

## Non-urban Passenger: Model overview

The ITF non-urban passenger model is a strategic tool that tests the impacts of multiple policies and trends on the non-urban passenger sector. The model provides scenario forecasts for non-urban transport activity and its related CO<sub>2</sub> emissions on all major transport modes up to 2050. The model estimates activity between urban areas (intercity travel) and passenger activity locally in non-urban areas (intra-regional travel). The latter includes travel in peri-urban and rural areas. The model is developed to assess the impact of transport, economic and environmental policy measures (air liberalisation, carbon pricing, etc.), and technological developments and breakthroughs (electric and hydrogen aircrafts, autonomous vehicles, etc.).

The combined non-urban passenger model was initially created for the 2019 ITF Transport Outlook (ITF, 2019). The model structure comprises several sub-models (or modules) that estimate the non-urban passenger transport activity and its effects on the environment in various steps. The model is entirely developed by the ITF and does not rely on any commercial transport modelling software. The current version of the model estimates passenger activity for five transport modes: air, rail, car, bus and moto. The underlying network contains 1191 centroids, where passenger intercity trips start and end, and 1191 regions, where passenger intra-regional travel occurs. Each of the links of the intercity network is described by several attributes. These include mode, distance, frequency, travel time, travel cost (per pkm).

### Model components

The model consists of the multiple model components/modules. Most components are interrelated, while some others work in parallel. There are two main demand modelling paths, one for intra-regional transport and one for intercity transport.

The modelling component that creates spatial discretisation:

- A **spatial discretisation model** to generate world passenger centroids and regions.

The modelling components that create and modify model inputs:

- A **global network evolution model** based on air routes and surface mode links;
- A **travel price model**.

Intercity travel demand modelling components:

- **Travel activity generation model**;
- **Destination choice model**;
- **Mode choice models**;
- **Route choice model** for intercity aviation.
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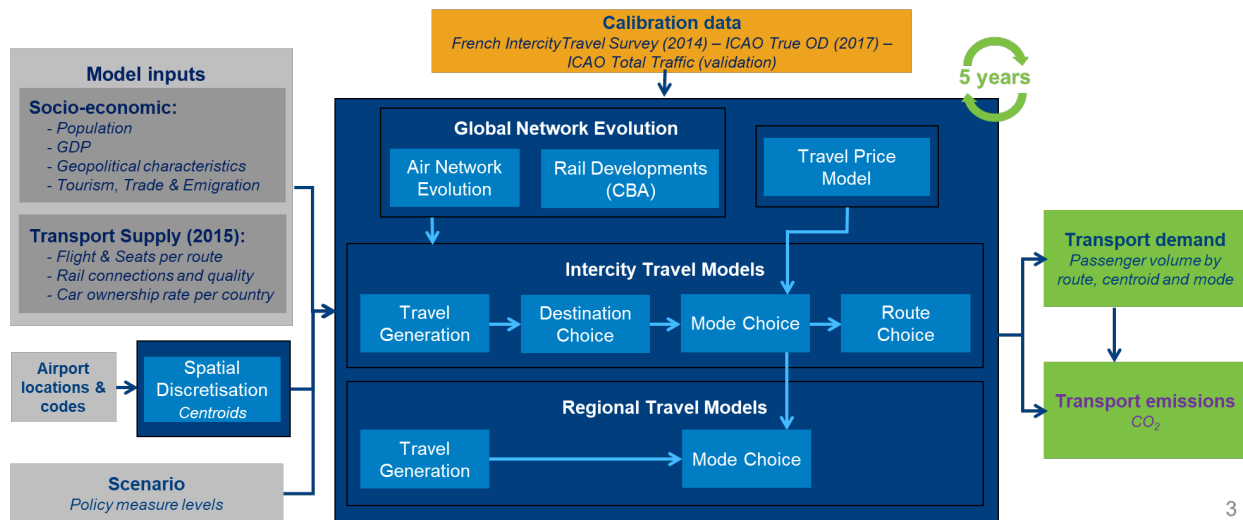
Intra-regional travel demand modelling components:

- **Travel activity generation model**;
- **Mode choice models**.

Once all the components are set, the model is computed sequentially as presented in Figure 1. The non-urban passenger model runs in 5-year intervals and makes scenario forecasts until 2050. In this timeframe, several elements of the global network may change. The air network evolves over time either by additional direct links, updating the frequency of flights on links, or by adding low-cost carriers (LCC) to an existing or new connection. Surface modes may benefit from increased infrastructure availability or frequency improvements. The high speed rail network (HSR) evolves over time by expanding the network to potential (further) connections.

