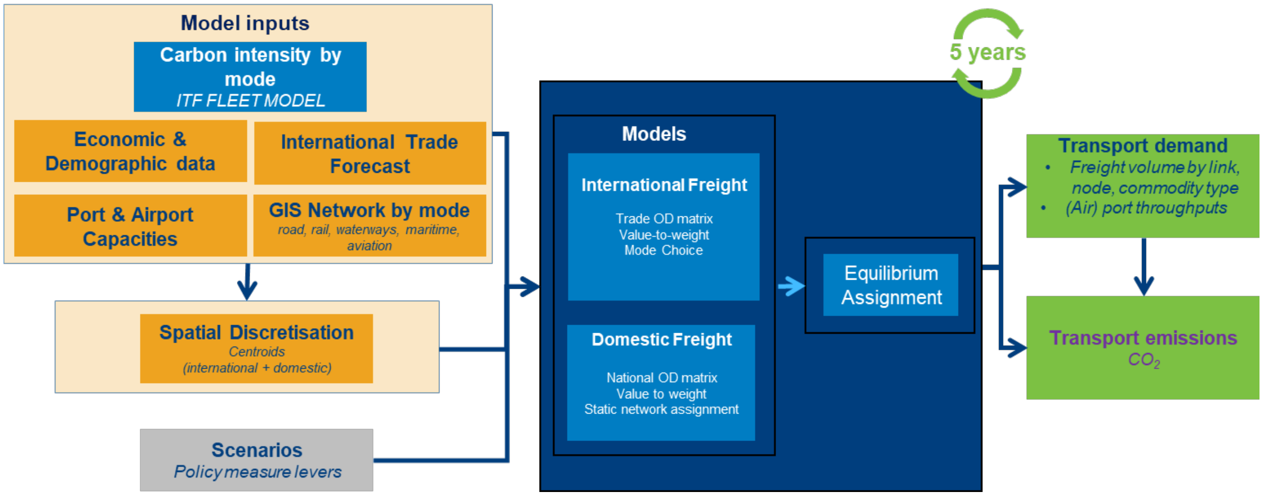
ITF Urban Freight Model Overview

Introduction to the model methodology

The ITF has developed the Urban Freight Model to estimate the impact of policy measures related to decarbonisation of urban freight transport under different scenarios. This section provides a high-level overview of the model development, methodology, inputs and outputs. Specific methodological details are available in the next section.

The general model framework is presented in Figure 1.

Figure 1. ITF Freight Model conceptual diagram



Source: ITF

The first version of the model was developed for a single urban area, Groot-Rijnmond (which includes Rotterdam) in the Netherlands. This was undertaken as a Master of Science Thesis co-supervised by the ITF (ter Laag, 2019). The initial model has since been expanded to the global level. The global model covers all of the world territory that belongs to a functional urban area (FUA). In Europe, these areas correspond to the European Commission's NUTS3 regions (Nomenclature of Territorial Units for Statistics, Level 3). FUAs that fall within the same larger NUTS2 region (e.g., state or province) and border one another were clustered together. This zoning system was then replicated for the rest of the world. Each FUA was further divided into a grid of smaller 2km by 2km zones to produce detailed results with a high spatial resolution. In the case of the Groot-Rijnmond model, the grid resolution is 1km by 1km.

Given the project objectives and using best practices from the literature, a commodity-based adjusted four-step model was created for Groot-Rijnmond and expanded to the global scale, with some modifications. The initial four-step model and its global modification were chosen to suit the model's objectives (i.e., quantitative assessment of transport decarbonisation measures) and to accommodate the limited availability of urban freight movement data.

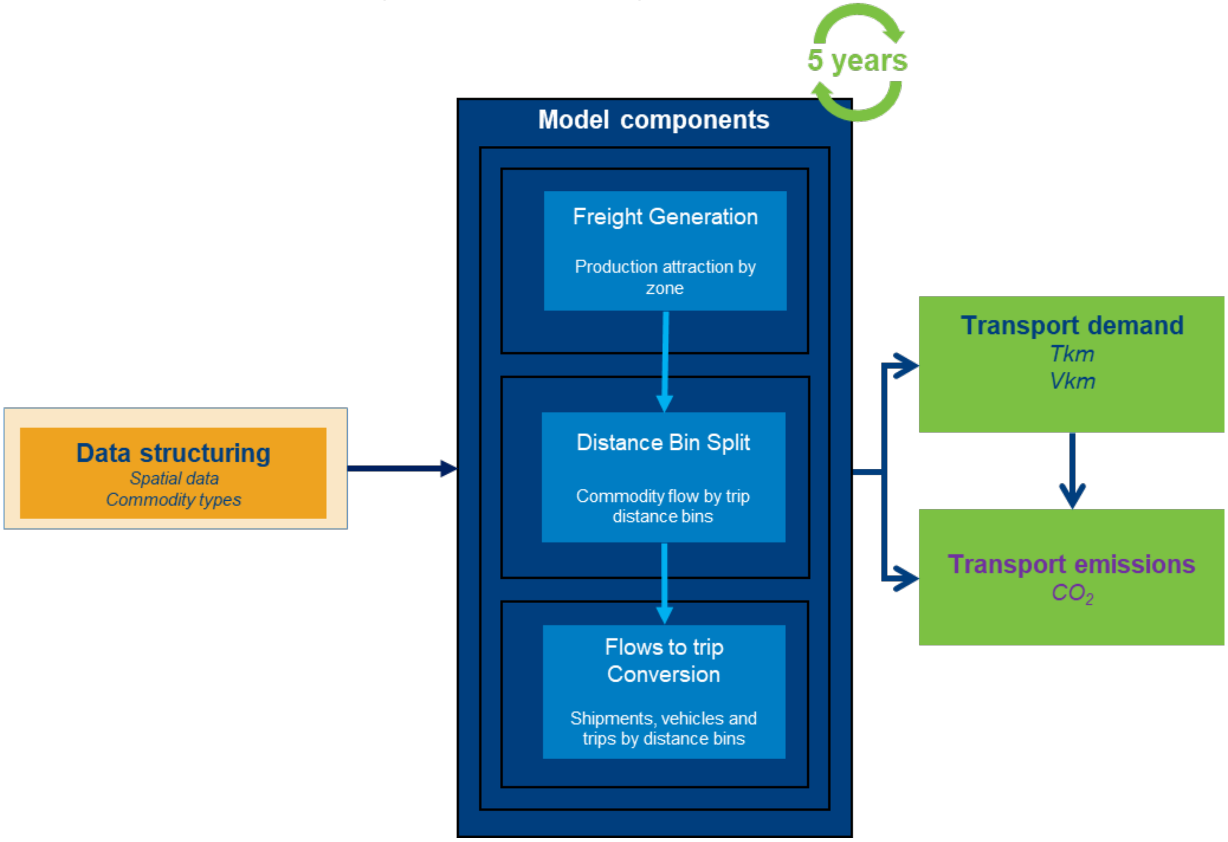
The modelling structure consists of five steps. The very first step is to clean and structure the input data into a homogenous format. The second step is the freight generation module, in which freight production and consumption in a zone are estimated with a generalised linear model (GLM) based on the spatial characteristics of the zone. The model is estimated for each of the commodity types described in Table 1.

