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HIGH TOOL

Deliverable D4.3

Elasticities and Equations of the HIGH-TOOL Model (Final Version)

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Glossary

BEV	Battery Electric Vehicle
CH	Switzerland
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DG MOVE	European Commission's Directorate-General for Mobility & Transport
EC	European Commission
ETCS	European Train Control System
ETISplus	European Transport Policy Information System
EU	European Union
EU28	28 Member States of the European Union
EUR	Euro
Eurostat	Statistical Office of the European Union
EXIOBASE	A global, detailed Multi-Regional Environmentally Extended Supply and Use/Input-Output Database
FCEV	Fuel Cell Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSM	Global System for Mobile Communications
GVA	Gross Value Added
HDV	Heavy Duty Vehicle
HFO	Heavy Fuel Oil
I/O	Input/Output
LCV	Low Carbon Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MOVEET	Mobility, Vehicle fleet, Energy use and Emissions forecast Tool
NO	Norway
NO_x	Nitrogen Oxides
NUTS	Nomenclature of Territorial Units for Statistics; A number assigned to it defines the level of granularity, such as 0 for the country level.
O/D	Origin/Destination; Used to describe a relation between two regions.
OECD	Organisation for Economic Co-operation and Development
P/A	Production/Attraction; Used to describe a relation between two regions.
Pkm	Passenger-kilometre
PM	Particulate Matter
PTE	Passenger Transport Executive
RP	Revealed Preference

SO_2	Sulphur Dioxide
SP	Stated Preference
SUMMA	Sustainable Mobility, Policy Measures and Assessment
TPM	Transport Policy Measure
Tkm	Tonne-kilometre
TRACCS	Transport data collection supporting the quantitative analysis of measures relating to transport and climate change.
TRANS-TOOLS	Network-based European Transport Model
VAT	Value Added Tax
Vkm	Vehicle-kilometre
WP	Work Package

Executive Summary

This deliverable is the final result from WP4, equations and elasticities. The objective of this third deliverable of WP4 is to outline equations and elasticities used in the final HIGH-TOOL model; this involves the following tasks:

- Determine the equations and elasticities that make up the HIGH-TOOL model (Chapter 3);
- Provide reference elasticities for the validation of the HIGH-TOOL model (Chapter 4);
- Provide elasticities to translate Transport Policy Measures (TPMs) into policy lever values (Chapter 5).

These tasks are elaborated in four main parts of this deliverable: an introduction on the concept of elasticities, a mathematical description of the final HIGH-TOOL model, a meta-analysis on transport elasticities from the literature, and an inventory of policy lever values by which transport policy measures (TPMs) can be modelled.

Deliverable D4.3 first elaborates on the general concept of elasticities and introduces how they are used in HIGH-TOOL (Chapter 2). Herein, explicit elasticities (elasticity parameters that are directly input to the model) and implicit elasticities (elasticities that are derived from the model output) are distinguished. It has to be noted that elasticities derived from models always have to be interpreted in the context of the specific model specification. This chapter on elasticities is an introduction to the subsequent chapters. Elasticities (both explicit and implicit) are used to validate the HIGH-TOOL model (further discussed in Chapter 4 on elasticities in the literature), while explicit elasticities and other model parameters are also the policy levers by which transport policy measures are in the HIGH-TOOL project (further discussed in Chapter 5 on operationalisation of transport policy measures).

After the description of the HIGH-TOOL modules, this deliverable describes the equations and elasticities of the final HIGH-TOOL model (Chapter 3). The HIGH-TOOL model consists of seven core modules:

- **Economy & Resources module.** Provide baseline (without policy measures) and scenario (including policy measures) economic projections as well as inter-regional trade flow predictions per commodity.
- **Demography module**. Provide estimates of the population size by gender and age (based on births, deaths, and migration) and the size of the labour force.
- **Passenger Demand module**. Provide passenger trip flows per origin-destination relation by mode and purpose and calculate related mobility indicators such as passenger-kilometres and vehicle-kilometres.

- **Freight Demand module**. Provide freight trip flows per origin-destination relation by mode and commodity and calculate related mobility indicators such as tonne-kilometres and vehicle-kilometres.
- **Vehicle Stock module**. Translate mobility predictions into the size of the vehicle fleet by vehicle type and calculate fixed and variable transport costs and tax revenues.
- **Environment module**. Provide fuel consumption estimates and corresponding emissions by vehicle type.
- **Safety module**. Provide safety projections in terms of number of fatalities, serious injuries, and slight injuries and calculate the associated social accident costs.

Each module is first described in a general way outlining structure and scope of the model approach as well as the required input and the output produced. As the HIGH-TOOL modules run in sequential order, special attention is given to their mutual interaction in terms of input and output variables. Thereafter, each module is described in detail. The adopted approach is explained and all relevant equations are presented in a stepwise manner. In addition, it is made clear which variables are the output of one module and input to another module. The description of each module is finalized with an overview of explicit elasticities and model parameters.

Furthermore, in order to validate the final HIGH-TOOL model, an extensive study to collect elasticities from the literature has been carried out (Chapter 4). Comparing elasticities from different sources is far from trivial. As anticipated, the collected elasticities cover a large range of values because they are derived in different contexts and use different methods. Hence, taking an average in a fair way is not possible. Therefore, a regression analysis has been carried out to identify the factors contributing to the size of elasticities. Based on this linear regression, four elasticity meta-models have been designed: a cost and time model for both passenger and freight. These elasticity meta-models for HIGH-TOOL account for, among others, the differences in elasticities among several modes of transport, trip purposes, and commodity types. The obtained estimated coefficients were found to have sizes and signs that are plausible.

Obtaining these elasticity meta-models has the very useful side effect that it allows for calculating elasticities for combinations of factors that are not available in the original dataset. In addition, the presented regression analysis provides confidence intervals on the calculated elasticities. This gives an indication of how much one should worry if derived elasticities from HIGH-TOOL do not directly correspond one-to-one to those from the meta-analysis. The constructed elasticity models are validated against established meta-models from the literature. The calculated elasticities sometimes fall in the range by the established meta-models, while in other cases they fall outside this range.

The four estimated elasticity meta-models for HIGH-TOOL are used to validate the HIGH-TOOL model. However, this is not necessarily an easy task. In the light of the large variance of results, the difficult interpretation of the elasticity values as they depend on various restrictions, and the uncertainty of data used for estimation, the results obtained have to be handled very carefully. Where the HIGH-TOOL elasticities comply with the meta-model elasticities a positive validation is the conclusion, whereas where the HIGH-TOOL elasticities fall outside the range provided by the elasticity meta-model for HIGH-TOOL the conclusion to simply invalidate the HIGH TOOL results is not necessarily correct. In the latter case the meta-model background provides a basis for further discussion and investigation.

Finally, the final HIGH-TOOL model is used to evaluate a set of selected transport policy measures (Chapter 5). Each of these TPMs is modelled by adjusting one or more policy levers. These policy levers are model input parameters (explicit elasticities or other model parameters) that are adjusted in order to model the implementation of a Transport Policy Measure (TPM). The HIGH-TOOL model only produces useful model output if these policy levers have realistic values that adequately represent the intensity by which a TPM is implemented. Therefore, first adequate policy levers have been selected for a total of 30 TPMs. Next, default, lower bound, and upper bound policy lever values have been determined on the basis of sources in the literature and expert judgement. Furthermore, a set of rules has been determined for the simultaneous implementation of a limited set of TPMs that are partly or largely overlapping.

1 Introduction

1.1 Objective of the HIGH-TOOL Model

The HIGH-TOOL project developed a free and open high-level strategic transport model to assess economic, social and environmental impacts of transport policy. The HIGH-TOOL model is intended to be a means to support policy makers assessing different policy measures. Figure 1 (Vanherle et al., 2013) shows the process flow in which HIGH-TOOL fits. In order to solve a problem or inefficiency in the transport system, the users looks for appropriate ideas for policy measures. These have to be assessed and their impacts evaluated before implementation. This is where the HIGH-TOOL model (and other complementary models, such as TRANSTOOLS) comes in. Some iteration may be necessary, perfecting intended policy measures so that they have the desired expected impacts on the transport system.

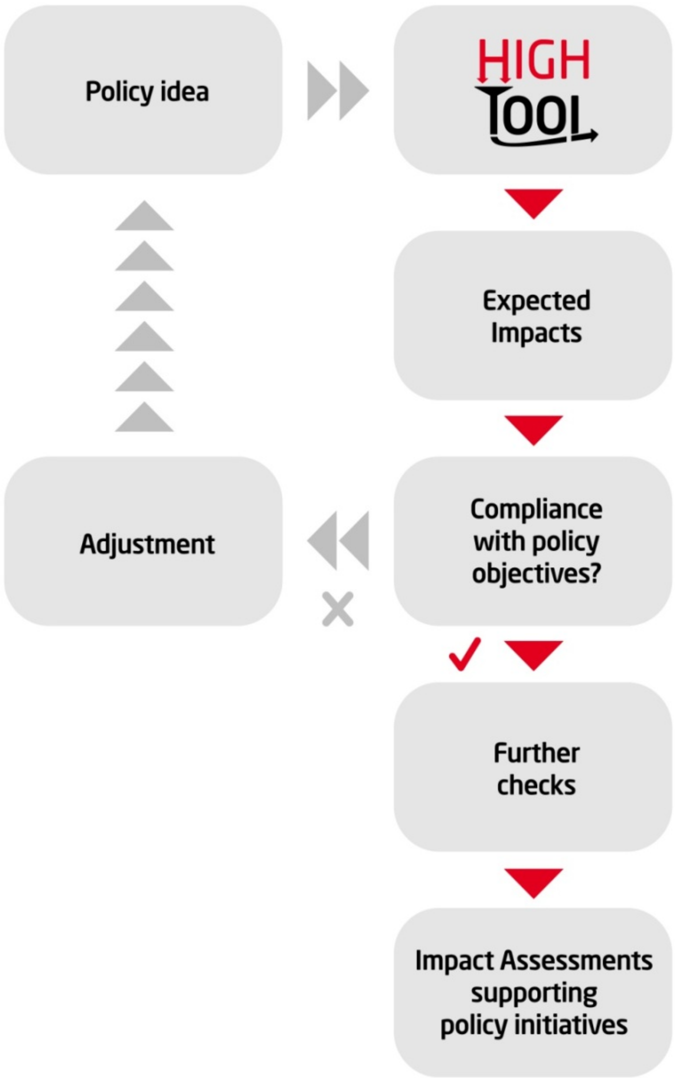

Figure 1: HIGH-TOOL process flow

The HIGH-TOOL model allows (quick) strategic assessment of transport policy options by the European Commission. Input and output indicators and variables of the model are based on policy targets of the Transport White Paper (European Commission, 2011), the Impact Assessment Guidelines (European Commission, 2009) and various other relevant EC documents. The HIGH-TOOL model is largely based on equations and explicit elasticities of existing models. Furthermore, the HIGH-TOOL model uses implicit elasticities derived from the application of model generated during the project lifetime using aggregated data, for instance from ETISplus. Any gaps occurring, especially in context with TPMs, are filled by elasticities found in the literature.

Previous Framework Programmes have already supported the development of transport models such as the network model TRANSTOOLS. Apart from a detailed analysis provided by the aforementioned model, the EC needs a high-level strategic transport model for quick assessment of transport policy options. The HIGH-TOOL model provides the answer to this need.

1.2 Objective of the Deliverable

This deliverable is the final result from WP4, which deals with equations and elasticities. The objective of this third deliverable of WP4 is to outline equations and elasticities used in the final HIGH-TOOL model; this involves the following tasks:

- Determine the equations and elasticities that make up the HIGH-TOOL model (Chapter 3)
- Provide reference elasticities for the validation of the HIGH-TOOL model (Chapter 4)
- Provide elasticities to translate Transport Policy Measures (TPMs) into policy lever values (Chapter 5).

1.3 Interdependencies with other Deliverables

WP4 has continuous interdependencies with the other work packages. Deliverable D4.3, and its successors, are fed by the deliverables from other work packages. Main inputs for Deliverable D4.3 have been:

- Deliverable D1.1: User Requirements (Vanherle et al., 2013)
- Deliverable D2.2: Structure of the HIGH-TOOL model (Mandel et al., 2016)

Deliverable D4.3 provides inputs for following project reports:

- Deliverable D5.2: Final Version of the HIGH-TOOL model
- Deliverable D8.2: Validating the final HIGH-TOOL model
- Deliverable D6.2: Design Criteria for the User Interface and Policy Assessment Reports (Final Version).

1.4 Content of this Deliverable

Chapter 2 first elaborates the concept of elasticities and how it is used in this Work package to refine the tool's architecture. Chapter 3 describes the elasticities and equations in the modules of the final HIGH-TOOL model. For each module it provides a general description, and all relevant equations and elasticities, including their values. Chapter 4 determines the transport elasticities that are representative for Europe. Thereafter, Chapter 5 describes the approach that was adopted to derive elasticities that are used to translate transport policy measures into policy levers.

2 Elasticities in HIGH-TOOL

This chapter elaborates the concept of elasticities and defines which kind of elasticities are distinguished in the HIGH-TOOL model. It also elaborates on elasticities to be used for the validation of the HIGH-TOOL model. Finally, it briefly introduces the collection of elasticities that play a role in the translation of transport policy measure into policy lever values.

2.1 Elasticities

A change in the price of a transport mode can, especially in the long run, have very diverse effects on transport demand for this and other modes, working through all kinds of behavioural mechanisms. These effects are often expressed in the form of elasticities.

2.1.1 The Concept of Elasticities

We will first provide a definition of the elasticity concept based on existing references (De Jong et al., 1998; 2010). The concept of elasticities was first thought of by the English economist Alfred Marshall (1890). Elasticities give the ratio of a percentage change in demand or supply (e.g. road tonne-kilometres) to a percentage change in one of the factors explaining demand or supply (e.g. price of road freight transport, the independent variable of an equation). The advantage of elasticities measured for linear variables is that they are dimensionless, i.e. a change in the unit of measurement (for instance from kilometres to miles) does not affect the elasticities. In case of a variable transformed into non-linear shape (for example through a Box Cox transformation (Mandel et al., 1997)), the elasticity depends on the level of the variable, which makes a comparison quite difficult. In general the model specification as well as the functional form have to be considered when comparing elasticities (Mandel, 1992; Gaudry et al., 1994).

In this deliverable we use the following **general definition of elasticity**:

"An elasticity gives the impact of a change in an independent (or stimulus) variable on a dependent (or response) variable, both measured in percentage changes."

If the impact of a 1% increase of the transport price for a road freight tonne-kilometre results in a decrease in truck tonne-kilometres by 0.3%, the transport price elasticity of the demand for road freight tonne kilometres is -0.3 (=-0.3/1). Elasticities are defined using the 'ceteris paribus' condition: they are valid under the assumption that all other things (i.e. other independent variables) do not change (i.e. the transport time remains untouched).

An elasticity can be positive or negative. If an elasticity (in absolute values) exceeds 1, the dependent variable is called 'elastic' (e.g. elastic demand) with respect to the independent variable. If the elasticity value (in absolute terms) is between 0 and 1, the dependent variable is 'inelastic'.

To give an example of elastic and inelastic price elasticities in mobility: obligatory travel purposes, such as commuting or business, are less price elastic compared to non-obligatory purposes, such as leisure. The convention in economics is that the name of the independent variable comes first (before the word 'elasticity') and the dependent variable follows after the words 'elasticity of'.

Some basic distinctions

A first distinction is between **point elasticities** and **arc elasticities**. A point elasticity measures the proportionate change in the dependent variable resulting from a very small proportionate change in the independent variable. The price *P* elasticity of demand *D* for commodity *Q* in terms of a point elasticity is:

$$e^p = \frac{(\frac{dD^Q}{D^Q})}{(\frac{dP^Q}{P^Q})} = (\frac{dD^Q}{dP^Q}) \cdot (\frac{P^Q}{D^Q})$$

Where:

e^p	Price elasticity of demand for commodity Q
PQ	Price of commodity Q
DQ	Demand for commodity Q.

In this formula dD/dP is the derivative of the (ordinary or Marshallian) demand function with regard to *P* (the slope of the demand function).

An arc elasticity is applicable if the change in the independent variable is not very small, whereas point elasticities are appropriate for small changes. An arc elasticity is defined as:

$$e^p = (\frac{P_2^Q - P_1^Q}{D_2^Q - D_1^Q}) \cdot \frac{(P_1^Q + P_2^Q)}{(D_1^Q + D_2^Q)}$$

Where:

e^p	Price elasticity of demand for commodity Q
P_1^Q	Price of commodity Q before price change
P_2^Q	Price of commodity Q after price change
D_1^Q	Demand of commodity Q before price change
D_2^Q	Demand of commodity Q after price change.

In which the subscripts 1 and 2 represent the situation before and after the change in price. Whether an arc elasticity will be higher or lower than a point elasticity depends on the shape of the demand function (e.g. concave or convex).

In travel demand analyses three specifications are most often used: the Constant Elasticity of Substitution (CES) function, the log-linear model, and the multinomial logit model (MNL). The CES model is specified as follows:

$$ln\,(K) = \alpha \cdot ln\,(P) + \ldots$$

Where:

K	Dependent variable (for example mileage);
P	Independent variable (for example price).

In this case, the elasticity for the impact of changes in price P on mileage K is simply α.

The elasticity is constant. The model is also called 'log-log' model or 'double-logarithmic' model.

The log-linear model is used in similar situations as the above model. Its specification is:

$$ln\,(K) = \beta \cdot P + \ldots$$

The elasticity is now βP and thus depends on the level of the independent variable P. The Multinomial Logit (MNL) model simulates the choice by an individual decision maker n for a discrete alternative i by applying e.g. a linear utility function U using price P as an attribute:

$U_{ni} = \gamma \cdot P_{ni} + \ldots$

The own price elasticity in the MNL model can be calculated from the probability that the decision maker *n* chooses alternative *i*, $Prob_{ni}$ as:

$$e^p = \gamma \, P_{ni} \cdot (1 - Prob_{ni})$$

Another distinction is between **own** and **cross elasticities**. If for instance we are studying mode choice, the own (or direct) elasticity gives the impact of an attribute of some mode on the demand for that same mode, e.g. the road transport cost elasticity of road freight tonne-kilometres. A cross elasticity measures the impacts on other modes, e.g. the road transport cost elasticity of rail freight tonne-kilometres.

A **disaggregate elasticity** measures the reaction of an individual (can be an individual person or firm). Such elasticities can only be derived from disaggregate models, e.g. the (logit) mode choice models. For policy-making, **aggregate elasticities** are mostly more interesting. They refer to the responsiveness of a group of persons/individual firms (possibly the entire market). Aggregate elasticities can be derived from aggregate models respectively from disaggregate models.

Elasticities usually stem from **models**, or are estimated on empirical data (either aggregated data like statistics or disaggregated observations like surveys). However, in some cases, elasticities can be calculated from **direct observations of the impact of a change** (e.g. introduction of a toll), from before and after studies. The data used for model estimation can be time series data, cross section data or panel data. If a time-series model contains lagged parameters, the model can distinguish between short and long term effects. Whether the effects from a cross-section are short or long term depends on the nature of the behavioural mechanisms included (e. g. location decisions are regarded as long run). Using these distinctions, Goodwin (1992) did not find systematic differences between elasticities in passenger transport from time series and cross section (but in general, long run elasticities were larger than short run elasticities). Cross section (and panel) data can be based on **observed choices** (revealed preference or RP data) or on **choices under experimental** (hypothetical) circumstances (stated preference or SP data).

2.1.2 Variation in Elasticity Values

Very often considerable heterogeneity in elasticity values has been found. There are several explanations for this (De Jong et al., 2010). First of all, different elasticities may refer to the same thing, but are taking into account different response mechanisms, that may be working at different timescales. In the long run there are more possibilities to react, so demand will be more elastic.

Furthermore, there is heterogeneity outside of timescale effects. As an example, we describe this for price elasticity, while the same holds for other independent variables like time or frequency. Price elasticities can be different because they refer to:

- Different market segments (e.g. commodity classes, distance classes, geographic markets, trip purposes), with different substitution possibilities: if two goods are close substitutes, the cross-price elasticity can be expected to be high and the own-price elasticity (in absolute terms) will also be higher if close substitutes exist.
- Different components of total transport costs (e.g. toll cost, fuel cost or fixed transport costs).
- Price increases versus decreases; according to prospect theory, decision-makers will react more strongly to losses than to gains, so elasticities for price increases could be larger than for price reductions (however, in practice this is not always taken into account).
- Price changes of different magnitude (this refers to the distinction between point and arc elasticities, but also arc elasticities for changes of different magnitude can be different); if the slope of the inverse demand function decreases with increasing price (reflecting satiation), then large price changes will lead to smaller elasticities than small price changes.
- Different definitions of a transport mode.

Finally, especially cross-elasticities (e.g. effect of road transport prices on rail demand) can be very different depending on the market shares of the modes in the base situation. This also means that cross elasticities are not really transferable from one country to the other if these countries have different mode shares.

In this Deliverable we investigate the existing literature on passenger and road freight transport price elasticities to find out which response mechanisms are included in each, to explain observed differences in published elasticities and obtain insight in the most likely values and how these can be decomposed.

2.1.3 Sensitivities and Elasticities in HIGH-TOOL

An elasticity measures how changing one variable affects another variable, both measured in percentage changes. The affected variable can be an intermediate variable or an output indicator. Important elasticities within the HIGH-TOOL model are those that relate the policy measures to outcomes relevant for the impact assessment: the outcome indicators. Before we can identify the elasticities in the HIGH-TOOL model we need to elaborate on the concept of elasticity and explain the different form an elasticity can have.

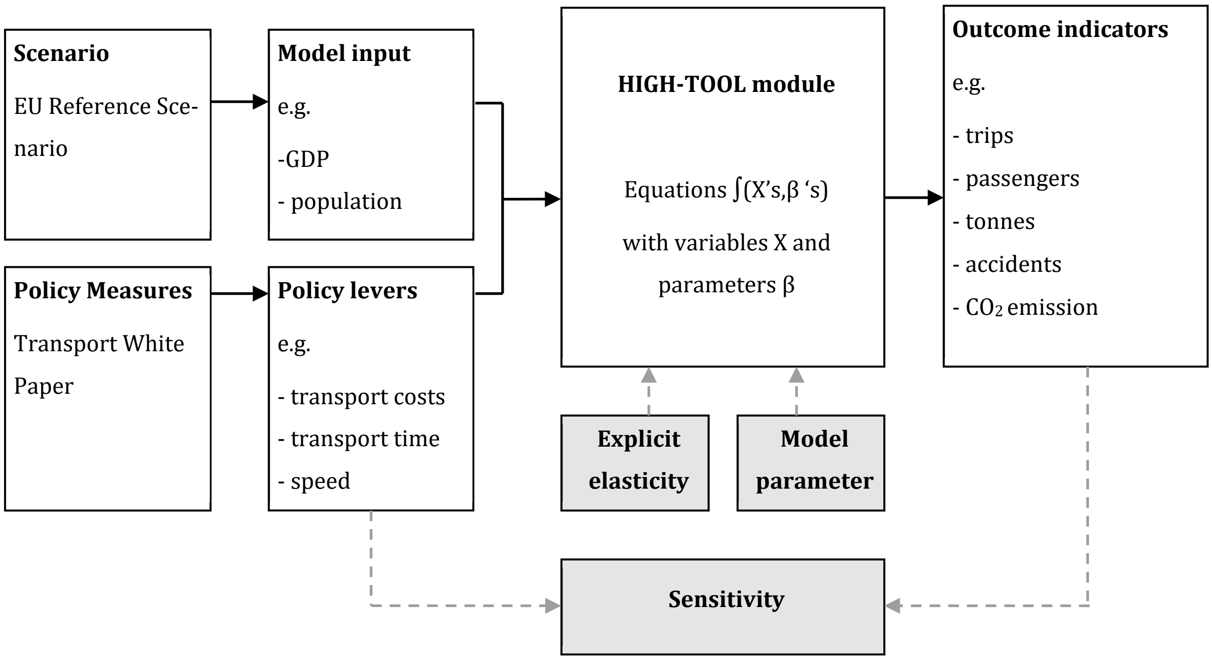

Figure 2: The concept of elasticities in HIGH-TOOL

Figure 2 illustrates the concept of elasticity in a modelling context such as HIGH-TOOL. The equations in HIGH-TOOL are composed of variables and parameters. Variables are external model inputs such as price, time, etc. Parameters, on the other hand, work on these variables as weighting factors and are generally estimated.

Regarding elasticities, we can distinguish between explicit elasticities and implicit elasticities. **Explicit elasticities** are used as a direct input parameter in the equations of the model. However, outcome indicators are not only sensitive to elasticity parameters, but also to other variables in the equations that are not modelled as elasticity. **Implicit elasticities** refer to the sensitivity to changes in input variables (including policy levers). An example of a relevant model parameter is a cost variable in a mode choice model. In this case, modal choice and mode shifts are not modelled with explicit elasticities and cross-elasticities but with cost variables in a utility function of a discrete choice model (e.g. Multinomial Logit model).

Elasticities can also be expressed in the form of **sensitivities**, which are used for the validation process of the final model. Examples: the elasticity of transport by mode A to cost changes in mode B; the risk of accidents to changes in average driving speed.

2.2 Using Elasticity Values for Validation

The majority of studies on transport and models to forecast passenger and freight flows are on national scale or focus on even smaller regions. This implies that the calculated and implemented elasticities are usually determined for regions much smaller than the regions the HIGH-TOOL model is designed for. Therefore, it is not straightforward to find appropriate elasticities in the literature that are usable for HIGH-TOOL.

By studying the literature on transport elasticities one will notice that the values cover a large range. The reasons for the variations are on the one hand differences in behaviour of people and circumstances (existing infrastructure, welfare, etc.) they live in, and on the other hand study specific effects, like the method that has been used to calculate the elasticities. One method to get a finger on the pulse of the variations is to disentangle the different influences using a meta-analysis. In Chapter 4 such meta-analyses are performed on data from literature of different EU countries. Based on linear regression four meta-models have been designed. These models can be used to calculate:

- Passenger time elasticities
- Passenger cost elasticities
- Freight time elasticities
- Freight cost elasticities.

In the analyses significant coefficients have been found among others for different purposes, modes and kinds of elasticities (such as for vehicle-km, trips, etc.). All coefficients are listed in tables and can be used to calculate elasticities valid in the European Union. Finally the results from the meta-models are compared to other meta-analyses, which had different objectives, like for instance focusing on the UK or on public transport. Due to these differences one has to be careful with drawing hard conclusions from the comparison. In this context it has to be stated that no model follows the same specification. In addition, methods that are used in the literature vary strongly and used data differs in type and quality.

2.3 Operationalisation of Transport Policy Measures

HIGH-TOOL does not work with a limited set of pre-defined Transport Policy Measures (TPMs) that are coded into the model. Instead, the model allows users to analyse a wide range of custom policy measures by adjusting a set of input parameters. Therewith, the model provides maximum flexibility in policy specifications and the evaluation of future policies.

Moreover, in case of unsatisfactory or undesirable impacts, a TPM can be reconsidered, adapted, and thereafter re-evaluated with the HIGH-TOOL model in a subsequent iteration. However, this implies that before it can be evaluated, a TPM needs to be translated into a set of numerical input parameter values that adequately reflect the actual policy measure.

Within the course of the HIGH-TOOL project, a selection of TPMs (see chapter 5) is evaluated. Each of these TPMs is translated into viable model inputs by answering the questions which input variables have to be adjusted (the policy levers) and to what extent. This Deliverable describes the analysis that was conducted regarding the second question: the appropriate range of variable values. To this end, an inventory is made of examples where TPMs are translated into model input values. The main sources of such examples are existing large-scale modelling projects (see for example SUMMA, 2005; TRANSTOOLS, 2006; and ASTRA, 2014) and scientific publications. These findings can serve as a reference and aims to support the translation of HIGH-TOOL TPMs into model input. Results are presented in detail in an accompanying Excel sheet.

3 Description of the Final Version of the HIGH-TOOL Model

This chapter describes the formulation of each module in the final version of the HIGH-TOOL model and presents the underlying equations. In addition, the sensitivities of the model to input variables and model variables are addressed. The description of the modules in the final version includes an inventory of elasticities. This inventory includes the first two of all three relevant types of elasticities as defined in Chapter 2:

- Explicit elasticities (elasticity variables in an equation)
- Model variables (indirect elasticity through variables in an equation)

The third one (model sensitivities) are derived from output indicators while varying the variable values and are presented in the validation of the model.

3.1 Overview of Functional Modules in the HIGH-TOOL Model

Figure 3 illustrates the structure of the HIGH-TOOL model (Mandel et al., 2016). A full overview and a description of inputs and outputs for each module are provided in Deliverable D2.2 (Mandel et al., 2016). The core of the HIGH-TOOL model consists of the following functional modules:

- Demography (DEM)
- Economy & Resources (ECR)
- Vehicle Stock (VES)
- Passenger Demand (PAD)
- Freight Demand (FRD)
- Environment (ENV)
- Safety (SAF).

In the subsequent paragraphs, each of these modules is first described in general terms. The description concerns the main objective of the module, its structure, and its main input and output. It is furthermore indicated which variables are output to one module and input to another. Thereafter, each module is described in more detail. The adopted approach is explained and all relevant equations are presented in a stepwise manner. Herein, a consistent mathematical specification is applied. Finally, each module's description is finalised with an overview of explicit elasticities and model variables.

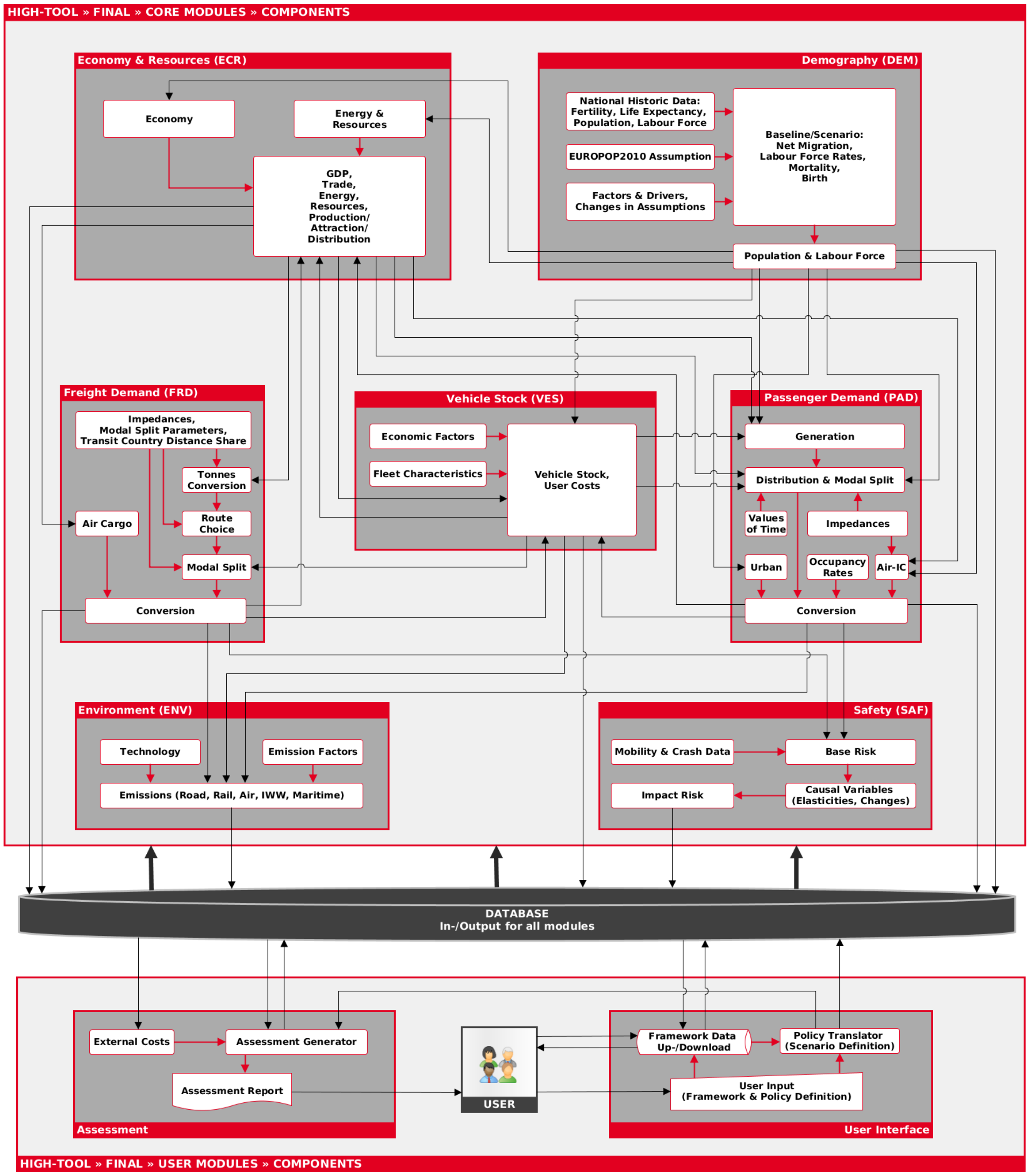

Figure 3: Structure of the final HIGH-TOOL model

To compute a five-year time step the seven modules of the HIGH-TOOL model are run sequentially. The model starts with the Demography module and then successively runs the Economy & Resources, Vehicle Stock, Passenger Demand, Freight Demand, Environment, and Safety modules. Figure 4 displays the sequence of processing the computation of a five-year time slice as outlined in Deliverable D2.2 (Mandel et al., 2016).

For example running the Economy & Resources module requires input from the Demography module (time slice t, the time step in focus) and the Passenger and Freight Demand modules as well as the Vehicle Stock module (time slice t-1, the previous time step).