The cost of travelling of each of the transport modes may also change over time. It depends on expected technological and societal changes (e.g. autonomous vehicles, electric mobility, and shared mobility) but also on the introduction of carbon pricing, carbon offset policies or fuel prices. All such changes would alter the cost of travelling which may impact the propensity to travel and mode choice. The impact of such technological and societal changes can be assessed in the model via scenario analysis by changing the level with which the policy measures are implemented.

Figure 1: Non-urban passenger model scheme



## Model inputs

The data inputs for the model can be split in two main categories: socio-economic and geopolitical data, and transport infrastructure and supply data. Transport infrastructure and supply can be further broken down into the intra-regional and intercity level data inputs. Data inputs feed into the model in its various components.

The first category of data inputs is the socio-economic and geopolitical data. These data are used in multiple components of the model:

- **Population** estimates and forecasts at the city and region level: The population levels of each city representing a zone as a centroid and the accompanying region are used to estimate travel activity within the generation models. Population levels of each city are also used as an attraction variable in the destination choice model.
- **Gross Domestic Product (GDP)** estimates and forecasts at the city-centroid and region level: Similarly to the population estimates, GDP values are estimated for both the city-centroid and the region level. GDP is an important variable for the travel activity generation models and the destination choice model.

- **Geopolitical characteristics** of the city-centroid or the region: Geopolitical variables often play a key role in the non-urban transport activity. Travellers to *islands* often rely mainly on air to reach them. Therefore, they have a disproportional mode share by air compared to their size. *Capitals* also attract more transport activity from other cities of comparable size. Both variables are included as inputs to the model, feeding into the travel activity generation and destination choice models.
- **Tourism** estimates are a variable that is complimentary to population. Tourism arrival estimates are taken from official statistics and disaggregated at the city-centroid level. Areas with high tourism activity have more non-urban activity compared with similarly sized cities. Tourism is used in the travel generation model.
- **Trade and emigration** estimates between countries: Trade relations between countries influence the amount of people traveling from one to another for business purposes. Emigration has a similar effect in terms of personal/leisure travel. These variables feed into the destination choice model. Urbanisation rates and locations of urban areas are also used at the city-centroid and region level. Regions where the city has a higher share of the total population have higher travel activity. This variable is therefore used in the travel generation model.

Data on transport infrastructure and supply at the intercity level is mainly used to create the global intercity transport network.

- The location and names/codes of *airports* are vital for the model. They serve as the basis of the city-centroids. They also connect with flight information that is used to create the global network.
- **Flight information** includes all scheduled and non-scheduled flights that happen at an annual basis between all airports. The inputs used include *the number of flights and seats* between all airports with additional information on the airlines and the types of planes used. They are aggregated at the route level for computation simplicity. This information is used in most components of the model: travel activity generation, destination choice, mode choice, route choice, and CO<sub>2</sub> intensities.
- **Availability of rail** as mode for intercity travel depends on the available infrastructure. Information regarding the presence and the quality of rail connections is used to feed the global transport network component of the model. Quality of rail corresponds to the frequency of service and the type of service in terms of speed, distinguishing slow (<100 km per hour), fast (<200 km per hour), and high speed (>200 km per hour). This information is also essential for many model components.

Information on transport infrastructure and supply at the intra-regional level is also used to inform the activity that happens intra-regionally. For this, data inputs include the presence or not of *rail infrastructure* (to determine whether rail travel happens in that region) and the *car ownership rate* of the country. These inputs are used in the intra-regional travel activity generation and the intra-regional mode choice models.

Access modes to rail terminals or airports within the region are not considered in the model. It is assumed that if a rail connection exists between two cities or within a region, rail terminals will exist in these locations.

## Model outputs

The model provides results at the origin-destination (OD) pair level by mode and (in the case of air) route, for each 5-year model iteration from 2015 (the base year) to 2050. The main outputs are the number of passengers, passenger kilometres and the related CO<sub>2</sub> emissions of non-urban travel activity. Information regarding transfer locations (for air only) is also provided. While results for rail, car, bus and motorcycle are provided per OD pair, results for air are further split onto different routes for each OD pair. For example, between Paris and Barcelona for 2020 one result entry is generated for each of car, bus, moto and rail. It provides information about the number of passengers, passenger kilometres and CO<sub>2</sub> emissions for each. Multiple result entries are provided for travel by air, as one can travel between Paris and Barcelona directly, or transfer in other European cities such as Madrid. Each entry includes the aforementioned outputs and the city where the transfer is done.