At the third step of the model, a freight distribution sub-model is applied, distributing the produced and attracted freight flows to each origin and destination (OD) pair. In the case of the global model the second step is modified so that the freight production of each zone is split into six distance ranges for each commodity type. This procedure involves a distance bin split model which was estimated using data for the shares of shipments falling into a certain distance bin depending on city characteristics. This approach was necessary given the limited availability of disaggregated OD freight flow data at the global scale.

In the fourth step, the obtained flows for each distance bin and commodity type are converted into trips. First, shipments are created using an iterative procedure, after which vehicle types are assigned to the shipments. Then, these shipments are grouped into trips based on a probability function and vehicle capacities. Once trips are generated, the last step of the model is executed: the emissions of each trip are calculated based on the tonne-kilometres of the trip.

The overall urban freight model framework is illustrated in Figure 2. An overview of the data inputs, outputs, and the functions of each module are all described in the subsequent subsections. The technical modelling details are provided in the Methodology section. The procedure for modelling a diverse set of policy measures is described in the Implementing Outlook 2023 Scenarios section.

Figure 2. ITF Urban Freight Model structure



Model inputs

Eight different data sources from four different organisations are used as inputs for the Urban Freight model:

1. Socioeconomic statistics and XML shipments microdata from Statistics Netherlands (CBS)
2. Aggregated microdata on urban freight from Eurostat
3. Commercial services data, regional freight data and population/GDP data from the ITF/OECD
4. Land use data and road freight data from the EU.

The CBS microdata was used to estimate the parameters of the freight generation module. The other sources have been used either as independent variables, or as empirical data (e.g. vehicle choice distributions). Aggregated Eurostat data on urban freight is also used for estimating city-specific constants in the freight generation module.

Two data sources from the CBS were used for this model. One is publicly available, while the other is private. The public data contains socio-economic statistics at the neighbourhood level from 2017 (CBS, 2017). The variables that are included in this dataset can be used as independent variables to estimate freight demand. This dataset includes total neighbourhood population, composition of the population, number of establishments and residences. The size of a neighbourhood (in terms of land surface) varies across the dataset, and thus some neighbourhoods were merge to ensure a comparable scale. The second data source by the CBS contains XML microdata from a road transport survey conducted in the Netherlands. The entire dataset contains over 2.5 million shipments, with information about the vehicle type in which the shipment is transported, the weight of the shipment, the commodity type, the location of origin and destination, and the trip characteristics.

The ITF/OECD is the source of commercial services, regional freight and socioeconomic data. The ITF established the 1 x 1 km grid for the urban area of Groot-Rijnmond to use as a zoning system for the initial model. The grid contains data on the number and type of commercial services per zone, collected from TomTom. It is important to note that the commercial services are reported by users, and may therefore contain minor inaccuracies. The second data source that is used is output from the *regional* freight model of the ITF, which can be used to calibrate the freight flows that are estimated with the *urban* freight model. The last data source is a global map of population and GDP by the OECD. The map has a larger spatial resolution than the neighbourhood data from the CBS, so it was converted to a 1 x 1 km grid.

Two publicly available EU data sources are also used as inputs. The first is another spatial data source: the Corine Land Cover (CLC) by Copernicus (Copernicus Programme, 2018). Copernicus is an initiative from the EU that uses satellite image data to analyse spatial patterns, with the ultimate goal of improving the quality of life for the citizens of Europe. The CLC provides small-scale data on the land use of specific areas, which are publicly available as GIS shapefiles. The Copernicus data are also used to estimate unknown values outside of the European Union, where Copernicus data are not available. The second European data source that is used is the European Road Freight Transport (ERFT) survey by Eurostat (Eurostat, 2014a). The survey offers general, anonymised freight transport statistics on the NUTS3 level, differentiated by commodity. This includes statistics on average shipment size, type of vehicle used, and load factor.

To deal with the limited data availability, some assumptions have been made for the different modelling steps. The main transferability issue is freight demand, since it is highly location-specific. Holguín-Veras et al. (2013) showed that freight generation models can be transferred between areas under certain conditions. The generation model was initially estimated for Groot-Rijnmond and then the estimated coefficients were applied to generate freight in other cities. The ERFT data on freight shipments allows estimating an additional parameter in the generation model, a city-specific constant, accounting for the variability of the freight generation across different FUAs.

The steps that conver OD-flows to vehicle trips/tours were estimated based on ERFT data at the NUTS3 level. Koning et al. (2018) show that shipment size choice can be transferred between France and Germany. Based on this outcome, the assumption is made that shipment size choice is largely consistent across a single country. Additionally, the assumption is made that the ERFT data at the NUTS2 or NUTS3 level are accurate enough to predict vehicle choice from the shipments size and commodity type.

