

This gives rise to a question on our meaning of diversity: if we could travel to just four hypothetical destinations 200km north, south, east and west of our origin, is the diversity more or less than if we could only reach those same destinations, but from an origin 2,000km away? There are arguments in favour of each answer of "more", "less" or "the same". We choose to consider that the diversity is the same and so normalise our indicator against the absolute distances involved during the trips.

Diversity in destinations is shown by the examining the distance between them. Having determined the list of all possible destinations D_x reachable within 4 hours from a given door of origin O , the following metric looks at the distance between O and each of these possible destinations, as well as the pair-wise distance between all of the destinations themselves.

$$\delta_O = \sum_i \left(|\overline{OD_i}| \sum_j \frac{|\overline{D_i D_j}|}{|\overline{OD_j}|} \right) \Bigg/ \sum_j |\overline{OD_j}|$$

The value of δ_O increases with the distance between destinations. Many destinations very close to each other will not affect the value significantly from if there were one destination at that place.

δ_O should be computed for every possible origin. It can then be averaged over a given region. This could be the whole of Europe, to give a basic Europe-wide indicator, or it could be separate smaller areas (Country, NUTS1, etc.) to give an indication of cross-European disparity. Additionally, averages, or indeed the individual δ_O values themselves could be mapped as colour codes to show disparity graphically.

4.3.7 Transition-journey ratio

The better the "interoperability" between the different phases of a journey - be they different modes of transport for surface access or the different processes at the terminal - the lower the "cognitive load" on the passenger and, therefore, the smoother the journey. For example, integrated ticketing in a city's public transport system reduces the time and inconvenience of changing transport mode during airport access.

We consider that each of the different phases of a journey is separated from the next by a "transition". These transitions include waiting time, but not physical queuing time, which is considered part of the process of the phase. We can then measure the cognitive load by looking at the number of the transitions involved in a trip and how long they take. The more time, or the greater the proportion of time, spent in transitions the less inter-operable the phases of the journey.

For a given journey we take the ratio:

$$\frac{transitiontime}{totaltime}$$

where $transitiontime$ is the time spent during transitions and $totaltime$ is the total travel time for the journey.

The transition-journey ratio indicator is the average of this value for all journeys in a given day.

4.3.8 Probability that the traveller arrives more than 15 minutes late at destination

The door to door journey can be considered to be a series of legs that can fall into one of several transport categories:

- un-timetabled transport - car (self-drive or driven by someone else), taxi, shuttle (e.g. car-hire), bicycle, motorbike, etc. (walking is considered part of a transition - see below);

- pseudo random transport modes - bus, metro, tram, etc. where, though timetabled, these timetables are not published and they appear to the traveller to arrive at random intervals;
- short-interval timetabled services - train, tram, bus or shuttle (e.g hotel shuttle service) whose timetable is published but the interval between services is relatively short;
- long-interval timetabled services - trains or coaches with published timetables where the service interval is large (hereafter called "intercity service");

or can be airport processes:

- check-in/bag-drop;
- border control;
- security screening;
- luggage reclaim.

We can consider that each of these legs i is composed of three parts, a trip/airport-process p_i, a transition t_i from process p_i to process p_{i+1}, and a wait w_i for the next process, whose duration is $p_i + t_i + w_i$ such that the total journey time T is given by:

$$T = \sum_{i=1}^{n} (p_i + t_i + w_i)$$

---

where t_1 is the transition from the origin door to the first transport leg, p_1 being 0 (closing the door!). w_n is the number of minutes early the traveller arrives at their destination, with $w_n > -15 minutes$ for this indicator.

Decomposing the journey

T is a function of the predictability of the various modes of transport used for the various legs of the journey. It is, however, principally composed of two values:

- the time needed to be able to arrive at the airport in time (D2K) and to pass through airport formalities (K2G) to be able to catch the first flight leg;
- the time needed in planning to account for delay to the flights (G2G), passage through airport exit processes (G2K) and surface egress transport (K2D) to be able to arrive at destination in time.