The model also provides results for intra-regional transport activity in a similar format. Intra-regional trips can, however, only be done by rail, car, moto and bus.

Results can be aggregated at a centroid, country, or any larger geographical level. They can also be grouped by origin or destination, estimating the total passengers leaving an origin or arriving at a destination.

## Detailed model component descriptions

This section provides information on the methodologies applied in the different model components work.

### Spatial discretisation model (centroids and regions)

This model defines the regions that are used to estimate transport flows between or within the regions. Regions are based on the location of airports. More specifically, each region is represented by a centroid and an influence area around the centroid. The centroids are defined by all large and medium sized airports with international operating codes as classified by IATA (2019). They are clustered by city airport codes where several airports exist in the same city or where airports are within 100 km of the main airport and within the same country. This results in a total of 1191 centroids (Africa (118), Asia (107), China + India (76), EEA + Turkey (320), Latin America (171), Middle East (27), North America (216), OECD Pacific (75), Transition countries (81)). The name of the respective airport or city code designates each centroid. The influence areas around the centroid are defined by the use of a raster-based world surface map. Each raster cell is assigned to a centroid based on its distance from the centroid and considering country borders. Each centroid is characterised by population and GDP indicators. To obtain estimates for these indicators, the raster cells are linked to raster-based global (CIESIN- Columbia University, 2018) and raster based GDP estimates (Kummu, Taka and Guillaume, 2018).

### Global intercity transport network model

This model component creates a transport network between the 1191 centroids to accommodate intercity travel activity and determines the evolution of the global network over time. In the model, intercity travel can be done by five different modes (air, rail, car, bus and motorcycle). A connection between two centroids may exist for one or more modes.

A connection between two centroids is assumed to be possible **by road** (for car, bus and motorcycle) if there is a continuous surface transport connection, and if the Euclidian distance is less than 2000 km (or 3000 km in case both centroids are in the same country).

A **rail** connection is assumed to exist in 2015 if rail infrastructure connecting the respective two centroids exists in reality.

For connections by **air**, a different approach is taken. Information on all international and domestic flights for 2015 (obtained from the Innovata Schedules Reference Service database) is aggregated at the OD pair level. If all city-centroids were connected by air, that would amount to a total of 1 417 290 air links. According to the flight data from 2015, only 28 137 (2%) of those links were served by direct flights. However, in reality people also travel between cities that do not have direct flight connection, by making transfers. Therefore, to realistically represent the actual air network, an algorithm estimates indirect routes with up to two connections. This exercise increases the total number of air links in 2015 to 230 095. This number includes both direct and indirect links and amounts to 16% of all possible links. The frequency of an indirect route is set to be the minimum of the frequencies of the each connection on that route. The waiting time at a transfer airport is defined by the frequency of the inward and outward flights. Surface modes can also serve as feeders for aviation. For example, someone travelling from the centroid of Lyon (France) to Los Angeles (USA) can go to Paris by train or road and then take the plane to Los Angeles. This exercise brings the total number of all “air” links in 2015 (direct air links, indirect air links, or indirect links with surface feeder modes) to 987 127. This number represents 70% of all possible links between OD pairs. 75% of the total intercity travel demand is, however, met by “air-only” connections (whether direct or indirect).

The global network evolves over time either by including additional direct links or by improving the existent connections. Surface **road** modes may benefit from increased infrastructure availability or from improvements with regards to the capacity of and/or speed limits on the network.

The main changes for **rail** accounted for in the model are potential (further) developments of the high speed rail network (HSR) over time. A simple cost-benefit analysis (CBA) explores whether the demand generated or shifted to a HSR due to travel time savings would outweigh the high fixed costs and make the Net Present Value of the project greater than 0 or not. The following variables are considered in the CBA: fixed cost, maintenance cost and operation cost as cost items; generated traffic, time-savings and reduced negative externalities from other modes as benefits. For the financial assessment, the following assumptions are made:

- All capital expenditure costs occur before the operation of the transportation lines;
- An annual discount rate of 5%;
- Consistent, annual maintenance and operation costs;
- No asset renewal;
- Ticket price grows the same pace as the GDP per capita, independent of journey type.