Model outputs

The urban freight model assesses freight movements in cities under different policy scenarios, as well as their evolution over time from the 2019 base year to 2050. The outcomes of interest include transport flows and characteristics as well as transport-related sustainable development indicators. The model produces estimates of urban freight transport tonne-kilometres (tkm), vehicle-kilometres (vkm) and total cargo weight at the trip level. The model also estimates the number of trips, travel distances, and modal split. The corresponding total and mean values are available at the global, regional, and city levels, segmented by travel mode and commodity. The outcomes are computed every 5 years from the 2019 base year to 2050. The results in tkm and vkm are also converted to estimate emissions of CO_2, NO_X, SO_2 and PM_{10} from urban freight transport.

Model components

The model includes five main components (see **Figure 2**):

- Data structuring,
- Freight generation,
- Freight distribution (distance bin split),
- Conversion of the flows to trips, and;
- Emissions model.

The first step was to restructure the data into a homogenous format in order to be able to use data from various sources for the model estimation.

Once the data was structured, a freight generation model for the Groot-Rijnmond region was estimated. Then the estimated coefficients for the attraction and production of cargo by each zone were extrapolated globally with an additional city-specific constant varying across the FUAs. The city-specific constant is calibrated based on the urban freight data available for many of the countries (Eurostat, 2014b). The calibration results are extrapolated to the rest of the world based on cities' characteristics such as size, GDP and population. An ordinary least squares (OLS) method was found to be the most suitable for the estimating the generation model.

For the distance bin split, a traditional doubly constrained gravity model was applied with estimated parameters that express the sensitivity of the travel distance by commodity to generalised transportation costs (based on distance and travel time). The initial model was estimated for in the Groot-Rijnmond region using continuous distances. Most commodities were found to have comparable sensitivities, with the exception of climate-controlled goods and transportation equipment that are not as sensitive to transportation costs, and paper and wood that are more sensitive to transportation costs. For the global model, due to the lack of data and heavier computational burden, generated flows are assigned to one of six distance bins rather than a specific origin and destination.

The next component is the conversion of the flows obtained for each distance bin into trips. The conversion includes the following steps: conversion of the flows to shipments, assignment of the shipments to different types of vehicles and combining the shipments into trips for each vehicle type.

After trips are created, a final estimation of CO_2 and pollutant emissions is generated for different levels of spatial aggregation.

Methodology

Structuring of the data

Since various data sources were used, data cleaning and restructuring was a necessary procedure in order to prepare for model estimation.

Spatial data

Spatial structuring was used to ensure that all data sources represent the same regions and are assigned to the same zoning system. First, uniform grids with zones of 1km x 1km for Groot-Rijnmond and 2km x 2km for the global model were created to provide a consistent spatial unit of analysis. To define the boundaries of the FUAs for the global model, the OECD/Eurostat urban functional area definition was used. This resulted in 4 832 urban areas for the EU, divided into 1 008 FUAs with over 300 000 inhabitants and 3 824 FUAs representing small cities. For the world there are around 11 000 FUAs or FUA clusters.

The data were then cleaned, restructured and assigned to zones as follows:

- CBS XML-data freight transport survey for the generation step: only shipments with an origin and/or destination within the Groot-Rijnmond region were selected, based on their four-digit zip code number (PC4-code). Shipments with a transported weight of zero were removed, thus removing empty trips, as the load factors for different vehicles categories already account for empty trips. Based on the reported commodity volumes, the total productions and attractions of all commodity types were reported per PC4-code. These productions and attractions were then assigned to the spatial grid. The productions and attractions are the dependent variables in the estimation of the generation sub-model.
- CBS neighbourhood socioeconomic data (CBS Wijk- en buurtkaart 2017): these data were converted to fit the spatial resolution of the grid through a “data split procedure”. In this procedure, initial zones for which the data are available were geometrically overlapped with the grid, and the relevant data (e.g. population) were split among the grid cells proportionally to the sizes of the cells. The level of urbanity, which is given on a scale, is recoded using dummy variables.
- ITF/OECD Services in urban areas: these data are converted to fit the grid based on geographical overlap as well. A principal component analysis (PCA) was conducted to investigate whether some of these surfaces could be grouped together, to avoid unwanted correlations while estimating the generation model (see appendix C for details). However, the differences between sample sets of different urban areas in Europe were found to be too large. Grouping the different services together would not allow a generation model for one region to be transferred to another region.
- ITF/OECD Population and GDP: these data are converted to fit the grid using the data split procedure as described above.
- EU CLC land use data: these data are converted to fit the grid using the data split procedure as described above, while the land use type that has the largest surface within a given zone is assigned as the dominant type within that zone. This is recoded into dummy (binary) variables for each land use type. The land use of Maasvlakte 2 is changed from “construction area” to “port area”.
- An additional binary variable is added to indicate whether a zone is a logistics hub. This variable is set to one for zones that belong to the 90th percentile in either freight production or freight consumption across all zones.

Commodity types

It was also necessary to convert commodity types specific to urban freight to be consistent with the goods types in the XML data. Ten typical goods categories were defined, and the different NSTR (an EU classification system, the Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée) subclasses in the XML data were allocated to these categories. Table 1 presents the categorisation scheme.

This new categorisation offers commodity classes that are specifically oriented towards urban freight transport, and that are important to consider when implementing policy measures. For example, Type 1 contains fresh foods, flowers and plants, a category of goods that require climate controlled vehicles which may be more difficult to electrify due to their high power consumption. Another important category is that of transportation equipment, such as empty containers, because in cities with large ports they form a significant portion of the total goods transport. In terms of future trends, Type 10 is highly relevant, as e-commerce is expected to continue to grow.