In fact, there are possible sub-divisions to these times if an intercity service is taken, either in the D2K phase or the K2D phase. (We assume that in a 4-hour door-to-door journey, there is only time for one such intercity service either side of the flight.)

The journey then reduces to a series of macro steps, each composed of several $p_i + t_i + w_i$ legs, each ending at a make-or-break time:

- A: Catch an intercity service or NULL if no such service is taken
- B: Arrive at the airport in time for last check-in/bag-drop or NULL if pre-checked and no luggage
- C: Arrive at the gate in time for boarding
- X: Catch intermediate flights or NULL if only one flight is taken
- Y: Catch an intercity service or NULL if no such service is taken
- Z: Arrive at the destination with less than 15 minutes delay

The probability of arriving less than 15 minutes late is therefore:

$$Pr(A).R_A.Pr(B).Pr(C).R_C.Pr(X).R_X.Pr(Y).R_Y.Pr(Z)$$

where R_S is the reliability of the flight/intercity-service taken after macro step $S \in [A, C, X, Y]$. As stated, some of these macro steps may be null, depending on the conditions of the journey, and in this case the corresponding probability is 1:

In order to arrive at the gate in time for boarding

Condition				
Intercity service	y	y	n	n
Check-in/bag-drop necessary	y	n	y	n
Probability	Pr(A).R(A).Pr(B).Pr(C)	PR(A).R(A).1.Pr(C)	1.Pr(B).Pr(C)	1.1.Pr(C)

To get to the destination from the first departure gate:

Condition				
Multiple flights	y	y	n	n
Intercity service	y	n	y	n
Probability	Pr(X).Pr(Y).Pr(Z)	PR(X).1.Pr(Z)	1.Pr(Y).Pr(Z)	1.1.Pr(Z)

Each of these non-null macro steps will have its own planned (expected) duration $A^E \dots Z^E$, including a safety buffer, and this will depend on the existence or not of the preceding steps. For example, a passenger with no luggage, but who has not checked in on-line, and who will not take an intercity train as part of their journey to the airport will follow steps B and C. They will, therefore, have planned durations B^E and C^E separately, whereas if the same traveller has already checked in online, they will only follow step C and only define C^E

for the entire journey from the origin to the gate. In most cases, these planned durations only apply to the respective macro step. As a special case, however, any surplus time from step B, if there is a step B, is added to that of step C since, although check-in/bag-drop have a time after which they can be "missed", arriving early enables the traveller to pass early through this process and therefore have more time to do so.

These probabilities and the planned durations they define determine the flights (and trains/coaches) that have to be taken to complete the journey on time. The specific intercity or air transport legs will be chosen in advance, probably in reverse order, to "ensure" arrival on time.

In DATASET2050, the final probability is the simple ratio

$$\frac{n_l}{N}$$

---

where n_l is the number of exercises where the traveller was more than 15 minutes late arriving at the destination door and N is the total number of exercises.

In order to allow a better analysis of the reasons for late arrival, it would be useful to calculate the partial probabilities $[A, B, C, X, Y, Z]$ above. (Note that the product of these is the probability of NOT arriving 15 minutes late!)

4.3.9 Minimum buffer required for 95% chance of arrival on time

The purpose of this metric is to determine T, the minimum duration of the journey, or more precisely, T_0, the minimum time for leaving the origin door to have a certain probability of being at the destination door at the required time.

Section 4.3.8 discussed the chance of arriving more than 15 minutes late at the destination door. This probability will have been calculated using standard, pre-defined buffer times that the traveller leaves to be able to catch the first flight and, in their planning, between the published arrival time of the last flight and the time they require to be at the destination door. As explained in that section, there are a series of requirements for the journey to be accomplished on time $[A, B, C, X, Y, Z]$.

The amount of buffer, or indeed just "time", the traveller leaves depends very much on the circumstances of the journey. above all whether there are intercity coach or train legs where the interval between services is large and where missing it would entail missing the flight or being very late at destination.

Analysis of these buffer times should be performed for each of the macro steps $[Z, Y, X, C, B, A]$, adjusting departure times to ensure that the final arrival time is less than 15 minutes late for 95% of cases.

