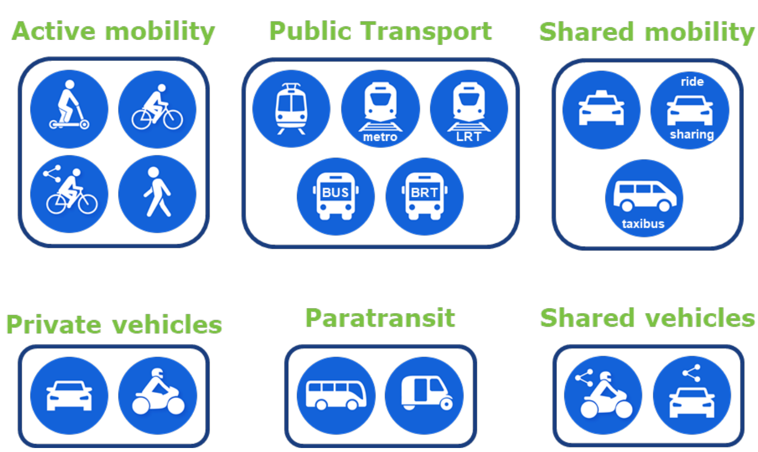
# Urban Passenger: Model overview

The ITF global urban passenger transport model is a strategic tool to test the impacts of policies and technology trends on urban travel demand, related $CO_2$ and pollutant emissions and alternative indicators. Outputs for various scenarios can be obtained to 2050. The model represents passenger mobility at the scale of Functional Urban Areas (FUAs).

The model is designed as a systems dynamic model (stock and flow model) to evaluate the development of urban mobility in all cities over 50 000 inhabitants around the world. It combines data from various sources to form one of the most extensive databases on global city mobility to account for 18 transport modes (Figure 1) ranging from the conventional private car and public transport to new alternative modes such as shared mobility. These 18 modes can be categorised into: Active mobility, Public Transport, Shared mobility, Private vehicles, Paratransit and Shared vehicles.

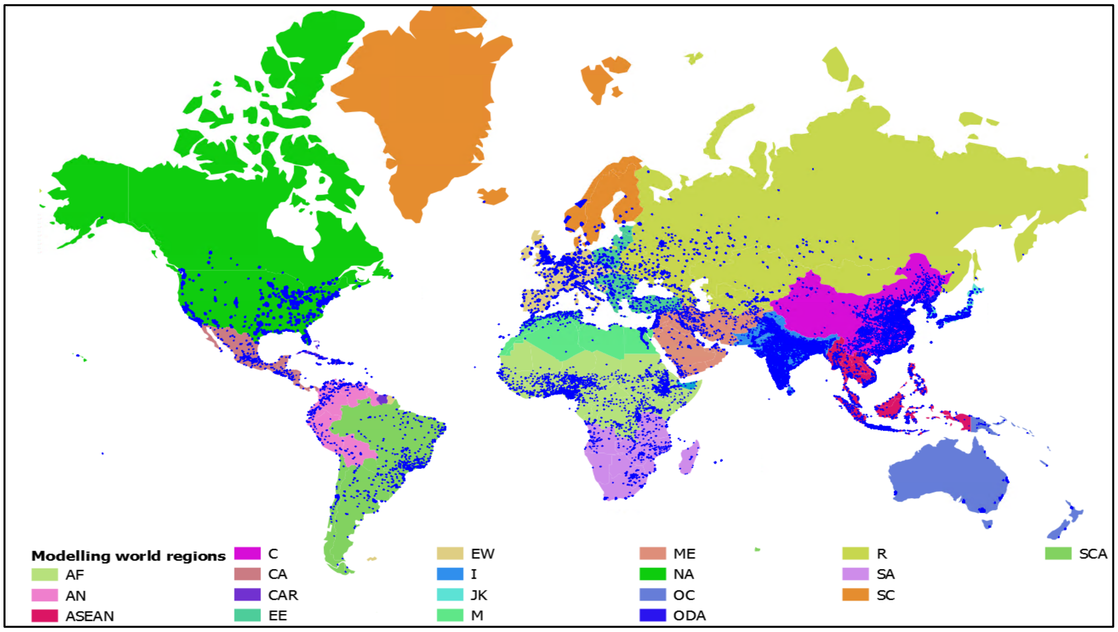
The urban passenger model represents travel behaviour by modelling aggregate travel behaviour by traveller segment, depending on the socio-economic characteristics of the respective segment. While the model is built at the FUA level, but the overall mobility patterns are standardised across 19 modelling regions (Figure 2). The model is entirely developed by the ITF and does not rely on any commercial mobility modelling software.