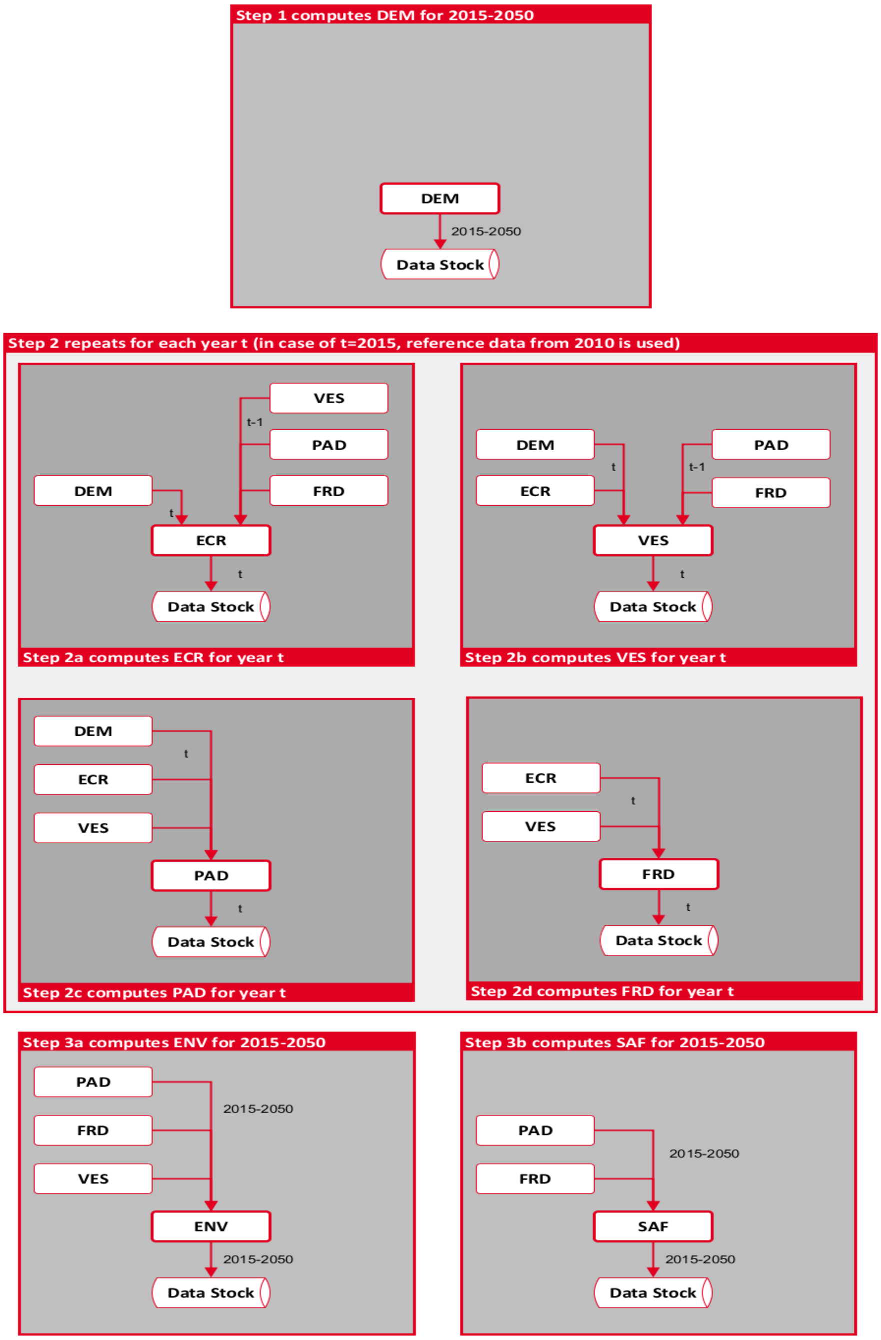

Figure 4: Sequence of processing the computation of a five-year time slice

Hence, within a single iteration, output variables of modules can only be passed on to modules that are executed later. This has a few implications for the model results that need to be considered when the HIGH-TOOL model is used.

Within a single model run, the impact of changes in input variables (policy levers) is passed on to the subsequent modules. For example, policies that are modelled in the Economy & Resources module impact the economic output variables (such as number of jobs and income level) of this module which are input to the Passenger Demand module. The impact on mobility is thereafter passed on to the Environment and Safety modules. These interactions are modelled within a single iteration. They are shown in Figure 5 above the diagonal.

Besides the interaction between modules described above, there are also variables that are output to one module and input to another module that is positioned earlier in the order of execution (feedbacks). Continuing on the example described before, the mobility calculated in the Passenger Demand modules is fed back into the Vehicle Stock module. Furthermore, the Economy & Resources module uses the user costs derived in the Vehicle Stock module. Due to the sequential structure of the HIGH-TOOL modules, these interactions are modelled with respectively one and two iterations delay. These interactions are shown in Figure 5 below the diagonal.

	Demography	**Economy**	**Vehicle Stock**	**Passenger**	**Freight**	**Environment**	**Safety**
Demography		population and labour force		population and labour force			
Economy				GDP, jobs, and income	GDP and trade flow		
Vehicle Stock		vehicle stock, user costs		fixed and variable vehicle costs		number of vehicles	
Passenger		passenger travel costs	mobility			mobility	mobility and number of trips
Freight		freight travel costs	mobility			mobility	mobility
Environment							
Safety							

Figure 5: Interaction between the HIGH-TOOL modules

Depending on the module on which policy levers of a TPM work, its first order effects are modelled without or with one iteration delay. The dynamics of this interaction needs to be taken into account when TPMs are modelled with the HIGH-TOOL model. There will be some modelling delay for the effect of policy measures to level out or stabilize. However, assuming that the first order effects are (much) stronger than the second and third order effects, this should have limited effect on the overall outcomes.

3.2 Economy & Resources Module

3.2.1 Description

The Economy & Resources module simulates the impact of transport policies on the economy. Its role is to provide baseline economic projections regarding GDP and value added, to provide projections for inter-regional trade-flows, and to calculate the impacts of changes in freight and passenger costs on the wider economy and on non-transport related and environmental and material use indicators.

To this end, the module first disaggregates national projections of GDP, productivity, and value added from the EU Reference scenario for 2015–2050 by region *i* (NUTS-2 level) and commodity type *c* (NSTR classification). Therewith, a baseline prediction is composed. In the next step, the impacts of specific transport policy measures (affecting passenger and freight transport costs) on this baseline prediction and on inter-regional trade flows are calculated. The calculations of the Economy & Resources module are implemented as a set of sequential algebraic equations.

Many of the transport policies considered in HIGH-TOOL have a regional character and thus have to be evaluated at the level of at least NUTS-2 regions. Therewith, the spatial disaggregation in zones *i* of the Economy and Resource module are consistent with the Freight Demand and Passenger Demand modules. In addition, the „rest of the world" is divided into 16 regions:

- Africa (Central and South, East, and North)
- America (Canada, Caribbean, Central, Mexico, South, and USA)
- Asia/Pacific (Australia and Oceania, Far East, Indian Subcontinent, and Southern Asia)
- Middle East (East and Mediterranean)
- Russia and CIS East.

The considered main transport modes *m* are road, railways, intercontinental and short sea shipping, inland waterway transport, and air.

Table 1 shows the list of aggregated economic sectors that are considered. Besides the transport sectors, these sectors correspond to the commodities c that are considered in the Freight Demand module. Furthermore, this table maps the activities of these economic sectors on specific environmental and resource use indicators. These indicators include (non combustion) GHG emissions (air, CO_2, NO_x and SO_2), non-GHG emissions (air, water and soil), domestic extraction used (primary crops and animals, metals, non-metal minerals, and fossil fuels), domestic extraction non-used (primary crops and animals, metals, non-metal minerals, and fossil fuels), land use (arable land, pasture, and forest), and water use (blue and green).

Table 1: List of commodity groups and related environmental and resource use indicators

NSTR1 group	Name	Code	GHG emissions	Non-GHG emissions	Domestic extraction used	Domestic extraction non-used	Land use	Water use
0	Agriculture, fishery, forestry	A_AGRI	x	x	x	x	x	x
1	Food	A_FOOD	x	x	x	x		x
2	Solid mineral fuels	A_SMIN	x	x	x	x		x
3	Petroleum products	A_PETR	x	x	x	x		x
4	Ores and metal waste	A_ORES	x	x	x	x		x
5	Metal products	A_METAL	x	x	x	x		x
6	Crude mineral and building materials	A_BMIN	x	x	x	x		x
7/8	Chemicals	A_CHEM	x	x	x	x		x
9	Manufacture	A_MANUF	x	x				x
9	Machinery and equipment	A_MACH	x	x				x
–	Electricity	A_ELEC	x	x				x
–	Private services	A_SERVPR	x	x				x
–	Public services	A_SERVPU	x	x				x
–	Hotels and restaurants	A_HORECA	x	x				x
–	Construction	A_CONSTR	x	x				x
–	Transport via railways	A_TRAI	x	x				x
–	Road transport	A_TLND	x	x				x
–	Sea and coastal water transport	A_TWAS	x	x				x
–	Inland water transport	A_TWAI	x	x				x
–	Air transport	A_TAIR	x	x				x

At the beginning of each time period, the Economy & Resources module provides projections of inter-regional trade flows and at the end it calculates the impacts of transport policy measures on GDP, employment and resource use. In the first time period t (in years), the HIGH-TOOL model starts from the demographic module that provides population projections to the Economy & Resources module. The Economy & Resources module in turn produces the necessary input to the rest of the HIGH-TOOL modules, such as inter-regional trade flow. Economic indicators are an important driver of passenger and freight demand, as well as demand for vehicle stock. Thus the Economy & Resources module provides inputs to Passenger, Freight Demand and Vehicle Stock. These outputs are taken into account in the calculation of the Economic module at time period $t+1$. Thus, the impact of transport policies are calculated with one time period delay. The position of the Economy and Resource module within HIGH-TOOL is shown in Figure 6.

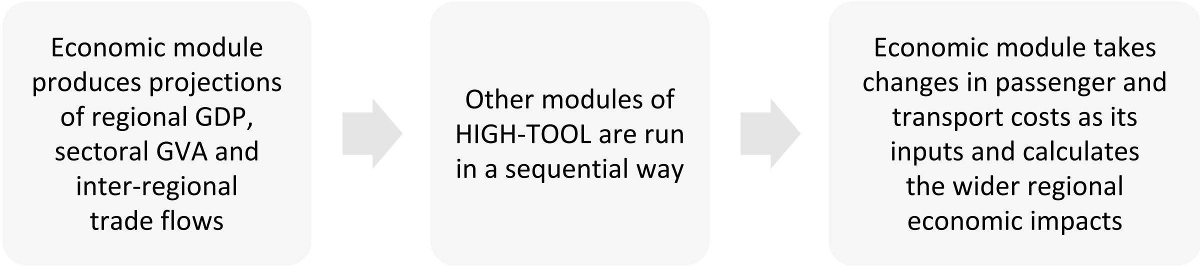

Figure 6: Position of the Economy & Resources module within the HIGH-TOOL model

A main goal of the HIGH-TOOL model is to assess the impacts of classic transport policy measures such as infrastructure investments, fuel and registration taxes, as well as changes in the level of service of public transport. In order to calculate the economic impacts of such changes, the total monetary costs of freight and passenger transport are used by multiplying the number of trips with the unit trip costs. Changes in costs affect the costs of final and intermediate products, demand of households, productivity of sectors, output of goods and services, trade patterns, non-transport related emissions and resource use, and sectoral employment.

Table 2: Interaction of the Economy & Resources module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module	Name in database
In	pop^{tot}	Population [persons]	time period *t*, country *ci*, gender *g*, age group *a*	Demography	o_de_pop
In	*LB*	Labour force [persons]	time period *t*, zone *i*, gender *g*, age group *a*	Demography	o_de_labour
In	*pkm*	Passenger transport mobility [pkm][1]	time period *t*, origin *i*, destination *j*, purpose *p*, mode *m*	Passenger Demand	od_pd_pkm_od and o_pd_airic_pkm_od
In	$vkm^{freight}$	Freight transport mobility [vkm][1]	time period *t*, origin *i*, destination *j*, commodity *c*, mode *m*	Freight Demand	o_fd_vkm_od
Out	*GDP*	Gross domestic product [million EUR]	time period *t*, country *ci*	Passenger Demand & Freight Demand	o_er_GDP
Out	*jobs*	Number of working places [jobs]	time period *t*, country *ci*	Passenger Demand	o_er_emp
Out	*income*	Income [EUR]	time period *t*, country *ci*	Passenger Demand	o_er_income
Out	T^{econ}	Trade flow [EUR]	time period *t*, origin *i*, destination *j*, mode *m*, commodity *c*	Freight Demand	o_er_trade

[1] These mobility variables are used to calculate the total monetary costs of passenger and freight transport, which is input to the Economy and Resources module.

The necessary input from other HIGH-TOOL modules includes changes in inter-regional passenger transport costs and mode choice (Passenger Demand module), changes in interregional freight transport costs and mode choice (Freight Demand module), population projections (Demography module) and changes related to the purchase of vehicles (Vehicle Stock module). These interactions with other HIGH-TOOL modules are shown in Table 2. The first column indicates whether a variable is input or output to the Economy & Resources module.

3.2.2 Equations

3.2.2.1 Baseline trajectory

The goal of this part of the analysis is to provide an economic baseline trajectory. It calculates the development of economic indicators such as GDP, labour force, and value added in case no additional transport policies are implemented and everything follows business as usual. To this end, the national level forecasts of the official EU Reference Scenario 2013 are translated to the regional level. This Reference Scenario is based on macro-economic and demographic projections of the Europe Aging Report 2012[2] and provides population projections (produced by EUROSTAT) and GDP projections (growth rates) for the period 2015–2050. For non-EU countries the same information is obtained from CEPII[3] projections for the period 2015–2050 that covers all countries of the world. In combination with the regional demographic projections of the Demography module, these data are translated into baseline regional level forecast of sectoral gross value added (GVA), output, and employment.

The projections are carried out in constant prices of the base year and do not take into account any type of inflation. The prices are assumed to be constant in the projections and normalized to one due to the lack of price data.

Change in sectoral structure

The first step of the Economy & Resources module is to translate the predictions of GDP per capita by country that can be derived from the EU Reference Scenario data to the projections of sectoral GVA over time at the country-level. One way to approach this is to assume that all economic sectors grow as much as the gross domestic product (GDP) in each country. This way, the changes in all the sectors are relatively equal and hence the structure of the economy, i.e. the relative sizes of sectors, is constant over time. This would be a major drawback and not realistic.

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2 See for more information: http://ec.europa.eu/economy_finance/publications/european_economy/2012/pdf/ee-2012-2_en.pdf.

3 See for more information: http://www.cepii.fr/PDF_PUB/wp/2012/wp2012-03.pdf.

Therefore, a two-step approach is proposed in which the sectoral share of the individual sectors are similar to the sectoral share in the EU reference scenario. Thus, total level of gross value added grows with the growth rate of GDP, but individual sectors grow on the sector specific pace derived from the EU Reference scenario.

The mapping from HIGH-TOOL sector classification to EU reference scenario sector classification is given in Table 3. It is not possible to have a perfect mapping from the 21 HIGH-TOOL sectors to the 15 EU reference scenario sectors, and aggregation of sectors is necessary. In order to further disaggregate the grouped sectors, we make use of sectoral shares in EXIOBASE[4].

Table 3 Mapping from HIGH-TOOL sector classification to EU reference scenario sector classification

HT sector classification	EU reference sector classification
a_agri	Agriculture
a_food	Food, drink and tobacco
a_mach a_manuf	Paper pulp, engineering, textiles, other industries (incl, printing)
a_elec	Energy sector and others
a_servpr a_hore	Market services
a_servpu	Non market services
a_trai a_tlnd a_twas a_twai a_tair	Trade
a_smin a_petr a_bmin	Non metallic minerals
a_cons	Construction
a_ores a_metal	Iron and steel Non ferrous metals
a_fert a_chem	Chemicals

[4] EXIOBASE is MRIO database with a highly disaggregated sector classification (augmenting environmentally sensitive sectors such as energy and agriculture), and a fully trade-linked SUT system, see http://www.exiobase.eu/

Regionalization of national level forecasts

In order to disaggregate national level sector-specific growth forecasts for the time periods *t=1,…,T* a sector-specific Cobb-Douglas production function is applied at the regional level. Production of each sector ($XD_{t,i,s}$) in the region is represented by using the Cobb-Douglas production function that includes labour and capital as its inputs (Varian, 1992):

$$XD_{t,i,s} = A_{t,i,s}.L_{t,i,s}{}^{\alpha_{i,s}}.K_{t,i,s}{}^{1-\alpha_{i,s}} \qquad \textit{(equation 1)}$$

Where:

$XD_{t,i,s}$	Output of sector *s* in zone *i* in time period *t*
$A_{t,i,s}$	Total factor productivity (TFP) parameter for sector *s* in zone *i* in time period *t*
$L_{t,i,s}$	Labour (cost) input for sector *s* in zone *i* in time period *t*
$K_{t,i,s}$	Capital input for sector *s* in zone *i* in time period *t*
$\alpha_{i,s}$	Output elasticity of labour for sector *s* in zone *i*.

In order to predict this sector-specific output, one needs to calculate the development over time of all underlying factors of production including the total productivity, labour, and capital inputs. It is assumed that sector-specific developments of productivity do not differ between the regions and are thus country specific. The country-level (ci is the country specify index) sector specific labour ($L_{t,ci,s}$) and capital stock ($K_{t,ci,s}$) over time are calculated according to the following formulas:

$$L_{t,ci,s} = LS_{t,ci}\frac{wage_{2010,ci,s}}{LS_{2010,ci}} \cdot \frac{(1+g^{GVA}_{t,ci,s})\cdot K_{t-1,ci,s}}{\sum_{s'\in SE}\left(1+g^{GVA}_{t,ci,s'}\right)\cdot K_{t-1,ci,s'}} \qquad \textit{(equation 2)}$$

Hence, we calculate country-level sector specific labour by disaggregating the country level labour supply using the sectoral share of capital and multiplying by the calibration factor $\frac{wage_{2010,ci,s}}{LS_{2010,ci}}$ obtaining labour cost. Note that $g^{GVA}_{t,ci,s}$ denotes the country and sector specific GVA growth rate. For $K_{t,ci,s}$ we disaggregate investments by again using sectoral share of capital and depreciation.

$$K_{t,ci,s} = K_{t-1,ci,s} \cdot (1-\delta_s) + INV_{t,ci} \cdot \frac{(1+g^{GVA}_{t,ci,s})\cdot K_{t-1,ci,s}}{\sum_{s'\in SE}\left(1+g^{GVA}_{t,ci,s'}\right)\cdot K_{t-1,ci,s'}} \qquad \textit{(equation 3)}$$

We assume that total labour supply ($LS_{t,ci}$) increases with the population growth rates, i.e.

$$LS_{t,ci} = LS_{t-1,ci} \cdot (1 + g_{t,ci}^{pop}), \qquad \textit{(equation 4)}$$

and total investments ($INV_{t,ci}$) are a share of GDP (savings rate).

$$INV_{t,ci} = GDP_{t,ci} \cdot \phi \qquad \textit{(equation 5)}$$

Where:

$L_{t,ci,s}$	Labour input for sector *s* in country *ci* in time period *t*
$K_{t,ci,s}$	Capital input for sector *s* in country *ci* in time period *t*
$LS_{t,ci}$	Total active labour force in country *ci* in time period *t* [persons]
$wage_{t,ci,s}$	Total wages of sector *s* in country *ci* in time period *t* [EUR]
$GVA_{t,ci,s}$	Gross value added per capita of sector *s* in country *ci* in time period *t* [EUR]
$INV_{t,ci}$	Total investment into fixed capital formation in country *ci* in time period *t*
$g_{t,ci}^{pop}$	Growth rate population in country *ci* in time period *t*
$g_{t,ci,s}^{gva}$	Growth rate output of sector *s* in country *ci* in time period *t*
ϕ	Savings rate [%]
SE	Set of all sectors *s*
δ_s	Depreciation rate in sector *s* [%].

Using the sector-specific Cobb-Douglas production function, the total factor productivity over time ($A_{t,ci,s}$) can now be derived as:

$$A_{t,ci,s} = \frac{GVA_{t,ci,s} \cdot \frac{XD_{2010,ci,s}}{GVA_{2010,ci,s}}}{{L_{t,ci,s}}^{\alpha_{ci,s}} \cdot {K_{t,ci,s}}^{1-\alpha_{ci,s}}} \qquad \textit{(equation 6)}$$

Where:

$A_{t,ci,s}$	Total factor productivity (TFP) parameter for sector *s* in country *ci* in time period *t*
$XD_{t,ci,s}$	Output of sector *s* in country *ci* in time period *t*
$GVA_{t,ci,s}$	Gross value added per capita of sector *s* in country *ci* in time period *t* [EUR]
$L_{t,ci,s}$	Labour input for sector *s* in country *ci* in time period *t*
$K_{t,ci,s}$	Capital input for sector *s* in country *ci* in time period *t*
$\alpha_{ci,s}$	Output elasticity of labour for sector *s* in country *ci*.

Having derived the development of the total factor productivity over time for all economic sectors, it is now possible to calculate the development of output over time at the regional level for zones *i* at NUTS-2 level. Herein, the active labour force predicted by the Demography module is used. The output ($XD_{t,i,s}$) per sector is:

$$XD_{t,i,s} = A_{t,i,s} \cdot L_{t,i,s}{}^{\alpha_{i,s}} \cdot K_{t,i,s}{}^{1-\alpha_{i,s}} \qquad \textit{(equation 7)}$$

In which we calculate labour costs ($L_{t,i,s}$) and regional GDP ($GDP_{t,i}$) by disaggregating county level GDP and labour cost using regional GDP shares of 2010, i.e.

$$L_{t,i,s} = L_{t,ci,s} \cdot \frac{GDP_{2010,i}}{\sum_{i' \in ci} GDP_{2010,i'}}, \qquad \textit{(equation 8)}$$

$$GDP_{t,i} = GDP_{t,ci} \cdot \frac{GDP_{2010,i}}{\sum_{i' \in ci} GDP_{2010,i'}} \qquad \textit{(equation 9)}$$

for regional capital stock ($K_{t,i,s}$) we disaggregate using the regional capital stock shares of 2010, i.e.

$$K_{t,i,s} = K_{t,ci,s} \cdot \frac{K_{2010,i,s}}{\sum_{i' \in ci} K_{2010,i',s}}. \qquad \textit{(equation 10)}$$

$$A_{t,i,s} = A_{t,ci,s|\, i \in ci} \qquad \textit{(equation 11)}$$

Where:

$XD_{t,i,s}$	Output of sector s in zone i in time period t
$L_{t,i,s}$	Labour input for sector s in zone i in time period t
$GDP_{t,i}$	Gross domestic product per capita in zone i in time period t [EUR]
$GDP_{t,ci}$	Gross domestic product per capita in country ci in time period t [EUR]
$K_{t,i,s}$	Capital input for sector s in zone i in time period t
$K_{t,ci,s}$	Capital input for sector s in country ci in time period t
$A_{t,i,s}$	Total factor productivity (TFP) parameter for sector s in zone i in time period t
$A_{t,ci,s}$	Total factor productivity (TFP) parameter for sector s in country ci in time period t;

3.2.2.2 Scenario trajectory

In this step, scenario projections are derived, in which the impact of transport policies on trade flows are taken into account with a delay of one time period. The required input data from the Database and other HIGH-TOOL modules is shown in Table 4. The listed data groups represent inputs that can be calculated on the basis of data/outputs from the Demography, Vehicle Stock, Passenger Demand, and Freight Demand modules. First, projections of inter-regional trade flows by sector s are made that are used as input to the Freight Demand module. Thereafter, some additional economic indicators are calculated.

Table 4: Outputs of other HIGH-TOOL modules used in the Economy & Resources module

Data/Input	Notation	Economic impact	Simulation setup
Labour force/Population	$LS_{t,i}$	Changes the regional labour endowment	Increases regional labour endowment, changes in the social security transfers
Total monetary O/D costs of passenger transport	$P_{t,i,j}^{costs}$	Changes in the households' budget available for non-transport related expenditures that leads to changes in the consumption of goods & services	Reduces/Increases the consumption budget of the households
Total monetary O/D costs of freight transport	$F_{t,i,j,s}^{costs}$	Changes in the production costs of firms	Reduces/Increases the intermediate inputs of transport sector services
Regional transport accessibility index	$ACC_{t,i}$	Changes in productivity of firms in the regions with improved accessibility	Reduces/Increases the total factor productivity of sector-specific production function

Data/Input	Notation	Economic impact	Simulation setup
Total spending on purchasing of new passenger vehicles	$C_{t,i}^{cars}$	Change in the demand of households for vehicles that leads to increase in their production	Reduces/Increases minimum demand level of the transport vehicles
Total spending on purchasing of new freight vehicles	$I_{t,i}^{vehicles}$	Change in the demand of firms for vehicles that leads to increase in their production	Reduces/Increases intermediate use of transport vehicles
Net tax revenues from sales of transport vehicles	$tax_{t,i}$	Change in the total tax revenues of federal government that leads to its higher consumption/spending	Reduces/Increases the households' consumption budget. Household's in the model represent all types of final consumption: household, government, fixed capital formation.
Total revenues from tolls for each O/D relationship	$T_{t,i,j}^{tolls}$	Change in the total tax revenues of government that leads to its higher consumption/spending	Reduces/Increases the households' consumption budget. Household's in the model represent all types of final consumption: household, government, fixed capital formation.
Investments in RTD	$RTD_{t,i}$	Change in output of RTD sector and its employment	Increase in the intermediate input of RTD in the transport sector (% relative to GDP)
Investments in infrastructure	$Inf_{t,i}^{inv}$	Change in output of construction sector and its employment	Increase in the minimum level of households' consumption of construction sector services (% relative to GDP)

In order to perform this type of analysis, the construction of the baseline trajectory is combined with the additional calculations presented below. The combination of these parts constitutes the full formulation of the Economy & Resources module. Changes in transport costs are calculated as the differences between the situation with the policy package and without it (baseline scenario).

First, the changes in total annual monetary costs of freight transport by mode m and commodity type c (calculated as the monetary costs of freight movements between the two regions in the baseline trajectory minus the policy scenario costs) are translated into the changes ($PC_{t,i,s}$) in consumer prices:

$$PC_{t,i,s} = \begin{cases} PD_{t-1,i,s} \cdot tc_{t-1,i,s} \cdot \frac{\sum_i (T_{t,i,j,s} + F_{t,i,j,s}^{costs} + \Delta F_{t,i,j,s}^{costs})}{T_{t,i,j,s} + F_{t,i,j,s}^{costs}} & if \;\; s \in SNS \\ PD_{t-1,i,s} \cdot tc_{t-1,i,s} & if \;\; s \in SS \end{cases} \qquad \text{(equation 12)}$$

Where:

$PC_{t,i,s}$	Consumer price of goods in zone i for sector s in time period t
$PD_{t,i,s}$	Producers price of goods in zone i for sector s in time period t
$tc_{t,i,s}$	Consumption tax of goods in zone i for sector s in time period t

$T_{t,i,j,s}$	Trade flow between origin *i* and destination *j* in sector *s* in time period *t* [EUR]
$F_{t,i,j,s}^{costs}$	Total annual costs of freight transport from origin *i* todestination *j* in sector *s* in time period *t* [EUR]
$\Delta F_{t,i,j,s}^{costs}$	Total absolute change in costs of freight transport from origin *i* to destination *j* in sector *s* in time period *t* [EUR]
SNS	Subset of all non-service sectors in SE, i.e. $A_{AGRI}, A_{FOOD}, A_{MACH}, A_{SMIN}, A_{PETR}, A_{ORES}, A_{METAL}, A_{BMIN}, A_{FERT}, A_{CHEM}, A_{MANF}$
SS	Subset of all service sectors in SE, i.e. $A_{ELEC}, A_{SERPR}, A_{TRAI}, A_{TLND}, A_{TWAS}, A_{TWAI}, A_{TAIR}, A_{HORE}, A_{CONS}, A_{SERVPU}$.

Output and demand

Changes in accessibility have a positive impact on the sector output at the regional level through provision of better access to labour markets and more varieties of intermediate goods. Hence, they are translated into higher outputs ($XD_{t,i,s}$) for the economic sectors as follows:

$$\overline{XD}_{t,i,s} = XD_{t,i,s} \cdot (1 + \Delta ACC_{t,i})^{e_s^{acc}} \qquad \textit{(equation 13)}$$

Where:

$XD_{t,i,s}$	(Baseline) output of sector *s* in zone *i* in time period *t*
$\overline{XD}_{t,i,s}$	Output after the policy scenario of sector s in zone *i* in time period *t*
$\Delta ACC_{t,i}$	Change in accessibility of zone *i* in time period *t* [%]
e_s^{acc}	Elasticity of production to accessibility for sector *s* [%].

The accessibility ($ACC_{t,i}$) is measured as the weighted average of the transportation costs, i.e:

$$ACC_{t,i} = \frac{\sum_j (P_{t,i,j}^{costs} + \sum_s F_{t,i,j,s}^{costs})}{\sum_{i,j} (P_{t,i,j}^{costs} + \sum_s F_{t,i,j,s}^{costs})} \qquad \textit{(equation 14)}$$

Next, the projected demand for goods and services in region *i* is calculated as the sum of the final demand of households and the intermediate demand of sectors. In equations the projected demand ($X_{t,i,s}$) is:

$$X_{t,i,s} = C_{t,i,s} + IO_{t,i,s} \quad \textit{(equation 15)}$$

Where:

$X_{t,i,s}$	Projected demand for goods and services of sector *s* in zone *i* in time period *t*
$C_{t,i,s}$	Demand of households for goods and services of sector *s* in zone *i* in time period *t*
$IO_{t,i,s}$	Intermediate demand of sector *s* in zone *i* in time period *t*.

The regional intermediate demand can be calculated as the sum of intermediate demand over all the sectors located in the region. Under the assumption that intermediate goods and services are used in production according to fixed Leontief technology, the intermediate demand ($IO_{t,i,s}$) can thus be calculated as follows:

$$IO_{t,i,s} = \sum_{s' \epsilon SE} \left(io_{i,s,s'} \cdot \overline{XD}_{t,i,s} \right) \cdot (1 + \Delta I_{t,i,s=A_{MACH}}^{vehicles}) \cdot (1 + \Delta RTD_{t,i,s=A_{SERVPR}}) \cdot (1 + \Delta Inf_{t,i,s=A_{CONSTR}}^{inv}) \quad \textit{(equation 16)}$$

Where:

$IO_{t,i,s}$	Intermediate demand of sector *s* in zone *i* in time period *t*
$io_{i,s,s'}$	Leontief input coefficient of sector *s* for sector *s'* in zone *i*
$\overline{XD}_{t,i,s}$	Output after policy scenario of sector *s* in zone *i* in time period *t*
SE	Set of all sectors *s*
$\Delta I_{t,i,s}^{vehicles}$	Spending on the purchase of new vehicles in sector *s* in zone *i* in time period *t* (% relative to GDP)
$\Delta RTD_{t,i,s}$	New transport investments in RTD in sector *s* in zone *i* in time period *t* (% relative to GDP)
$\Delta Inf_{t,i,s}^{inv}$	New infrastructure investments in sector *s* in zone *i* in time period *t* (% relative to GDP).

The Leontief coefficients are calculated on the basis of Input/Output (I/O) tables available at the country level from EUROSTAT and are the same for all regions *i* in the country *ci*. On top of the usual use of intermediate goods one also takes into account the changes in intermediate consumption of the transport sectors (denoted as sub-set of sectors that includes A_TRAI, A_TLND, A_TWAS, A_TWAI and A_TAIR).

Let us assume that regional households have a Cobb-Douglas utility function. Changes in the total costs of passenger transport have an impact on the level of disposable income of the households. Increase in the spending on passenger transportation reduces the amount of money available for purchasing of other goods and services. Their utility maximization problem results in the following system of final demand ($C_{t,i,s}$) equations:

$$C_{t,i,s} = \left(\sum_s\left(\overline{XD}_{t,i,s} \cdot PD_{t-1,i,s} - \sum_{s'}(io_{t,i,s',s} \cdot \overline{XD}_{t,i,s} \cdot PC_{t,i,s})\right) - \Delta P_{t,s}^{costs} - A_{t,i}^{costs} - \Delta tax_{t,i} - \Delta T_{t,i}^{tolls} + \Delta C_{t,i}^{cars}\right) \cdot \frac{\beta_{t,i,s}^{roc}}{PC_{t,i,s}} \qquad \textit{(equation 17)}$$

Where:

$C_{t,i,s}$	Demand of households for goods and services of sector *s* in zone *i* in time period *t*
$P_{t,i}^{costs}$	Costs of passenger transport in zone *i* in time period *t*
$\Delta P_{t,i}^{costs}$	Difference in costs of passenger transport in zone *i* in time period *t* between the baseline and policy scenario
$A_{t,i}^{costs}$	Administrative costs of new transport policies in zone *i* in time period *t*
$tax_{t,i}$	Net tax revenues from sales of transport vehicles in zone *i* in time period *t*
$\Delta tax_{t,i}$	Difference in net tax revenues from sales of transport vehicles in zone *i* in time period *t* between the baseline and policy scenario
$T_{t,i}^{tolls}$	Total revenues from tolls in zone *i* in time period *t*
$\Delta T_{t,i}^{tolls}$	Difference in total revenues from tolls in zone *i* in time period *t* between the baseline and policy scenario
$C_{t,i}^{cars}$	Spending on purchase of new passenger vehicles in zone *i* in time period *t*
$\Delta C_{t,i}^{cars}$	Difference in spending on purchase of new passenger vehicles in zone *i* in time period *t* between the baseline and policy scenario
$\beta_{i,s}^{roc}$	Marginal rate of consumption in zone *i* in sector *s*
$PC_{t,i,s}$	Consumer price of goods in zone *i* for sector *s* in time period *t*

$\overline{XD}_{t,i,s}$	Output after policy scenario of sector s in zone i in time period t
$PD_{t,i,s}$	Producers price of goods in zone i for sector s in time period t
$io_{t,i,s,s'}$	Leontief input coefficient of sector s' for sector s in zone i in time period t.