The final buffer times should be given for each of the D2G segment and the G2D segment, as a percentage of total time taken for that segment. The timings in the G2G segment will be determined by published flight times and MCTs.

4.3.10 Number of deaths per million passenger journeys

Air travel is very safe, especially in terms of the number of passenger kilometres travelled. But the number of kilometres travelled is not an important factor in air transport safety. It is, however, with other forms of transport. While indicators of safety will generally look at many aspects, this key performance indicator is concerned simply with the prospect of fatalities.

As each journey is composed of several legs, not all of them by air, and as each of which can be related to a known fatality rate, we can combine the fatality rates for all of the modes of travel used on a particular journey to find the probability of a passenger's being killed on their journey.

The probability of dying during a journey is 1.0 (i.e. 100%) minus the probability of not being killed during any of its legs. This in turn is the product of the probabilities of not being killed in each leg, which is is 1.0 (100%) minus the fatality rate for that leg. So we have:

$$\frac{\sum_{j=1}^{N}(1 - \prod_{i=1}^{n_j}(1 - m_{ij}d_{ij}))}{N} \times 1,000,000$$

where:

N is the number of journeys j in the reference period;

n_j is the number of legs i in the j^{th} journey

m_{ij} is the fatality rate per passenger km of the i^{th} leg of the jth journey

d_{ij} is the distance travelled in the ith leg of the j^{th} journey

In the case of rail and air legs whose fatality rate is given per passenger trip, m_{ij} is the fatality rate per passenger trip and $d_{ij} = 1$.

Fatality rates are very small, so it is essential that enough precision be used to ensure that rounding errors do not invalidate the indicator and therefore the understanding of the impact on safety of measures taken.

4.3.11 Total Global Warming Potential of intra-European air travel

It is generally well accepted that air travel is a significant contributor to anthropogenic climate change. There are several metrics that can be used to measure this impact. We use the Global Warming Potential (GWP) metric that gives the warming effect of the journey in terms of units of CO_2. While most studies only look at the GWP of aviation itself, our indicator shows the total GWP of journeys that involve an air leg.

The GWP of intra-European air travel can be computed as follows:

$$\sum_i \sum_j \sum_p v_{jp} GWP_{Jp}$$

for each pollutant p for each leg j, of transport mode J, in journey i,

where v_{jp} is the volume of pollutant p produced during leg j

and GWP_{Jp} is the unitary global warming potential of pollutant p for transport mode J. This transport-mode distinction is required since the GWP of a pollutant may depend on whether it is emitted at altitude by a flight (where it may interact with other chemical compounds) or at ground level.

4.3.12 Journeys under 4 hours

The EC high-level group objective being studied by the DATASET2050 project is that "90% of [air] passengers will be able to complete their journey, door-to-door, in under 4 hours [in 2050]". The "journeys under 4 hours" indicator is, therefore, the key indicator of this project.

Using real passenger data, this indicator is simple to calculate

$$\frac{j}{n} \times 100\%$$

where j is the number door-to-door journeys involving an air leg that were accomplished in 4 hours or under and n is the total number of journeys in the reporting period.

In our project, this value will depend highly on the conditions supplied to the models that will be responsible for providing the data. A major variable among these is the amount of buffer time each passenger is assumed to have left to ensure that they arrive in time for each planned leg. This indicator is, therefore, heavily linked with the "minimum buffer time" indicator described in section 4.2.9.

4.3.13 Delay elasticity with respect to throughput

As previously noted, capacity is not a strict upper bound for the throughput of the system but rather an indication of the typical throughput over which several issues appear, including additional delay. As a consequence, a measure of how much delay is created when a certain number of additional passengers pass through the system is directly related to the capacity of the system. This relationship between delay and throughput is often modelled or assumed in the literature. Typical shapes assumed or inferred for this functional relationship include exponential functions and linear relationships, for instance for single airports.