Table 1. Aggregation of NSTR subclasses into commodity types

Index	Commodity	NSTR references
1	Climate-controlled goods	02**, 03**, 06**, 1390, 14**
2	Non-fresh food	01**, 11**, 12**, 132*, 133*, 136*, 16**, 17**, 18**
3	Manufactured goods	91**, 92**, 03**, 94**, 96**, 97**
4	Construction	55**, 56**, 61**, 62**, 63**, 64**, 65**, 69**, 891*, 892*, 951*, 992*, 993*
5	Raw materials	2***, 31**, 32**, 33**, 515*, 542*
6	Paper and wood	05**, 972*, 973*, 974*
7	Chemicals	092*, 34**, 719*, 81**, 893*
8	Waste	049*, 462*, 842*, 896*
9	Transportation equipment	9761, 9910
10	Parcels	9790

Freight generation

The freight generation model is estimated from commodity volumes that are produced and consumed in 1km x 1km zones for the Groot-Rijnmond model. The variable “in model” defines if a certain zone should be used for demand generation. For example, zones that consist entirely of water are given a value of zero, meaning that they are not included for demand estimation. A generalised linear model (GLM) is estimated to predict the freight production and consumption in each included zone per commodity type.

The model uses observed volumes as dependent variable and a set of zonal characteristics as independent variables. Three different types of GLMs were assessed based on their fit to the data and the accuracy of their predictions: a zero truncated ordinary least squares (OLS) regression model, a tobit model, and a zero-inflated negative binomial (ZINB) model. The difference between the OLS, tobit, and ZINB models is the probability distribution of the error term: while following a normal distribution in the case of OLS and tobit GLMs, the error term follows a negative binomial distribution in the case of a ZINB GLM. The three models were tested on consumption and production generation sub-models for two different commodities: the consumption of climate-controlled goods and the production of manufactured goods. The results showed that in terms of goodness of fit, the ZINB model performs much worse than the OLS and tobit models, while the OLS and tobit methods showed no obvious difference in performance. Thus the choice was made to further continue with the OLS structure since it is easiest to interpret.

An OLS model has the following structure:

$$y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_n x_{in} + \epsilon_i$$

In this structure, y_i is the estimated production or consumption in zone i, β_0 is a constant in the equation, and β_n is the coefficient for variable n that should be multiplied by the value x_{in} of variable n in zone i. The variable ϵ_i is the error term of the model, which is normally distributed. Negative estimates are adjusted to zero as negative freight production or consumption is not possible.

The parameters estimated by the model include zone characteristics such as population, GDP, presence of logistics hubs and several parameters related to land-use. The latter are the binary variables describing the characteristics of each zone: whether the zone is a port area, a construction site, a green urban area, has a complex cultivation pattern, and so on. The set of the land-use variables included in the model varies across the commodity types. In the case of the global model, similar variables are used but aggregated to the city level. Instead of land-use dummies, new variables are applied such as the size of areas with different land-use characteristics within a city.

For the Groot-Rijnmond model, one external zone was defined to capture commodity flows coming into and going out of the region. The flows entering and exiting this zone were calibrated based on the ITF non-urban freight model that includes all urban NUTS3 regions in Europe as separate zones. For the global model, only the internal traffic of each FUA is represented by the model. That is, the urban freight model only accounts for emissions from trips with an origin and destination within each FUA. Emissions from trips that begin or end outside of the FUA are captured by other ITF freight models. Emissions in the FUA referring to the urban portion of an inter-urban freight trip (such as the first or last mile portion) are accounted for in the ITF international freight model at NUTS3 level, while non-urban freight trips are accounted for in the ITF non-urban freight model.

Distribution of freight flows

In the distribution step for the Groot-Rijnmond region, the freight flows are split between the OD pairs in order to match the total number of trips generated for each zone. The first step of the distribution stage is the creation of the OD-matrix with distances and travel times between all zones in the model. The OD matrices are based on the shortest path algorithm that calculates travel times based on an average speed of 80 percent of the maximum speed. The calibration of the distribution model was based on an uncongested network since much freight is transported during off-peak hours.

The distribution was performed based on a double- constrained gravity model. The mathematical formulation of the model is as follows:

$$V_{ij} = p_i * P_i * q_j * C_j * f(c_{ij})$$

In this equation, V_{ij} denotes the transported freight from zone i to zone j, while P_i and C_j are the reported production and consumption of freight in the corresponding zones, multiplied by zone-specific multiplication factors p_i and q_j. These are multiplied by function f that determines the accessibility of the destination zone based on the travel cost between zones c_{ij}:

$$f\left(c_{ij}\right) = e^{-\beta c_{ij}}$$

In this function, β is a sensitivity parameter, while c_{ij} is based on impedances between zones that are given by a skim matrix that takes into account uncongested travel times and travel distances. The skim matrix is based on the existing network definition that is used by the ITF, and a generalised cost function by Rijkswaterstaat (2016).

An iterative method was used to estimate the sensitivity parameters and thus to calibrate the accessibility functions, based on average kilometres driven per tonne for each commodity. The goal of the iterative method is to minimize the difference between the empirical tkms and the estimated tkms, determined by:

$$min \mid \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} V_{ij}d_{ij} - \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} V_{ij}D \mid$$

In this formula, V_{ij} is the transported flow between zones, d_{ij} is the distance between zones according to the skim matrix, and D is the average distance that is driven per tonne for a given commodity. The calibration of the final freight flows was achieved in 20 iterations, at which point all multiplication factors for most commodities had approached a value of 1.

The OD-flows were aggregated before the distribution model estimation. This is necessary as the spatial scale used to describe shipments in the CBS microdata is very different from the scale of the model. To overcome this issue, an aggregate approach was used based on total tkm. The location variables in the CBS microdata are linked to a skim matrix with distances between all postcodes in the Netherlands. Afterwards, the distance for each shipment within the Groot-Rijnmond region is estimated. Combined with the tonnage of each shipment, an average distance per transported tonne is estimated. Table 2 shows the average distances for each commodity and the estimated sensitivity coefficients. Using the average distances, total tkms are calculated for freight transport within the Groot-Rijnmond region.