Figure 1 Mobility modes considered in the ITF Urban passenger model




Source: ITF.

Figure 2 Modelling regions and location of Functional Urban Areas



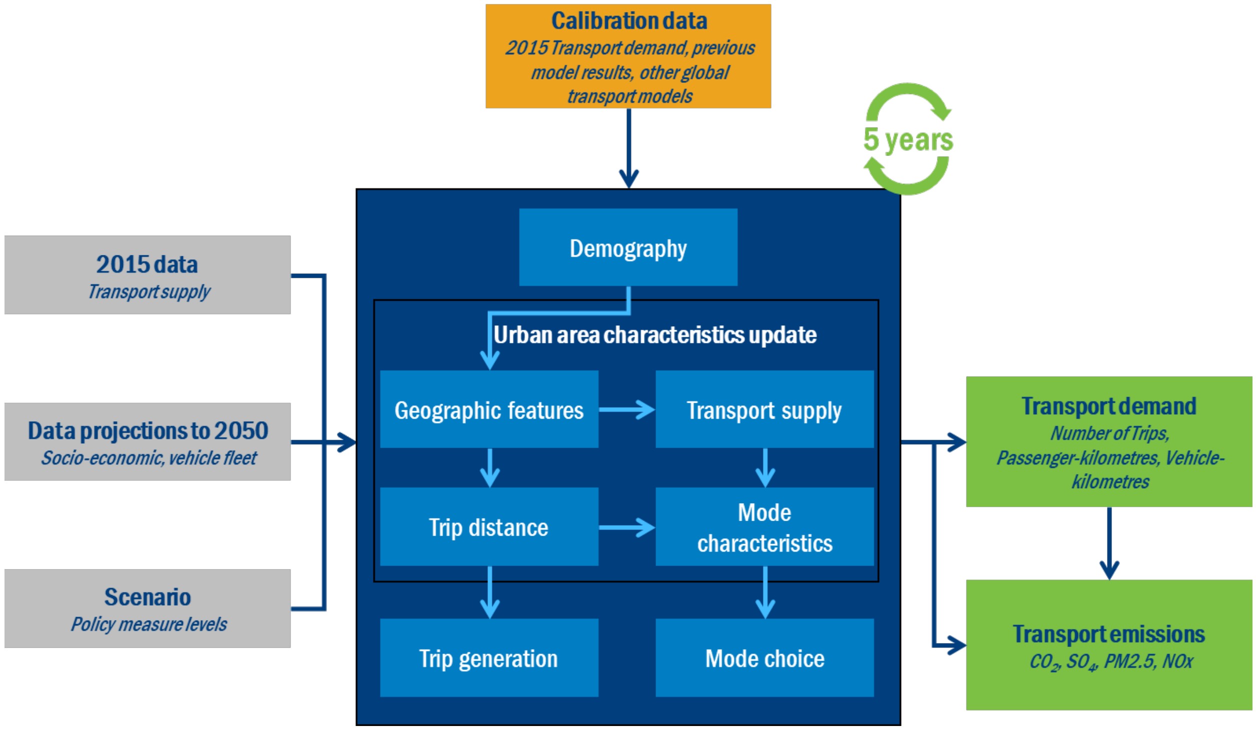

Source: ITF.

## Model components

The ITF global urban passenger model is organised around several blocks represented in Figure 3: The input blocks include the different types of input required for the model, these inputs are all exogenous; It computes the state of urban passenger transport for all the mFUAs from the base year 2015 to the target year 2050, with 5-year increments.