Measuring the full functional relationship is a complex task that involves higher degrees of modelling. Instead, measuring the elasticity of delay around the current functioning point of the system is easier. Indeed, since the throughput is naturally oscillating because of changing demand and supply conditions, e.g. seasonality, one can measure the evolution of delay when the throughput changes. The statistically linear relationship obtained can be seen as a local approximation of the full theoretical relationship around a point close to the current capacity. Notionally, one can write the delay elasticity as:

$$k_\delta = \frac{\Delta\delta}{\Delta N}$$

where $\Delta\delta$ is the variation of delay and ΔN is the variation of throughput. In practice, one would write the following equation:

$$\delta = k_\delta N + c$$

and use is it for a linear regression of the delays versus the throughput measured over a year.

Small values of k_δ mean that the additional passengers do not create much additional delay, and thus that the system is far from its capacity. High values of k_δ, on the other hand, mean that delay is rapidly increasing with the number passengers, and thus that the system is congested.

5. Conclusions

There are many aspects to measuring and assessing mobility. These aspects have been re-grouped into key performance areas (KPAs) each subdivided into several mobility focus are-as (MFAs). It is important that DATASET2050 assess each of these areas to ensure that actions taken under the guise of improving 4-hour door-to-door (4HD2D) mobility provide across-the-board improvements rather than just furthering one particular domain or worse, producing degradation in some domains.

This document has defined 13 key performance indicators (KPIs) for this, together with the method of calculating them with the DATASET2050 models. It has also suggested 30 other indicators, though without addressing their calculation.

It is hoped that this document will help research by DATASET2050 and other projects move towards the 4HD2D objective in a way that benefits all sections of the transport industry, human society, and the planet we live on.

6. Bibliography, references

ACI EUROPE, 2017a. Airports welcome improvements to EU rules supporting connectivity (press release, 8 June 2017). ACI EUROPE, Brussels, Belgium.

ACI EUROPE, 2017b. Airport industry connectivity report 2017. ACI EUROPE, Brussels, Belgium.

Boeing, 2016. Statistical Summary of Commercial Jet Airplane Accidents - Worldwide Operations 1959–2015, Boeing Commercial Airplanes, Seattle USA, July 2016

Brooker, P. et al, 1985. "United Kingdom Aircraft Noise Index Study (ANIS): Main Report" DR Report 8402, for CAA on behalf of the UK Department of Transport, CAA, London

Chapman, L., 2007. "Transport and climate change: a review", Journal of Transport Geography Volume 15, Issue 5, September 2007, Pages 354–367

Deutsche Bahn AG, 2017 "Pünktlichkeitsentwicklung in 2017". http://www.deutschebahn.com/de/konzern/konzernprofil/zahlen_fakten/puenktlichkeitswerte.html

DfT, 2016. National Travel Survey: England 2015. UK Department for Transport - available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/551437/national-travel-survey-2015.pdf

DfT, 2017. Average excess waiting time for frequent services, by local authority: England. UK Department for Transport - available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/489753/bus0903.xls

DfT, 2017a. Travel time measures for the Strategic Road Network, England: Year Ending March 2017 - available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/614583/travel-time-measures-srn-england-year-ending-march-2017.pdf

Elkington, J., 1997. "Cannibals with Forks: the Triple Bottom Line of 21st Century Business", Capstone

ENISA, 2011. Resilience Metrics and Measurements: Technical Report, European Union Agency for Network and Information Security, Brussels

EUROCONTROL, 2015. Risk Analysis Tool - RAT: Guidance Material - available at http://www.skybrary.aero/bookshelf/books/3276.pdf

European Commission, 2010. Intelligent Transport Systems Directive (Directive 2010/40/EU)

European Commission, 2011. Flightpath 2050, Europe's vision for Aviation. Report of the High Level Group of Aviation Research.

European Commission, 2015. An Aviation Strategy for Europe, European Commission COM(2015) 598 final.