The consumer prices include both transport and trade margins as well as consumption taxes and subsidies. This demand equation is written down for one representative agent in each region that consists of both the households and the governmental sector. This means that this representative agent receives all the taxes and pays subsidies. The households' consumption of cars depends on the changes in transport policies. The parameters of the Cobb-Douglas demand functions are calibrated on the data from national-level I/O tables available from Eurostat. Following the zero profit condition, the sum of sectoral wages and returns to capital can be rewritten as the sum of sectoral revenue minus the sum of sector-specific intermediate inputs. Intermediate inputs are evaluated at consumer prices (net of trade and transport margins, taxes and subsidies) whereas the revenues are measured in producer prices. The producer prices take into account taxes and subsidies related directly to output of the firms.

Trade flows

Trade flows in the base year are derived from the ETIS-plus database. These include worldwide trade flows on country and NTS product level. ETIS-plus does not include intra country trade flows. Several steps are taken to bring the ETIS-plus database to the regional level, including intra-regional trade.

First, we bring trade to the HIGH-TOOL regional level. In cases where the HIGH-TOOL region classification has more regions than the corresponding country, we use Eurostat GVA sectoral data at NUTS-2 level to break down country-level trade. This creates different trade shares per commodity for each region. In this way we incorporate the heterogenity of each region in a country, i.e. not all regions export the same product mix. On the import side, we use the regional GDP share to disaggregate. In cases where HIGH-TOOL region classification consists of several countries („rest of the world" regions), ETISplus trade is aggregated to the HIGH-TOOL zoning level.

Next, we estimate intra-regional trade. We start by looking at the RHOMOLO trade database, which contains regional trade data (with European countries) and which is defined for the agricultural and manufacturing sector. However, this database does not consider as many regions and sectors as the HIGH-TOOL specification. A correction for the commodity level is necessary, and trade for the „rest of the world" regions needs to be estimated.

Combining RHOMOLO intra-regional trade with ETISplus inter-regional trade gives shares of intra-regional trade with respect to outgoing inter-regional trade, for those regions where both data is available. The average share is used to estimate the intra-regional trade for the remaining regions. Hence, we assume that the freight handling factor for intra-regional trade is at least equal to the inter-regional trade.

Intra-regional trade is not yet defined on the correct commodity level. ETISplus gives the commodity division of trade from one region to all other regions. We assume that intra-regional share of a commodity is equal to the total value of trade from this commodity to all other regions, divided by the total value of all trade to other regions.

This way, trade in the base year has been defined. Future trade is forecasted using the projections of output ($XD_{t,i,s}$):

$$T^{econ}_{t,i,j,s} = \frac{XD_{t,i,s}}{XD_{2010,i,s}} \cdot T^{econ}_{2010,i,j,s} \qquad \textit{(equation 18)}$$

Where:

$T^{econ}_{t,i,j,s}$ Trade flow between origin *i* and destination *j* in sector *s* in time period *t* [EUR];

$XD_{t,i,s}$ Output of sector *s* in zone *i* in time period *t*.

Economic indicators

For the scenario several economic indicators are produced. New employment levels by sector *s* and region *i* are expressed as the sectoral demand for labour inputs. Herein, the regional wages ($w_{t,i}$) are determined such that the total demand for labour ($L_{t,i,s}$) is equal to the total active labour force in the region:

$$w_{t,i} = \frac{\sum_s (\overline{XD}_{t,i,s} \cdot PD_{t-1,i,s} \cdot \frac{\alpha_{i,s}}{LS_{t,i}})}{\sum_s (\overline{XD}_{2010,i,s} \cdot PD_{2010,i,s} \cdot \frac{\alpha_{i,s}}{LS_{2010,i}})} \qquad \textit{(equation 19)}$$

$$\bar{L}_{t,i,s} = L_{t,i,s} \cdot w_{t,i} \qquad \textit{(equation 20)}$$

Where:

$L_{t,i,s}$	Labour input for sector *s* in zone *i* in time period *t*
$\bar{L}_{t,i,s}$	Labour input after policy scenario for sector *s* in zone *i* in time period *t*
$\overline{XD}_{t,i,s}$	Output after policy scenario of sector *s* in zone *i* in time period *t*
$PD_{t,i,s}$	Producers price of goods in zone *i* for sector *s* in time period *t*
$\alpha_{i,s}$	Output elasticity of labour for sector *s* in zone *i*
$w_{t,i}$	Wage index in zone *i* in time period *t* after policy scenario
$LS_{t,i}$	Total active labour force in zone *i* in time period *t*.

Return to capital by sector ($r_{t,i,s}$) and region can be determined as the inverse capital demand function:

$$r_{t,i,s} = \frac{\overline{XD}_{t,i,s} \cdot PD_{t-1,i,s} \cdot \frac{(1-\alpha_{i,s})}{K_{t,i,s}}}{\overline{XD}_{2010,i,s} \cdot PD_{2010,i,s} \cdot \frac{(1-\alpha_{i,s})}{K_{t,i,s}}} \quad \textit{(equation 21)}$$

Where:

$r_{t,i,s}$	Return index to capital in zone *i* for sector *s* in time period *t* after policy scenario
$\overline{XD}_{t,i,s}$	Output after policy scenario of sector *s* in zone *i* in time period *t*
$PD_{t,i,s}$	Change in automotive production costs due to innovations in zone *i* in sector *s* at time period *t*
$\alpha_{i,s}$	Output elasticity of labour for sector *s* in zone *i*
$K_{t,i,s}$	Capital input for sector *s* in zone *i* in time period *t*.

Given the changes in wages and prices of intermediate goods the producer prices/average production costs ($PD_{t,i,s}$) as well as consumer prices ($PC_{t,i,s}$) can be calculated, taking into account that the sectors do not make excess profits:

$$PD_{t,i,s} = \frac{\bar{L}_{t,i,s} + K_{t,i,s} \cdot r_{t,i,s}}{L_{2010,i,s} + K_{2010,i,s} \cdot r_{2010,i,s}} \cdot \frac{\overline{XD}_{t,i,s}}{\overline{XD}_{2010,i,s}} \quad \textit{(equation 22)}$$

$$PC_{t,i,s} = PD_{t,i,s} \cdot (1 + tc_{t,ci,s}) \quad \textit{(equation 23)}$$

Where:

$PD_{t,i,s}$	Change in automotive production costs due to innovations in zone *i* in sector *s* at time period *t*
$\bar{L}_{t,i,s}$	Labour input after policy scenario for sector *s* in zone *i* in time period *t*
$K_{t,i,s}$	Capital input for sector *s* in zone *i* in time period *t*
$\overline{XD}_{t,i,s}$	Output after policy scenario of sector *s* in zone *i* in time period *t*
$r_{t,i,s}$	Return to capital in zone *i* for sector *s* in time period *t*
$PC_{t,i,s}$	Consumer price of goods in zone *i* for sector *s* in time period *t*
$tc_{t,ci,s}$	Final consumption tax rates for country *ci* in sector *s* in time period *t*.

Thereafter, the emissions and material use as a proportion of total regional energy inputs and/or outputs of all sectors can be calculated. Finally, the regional level gross domestic product ($GDP_{t,i}$) is derived on the basis of the variables calculated above as the sum of the value added of individual sectors plus taxes on final demand:

$$GDP_{t,i} = \sum_s \left(\bar{L}_{t,i,s} \cdot w_{t,i} + K_{t,i,s} \cdot r_{t,i,s}\right) + \sum_s (C_{t,s} \cdot PC_{t,i,s} \cdot tc_{t,i,s}) \qquad \textit{(equation 24)}$$

Where:

$GDP_{t,i}$	Gross domestic product per capita in zone *i* in time period *t*
$\bar{L}_{t,i,s}$	Labour input after policy scenario for sector *s* in zone *i* in time period *t*
$w_{t,i}$	Wage index in zone *i* in time period *t*
$K_{t,i,s}$	Capital input for sector *s* in zone *i* in time period *t*
$r_{t,i,s}$	Return to capital in zone *i* for sector *s* in time period *t*
$PC_{t,i,s}$	Consumer price of goods in zone *i* for sector *s* in time period *t*
$tc_{t,i,s}$	Final consumption tax rates for zone *i* in sector *s* in time period *t*
$C_{t,i,s}$	Demand of households for goods and services of sector *s* in zone *i* in time period *t*
$XD_{t,i,s}$	Output of sector *s* in zone *i* in time period *t*;
$PD_{t,i,s}$	Change in automotive production costs due to innovations in zone *i* in sector *s* at time period *t*
$io_{t,i,s,s'}$	Leontief input coefficient of sector *s* for sector *s'* in zone *i* in time period *t*.

3.2.3 Elasticities

Explicit elasticities

The explicit elasticity in the Economy & Resources module is shown in Table 5.

Table 5: Explicit elasticities in the Economy & Resources module

Elasticity	Description	Sector s	Value	Sources
eacc	Elasticity of production to accessibility [%]	a_agri	0	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_food	0	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_smin	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_petr	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_ores	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_metal	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_bmin	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_chem	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_manuf	0.04	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_mach	0.055	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_elec	0.168	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_servpr	0.02	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_servpu	0.004	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_trai	0.168	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_tlnd	0.168	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_twas	0.168	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_twai	0.168	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_tair	0.168	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_horeca	0.042	Graham (2005)
eacc	Elasticity of production to accessibility [%]	a_constr	0.072	Graham (2005)

Model variables

An overview of relevant model variables for the Economy & Resources module is given in Table 6. These are the policy levers that are selected for modelling transport policy measures in HIGH-TOOL.

Table 6: Model variables in the Economy & Resources module

Policy lever	Description	Dimensions	Equation	Name in database
Inf^{Inv}	Infrastructures investment	time period *t*, zone *i*, sector *s*	16	i_er_delta_inf_inv
RTD	Transport investments into RTD	time period *t*, zone *i*, sector *s*	16	i_er_delta_rtd

3.3 Demography Module

3.3.1 Description

The Demographic module reflects the demographic development of the regions considered within HIGH-TOOL. Calculations are performed at the level of countries *ci* (NUTS-0 level) and thereafter disaggregated to zones *i* at NUTS-2 level. The development of the population is simulated by the Demography module with a cohort component model that takes the effects of demographic drivers and migration into account. The module is sensitive to changes affecting the exogenous demographics (e.g. fertility rates per specific age group). For the development of the final HIGH-TOOL model, exogenous drivers are considered, i.e. the fertility, mortality, and migration rates per gender g and age group a. The population variable is considered as an external variable to the model together with GDP, fuel prices, urbanisation rate, etc.

Alternatively, exogenously defined demographic scenario data can be uploaded to the Demography module. The final output of the Demography model is the estimation of population for the EU28 including Switzerland and Norway at NUTS-2 level by gender g and age group a. The Demography module also estimates the labour force up to 2050 by gender g and age group a. The output of the Demography module is shown in Table 7. The module does not use any inputs from other HIGH-TOOL modules.

Table 7: Interaction of the Demography module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module(s)	Equation	Name in database
Out	pop^{tot}	Population [persons]	time period *t*, zone *i*, gender *g,* and age group *a*	Passenger Demand and Economy & Resources		o_de_pop
Out	*LB*	Labour force [persons]	time period *t*, zone *i*, gender *g,* and age group *a*	Passenger Demand and Economy & Resources		o_de_labour

3.3.2 Equations

3.3.2.1 Demographic drivers

The Demographic Drivers component handles the influencing factors on the demographic development like the fertility, mortality, and migration rates per gender g and age group a. It applies an exponential growth model for the calculation of the population in period *t* based on the population in the previous period *t-1* and the growth rates for birth and mortality; these equations are at the national level (NUTS-0). The birth rates ($br_{t,ci,a}$) and mortality rates ($dr_{t,ci,a}$) per mothers' age group *a* are calculated from EUROSTAT observed data for the years 1995–2010 as follows:

$$br_{t,ci,a} = \frac{births_{t-1,ci,a}}{pop^{tot}_{t,ci,g=f,em,a}} \qquad \text{(equation 1)}$$

$$dr_{t,ci,a} = \frac{deaths_{t-1,ci,a}}{pop^{tot}_{t-1,ci,a}} \qquad \text{(equation 2)}$$

Where:

$br_{t,ci,a}$	Birth rate in country *ci* for mothers in age group *a* in time period *t* [person/person]
$dr_{t,ci,a}$	Mortality rate in country *ci* for people in age group *a* in time period *t* [person/person]
$births_{t,ci,a}$	Number of births in country *ci* with mothers in age group *a* in time period *t* [person]
$pop^{tot}_{t,ci,g=fem,a}$	Female (*g=fem*) population in country *ci* in age group *a* and time period *t* [persons]
$deaths_{t,ci,a}$	Number of deaths in country *ci* in age group *a* and time period *t* [person]
$pop^{tot}_{t,ci,a}$	Population in country *ci* in age group *a* in time period *t* [persons].

Number of births

The birth and mortality rates from 2010 onwards are estimated based on the total fertility rate (TFR) assumptions of the EU Reference Scenario. The number of births ($births_{t,ci,g,a}$) per gender *g* and age group *a* is calculated as follows:

$$births_{t,ci,g,a} = \frac{TFR_{t-1,ci,a}/(5 \cdot average(\sum_a (pop^{tot}_{t-1,ci,g=fem,a}))}{2} \qquad \text{(equation 3)}$$

Where:

$births_{t,ci,g,a}$	Number of births by gender *g* in country *ci* with mothers in age group *a* in time period *t* [persons]
$TFR_{t,ci,a}$	Total Fertility Rate in country *ci* for (mother's) age group *a* in time period *t* [person/person]
$pop^{tot}_{t,ci,g=fem,a}$	Female (*g=fem*) population in country *ci* in age group *a* and time period *t* [persons].

The constant 5 is used due to the fact that the assumption is given every five years, i.e. the TFR is spread evenly over a five-year time period. The total number of births is added to the zero-age cohort *a* for time period *t+1* and is assumed to be equally distributed by gender.

Number of deaths

The number of deaths per age group from 2010 onwards is estimated based on the life expectancy assumptions of the EU Reference Scenario and follows the EUROSTAT methodology for estimating the number of deaths in a specific age group. The life expectancies are provided at birth and are broken down by age group *a* and gender *g* (specified per country *ci*) based on the 2010 historical data. The number of survivors ($l^{sur}_{t,ci,g,a}$) is calculated as following:

$$l^{sur}_{t,ci,g,a} = \begin{cases} 100000 & if\ a = 0 \\ P^{sur}_{t,ci,g.a-1} \cdot l^{sur}_{t,ci,g,a-1} & otherwise \end{cases} \qquad \textit{(equation 4)}$$

In which:

$$P^{sur}_{t,ci,g,a-1} = \begin{cases} 1 - P^{death}_{t,ci,g,a-1} & if\ a < 85 \\ 0 & if\ a \geq 85 \end{cases} \qquad \textit{(equation 5)}$$

$$P^{death}_{t,ci,g,a-1} = \begin{cases} \dfrac{M^{mor}_{t,ci,g,a-1}}{1+(1-a_{ci,g,a-1})\cdot M^{mor}_{t,ci,g,a-1}} & if\ a < 85 \\ 1 & if\ a \geq 85 \end{cases} \qquad \textit{(equation 6)}$$

$$M^{mor}_{t,ci,g,a-1} = \frac{deaths_{t-1,ci,g,a-1}}{pop^{tot}_{t-1,ci,g,a-1}} \qquad \textit{(equation 7)}$$

Where:

$l^{sur}_{t,ci,g,a}$	Survivors in country *ci* by gender *g* and age group *a* and time period *t* [persons]
$P^{sur}_{t,ci,g,a}$	Probability of surviving in country *ci* by gender *g* and age group *a* and time period *t* [%]
$P^{death}_{t,ci,g,a}$	Probability of dying in country *ci* by gender *g* and age group *a* and time period *t* [%]
$M^{mor}_{t,ci,g,a}$	Mortality rate in country *ci* by gender *g* and age group *a* and time period *t* [%]

$a_{ci,g,a}$	Country *ci* and age group *a* specific coefficient set to 0.5 for all age groups *a* besides age cohort (0–4), where its value is 0.2
$deaths_{t,ci,g,a}$	Number of deaths in country *ci* by gender *g* in age group *a* and time period *t* [persons]
$pop^{tot}_{t,ci,g,a}$	Population in country *ci* by gender *g* in age group *a* in time period *t* [persons].

Based on the number of survivors in the previous year, the number of deaths ($deaths_{t,ci,g,a}$) is estimated as follows:

$$deaths_{t,ci,g,a} = \begin{cases} 0{,}9 \cdot M^{mor}_{t,ci,g,a} \cdot pop^{tot}_{t,ci,g,a} & if\ a < 5 \\ 0{,}1 \cdot M^{mor}_{t,ci,g,a} \cdot pop^{tot}_{t,ci,g,a} & if\ a < 10 \\ M^{mor}_{t,ci,g,a} \cdot pop^{tot}_{t,ci,g,a} & otherwise \end{cases} \qquad (equation\ 8)$$

With:

$$M^{mor}_{t,ci,a,g} = \frac{P^{death}_{t,ci,g,a}}{5 - 2.5 \cdot P^{death}_{t,ci,g,a}} \qquad (equation\ 9)$$

$$P^{death}_{t,ci,g,a} = 1 - P^{sur}_{t,ci,g,a} = 1 - \frac{l^{sur}_{t,ci,g,a-1}}{l^{sur}_{t,ci,g,a}} \qquad (equation\ 10)$$

Where:

$deaths_{t,ci,g,a}$	Number of deaths in country *ci* by gender *g* in age group *a* and time period *t* [persons]
$M^{mor}_{t,ci,g,a}$	Mortality rate in country *ci* by gender *g* and age group *a* and time period *t* [%]
$P^{death}_{t,ci,g,a}$	Probability of dying in country *ci* by gender *g* and age group *a* and time period *t* [%]
$pop^{tot}_{t,ci,g,a}$	Population in country *ci* by gender *g* in age group *a* in time period *t* [persons]
$P^{sur}_{t,ci,g,a}$	Probability of surviving in country *ci* by gender *g* and age group *a* and time period *t* [%]
$l^{sur}_{t,ci,g,a}$	Survivors in country *ci* by gender *g* and age group *a* and time period *t* [persons].

Population

The population ($pop^{dem}_{t,ci,g,a}$) per gender g and age group a based on demographic drivers (without migration) is now calculated as follows:

$$pop^{dem}_{t,ci,g,a} = pop^{tot}_{t-1,ci,g,a} + births_{t-1,ci,g,a} - deaths_{t-1,ci,g,a} \qquad \text{(equation 11)}$$

Where:

$pop^{dem}_{t,ci,g,a}$	Population in country *ci* by gender g and age group a in time period t based on demographic drivers [people]
$pop^{tot}_{t,ci,g,a}$	Population in country *ci* by gender g and age group a in time period t [persons]
$births_{t,ci,g,a}$	Number of births by gender g in country *ci* with mothers in age group a in time period t [persons]
$deaths_{t,ci,g,a}$	Number of deaths in country *ci* by gender g in age group a and time period t [persons].

Disaggregation

The analysis for disaggregation of population without migration to NUTS-2 level was performed based on the 2010 historical regional distribution. Various statistical tests were performed in order to identify what drives internal -within a country-migration, using as dependent variables the NUTS-2 population (normalised by total population) against various economic parameters such as GDP per capita, median/ mean household income, unemployment rates, population density and an urban proxy (indicating the number of urban centres within a NUTS-2 region). The analysis showed that none of these parameters were strongly correlated to population and therefore the disaggregation ($pop^{dem}_{t,i,g,a}$) to NUTS-2 is simply based on the historic distribution over regions i:

$$pop^{dem}_{t,i,g,a} = pop^{dem}_{t,ci\ni i,g,a} \cdot \frac{pop^{dem}_{t-1,i,g,a}}{pop^{dem}_{t-1,ci\ni i,g,a}} \qquad \text{(equation 12)}$$

Where:

$pop_{t,i,g,a}^{dem}$	Population in zone *i* by gender *g* and age group *a* in time period *t* based on demographic drivers [persons]
$pop_{t,ci,g,a}^{dem}$	Population in country *ci* by gender *g* and age group *a* in time period *t* based on demographic drivers [persons].

3.3.2.2 Migration drivers

The change in population due to net migration is taken directly from the EU Reference scenario and is not modelled explicitly in the HIGH-TOOL model. The total population ($pop_{t,ci,g,a}^{tot}$) per age group including migration is thus calculated as follows:

$$pop_{t,ci,g,a}^{tot} = pop_{t,ci,g,a}^{dem} + MP_{t,ci,g,a} \quad (equation\ 13)$$

Where:

$pop_{t,ci,g,a}^{tot}$	Total population in country *ci* by gender *g* and age group *a* in time period *t* [persons]
$pop_{t,ci,g,a}^{dem}$	Population in country *ci* by gender *g* and age group *a* in time period *t* based on demographic drivers [persons]
$MP_{t,ci,g,a}$	Change in population in country *ci* by gender *g* and age group *a* in time period *t* as the result of net migration [persons].

Disaggregation

An analysis was performed for the identification of drivers for external (emigration/immigration) migration. The net migration figures from the EU Reference Scenario were normalised to the country's total population and were tested against GDP per capita, median income, mean income and unemployment rates. Due to the high correlation of independent parameters the GDP per capita and median income parameters were dropped. In the final test, only unemployment and income were statistically significant, the higher the income and the lower the unemployment rate, the higher the amount of migration. These parameters were used to identify weights ($DP_{t,i}$) for the distribution of migration to NUTS-2 level:

$$DP_{t,i} = \frac{I_{t,i}}{I_{t,ci \ni i}} \cdot \frac{E_{t,i}}{E_{t,ci \ni i}} \cdot \frac{P_{t,i}}{P_{t,ci \ni i}} \quad (equation\ 14)$$

Where:

$DP_{t,i}$ Distribution proxy (weight) for the net migration of region *i* in time period t [%]

$I_{t,i}$ Average income of zone *i* in time period t

$I_{t,ci}$ Average income of country *ci* in time period t

$E_{t,i}$ Employment rate of zone *i* in time period t [%]

$E_{t,ci}$ Employment rate of country *ci* in time period t [%]

$P_{t,i}$ Population of zone *i* in time period t [persons]

$P_{t,ci}$ Population of country *ci* in time period t [persons].

The distribution proxy is identified per NUTS-2 region *i* and is multiplied by the net migration in a NUTS-0 area (country *ci*) in order to derive the net migration at NUTS-2 level. This proxy can be externally modified over the years to depict the effect of higher income and employment of the migration trends by modifying the data in the Database. In the present version it is estimated based on the 2010 values.

The change in population ($MP_{t,i,a,g}$) due to migration at NUTS-2 level is:

$$MP_{t,i,g,a} = DP_{t,i} \cdot MP_{t,ci,g,a} \qquad \textit{(equation 15)}$$

Where:

$MP_{t,i,g,a}$ Change in population in zone *i* by gender g and age group a in time period t as the result of net migration [persons]

$DP_{t,i}$ Distribution proxy (weight) for the net migration of region *i* in time period t [%]

$MP_{t,ci,g,a}$ Change in population in country *ci* with gender g and age group a in time period t as the result of net migration [persons].

The total population ($pop^{tot}_{t,i,a,g}$) at NUTS-2 level can now be calculated as follows:

$$pop^{tot}_{t,i,g,a} = pop^{dem}_{t,i,g,a} + MP_{t,i,g,a} \qquad \textit{(equation 16)}$$

Where:

$pop_{t,i,g,a}^{tot}$ Total population in zone i by gender g and age group a in time period t [persons]

$pop_{t,i,g,a}^{dem}$ Population in zone i by gender g and age group g in time period t based on demographic drivers [persons]

$MP_{t,i,g,a}$ Change in population in zone i by gender g and age group a in time period t as the result of net migration [persons].

3.3.2.3 Labour force estimation

The labour force estimation is based on two parameters: the population by gender g and age group a and the labour force percentage, again by gender and age group. Multiplying the two provides the total labour force by gender and age group as shown in the following formula. The labour force ($LB_{t,i,g,a}$) is calculated as follows:

$$LB_{t,i,g,a} = P_{t,i,g,a}^{tot} \cdot lb_{t,i,g,a}^{perc} \qquad \textit{(equation 17)}$$

Where:

$LB_{t,i,g,a}$ Total labour force in zone i by gender g and age group a in time period t [persons]

$pop_{t,i,g,a}^{tot}$ Total population in zone i by gender g and age group a in time period t [persons]

$lb_{t,i,g,a}^{perc}$ Labour force percentage in zone i by gender g and age group a in time period t [%].

The labour force percentage is defined by the EU reference scenario and its underlying assumptions and is used in the current calculations for all the time steps. The labour force assumptions can be changed externally by modifying the data in the Database to, for instance, assume that age groups increase their labour force or vice versa.

3.3.3 Elasticities

The Demography module does not include any explicit elasticities. The module is sensitive to changes affecting the demographic and socio-economic drivers which depend mostly on the demographic structure of a country (age/gender). This demographic structure affects birth, fertility, and mortality. The final model uses national immigration and emigration rates from the EU Reference Scenario as inputs, without sensitivity to policy levers.

3.4 Passenger Demand Module

3.4.1 Description

This paragraph gives an overview on the structure of the Passenger Demand module of the final version. The module largely follows the classical “four-step approach” of transport demand modelling (without the fourth step, network assignment) (Ortúzar and Willumsen, 2011). It consists of four sub-models: generation, distribution, modal split and conversion. The generation model computes the trip demand for each origin. The distribution model calculates the origin-destination trip matrix and the modal split model further splits the origin-destination matrix by transport modes. The conversion model derives other transport indicators like passenger-kilometres and vehicle-kilometres. Furthermore, the Passenger Demand module is complemented by two additional sub-models focusing on urban passenger transport as well as on intercontinental air passenger transport. Figure 7 shows the overall structure of the Passenger Demand module.

The generation and the conversion components follow a straightforward approach, while the distribution and the model split components are integrated by using the Expected Minimum Cost (EMC) measure (Liedtke and Carrillo, 2012). The EMC measure relies on the Expected Maximum Utility (EMU) or logsum measure which is more frequently discussed in economic literature (De Jong et al., 2007). For the cost functions, the concept of “generalised time” is used, i.e. cost unit refers to minutes and not to monetary terms. For the computation, cost rates of the Vehicle Stock module are considered (see Table 9).

Infrastructure measures can be modelled via a hypernet approach which influences the impedance matrices.

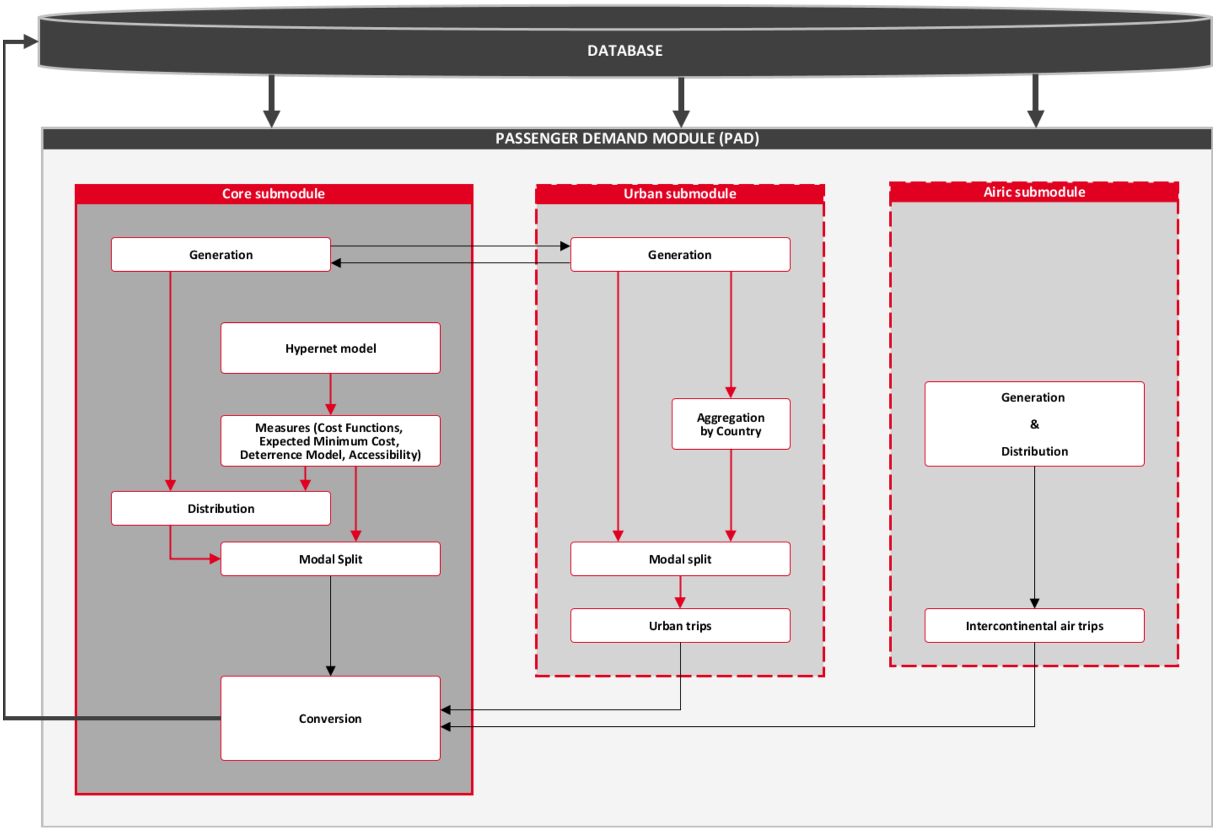

Figure 7: Structure of the Passenger Demand module

The Passenger Demand module is designated to compute trip flows at the level of origin-destination relations for the European regions (at NUTS-2 level) and neighbouring countries. It distinguishes four trip purposes *p*, namely business, commuting, private and vacation in accordance to the definition of the European Transport Information System (Szimba et al., 2013) and four basic transport modes *m*, namely rail, road, air, coach. Road trips are further disaggregated in a subsequent step into trips by car and trips by powered two-wheelers (motorcycles). Due to European NUTS-2 regions' relatively large average diameter of nearly 125 km and consequently the use of comparatively aggregated data, the Passenger Demand module's core competence is the coverage of inter-zonal trips rather than intra-zonal traffic.

In order to make the module sensitive to urban transport policy measures and to cover long-distance air trips, it is complemented by two additional sub-models: the urban passenger demand module and the intercontinental air passenger module. The modelling approaches of both additional sub-modules differ from that of the Passenger Demand module. For instance, the urban passenger demand model introduces additional transport modes like cycling, bus, and tram and computes output indicators at country level while the intercontinental passenger model applies a direct demand model just reflecting the air mode.

Table 8 shows how the Passenger Demand Module interacts with the other HIGH-TOOL modules. The main outcomes of the Passenger Demand module are the origin-destination trip matrices by mode *m* and purpose *p* which are calculated within the sub-models generation, distribution, and modal split. These trip matrices focus on long distance transport modes and feed into the conversion sub-model in order to derive other transport performance indicators such as passenger-kilometres and vehicle-kilometres. The urban passenger demand model and the intercontinental air passenger model are closely linked to the Passenger Demand module in order to ensure consistency (e.g., the calibration of the generation sub-model is carried out in one single step for all modes).

Table 8: Interaction of the Passenger Demand module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module(s)	Name in database
In	pop^{tot}	Population [people]	time period *t*, country *ci*, gender *g*, age group *a*	Demography	o_de_pop
In	*LB*	Labour force	time period *t*, zone *i*, gender *g*, age group *a*	Demography	o_de_labour
In	*GDP*	Gross domestic product [million EUR]	time period *t*, country *ci*	Economy & Resources	o_er_GDP
In	*jobs*	Number of working places [jobs]	time period *t*, country *ci*	Economy & Resources	o_er_empl
In	*income*	Income [EUR]	time period *t*, country *ci*	Economy & Resources	o_er_income
In	$cost^{fix}$	Fixed vehicle costs [EUR/vkm]	time period *t*, country ci, mode *m*	Vehicle Stock	o_vs_cstavggen_fix_vkm, o_vs_cstavggen_fix_pkm
In	$cost^{var}$	Variable vehicle costs [EUR/vkm]	time period *t*, country ci, mode *m*	Vehicle Stock	o_vs_cstavggen_var_vkm, o_vs_cstavggen_var_pkm
Out	*pkm*	Passenger transport mobility [pkm]	time period *t*, destination *j*, origin *i*, purpose *p*, mode *m*	Economy & Resources	o_pd_pkm_od and o_pd_airic_pkm_od
Out	*pkm*	Passenger transport mobility by country [pkm]	time period *t*, country *ci*, mode *m*	Safety	od_pd_pkm_transit_safety, o_pd_pkm_orig_safety, o_pd_urban_pkm_ctry
Out	vkm^{pas}	Passenger transport mobility [vkm]	time period *t*, destination *j*, origin *i*, purpose *p*, mode *m*	Vehicle Stock & Environment	o_pd_vkm_od
Out	vkm^{pas}	Passenger transport mobility by country [vkm]	time period *t*, country *ci*, mode *m*	Safety	o_pd_vkm_orig, o_pd_urban_vkm_crty
Out	T^{pas}	Number of passenger trips [trips]	time period *t*, destination *j*, origin *i*, purpose *p*, mode *m*	Safety	o_pd_airic_trips_od

3.4.2 Equations

3.4.2.1 Generation

The generation model computes the number of trips that are generated in an origin region. For each origin *i* its specific trip rates are estimated, taking into account economic and demographic differences between European countries. Trip rates in terms of trips per capita are calculated by purpose *p*, age group *a* and gender *g*, while not all purpose/age group combinations are assumed to be relevant (see Table 9). The generation model relies on two basic assumptions: (1) the time budget for daily trips is almost invariant among all cultures (Infas, 2010), and (2) a trip can be further classified by its purpose as a compulsory or optional trip (Ortúzar and Willumsen, 2011). For these reasons, the generation model comprises a parameter that refers to invariant parts, and considers two different approaches for deriving compulsory and optional trips. In the first step, country-specific mobility levels (0 to 100%) are calculated and then applied to a purpose-specific, basic trip rate.