- The input blocks in grey are aggregations of input data categories, which are entirely exogenous to the model. 2015 transport supply data is used as a starting value to set up initial transport supply characteristics within the model, that will evolve based on other indicators in the future, within the model. Data projections from 2015 to 2050 on socio-economic characteristics and vehicle fleet characteristics and emissions are entirely exogenous. Last, the scenario input includes different transport and land-use policy levels, and several societal trends or technology assumptions impacting the development of the metropolitan area or the transport system. This input is used to test the impact of different scenario setting on future transport system states and related emissions.
- The calibration block in yellow illustrates that the 2015 demand data input is not used as a direct input within the model but as calibration values. The model parameters are set to reproduce these travel demand values based on the 2015 data inputs available. Expert analyses on the evolution of the model results are also conducted to ensure a proper calibration over time. This includes comparisons with other international studies on urban passenger transport and previous model version results.
- The core model component blocks in blue are blocks happening within the model process and are endogenous.

- Figure 3 Structure of the ITF Global Urban Passenger Transport Model 2020

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- Source: ITF.

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First, a demographic module has been set up, estimating the evolution of the population and its composition based on a survival stock model approach. It follows the formula:

Equation 1

$$pop_{a+1,g,t+1}{}^{MFUA} = pop_{a,g,t}{}^{MFUA} \times \left(1 - dr_{a,g,t}{}^{country}\right) + mig_{a,g,t}{}^{national,MFUA} + mig_{a,g,t}{}^{international,MFUA}$$

with $pop_{a,g,t}{}^{MFUA}$ the population of the age category $a$ and gender category $g$ for the time step $t$ in the city $MFUA$; $dr_{a,g,t}{}^{country}$ the average death rate of the age category $a$ and gender category $g$ for the time step $t$ in the $country$; $mig_{a,g,t}{}^{national,MFUA}$ and $mig_{a,g,t}{}^{international,MFUA}$ the respective national and international net population migrations to the city $MFUA$ for the population of the age category $a$ and gender category $g$ for the time step $t$. Limit formulas for this demographic model are as follow:

Equation 2

$$pop_{0-4,g,t+1}{}^{MFUA} = \sum_{15 \le a < 50} \left(pop_{a,F,t}{}^{MFUA} \times br_{a,g,t}{}^{country}\right) \times \left(1 - dr_{0-4,g,t}{}^{country}\right) + mig_{0-4,g,t}{}^{national,MFUA} + mig_{0-4,g,t}{}^{international,MFUA}$$

and

Equation 3

$$pop_{80+,g,t+1}{}^{MFUA} = pop_{75-79,g,t}{}^{MFUA} \times \left(1 - dr_{75-79,g,t}{}^{country}\right) + pop_{80+,g,t}{}^{MFUA} \times \left(1 - dr_{80+,g,t}{}^{country}\right) + mig_{a,g,t}{}^{national,MFUA} + mig_{a,g,t}{}^{international,MFUA}$$

with $pop_{0-4,g,t}{}^{MFUA}$ and $pop_{80+,g,t}{}^{MFUA}$ the population aged between 0 and 4, and over 80 years old respectively, of gender category $g$ for the time step $t$ in the city $MFUA$; $pop_{a,F,t}{}^{MFUA}$ the population of age $a$, of gender category $F$ (female) for the time step $t$ in the city $MFUA$; $br_{a,g,t}{}^{country}$ the average birth rate for babies of gender $g$, for the females of age $a$ for the time step $t$ in the city $MFUA$.

Second, the characteristics of urban areas are updated beginning with spatial geographic features (i.e. area, density), which impacts transport supply (evolving along with the area, density and GDP evolution) and trip distance distribution (based on a utility approach of each trip distance category with a logit distribution), which impacts the mode characteristics in turn.