EEA, 2016. European Aviation Environmental Report 2016 (European Environment Agency, EASA, EUROCONTROL) - available at https://ec.europa.eu/transport/sites/transport/files/european-aviation-environmental-report-2016-72dpi.pdf

Fields, J.M, 1998. "Reactions to environmental noise in an ambient noise context in residential areas" J. Acoust Soc Am. Volume 104, Issue 4, pp. 2245-2260

Fietelson, E.I. et al, 1996. "The Impact of Aircraft Noise on Willingness to Pay for Residences" Transportation Research Vol.1 No. 1 pp. 1-14, 1996.

Heaver, C., 2002. "Attitudes to Aircraft Annoyance around Airports (5A): Focus Group Report" EEC/ENV/2002/009 - available at http://www.eurocontrol.fr/Newsletter/2002/November/5A/Final_5A_Focus_Group_report.pdf

Hobday I, 1988. Economics: a first course. Second Ed. Edward Arnold, London.

International Civil Aviation Organisation, 2003. The impact of Low Cost Carriers - available at https://www.icao.int/sustainability/CaseStudies/StatesReplies/Europe_LowCost_En.pdf

International Civil Aviation Organisation, 2005. Global Air Traffic Management Operational Concept, first edition, Doc 9854.

International Civil Aviation Organisation, 2009. Manual on Global Performance of the Air Navigation System, first edition, Doc 9883. (KPA defined in Chapter 2, 2.2.4, Appendix A, Figure I-A-2 and 3.3)

International Civil Aviation Organisation, 2015. Low Cost Carriers sustainability - available at https://www.icao.int/sustainability/Pages/Low-Cost-Carriers.aspx

JACDEC, 2017. Airline Safety ranking 2017, Jet Airliner Crash Data Evaluation Centre, 2017 - available at http://www.jacdec.de/airline-safety-ranking-2017

Kahneman, D., 2011. Thinking fast and slow; Farrar, Straus and Giroux, New York, 2011

Kampa, M. & Castanas, E., 2008. "Human health effects of air pollution". Environmental Pollution Volume 151, Issue 2, January 2008, Pages 362-367

Leverton, J.W., 2009. “Public acceptance of helicopters – the virtual noise component” Euro-noise 2009

Lu, C., 2011. “The economic benefits and environmental costs of airport operations: Taiwan Taoyuan International Airport” J.ATM, Vol 17, Issue 6, pp. 360-363

Maris, E. et al, 2006. “Noise within the social context: Annoyance reduction through fair procedures” Journal of the Acoustical Society of America, 121(4), 2000-2010.

Miedema, H.M.E. and Oudshoorn C.G., 2001. “Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals” Environ Health Perspect 109: 409-416.

Miedema, H.M.E. and Vos, H., 1999. “Demographic and attitudinal factors that modify annoyance from transportation noise” J Acoust Soc Am 105: 3336-3344.

Network Rail, 2017. Public Performance Measure - available at https://www.networkrail.co.uk/who-we-are/how-we-work/performance/public-performance-measure/

OAG, 2017. OAG Airline Punctuality League - On-time performance results for airlines and airports, OAG, January 2017

PRR, 2016. Performance Review Report 2015, EUROCONTROL, June 2016.

Savage, I., 2013. "Comparing the fatality risks in United States transportation across modes and over time", The Economics of Transportation Safety, Research in Transportation Economics Volume 43, Issue 1, Pages 9-22, 2013

SESAR, 2014. Guidance on KPIs and Data Collection Version 1 (D85, Ed. 00.01.01)

Tomkins, J. et al, 1998. “Noise versus Access: The Impact of an Airport in an Urban Property Market.” Urban Studies. 35(2):243-258

UN, 1992. United Nations Framework Convention on Climate Change. United Nations, New York. 1992 - available at http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

UN, 2015. Paris Agreement, United Nations, New York, 2015 - available at http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