The computation of trip rates within the HIGH-TOOL model largely relies on experiences made by passenger demand modelling within the ETISplus project with regard to collecting and harmonising European travel surveys (see Szimba et al., 2013, chapter "Analysis of travel surveys and statistics"), such as the UK NTS (DfT, 2008), the German MOP (Zumkeller et al., 2007), the Danish NTS (DTU, 2011), Mobilität in der Schweiz (BFS et al., 2007), the German MiD (Infas., 2010), the Finnish NTS (Finnra and The Finnish Rail Administration, 2006), the Netherlands NTS (MVW, 2010), and the Italian NTS (ISFORT, 2010).

Table 9: Demand segments by purpose

Purpose	0–14 female	0–14 male	15–24 female	15–24 male	25–64 female	25–64 male	65+ female	65+ male
Business			x	x	x	x		
Commuting			x	x	x	x		
Private	x	x	x	x	x	x	x	x
Vacation	x	x	x	x	x	x	x	x

Based on trip rates from ETISplus, a regression model was formulated to estimate model parameters of the generation model. Figure 8 shows estimated trip rates (number of trips per year per person) for EU28+CH+NO by country in ascending order (red line) of trip rates from ETISplus (blue bars).

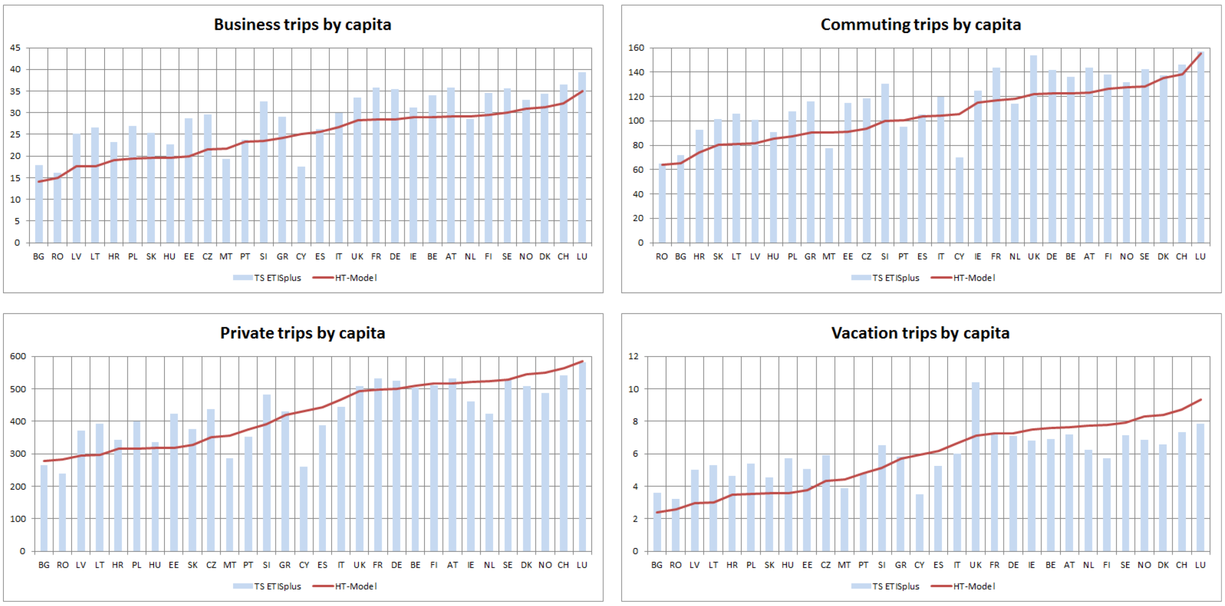

Figure 8: Comparison of trip rates (uncalibrated HIGH-TOOL estimates vs. ETISplus)

Some differences, e.g. for Malta or Cyprus (all purposes) or United Kingdom (vacation), are evident and can be explained by the particular geographical position of these islands. In order to close gaps between estimated- and ETISplus trip rates (see Figure 8), purpose and country specific calibration factors $kp_{ci,p}$ are applied. Calibration factors have been derived by comparing the uncalibrated generation model with ETISplus. Note that this does not restrict the sensitivity of the generation model, since the same calibration factors are also applied for forecast years. The generation model is calibrated to 2010 and thus to a specific economic, employment, and income level. To allow an application of the model for forecast years, trend factors are applied adjusting the model to the corresponding level. These trend factors were derived based on EU Reference Scenario by comparing the non-adjusted generation model with EU Reference Scenario.

Subsequently, calculated trip rates are adjusted to specific mobility behaviour for a total of 24 demand segments (see Table 9) and extrapolated on the basis of the number of inhabitants to calculate the trip demand by region. These 24 demand segments are finally aggregated by purpose to reduce the complexity of the integrated modelling approach for distribution and modal split.

Mobility level for business and commuting trips

For each origin i the number of generated trips ($T_{t,i,p,g,a}$) is calculated for each demand segment as follows:

$$T^{pas}_{t,i,p,g,a} = pop^{tot}_{t,i,g,a} \cdot R_{t,ci\ni i,p,g,a} \qquad \text{(equation 1)}$$

In which:

$$R_{t,ci,p,g,a} = \left(\hat{R}_{t,ci,p} \cdot kp_{ci,p}\right) \cdot mb_{ci,p,g,a} \qquad \text{(equation 2)}$$

$$\hat{R}_{t,ci} = N_{t,p} \cdot (\omega t_p + \left(1 - \omega t_p\right) \cdot M_{t,ci,p}) \qquad \text{(equation 3)}$$

$$M_{t,ci,p} = 1 - \frac{1}{1+\left(\left(\frac{L_{t,ci}}{L_{\emptyset}}\right)^{e^L} \cdot \left(\frac{E_{t,ci}}{E_{\emptyset}}\right)^{e^E}\right)} \qquad \text{(equation 4)}$$

$$L_{t,ci} = \sum_{i \in ci} \left(\frac{GDP_{t,i}}{jobs_{t,i}}\right) \cdot tpl_{t,ci} \qquad \text{(equation 5)}$$

$$E_{t,ci} = \sum_{i \in ci} \sum_{g} \sum_{\substack{a \in \\ \{15-24;\ 25-64\}}} \left(\frac{jobs_{t,i}}{pop^{tot}_{t,i,g,a}}\right) \cdot tpe_{t,ci} \qquad \text{(equation 6)}$$

Where:

$T^{pas}_{t,i,p,g,a}$	Generated number of passenger trips in zone *i* by purpose *p* for gender *g* and age group *a* in time period *t* [trips]
$R_{t,i,p,g,a}$	Trip rate for zone *i* by purpose *p* for gender *g* and age group *a* in time period *t* [trips/person]
$\hat{R}_{t,p,ci}$	Estimated trip rate of country *ci* by purpose *p* in time period *t* [trips/person]
$M_{t,ci,p}$	Mobility level of country *ci* by purpose *p* in time period *t*
$L_{t,ci}$	Economic level of country *ci* in time period *t*
$tpl_{t,ci}$	Trend parameter related to economic level of country *ci* in time period *t*
$E_{t,ci}$	Employment level of country *ci* in time period *t*

$tpe_{t,ci}$	Trend parameter related to employment level of country *ci* in time period *t*
$pop^{tot}_{t,i,g,a}$	Population in zone *i* by gender *g* and age group *a* in time period *t* [people]
$kp_{ci,p}$	Calibration parameter for country *ci* by purpose *p*
$mb_{ci,p,g,a}$	Model parameter referring to mobility behaviour of demand segment by country *ci* and purpose *p* for gender *g* and age group *a*
$N_{t,p}$	Basic trip rate by purpose *p* in time period *t*
ωt_p	Effect of invariant parameters regarding to trip generation for purpose *p*
$L_{\emptyset}$	Average European economic level
e^L	Model parameter referring to economic elasticity [%]
$E_{\emptyset}$	Average European employment level
e^E	Model parameter referring to employment elasticity [%]
$GDP_{t,ci}$	Gross domestic product of country *ci* in time period *t* [EUR]
$jobs_{t,i}$	Number of working places by country *ci* in time period *t* [jobs].

Generation of private and vacation trips

For each origin i the number of generated trips ($T_{t,i,p,g,a}$) is calculated for each demand segment as:

$$T^{pas}_{t,i,p,g,a} = pop^{tot}_{t,i,g,a} \cdot R_{t,ci,p,g,a} \qquad \textit{(equation 7)}$$

In which:

$$R_{t,ci,p,g,a} = \left(\hat{R}_{t.p,ci} \cdot kp_{ci,p}\right) \cdot mb_{ci,p,g,a} \qquad \textit{(equation 8)}$$

$$\hat{R}_{t,ci} = N_{t,p} \cdot (\omega t_p + \left(1 - \omega t_p\right) \cdot M_{t,ci,p}) \qquad \textit{(equation 9)}$$

$$M_{t,ci,p} = 1 - \frac{1}{1+\left(\frac{I_{t,ci}}{I_{\emptyset}}\right)^{e^I}} \qquad \textit{(equation 10)}$$

$$I_{t,ci} = \sum_{i \in ci} \frac{income_{t,i}}{\sum_g \sum_a (pop^{tot}_{t,i,g,a})} \cdot tpi_{t,ci} \qquad \textit{(equation 11)}$$

Where:

$T_{t,i,p,g,a}^{pas}$	Generated number of passenger trips in zone *i* by purpose *p* for gender *g* and age group *a* in time period *t* [trips]
$R_{t,i,p,g,a}$	Trip rate for zone *i* by purpose *p* for gender *g* and age group *a* in time period *t* [trips/person]
$\hat{R}_{t,p,ci}$	Estimated trip rate of country *ci* by purpose *p* in time period *t* [trips/person]
$M_{t,ci,p}$	Mobility level of country *ci* by purpose *p* in time period *t*
$I_{t,ci}$	Income level of country *ci* in time period *t*
$tpi_{t,ci}$	Trend parameter related to income level of country *ci* in time period *t*
$pop_{t,i,g,a}^{tot}$	Population in zone *i* by gender *g* and age group *a* in time period *t* [people]
$kp_{ci,p}$	Calibration parameter for country *ci* by purpose *p*
$mb_{ci,p,g,a}$	Model parameter referring to mobility behaviour of demand segment by country *ci* and purpose *p* for gender *g* and age group *a*
$N_{t,p}$	Basic trip rate by purpose *p* in time period *t*
ωt_p	Effect of invariant parameters regarding to trip generation for purpose *p*
$M_{t,ci,p}$	Mobility level of country *ci* by purpose *p* in time period *t*
$I_{\emptyset}$	Average European income level
e^I	Model parameter referring to income elasticity [%]
$income_{t,i}$	Income of zone *i* in time period *t*.

Aggregation of generated trips by purpose

For each origin *i* the number of generated trips are thereafter aggregated by purpose ($T_{t,i,p}^{pas}$) to:

$$T_{t,i,p}^{pas} = \sum_g \sum_a (T_{t,i,p,g,a}^{pas}) \qquad \text{(equation 12)}$$

Where:

$T_{t,i,p}^{pas}$ Generated number of passenger trips in zone *i* by purpose *p* in time period *i* [trips]

$T_{t,i,p,g,a}^{pas}$ Generated number of passenger trips in zone *i* by purpose *p* for gender *g* and age group *a* in time period *t* [trips].

3.4.2.2 Hypernet

The hypernet is an optional submodule for simulating corridor effects in passenger transport. It is based on simplified network models for rail and road. Neighbouring regions are connected in the hypernet if there is a link in the ETISplus networks which connects both regions. The impedances are based on the ETISplus impedance matrices. Future impedances were calculated from enhanced ETISplus networks. The enhancement included TEN-T core and comprehensive network projects.

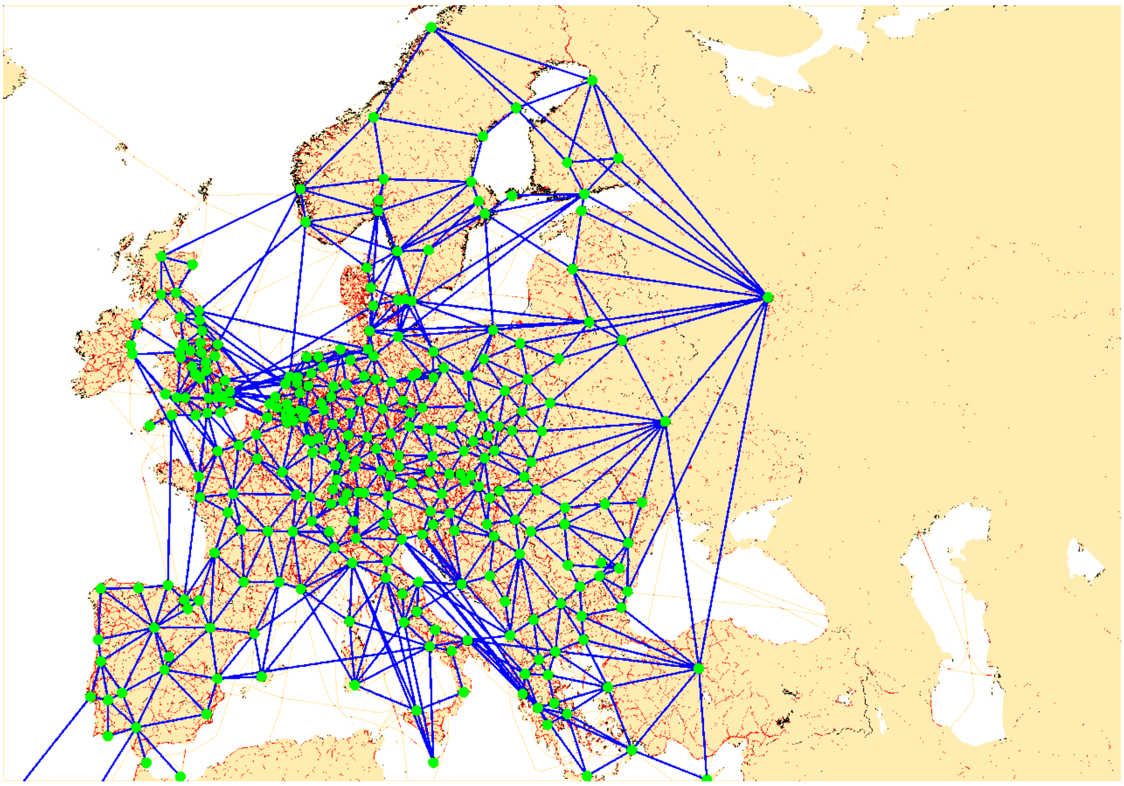

Figure 9: ETISplus road network (red), Zone centroids (green) and constructed HIGH-TOOL road hypernet (blue) for the base year 2010.

Construction of the hypernet nodes

Representative NUTS-3 zones are chosen for each NUTS-2 zone. The NUTS-3 zone containing the largest city/capital city within the NUTS-2 zone is used for this purpose.

Each hypernet node is allocated an access/egress impedance to model travel impedances to access the intra-regional hypernet links. These impedances are based on ETISplus values and can be influence by policy weights.

Construction of the hypernet links

A hyper-network link is created if the zones are either:

- bordering each other and have a ETISplus network link that connects both zones, or
- they are connected by a ferry link in the ETISplus network.

Attributes of the links are as follows:

- Time $Time_{l,m,t}$ of the NUTS-2/NUTS-2 relation in minutes
- Distance $Dist_{l,m,t}$ of the NUTS-2/NUTS-2 relation in kilometres
- National share $NS_{l,m,t}$ of the origin country of the NUTS-2/NUTS-2 relation in percent (for national transit purposes)
- Time weight $TW_{l,m,t}$ in percent, default 100% (for operationalisation of policies)
- Distance weight $DW_{l,m,t}$ in percent, default 100% (for operationalisation of policies)
- Generalised costs $GC_{l,\mathrm{m},t}$ in EUR of the link.

Figure 9 shows the constructed hyper-network links for road.

Generalised costs $GC_{l,road,t}$ for road links are computed as follows:

$$\begin{aligned} GC_{l,road,t} = {} & Time_{l,\mathrm{road},t} * TW_{l,\mathrm{road},t} * NS_{l,\mathrm{road},t} * VOT_{country(orig),t} * OR_{country(orig),road,t} \\ & + Time_{l,\mathrm{road},t} * TW_{l,\mathrm{road},t} * \left(1 - NS_{l,\mathrm{road},t}\right) * VOT_{country(dest),t} * OR_{country(dest),road,t} \\ & + Dist_{l,\mathrm{road},t} * DW_{l,\mathrm{road},t} * NS_{l,\mathrm{road},t} * CST_{country(orig),road,t} \\ & + Dist_{l,\mathrm{road},t} * DW_{l,\mathrm{road},t} * (1 - NS_{l,\mathrm{road},t}) * CST_{country(dest),road,t} \end{aligned}$$

Where:

$GC_{l,road,t}$	Generalised costs of road link *l* in the time period t
$Time_{l,\text{road},t}$	Travel time in minutes on road link *l* in the time period t
$TW_{l,\text{road},t}$	Time weight in percent on road link *l* in the time period t
$NS_{l,\text{road},t}$	National share of origin country of on road link *l m* in the time period t
$VOT_{country(orig),t}$	Value of time in the origin country in the time period t
$OR_{country(orig),road,t}$	Road occupancy rate in the origin country in the time period t
$OR_{country(dest),road,t}$	Road occupancy rate in the destination country in the time period t
$VOT_{country(orig),t}$	Value of time in the destination country in the time period t
$Dist_{l,\text{road},t}$	Travel distance in kilometres on road link *l* in the time period t
$DW_{l,\text{road},t}$	Distance weight in percent on road link *l* in the time period t
$CST_{country(orig),\text{road},t}$	Generalised costs per car vehicle kilometre of the origin country in the time period t
$CST_{country(dest),\text{road},t}$	Generalised costs per car vehicle kilometre of the destination country in the time period t

Generalised costs $GC_{l,rail,t}$ for rail links are computed as follows:

$$\begin{aligned}GC_{l,rail,t} = {} & Time_{l,\text{rail},t} * TW_{l,\text{rail},t} * NS_{l,\text{rail},t} * VOT_{country(orig),t} \\ & + Time_{l,\text{rail},t} * TW_{l,\text{rail},t} * \left(1 - NS_{l,\text{rail},t}\right) * VOT_{country(dest),t} \\ & + Dist_{l,\text{rail},t} * DW_{l,\text{rail},t} * NS_{l,\text{rail},t} * CST_{country(orig),rail,t} \\ & + Dist_{l,\text{rail},t} * DW_{l,\text{rail},t} * (1 - NS_{l,\text{rail},t}) * CST_{country(dest),rail,t}\end{aligned}$$

Where:

$GC_{l,rail,t}$	Generalised costs of rail link *l* in the time period t
$Time_{l,\text{rail},t}$	Travel time in minutes on rail link *l* in the time period t
$TW_{l,\text{rail},t}$	Time weight in percent on rail link *l* in the time period t
$NS_{l,\text{rail},t}$	National share of origin country of on rail link *l m* in the time period t
$VOT_{country(orig),t}$	Value of time in the origin country in the time period t

$VOT_{country(dest),t}$	Value of time in the destination country in the time period t
$Dist_{l,\text{rail},t}$	Travel distance in kilometres on rail link *l* in the time period t
$DW_{l,\text{rail},t}$	Distance weight in percent on rail link *l* in the time period t
$CST_{country(orig),rail,t}$	Generalised costs per rail person kilometre of the origin country in the time period t
$CST_{country(dest),rail,t}$	Generalised costs per rail person kilometre of the destination country in the time period t

Application of the hyper-network

The generalised costs $GC_{l,m,t}$ are used for the shortest-path search.

The impedance matrix $IMP_{i,j,m,t}^{base}$ which is derived from the ETISplus networks is used as a basis. Future TEN-T core and comprepensive projects are considered in these impedances.

First the base case impedances $HNIMP_{i,j,m,t}^{base}$ are computed from the hypernet. Subsequently for the computation of the scenario impedances $HNIMP_{i,j,m,t}^{scen}$ the time and distance weights and tolls get adjusted and the generalised costs are updated. $HNIMP_{i,j,m,t}^{scen}$ is then computed by a shortest-path calculation based on the generalised costs. The scenario impedance $IMP_{i,j,m,t}^{scen}$ is calculated follows:

$$IMP_{i,j,m,t}^{scen} = IMP_{i,j,m,t}^{base} * \frac{HNIMP_{i,j,m,t}^{scen}}{HNIMP_{i,j,m,t}^{base}}$$

Where:

$IMP_{i,j,m,t}^{scen}$	Scenario impedances between origin *i* and destination *j* for mode *m* in the time period t
$IMP_{i,j,m,t}^{base}$	Base impedances between origin *i* and destination *j* for mode *m* in the time period t
$HNIMP_{i,j,m,t}^{scen}$	Scenario hypernet impedances between origin *i* and destination *j* for mode *m* in the time period t
$HNIMP_{i,j,m,t}^{base}$	Base hypernet impedances between origin *i* and destination *j* for mode *m* in the time period t

3.4.2.3 Measures for integrating distribution and modal split

In order to ensure consistency among the distribution and the modal split calculations, both sub-models rely on the Expected Minimum Costs (EMC) measure. This measure is calculated at the level of origin-destination relations and integrates for each of the four main transport modes (rail, road, air, coach) a Generalised Travel Time (GTT) measure, which is related to mode-specific travel costs. The EMC measure feeds into the deterrence model which considers three sub-functions which are calibrated to trip categories: short-, medium- and long-distance trips. Consequently, three deterrence measures are derived which feed into the calculation of three EMC accessibility measures. Furthermore, accessibility measures consider the number of destination opportunities. For the GTT measures and for the EMC accessibility measures, the concept of generalised times is used.

GTT measure (generalised travel time)

For each mode *m* (rail, road, air, and coach) and each purpose *p* (business, commuting, private, and vacation) a specific cost function ($c_{t,i,j,p,m}$) is estimated according to the following equation:

$$c_{t,i,j,p,m} = (1 - \Delta los_{t,i,j,m}) \cdot \left(wT \cdot \left(\beta^{time}_{ci,p,m} \cdot c^{time}_{t,i,j,p,m}\right) + (1 - wT) \cdot \left(\beta^{dist}_{ci,p,m} \cdot c^{dist}_{t,i,j,p,m}\right) + con_{ci,p,m}\right) \cdot tpm_{t,ci,m} \qquad \textit{(equation 13)}$$

In which:

$$c^{time}_{t,i,j,p,m} = \left(\left(time_{t,i,j,m}\right)^{\lambda^{time}_{ci,p,m}} + time^{ae}_{t,i,j,m}\right) \qquad \textit{(equation 14)}$$

$$c^{dist}_{t,i,j,p,m} = \left(\frac{60}{vot_{ci,p}}\right) \cdot \left(\left(cost^{tot}_{t,ci} \cdot \left(dist_{t,i,j,m}\right)^{\lambda^{dist}_{ci,p,m}}\right) + cost^{ae}_{t,i,j,m}\right) \qquad \textit{(equation 15)}$$

Where:

$c_{t,i,j,p,m}$	Generalised travel time measure for origin-destination relation *ij* by purpose *p* and mode *m* in time period *t* [minutes]
$c^{time}_{t,i,j,p,m}$	Time generalised cost component for origin-destination relation *ij* by purpose *p* and mode *m* in time period *t* [minutes]

$c_{t,i,j,p,m}^{dist}$	Distance generalised cost component for origin-destination relation *ij* by purpose *p* and mode *m* in time period *t* [minutes]
$\Delta los_{t,i,j,m}$	Change of Level of Service indicator for origin-destination relation *ij* for mode *m* in time period *t*
wT	Calibration factor for weighting time and distance cost components
$tpm_{t,ci,m}$	Trend parameter related to changing mode choice behaviour in country *ci* for mode *m* in time period *t*
$\beta_{ci,p,m}^{time}$	Weighting factor for time cost component by country *ci*, purpose *p* and mode *m*
$\beta_{ci,p,m}^{dist}$	Weighting factor for distance cost component by country *ci*, purpose *p*, and mode *m*
$con_{ci,p,m}$	Regression constant for mode *m* by country *ci* and purpose *p*
$time_{t,i,j,m}$	Travel time for origin-destination relation *ij* for mode *m* in time period *t* [minutes]
$\lambda_{ci,p,m}^{time}$	Parameter of Box-Cox transformation related to travel time by country *ci*, purpose *p*, and mode *m*
$time_{t,i,j,m}^{ae}$	Access and egress time for origin-destination relation *ij* by mode *m* in time period *t* [minutes]
$vot_{ci,p}$	Value of time in country *ci* and purpose *p* [EUR/minute]
$cost_{t,ci,m}^{tot}$	Total costs for mode *m* in country *ci* and time period *t* [EUR/vehicle-kilometre]
$dist_{t,i,j,m}$	Travel distance for origin-destination relation *ij* per mode *m* in time period *t* [kilometre]
$\lambda_{ci,p,m}^{dist}$	Parameter of Box-Cox transformation related to distance based travel cost by country *ci*, purpose *p*, and mode *m*
$cost_{t,i,j,m}^{ae}$	Travel cost related to access and egress distance for origin-destination relation *ij* by mode *m* in time period *t* [EUR].

The cost-functions are calibrated for each mode and purpose at country level by considering country-specific value of time variables (based on TRANSTOOLS and ETISplus), regression constants, and weighting factors (parameters) to fit the model to the dependent variable. Cost functions are calibrated to 2010 and thus to specific ratios between time- and distance-related cost components for different modes. To allow an application of the model for forecast years, trend factors are applied. These trend factors were estimated on the basis of a comparison of the non-adjusted model with EU Reference Scenario.

International trips may pass through several countries. In this case, the origin-destination specific distance based travel cost consists of several country-specific user cost components. For its computation, it is considered how many kilometres are travelled in each country. The indicator Δlos is to be understood as a quality indicator which describes the level-of-service of a transport mode for a certain origin-destination relation. Commonly, level-of-service indicators are not directly related to travel time or travel cost, but to indicators like frequency of train connections, travel comfort or safety aspects. Deriving level-of-service indicators at the level of origin-destination relations automatically would require extensive network analysis. Due to the run time constraints of HIGH-TOOL a simplified approach is applied considering relative changes of the level-of-service indicator between a user-defined policy scenario and the reference scenario. The level-of-service indicator can be adjusted in the User Interface and is considered when computing Generalised Travel Time (GTT) measures. Mode-specific GTT measures feed into a Nested Logit model to compute the modal shares and the EMC measures (see next section). In order to overcome disadvantages of linear cost functions a Box-Cox transformation is applied to some of the time- and distance-related cost components of the GTT measure:

$$X_k^{\lambda_k} = \begin{cases} \frac{x_k^{\lambda_k}-1}{\lambda_k} & , \quad \lambda_k \neq 0 \\ ln(x_k) & , \quad \lambda_k = 0 \end{cases}$$ *(equation 16)*

Where:

$X_k^{\lambda_k}$	Non-linear variable after application of Box-Cox transformation
x_k	Linear variable (such as travel time or distance costs)
λ_k	Parameter of the Box-Cox transformation.

Specification of cost functions as well as estimating parameters relies on experiences of over 20 years in transport modelling at KIT (e.g. Szimba and Kraft, 2011; Eberhard et al., 1998; or Mandel, 1992).

Expected Minimum Cost (EMC)

The EMC measure is calculated at the level of origin-destination relations and refers to the Expected Maximum Utility (EMU) or respectively the logsum measure (De Jong et al., 2007). A Nested Logit modelling approach is applied, where mode-specific travel costs are integrated at different levels by calculating several EMC sub-measures. An EMC measure which refers to an intermediate level, is called “nest”. Within each nest, several mode specific cost measures or nests of the subjacent level are integrated and provided to the level above. The nest at the top refers to the EMC measure, while mode-specific travel costs are considered at the lowest level of each branch (see Figure 9). EMC (sub-) measures ($EMC_{t,i,j,p}$) are computed as follows:

$$EMC_{t,i,j,p} = \frac{1}{-\delta_p^{nest}(R_{ij})} \cdot \ln(\sum_m (e^{-\delta_p^{nest}(R_{ij}) \cdot c_{t,i,j,p,m}}) + \kappa_p) \qquad \textit{(equation 17)}$$

Where:

$EMC_{t,i,j,p}$	Expected Minimum Costs (sub-) measure for origin-destination relation *ij* by purpose *p* in time period *t*
$c_{t,i,j,p,m}$	Generalised Travel Time measure for origin-destination relation *ij* by purpose *p* and mode *m* in time period *t* [minutes]
δ_p^{nest}	Nest heterogeneity parameter by purpose *p*
R_{ij}	Reference distance for origin-destination relation *ij*
κ_p	Model constant by purpose *p*.

Expected Minimum Costs (EMC) measures are calculated for a large range of travel distances and accordingly at different cost levels. Therefore, it is not adequate to consider a constant heterogeneity parameter for each nest, and parameters δ are decreasing continuously.

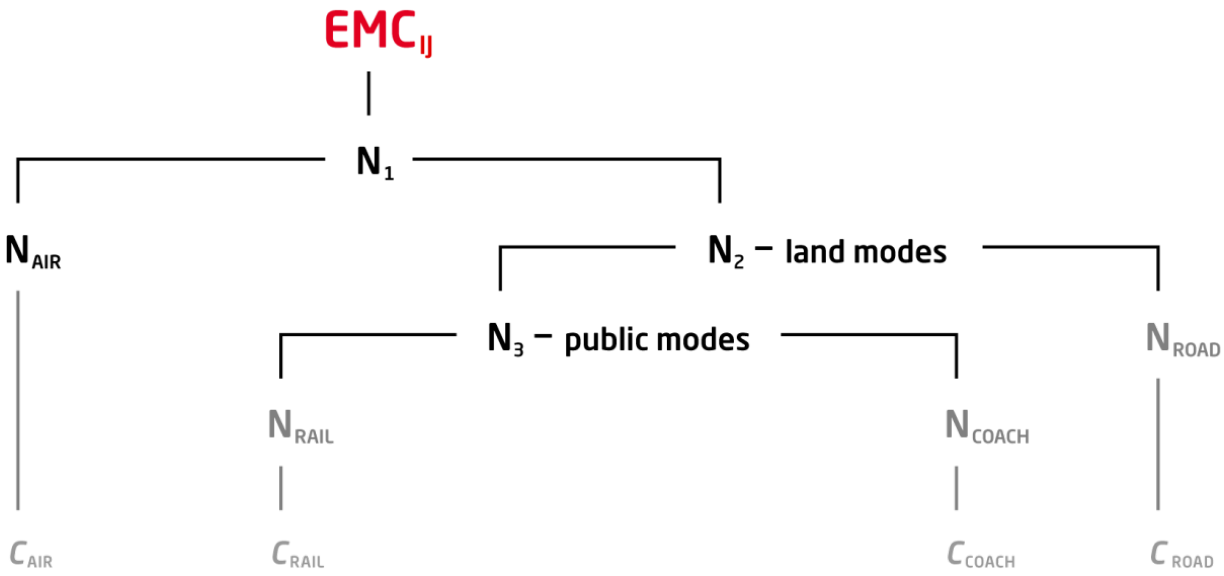

Figure 10: Nested logit approach for calculating the EMC measure

Deterrence model

With increasing travel costs the likelihood of occurrence of a trip decreases. This relationship is tackled by using a deterrence function (Ortúzar and Willumsen, 2011). Three deterrence functions with polynomial and exponential shapes are considered in order to improve the explanatory power of the deterrence model with regard to short-distance, medium-distance and long-distance trips. The resulting shape of the three deterrence functions can be understood as a rough approximation of the more complex EVA (Erzeugung, Verteilung, Aufteilung) function, which was introduced with the EVA model (Lohse et al., 1997) and which provides certain advantages compared to the sole application of classical deterrence functions such as the exponential, the power or the combined function.

Beside the deterrence functions, the deterrence model comprises three other factors. Two of these factors are related to border effects like economic differences between origin and destination (RC) and to specific barriers at international borders (B). The third factor (S) is related to a spatial transformation which allows a direct comparison of the shape of the so-called trip length distribution (TLD) and the shape of the deterrence functions. The TLD is indicating the frequency of trips which occur within a certain distance range and is therefore aggregating observations made for several origin-destination relations. On the contrary, deterrence functions are applied each time for one NUTS-2/NUTS-2 relation, only. The deterrence model ($F_{t,i,j,p,z}$) is defined as follows:

$$F_{t,i,j,p,z} = B_{t,ci\ni i,cj\ni j,p} \cdot RC_{t,i,j,p} \cdot S_t(L_{ij}) \cdot f_{p,z}(\Omega_{t,i,j,p,z}) \cdot tpd_{t,ci,m} \cdot lop_{i,j,p} \cdot rop_{i,j,p} \quad \textit{(equation 18)}$$

In which:

$$f_{p,z=short}\left(\Omega_{t,i,j,p,z=short}\right) = \left(1 + \Omega_{t,i,j,p,z=short}\right)^{\alpha^1_{p,z=short}} \cdot e^{\alpha^2_{p,z=short}\cdot\left(1+\Omega_{t,i,j,p,z=short}\right)} \quad \textit{(equation 19)}$$

$$f_{p,z=medium}\left(\Omega_{t,i,j,p,z=medium}\right) = \left(e^{\alpha^2_{p,z=medium}\cdot\left(1+\Omega_{t,i,j,p,z=medium}\right)}\right)^{hp_i} \quad \textit{(equation 20)}$$

$$f_{p,z=long}\left(\Omega_{t,i,j,p,z=long}\right) = \left(\left(1 + \Omega_{t,i,j,p,z=long}\right)^{\alpha^1_{p,z=long}}\right)^{hp_i} \quad \textit{(equation 21)}$$

$$\Omega_{t,i,j,p,z} = l_z \cdot EMC_{t,i,j,p} + k_z \quad \textit{(equation 22)}$$

Where:

$F_{t,i,j,p,z}$	Deterrence factor for origin-destination relation *ij*, purpose *p*, and distance class *z* in time period *t*
$f_{p,z}$	Deterrence function by purpose *p* and distance class *z*
$\Omega_{t,i,j,p,z}$	Transformed measure from expected minimum costs (EMC) “scale” to the trip length distribution (TLD) “scale” for origin-destination relation *ij* by purpose *p* and distance class *z* in time period *t*
$B_{t,ci,cj,p}$	Border effect for international relations between the countries *ci* and *cj* by purpose *p* in time period *t*
$RC_{t,i,j,p}$	Ranking coefficient for opportunities in destination *j* in relation to origin *i* by purpose *p* in time period *t*
S_t	Spatial indicator referring to the accessibility of destinations in time period *t*
L_{ij}	Distance level for origin-destination relation *ij*
$tpd_{t,ci,m}$	Trend parameter related to changing trip distances in country *ci,* mode *m* in time period *t*
$lop_{i,j,p}$	Parameter related to local opportunities by origin *i*, purpose *p*, only applied for intra-zonal origin-destination relations *ii* ($i = j$)
$rop_{i,j,p}$	Calibration parameter related to regional opportunities by origin-destination relation *ij*, only applied for inter-zonal relations ($i \neq j$)

hp_i	Historic parameter for origin i
l_z, k_z	Parameters by distance class z referring to linear transformation between the expected minimum costs (EMC) and the trip length distribution (TLD) scale
$EMC_{t,i,j,p}$	Expected minimum costs (sub-) measure for origin-destination relation ij by purpose p in time period t
$\alpha^1_{p,z}$	Decay factor for calibrating the deterrence functions purpose p, distance class z
$\alpha^2_{p,z}$	Decay factor for calibrating the deterrence functions purpose p, distance class z.