The development plans are estimated exogenously to the main model in this simple CBA and inputted into the main model. As the model considers the update of routes for OD pairs and the presence of intermodal solutions, the new services are integrated dynamically as options.

The main evolution of the **air** network is assumed to be the addition of new direct links between OD pairs. The module creates new links on the basis of a binomial regression analysis which assesses the likelihood of whether a direct link exists. This likelihood is defined as a function of economic mass (the product of the GDP at the origin and the GDP at the destination of each OD pair), cultural connection and distance. In each iteration, the module may create additional air links or remove existing ones. A link is removed in case the travel demand on the link of the previous iteration did not reach a minimum passenger threshold: 15 000 passengers annually for distances over 3500 km and 45 000 for smaller distances. If both origin and destination are within the same country, these thresholds are lowered by 50%.

The existence (and introduction) of low-cost carriers (LCC) links is also updated at each iteration. A higher economic mass is required for a LCC link to be created. LCC links are constrained to distances of up to 3500 km. A new LCC link starts with an initial share between 2.5% and 10%. This value may grow over time to represent 25% of the market, or more if the prospective demand of the OD pair grows.

The frequency of air connections is updated at each iteration based on the new demand with the use of elasticity values. These are extracted by the Innovata Schedules Reference Service database and are differentiated by two parameters, distance and frequency (in binary terms – high or low). The elasticity values are:

- High frequency (> 2,000 flights/year) and short/medium-haul (<= 3,500 km): 0.6;
- High frequency (> 2,000 flights/year) and long-haul (> 3,500 km): 0.5;
- Low frequency (<= 2,000 flights/year) and short/medium-haul (<= 3,500 km): 0.8;
- Low frequency (<= 2,000 flights/year) and long-haul (> 3,500 km): 0.7.

### Travel Price Model

The travel price model estimates travel prices across different modes. Prices are essential to model demand for passenger travel. This is especially the case for air travel where price variations across different airlines and routing options are significant.

The estimation of **air travel** prices does not include price differentiation across different airlines; price variations between two centroids however do exist by itinerary. The estimation procedure presents a refinement of the model discussed in (Benezech, Martinez and Kauppila, 2016). The data used to calibrate the airline route price

setting module was provided by the operators of the website Skyscanner ([www.skyscanner.com](http://www.skyscanner.com)). The data provides information on all requests made by the website's users between November 2012 and October 2013 for return economy trips between any of the main airports associated with countries represented in the model. For each request, the dataset contains details on the date of the request, the origin and departure of the trip, the dates of the outbound and inbound legs of the trip, the airline, the price for the return trip, and the number of transfers for outbound and/or inbound trips.

Competition and low-cost carriers have a very significant impact on prices. This impact is strongest for direct flights. The price model does not attempt to realistically explain prices between competitors- this would require airline modelling and game theoretical approaches (Grauberger and Kimms, 2016; Hansen, 1990). However, the model does attempt to reflect the main impacts of competition levels and low-cost carriers on the different routes. The base prices for the model are obtained from the average prices observed in the dataset. The prices are grouped by origin-destination pair differentiated by the number of transfers. Therefore, for a given origin-destination pair, all itineraries with the same number of stops are assumed to have the same price. The other element that plays a role in air travel prices is the effect of frequency and the HH-index (airline concentration indicator by number of offered seats – an indicator of the competition on a route). Itineraries with higher flight frequencies and lower airline concentration (lower HH-index) have lower prices. Finally, the presence of low-cost carriers also influences air travel prices. As observed in the data, origin-destination pairs that are served by low-cost carriers have lower prices compared to origin-destination pairs that are not served by low-cost carriers. Prices differences show to vary little across different itineraries. This difference in prices however, is sufficient to highlight the differences between direct and indirect routes and different competition environments.

**Rail travel** costs are estimated on a per passenger kilometre basis. Data for rail fares in France are used to compute the cost structure. Prices are indexed for the type of service (slow, fast, and high-speed). The costs are also indexed to the GDP per capita of France, which allows the extrapolation of these costs to the rest of the world. This extrapolation works as follows: The cost of rail fares is estimated in relation to France's GDP per capita. This relation remains steady for all countries. Countries with higher GDP per capita than France will have higher rail travel costs; whereas countries with lower GDP per capita will have lower rail travel costs.