Table 2. Estimated sensitivity parameters of the distribution model

Commodity	Avg. distance per tonne	β
Climate-controlled goods	2.37	-0.41
Non-fresh food	1.30	-0.64
Manufactured goods	1.51	-0.60
Construction and building materials	1.50	-0.64
Raw materials	1.47	-0.60
Paper and wood	0.60	-0.79
Chemicals	1.30	-0.62
Waste	2.59	-0.61
Transportation equipment	2.00	-0.49
Parcels	1.56	-0.57

For the globally expanded version of the model, a different approach for freight distribution was applied. This choice is aligned with existing data constraints and the heavier computational burden of the global model. Instead of assigning generated flows to OD pairs, the flows for each commodity type are assigned to six different distance bins by mean. The six distance bins are: less than 1.0 km, 1.0-2.5 km, 2.5-5.0 km, 5.0-10.0 km, 10.0-20.0 km and more than 20 km. The assignment is performed based on a model that estimates the share of a cargo falling into a certain distance bin from city characteristics. Model parameters are calibrated to match the known tonne shares for each NUTS3 from Eurostat within the respective FUA. The model is estimated using the formula:

$$P_{ic}D_jS_{ijc} = \beta_{0ijc} + \beta_{1i}x_{1i} + \cdots + \beta_{ni}x_{ni} + \epsilon_{ijc}$$

In this equation, P_{ic} is the production of city i for commodity c in tonnes that is obtained from the generation step; D_j is the average distance of bin j; S_{ijc} is the share of commodity c in city i that falls in distance bin j; β_{0gjc} is a term specific to the combination of city type (defined by size, population and GDP), commodity type and distance bin; β_{ni} are parameters representing sensitivity of the distance bin share to city-specific variables x_{nc} for city c; ϵ_{ijc} is the error term representing probabilistic nature of the model. Variables x_{nc} are related to geographical characteristics of the cities, presence and size of its main freight hubs (such as ports and airports).

From freight flows to trips

In order to calculate emissions, estimated freight flows have to be converted into trips. This is done in three steps: distance-based volumes are converted into shipments, shipments are assigned to vehicles, then shipments that are assigned to the same vehicles are combined into trips. Return trips of the empty vehicle are not accounted for in the model, as such trips account for a small percentage of all transported goods.

The creation of shipments entails an iterative procedure for each OD-flow. Each OD-flow is split into shipments based on an empirical shipment size distribution (Table 3). Based on shipment size clusters, vehicles are allocated to shipments. Additionally, the distance travelled is adjusted based on the congestion in the network at the allocated hour of departure. Peak hours were determined from TomTom traffic reports (TomTom, 2019), which found that 7:00-8:00 AM and 4:00-5:00 PM are the peak hours. When there is no freight volume left for the OD pair, the procedure terminates. Table 4 presents the vehicle split for each of the six urban freight transport modes by commodity type.

Table 3. Shipment size statistics by commodity type

Commodity type	Mean weight (tonne)	Standard deviation
Climate-controlled goods	10.188	6.196
Non-fresh food	10.677	4.874
Manufactured goods	9.779	5.741
Construction and building materials	8.687	4.858
Raw materials	9.616	4.59
Paper and wood	10.433	4.924
Chemicals	9.19	4.083
Waste	8.074	4.658
Transportation equipment	10.645	4.264
Parcels	5.864	6.926

The distribution step in the initial Groot-Rijnmond model did not account for departure time variations or possible congestion due to the lack of data and assumption that most of freight is transported off-peak. These two factors were introduced into the global model so that the model could reflect relevant policy scenarios. The distance bin step, which substitutes for the OD distribution step in the global version of the model, can also reflect policy scenarios that affect travel distances and congestion.

Finally, shipments assigned to the same vehicle types were combined into trips. This procedure was performed for each OD-pair for the Groot-Rijnmond model. For the global model it is performed for each distance bin. Within the list of shipments for each OD-pair and distance bin, a shipment that is not a part of a trip yet will be assigned a number from an empirical (commodity specific) distribution that gives the probability of the number of shipments within the trip. If this number is larger than 1, then an iterative procedure starts that adds shipments to the trip, until the maximum permissible weight (defined by ITF, 2015) or the maximum number of shipments is reached.

Table 4. Vehicle split and cargo type by commodity

Commodity type	Truck without trailer	Truck with trailer	Tractor without trailer	Tractor with trailer	Other without trailer	Other with trailer	Dominant, cargo time
Climate-controlled goods	2.85%	29.32%	0.00%	67.83%	0.00%	0.00%	Bulk/piece
Non-fresh food	5.02%	24.92%	0.00%	70.06%	0.00%	0.00%	Bulk/piece
Manufactured goods	11.58%	8.66%	1.03%	75.92%	1.06%	1.75%	Bulk/piece
Construction and building materials	20.11%	42.03%	0.00%	37.86%	0.00%	0.00%	Bulk/piece
Raw materials	13.37%	11.76%	0.00%	74.87%	0.00%	0.00%	Bulk/piece
Paper and wood	11.23%	30.75%	0.00%	58.02%	0.00%	0.00%	Container
Chemicals	7.96%	1.95%	0.00%	90.10%	0.00%	0.00%	Bulk/piece
Waste	52.97%	37.38%	0.00%	9.64%	0.00%	0.00%	Bulk/piece
Transportation equipment	7.23%	7.63%	1.17%	83.94%	0.02%	0.00%	Container
Parcels	4.15%	14.24%	0.00%	81.60%	0.00%	0.00%	Bulk/piece

Emissions model

The emission model is based on the distances driven per vehicle type and the load of the vehicle, determined by the previous modelling steps, using emissions values from Otten et al. (2017). Vehicle speed and acceleration of the vehicle are not accounted for.

Emission values are based on the six vehicle types in the data. There is a differentiation between two cargo groups: one emissions model is applied to commodity types that mainly consist of bulk and general cargo, and another emissions model is applied to commodities that are mainly transported in containers. **Table 5** presents emissions per tkm for each vehicle type.