The deterrence functions are calibrated differently with regard to distance categories z and trip purpose p. In a first step, the deterrence functions are calibrated to meet the shape of the empirically observed trip length distribution (TLD). For this reason, expected minimum cost (EMC) measures are transformed to TLD scale. Having applied the model for the base scenario, decay factors α are adjusted based on differences between modelled and observed aggregated indicators such as average travel time.

Deterrence functions are monotonically decreasing and may not be applied to intra-zonal trips for following reason: the model computes comparatively few intra-zonal trips for larger regions, since the average generalised costs in large regions are relatively high due to long intra-zonal distances. This pattern however does not necessarily reflect reality. To overcome this discrepancy, the parameter $lop_{i,j,p}$ is applied. The calibration parameter $rop_{i,j,p}$ is derived by comparing modelled output indicators to ETISplus and only applied for inter-zonal relations. For modelling capital effects, i.e. particularly high transport demand to capitals, an additional parameter hp_i is introduced. The deterrence model is calibrated to 2010 and thus to specific ratios between decay factors and derived expected minimum costs. To allow an application of the model for forecast years, trend factors are applied. These trend factors were estimated based on a comparison of the non-adjusted model with EU Reference Scenario.

EMC accessibility measure

The EMC accessibility measure is calculated at the level of origin regions and indicates the accessibility of destination opportunities. It relies on the classical gravity accessibility measure (Hansen, 1959), but is improved by considering competition aspects. The EMC accessibility measure ($A_{t,i,p,z}$) is computed as follows:

$$A_{t,i,p,z} = \sum_j (A_{t,i,j,p,z}) \qquad \textit{(equation 23)}$$

In which:

$$A_{t,i,j,p,z} = \frac{1}{\gamma_{t,j,p}} . \omega_{p,z} . F_{t,i,j,p,z} . D_{t,j,p}$$ *(equation 24)*

Where:

$A_{t,i,p,z}$	Accessibility measure of origin *i* for purpose *p* and distance class *z* in time period *t*
$A_{t,i,j,p,z}$	Accessibility of opportunities in destination *j* from origin *i* for purpose *p* and distance class *z* in time period *t*
$\gamma_{t,j,p}$	Level of competition on opportunities in destination *j* by purpose *p* in time period *t*
$\omega_{p,z}$	Model parameter by purpose *p* and distance class *z*
$F_{t,i,j,p,z}$	Deterrence factor for origin-destination relation *ij* for purpose *p* and distance class *z* in time period *t*
$D_{t,j,p}$	Opportunities in destination *j* by purpose *p* in time period *t*.

In order to determine the attractiveness of each destination, purpose specific indicators are assumed as a proxy indicator: {GDP, jobs, population, number of beds in accommodation facilities} for the purposes *p* {business, commuting, private, vacation}. Based on these attractiveness indicators and under consideration of the estimated total trip demand, the number of opportunities by purpose is derived for each destination. The competition weighted accessibility measure ($\gamma_{t,j,p}$) is calculated as follows (Crozet et al., 2012):

$$\gamma_{t,j,p} = \sum_k (\frac{1}{v_{t,k,p}} \cdot \left(\omega_{p,z} \cdot F_{t,k,j,p,z}\right) \cdot N^T_{t,p,k})$$ *(equation 25)*

In which:

$$v_{t,k,p} = \sum_l \left(\omega_{p,z} \cdot F_{t,k,l,p,z} \cdot N^D_{t,p,l}\right)$$ *(equation 26)*

$$N^T_{t,p,k} = \frac{T_{t,k,p}}{\sum_l (T_{t,k,p})}$$ *(equation 27)*

$$N^{D}_{t,p,l} = \frac{D_{t,l,p}}{\sum_{l}(D_{t,l,p})}$$ *(equation 28)*

Where:

$\gamma_{t,j,p}$	Level of competition on opportunities in destination *j* by purpose *p* in time period *t*
$v_{t,k,p}$	Indicator referring to accessibility of destinations for origin *k* by purpose *p* in time period *t*
$N^{T}_{t,p,k}$	Normalised indicator referring to trip demand in origin *k* by purpose *p* in time period *t*
$N^{D}_{t,p,l}$	Normalised indicator referring to opportunities in destination *l* by purpose *p* in time period *t*
$F_{t,k,j,p,z}$	Deterrence factor for origin-destination relation *kj*, purpose *p*, and distance class *z* in time period *t*
$\omega_{p,z}$	Model parameter by purpose *p* and distance class *z*
$F_{t,k,l,p,z}$	Deterrence factor for origin-destination relation *kl*, purpose *p*, and distance class *z* in time period *t*
$T_{t,k,p}$	Trip demand in origin *k* by purpose *p* in time period *t*
$D_{t,l,p}$	Opportunities in destination *l* by purpose *p* in time period *t*.

3.4.2.4 Distribution

The number of trips ($T^{pas}_{t,i,j,p}$) between origin *i* and destination *j* is computed under consideration of the EMC accessibility measures ($A_{t,i,j,p,z}$) and ($A_{t,i,j,p,z}$) which have been determined within the previous step:

$$T^{pas}_{t,i,j,p} = \sum_{z}(T^{pas}_{t,i,j,p,z})$$ *(equation 29)*

$$T^{pas}_{t,i,j,p,z} = \left(\omega_{p,z} \cdot T^{pas}_{t,i,p}\right) \cdot \frac{A_{t,i,j,p,z}}{A_{t,i,p,z}}$$ *(equation 30)*

Where:

$T^{pas}_{t,i,j,p}$	Number of passenger trips for origin-destination relation *ij* by purpose *p* in time period *t* [trips]
$T^{pas}_{t,i,j,p,z}$	Number of passenger trips for origin-destination relation *ij* by purpose *p* and distance class *z* in time period *t* [trips]
$\omega_{p,z}$	Model parameter by purpose *p* and distance class *z*
$T^{pas}_{t,i,p}$	Generated passenger trips in zone *i* by purpose *p* in time period *i* [trips]
$A_{t,i,j,p,z}$	Accessibility of opportunities in destination *j* from origin *i* for purpose *p* and distance class *z* in time period *t*
$A_{t,i,p,z}$	Accessibility measure of origin *i* for purpose *p* and distance class *z* in time period *t*.

Note that the model parameter $\omega_{p,z}$ refers to the three sub-functions of the deterrence model indicating their shares when approximating the EVA function with regard to short, medium and long-distance trips. Due to the modelling approach, asymmetric origin-destination trip flows are calculated.

3.4.2.5 Modal split

For the computation of the market shares ($P_{t,i,j,m,p}$) of the four main transport modes *m*, a Nested Logit Model is applied, following the structure illustrated by Figure 9:

$$P_{t,i,j,m,p} = \frac{e^{\delta_p^{nest}(R_{ij})\cdot c_{t,i,j,p,m}}}{\sum_{m'}(e^{\delta_p^{nest}(R_{ij})\cdot c_{t,i,j,p,m'}})} \qquad \textit{(equation 31)}$$

Where:

$P_{t,i,j,p,m}$	Market share of mode m on origin-destination relation *ij* by purpose *p* in time period *t* [%]
δ_p^{nest}	Nest heterogeneity parameter by purpose *p*
R_{ij}	Reference distance for origin-destination relation *ij*
$c_{t,i,j,p,m}$	Generalised travel time measure for origin-destination relation *ij* by purpose *p* and mode *m* in time period *t* [minutes].

Subsequently, the number of trips per mode m ($T^{pas}_{t,i,j,p,m}$) are computed as follows:

$$T^{pas}_{t,i,j,p,m} = T^{pas}_{t,i,j,p} \cdot P_{t,i,j,p,m} \qquad \textit{(equation 32)}$$

Where:

$T^{pas}_{t,i,j,p,m}$	Number of passenger trips between origin *i* and destination *j* by mode m and purpose p in time period t [trips]
$T^{pas}_{t,i,j,p}$	Number of passenger trips for origin-destination relation *ij* by purpose p in time period t [trips]
$P_{t,i,j,p,m}$	Market share of mode m on origin-destination relation *ij* by purpose p in time period t [%].

The heterogeneity parameters applied for the modal split computation are identical with those heterogeneity parameters applied for the computation of the ECM measures, ensuring consistency within the integrated distribution/modal split modelling approach.

3.4.2.6 Conversion

The conversion step replaces the assignment model of a classical fourth step approach and is used for deriving transport performance indicators like passenger kilometres or vehicle kilometres. Several post-processing operations on modelled output indicators like aggregation or disaggregation are also carried out within this step in order to produce tailored datasets according to the needs of other modules of the HIGH-TOOL model. The disaggregated transport indicators such as number of trips, passenger-kilometres or vehicle-kilometres per O/D relation reflect only transport demand which is related to outgoing trips and therefore half of transport demand; i.e. the returning trip has to be added when processing these indicators further. However, the conversion step also produces “aggregated” transport indicators by origin or country which reflect full passenger transport demand; i.e. the returning trip is added by the conversion step.

Trips by car and powered two-wheelers

Within the first three steps of the Passenger Demand model, only the four main transport modes (rail, road, air, coach) covering the continental traffic are considered. “Road” comprises several different vehicle types. In order to distinguish further, road trip demand is disaggregated into “trips by cars” and “trips by powered two-wheelers (p2w)” based on the vehicle ownerships (VO) per 1000 inhabitants. The number of trips per road mode ($T_{t,i,j,p,m}$) is calculated as follows:

$$T^{pas}_{t,i,j,p,m} = T^{pas}_{t,i,j,p,m=road} \cdot \frac{L_{t,i,p,m}}{L_{t,i,p,m=car} \cdot L_{t,i,p,m=p2w}} \qquad \textit{(equation 33)}$$

In which:

$$L_{t,i,p,m=car} = \left(VO_{t,i,m=car}\right)^{\lambda_{ci\ni i,p,m=car}} \qquad \textit{(equation 34)}$$

$$L_{t,i,p,m=p2w} = \left(VO_{t,i,m=p2w}\right)^{\lambda_{ci\ni i,p,m=p2w}} \qquad \textit{(equation 35)}$$

Where:

$T^{pas}_{t,i,j,p,m}$	Number of passenger trips between origin *i* and destination *j* by mode *m (m ∊ {car, p2w})* and purpose *p* in time period *t* [trips]
$T^{pas}_{t,i,j,p,m=road}$	Number of passenger trips between origin *i* and destination *j* by *road (m = road)* and purpose *p* in time period *t* [trips]
$L_{t,i,p,m}$	Leverage of road mode *m (m ∊ {car, p2w})* by purpose *p* and origin *i* in time period *t* [%]
$VO_{t,i,m}$	Vehicle ownership of mode *m (m ∊ {car, p2w})* in origin *i* at time period *t* [vehicles/1000 inhabitants]
$\lambda^{road}_{ci,p}$	Sensitivity by purpose preferring to the country of origin *ci*.

Passenger-kilometres by mode and purpose

Passenger kilometres ($pkm_{t,i,j,p,m}$) are derived as follows:

$$pkm_{t,i,j,p,m} = T^{pas}_{t,i,j,p,m} \cdot dist^{net}_{t,i,j,m} \qquad \textit{(equation 36)}$$

Where:

$pkm_{t,i,j,p,m}$ Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [passenger-kilometre]

$T^{pas}_{t,i,j,p,m}$ Number of passenger trips between origin *i* and destination *j* by mode *m* and purpose *p* in time period *t* [trips]

$dist^{net}_{t,i,j,m}$ Average travelled net distance on origin-destination relation *ij* for trips by mode *m* in time period *t* [kilometre].

A passenger trip or respectively travelled passenger-kilometres can be broken down into two parts: one part which is related to an (almost negligible) short trip to access and to egress the main transport mode, e.g. the access trip by car or by train from home to the airport, and the part that is related to the main transport mode such as a flight from Rome to Brussels. The presented indicator passenger-kilometres by mode and purpose refers to the travel distance carried out by the main transport mode. This simplification is tolerable since the access-egress trip commonly is negligible in relation to the main trip. In any case, it would be required to distinguish passenger-kilometres which are carried out by the main transport mode and by the access-egress mode to derive the indicator vehicle-kilometres.

Vehicle kilometres by mode and purpose

Vehicle-kilometres ($vkm^{pas}_{t,i,j,p,m}$) are calculated as follows:

$$vkm^{pas}_{t,i,j,p,m} = pkm_{t,i,j,p,m} \ / \ occ_{t,ci,m}$$ *(equation 37)*

Where:

$vkm^{pas}_{t,i,j,p,m}$ Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [vehicle-kilometre]

$pkm_{t,i,j,p,m}$ Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [passenger-kilometre]

$occ_{t,ci,m}$ Average passenger occupancy rate for mode *m* in country *ci* [passenger/vehicle].

From the three modelled indicators introduced above (trips, passenger-kilometres or vehicle-kilometres at the level of origin-destination relations) aggregated indicators along a dimension (mode, purpose, origin or destination) can be produced.

Aggregated transport flows by mode at country level

Transport flows for passenger-kilometre ($pkm_{t,ci,m}$) and vehicle-kilometre ($vkm_{t,ci,m}$) are aggregated at country level by considering the average percentage of a trip travelled in each country. Based on the routing of a trip, the hyper-net model computes country-share factors for each O/D relation. Hence, these factors may change over time, for instance, if routing changes due to network changes. Country-share factors are applied when aggregating transport flows to country level:

$$pkm_{t,ci,m} = 2 \cdot \sum_{i \epsilon ci} \sum_j \sum_p (s_{ci \ni i, cj \ni j} \cdot pkm_{t,i,j,m,p}) \qquad \textit{(equation 38)}$$

$$vkm_{t,ci,m} = 2 \cdot \sum_{i \epsilon ci} \sum_j \sum_p (s_{ci \ni i, cj \ni j} \cdot vkm_{t,i,j,m,p}) \qquad \textit{(equation 39)}$$

Where:

$pkm_{t,ci,m}$	Passenger mobility in country *ci* by mode *m* in time period *t* [passenger-kilometre]
$vkm_{t,ci,m}$	Passenger mobility in country *ci* by mode *m* in time period *t* [vehicle-kilometre]
$s_{t,ci,cj}$	Share of trips for origin-destination relation *ij* that took place in country *ci* in time period *t* [%]
$pkm_{t,i,j,p,m}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [passenger-kilometre]
$vkm^{pas}_{t,i,j,p,m}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [vehicle-kilometre].

Aggregated transport flows by distance band, by mode and originating country

Aggregated transport flows by originating country for passenger-kilometre $\left(pkm_{t,ci,m}^{(db)}\right)$ and vehicle-kilometre $\left(vkm_{t,ci,m}^{(db)}\right)$ are further distinguished by distance band db. Each O/D relation is assigned to exactly one distance band based on the corresponding average travelled net distance. Note that intra-zonal transport flows are always assigned to the first distance band (< 50 km).

$$pkm_{t,ci,m}^{(db)} = 2 \cdot \sum_{i \epsilon ci} \sum_j \sum_p \left(pkm_{t,i,j,m,p} \cdot \delta_{t,i,j,m}^{(db)}\right) \quad \textit{(equation 40)}$$

$$vkm_{t,ci,m}^{(db)} = 2 \cdot \sum_{i \epsilon ci} \sum_j \sum_p \left(vkm_{t,i,j,m,p} \cdot \delta_{t,i,j,m}^{(db)}\right) \quad \textit{(equation 41)}$$

$$\delta_{t,i,j,m}^{(db)} = \begin{cases} 1 & , \quad dist_{t,i,j,m}^{net} \in db \\ 0 & , \quad else \end{cases} \quad \textit{(equation 42)}$$

Where:

$pkm_{t,ci,m}^{(db)}$	Passenger mobility by distance band db, by originating country *ci* by mode *m* in time period *t* [passenger-kilometre]
$vkm_{t,ci,m}^{(db)}$	Passenger mobility by distance band db, by originating country *ci* by mode *m* in time period *t* [vehicle-kilometre]
db	Distance bands are: {[0; 50), [50; 300), [300; 1000), [1000; inf)} km
$\delta_{t,i,j,m}^{(db)}$	Delta function equals 1, if O/D relation belongs to current distance band db
$dist_{t,i,j,m}^{net}$	Average travelled net distance on origin-destination relation *ij* for trips by mode *m* in time period *t* [kilometre]
$pkm_{t,i,j,p,m}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [passenger-kilometre]
$vkm_{t,i,j,p,m}^{pas}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [vehicle-kilometre].

Disaggregation of transport indicators by age group and gender

Transport indicators ($pkm_{t,i,j,p,m,g,a}$ and $vkm_{t,i,j,p,m,g,a}$) can be further disaggregated by gender g and age group a by a simplified approach according to their contribution to the origin trip demand by purpose, as follows:

$$pkm_{t,i,j,p,m,g,a} = pkm_{t,i,j,p,m} \cdot \frac{T^{pas}_{t,i,p,g,a}}{T^{pas}_{t,i,p}} \qquad \textit{(equation 43)}$$

$$vkm^{pas}_{t,i,j,p,m,g,a} = vkm^{pas}_{t,i,j,p,m} \cdot \frac{T^{pas}_{t,i,p,g,a}}{T^{pas}_{t,i,p}} \qquad \textit{(equation 44)}$$

Where:

$pkm_{t,i,j,p,m,g,a}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* of gender *g* and age group *a* in time period *t* [passenger-kilometre]
$vkm^{pas}_{t,i,j,p,m.g,a}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* of gender *g* and age group *a* in time period *t* [vehicle-kilometre]
$pkm_{t,i,j,p,m}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [passenger-kilometre]
$T^{pas}_{t,i,p,g,a}$	Generated number of passenger trips in zone *i* by purpose *p* for gender *g* and age group *a* in time period *t* [trips]
$T_{t,i,p}$	Generated number of passenger trips in zone *i* by purpose *p* in time period *i* [trips]
$vkm^{pas}_{t,i,j,p,m}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [vehicle-kilometre].

3.4.2.7 Sub-module intercontinental air transport

This sub-section describes the data background and the formulation of the model for intercontinental air transport passenger demand.

Data background

For the calculation of intercontinental air passenger transport a separate model has been developed. For the representation of the traffic to the "rest of the world" the bundles in Table 10 have been defined, where Antarctica was left aside as the transport flows are out of scope.

While for the purpose of a strategic simulation model the regionalisation is sufficient, the necessary data to be used for modelling (e.g., passenger demand, energy consumption, emissions) and later on for the simulation needs to be aggregated. The basic source of the HIGH-TOOL model for impedances is the ETISplus database, displaying flows as well as impedances for the "rest of the world" at NUTS-0 level without a diversification of travelling paths. To cope with the necessary degree of correctness for the simulation feature of the HIGH-TOOL model and to encounter the basic changes in the aviation world after 9/11, we decided to use the year 2013 as a reference. Thus, impedances have been generated on a much more detailed level based on the available airport/route choice model developed by MKmetric (Mandel, 2014). Although the model is generated based on 2013, which just concerns the parameters, the model is applied for the reference year 2010 based on 2010 input data (ex-post forecasting) to ensure consistency with the overall HIGH-TOOL approach.

Table 10: Regionalisation of the „rest of the world" – Intercontinental region bundles

Region identifier	Region name	ETIS Country_ID	ETIS Zone1_ID	ISO Country_ID and HIGH-TOOL bundle
1170000	Iceland	117	11700	IS
4000000	Africa Nord	400	40000	AFC_NORD
5000000	Africa Central and South	500	50000	AFC_SOUTH
6000000	Africa East	600	60000	AFC_EAST
7000000	Middle East Mediterranean	700	70000	MEA_MEDITERRANEAN
8000000	Middle East East	800	80000	MEA_EAST
10000000	Commonwealth of Independent States	1000	100000	CIS
11000000	Russia, East of Urals	1100	110000	RU_EAST
12000000	Asia/Pacific Indian Subcontinent	1200	120000	ASP_IND
13000000	Asia/Pacific Southern Asia	1300	130000	ASP_SOUTH
14000000	Asia/Pacific Australia/Oceania	1400	140000	ASC_AUS
15000000	Asia/Pacific Far East	1500	150000	ASC_EAST
16000000	America Canada	1600	160000	CDN
17000000	America USA	1700	170000	USA
18000000	America Mexico	1800	180000	MEX
19000000	America Central	1900	190000	AMC_CENTRAL

Region identifier	Region name	ETIS Country_ID	ETIS Zone1_ID	ISO Country_ID and HIGH-TOOL bundle
20000000	America Caribbean	2000	200000	AMC_CARIBBEAN
21000000	America South	2100	210000	AMC_SOUTH
22000000	Antarctica	2200	220000	ANC_ANTARCTICA

Passengers between a region of origin and a region of destination may use different paths, which may include different starting or destination airports, as well as transfer points during trips. So the calculations have been executed for each of the different travel alternatives travellers have for a distinct trip. The resulting impedances have been aggregated with the weight of the choice probability calculated for the different alternatives for travelling by air mode between the regions of origin and destination. As these calculations were done at NUTS-3-level (Europe) and country or even more detailed level for regions outside Europe, the origin-destination pair specific results were aggregated to the NUTS-2-level (Europe) or the bundles covering the „rest of the world" outside Europe as defined above, using the flow pattern of air transport applying for the reference year 2013. These spatial areas are indicated by *i* in this section.

The data for the intercontinental air transport produced as input to the HIGH-TOOL database show for each origin destination pair the information outlined in the code plan shown in Table 11.

Table 11: Variable code plan of the intercontinental air passenger demand

Data	Description	Dimensions	Unit
i	Region identifier of origin	origin *i*	NUTS-2 regions of EU28+CH+NO
j	Region identifier of destination	destination *j*	rest of world bundle
$cost^{ea}$	Access/Egress costs from the regions to the airport	time period *t*, origin *i*, destination *j*, purpose *p*	EUR
$time^{ea}$	Access/Egress time from the regions to the airport	time period *t*, origin *i*, destination *j*, purpose *p*	minutes
$cost^{flight}$	Travel costs for the air mode (includes charges, fees, air fare)	time period *t*, origin *i*, destination *j*, purpose *p*	EUR
$time^{flight}$	Travel time spent in the air mode (includes time spent for airport entering, check in/out, security, boarding, transfer, de-boarding, baggage pick up, airport exit)	time period *t*, origin *i*, destination *j*, purpose *p*	minutes
f^{flight}	Level of service: frequency	time period *t*, origin *i*, destination *j*, purpose *p*	flights/day
dist	Flight distance for business flights	time period t, origin *i*, destination *j*, purpose *p* and mode *m*	kilometre
$GDP_{t\,i}$	GDP of origin region	time period *t*, origin *i*	million EUR
GDPt j	GDP of destination region	time period *t*, destination *j*	million EUR

Data	Description	Dimensions	Unit
pop[tot]	Population of origin region	time period *t*, origin *i*	persons
pop[tot]	Population of destination region	time period *t*, destination *j*	persons
emp	Employees of origin region	time period *t*, origin *i*	persons
att	Weighted sum of regional attractors by origin and destination (e.g. language similarity, beach & sun, snow, touristic centres, production facilities, resources)	origin *i*, destination *j*, purpose *p*	–
T	Business travellers from origin to destination	time period t, origin *i*, destination *j*, purpose *p*	trips

As symmetric flows were assumed, the data are just displayed from the NUTS-2 EU28+CH+NO origin region to the intercontinental destination bundles.

Demand model for intercontinental air transport

The demand model for intercontinental air transport delivers trips between the EU28 Member States plus Norway and Switzerland and the intercontinental destination bundles reflecting the „rest of the world". The model is split by trip purpose (business and non-business travellers) and based on a gravity approach to cope with the requirement of a fast computation time. The demand model for business trips ($T_{t,i,j,p=buss,m=air}$) has the following equation:

$$T_{t,i,j,p=buss,m=air} = con^{dem}_{p=buss} + \beta^{mob}_{p=buss} \cdot mob^{ref}_{i,j,p=buss} + \beta^{att}_{p=buss} \cdot att^{ref}_{i,j,p=buss} + \beta^{pop}_{p=buss} \cdot pop^{nw}_{t,i} + \beta^{emp}_{p=buss} \cdot emp_{t,i} + \beta^{gdp}_{p=buss} \cdot GDP_{t,i,j} + \beta^{f}_{p=buss} \cdot f_{t,i,j,p=buss} + \beta^{c}_{p=buss} \cdot cost_{t,i,j,p=buss} + \beta^{t}_{p=buss} \cdot t_{imet,i,j,p=buss} \quad \text{(equation 45)}$$

In which:

$$mob^{ref}_{i,j,p=buss} = \frac{T^{ref}_{i,j,p=buss}}{\sqrt[2]{pop^{totref}_{t,i} \cdot pop^{totref}_{t,j}}} \quad \text{(equation 46)}$$

$$pop^{nw}_{t,i} = pop^{tot}_{t,i} - emp_{t,i} \quad \text{(equation 47)}$$

$$emp_{t,i} = \frac{{emp_{t,i}}^{\lambda} - 1}{\lambda} \quad \text{(Box-Cox Transformation)} \quad \text{(equation 48)}$$

$$GDP_{t,i,j} = \frac{\sqrt[2]{GDP_{t,i} \cdot GDP_{t,j}}^{\lambda} - 1}{\lambda} \quad \text{(Box-Cox Transformation)}$$ *(equation 49)*

$$cost_{t,i,j,p=buss} = cost^{ea}_{t,i,j,p=buss} + cost^{flight}_{t,i,j,p=buss}$$ *(equation 50)*

$$time_{t,i,j,p=buss} = time^{ea}_{t,i,j,p=buss} + time^{flight}_{t,i,j,p=buss}$$ *(equation 51)*

Where:

$T_{t,i,j,p=buss,m=air}$	Number of air (m=air) trips with purpose business (p=buss) from origin i to destination j in time period t [trips]
$mob^{ref}_{i,j,p=buss}$	Mobility for business trips (*p=buss*) from origin *i* to destination *j* in reference year *t=2013*
$pop^{nw}_{t,i}$	Non-working population in origin *i* in time period *t* [people]
$emp_{t,i}$	Employees in origin *i* in time period *t* [people]
$GDP_{t,i,j}$	Gross domestic product indicator for origin *i* and destination *j* in time period *t*
$cost_{t,i,j,p=buss}$	Travel costs for business trips (*p=buss*) from origin i to destination *j* in time period *t* [EUR]
$time_{t,i,j,p=buss}$	Travel time for business trips (*p=buss*) from origin i to destination *j* in time period *t* [minutes]
$con^{dem}_{p=buss}$	Regression constant for air demand model for purpose business (*p=buss*)
β_p	Weight for business trips (*p=buss*)
$att^{ref}_{i,j,p=buss}$	Attractor for business trips (*p=buss*) from origin *i* to destination *j* in reference year *t=2013*
$f_{t,i,j,p=buss}$	Level of service, frequency for business trips (*p=buss*) from origin i to destination *j* in time period *t* [flights/day]
$T^{ref}_{i,j,p=buss}$	Business trips (*p=buss*) from origin *i* to destination *j* in reference year *t=2013* [trips]
$pop^{totref}_{t,i}$	Population in origin i in the reference year *t=2013* [people]
$pop^{totref}_{t,j}$	Population in destination j in the reference year *t=2013* [people]
$pop^{tot}_{t,i}$	Population in origin *i* in time period *t* [people]

$GDP_{t,i}$	Gross domestic product in origin *i* in time period *t* [million EUR]
$GDP_{t,j}$	Gross domestic product in destination *j* in time period *t* [million EUR]
$cost^{ea}_{t,i,j,p=buss}$	Access/egress costs for business trips (*p=buss*) from origin *i* to destination *j* in time period *t* [EUR]
$cost^{flight}_{t,i,j,p=buss}$	Flight costs for business trips (p=buss) from origin *i* to destination *j* in time period t [EUR]
$time^{ea}_{t,i,j,p=buss}$	Access/Egress time for business trips (*p=buss*) from origin *i* to destination *j* in time period *t* [minutes]
$time^{flight}_{t,i,j,p=buss}$	Flight time for business trips (*p=buss*) from origin *i* to destination *j* in time period *t* [minutes].

The demand model for non-business trips ($T_{t,i,j,p=nb,m=air}$) is reflected by the following equation:

$$T_{t,i,j,p=nb,m=air} = con^{dem}_{p=nb} + \beta^{mob}_{p=nb} \cdot mob^{ref}_{i,j,p=nb} + \beta^{att}_{p=nb} \cdot att^{ref}_{i,j,p=nb} + \beta^{pop}_{p=nb} \cdot pop^{tot}_{t,i} + \beta^{gdp}_{p=nb} \cdot GDP_{t,i,j} + \beta^{f}_{p=nb} \cdot f_{t,i,j,p=nb} + \beta^{c}_{p=nb} \cdot cost_{t,i,j,p=nb} + \beta^{t}_{p=nb} \cdot time_{t,i,j,p=nb}$$

(equation 52)

In which:

$$mob^{ref}_{i,j,p=nb} = \frac{T^{ref}_{i,j,p=nb}}{\sqrt[2]{pop^{totref}_{t,i} \cdot pop^{totref}_{t,j}}}$$ *(equation 53)*

$$GDP_{t,i,j} = \frac{\sqrt[2]{GDP_{t,i} \cdot GDP_{t,j}}^{\lambda} - 1}{\lambda} \quad \text{(Box-Cox Transformation)}$$ *(equation 54)*

$$cost_{t,i,j,p=nb} = cost^{ea}_{t,i,j,p=nb} + cost^{flight}_{t,i,j,p=nb}$$ *(equation 55)*

$$time_{t,i,j,p=nb} = time^{ea}_{t,i,j,p=nb} + time^{flight}_{t,i,j,p=nb}$$ *(equation 56)*

Where:

$T_{t,i,j,p=nb,m=air}$	Number of air (*m=air*) trips with purpose non-business (*p=nb*) from origin i to destination j in time period t [trips]
$mob_{i,j,p=nb}^{ref}$	Mobility for non-business trips (*p=nb*) from origin *i* to destination *j* in reference year *t=2013*
$GDP_{t,i,j}$	Gross domestic product indicator for origin *i* and destination *j* in time period *t*
$cost_{t,i,j,p=nb}$	Travel costs for non-business trips (*p=nb*) from origin i to destination j in time period t [EUR]
$time_{t,i,j,p=nb}$	Travel time for non-business trips (*p=nb*) from origin i to destination j in time period t [minutes]
$con_{p=nb}^{dem}$	Regression constant for air demand model with purpose non-business (*p=nb*)
β_p	Weight for non-business trips (*p=nb*)
$att_{i,j,p=nb}^{ref}$	Attractor for non-business trips (*p=nb*) from origin *i* to destination *j* in reference year *t=2013*
$pop_{t,i}^{tot}$	Population in origin *i* in time period *t* [people]
$f_{t,i,j,p=nb}$	Level of service, frequency for non-business trips (*p=nb*) from origin i to destination j in time period t [flights/day]
$T_{i,j,p=nb}^{ref}$	Business trips (*p=nb*) from origin *i* to destination *j* in reference year *t=2013* [trips]
$pop_{t,i}^{totref}$	Population in origin i in the reference year *t=2013* [people]
$pop_{t,j}^{totref}$	Population in destination j in the reference year *t=2013* [people]
$GDP_{t,i}$	Gross domestic product in origin *i* in time period *t* [million EUR]
$GDP_{t,j}$	Gross domestic product in destination *j* in time period *t* [million EUR]
$cost_{t,i,j,p=nb}^{ea}$	Access/egress costs for non-business trips (*p=nb*) from origin i to destination j in time period t [EUR]
$cost_{t,i,j,p=nb}^{flight}$	Flight costs for non-business trips (*p=nb*) from origin i to destination j in time period t [EUR]
$time_{t,i,j,p=nb}^{ea}$	Access/egress time for non-business trips (*p=nb*) from origin i to destination j in time period t [minutes]

$time^{flight}_{t,i,j,p=nb}$ Flight time for non-business trips (*p=nb*) from origin i to destination j in time period t [minutes].

Passenger-kilometres for intercontinental air transport by purpose

Based on the demand volume of passenger trips the passenger-kilometres ($pkm_{t,i,p,m=air}$) from origin zone *i* are computed as follows:

$$pkm_{t,i,p,m=air} = \sum_{j \neq i}(pkm_{t,i,j,p,m}) \qquad \textit{(equation 57)}$$

In which:

$$pkm_{t,i,j,p,m=air} = T_{t,i,j,p,m} \cdot dist_{t,i,j,p,m} \text{with } (i \neq j) \qquad \textit{(equation 58)}$$

Where:

$pkm_{t,i,p,m=air}$ Mobility of air transport (*m=air*) evoking from origin i by travel purpose p in time period t [passenger-kilometre]

$pkm_{t,i,j,p,m=air}$ Mobility of air transport (*m=air*) for inter zonal trips from origin i to destination j by travel purpose p in time period t [passenger-kilometre]

$T_{t,i,j,p,m=air}$ Number of air (*m=air*) trips with purpose p from origin i to destination j in time period t [trips]

$dist_{t,i,j,p,m=air}$ Flight (*m=air*) distance from origin i to destination j by travel purpose p in time period t [kilometre].

The passenger-kilometres for a trip are assigned to the country of origin.