Equation 4

$$U_d{}^{MFUA} = ASC_d + \lambda_{d,s} \times s^{MFUA} + \lambda_{d,s\_core} \times s_{core}{}^{MFUA} + \lambda_{d,dens} \times dens^{MFUA} + \lambda_{d,dens\_core} \times dens^{MFUA} + \lambda_{d,LU} \times LU^{MFUA}$$

with $U_d{}^{MFUA}$ the utility for the distance bin $d$; $ASC_d$ the alternative specific constant for the distance bin $d$ of the city $MFUA$; $\lambda_{d,s}$, $\lambda_{d,s\_core}$, $\lambda_{d,dens}$, $\lambda_{d,dens\_core}$, $\lambda_{d,LU}$, the utility parameters respectively for the MFUA surface $s^{MFUA}$, the city centre surface $s_{core}{}^{MFUA}$, the MFUA population density $dens^{MFUA}$, the population density of the city centre $dens^{MFUA}$, and the land-use mixture of the MFUA $LU^{MFUA}$. The final computation of the shares of each distance bin in the total number of trips can be done with the formula:

Equation 5

$$Share_d^{MFUA} = \frac{\exp\left(\mu \times U_d{}^{MFUA}\right)}{\sum_{i,U_i{}^{MFUA} \neq 0} \exp\left(\mu \times U_i{}^{MFUA}\right)}$$

with $Share_d^{MFUA}$ the share of the trips for the distance bin $d$ in the city $MFUA$, $\mu$ a standardisation parameter.

Third, the proper travel demand generation steps run with the trip generation and mode choice blocks for each population category. The trip generation is based on a regression including GDP per capita and population category explanatory variables, while the mode choice is based on a discrete choice model sensitive to modal characteristics and population category. The initial availability of a mode alternative for the mode choice within a mFUA and for a distance bin is determined by the existing transport supply and a mode applicability matric by distance bin. Table 1 displays this matrix, with 1 indicating the presence of the mode in the choice set for the related distance bin. This applicability matrix also varies based on the age group of the population and can vary by gender.

Table 1 Illustration of the mode applicability matrix

| Mode Applicability by Distance Bin<br>*1: mode available, 0: mode not available* | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Distance bin id** | **0** | **1** | **2** | **3** | **4** | **5** |
| **Mode** | **Mode code** | < 1km | 1 - 2.5 km | 2.5 km - 5 km | 5 km - 10 km | 10 - 20 km | > 20 km |
| **Walk** | M_1 | 1 | 1 | 1 | - | - | - |
| **Bicycle** | M_2 | 1 | 1 | 1 | 1 | - | - |
| **Motorcycle** | M_3 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PrivateCar** | M_4 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Taxi** | M_5 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PT-Rail** | M_6 | - | - | 1 | 1 | 1 | 1 |
| **PT-Metro** | M_7 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PT-LRT** | M_8 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PT-Bus** | M_9 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PT-BRT** | M_10 | - | - | 1 | 1 | 1 | 1 |
| **PT-InformalBusDRTv** | M_11 | - | 1 | 1 | 1 | 1 | 1 |
| **PT-ThreeWheeler** | M_12 | - | - | - | - | - | - |
| **Scooter-sharing** | M_13 | 1 | 1 | - | - | - | - |
| **Bike-sharing** | M_14 | 1 | 1 | 1 | 1 | - | - |
| **Ride-sharing** | M_15 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Motorcycle-sharing** | M_16 | - | 1 | 1 | 1 | 1 | 1 |
| **Car-Sharing** | M_17 | - | 1 | 1 | 1 | 1 | 1 |
| **Minibus-sharing** | M_18 | - | - | 1 | 1 | 1 | 1 |

The formula for the utility of each mode alternative of the mode choice is computed as follows:

Equation 6

$$
\begin{aligned}
{U_m}^{a,g,d,MFUA} = {} & ASC_m^{g,market} + \lambda_{m,r}^{market} \times r_m^{MFUA} + \lambda_{m,access}^{market} \times {access_m}^{MFUA} \\
& + \lambda_{m,wait}^{market} \times wait_m^{MFUA} + \lambda_{m,time}^{market} \times time_m^{a,d,MFUA} + \lambda_{m,tr}^{market} \times tr_m^{MFUA} \\
& + \lambda_{m,pk}^{market} \times pk_m^{MFUA} + \lambda_{m,cost}^{market} \times cost_m^{d,MFUA} + \lambda_{m,infra}^{market} \times infra_m^{MFUA}
\end{aligned}
$$

with ${U_m}^{a,g,d,MFUA}$, the utility of the mode $m$ for the age $a$, gender $g$ and distance $d$ category of the city $MFUA$; $ASC_m^{g,market}$, the alternative specific constant for the mode $m$, depending on the gender $g$ category, and on the regional market $market$ to which the mFUA belongs; $\lambda_{m,r}^{market}$, $\lambda_{m,access}^{market}$, $\lambda_{m,wait}^{market}$, $\lambda_{m,time}^{market}$, $\lambda_{m,tr}^{market}$, $\lambda_{m,pk}^{market}$, $\lambda_{m,cost}^{market}$, $\lambda_{m,infra}^{market}$ the utility parameters respectively for the resilience $r_m^{MFUA}$, time to access ${access_m}^{MFUA}$, waiting time $wait_m^{MFUA}$, travel time $time_m^{a,d,MFUA}$, transfer connectivity $tr_m^{MFUA}$, parking cost $pk_m^{MFUA}$, cost $cost_m^{d,MFUA}$, and infrastructure attractiveness $infra_m^{MFUA}$ of the mode $m$ and city $MFUA$ variables; the travel time variable also varies depending on the age $a$ and distance bin $d$ category, and the cost variable by the distance bin $d$ category. In specific cases, the parameters can be found at a more accurate national or city level rather than the market one, which is available by default for all cases.

The final mode shares are computed following the multinomial logit discrete choice formula:

Equation 7

$$
Share_m^{a,g,d,MFUA} = \frac{\exp\left({U_m}^{a,g,d,MFUA}\right)}{\sum_{i,available} \exp\left({U_i}^{a,g,d,MFUA}\right)}
$$

with $Share_m^{a,g,d,MFUA}$ the shares of mode $m$ in the age $a$, gender $g$, distance bin category $d$ of the city $MFUA$.

Different mode choice formulas are also employed for the mFUA centre and for its suburb.

- Finally, model outputs are generated by the output blocks. All previous results from the other model blocks are gathered within the Transport demand output block. It provides the overall travel demand in terms of trip number, passenger-kilometre and vehicle-kilometres volumes for each population category, distance category, mode, and 5-year step iteration.

## Model inputs

The inputs of the ITF 2020 global urban passenger transport model can be segmented among five input categories, each highlighting a side of the urban passenger transport system. First geographic data provides the limits of the study field, its geographic composition and the activities available. Second, socio-economic data describes the urban population characteristics. Third, transport supply data characterises the different transport networks available in the study field. Fourth, travel demand data is the key one, only used as an input for the calibration step in the reference year. It focuses on how individuals travel in the urban area and is expressed in volume of travel and trips. Fifth and last, vehicle fleet and environment data connecting travel volumes to transport emissions are also necessary for running the model. While all these data inputs are required for the reference year 2015, the travel demand data is not an input but an output of the model for future years. Most of the time, the data is not available for every urban area, and several extrapolations are made to rebuild unobserved attributes from similar cases (in the same world region or country when available, with similar population or GDP per capita).

### Geographic data

The boundaries and areas of each urban area for 2015 considered in this modelling exercise directly come from(**OECD, 2020**). Each urban area is a macro Functional Urban Area (mFUA): an FUA is the aggregation of 1km grid cells with significant population concentration. In the model, FUAs are aggregated into an mFUA if contiguous and belonging to the same administrative region within a country. Along with this main perimeter description, a city centre can be distinguished from the suburb for the larger mFUAs. OECD/EC **(2020)** also provides the perimeter of this city centre, also defined on population concentration criteria. A total of 9 234 mFUAs representing all the urban areas over the world are within the scope of this model. The different mFUAs display patterns grouped into 19 world regions built based on similar country cultures and characteristics. The mFUAs and world region are displayed in Figure 2.