**Car and bus travel** prices depend on two components. The first component is the price of gasoline in a country (relevant time series data including forecasts stem from the IEA (2019)). The second component is a fixed price component that depends on distance ranges and reflects toll costs. For both these modes, prices are affected by vehicle load factors, which may change over time. Furthermore, they can be affected by any trends that influence the unit cost of transport (e.g. development of gas prices, automation, etc.).

Price plays an important role in the propensity to travel (i.e. in generation models), mode choice and route choice components.

### Passenger transport activity generation model

Transport generation is handled via two different sub-models: one for intercity travel and one for intra-regional travel. Both these sub-models are Poisson models. A Poisson model is a generalised linear regression model where the link function (the relation between the estimated value and the expected value) follows the Poisson distribution.

The **inter-city demand generation sub-model** has four different formulations – one for each type of inter-city travel: domestic trip, international trip without border controls (e.g. Schengen zone, US-Canada), short and medium haul international trips (less than 4 hours flight time), and long haul international trips (more than 4 hours flight time). The model estimates how many trips will be generated by a region (a city and the surrounding region) for each of the four types of intercity travel. The main variable affecting this is the sum of the population of the region and the number of tourist visitors in that region. Tourists generate about half of the intercity travel activity of inhabitants. This means that a region with two million inhabitants and one million tourists will have the same intercity travel activity generation as a region with 2.5 million inhabitants, all other variables being equal. Next to population and tourists, the economic activity of the centroid, expressed in GDP per capita, is one

of the most influential explanatory variables, especially in the long-haul segment. The variable ratio between the regional population and the city population also influences demand generation: a high ratio signifies a region where the population is evenly spread across the region, while a low ratio typically identifies a big city. This ratio therefore has a negative effect on travel generation for long haul travel, i.e. as the ratio decreases (the city becoming bigger), the demand for long haul travel increases. This is because big cities attract/generate more travel demand from/to faraway destinations. Being an island is positively correlated with inter-city travel demand, with the exception of international short- and medium-haul travel where it is strongly negative. Very few cases of islands fall in the short- and medium-haul segment for reaching destinations, which explains this fact. On the other hand, being a capital positively influences travel demand for international travel. It has a rather weak effect when it comes to domestic or no border control travel segments. Transport connectivity variables, such as the presence of high speed rail and the amount of airport throughput, increase activity generation quite significantly for most travel segments.

The output of this sub-model is the number of trips that each region generates for each of the four segments of intercity travel. These can be described as the propensity to travel segments for each centroid.

The intra-**regional generation sub-model** has a simpler configuration. Little information exists on the number of trips that are done within regions. Therefore, the results are aggregated on a country level. The model uses non-urban population, GDP per capita and the size of the country as explanatory variables. GDP per capita defines transport costs and how these costs evolve over time. The transport costs are indexed to the 2015 value. The results are validated on the country level where data is available by subtracting urban activity as estimated by the ITF Urban Passenger Model (ITF, 2020) from the total. The estimated model is given by:

$$\begin{aligned} \text{Regional surface } pkm_i \\ = \text{rural } pop_i \cdot \left( \frac{0.004 \cdot \ln(\text{Equivalent area}_i + 0.027)}{1 + e^{10.5116 - 1.823 \cdot \text{GDP capita available}_i}} \right) \end{aligned} \quad (1)$$

$$\text{GDP capita available}_i = \text{GDP capita}_i \cdot \text{Transport costs (indexed to 2015)} \quad (2)$$

When forecasting trip generation for the study period, socio economic information is updated based on the economic and population forecasts of the UN-DESA (2022) and GDP data for regions (OECD, 2022). Transport supply variables are updated based on the model results of the previous year.