3.4.2.8 Sub-module urban transport demand

The urban sub-module produces trip demand and transport volumes (passenger- and vehicle kilometres) for the EU28 Member States plus Norway and Switzerland. The model is designated to forecast modal shift between urban transport modes given a chosen policy scenario and therefore only focuses on “intra-city” trip demand. It is assumed that this demand segment is mostly influenced by urban TPMs and the effects of urban TPMs on “inter-city” or transit trips are less significant.

Data background

The model is calibrated to the EU Reference Scenario 2013, section ”Urban transport activity per category”. For slow modes, walking and cycling, the model is calibrated to the TRACCS database (Papadimitriou et al., 2013). Due to the large size of NUTS-2 regions with an average diameter of over 100km, a clear disaggregation of intra NUTS-2 transport demand into "intra-city"- and "inter-city" transport demand is hardly possible. Urban transport activities by cars and powered-two-wheelers may therefore not be added up to output indicators of the core module to avoid double-counting. Urban transport activities by bus, metro-tram, walking and cycling are only considered by the urban sub-module, while activities by slow passenger trains as being part of the rail transport mode are only considered by the core module. Hence, the urban sub-module introduces four "new" specific urban transport modes: bus, metro-tram, walking and cycling.

Exogenous indicators

The modelling approach introduces several indicators which are disaggregated from exogenous data sources by exogenous models. The methodology for each indicator is described more in detail in the following sections. Table 12 gives a brief overview on these indicators and indicators the modelling step where the indicator is applied.

Table 12: Exogenous indicators and their application within the urban model

Indicator name	Sub-model
Average daily urban trip rate per capita for region i in the reference year 2010	Generation
Share of city dwellers in region i and direct catchment area in the reference year 2010	Generation
Weighting coefficient by simple mode $\tilde{m}$, region i in the reference year 2010	Modal split
Split ratio by urban transport mode m in country ci in the reference year 2010	Modal split
Average trip length in country ci by mode m	Conversion
Occupancy rate in country ci by mode m	Conversion

Average daily urban trip rate per capita

Purpose-specific trip rates are the basis for deriving urban trip demand. Trip rates are affected by several geographical, economic and demographic factors and differ from region to region. For estimating trip rates a regression model was formulated:

$$R_i = \sum_p R_{p_i} \quad \text{(equation 59)}$$

$$R_{p_i} = \alpha_i \overline{R_p} \left(\beta_p {z_{p_i}}^{\lambda_p} + c_p\right) \quad \text{(equation 60)}$$

Where:

R_i	Average daily urban trip demand per capita by in the reference year 2010
R_{p_i}	Trip rate for purpose p and region i
α_i	Split coefficient $\alpha_i \in (0,1)$ to distinguish between urban- and non-urban trips in i
$\overline{R_p}$	Average trip rate for purpose p
z_{p_i}	Standard score of explanatory variable for purpose p and region i
β_p, λ_p, c_p	Regression coefficients for purpose p.

Regression coefficients were calculated based on household surveys from Hungary (MNDH, 2014) and Croatia (MMATIC, 2014). The model was transferred to other regions under application of the ArcGIS layer World Cities[5] which covers European cities above 5 000 inhabitants and provides demographic and economic data for these cities. The new OECD-EC definition of cities in Europe (Dijkstra and Poelman, 2012) covering cities above 50 000 inhabitants was regarded as complementary data source. For each city, a split coefficient is derived to distinguish between urban- and non-urban trips based on the distribution of trip length and the spatial extension of a city e.g., the larger the city, the higher the share of urban trips. The regression model was validated with available household- and mobility surveys from other countries (see Table 16). Table 13 gives an overview on the range of estimated urban trip rates per purpose.

Table 13: Estimated daily trips by city dwellers per purpose

Trip purpose	Affecting factor	Estimated trip rates
Commuting and school	GDP/capita	0.8–1.7
Shopping	Household size	0.17–0.82
Business	GDP	1.1–1.5
Other	GDP	0.01–1.5
Return to home	Based on tested household surveys	0.7

[5] http://www.arcgis.com/home/item.html?id=dfab3b294ab24961899b2a98e9e8cd3d (accessed 30 Jun 2016)

Share of city dwellers and direct catchment area

The urban module is applied at the level of NUTS-2 regions and calculates urban trip demand which is generated by the “urban population”. It is assumed that urban trips are only generated by city dwellers and people living in direct catchment areas (in-commuters) of a city. The “urban population” is derived based on the ArcGIS city layer by matching cities to NUTS-2 regions. The share factor is then calculated as follows:

$$CDS_i = \sum_{k \in i} CD_k / pop_i \qquad \text{(equation 61)}$$

Where:

CDS_i	Share of city dwellers in region i in the reference year 2010
CD_k	City dwellers in city k located in region i in the reference year 2010
pop_i	Population in region i in the reference year 2010.

Weighting coefficient by simple transport mode

Modal split weighting coefficients (see Table 14) are applied within the modal split sub model and were derived based on the following exogenous data sources:

- The EPOMM Modal Split (TEMS) database is maintained by the European Platform on Mobility Management (EPOMM)[6] which is a network of governments in European countries that are engaged in Mobility Management. The tool comprises modal split data and other factors which are uploaded by contributing cities, themselves. All uploaded data is checked by an administrator of the database before the data is put online.
- The Urban Audit database (2010) is the city database of the European Union and is maintained by Eurostat[7]. The database reports modal split indicators and other factors which are defined by Eurostat and then collected for each city according to a consistent methodology.

Both databases comprise obviously implausible datasets which were identified and removed for further analysis (Düpmeier, 2015). Since their scope does not exactly match, both databases were used complementary. To further extend their scope for deriving modal split coefficients, several European documents on urban mobility (e.g., studies, or mobility plans) were also evaluated (see Table 16).

[6] http://www.epomm.eu/tems/ (accessed 4 Feb 2016)
[7] http://ec.europa.eu/eurostat/web/cities/data/database (accessed 4 Feb 2016)

Table 14: Modal split by aggregated transport modes

Aggregated transport mode	Source	Mean (std.)
Motorised individual transport (cars and motorcycles)	EPOMM-TEMS & Urban audit	0.33 (0.11)
Public transport (tram/metro and bus)	EPOMM-TEMS & Urban audit	0.25 (0.15)
Non-motorised modes (cycling and walking)	EPOMM-TEMS & Urban audit	0.51 (0.15)

Average trip length and occupancy rates

Average trip length coefficients and occupancy rates (see Table 15) are applied within the conversion sub model to derive pass-km and vehicle-km from previously calculated urban trip demand. For the identification of parameters, travel surveys and transport statistics of European countries were exploited (see Table 16). European trends and experiences show, that non-motorised- and public transport modes, trip length coefficients are practically more or less the same for different countries at country level (low correlation between income level and trip length). However, there is a strong relation between the two mentioned factors in the case of motorised individual transport[8]. Therefore different levels for average car trip length were defined to introduce the different levels between countries.

Table 15: Average trip length and occupancy rate by urban transport mode

Transport mode	Average trip length	Occupancy rate
Car	7.8–13	1.22–1.45
Motorcycle	7.9–13	1
Tram/metro	6.0	24
Bus	5.3	26
Cycling	2.5	1.0
Walking	0.6	1.0

Exogenous data sources

Table 16 lists most relevant exogenous data sources which were considered for the calculation of exogenous modelling coefficients.

Table 16: Overview of considered data sources

Source	Applied for
ArcGIS layer: World Cities, OECD-EC: Cities in Europe	Economical, demographical dataset
EPOMM	Trip generation coefficients
Eurostat: The Urban Audit database (2010)	Modal split coefficients

[8] National Travel Survey England 2013, p10 – see reference list

Mobility surveys and transport statistics	
Annual reports – (BKV Budapest Transport Operator) 2010–2014	Vehicle-km, pass km, seat km
Mobilität in Deutschland (Infas, 2000)	Average trip distance
Transport in figures, Statistical pocketbook (European Commission, 2014), Mobilität in der Schweiz (BFS et al., 2007), The Danish NTS Transportvaneundersøgelsen (DTU, 2011)	Validation, calibration
Local Public Transport Trends in the European Union (UITP, 2014)	Vehicle-km, pass km, seat km
National Travel Survey England (DfT, 2008/2014)	Pass km, avg. trip distance

Modelling approach

The urban sub-module follows a generic, elasticity-based approach and consists of a generation, a modal split, and a conversion model. The generation model produces trip demand at NUTS-2 level, the modal split model computes market shares for simple transport modes (see Table 17). The conversion model further disaggregates simple transport modes and derives output indicators by age group and gender (see Table 18) at NUTS-0 level.

Table 17: Overview of considered urban transport modes

Simple transport mode (abbr.)	**Disaggregated transport mode (abbr.)**
Motorised individual transport modes (MIT)	
	Car (car)
	Motorcycles (p2w)
Public transport modes (PT)	
	Tram and metro (tram) Bus (bus)
Non-motorised transport modes (NMT)	
	Bicycle (bike)
	Pedestrian (walk)

Table 18: Overview of considered demand segments

	0–14		**15–24**		**25–64**		**65+**	
	female	**male**	**female**	**male**	**female**	**male**	**female**	**male**
Demand segment	x	x	x	x	x	x	x	x

Generation of trip demand

The generation model produces the number of "intra-city" trips. In a first step, the number of city dwellers per NUTS-2 region is calculated. In a second step, the number of urban trips is calculated based on trip rates. For each NUTS-2 region urban trip demand is then calculated as follows:

$$T_i = \sum_{a,g} T_i^{a,g} \qquad \textit{(equation 62)}$$

$$T_i^{a,g} = \left(pop_i^{a,g} \cdot CDS_i\right) \cdot \left(R_i^{a,g} \cdot 365\right) \qquad \textit{(equation 63)}$$

Where:

T_i	Urban trip demand in region i
$T_i^{a,g}$	Urban trip demand in region i by age group a and gender g
$pop_i^{a,g}$	Population in region i by age group a and gender g
CDS_i	Share of city dwellers in region i in the reference year 2010
$R_i^{a,g}$	Average daily urban trip demand per capita by i, a, g in the reference year 2010.

Modal split

The modal split model produces urban trip demand by simple transport mode (Table 17) for each NUTS-2 region. For the computation of market shares, weighting coefficients referring to the reference year 2010 and specific utility indicators referring to a policy scenario which can be defined in the User Interface, are considered. Urban trip demand by simple transport mode is calculated as follows:

$$T_i^{\widetilde{m}} = T_i \cdot MS_i^{\widetilde{m}} \qquad \textit{(equation 64)}$$

$$MS_i^{\widetilde{m}} = \frac{\mathrm{w}_i^{\widetilde{m}}}{\sum_m \mathrm{w}_i^{\widetilde{m}}} \qquad \textit{(equation 65)}$$

$$\mathrm{w}_i^{\widetilde{m}} = W_i^{\widetilde{m}} \cdot \left(1 + \varepsilon_{ci}^{\widetilde{m}} * \mathrm{u}_{ci}^{\widetilde{m}}\right) \qquad \textit{(equation 66)}$$

Where:

$T_i^{\widetilde{m}}$	Urban trip demand in region i by simple mode $\widetilde{m}$
T_i	Urban trip demand in region i
$MS_i^{\widetilde{m}}$	Market share for simple mode $\widetilde{m}$ in region i
$\widetilde{m}$	Simple mode $\widetilde{m} \epsilon \{MIT, PT, NMT\}$
$\mathrm{w}_i^{\widetilde{m}}$	Weighting coefficient referring to simple mode $\widetilde{m}$ by region i
$\mathrm{W}_i^{\widetilde{m}}$	Weighting coefficient by simple mode $\widetilde{m}$, region i in the reference year 2010
$\varepsilon_{ci}^{\widetilde{m}}$	Elasticity coefficient by simple mode $\widetilde{m}$ and country ci
$u_{ci}^{\widetilde{m}}$	Utility coefficient by simple mode $\widetilde{m}$ and country ci.

Conversion

The conversion model produces output indicators of the urban model and distinguishes disaggregated transport modes, and disaggregated demand segments at country level. The calculation involves several consecutive steps.

Aggregation to country level

In the first step, urban trip demand by simple transport mode is aggregated to country level as follows:

$$T_{ci}^{\widetilde{m}} = \sum_{i \in ci} T_i^{\widetilde{m}} \qquad \textit{(equation 67)}$$

Where:

$T_{ci}^{\widetilde{m}}$	Urban trip demand in country ci by simple mode $\widetilde{m}$
$T_i^{\widetilde{m}}$	Urban trip demand in region i by simple mode $\widetilde{m}$.

Disaggregation of transport modes

Simple transport modes are then disaggregated as follows:

$$T_{ci}^{m} = T_i^{\widetilde{m}} \cdot \varsigma_{ci}^{m} \cdot \left(kp_{ci}^{m} * tp_{ci,y}^{m}\right) \quad (\widetilde{m} \supset m) \qquad \textit{(equation 68)}$$

Where:

T_{ci}^{m} Urban trip demand in country ci by mode m

$T_{i}^{\widetilde{m}}$ Urban trip demand in region i by simple mode $\widetilde{m}$

ς_{ci}^{m} Split ratio by disaggregated mode m in country ci

kp_{ci}^{m} Calibration parameter for country ci by mode m

$tp_{ci,y}^{m}$ Mobility trend parameter for country ci by mode m and year y

$\widetilde{m}$ Simple mode $\widetilde{m} \epsilon \{MIT, PT, NMT\}$

m Disaggregated mode $m \epsilon \{car, p2w, tram, bus, bike, walk\}$.

Disaggregation of trip demand by age group and gender

In the third step, urban trip demand by country is further disaggregated into age group and gender according to the contribution of each demand segment (see Table 18) to the trip demand. The calculation is carried out as follows:

$$T_{ci}^{m,a,g} = T_{ci}^{m} \cdot {T_{ci}^{a,g}}/{T_{ci}} \qquad \text{(equation 69)}$$

$$T_{ci}^{a,g} = \sum_{i \in ci} T_{i}^{a,g} \qquad \text{(equation 70)}$$

$$T_{ci} = \sum_{i \in ci} T_{i} \qquad \text{(equation 71)}$$

Where:

$T_{ci}^{m,a,g}$ Urban trip demand in country ci by mode m, age group a and gender g

T_{ci}^{m} Urban trip demand in country ci by mode m

$T_{ci}^{a,g}$ Urban trip demand in country ci by age group a and gender g

T_{ci} Urban trip demand in country ci

$T_{i}^{a,g}$ Urban trip demand in region i by age group a and gender g

T_{i} Urban trip demand in region i.

Passenger kilometres by mode

Then, passenger kilometres are derived as follows:

$$PKM_{ci}^{m,a,g} = T_{ci}^{m,a,g} \cdot d_{ci}^{m} \quad \textit{(equation 72)}$$

Where:

$PKM_{ci}^{m,a,g}$ Passenger kilometres in country ci by mode m, age group a and gender g

$T_{ci}^{m,a,g}$ Urban trip demand in country ci by mode m, age group a and gender g

d_{ci}^{m} Average trip length in country ci by mode m, age group a and gender g.

Vehicle kilometres by mode

In the last step, vehicle kilometres are derived as follows:

$$VKM_{ci}^{m,a,g} = PKM_{ci}^{m,a,g} / OR_{ci}^{m} \quad \textit{(equation 73)}$$

Where:

$VKM_{ci}^{m,a,g}$ Vehicle kilometres in country ci by mode m, age group a and gender g

$PKM_{ci}^{m,a,g}$ Passenger kilometres in country ci by mode m, age group a and gender g

OR_{ci}^{m} Occupancy rate in country ci by mode m, age group a and gender g.

Model fitting

Having derived all output indicators, two sets of calibration factors are applied to allow a direct comparison between HIGH-TOOL and EU Reference Scenario 2013. The first set is related to a basic model fitting of HIGH-TOOL to EU Reference Scenario 2013 and overcomes implicit differences between both modelling approaches. The second set is related to forecast years and overcomes implicit mobility trend assumptions of EU Reference Scenario 2013.

$$\tilde{T}_{y,ci}^{m,a,g} = T_{y,ci}^{m,a,g} \cdot \left(calib_{ci}^{m} \cdot trend_{y,ci}^{m}\right) \quad \textit{(equation 74)}$$

$$\widetilde{PKM}_{y,ci}^{m,a,g} = PKM_{y,ci}^{m,a,g} \cdot \left(calib_{ci}^{m} \cdot trend_{y,ci}^{m}\right) \quad \textit{(equation 75)}$$

$$\widetilde{VKM}_{y,ci}^{m,a,g} = VKM_{y,ci}^{m,a,g} \cdot \left(calib_{ci}^{m} \cdot trend_{y,ci}^{m}\right) \qquad \textit{(equation 76)}$$

Where:

$\tilde{T}_{y,ci}^{m,a,g}$	Fitted urban trip demand in year y, country ci by mode m, age group a and gender g
$\widetilde{PKM}_{y,ci}^{m,a,g}$	Fitted passenger km in year y, in country ci by mode m, age group a and gender g
$\widetilde{VKM}_{y,ci}^{m,a,g}$	Fitted vehicle km in year y, in country ci by mode m, age group a and gender g
$calib_{ci}^{m}$	Calibration factor by country ci, mode m
$trend_{y,ci}^{m}$	Trend factor by country ci, year y, mode m.

3.4.3 Elasticities

Explicit elasticities

The Passenger demand module does not include any explicit elasticities.

Model variables

The Passenger demand module is sensitive to other model variables. Table 19 summarises the variables that are relevant for the transport policy measures that affect the passenger transport demand. These are the policy levers of the Passenger Demand module.

Table 19: Model variables in the Passenger Demand module

Policy lever	Description	Dimensions	Equation	EquationName in database
$time^{ae}$	Access/Egress travel time [min]	time period *t*, country *ci*, mode *m*, purpose *p*	14	i_pd_core_lever_ae_time
Δlos	Change in level of service indicator	time period *t*, country *ci*, mode *m*, purpose *p*	15	i_pd_core_lever_delta_los
$cost^{toll}$	Toll costs [EUR/vkm]	time period *t*, country *ci*, mode *m*, purpose *p*	15	i_pd_core_toll_costs
dist	Travel distance [km]	time period *t*, origin country *ci*, destination country *cj*	15	i_pd_core_lever_net_dist
time	Travel time [min]	time period *t*, origin *i*, destination *j,* mode *m*	14	i_pd_core_lever_net_time
urban_toll	Utility indicator referring to changes in urban toll	time period *t*, country *c*	15	i_pd_urban_dutoll

Policy lever	Description	Dimensions	Equation	EquationName in database
urban_time^{ae}	Utility indicator referring to changes in urban Access/Egress travel time	time period *t*, country *c*	14	i_pd_urban_duaetime
urban_dist	Utility indicator referring to changes in urban travel distance	time period *t*, country *c*	15	i_pd_urban_dutraveldist
urban_time	Utility indicator referring to changes in urban travel time	time period *t*, country *c*	15	i_pd_urban_dutraveltime

3.5 Freight Demand Module

3.5.1 Description

The Freight Demand module consists of four components: generation/attraction, distribution, modal split, and a final conversion component that produces final outputs and derives mobility in terms of tonne-kilometres and vehicle-kilometres. The Freight Demand module uses as input the trade projections (by origin-destination pair *ij* and commodity *c*) produced by the Economy & Resources module. This means that the generation-attraction step is already performed by the Economy & Resources module. The projections are provided in EUR (2010, constant values) and are transformed into tonnes using volume-density assumptions.

Table 20: Interaction of the Freight Demand module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module(s)	Database name
In	T^{econ}	Trade flow [EUR]	time period *t*, origin *i*, mode *m*, commodity *c*, destination *j*	Economy & Resources	o_er_trade
Out	$vkm^{freight}$	Freight transport mobility [vkm]	time period *t*, origin *i*, mode *m*, commodity *c*, destination *j*	Vehicle stock, Environment	o_fd_vkm_od
Out	$vkm^{freight}$	Freight transport mobility [vkm]	time period *t*, country *ci*, mode *m*	Safety	o_fd_vkm_transit
Out	*tkm*	Freight transport performance [tonne-kilometre]	time period *t*, origin *i*, mode *m*, commodity *c*, destination *j*	Economy & Resources	o_fd_tkm_od

The trade in origin-destination form is then distributed using a multinomial logit function distributed across the routes represented by multimodal chains (origin-destination flows routed through transhipment points) collected from the ETISplus database. This component distributes freight flows according to the consolidated generalised cost of the complete chain which includes policy effects and is based on the approach applied in the ETISplus model.

The modal split component applies a multinomial logit function based on commodity types *c*, cost and time parameters to estimate the modal shares in the legs of the multimodal chains. The cost functions and utilities in the modal split component are based on TRANSTOOLS v2. Finally, conversion is applied to obtain transport performance in tonne-km and vehicle-km by O/D and Table 21 shows the interaction of the Freight Demand model with other HIGH-TOOL modules.

3.5.2 Equations

3.5.2.1 Trade value/Volume conversion and distribution

The trade projections are produced in EUR (2010, constant values) by the Economy & Resources module. The input from Economy & Resources is defined by sectors that (apart from transport sectors) match commodity types *c*. The Freight Demand module uses trade per commodities *c* (NST/R 1-digit nomenclature). The Freight Demand module applies the value/volume conversion method from NEAC-10 to ETISplus data to estimate the volumes in tonnes per year ($T_{t,i,j,c}^{freight}$) by commodity type *c* and origin-destination relation *ij* as follows:

$$T_{t,i,j,c}^{freight\_ia} = a_{ci\ni i,cj\ni j,c} \cdot b_{ci\ni i,cj\ni j,ci=cj,c} \cdot c_{ci\ni i,cj\ni j,i=j,c} \cdot T_{t,i,j,c}^{econ} \qquad \textit{(equation 77)}$$

Where:

$T_{t,i,j,c}^{freight\_ia}$	Freight trade flow (including air freight) of commodity type *c* between origin *i* and destination *j* in time period *t* [tonnes]
$T_{t,i,j,c}^{econ}$	Freight trade flow of commodity type c between origin *i* and destination *j* in time period *t* [EUR]
$a_{ci,cj,c}$	Value-volume ratio for trade from origin country *ci* to destination country *cj* per commodity type *c* [EUR]
$b_{ci,cj,c}$	Logistics factor for domestic trade, when country *ci* = country *cj*
$c_{ci,cj,c}$	Logistics factor for intra-zonal trade, when origin *i* = destination *j*.

The air freight demand

Air is separated from the total demand in this step of the Freight Demand module. This demand is of higher value or time sensitivity. It is assumed that the total demand is of commodity type *c* NSTR/1 Commodity 9, Machinery, transport equipment, manufactured articles and miscellaneous articles[9]. The air freight demand from 2010 onwards ($T_{t,i,j,c}^{air}$) is estimated using constant growth rates, differentiated per origin-destination pair *ij*, using the following formula:

$$T_{t,i,j,c}^{air} = T_{t-1,i,j,c}^{air} \cdot (1 + g_{t,i,j}^{air})^t \quad \textit{(equation 78)}$$

Where:

$T_{t,i,j,c}^{air}$ Air freight trade flow of commodity type *c* from origin *i* to destination *j* in time period *t* [tonnes]

$g_{t,i,j}^{air}$ Growth of air freight from origin *i* to destination *j* in time period *t*.

For the start year (2010), the trade in tonnes is imported from ETISplus. The growth factor for air trade differentiated per origin *i* and destination *j*, is based on growth rates of trade between origin *i* and destination *j*. For the next step (modal split), the demand used ($T_{t,i,j,c}^{freight}$) is the total demand minus the air freight demand:

$$T_{t,i,j,c}^{freight} = T_{t,i,j,c}^{freight\_ia} - T_{t,i,j,c}^{air} \quad \textit{(equation 79)}$$

Where:

$T_{t,i,j,c}^{freight}$ Freight flow for commodity type *c* from origin *i* to destination *j* in time period *t* [tonnes]

$T_{t,i,j,c}^{freight\_ia}$ Freight trade flow (including air freight) of commodity type *c* between origin *i* and destination *j* in time period *t* [tonnes]

$T_{t,i,j,c}^{air}$ Air freight trade flow of commodity type *c* from origin *i* to destination *j* in time period *t* [tonnes].

[9] See for more information: http://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC.

3.5.2.2 Distribution among mode chains

The distribution among mode chains follows a multinomial logit model and distributes the freight flow across multimodal transport chains (route through transhipment points) collected from the ETISplus database. In this case a mode chain constitutes of the multimodal routing from origin to destination through up to two transhipment points. For example, a trade flow from Rotterdam to Hamburg may be represented by a direct short-sea chain, a chain transhipping in Felixstowe, a chain consisting of an inland waterway leg combined with a final road leg, etc. The ETISplus database provides multiple modelled multimodal freight flows per origin-destination pair *ij* in forms of mode chains *r* using at most two transhipment points: T1 and T2. The probability ($P_{t,i,j,c,r}$) of using a specific route *r* is:

$$P_{t,i,j,c,r} = \frac{e^{TC_{t,i,j,c,r}}}{\sum_{r \epsilon RS_{i,j}} (e^{TC_{t,i,j,c,r}})} \qquad \textit{(equation 80)}$$

In which:

$$TC_{t,i,j,c,r} = \beta^0 * \min\_cost_{t,i,j,c,r} \qquad \textit{(equation 81)}$$

Where:

$P_{t,i,j,c,r\|m}$	Probability of choosing route *r* between origin *i* and destination *j* for commodity *c* in time period *t* given mode *m* [%]
$TC_{t,i,j,c,r}$	Minimum total cost of route *r* between origin *i* and destination *j* for commodity *c* at time period *t*
$RS_{i,j}$	The set of available routes between origin *i* and destination *j*
$\min\_cost_{t,i,j,c,r}$	Minimum cost (modal combination with lowest total cost) for route *r* between origin *i* and destination *j* for commodity *c* in time period *t*
β^0	Constant.

Where *r* is the route for an origin-destination pair given the set of mode(s) *m* used to traverse it. The specific set of modes used in a route allows it to be differentiated from another route going through the same transhipment points. The cheapest modal combination that forms the route is used as a proxy for the attractiveness of all routes connection origin-destination pair *ij*.

Here, the probability that a specific route is selected for an origin-destination pair *ij* is calculated by comparing the estimated costs for all available routes. The total tonnes as provided in the previous step is applied on these routes to obtain route flows ($T_{t,i,j,c,r}^{freight}$):

$$T_{t,i,j,c,r}^{freight} = T_{t,i,j,c}^{freight} \cdot P_{t,i,j,c,r} \qquad \textit{(equation 82)}$$

Where:

$T_{t,i,j,c,r}^{freight}$ Freight flow for commodity c from origin i to destination j in time period t using route r [tonnes]

$P_{t,i,j,c,r}$ Probability of choosing route r between origin i and destination j for commodity c in time period t [%]

$T_{t,i,j,c}^{freight}$ Freight flow for commodity c from origin i to destination j in time period t [tonnes].

The end product of this step is for each origin-destination pair *ij* a list of chains with allocated tonnes. The example in Table 21 shows a (non-exhaustive) list of routes from Sjaelland (1080002) to Dorset (1332002). Most tonnes are transported through Hampshire (fourth row) via sea (first transhipment point) and road (second transhipment point).

Table 21: Example freight distribution

ON2	DN2	T1N2	T2N2	Probability	Tonnes
1080002	1332002	1331904		0.14	608
1080002	1332002	1332001		0.15	633
1080002	1332002	1080001	1331903	0.11	491
1080002	1332002	1331903		0.35	1532
1080002	1332002	1331903		0.09	420
…				…	…
Total				**1**	**4373**

3.5.2.3 Modal split

The equations and parameters in the modal split component in the Freight Demand module are derived from TRANSTOOLS v2 and the Vehicle module. The different types of costs are transformed into two main types: variable and fixed[10] coming from TRANSTOOLS v2 and Vehicle Stock.

The modal-split calculation performs a modal-split for each leg of the chains produced by the distribution step. For each of these legs the total leg costs are the summation of the costs encountered in each country traversed along the leg.

The modal split module calculates different types of costs. The fixed ($cost_{t,c,m}^{fix}$) and variable ($cost_{t,c,m}^{var}$) cost rates are calculated as the summation of all country-specific costs encountered along the leg that modal-split is calculated for:

$$cost_{cl,ci,cj,t,c,m}^{fix} = \frac{cr_{cl,t,c,m}^{fix}}{load_{ci,t,c,m} \cdot cap_{ci,t,c,m} \cdot v_{cl,t,c,m}} \cdot gves_{cl,t,c,m}^{fix} \qquad \textit{(equation 83)}$$

$$cost_{cl,ci,cj,t,c,m}^{var} = \frac{cr_{cl,t,c,m}^{var} + cr_{cl,t,c,m}^{ener}}{load_{ci,t,c,m} \cdot cap_{ci,t,c,m}} \cdot gves_{cl,t,c,m}^{var} \qquad \textit{(equation 84)}$$

Where:

$cost_{cl,ci,cj,t,c,m}^{fix}$ Fixed cost rate for commodity type *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* and destination country *cj* [EUR/tonne-kilometre]

$cost_{cl,ci,cjt,c,m}^{var}$ Variable cost rate for commodity type *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* and destination country *cj* [EUR/tonne-kilometre]

$cr_{cl,t,c,m}^{fix}$ Fixed cost for commodity type *c* and mode *m* in time period *t* for current country *cl* [EUR/vehicle-hour]

$load_{ci,t,c,m}$ Average freight load factor for mode *m* and commodity type *c* in time period *t* for an O-D with origin country *ci*

$cap_{ci,t,c,m}$ Loading capacity for commodity *c* and mode *m* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle]

[10] Cost items are termed "variable" if dependent on distance and "fixed" if not. Wages and capital costs are considered fixed are they are more time-based rather than distance-based.

$v_{cl,t,c,m}$ Speed for commodity *c* and mode *m* in time period *t* for current country *cl* [kilometre/hour]

$gves_{cl,t,c,m}^{fix}$ Growth of fixed costs modelled by VES from *t-1* to *t* for current country *cl* providing the change of fixed costs over time

$gves_{cl,t,c,m}^{var}$ Growth of variable costs modelled by VES from *t-1* to *t* for current country *cl* providing the change of variable costs over time

$cr_{cl,t,c,m}^{var}$ Variable cost for commodity *c* and mode *m* in time period *t* for current country *cl* [EUR/vehicle-kilometre]

$cr_{cl,t,c,m}^{ener}$ Energy cost for commodity *c* and mode *m* in time period *t* for current country *cl* [EUR/vehicle-kilometre].

The toll/vignette costs sourced from the TRACCS database are imported from the Database as a separate table and converted from [EUR/vehicle-kilometre] to [EUR/tonne-kilometre]. The total mobility costs ($cost_{t,i,j,c,m}^{mob}$) are calculated from the variable and fixed cost rates as follows:

$$cost_{cl,t,m}^{toll} = \frac{toll_{cl,t,m}}{load_{ci,t,c,m} \cdot cap_{ci,t,c,m}} \qquad \text{(equation 85)}$$

$$cost_{cl,t,i,j,c,m}^{mob} = \left((cost_{cl,ci,cj,t,c,m}^{fix} + cost_{cl,ci,cj,t,c,m}^{var}) \cdot dist_{cl,t,i,j,m} \right) + cost_{cl,t,c,m}^{toll} \qquad \text{(equation 86)}$$

Where:

$cost_{cl,t,i,j,c,m}^{mob}$ Total mobility cost between origin *i* and destination *j* by mode *m* for commodity *c* in year *t* including toll fees [EUR]

$cost_{cl,ci,cj,t,c,m}^{fix}$ Fixed cost rate for commodity type *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* and destination country *cj* [EUR/tonne-kilometre]

$cost_{cl,ci,cjt,c,m}^{var}$ Variable cost rate for commodity type *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* and destination country *cj* [EUR/tonne-kilometre]

$cost_{cl,t,c,m}^{toll}$ Toll cost rate for commodity *c* and mode *m* in time period *t* for current country *cl* [EUR/tonne-kilometre]

$dist_{cl,t,i,j,m}$ Distance between origin *i* and destination *j* by mode *m* in time period *t* for current country *cl* [kilometre].

In addition, the loading costs ($cost^{load}_{cl,ci,cj,t,c,m}$) are calculated as:

$$cost^{load}_{cl,ci,cj,t,c,m} = \frac{\left(t^{load}_{cl,ci,t,c,m} + t^{unload}_{cl,cj,t,c,m} + t^{wait}_{cl,t,c,m}\right) \cdot cr^{fix}_{cl,t,c,m}}{load_{ci,t,c,m} \cdot cap_{ci,t,c,m}} \quad \textit{(equation 87)}$$

Where:

$cost^{load}_{cl,ci,cj,t,c,m}$ Loading and unloading cost for commodity *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* and destination country *cj* [EUR]

$t^{load}_{cl,ci,t,c,m}$ Loading time for commodity *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* [hour]

$t^{unload}_{cl,cj,t,c,m}$ Unloading time for commodity *c* and mode *m* in time period *t* for current country *cl* for an O-D with destination country *cj* [hour]

$t^{wait}_{cl,t,c,m}$ Wait time for commodity *c* and mode *m* in time period *t* for current country *cl* [hour]

$cr^{fix}_{cl,t,c,m}$ Fixed cost for commodity type *c* and mode *m* in time period *t* for current country *cl* [EUR/vehicle-hour]

$load_{ci,t,c,m}$ Average freight load factor for mode *m* and commodity type *c* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle]

$cap_{ci,t,c,m}$ Loading capacity for commodity *c* and mode *m* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle].