### Socio-economic data

In the ITF global urban passenger model, urban population characteristics are mostly condensed into demographic and economic attributes. The demographic data required is disaggregated at the age (18 age groups: below 1, 1 to 4, 5 to 9… 75 to 79, 80 and over) and gender (female or male) level for each mFUA. Initial 2015 population come from an interpolation of **(OECD, 2020)**, UN DESA World Urbanization Prospect 2018[1] and WorldPop[2] data. Expected death rates, birth rates and international migrations at the country level from the UN DESA World Population Prospect 2022[3] database and 2015 mFUA gender and age composition from WorldPop are collected for calibrating an in-house demographic model. The economic data focuses on Gross Metropolitan Product (GMP) for each mFUA. It is estimated from the economic directorate of OECD country GDP estimations between 2015 and 2050, and NASA Landsat geographical distribution of GDP **(Nordhaus and Chen, 2016)**. An example of the GDP distribution is displayed in Figure 4.

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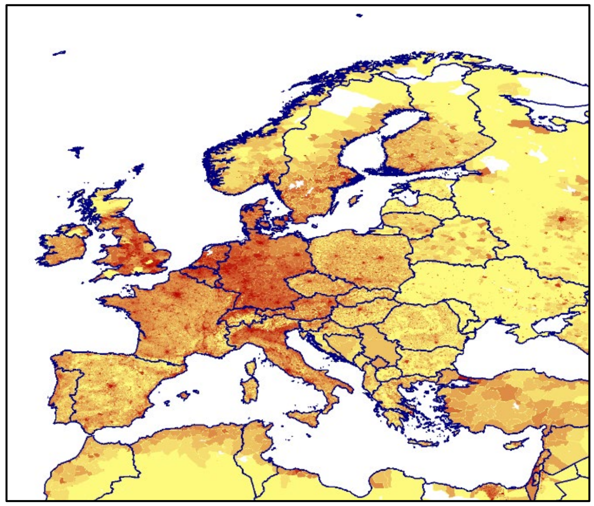
[1] UN Department of Economic and Social Affairs, World Urbanization Prospects 2018, https://population.un.org/wup/

[2] WorldPop 2020 dataset, https://www.worldpop.org/



[3] UN Department of Economic and Social Affairs, World Population Prospects 2022,https://population.un.org/wpp/

Figure 4 Landsat Map of GDP distribution in the European Union



## Transport supply data

Characterising the transport networks and setting up initial attributes of the 18 different transport modes listed in Figure 1 is key for the core of the transport model. Existing 2015 public transport and road infrastructure data comes from OpenStreetMap[4] and the Global BRT database[5], while service data is obtained from GTFS. They enable getting network length by five link types characterised by their speed and the number of PT stops by PT mode. Taxi, parking, gasoline, ticket costs and fare information is collected from various sources[6]. Modal characteristics (i.e. costs, travel time, reliability, access time, waiting time, average number of transfers, speed) for each mode and by distance category (0-1km, 1-2.5km, 2.5-5km, 5-10km, 10-20km, over 20km) are estimated based on these data sets and expert judgement. The evolution of these supply characteristics is implemented based on GDP per capita, population and area, among other explanatory variables.

## Travel demand data

Travel demand data for 2015 household travel surveys were collected from several ITF country members as an input to calibrate the central part of the transport model estimating future travel demand data based on the evolution of all the other input data. This data is made of a collection of travel surveys describing mode shares and trip characteristics that the model will try to reproduce.

## Vehicle fleet and environment data

Data on vehicle technology pathways comes from two primary sources. For each mode, the vehicle fleet composition (by fuel, engine and vehicle type), respective $CO_2$ emission factors (tank-to-wheel (TTW) and well-to-tank (WTT)), and vehicle load factors between 2015 and 2050 come from the ITF Vehicle Fleet model of the International Energy Agency (IEA). The emission factors of local pollutants (e.g. BC, CO, $NH_3$, Nox, $Pm_{se}$, $SO_2$, VOC) by mode and fuel type come from the ICCT Transport Roadmap Model[7]. They enable converting travel demand into related emissions, and also have some impact on the modal characteristics.