Table 5. Emissions for two cargo groups by vehicle type

Vehicle	Bulk and general cargo transport				Container transport			
	CO_2 [g/tkm]	SO_2 [g/tkm]	PM_{10} [g/tkm]	NO_x [g/tkm]	CO_2 [g/tkm]	SO_2 [g/tkm]	PM_{10} [g/tkm]	NO_x [g/tkm]
Van	1298	0.00825	0.589	6.25	NA	NA	NA	NA
Truck/lorry without trailer	390	0.00239	0.106	3.98	287	0.00200	0.0483	2.53
Truck/lorry with trailer	171	0.00100	0.031	1.32	167	0.00100	0.0270	1.23
Tractor without trailer	239	0.00100	0.027	1.97	189	0.00133	0.0203	1.03
Tractor with trailer	131	0.00100	0.017	0.70	189	0.00133	0.0203	1.03
Other vehicle without trailer	293	0.00167	0.050	2.60	287	0.00200	0.0483	2.53
Other vehicle with trailer	157	0.00100	0.026	1.17	167	0.00100	0.0270	1.23

Source: (Otten et al., 2017)

Implementing Outlook 2023 Scenarios

The ITF 2023 Outlook

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

The *Current Ambition* scenario builds on existing policies and commitments to estimate current pathways for transport demand and related emissions. In contrast, *High Ambition* targets more profound changes in the transport sector related to demand management (generation control and sustainable modal diversion) and technological breakthroughs. These scenarios were designed by the ITF in 2020 for the preparation of the ITF Transport Outlook 2021 **(ITF, 2021)**, and subsequently adjusted for the ITF Transport Outlook 2023 **(ITF, 2023a)**. They are largely informed by an international survey on current transport policies and technology development issued to subject matter experts in the ITF network.

Table 6 shows the measures implemented in the model with target values by 2050, aggregated in two simplified categories: Global North and Global South contexts. They include enhancement to infrastructure, economic instruments, regulatory instruments and policy measures to stimulate innovation and development. Each of the measures and their implementation within the urban freight model are described in the subsections that follow.

Table 6. List of measures for urban freight transport and their implementation in the model

Type	Policy measures	**Model implementation**	**Global North**	**Global South**
Infrastructure Enhancement	**Urban consolidation centres**	Reduces vkm and costs for first-mile and last-mile distributions of goods that can migrate to soft modes.	5% - 20% of TKM	2% - 5% of TKM
Economic Instruments	**Congestion and zone charging**	Routes for OD pairs crossing the congestion zones may lengthen, increasing vkm. The additional average vkms are estimated for each FUA as a function of the OD pairs affected and the charge introduced.	6.2 cents / TKM	2.4 cents / TKM
	Fuel economy standards – for vehicles and fuel	Reduces the CO2 intensity of the affected modes and the conversion of vkm to CO2 emissions.	ITF ‘High Ambition’ scenario	
Regulatory Instruments	**Restricted access to zones**	Routes for OD pairs crossing the access zones may lengthen, increasing vkm. The additional average vkms are estimated for each FUA as a function of the OD pairs affected. Simultaneously, the pace of deployment of cleaner vehicle fleets is increased.	10% improvement	5% improvement
	Zero/low emissions vehicles	Adoption of these vehicles reduces emissions per vkm proportionally.	ITF ‘High Ambition’ scenario	
Innovation and Development	**Intelligent Transport Systems**	Reduces vkm and costs for first-mile and last-mile distributions of goods that can migrate to soft modes.	2%-10% improvement	1%-5% improvement

Education and Training	**Eco-driving/driver training**	Adapt the emissions intensity per vehicle kilometres travelled based on values in the literature.	ITF 'High Ambition' scenario

Urban consolidation centres

Urban consolidation centres (UCCs), also called urban distribution centres or logistics hubs, are facilities located near the city centre to which goods can be transported, and from which shipments can be consolidated and transported into the inner city in lighter vehicles. Their main purpose is to avoid lightly loaded trucks delivering goods in urban centres (Browne et al., 2005). This makes them very suitable for combination with measures to promote the use of zero/low emissions vehicles. The combination of increased vehicle load factors and the use of zero emissions vehicles leads to environmental and social benefits in urban areas (Browne et al., 2005). Van Duin et al. (2010) discovered that the use of electric vehicles for the last mile deliveries can be a success factor, although only if support infrastructure is available.

There are a couple of other context variables that improve the success of UCCs, according to Browne et al. (2005): availability of funding, strong public sector involvement, existing congestion/ pollution problems in the area, bottom-up pressure from local interests, and UCCs with a single manager. The authors also state that the focus of a UCC should be on improving vehicle capacity utilisation, as opposed to the traditional view of just transferring loads into smaller vehicles. Additionally, Van Duin et al. (2010) mention that in order for the business case of a UCC to work, the municipality should actively help to bring costs and benefits together.

The implementation of UCCs has experienced several issues that require attention. First, traffic conditions around the UCCs can deteriorate. Secondly, implementation creates difficulties for logistics service providers (Van Duin et al., 2010), who have to deal with the costs of additional handling (Browne et al., 2005) and changes in practices and contract forms. Logistics providers often already have efficient distribution structures in place and are not keen on change. Another issue, per Aljohani and Thompson (2016), is that urban sprawl may result in the relocation of UCCs to areas outside of the city centre, which would increase the distance travelled by vehicles. This is confirmed by Dablanc and Rakotonarivo (2010), who did a study on the CO_2 impacts of logistics sprawl in the Paris urban area. They conclude that 15,000 additional tonnes of CO_2 are generated annually due to urban sprawl since the 1970s. They also state that this could be mitigated by using zero-emission vehicles for inner-city transport.