The rest break costs ($cost^{rest}_{t,i,j,c,m}$) are calculated as:

$$cost^{rest}_{cl,t,i,j,c,m} = \frac{10 \cdot rb_{t,i,j,m,c} \cdot cr^{fix}_{cl,t,c,m}}{load_{ci,t,c,m} \cdot cap_{ci,t,c,m}} \quad \textit{(equation 88)}$$

In which:

$$rb_{t,i,j,m,c} = \begin{cases} \left\lceil \frac{\left(\frac{dist_{cl,t,i,j,m}}{v_{cl,t,c,m}}\right)}{8} \right\rceil & if\ m = 1 \\ 0 & otherwise \end{cases}$$ *(equation 89)*

Where:

$cost^{rest}_{cl,t,i,j,c,m}$ Costs of mandatory rest breaks between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* for current country *cl* [EUR]

10 Rest break duration [hours]

8 Driving time after which a mandatory rest break is required [hours]

$rb_{cl,t,i,j,m,c}$ Total number of mandatory rest breaks on origin-destination relation *ij* for mode *m* and commodity type *c* in time period *t* for current country *cl* [breaks]

$cr^{fix}_{cl,t,c,m}$ Fixed cost for commodity type *c* and mode *m* in time period *t* for current country *cl* [EUR/vehicle-hour]

$load_{ci,t,c,m}$ Average freight load factor for mode *m* and commodity type *c* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle]

$cap_{ci,t,c,m}$ Loading capacity for commodity *c* and mode *m* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle]

$dist_{cl,t,i,j,m}$ Distance between origin *i* and destination *j* by mode *m* in time period *t* for current country *cl* [kilometre]

$v_{cl,t,c,m}$ Speed for commodity *c* and mode *m* in time period *t* for current country *cl* [kilometre/hour].

The total costs ($cost_{cl,t,i,j,c,m}$) are estimated as follows:

$$cost_{cl,t,i,j,c,m} = cost^{mob}_{cl,t,i,j,c,m} + cost^{load}_{cl,ci,cj,t,c,m} + cost^{rest}_{cl,t,i,j,c,m}$$ *(equation 90)*

Where:

$cost_{cl,t,i,j,c,m}$ Total transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* for current country *cl* [EUR]

$cost^{mob}_{cl,t,i,j,c,m}$ Total mobility cost between origin *i* and destination *j* by mode *m* for commodity *c* in year *t* including toll fees for current country *cl* [EUR]

$cost^{load}_{cl,ci,cj,t,c,m}$ Loading and unloading cost for commodity *c* and mode *m* in time period *t* for current country *cl* for an O-D with origin country *ci* and destination country *cj* [EUR]

$cost^{rest}_{cl,t,i,j,c,m}$ Costs of mandatory rest breaks between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* for current country *cl* [EUR].

The total costs for the leg are then the summation of all current country costs:

$$legcost_{cl,t,i,j,c,m} = \sum_{cl}(cost_{cl,t,i,j,c,m}) \qquad \textit{(equation 91)}$$

Where:

$legcost_{cl,t,i,j,c,m}$ Leg transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* for current country *cl* [EUR]

$cost_{cl,t,i,j,c,m}$ Total transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* for current country *cl* [EUR].

For each mode separate utility functions are applied. The utility functions are further adjusted for cross-border movements from and to Europe, travel from East to West as well as for distinct gauge (for rail). More specifically:

When m=road

The general road utility function ($U_{t,i,j,c,m=road}$) is:

$$U_{t,i,j,c,m=road} = \left(\beta_{c,m} \cdot cost^{mob}_{t,i,j,c,m}\right) \qquad \textit{(equation 92)}$$

With the additional cases:

$$U_{t,i,j,c,m=road} = U_{t,i,j,c,m=road} + \begin{cases} \beta^{road}_{i,j,c} \\ \beta^{roade}_{i,j,c} \cdot cost_{t,i,j,c,m} \\ \beta^{roadwe}_{i,j,c} \cdot cost_{t,i,j,c,m} \end{cases} \qquad \textit{(equation 93)}$$

Where:

$U_{t,i,j,c,m=road}$	Utility between origin *i* and destination *j* for commodity *c* by road (*m=road*) in time period *t*
$\beta_{c,m}$	Cost parameter for mode *m* and commodity *c*
$cost^{mob}_{t,i,j,c,m}$	Total mobility cost between origin *i* and destination *j* by mode *m* for commodity *c* in year *t* including toll fees [EUR]
$cost_{t,i,j,c,m}$	Total transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* [EUR];
$\beta^{road}_{i,j,c}$	Road dummy parameter for commodity *c* for origin-destination pairs *ij* that cross the EU border
$\beta^{roade}_{i,j,c}$	Road dummy parameter for commodity *c* for origins *i* and destinations *j* that are both in Eastern Europe
$\beta^{roadwe}_{i,j,c}$	Road dummy parameter for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around).

When m=rail

The general rail utility function ($U_{t,i,j,c,m=rail}$) is:

$$U_{t,i,j,c,m=rail} = a\_RAIL_c + \left(\beta_{c,m} \cdot cost^{mob}_{t,i,j,c,m}\right) \qquad \text{(equation 94)}$$

With the additional cases:

$$U_{t,i,j,c,m=rail} = U_{t,i,j,c,m=rail} + \begin{cases} \beta^{rail}_{i,j,c} \\ \alpha^{raile}_{i,j,c} + \beta^{raile}_{i,j,c} \cdot cost_{t,i,j,c,m} \\ \alpha^{railwe}_{i,j,c} + \beta^{railwe}_{i,j,c} \cdot cost_{t,i,j,c,m} \end{cases} \qquad \text{(equation 95)}$$

Where:

$U_{t,i,j,c,m=rail}$	Utility between origin *i* and destination *j* for commodity *c* by rail (*m=rail*) in time period *t*
a_RAIL_c	Constant for commodity *c*
$\beta_{c,m}$	Cost parameter for mode *m* and commodity *c*

$cost^{mob}_{t,i,j,c,m}$	Total mobility cost between origin *i* and destination *j* by mode *m* for commodity *c* in year *t* including toll fees [EUR]
$cost_{t,i,j,c,m}$	Total transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* [EUR]
$\beta^{rail}_{i,j,c}$	Rail dummy parameter for commodity *c* for distinct gauge origin-destination pairs *ij*
$\alpha^{raile}_{i,j,c}$	Rail specific constant for commodity *c* for origins *i* and destination *j* that are both in Eastern Europe
$\beta^{raile}_{i,j,c}$	Rail dummy parameter for commodity *c* for origins *i* and destinations *j* that are both in Eastern Europe
$\alpha^{railwe}_{i,j,c}$	Rail specific constant for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around)
$\beta^{railwe}_{i,j,c}$	Rail dummy parameter for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around).

When m=IWW

The general inland waterway utility function ($U_{t,i,j,c,m=IWW}$) is:

$$U_{t,i,j,c,m=IWW} = a\_IWW_c + \left(\beta_{c,m} \cdot cost^{mob}_{t,i,j,c,m}\right) \quad \textit{(equation 96)}$$

With the additional cases:

$$U_{t,i,j,c,m=IWW} = U_{t,i,j,c,m=IWW} + \begin{cases} \alpha^{iwwe}_{i,j,c} \\ \alpha^{iwwwe}_{i,j,c} + \beta^{iwwwe}_{i,j,c} \cdot cost_{t,i,j,c,m} \end{cases} \quad \textit{(equation 97)}$$

Where:

$U_{t,i,j,c,m=IWW}$	Utility between origin *i* and destination *j* for commodity *c* by inland waterways (*m=IWW*) in time period *t*
a_IWW_c	Constant for commodity *c*
$\beta_{c,m}$	Cost parameter for mode *m* and commodity *c*

$cost^{mob}_{t,i,j,c,m}$	Total mobility cost between origin *i* and destination *j* by mode *m* for commodity *c* in year *t* including toll fees [EUR]
$cost_{t,i,j,c,m}$	Total transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* [EUR]
$\alpha^{iwwe}_{i,j,c}$	Inland waterway dummy parameter for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around)
$\alpha^{iwwwe}_{i,j,c}$	Inland waterway specific constant for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around)
$\beta^{iwwwe}_{i,j,c}$	Inland waterway dummy parameter for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around).

When m=short/deep sea

The general sea utility function ($U_{t,i,j,c,m=ship}$) is as follows:

$$U_{t,i,j,c,m=ship} = a\_SEA_c + \left(\beta_{c,m} \cdot cost^{mob}_{t,i,j,c,m}\right) \qquad \textit{(equation 98)}$$

With the additional cases:

$$U_{t,i,j,c,m=ship} = U_{t,i,j,c,m=ship} + \begin{cases} \alpha^{sea}_{c} \\ \alpha^{seawe}_{i,j,c} + \beta^{seawe}_{i,j,c} \cdot cost_{t,i,j,c,m} \\ \alpha^{sss}_{i,j,c} + \beta^{sss}_{i,j,c} \cdot cost_{t,i,j,c,m} \end{cases} \qquad \textit{(equation 99)}$$

Where:

$U_{t,i,j,c,m=ship}$	Utility between origin *i* and destination *j* for commodity *c* by ship (*m=ship*) in time period *t*
a_SEA_c	Constant for commodity *c*
$\beta_{c,m}$	Cost parameter for mode *m* and commodity *c*
$cost^{mob}_{t,i,j,c,m}$	Total mobility cost between origin *i* and destination *j* by mode *m* for commodity *c* in year *t* including toll fees [EUR]
$cost_{t,i,j,c,m}$	Total transport costs on origin-destination relation *ij* for commodity *c* with mode *m* in time period *t* [EUR]

α_{c}^{sea} Sea specific constant for commodity *c*

$\alpha_{i,j,c}^{seawe}$ Sea specific constant for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around)

$\beta_{i,j,c}^{seawe}$ Sea dummy parameter for commodity *c* for cargo on origin-destination pair *ij* that moves from east to west (or the other way around)

$\alpha_{i,j,c}^{sss}$ Sea specific constant for commodity *c* for short sea shipping on origin destination pair *ij*

$\beta_{i,j,c}^{sss}$ Sea dummy parameter for commodity *c* for short sea shipping on origin-destination pair *ij*.

The modal split is calculated using a multinomial logit model, which calculates the probability ($P_{t,i,j,c,m}$) of selecting a specific mode on a specific origin-destination relation *ij* and for a specific commodity *c* as follows:

$$P_{t,i,j,c,m} = \frac{e^{U_{t,i,j,c,m}}}{\sum_{m}(e^{U_{t,i,j,c,m}})} \qquad \text{(equation 100)}$$

Where:

$P_{t,i,j,c,m}$ Probability of mode *m* being chosen on origin-destination relation *ij* for commodity *c* in time period *t* [%]

$U_{t,i,j,c,m}$ Utility between origin *i* and destination *j* for commodity *c* by mode *m* in time period *t*.

The freight demand ($T_{t,i,j,c,m}^{freight}$) by mode is then calculated as:

$$T_{t,i,j,c,m}^{freight} = T_{t,i,j,c}^{freight} \cdot P_{t,i,j,c,m} \qquad \text{(equation 101)}$$

Where:

$T_{t,i,j,c,m}^{freight}$ Freight flow for commodity type *c* by mode *m* from origin *i* to destination *j* in time period *t* [tonnes]

$T_{t,i,j,c}^{freight}$	Freight flow for commodity type *c* from origin *i* to destination *j* in time period *t* [tonnes]
$P_{t,i,j,c,m}$	Probability of mode *m* being chosen on origin-destination relation *ij* for commodity *c* in time period *t* [%].

The Short Sea Shipping demand is estimated as the Sea demand within the EU, Iceland and Norway, candidate countries, the Baltic Sea, the Mediterranean Sea and the Black Sea.

Full freighters demand

A distinction is made between the freight transported in passenger flights or using full freight aircrafts. Based on the TOSCA project (2010) "around 58% of air cargo is carried in the holds of passenger aircraft"[11], leaving 42% transported by full freighters[12]. Boeing (2014) mentions that more than 56% of all cargo is transported with freighters and expects that this ratio remains almost constant until 2030. Airbus points out that 49% of all cargo is transported with freighters, and expects it will decline to 43% in 2030, with existing historical figures depicting a decline. Finally, Eurocontrol mentions that 50% of all cargo is transported in dedicated freighter planes. All studies highlight that the ratios can be very different for different trip lengths. HIGH-TOOL uses the Airbus (2014) projections which are more adequate in the light of the ongoing shift to larger aircrafts in passenger transport across Europe as well as the actual aircraft orders at the large manufacturers Airbus and Boeing. The amount of freight demand transferred by full freight aircraft flights ($T_{t,i,j,c,m=ffa}$) for a specific origin-destination is therefore estimated as:

$$T_{t,i,j,c,m=ffa}^{freight} = fm_{t,z} \cdot T_{t,i,j,c}^{air} \quad \textit{(equation 102)}$$

Where:

$T_{t,i,j,c,m=ffa}^{freight}$	Full freight air (*m=ffa*) flow for commodity type *c* by mode *m* from origin *i* to destination *j* in time period *t* [tonnes]
$fm_{t,z}$	Distance band *z* and time period *t* specific multiplier factor [%]
$T_{t,i,j,c}^{air}$	Air freight trade flow of commodity type *c* from origin *i* to destination *j* in time period *t* [tonnes].

[11] Belly cargo
[12] Cargo liner

The multiplier factor depends on the distance band *z* (from and to Europe) and the time period *t*.

3.5.2.4 Conversion

The conversion module calculates the tonne-kilometres ($tkm_{t,i,j,c,m}$) and vehicle-kilometres ($vkm_{t,i,j,c,m}^{freight}$) as follows:

$$tkm_{t,i,j,c,m} = T_{t,i,j,c,m}^{freight} \cdot dist_{t,i,j,m} \qquad \text{(equation 103)}$$

$$vkm_{t,i,j,c,m}^{freight} = \frac{tkm_{t,i,j,c,m}}{load_{ci,t,c,m} \cdot cap_{ci,t,c,m}} \qquad \text{(equation 104)}$$

Where:

$tkm_{t,i,j,c,m}$	Freight mobility between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* [tonne-kilometre]
$vkm_{t,i,j,c,m}^{freight}$	Freight mobility between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* [vehicle kilometre]
$T_{t,i,j,c,m}^{freight}$	Freight flow for commodity type *c* by mode *m* from origin *i* to destination *j* in time period *t* [tonnes]
$dist_{t,i,j,m}$	Distance between origin *i* and destination *j* by mode *m* in time period *t* [kilometre];
$load_{ci,t,c,m}$	Average freight load factor for mode *m* and commodity type *c* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle]
$cap_{ci,t,c,m}$	Loading capacity for commodity *c* and mode *m* in time period *t* for an O-D with origin country *ci* [tonnes/vehicle].

Tonne-kilometres and vehicle-kilometres are estimated based on the demand for road, rail, inland waterways, sea (short, deep). The conversion module furthermore calculates the total tonne-kilometres ($tkm_{t,ci,m}$) and vehicle-kilometres ($vkm_{t,ci,m}^{freight}$) within a country *ci* by applying the distance share of a route in every country along that route to the origin-destination demand. The shares are derived from the underlying ETISplus data that is also used to generate the impedance and route chain matrices.

$$tkm_{t,ci,m} = \sum_c \sum_i \sum_j (tkm_{t,i,j,c,m} \cdot share^{dist}_{t,ci,i,j,m}) \qquad \textit{(equation 105)}$$

$$vkm^{freight}_{t,ci,m} = \frac{tkm_{t,ci,m}}{load_{t,c,m} \cdot cap_{t,c,m}} \qquad \textit{(equation 106)}$$

Where:

$tkm_{t,ci,m}$	Freight mobility between country *ci* for mode *m* in time period *t* [tonne-kilometre]
$vkm^{freight}_{t,ci,m}$	Freight mobility between country *ci* for mode *m* in time period *t* [vehicle kilometre]
$tkm_{t,i,j,c,m}$	Freight mobility between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* [tonne-kilometre]
$share^{dist}_{t,ci,i,j,m}$	Share of freight mobility between origin *i* and destination *j* the share is derived from ETISplus based on the impedances and chain routes for mode *m* taking place in country *ci* in time period *t* [%]
$load_{t,c,m}$	Average freight load factor for mode *m* and commodity type *c* in time period *t* [tonnes/vehicle]
$cap_{t,c,m}$	Loading capacity for commodity *c* and mode *m* in time period *t* [tonnes/vehicle].

3.5.3 Elasticities

Explicit elasticities

The Freight demand module does not include any explicit elasticities.

Model variables

Table 22 summarises the model variables (or policy levers) in the Freight Demand module that are relevant for the policy measures that may affect freight transport demand.

Table 22: Relevant model variables in the Freight Demand module

Policy lever	Description	Dimensions	Equation	Name in database
cr^{fix}	Fixed cost [EUR/vehicle-hour]	time period *t*, mode *m*, commodity type *c*	83	p_fd_fix_cost
cr^{var}	Variable cost [EUR/vkm]	time period *t*, mode *m*, commodity type *c*	84	p_fd_var_cost
load	Average freight load factor [tonnes/vehicle]	time period *t*, mode *m*, commodity type *c*	87	p_fd_load_factor
cap	Loading capacity [tonnes/vehicle]	time period *t*, mode *m*, commodity type *c*	87	p_fd_load_capacity
$cost^{toll}$	Toll cost rate [EUR/vkm]	time period *t*, mode *m*, commodity type *c*	85	i_fd_toll_cost
$time^{load}$	Loading time [hour]	time period *t*, mode *m*, commodity type *c*	87	p_fd_load_time
$time^{unload}$	Unloading time [hour]	time period *t*, mode *m*, commodity type *c*	87	p_fd_unload_time
$time^{wait}$	Waiting time [hour]	time period *t*, mode *m*, commodity type *c*	87	p_fd_wait_time
v	Speed [kilometre/hour]	time period *t*, mode *m*, commodity type *c*	83	p_fd_speed

3.6 Vehicle Stock Module

3.6.1 Description

The main task of the Vehicle Stock module is to convert passenger and freight demand into the vehicle fleet size. This fleet size is disaggregated by vehicle type *vt* and vehicle age cohort *ac*, which is important for emission and energy use calculations. The adopted classification of vehicle types is shown in Table 23 (for road modes) and Table 24 (for non-road modes) and is based on both propulsion and fuel type, as well as on vehicle size. In total, the Vehicle Stock module covers 61 road mode vehicle types (Table 23) and 12 non-road mode vehicle types (Table 24). In principle, we base our vehicle type segmentation on TRACCS project database. We base also our segmentation on TREMOVE and MOVEET models, especially in the area where TRACCS database segmentations are more aggregated, namely in non-road modes. Age cohorts cover a period of one year and the considered cohorts range from 0 to 29 year old vehicles.

The results of the fleet stock calculations are provided per zone *i* (at NUTS-2 level for EU28 countries) and for each time period *t* (in 5-year intervals) within the time horizon. Apart from fleet stock forecasts, the Vehicle Stock module also delivers forecasts of average fixed and variable generalised costs for each transport vehicle type *vt* as well as total tax revenues per country *ci* (NUTS-0 level).

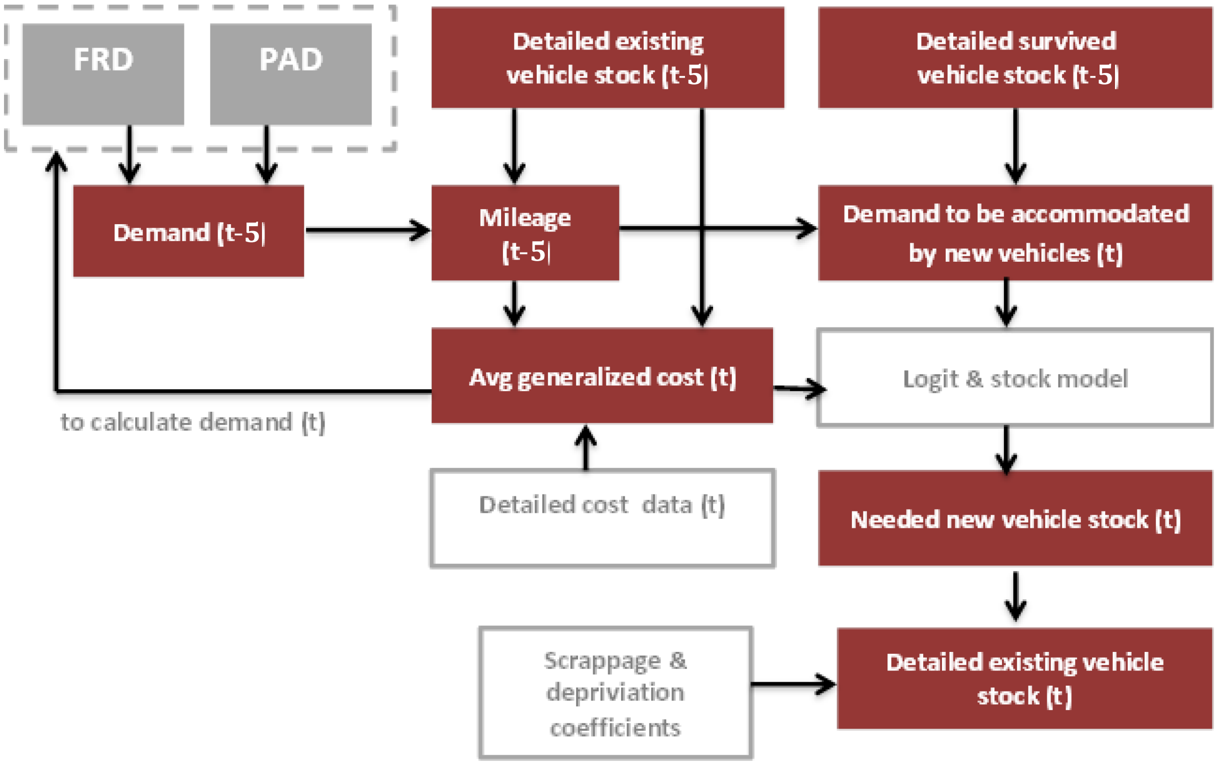

Figure 11: Structure of the Vehicle Stock module

Figure 10 shows the main steps of the Vehicle Stock module and the order in which these steps are performed. The module's main input is transport demand from the previous period, i.e. period (t-5). This 5-year gap is compensated by multiplying this transport demand with a multiplicator. This multiplicator is the ratio between the number of vehicle stock data in 2010 and the number of vehicle stock in 2015 calculated using 2010 transport demand. The drop in 2015 vehicle stock calculated using 2010 transport demand in comparison to 2010 vehicle stock data, makes that the multiplicator is a coefficient with value bigger than 1 (one). The current validated vehicle stock module multiplicator value is 1.12.

Knowing the detailed existing vehicle stock from the same period of (t-5) including the number of survived vehicles from that period, the average mileage in term of the average kilometres per vehicle is calculated. The difference between the demand that can be accommodated by the survived vehicle stock and the demand of (t-5) period furnished as input by the freight and passenger demand modules makes the demand that needs to be accommodated by new vehicles in the t period. The logit and the stock dynamic model inside the Vehicle Stock module use the calculated average generalised costs to define the shares of the different types of new vehicles entering the market as well as their numbers. This calculation produces the detailed existing vehicle stock of the year t.

Table 23 and Table 24 respectively show vehicle types, fuel and/or propulsion technologies taken into consideration in the model. The vehicle stock module concerns not only convensional fuel or propulsion technologies but also new alternative technologies. For example, rechargeable electric powered road vehicles are considered for passenger cars (battery electric vehicles or BEV and plug-in hybrid electric vehicles or HEV), buses (BEV) and light commercial vehicles (BEV). On the other hand, conventional hybrid vehicles, gasoline and diesel based are considered respectively as conventional gasoline and diesel fuels.

It is assumed that there will be a gradual penetration of biofuel additives from 0% in 2005 towards 5.75% in 2010[13] in all petrol and of all diesel fuel consumed by road transport. The biofuel share remains equal to 5.75% up to the end of the simulation period, i.e. the year 2050.

Consideration of the biofuels use in aviation is in line with the European Advanced Biofuels Flightpath: 1.2 million tons of biofuel are assumed to be blended with jet fuel in the simulation year of 2015 and 2 million tons are assumed to be blended in the simulation year 2020 and beyond.

Both assumptions of biofuel use will be treated in term of emissions and will be discussed later on in the environment module (Section 3.7). However it is assumed that this biofuel blend growth has no impact in term of aircraft operating costs and therefore no impact on vehicle stock calculation.

Table 23: Considered road vehicle types

Vehicle type road	Bio-diesel (B30)	CNG/ Bio-gas	Diesel	Gasoline	LPG	BEV	FCEV	LNG	Flexy fuel (E85)
Bus	x	x	x	x				x	
HDV > 3.5 t	x		x					x	
HDV articulated 14–20 t	x		x					x	
HDV articulated 20–28 t	x		x					x	
HDV articulated 28–34 t	x		x					x	
HDV articulated 34–40 t	x		x					x	
HDV articulated 40–50 t	x		x					x	
HDV articulated 50–60 t	x		x					x	
HDV rigid <= 7.5 t	x		x					x	
HDV rigid 7.5–12 t	x		x					x	
HDV rigid 12–14 t	x		x					x	
HDV rigid 14–20 t	x		x					x	

[13] Directive 2003/30/EC of the European Parliament and the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport

Vehicle type road	Bio-diesel (B30)	CNG/ Bio-gas	Diesel	Gasoline	LPG	BEV	FCEV	LNG	Flexy fuel (E85)
HDV rigid 20–26 t	x		x					x	
HDV rigid 26–28 t	x		x					x	
HDV rigid 28–32 t	x		x					x	
HDV rigid > 32 t	x		x					x	
LCV			x					x	
Moped				x					
Motorcycle				x					
Passenger car		x	x	x	x	x	x		x

Table 24: Considered non-road vehicle types

Vehicle type non-road	Electric	Diesel	Jet fuel	LNG	HFO	MDO/MGO
Rail passenger	X	x				
Rail freight	X	x				
Air passenger			x			
Air freight			x			
Sea				x	x	x

The choice between different vehicle types *vt* to enter the market is thereafter estimated by a logit model that basically represents user's choices when purchasing a vehicle. Based on their mobility prediction, or more specifically the generated transport demand of the concerned region, the calculated national fleet stock size is distributed over regions *i* at NUTS-2 level. The distribution over age cohort *ac* is hereby assumed to be constant over the regions of a country.

Subsequently, average generalised costs and tax revenues are calculated. For the calculation of average costs, detailed cost data[14] collected from different sources and stored in the Database is used.

[14] Historical (2005–2010) cost data is mainly taken from the TRACCS database as well as several other existing models' databases such as those of the TREMOVE and MOVEET models. References to these sources can be found in the 'other project sources' section. Future costs (2015–2050) are estimation results of the project.

Table 25: Interaction of the Vehicle Stock module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module(s)	Name in Database
In	vkm^{pas}	Passenger transport mobility [vkm]	time period *t*, origin *i*, destination *j*, purpose *p*, mode *m*	Passenger Demand	o_pd_vkm_od
In	$vkm^{freight}$	Freight transport mobility [vkm]	time period *t*, origin *i*, destination *j*, mode *m*, commodity *c*	Vehicle stock, Environment	o_fd_vkm_od
Out	$cost^{fix}$	Fixed vehicle costs [EUR/vkm]	time period *t*, mode *m,* country *ci*	Passenger Demand	o_vs_cstavggen_fix_vkm, o_vs_cstavggen_fix_pkm
Out	$cost^{var}$	Variable vehicle costs [EUR/vkm]	time period *t*, mode *m,* country *ci*	Passenger Demand	o_vs_cstavggen_var_vkm, o_vs_cstavggen_var_pkm
Out	*stock*	Total number of vehicles	time period t, mode *m,* zone *i*, vehicle type *vt*, age cohort *ac*	Environment	i_vs_veh_stock

The Vehicle Stock module receives mobility predictions from the Passenger and Freight Demand modules. In turn, the average generalised costs that are used to derive these predictions are obtained from the Vehicle Stock module. Furthermore, the calculated vehicle stock is utilised for emission calculations in the Environment model, while the calculated tax revenues are used by the Economy & Resources module. These interactions with other HIGH-TOOL modules are shown in Table 25.

3.6.2 Equations

The Vehicle Stock module utilizes the mobility predicted by the Passenger and Freight Demand modules in order to produce three main results:

- vehicle stock for each vehicle type *vt* and age cohort *ac* at NUTS-2 level
- average generalised costs for each vehicle type at NUTS-0 level, and finally
- total tax revenues at NUTS-0 level.

The considered modes m include passenger road, freight road, passenger rail, freight rail, passenger air, freight air, freight inland waterways, and freight sea. For each of these modes the same procedure is followed; hence, the equations presented in this section apply to all modes.

3.6.2.1 Vehicle stock

The Vehicle Stock module receives the mode-specific mobility between origins *i* and destinations *j* in terms of vehicle-kilometres. The estimates of the Vehicle Stock module are based on the total transport demand originating from countries. To this end, all demand that originates from the same country *ci* is aggregated. Passenger mobility ($vkm_{t,ci,m}$) is thus calculated as follows:

$$vkm_{t,ci,m} = \sum_{i \in ci} \sum_{j} \sum_{p} (vkm^{pas}_{t,i,j,p,m}) \qquad \text{(equation 107)}$$

For freight modes the equation is similar:

$$vkm_{t,ci,m} = \sum_{i \in ci} \sum_{j} \sum_{c} (vkm^{freight}_{t,i,j,c,m}) \qquad \text{(equation 108)}$$

Where:

$vkm_{t,ci,m}$	Mobility of mode *m* originating from country *ci* in time period *t* [vehicle-kilometre]
$vkm^{pas}_{t,i,j,p,m}$	Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [vehicle-kilometre]
$vkm^{freight}_{t,i,j,c,m}$	Predicted freight mobility between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* [vehicle-kilometre].

Surviving vehicle stock

Next, the number of non-new vehicles of each vehicle type *vt* and (vehicle) age cohort *ac* is calculated by multiplying the previous year's number of vehicles in each age cohort by two parameters: the scrappage rate and the depreciation rate. As the model calculation is performed in 5-year interval, the new vehicles to enter the market are vehicles that belong to age cohort 0 (zero) to 4 year-old (age cohort *ac*<5).

The total number of vehicles ($stock_{t,ci,m,vt,ac>0}$) remaining from the previous time period *(t-5)* is calculated as:

$$stock_{t,ci,m,vt,ac>4} = stock_{t,ci,m,vt,ac-5} \cdot scrap_{ci,m,ac} \cdot dep_{ci,m,ac} \qquad \text{(equation 109)}$$

Where:

$stock_{t,ci,m,vt,ac>4}$	The number of surviving vehicles (*ac>4*) of mode *m* of vehicle type *vt* in country *ci* in age cohort *ac* and time period *t* [vehicles]
$scrap_{ci,m,ac}$	(Non-)scrappage rate of mode *m* in country *ci* for vehicles in age cohort *ac* [%]
$dep_{ci,m,ac}$	(Non-)depreciation rate of mode *m* in country *ci* for vehicles in age cohort *ac* [%].

New vehicle stock

The difference between the total predicted mobility and the amount of transport demand that can be accommodated by the non-new vehicles (surviving from time period *t-5*) yields the transport demand that is to be accommodated by new vehicles (to be introduced to the market in time period *t*). The demand that can be accommodated by surviving vehicles is calculated by multiplying the vehicle stock in each age cohort *ac* by the average number of kilometres (mileage) per vehicle in this age cohort in time period *t-5*, and taking the sum over all age cohorts. Subsequently, the demand that has to be facilitated by new vehicles is divided by the average number of kilometres of new vehicles in time period *t-5* in order to obtain the number of new vehicles that is needed in time period *t*. The number of new vehicles ($stock_{t,ci,m,ac<5}$) is thus calculated as:

$$stock_{t,ci,m,ac<5} = \frac{vkm_{t,ci,m,ac<5}}{\left(\frac{vkm_{t-5,ci,m,ac<5}}{\sum_{vt\in VT_m}(stock_{t-5,ci,m,vt,ac<5})}\right)} \quad \textit{(equation 110)}$$

In which:

$$vkm_{t,ci,m,ac<5} = vkm_{t,ci,m} - \sum_{ac}\left(\frac{vkm_{t-5,ci,m,ac>4}}{\sum_{vt\in VT_m} stock_{t-5,ci,m,vt,ac>4}} \cdot \sum_{vt\in VT_m}(stock_{t,ci,m,vt,ac>4})\right)$$

(equation 111)

Where:

$stock_{t,ci,m,ac<5}$	Number of new vehicles (*ac<5*) of mode *m* that is needed in country *ci* in time period *t* [vehicles]
$vkm_{t,ci,m,ac<5}$	Mobility to be accommodated by new vehicles (*ac<5*) originating from country *ci* by mode *m* in time period *t* [vehicle-kilometre]

$stock_{t,ci,m,vt,ac>4}$	The number of surviving vehicles (*ac>40*) of mode *m* and vehicle type *vt* in age cohort *ac*, country *ci* and time period *t* [vehicles]
$vkm_{t,ci,m,ac>4}$	Mobility of old vehicles (*ac>4*) originating from country *ci* by mode *m* in time period *t* [vehicle-kilometre]
VT_m	The set of all considered vehicle types for mode *m*.

Vehicle types

The total amount of new vehicles is then shared out among the different vehicle types *vt* according to the previous year's fleet structure and the unit costs per vehicle modulated by a mode-dependent cost elasticity. The calculation of unit costs per vehicle is described in the next section. Vehicle type shares of newly purchases vehicles ($P_{t,ci,m,vt,ac<5}$) are calculated as:

$$P^{veh}_{t,ci,m,vt,ac<5} = \frac{(stock_{t-5,ci,m,vt} \cdot e^{cost^{tot}_{t,ci,vt}{}^{e^{cost}_{ci,vt}}})}{\sum_{vt\epsilon VT_m}(stock_{t-5,ci,m,vt} \cdot e^{cost^{tot}_{t,ci,vt}{}^{e^{cost}_{ci,vt}}})} \qquad \textit{(equation 112)}$$

Where:

$P^{veh}_{t,ci,m,vt,ac<5}$	The share of new vehicles (*ac<5*) of mode *m* and vehicle type *vt* in country *ci* in time period *t* [%]
$stock_{t,ci,m,vt}$	The number of vehicles of mode *m* and vehicle type *vt* in country *ci* and time period *t* [vehicles]
$cost^{tot}_{t,ci,vt}$	Total costs for vehicle type *vt* in country *ci* and time period *t* [EUR/vehicle-kilometre]
$e^{cost}_{ci,vt}$	Model parameter referring to the cost elasticity of vehicle purchase for vehicle of mode *m* and type *vt* in country *ci* [%]
VT_m	The set of all considered road vehicle types for mode *m*.