7. Acronyms and abbreviations

- 4HD2D: Four-hour door-to-door
- ACARE: Advisory Council for Aviation Research and Innovation in Europe
- ACI: Airports Council International
- ATM: Air Traffic Management
- BHL: Short name of DATASET2050 partner: Bauhaus Luftfahrt
- CSA: Coordination and Support Action
- D2D: Door-to-door (mobility concept)
- D2K: Door-to-kerb
- DATASET2050: Data-driven approach for a seamless efficient travelling in 2050
- DX.Y: Deliverable’s name (X=workpackage, Y=deliverable numbering within workpackage)
- EC: European Commission
- ECTL: Short name of DATASET2050 partner: EUROCONTROL
- EU: European Union
- EU-28: European Union 28 member countries (since July 2013)
- FP7: Seventh Framework Programme for Research and Technological Development
- G2G: Gate-to-gate
- G2K: Gate-to-kerb
- GCD: Great circle distance
- H2020: Horizon 2020 research programme
- IATA: International Air Transport Association
- ICAO: International Civil Aviation Organization
- INX: Short name of DATASET2050 coordinator: Innaxis
- K2G: Kerb-to-gate
- KPA: Key performance area
- KPI: Key performance indicator
- MCT: Minimum connecting time
- MFA: Mobility Focus Areas
- MG: Mobility for growth (H2020 theme)
- NOx: Oxides of nitrogen
- PRU: Performance Review Unit (EUROCONTROL)
- R&D: Research and development
- SESAR: Single European Sky ATM Research
- STEEP-M: Social, technological, economic, environmental, political and mobility
- TBO: Time-Based Operations

- TE: Time-efficient (airport)
- UN: United Nations
- UoW: Short name of DATASET2050 partner: University of Westminster
- WP: Workpackage

Appendix I. Safety data: traffic deaths (EUROSTAT)

Transport traffic and deaths per year in EU28+4 (Eurostat data)

Transport mode	Pedestrian	Bicycle			Motorcycle								Car					Local public transport (LPT)									Rail					Air				
	Pedestrian deaths	Bicycle deaths	Mpkm	Deaths/ Mpkm	Moped deaths	Motorbike <=125cm3 deaths	Motorbike >125cm3 deaths	Unspecified Motorbike deaths	Unspecified Motorcycle deaths	Total Motorcycle deaths	Mpkm	Deaths/ Mpkm	Driver deaths	Passenger deaths	Total deaths	Mpkm	Deaths/ Mpkm	Bus deaths	Minibus deaths	Trolleybus deaths	Coach deaths	Tram/LR deaths	Unspecified LPT passenger deaths	Total LPT passenger deaths	Mpkm	Deaths/ Mpkm	Railway passenger deaths	Mpkm	Deaths/ Mpkm	kpax	Deaths/ Mpax	Air deaths	Domestic Passengers	Inter-EU Passengers (departures)	Total Intra-EU Passengers (Departures)	Deaths/ Mpax

Germany	Denmark	Czech Republic	Bulgaria	Belgium	Country/Period
555	29	156	:	103	Ave 2011-2015
388	28	73	:	74	Ave 2011-2015
:	:	:	:	:	2014
:	:	:	:	:	2014
77	14	7	:	17	Ave 2011-2015
64	:	:	:	:	Ave 2011-2015
532	:	:	:	:	Ave 2011-2015
708	17	82	:	100	Ave 2011-2015
:	:	:	:	:	Ave 2011-2015
1,380	31	88	:	117	Ave 2011-2015
:	:	:	:	1,268	Ave 2011-2015
:	:	:	:	0.0923	Ave 2011-2015
2,527	128	441	:	551	Ave 2011-2015
475	30	121	:	104	Ave 2011-2015
3,002	158	562	:	655	Ave 2011-2015
:	:	64,493	:	112,088	Ave 2011-2015
:	:	0.0087	:	0.0058	Ave 2011-2015
6	:	2	:	5	Ave 2011-2015
:	:	:	:	:	Ave 2011-2015
0	:	:	:	:	Ave 2011-2015
3	:	:	:	:	Ave 2011-2015
1	:	:	:	:	Ave 2011-2015
:	0	:	:	:	Ave 2011-2015
10	0	2	:	5	Ave 2011-2015
:	:	15095	9330	18589	Ave 2011-2015
:	:	0.0002	:	0.0003	Ave 2011-2015
3	0	3	1	0	Ave 2011-2015
91,449	6,735	7,429	1,799	10,669	Ave 2011-2015
0.0000	0.0000	0.0004	0.0007	0.0000	Ave 2011-2015
2,623,447	203,110	173,282	25,797	228,753	Ave 2011-2015
0.0012	0.0010	0.0173	0.0465	0.0000	Ave 2011-2015
0.0	0.0	0.0	0.0	0.2	Ave 2011-2015
23,343,425	1,968,690	150,395	174,233	28,493	2015
51,354,976	10,035,050	4,503,918	2,749,948	11,141,383	2015
74,698,401	12,003,740	4,654,313	2,924,181	11,169,876	2015
0.0000	0.0000	0.0000	0.0000	0.0179	2015