### Destination choice model

The destination choice model allocates the trips of each destination segment to the different destinations. The destination choice component only applies for the intercity non-urban travel. The intercity travel generation model generates activity for four destination segments. The destination choice model distributes this activity across the different destinations in each segment. A discrete choice sub-model with a non-linear utility function is used. The utility function for this model contains multiple variables. These are socioeconomic variables (population – pop, trade – T, and emigration – E), geopolitical and cultural variables (use of same language – L, being a capitol – C, and being an island – I), and transport services provision for each OD pair (road highway connection – Rh, rail travel time – Rc, frequency of services of high speed rail services – HSR, direct daily flight frequency – FF, availability of low cost carriers – LCC, and air travel time – TTair). The probability  $P$  of travelling an origin-destination (OD) pair is then multiplied by the total number of trips originating from a centroid to derive a centroids pairs OD matrix. The model equation is:

$$\begin{aligned} V_{oi} = & (C_i \cdot \alpha_0 + I_i \cdot \alpha_1) \cdot (FF_{oi} \cdot \alpha_2 + HSR_{oi} \cdot \alpha_3) \\ & \cdot (T_{oi} \cdot \alpha_4 + pop_{oi} \cdot \alpha_5 + E_{oi} \cdot \alpha_6) \\ & \cdot (Rf_{oi} \cdot \alpha_7 + Rh_{oi} \cdot \alpha_8 + LCC_{oi} \cdot \alpha_9 + L_{oi} \cdot \alpha_{10}) \cdot e^{TTair_{oi} \cdot \alpha_{11}} \end{aligned} \quad (3)$$



$$P_{oi} = \frac{e^{Sc \cdot V_{oi}}}{\sum_{j \in D} e^{Sc \cdot V_{oj}}} \quad (4)$$

where  $o$  is the origin and  $i$  the destinations.

As in the trip generation model, socioeconomic variables are the most impactful. Population of the destination region and the trade relation between the origin and destination regions are the two most impactful elements of attraction, regardless of the travel segment. Other socioeconomic variables such as same language and emigration relations are also significant predictors of travel flows between regions. Similar to the generation model, capital cities are much more important in the long-haul travel segment. Regions with higher levels of transport connectivity have a higher attractiveness as a destination, particularly in terms of daily flight and high-speed rail frequencies. Finally, distance, measured by the travel time of a direct flight, is a negative factor. Its importance increases with travel distance (i.e. it has more impact for destination choice in the long haul segment, than in the short haul segment).

### Mode choice models

Two mode choice sub-models distribute the flows between and within regions across the different modes. In both cases, this is done by a discrete choice model. For intercity travel, five mode alternatives are available, car, moto, bus, rail, and air. Air is not available for intra-regional travel. In both sub-models, the availability of rail depends on the actual rail infrastructure that is in place (or assumed to be in place in the future). Both models are multinomial logit models.

The utility function includes regional mode preferences (panel terms), specific attributes of the best route that represents the mode (price, travel time and number of transfers) and indicators of connectivity that highlight the role of frequent connections and reliability in intercity mode choice. The most interesting results from the intercity mode choice sub-model are the differences between the regions in the panel terms and the variables. North America has a high positive panel term for car and air travel, which can be associated with the driving culture and the high distances involved respectively. China, on the other hand, has a positive panel term for bus and a negative one for air, whereas India and Russia have a positive panel term for rail travel. Finally, in Europe, the highly developed rail network and the ease of travelling within the Schengen zone gives positive panel terms for rail and air travel and negative ones for bus and car. The other variables such as price, travel time, and the number of transfers are all significant and negatively impact the choice of each mode, while flight frequency and high speed rail frequency are positive for air and rail respectively.

The intra-regional sub-model uses fewer variables in the utility functions. These are GDP per capita, car ownership rate, rail infrastructure availability and a panel term by region for rail. Car is the natural preference, whereas rail gets a boost by higher levels of rail infrastructure. Finally, bus has a negative relation with GDP per capita (as GDP increases, preferences shift from bus to car).

### Route choice model for aviation

The route choice model allocates passengers on the different possible itineraries for each origin-destination pair. This model is implemented only for travel by air within intercity travel to incorporate the use of different flight routes. Road, rail and bus, on the other hand, are assigned to the shortest path between each OD pair.

The final route choice model for aviation has a nested structure based on the number of required stops for the itinerary. The variables in the utility function for each route are travel time (including the estimated transfer time), price, frequency, and a transfer penalty. A Box-Cox transformation is applied to travel time to account for the varying impact of travel time savings that depend on the base travel time. For example, a travel time saving of 1 hour is more relevant if the total duration of the trip is 3 hours rather than 10 hours. The generated routes are limited to three legs, while each of them is characterised by a quality of service index. This index takes into account the various characteristics of each route: travel time, frequency, and transfer time. In an improvement from the pre-existing international aviation model, air travel can also use surface modes as feeders. For example,



a traveller might travel by road or rail to a centroid nearby and then fly to their destination. This feeder mode is counted as one of the possible three legs that are allowed for in the route choice model for aviation.