Variants of UCCs include the use of active modes and pick-up consolidation. Active modes are when the last mile is covered on foot or by bicycle. The feasibility of active modes for distribution depends on the commodity type and the shipment size. The idea behind pick-up consolidation is to not bring goods to the customer, but to let the customer pick up the goods themselves from pick-up points, also referred to as drop-off collection points. There are two main types of pick-up points: (1) self-service lockers where the parcels are stored and the consumer uses an identifier to access the goods and (2) service points that are usually incorporated into existing stores or post offices. Service points can be very successful in some cases, as they allow greater flexibility with respect to the size of the parcel and the method of payment. However, lockers are less time constrained, which has a strong influence on consumers' choice between pick-up point delivery and home delivery. In terms of modelling, this measure is implemented in a similar fashion to the use of active modes.

There are numerous examples of the implementation of UCCs. The city of Utrecht saw a 73% reduction in CO_2 emissions (5.8 tonnes) after implementing a low emissions zone combined with a UCC and delivery by an electric train (van Rooijen and Quak, 2014). An experiment in Paris with delivery with electric tricycles saved 112 tonnes of CO_2 (Worsey, 2000; Allen et al., 2007). London is another example in which tricycles were used, with the addition of electric vans and one diesel truck. The introduction of a micro consolidation centre caused a 54% CO_2 reduction across the entire system (Michael Browne et al., 2011). In Bristol, two Euro III vehicles were used for deliveries from a UCC, which saved 5.29 tonnes of CO_2 (Allen et al., 2007).

Model implementation

The implementation of this measure would be quite time-consuming, considering the change in distribution structures caused by this measure. First of all, zones with UCCs would have larger freight productions and consumption rates. Second, these zones could be expected to have specific vehicle split functions, and drastically different factors for consolidating shipments into trips. Moreover, tour formation should be included in routing to account for the fact that tours would start or end more often in zones with a UCC.

The use of active modes would imply the use of new, entirely different modes that can be used only for very short distances and for very small shipment sizes (e.g., up to 30kg). The implementation of pick-up consolidation would be similar to the general implementation of UCCs. There would also be a reduction in freight consumption rates for zones near the pick-up consolidation centres.

Congestion and zone charging

Pricing measures, similar to restricted access, come with many different implementations. The implementations can be divided into two categories:

- Congestion charging: charging vehicles for transporting goods during peak hours.
- Zone charging: also called road tolls, zone tolls or road charging. This means that vehicles are charged when they enter certain zones or use certain roads.

The direct impact of these measures is that they reduce congestion, but they also reduce emissions indirectly. Carriers are forced to improve their efficiency and reduce their logistics costs to make up for higher operating costs. However, the initial effect of pricing measures on carrier operations is questionable, as carriers are often able to pass higher costs on to customers (Van Duin, Quak and Muñuzuri, 2010).

Empirical examples of pricing measures are found in Trondheim, Singapore, and London. In London, the introduction of a congestion charging system caused an 18 percent reduction in traffic volume and a reduction in delays of 30 percent, indirectly decreasing CO_2 emissions (Allen, Thorne and Browne, 2007).

Model implementation

This measure is implemented by first determining the OD pairs affected by the pricing scheme. The generalised costs of the concerned links/paths are increased accordingly, and the shortest (least costly) paths are re-defined. As a result, the new travel distance matrix updates the average variation in vkm for each FUA. If the restriction is targeted at certain vehicle types, this incentive also increases the pace of penetration of cleaner vehicles in the FUA. Elasticities for the effect of road pricing on the adoption rate of cleaner vehicles are taken from Zhang et al. (2016).

Fuel economy standards – for vehicles and fuel

A low carbon fuel standard (LCFS) is a market-based policy mechanism aiming to reduce the life-cycle greenhouse gas (GHG) emission intensity of transportation fuels and energy vectors.

The mechanism is grounded on the definition of progressively tightened regulatory thresholds/limits for the average life cycle (including production, distribution and use) GHG emission intensity of transport fuels and energy vectors (typically gasoline, diesel oil and jet kerosene) distributed by regulated parties. Fuels with a carbon intensity that is lower than the regulated threshold generate credits; fuels with higher GHG emission intensity generate deficits. In any given year, regulated parties need to have enough credits to compensate for any deficits created by the sale of carbon-intensive fuels. Regulated entities can trade credits and use credits banked from previous years to ensure they meet the policy requirements in any given year.

Mandatory vehicle efficiency standards require newly registered vehicles to emit less tailpipe CO_2 emissions than a specified threshold value (usually specified in gCO_2/km or similar) by a certain target date. Alternatively, such standards may be expressed as fuel economy standards that require vehicles to surpass a certain fuel-efficiency value (usually provided in miles/gallon fuel or similar). Vehicle tailpipe CO_2 emissions and fuel consumption are typically assessed in standardised laboratory vehicle test procedures (ITF, 2023b).

Model implementation

This measure is implemented in the model as a reduction of carbon intensity per vkm for the road sector, with a calendar of development by vehicle type and region in the ITF fleet model.

Restricted access to zones

Restricted access to zones is predominantly meant to reduce congestion and local pollutant issues, but it has other beneficial environmental effects as well (Muñuzuri et al., 2005). Different implementations for restricted access to zones are possible, the main differences being based on time windows, weight and size of vehicles, and vehicle emissions:

- Time windows: this measure implies fixed time windows during which certain vehicle types are allowed to enter the zone, permission for night time deliveries in zones, and off-peak deliveries. The general idea behind this measure is that a vehicle is only allowed into a zone for a limited period during the day.
- Weight and size: this measure bans vehicles from entering certain zones based on their weight and size.
- Emissions: this measure bans vehicles from entering certain zones based on their emissions. This is often closely related to the weight and size of the vehicles.

Naturally, a combination of these three measures is possible as well. Moreover, access restrictions based on weight, size and emissions are closely related to one another. One could also ban certain vehicle types, such as all non-electric vehicles, from a zone for a certain time during the day.