Croatia	France	Spain	Greece	Ireland	Estonia
69	488	363	159	36	26
25	152	64	16	7	0
:	:	:	:	:	:
:	:	:	:	:	:
13	176	60	29	:	0
:	88	4	:	:	:
:	526	211	:	:	:
58	696	226	275	21	0
:	:	:	:	:	:
71	1,486	501	304	21	0
1,181	13,918	2,164	:	114	:
0.0600	0.1068	0.2314	:	0.1842	:
229	2,460	1,107	606	110	41
69	598	323	154	33	15
298	3,058	1,430	760	143	56
25,898	809,371	328,309	:	33,229	:
0.0115	0.0038	0.0044	:	0.0043	:
2	5	9	4	0	3
:	:	0	:	:	:
:	:	:	:	:	:
:	42	:	:	:	:
:	0	0	:	:	:
:	:	:	:	:	:
2	47	9	4	0	3
3367	50899	53252	:	343	1849
0.0006	0.0009	0.0002	:	0.0010	0.0015
0	3	19	0	0	0
1,066	90,711	24,110	1,036	1,686	253
0.0000	0.0000	0.0008	0.0000	0.0000	0.0000
29,036	1,178,469	569,049	13,719	37,920	5,186
0.0000	0.0029	0.0330	0.0000	0.0000	0.0000
0.0	30.4	0.6	0.0	1.2	0.0
517,639	28,680,322	30,880,817	7,467,327	79,591	19,559
2,514,617	31,201,137	59,176,327	13,931,738	12,565,296	826,736
3,032,256	59,881,459	90,057,144	21,399,065	12,644,887	846,295
0.0000	0.5077	0.0067	0.0000	0.0949	0.0000

Malta	Hungary	Luxembourg	Lithuania	Latvia	Cyprus	Italy
:	146	5	95	65	11	579
:	84	0	20	14	1	270
:	:	:	:	:	:	:
:	:	:	:	:	:	:
:	25	0	3	5	2	127
:	:	1	:	1	:	:
:	:	5	:	4	:	:
:	51	:	14	:	12	:
:	:	:	:	3	:	795
0	76	6	16	13	15	922
:	:	:	276	:	:	41,762
:	:	:	0.0591	:	:	0.0221
:	347	26	102	85	35	2,452
:	128	5	56	37	7	533
:	475	31	158	122	42	2,985
:	52,251	:	30,872	11,910	:	641,135
:	0.0091	:	0.0051	0.0102	:	0.0047
:	8	0	0	0	0	1
:	:	0	0	1	:	:
:	0	:	:	0	:	:
:	:	0	:	:	:	:
:	0	:	0	0	:	0
:	:	:	:	1	:	12
:	8	0	1	2	0	14
:	16408	:	2799	2744	:	108898
:	0.0005	:	0.0002	0.0007	:	0.0001
:	3	0	0	0	:	2
:	7,762	380	271	681	:	49,416
:	0.0004	0.0000	0.0000	0.0000	:	0.0000
:	146,910	20,488	4,128	19,228	:	861,585
:	0.0218	0.0000	0.0000	0.0000	:	0.0026
0.0	0.0	0.0	0.0	0.0	0.0	0.4
259	0	961	885	174	6,434	29,755,048
2,126,669	4,093,062	1,144,084	1,637,031	1,903,080	2,715,831	37,110,377
2,126,928	4,093,062	1,145,045	1,637,916	1,903,254	2,722,265	66,865,425
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060