### Calculation of the outputs

The model provides passenger-kilometres (pkm) and vehicle-kilometres (vkm) for each OD pair and centroid, disaggregated by transport mode. These outputs can be further aggregated at country and regional levels.

CO<sub>2</sub> emissions by mode are estimated via transport activity expressed in either pkm or vkm, depending on the mode. For road transport (car, moto and bus), CO<sub>2</sub> is estimated via vkm, assuming vehicle load factors (to get from pkm to vkm) defined by:

$$\begin{aligned} \text{car load factor}_{ij} &= \min(4, 1.306 \cdot (1 - \%SM_{ij}) + 0.0006 \cdot \text{distance}_{ij} \\ &\quad + 2.800 \cdot \%SM_{ij} + 0.101 \cdot \%Saut_{ij}) \end{aligned} \quad (5)$$

$$\text{bus load factor}_{ij} = \min(50, 22.544 + 0.006 \cdot \text{distance}_{ij}) \quad (6)$$

These load factors are estimated on data stemming from ITF member countries and depend on the average distance driven and the effect of potential organisational or technological disruptive elements. These are shared mobility (identified as SM in equation 5) and automation (identified as Saut in equation 5). For other modes, CO<sub>2</sub> estimates are estimated via transport activity in pkm.

CO<sub>2</sub> intensities per vkm (for bus, moto and car) and pkm (for rail and air) and the future development of these CO<sub>2</sub> intensities for the different modes are calculated within the framework of the in-house fleet model.

### Implementing Outlook 2023 scenarios

The ITF models were designed and further updated to estimate and evaluate the impact of policy measures on transport activity and related emissions under two main scenarios: *Current Ambition* and *High Ambition*.

The *Current Ambition* scenario builds on existing policies and commitments to estimate the current pathways of transport demand and related emissions. In contrast, *High Ambition* targets more profound changes in the transport sector on demand management (generation control and sustainable modal diversion) and technological breakthrough. It was built by the ITF in 2020 for the preparation of the ITF Transport Outlook 2021 (ITF, 2021), and adjusted for the ITF Transport Outlook 2023 (ITF, 2023) since. It is the result of an international survey on current transport policies and technology development implementation worldwide, filled by many experts in the ITF network.

Table 1 shows measures implemented in the Non-urban Passenger Model with target values by 2050 aggregated in two simplified categories: Global North and Global South contexts.

**Table 1 List of measures for non-urban passenger transport and their 2050 targets implemented in the model**

Policy measures	Description	Global North	Global South
<b>Reduced propensity to fly</b>	Percentage of the population that avoid flying due to climate considerations	20% - 30%	0%
<b>Reduction in business travel due to teleconferencing</b>	Percentage of air trips reduction due to teleconferencing	12.5%	2.5%

<b>Shared mobility</b>	Percentage of shared trips of the total trips by car	30%	20.0%
<b>Carbon pricing (all modes) *</b>	Increases cost of all carbon emitting modes via a carbon tax (USD)	450 – 600 USD/tonne CO <sub>2</sub> e	200 – 300 USD/tonne CO <sub>2</sub> e
<b>Ticket taxes (air travel) *</b>	Increases cost of air travel as a percentage of the air fare	30 – 45%	8 – 25%
<b>Electric vehicles</b>	Increases the uptake of electric vehicles in all modes	ITF High Ambition scenario	
<b>New propulsion aircrafts</b>	Battery electric and hydrogen propelled aircrafts	Battery electric and hydrogen-propelled aircrafts are commercially available and a competitive alternative for short and medium haul travel, respectively.	
<b>Sustainable Aviation Fuel (SAF) mandates</b>	Percentage of the total fuels of aviation required to be SAF	100% to 73% depending on the regions.	
<b>Short haul flight (&lt;500 km) ban</b>	Introduced to encourage the uptake of rail where good quality connections exist	Progressive implementation towards 2050 depending on the region. By 2050, measure implemented in all regions.	
<b>Development high-speed rail (HSR)</b>	Development of high-speed-rail infrastructure between cities where it is economically feasible		
<b>Rail frequency improvement and electrification</b>	Investment in rail and electrification of rail networks	Frequency (50%) and speed (20%) improvements across regions.	

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