There are several examples of successful and unsuccessful implementation of restricted access zones. Between 2008 and 2013, a low emission zone was installed in the city of Aalborg (DK), where only trucks complying with the latest environmental performance standards were allowed. This caused an increase in trucks complying with Euro IV standards from 28 to 54 percent, and a reduction in trucks with engine standard Euro II or lower from 26 percent to 15 percent. During the same time period, similar results were found in the city of Utrecht (NL), when a low-emission zone combined with an urban consolidation centre was introduced. This caused a 73 percent decrease in CO_2 emissions. However, a similar project in Zagreb (HR) failed (van Rooijen and Quak, 2014). In Gothenborg (SE), a low emissions zone was installed as early as 1997, requiring HGVs to meet Euro IV emissions standards. In 2012, 96 percent of HGVs operating in the city complied to Euro IV emissions standards (DG MOVE, 2012).

Restricted access to zones may seem similar to pricing measures, especially road and zone tolls, since these also limit access to certain areas of the city. The distinction that can be made is that restricted access to zones refers to a physical barrier, which makes it physically impossible to enter a certain area, while road and zone tolls simply discourage by setting certain monetary costs to enter.

Model implementation

Access restrictions may be implemented by significant increases in the generalised cost of road links within the restricted zone and by rerunning the shortest (least costly) path algorithm. Potential exemptions of some vehicle types from these restrictions will also affect the vehicle choice model towards the vehicles that can access the zone and, as a consequence, will reduce the vehicle emission factor per vkm.

Zero/low emissions vehicles

The stop-and-go traffic conditions in urban settings lead to extra pollution from fossil-fuelled LDV, therefore zero-emission alternatives can be a useful option to respond to the need for deliveries while also greatly lowering CO_2 emissions.

Zero/low emission vehicles are a bundling term for electric vehicles and vehicles that use alternative low carbon fuels. They include liquid fuels (e.g. biofuels, synthetic and paraffinic fuels), gaseous fuels (e.g. methane, ammonia and hydrogen) and electricity and require production processes that lead to low well-to-tank emissions (ITF, n.d.). These are all bundled because when viewed from a tank-to-wheel modelling perspective, their effect is the same. A wider use of these vehicles reduces CO_2 emissions, but the magnitude of this reduction depends on the type of vehicle and the energy source that is used. Regarding electric vehicles (EVs), the reduced noise pollution makes them a better option for night deliveries. In terms of trip patterns and travel distances, EVs correspond well to the logistics and freight transport needs in urban areas.

The increased use of zero / low emission vehicles can be encouraged through a range of policy measures, including access restrictions and charges for polluting vehicles, construction of necessary supporting infrastructure, such as charging stations for EVs, differentiation of taxation based on emissions and advantageous terms for lower-emitting vehicles. In addition, to encourage industry, regulatory measures such as Low Carbon Fuel Mandates, Fuel blending mandates and vehicle efficiency standards.

There are two issues that should be taken into account when promoting the use of zero/low emissions vehicles. The first is that the source of energy should be considered. There should also be sufficient capacity to produce the fuel that is needed. The second issue is that not all vehicle types are suitable for using certain fuel types. For example, full-electric vehicles are more suitable for short trips and lighter vehicle types because of their limited range and battery power (ITF, 2018), whereas it could be difficult to electrify HGVs. Van Duin et al. (2013) already showed six years ago, using a vehicle routing problem, that with the available technology at the time, electric vehicles could reduce CO_2 emissions in the centre of Amsterdam by 90 percent. They did remark that a high load factor is essential to an economically feasible scenario.

Model implementation

The uptake of zero/low emissions vehicles are considered in the emissions model. The emissions per alternative fuel type is estimated, and multiplied by a share of alternative fuel vehicles within a vehicle type.

For a future version of the model the inclusion of alternative fuel vehicles as a separate vehicle type may be considered. This new type of vehicle could take the characteristics of an existing vehicle type in terms of their probability to be used for different commodity types but have a different tonne-km to emissions conversion in the emissions model. For the probability density function that defines the choice of a certain vehicle type, new estimates (based on literature, expert judgment or observed data) would be required. This approach would also have implications for the creation of shipments, as certain goods would not be as suitable to be transported by electric vehicles (e.g. cooled goods and very large goods would cause difficulties).

Intelligent Transport Systems

Intelligent Transportation Systems (ITS) combine leading-edge information and communication technologies that allow improvements in the efficiency and performance of transportation networks. While ITS is mainly used to aid in the implementation of some of the other measures, they also directly help to reduce emissions.

An example of specific measures related to ITS is more efficient routing. First of all, more efficient routing can help truck drivers to avoid congested areas, use major roads for longer distances and avoid steep ramps or junctions (Allen et al., 2007; ITF, 2018). ITF (2018) explains how this leads to a reduction in emissions by optimising fuel consumption.

The ITF (2018) mentions it as one of the main options to make urban freight transport more sustainable, while Bosetti et al. (2014) express doubts about the ease of implementation. Moreover, Allen et al. (2007) state that more efficient routing could lead to journey time savings, but ITF (2018) contradicts this, stating that the optimisation of fuel consumption could lead to longer trips.

Model implementation

As for the two sub-measures that fall under ITS, for more efficient routing, instead of using an all-or-nothing assignment with capacity restraints (Ortúzar and Willumsen, 2011), which is generally sufficient for modelling urban freight transport, system optimum assignment procedures could be applied.

Eco-driving

Eco-driving/driver training/eco-driving training refers to changing the behaviour of truck drivers to a driving style that would be less polluting, by reducing speed and smoother driving. If adopted, it would cause a reduction in fuel use and therefore a reduction in CO_2 emissions. According to International Transport Forum (2018), it could be very effective to reduce emissions, and has already shown to be a proven concept. Governments could encourage eco-driving through funding of training and the introduction of voluntary schemes.

Model implementation

Accounting for eco-driving measures in the model environment is fairly straightforward. It can be done by adjusting the emissions model with a lower factor for CO_2 emissions, based on values found in the literature or in empirical examples.

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