Slovakia	Slovenia	Romania	Portugal	Poland	Austria	Netherlands
:	18	709	159	1,147	81	58
:	14	154	33	301	46	125
:	:	:	:	:	:	:
:	:	:	:	:	:	:
:	2	58	53	73	15	37
:	:	:	18	:	:	:
:	:	:	69	:	:	:
:	20	57	54	250	76	45
:	20	:	28	:	:	:
:	42	114	220	324	91	82
:	:	:	:	3,811	1,750	:
:	:	:	:	0.0849	0.0522	:
:	87	769	424	1,659	340	404
:	20	448	113	645	62	47
:	106	1,217	537	2,304	403	451
:	25,636	:	:	205,441	74,495	144,600
:	0.0042	:	:	0.0112	0.0054	0.0031
:	0	11	:	15	1	1
:	:	:	:	:	:	:
:	:	:	:	:	:	:
:	:	:	:	:	:	:
:	:	:	0	2	:	:
:	0	:	5	:	:	:
:	0	11	5	16	1	1
5284	3183	:	4684	39627	9506	5633
:	0.0000	:	0.0010	0.0004	0.0001	0.0001
0	0	1	0	7	0	0
2,674	655	4,823	3,900	17,018	11,576	:
0.0001	0.0000	0.0002	0.0001	0.0004	0.0000	:
49,480	14,994	61,425	133,239	259,474	264,981	:
0.0081	0.0000	0.0195	0.0015	0.0270	0.0008	:
0.8	1.2	1.4	0.0	0.0	0.0	0.0
28,108	132	536,700	3,466,547	1,626,907	565,809	12,391
799,287	407,906	5,191,508	12,898,835	10,836,101	9,164,268	19,682,800
827,395	408,038	5,728,208	16,365,382	12,463,008	9,730,077	19,695,191
0.9669	2.9409	0.2444	0.0000	0.0000	0.0000	0.0000

Norway	Liechtenstein	Iceland	United Kingdom	Sweden	Finland
17	:	2	438	49	34
10	:	0	112	24	23
1,114	:	:	:	:	:
0.0090	:	:	:	:	:
3	:	0	8	8	5
2	:	0	57	8	:
16	:	0	282	29	:
:	:	:	:	:	29
:	:	:	5	:	21
21	:	1	353	45	55
1,440	:	:	4,886	919	1,161
0.0146	:	:	0.0722	0.0484	0.0473
108	:	7	1,110	182	184
27	:	3	290	41	42
136	:	10	1,400	223	226
60,886	:	:	642,655	99,207	65,228
0.0022	:	:	0.0022	0.0022	0.0035
1	:	:	:	2	2
1	:	0	3	:	:
0	:	:	:	:	:
2	:	:	:	:	:
:	:	:	0	0	0
:	:	0	8	:	1
4	:	0	11	2	3
4128	:	:	41900	8560	7540
0.0009	:	:	0.0003	0.0002	0.0003
0	0	:	0	0	0
3,285	1	:	62,461	11,975	3,992
0.0000	0.0000	:	0.0000	0.0000	0.0000
66,700	96	0	1,601,637	200,528	70,248
0.0000	0.0000	:	0.0000	0.0000	0.0000
			1.4	0.0	0.0
			22,914,894	7,538,173	2,602,612
			68,873,521	9,998,346	5,401,427
			91,788,415	17,536,519	8,004,039
			0.0153	0.0000	0.0000

Switzerland	Total
63	5,661
34	2,093
:	1,114
:	0.0090
4	820
15	257
48	1,722
:	2,791
:	872
67	6,462
2,503	77,152
0.0268	0.0838
187	16,709
35	4,461
222	21,169
82,774	3,510,475
0.0027	0.0060
7	85
:	4
1	1
:	47
0	3
0	27
8	167
5649	419268
0.0014	0.0004
1	45
19,636	437,447
0.0000	0.0001
547,060	9,409,968
0.0011	0.0048
	37.6
	162,366,525
	393,985,259
	556,351,784
	0.0676