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[4] OpenStreetMap database, https://www.openstreetmap.org/

[5] Global BRT Data, https://brtdata.org/

[6] Main sources include UITP database https://www.uitp.org/data/, EMTA data https://www.emta.com/, generic studies and papers

[7] ICCT (2019), Transportation Roadmap, https://www.theicct.org/transportation-roadmap (accessed on 13 March 2019).

## 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 2 shows measures implemented in the Urban Passenger Model with target values by 2050 aggregated in two simplified categories: Global North and Global South contexts.

Table 2 List of measures for urban passenger transport and their 2050 targets implemented in the model

| Policy measures | Description | Global North | Global South |
|---|---|---|---|
| **Carbon pricing*** | Pricing of carbon-based fuels based on the emissions they produce | 750 USD/ tonne $CO_2$ | 300 USD/ tonne $CO_2$ |
| **Parking pricing and restrictions*** | Regulations to control availability and price of parking spaces for motorised vehicles | 30-225% fare increase | 40-75% fare increase |
| **Road pricing*** | Charges applied to motorised vehicles for the use of road infrastructure | 2.5-25% cost increase | 5-10% cost increase |
| **Bike and Pedestrian infrastructure improvements** | Increase in dedicated infrastructure for active mobility | 40-100% network increase | 100-500% network increase |
| **Land-use planning** | Densification of cities differentiated between the city centre and the suburbs for cities over 300 000 inhabitants | 0-30% density increase | 10-40% density increase |
| **Public transport infrastructure improvements** | Improvements to public transport network density and size differentiated for cities over and under 1 000 000 inhabitants | 0-75% network increase | 60-200% network increase |
| **Public transport service improvements** | Improvements to public transport service frequency and capacity differentiated for bus and mass transit services | 10-50% service increase | 10-30% service increase |
| **Integrated public transport ticketing** | Integration of public transport ticketing systems | 3-7.5% fare decrease | 1.5-7.5% fare decrease |
| **Public transport priority and express lanes** | Prioritising circulation of public transport vehicles in traffic through signal priority or express lanes | 10-75% network prioritised | 20-60% network prioritised |

| | | | |
|---|---|---|---|
| **Transit-Oriented Development (TOD)** | Increase in mixed-use development in neighbourhoods around public transport hubs | 9.5% land-use diversity increase | 7.5% land-use diversity increase |
| **Teleworking** | Policies favouring and trends regarding the practice of home office | 10-40% of active population teleworking | 3.5-9% of active population teleworking |
| **Urban vehicle restriction scheme** | Car restriction policies in certain areas and during certain times to limit congestion. Typically applied in the city centre | 10-31.5% of vehicles restricted from circulated in centre | 3.5-15% of vehicles restricted from circulated in centre |
| **Speed limitations** | Traffic calming measure to reduce speed and dominance of motor vehicles through low-speed zones or infrastructure | 12.5-50% speed decrease | 5-50% of vehicles speed decrease |
| **Carpooling policies** | Carpooling policies encourage consolidating private vehicle trips with similar origins and destinations | 7.2-16.6% occupancy rate increase | 7.6-9% occupancy rate increase |
| **Vehicle sharing incentives** | Incentives to encourage car or motorcycle rental schemes where members have access to a pool of vehicles as needed | 5-60% shared vehicles per capita increase | 5-60% shared vehicles per capita increase |
| **Mobility as a Service (MaaS) and multimodal travel services** | Improved integration between public transport and shared mobility (app integration, as well as physical infrastructure, ticketing and schedule integration) | 30-90% increase of population covered by a MaaS system | 10-20% increase of population covered by a MaaS system |
| **Ride sharing and shared mobility** | Increased ridership in non-urban road transport differentiated for car and bus-based services | 25-300% ride sharing vehicles per capita increase | 50-300% ride sharing vehicles per capita increase |

## References


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