The values of the elasticity parameters are taken from the MOVEET model. These values have been calibrated to the Baseline scenario of the PRIMES Energy model in combination with the EUROSTAT transport statistics database "EU Energy and Transport in figures, statistical pocketbook 2009" and TREMOVE v3.1.1 used in the iTREN-2030 project. The combination of these three sources was necessary as no single source could be used to cover all the modes provided by MOVEET. Concerning road transport vehicles, elasticities are taken from the TRACCS database.

These values are calibrated against TRACCS historical data between 2005 and 2010. The number of new vehicles ($stock_{t,ci,m,vt,ac<5}$) for each vehicle type vt is thereafter obtained by multiplying the total number of new vehicles by the share of each vehicle type:

$$stock_{t,ci,m,vt,ac<5} = P^{veh}_{t,ci,m,vt,ac<5} \cdot stock_{t,ci,m,ac<5}$$ *(equation 113)*

Where:

$stock_{t,ci,m,vt,ac<5}$ Number of new vehicles (*ac<5*) of mode m and vehicle type vt that is purchased in country ci in time period t [vehicles]

$P^{veh}_{t,ci,m,vt,ac<5}$ The share of new vehicles (*ac<5*) of mode m and vehicle type vt in country ci in time period t [%]

$stock_{t,ci,m,ac<5}$ Number of new vehicles (*ac<5*) of mode m that is needed in country ci in time period t [vehicles].

Conversion

The total number of vehicles per vehicle type vt at country (NUTS-0) level ($stock_{t,ci,m,vt}$) is calculated by summing up the total number of vehicles of all 29 age cohorts as given below:

$$stock_{t,ci,m,vt} = \sum_{ac}(stock_{t,ci,m,vt,ac})$$ *(equation 114)*

Where:

$stock_{t,ci,m,vt}$ Number of vehicles of mode m and vehicle type vt in country ci in time period t [vehicles]

$stock_{t,ci,m,vt,ac}$ Number of vehicles of mode m and vehicle type vt in age cohort ac, country ci and time period t [vehicles].

Subsequently, the total number of vehicles at NUTS-2 level is calculated by multiplying the total number of vehicles at NUTS-0 level by a share coefficient for each NUTS-2 region. These share coefficients are equal to the demand shares of regions at country level (in vehicle-kilometres).

The number of vehicles ($stock_{t,i,m,vt}$) per region *i* and vehicle type *vt* is thus:

$$stock_{t,i,m,vt} = stock_{t,ci,m,vt} \cdot \frac{vkm_{t,i,m}}{vkm_{t,ci\ni i,m}} \qquad \text{(equation 115)}$$

Where:

$stock_{t,i,m,vt}$ Number of vehicles of mode *m* and vehicle type *vt* in zone *i* in time period *t* [vehicles]

$stock_{t,ci,m,vt}$ Number of vehicles of mode *m* and vehicle type *vt* in country *ci* in time period *t* [vehicles]

$vkm_{t,i,m}$ Mobility of mode *m* originating from zone *i* in time period *t* [vehicle-kilometre]

$vkm_{t,ci,m}$ Mobility of mode *m* originating from country *ci* in time period *t* [vehicle-kilometre].

Finally, the number of vehicles ($stock_{t,i,m,vt,ac}$) at NUTS-2 level by age cohort *ac* is calculated as follows:

$$stock_{t,i,m,vt,ac} = stock_{t,i,m,vt} \cdot \frac{stock_{t,ci,m,vt,ac}}{\sum_{ac}(stock_{t,ci,m,vt,ac})} \qquad \text{(equation 116)}$$

Where:

$stock_{t,i,m,vt,ac}$ Number of vehicles of mode *m* and vehicle type *vt* in age cohort *ac*, zone *i*, and time period *t* [vehicles]

$stock_{t,i,m,vt}$ Number of vehicles of mode *m* and vehicle type *vt* in zone *i* in time period *t* [vehicles]

$stock_{t,ci,m,vt,ac}$ Number of vehicles of mode *m* and vehicle type *vt* in age cohort *ac*, country *ci*, and time period *t* [vehicles].

3.6.2.2 Average generalised costs

The second output of the Vehicle Stock module yields the average variable and fixed costs for each vehicle type *vt*. Table 26 provides an overview of all cost components that are considered, grouped into fixed and variable costs. For each country *ci* and vehicle type *vt* values of these cost components are stored in the Database.

Table 26: Variable and fixed vehicle cost components

Cost component	Short description	Unit	Cost type
i_vs_cap_rail_capc	Average rail vehicle purchase price	EUR/vehicle	fixed
i_vs_nf_rail_crec	Crew costs of passenger and freight rail transport	EUR/hour	variable
i_vs_nf_rail_damc	Damage load cost for rail transport	EUR/vehicle	variable
i_vs_nf_rail_othc	Other costs for rail passenger and freight transport	EUR/tkm	variable
i_vs_nf_rail_repmaintc	Service, repair and maintenance costs of rail vehicles	EUR/vkm	variable
i_vs_cap_rpcs	Average road vehicle purchase price without VAT	EUR/vehicle	fixed
i_vs_cap_rpcs_mkt	Average road vehicle purchase price with VAT	EUR/vehicle	fixed
i_vs_cap_rpcs_vat	Road vehicle purchase VAT	%	fixed
i_vs_cap_tech	Technology related additional capital cost	EUR/vehicle	fixed
i_vs_nf_cstinsu	Insurance costs for road transport	EUR/tkm	variable
i_vs_cap_subsidy	State subsidy to buy cleaner car	EUR/vehicle	fixed
I_vs_cap_scrap_subs	State subsidy to scrap old dirty car	EUR/vehicle	fixed
i_vs_nf_road_repmaintc	Repair and maintenance costs of road vehicles	EUR/vkm	fixed
i_vs_nf_rof_cst_labo	Labour cost for freight road transport	EUR/tkm	variable
i_vs_nf_rof_cst_othr	Other non-fuel operational costs for freight road transport	EUR/tkm	variable
i_vs_nf_rof_cst_time	Non fuel operational time cost for road transport	EUR/tkm	variable
i_vs_nf_taxinsu	Insurance tax for road transport	EUR/vehicle	fixed
i_vs_nf_taxown	Ownership tax for road transport	EUR/vehicle	fixed
i_vs_nf_taxregs	Registration tax for road transport	EUR/vehicle	fixed
i_vs_cstiww	Freight inland water ways prices	EUR/tkm	variable
i_vs_fu_ct	Carbon tax	EUR/tonne CO_2	variable
i_vs_fu_fuel_g	Fuel costs per gram of fuel	EUR/gram fuel	variable
i_vs_fu_fuel_l	Fuel costs per litre of fuel	EUR/litre fuel	variable
i_vs_fu_fuel_resource_toe	Fuel resource cost in EUR per toe	EUR/tonne of oil equivalent	variable
i_vs_fu_fuel_vat	Fuel value added tax (VAT) in %	%	variable
i_vs_fu_energy_tax	Energy tax part in total fuel cost	EUR/1000 litre	variable
i_vs_cap_mar_capc	Maritime capital cost	EUR/vehicle	fixed
i_vs_nf_air_neoe	Non energy related variable air transport costs	EUR/pkm	variable
i_vs_nf_mar_chcost	Cargo handling cost for maritime transport	EUR/vehicle	fixed

Cost component	Short description	Unit	Cost type
i_vs_nf_mar_oi_vcost	Other voyage cost for maritime transport	EUR/vehicle	fixed
i_vs_nf_mar_oi_othvcost	Other voyage cost for maritime transport, annual: Port and light dues, tugs and pilotage, canal dues	EUR/vehicle	fixed
i_vs_nf_mar_opcost	Non fuel operating cost for maritime transport	EUR/vehicle	fixed
i_vs_nf_mar_repmaintc	Repair and maintenance costs of maritime vehicles	EUR/vehicle	fixed

As mentioned in the previous section, the Vehicle Stock module uses average unit costs at vehicle type level in the logit equation to calculate the shares of vehicle types in the total number of newly purchased vehicles. For a given vehicle type *vt*, the average fixed and variable unit cost is obtained by summing up all corresponding cost components *cc* from Table 26 within each cost type category (fixed and variable). The total costs ($cost_{t,ci,vt}^{tot}$) are then calculated as the sum of the fixed and variable costs:

$$cost_{t,ci,vt}^{tot} = cost_{t,ci,vt}^{fix} + cost_{t,ci,vt}^{var} \qquad \text{(equation 117)}$$

In which:

$$cost_{t,ci,vt}^{fix} = \sum_{cc \in XF} (c_{t,ci,vt}^{cc}) \qquad \text{(equation 118)}$$

$$cost_{t,ci,vt}^{var} = \sum_{cc \in XV} (c_{t,ci,vt}^{cc}) \qquad \text{(equation 119)}$$

Where:

$cost_{t,ci,vt}^{tot}$	Total costs for vehicle type *vt* in country *ci* and time period *t* [EUR/vehicle-kilometre]
$cost_{t,ci,vt}^{fix}$	Fixed costs for vehicle type *vt* in country *ci* and time period *t* [EUR/vehicle-kilometre]
$cost_{t,ci,vt}^{var}$	Variable costs for vehicle type *vt* in country *ci* and time period *t* [EUR/vehicle-kilometre]
$c_{t,ci,vt}^{cc}$	Cost component *cc* for vehicle type *vt* in country *ci* [EUR/vehicle-kilometre]
XF	Set of fixed cost components
XV	Set of variable cost components.

However, before doing so, those cost elements having units other than EUR/vehicle-kilometre need to be converted. For this purpose, the following variables are applied:

$occ_{m,ci}$	Average passenger occupancy rate for mode *m* in country *ci* [passenger/vehicle]
$load_{m,ci}$	Average freight load factor for mode *m* in country *ci* [%]
$hours_{ci}^{rail}$	Working hours per year for rail transport in country *ci* [hours]
$fuel_{vt}^{equi}$	Tonnes of oil equivalent fuel per litre of fuel for vehicle type *vt* [tonne/litre]
$fuel_{vt}^{econ}$	Fuel efficiency in terms of litre per 100 kilometres for vehicle type *vt* [litre/100 kilometre].

Having the different variable and fixed vehicle cost components (Table 26) as inputs means the possibility of developing different scenarios based on variation of these cost components. For example implementation of carbon tax will affect the average generalised cost of some carbon intensive fuel and vehicle types and thereby affecting the shares of the different new vehicle types and fuels entering the market and therefore varying the vehicle stock structure in comparison to the Reference scenario.

3.6.2.3 Tax revenues

Finally, the module delivers the total tax revenues at country level (NUTS-0) to be used as input by the Economy & Resources module. These revenues are calculated by multiplying the transport demand (in vehicle-kilometre) by the tax costs (in EUR/vehicle-kilometre) and taking the sum of all tax components *tc* and vehicle types *vt*. Considered tax elements are carbon tax, fuel value added tax (VAT), car purchase VAT, energy tax part in total fuel costs, non-fuel operational fuel tax for freight road transport, insurance tax for road transport, ownership tax for road transport, and registration tax for road transport.

Tolls and vignette are nevertheless not covered in the calculation of tax revenues as these operating components are calculated in the freight demand module. Whenever possible, we take also into consideration country specific rates, namely in relation to all road modes, to vehicle capital (purchase) costs, and to all fuel related costs. The total tax ($tax_{t,ci}$) is calculated as:

$$tax_{t,ci} = \sum_{vt}(vkm_{t,ci,vt} \cdot \sum_{tc}(tax_{t,ci,vt}^{tc})) \qquad \textit{(equation 120)}$$

Where:

$tax_{t,ci}$	Tax revenues for country ci in time period t [EUR]
$vkm_{t,ci,vt}$	Mobility by vehicle type vt in country ci and time period t [vehicle-kilometre]
$tax_{t,ci,vt}^{tc}$	Tax value of tax component tc for vehicle type vt in country ci and time period t [EUR/vehicle-kilometre].

3.6.3 Elasticities

Explicit elasticities

The Vehicle Stock module does not include any explicit elasticities.

Model variables

In addition to the elasticities, there are several other model variables which are presented in Table 27. These are the policy levers of the Vehicle Stock module that are used to assess transport policy measures in HIGH-TOOL.

Table 27: Model variables in the Vehicle Stock module

Policy lever	**Description**	**Dimensions**	**Equation**
i_vs_nf_rail_othc	Other costs for rail passenger and freight demand [EUR/tonne-kilometre]	vehicle type *vt*	117
*i_vs_fu*_exduty_eur_1000ll	Fuel costs [EUR/1000 litre]	vehicle type *vt*	117
i_vs_nf_rof_cst_othr	Other non-fuel operational costs for freight road transport [EUR/tonne-kilometre]	vehicle type *vt*	117
i_vs_cap_rpcs	Average road vehicle purchase price without VAT [EUR/vehicle]	vehicle type *vt*	117
i_vs_cap_tech	Technology related additional capital costs [EUR/vehicle]	vehicle type *vt*	117
i_vs_nf_taxfuel	Energy tax part in total fuel costs	vehicle type *vt*	117
i_vs_nf_mar_opcost	Non-fuel operating cost for maritime transport [EUR/vehicle]	vehicle type *vt*	117
i_vs_cstiww	Freight inland water ways prices [EUR/tonne-kilometre]	vehicle type *vt*	117
i_vs_nf_rof_cstlabo	Labour costs for freight road transport [EUR/tonne-kilometre]	vehicle type *vt*	117
i_vs_nf_cstinsu	Insurance costs for road transport [EUR/tonne-kilometre]	vehicle type *vt*	117

Policy lever	Description	Dimensions	Equation
i_vs_cap_rail_capc	Average rail vehicle purchase price [EUR/vehicle)	vehicle type *vt*	117
i_vs_nf_air_neoe	Non-energy related variable air transport costs [EUR/pkme]	vehicle type *vt*	117

3.7 Environment Module

3.7.1 Description

The main task of the Environment module is to calculate wheel-to-tank (wtt) fuel consumption and emissions for each vehicle type *vt* for each 5 year interval period. Fuel consumption or fuel intensity and emission factors or emisision index are the key input variables in this calculation. These factors are distinguished into technologies which are represented in the model by the age-cohort or vintage. This way, a policy like CO_2 standard or other policies such as Euro standards that put limit for certain pollutants can be applied by defining the emission (or fuel consumption) factors of the new vehicles or vehicles of 0 (zero) to 4 year-old, entering the market in a particular point in time (year) concerned by the policy. In this module, it is assumed that 100% of the average new vehicles entering the market at a given point in time in EU28 will comply with the standard. The current baseline values of the emission and fuel consumption factors of the different types of new vehicles entering the market at a given time have been obtained through two different ways. First for the base year 2010, detailed new vehicle stock data from TRACCS database and estimates of emission and fuel consumption factors of new vehicles that come mostly from TREMOVE and MOVEET, have been used to calculate the average new vehicles emission and fuel consumption factors which are calibrated to the EU Reference Scenario 2013 results for the same year (2010). From this process, the allocation of the emission and fuel consumption factors of the different types of the new vehicles entering the market in 2010 is obtained. Second, for the following simulation period, i.e. beyond 2010, the current emission and consumption factors have been allocated through the calibration process with regards to the total emission and fuel consumption results of the EU Reference Scenario 2013. Apart from the EU Reference 2013 values used as benchmarks, taken into account in this calibration process are the endogenously calculated vehicle stock of the different types and age (technology) cohorts performed by the vehicle stock module and the policies implemented during the simulation period, e.g. Regulation (EC) 442/2009 and 510/2011 for cars and LCVs.

Depending on the modes, the module produces estimates for CO_2 emissions as well as five other pollutants, i.e. CO, VOC, NO_x, SO_2 and $PM_{2.5}$. Fuel consumption and emissions are calculated per origin country *ci* (NUTS-0 level). The Environment module receives input from the Passenger and Freight Demand modules (mobility) and from the Vehicle Stock module (fleet size). Table 32 shows these interactions with other HIGH-TOOL modules.

Table 28: Interaction of the Environment module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module(s)	Name in Database
In	vkm^{pas}	Passenger transport mobility [vkm]	time period *t*, origin *i*, mode *m*, destination *j*, purpose *p*	Passenger Demand	o_pd_vkm_od
In	$vkm^{freight}$	Freight transport mobility [vkm]	time period *t*, origin *i*, mode *m*, destination *j*, commodity *c*	Freight Demand	o_fd_vkm_od
In	*stock*	Total number of vehicles [vehicles]	time period *t*, zone *i*, mode *m*, vehicle type *vt*, age cohort *ac*	Vehicle Stock	i_vs_veh_stock

The Environment module has two main parts. First, the predicted transport demand is disaggregated by vehicle type *vt* and origin country *ci*. Secondly, fuel consumption and emissions are derived. The following section on equations explains how both parts are performed.

3.7.2 Equations

3.7.2.1 Disaggregation of transport demand

Results of the Environment module are presented per country *ci*. To this end, all demand that originates from the same country *ci* is aggregated. Furthermore, no distinction among purposes *p* is made. Passenger and freight mobility ($vkm_{t,ci,m}$) is thus calculated as:

$$vkm_{t,ci,m} = \sum_{i \in ci} \sum_j \sum_p (vkm^{pas}_{t,i,j,p,m}) \quad \textit{(equation 121)}$$

Similarly for freight modes:

$$vkm_{t,ci,m} = \sum_{i \in ci} \sum_j \sum_c (vkm^{freight}_{t,i,j,c,m}) \quad \textit{(equation 122)}$$

Where:

$vkm_{t,ci,m}$ Mobility of mode *m* originating from country *ci* in time period *t* [vehicle-kilometre]

$vkm^{pas}_{t,i,j,p,m}$ Predicted passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [vehicle-kilometre]

$vkm^{freight}_{t,i,j,c,m}$ Predicted freight mobility between origin *i* and destination *j* for mode *m* and commodity type *c* in time period *t* [vehicle-kilometre].

Thereafter, a disaggregation by vehicle type *vt* is made based on the fleet size of each vehicle type. This mobility ($vkm_{t,ci,vt}$) by vehicle type is:

$$vkm_{t,ci,vt} = vkm_{t,ci,m} \cdot \frac{stockt_{t,ci,m,vt}}{\sum_{vt \in VT_m}(stock_{t,ci,m,vt})} \qquad \textit{(equation 123)}$$

Where:

$vkm_{t,ci,vt}$ Mobility of vehicle type *vt* originating from country *ci* in time period *t* [vehicle-kilometre]

$vkm_{t,ci,m}$ Mobility of mode *m* originating from country *ci* in time period *t* [vehicle-kilometre]

$stock_{t,ci,m,vt}$ Number of vehicles of mode *m* and vehicle type *vt* in country *ci* in time period *t* [vehicles]

VT_m The set of all considered vehicle types for mode *m*.

3.7.2.2 Fuel consumption and emissions

The following paragraphs explain how fuel consumption and emission calculation are basically performed for each transport mode.

Rail transport

The national energy consumption by country *ci* and vehicle type *vt* is the result of an age cohort based aggregation. For each age cohort *ac* the average fuel intensities are multiplied by the performance of the rail vehicles and the corresponding vehicle stock. Herein, load factors are used to make a conversion from vehicles to tonnes of freight. The total fuel consumption ($fuel_{t,ci,m=rf,vt}$) is now calculated by taking the summation over all age cohorts *ac*:

$$fuel_{t,ci,m=rf,vt} = \frac{\sum_{ac=0}^{29}(stock_{t,ci,m=rf,vt,ac} \cdot \left(\frac{vkm_{t,ci,m=rf}}{stock_{t,ci,m=rf}}\right) \cdot load_{t,m=rf} \cdot int_{vt,ac}^{fuel})}{10^6}$$ *(equation 124)*

Where:

$fuel_{t,ci,m=rf,vt}$ Energy consumption of freight rail transport (*m=rf*) by vehicle type *vt* in country *ci* in time period *t* [million tonnes of oil equivalent]

$stock_{t,ci,m=rf,vt,ac}$ The number of rail freight (*m=rf*) vehicles of vehicle type *vt* in age cohort *ac*, country *ci*, and time period *t* [vehicles]

$vkm_{t,ci,m=rf}$ Rail freight (*m=rf*) mobility in country *ci* in time period *t* [vehicle-kilometre]

$stock_{t,ci,m=rf}$ The number of rail freight (*m=rf*) vehicles in country *ci* in time period *t* [vehicles]

$load_{t,m=rf}$ Average freight load factor for mode *m* and commodity type *c* in time period *t* [%]

$int_{vt,ac}^{fuel}$ Fuel intensity of rail freight transport vehicle of type *vt* in age cohort *ac* [tonnes of oil equivalent/vehicle-kilometre].

For passenger rail, the calculation of energy consumption is similar, except that fuel intensities are given in terms of tonnes of oil equivalent/passenger-kilometre. Hence, instead of the load rate, an occupation factor ($occ_{t,m}$) is applied (average passenger occupancy rate for mode *m* in time period *t* [passengers/vehicle]). Emissions ($emm_{t,ci,m=rf,vt}^{et}$) are calculated by multiplying the fuel consumption per vehicle type with the emission index (e.g. carbon content) of the corresponding fuel:

$$emm_{t,ci,m=rf,vt}^{et} = fuel_{t,ci,m=rf,vt} \cdot ind_{vt}^{et}$$ *(equation 125)*

Where:

$emm_{t,ci,m=rf,vt}^{et}$ Emissions of type *et* of freight rail transport (*m=rf*) by vehicle type *vt* in country *ci* and time period *t* [million tonnes]

$fuel_{t,ci,m=rf,vt}$ Energy consumption of freight rail transport vehicles of vehicle type *vt* in country *ci* in time period *t* [million tonnes of oil equivalent]

ind_{vt}^{et} Emission index of fuel related to vehicle type *vt* [tonne/tonnes of oil equivalent].

Air transport

Jet fuel consumption per vehicle type *vt* results from combining aircraft usage with the average fuel consumption by age cohort *ac*. Herein, the aircraft utilization results from dividing the total number of predicted vehicle-kilometre by the average speed of aircrafts. In equational form the fuel consumption ($fuel_{t,ci,m=air,vt}$) is:

$$fuel_{t,ci,m=air,vt} = fh_{t,ci,vt} \cdot den^{jet} \cdot \frac{\sum_{age}\left(stock_{t,ci,vt,ac} \cdot int_{vt,ac}^{fuel}\right)}{\sum_{age}(stock_{t,ci,vt,ac})} \qquad \textit{(equation 126)}$$

In which:

$$fh_{t,ci,vt} = \frac{vkm_{t,ci,vt}}{\bar{v}_{vt}} \qquad \textit{(equation 127)}$$

Where:

$fuel_{t,ci,m=air,vt}$	Energy consumption of planes (*m=air*) of vehicle type *vt* in country *ci* in time period *t* [kilogram]
$fh_{t,ci,vt}$	Aircraft usage in country *ci* for vehicle type *vt* in time period *t* [hours];
den^{jet}	Jet fuel density [kilogram/litre]
$stock_{t,ci,vt,ac}$	Number of vehicles in country ci of vehicle type *vt* in age cohort *ac* and time period *t* [vehicles]
$int_{vt,ac}^{fuel}$	Fuel intensity of planes of type *vt* in age cohort *ac* [litre/hour]
$vkm_{t,ci,vt}$	Mobility in country *ci* of airplanes of vehicle type *vt* in time period *t* [vehicle-kilometre]
$\bar{v}_{vt}$	Average speed of air planes of vehicle type *vt* [kilometre/hour].

The pollutants considered by the model are CO_2, SO_2, NO_X, and CO. Emissions of CO_2, and SO_2 are proportional to fuel consumption, while emissions of NO_X, and CO also depend on flight altitude and other operational conditions. To this end, two different emission indexes are considered (Sutkus et al., 2001, 2003), corresponding to the climb and descent stages (which take place between ground level and nine kilometre of altitude) and the cruising phase (between the nine and 13 kilometre level). The share of each part of the total emission is given by the distance percentage of each part. Emissions ($emm_{t,i,m=air,vt}^{et}$) are thus calculated as:

$$emm_{t,ci,m=air,vt}^{co2} = fuel_{t,ci,m=air,vt} \cdot ind_{vt}^{co_2}$$ *(equation 128)*

$$emm_{t,ci,m=air,vt}^{so2} = fuel_{t,ci,m=air,vt} \cdot ind_{vt}^{so_2}$$ *(equation 129)*

$$emm_{t,ci,m=air,vt}^{no_x} = fuel_{t,ci,m=air,vt} \cdot (pct^{climb} \cdot ind_{vt}^{climb,no_x} + (1 - pct) \cdot ind_{vt}^{cruise,no_x})$$

(equation 130)

$$emm_{t,ci,m=air,vt}^{co} = fuel_{t,ci,m=air,vt} \cdot (pct^{climb} \cdot ind_{vt}^{climb,co} + (1 - pct) \cdot ind_{vt}^{cruise,co})$$

(equation 131)

Where:

$emm_{t,ci,m=air,vt}^{et}$	Emissions of type *et* of air transport (*m=air*) by vehicle type *vt* in country *ci* and time period *t* [million tonnes]
$fuel_{t,ci,m=air,vt}$	Energy consumption of planes (*m=air*) of type *vt* in country *ci* in time period *t* [kg fuel/year]
ind_{vt}^{et}	Emission index of fuel related to vehicle type *vt* and emission type *et* [gram/kg fuel]
pct^{climb}	Distance percentage of climb and descent phase [%].

Sea transport

The total 5-yearly demand of bunker fuels by vessel class is obtained by multiplying the average bunker consumption by the ratio between the active fleet and the average ship tonnage. The active fleet by age cohort *ac* and vehicle type *vt* is the result of subtracting the initial amount of vessels laid-up for storage (modified according to changes in freight rates) from the total fleet size. The fuel consumption ($fuel_{t,i,m=sea,vt}$) is:

$$fuel_{t,ci,m=sea,vt} = \sum_{ac}\left(365 \cdot int_{vt,ac}^{fuel} \cdot \frac{stock_{t,ci,vt,ac}^{act}}{\overline{wgth_{vt,ac}}}\right)$$ *(equation 132)*

In which:

$$stock^{act}_{t,ci,vt,ac} = stock_{t,ci,vt,ac} \cdot \left(1 - \frac{stock^{store}_{t,ci,vt,ac}}{rate_{vt}}\right) \quad \textit{(equation 133)}$$

Where:

$fuel_{t,ci,m=sea,vt}$	Energy consumption of ships (*m=ship*) of type *vt* in country *ci* in time period *t* [million tonne fuel/year]
$stock^{act}_{t,ci,vt,ac}$	Number of active vehicles in country *ci* of vehicle type *vt* in age cohort *ac* and time period *t*
$int^{fuel}_{vt,ac}$	Fuel intensity of ships of type *vt* in age cohort *ac* [tonne/day/ship]
$wgth_{vt,ca}$	Average ship tonnage for vehicle type *vt* in time period *t* [tonnes]
$stock^{act}_{t,ci,vt,ac}$	Number of vehicles in country *ci* of vehicle type *vt* in age cohort *ac* and time period *t* [vehicles]
$stock^{store}_{t,ci,vt,ac}$	Initial number of vessels of vehicle type *vt* in age cohort *ac* laid up in storage in country *ci* and time period *t* [vehicles]
$rate_{vt}$	Freight rates of vehicle type *vt* [%].

CO_2 emissions ($emm^{co2}_{t,ci,m=ship,vt}$) by vessel class is the result of multiplying marine bunker consumption by the corresponding emission factor:

$$emm^{co2}_{t,ci,m=ship,vt} = fuel_{t,ci,m=ship,vt} \cdot ind^{co_2}_{vt} \quad \textit{(equation 134)}$$

Where:

$emm^{et}_{t,ci,m=ship,vt}$	Emissions of type *et* of sea transport (*m=sea*) by vehicle type *vt* in country *ci* and time period *t* [million tonnes]
$fuel_{t,ci,m=ship,vt}$	Energy consumption of planes (*m=sea*) of type *vt* in country *ci* in time period *t* [kg fuel/year]
ind^{et}_{vt}	Emission index of fuel related to vehicle type *vt* and emission *et* [kilogram/tonne fuel].

The fuel consumption for air and maritime transport of the year 2010 is calibrated based on Eurostat energy balance. EEA results of CO_2 emission are also compared to the check the calculated calculated CO_2 emission for both modes.

If the calculated CO_2 emission whose fuel consumption are calibrated with the Eurostat energy balance differs from those figures in EEA results, the Eurostat energy balance based calculation is used and the differences are reported in the validation report.

Road transport

The approach implemented in road transport fuel consumption and emission calculation is slightly different in comparison to that in other modes. In road transport fuel consumption and emission factors both in term of grams of fuel or pollutant per vehicle-kilometre is used instead of fuel intensity ($int_{vt,ac}^{fuel}$) in toe/vehicle-kilometre and emission index (ind_{vt}^{et}) in tonnes/toe. This way, the road transport fuel consumption and emission calculation is more intuitive, namely policy measure such as CO_2 emission standard or Euro standards where certain pollution emission are capped can be performed directly. In this kind of policies, emission factors are always given in term of grams of emission per vehicle-kilometre instead of in tonnes of pollutant per toe. The user can directly assign a maximum emission factor for a specific type of vehicle starting in a particular point in time (year). Using this approach the calculation of national road energy consumption ($fuel_{t,i,m=road,vt}$) is the result of multiplying the vehicle fleet stocksize with fleet performance and fuel economics, in this case fuel consumption factor by age cohort *ac*:

$$fuel_{t,ci,m=road,vt} = \frac{\sum_{ac=0}^{29}\left(stock_{t,ci,m=road,vt,ac}\cdot\left(\frac{vkm_{t,ci,m=road}}{stock_{t,ci,m=road}}\right)\cdot conv\cdot fcf_{vt,ac}^{fuel}\right)}{10^6} \quad \text{(equation 135)}$$

Where:

$fuel_{t,ci,m=road,vt}$	Energy consumption of road transport vehicles (*m=road*) by vehicle type *vt* in country *ci* in time period *t* [tonnes of fuel]
$stock_{t,ci,m=road,vt,ac}$	The number of road (*m=road*) vehicles of vehicle type *vt* in age cohort *ac*, country *ci*, and time period *t*
$vkm_{t,ci,m=road}$	Road (*m=road*) mobility in country *ci* in time period *t* [vehicle-kilometre]
$stock_{t,ci,m=road}$	The number of road (*m=road*) vehicles in country *ci* in time period *t* [vehicles]
$conv$	Conversion factor from grams to tonnes of fuel, i.e. 10^{-6}

$fcf_{vt,ac}^{fuel}$	Fuel consumption factor of transport vehicle type *vt* in age cohort *ac* [grams of fuel/vehicle-kilometre].

This fuel consumption factor changes over time. The evolution of this fuel intensity reflects the different policies, especially emission standards applied in the concerned scenario.

Similarly ($emm_{t,ci,m=road,vt}^{et}$) are calculated by multiplying the vehicle fleet stock size with fleet performance and fuel economics, in this case fuel emission factor by age cohort ac:

$$emm_{t,ci,m=road,vt} = \frac{\sum_{ac=0}^{29}(stock_{t,ci,m=road,vt,ac} \cdot \left(\frac{vkm_{t,ci,m=road}}{stock_{t,ci,m=road}}\right) \cdot conv \cdot emf_{vt,ac}^{fuel})}{10^6} \qquad \textit{(equation 136)}$$

Where:

$emm_{t,ci,m=road,vt}$	Emissions of type *et* of road transport vehicles (*m=road*) by vehicle type *vt* in country *ci* in time period *t* [tonnes of fuel]
$stock_{t,ci,m=road,vt,ac}$	The number of road (*m=road*) vehicles of vehicle type *vt* in age cohort *ac*, country *ci*, and time period *t*
$vkm_{t,ci,m=road}$	Road (*m=road*) mobility in country *ci* in time period *t* [vehicle-kilometre]
$stock_{t,ci,m=road}$	The number of road (*m=road*) vehicles in country *ci* in time period *t* [vehicles]
$conv$	Conversion factor from grams to tonnes of fuel, i.e. 10^{-6}
$emf_{vt,ac}^{fuel}$	Fuel consumption factor of transport vehicle type *vt* in age cohort *ac* [grams of fuel/vehicle-kilometre].This emission factor changes over time.

The evolution of this emission factor reflects the different policies, especially emission standards applied in the concerned scenario.

As mentioned previously in the section 3.6.1 it is assumed that there will be a gradual penetration of biofuel additives from 0% in 2005 towards 5.75% in 2010 in all petrol and of all diesel fuel consumed by road transport. The biofuel share remains equal to 5.75% up to 2030.

However, we assume that the energy content of the biofuel and the fuel it is blended into is equal.

It is also assumed that the carbon and sulphur content of the blended fuels are equal to that of the pure diesel and pure petrol. This way, modelled exhaust CO_2 and SO_2 emissions per vehicle-km are equal for blended and unblended fuels. This is also the case for the other pollutants. No sufficient measurements exist to introduce solid assumptions on changes in exhaust emission factors resulting from the use of blended fuels.

Finally, MOVEET and TREMOVE are used as the main sources of fuel consumption (fuel intensity) and emission factors (emission index). According to De Ceuster (2007), in TREMOVE (which is further adopted in MOVEET), it is assumed that the difference between test cycle and real world amounts to about 15 % in all EU countries (excluding the extra fuel consumption related to mobile air conditioners). In HIGH-TOOL, initially values from MOVEET and TREMOVE were adopted, including this assumption of 15% gap between test cycle and real world values. The calibration process of High-Tool model that used EU Reference Scenario 2013 total emission and fuel consumption results has in all cases increased the emission and fuel consumption factors from their initial values. The higher gaps after the calibration which are currently around 25% (for the simulation year of 2015 and beyond) which are relatively low but approaching the gaps estimated by ICCT (2015) who estimates around 40% of gaps nowadays and around 50% in 2020 if the current test procedure of the New European Driving Cycle (NEDC) is kept or to around 25% in 2020 if the new test procedure called the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) is implemented to replace NEDC.

3.7.3 Elasticities

Explicit elasticities

The Environment module does not include any explicit elasticities.

Model variables

Table 29 indicates the model variables in the Environment module that are used as a policy lever to model several transport policy measures.

Table 29: Model variables in the Environment module

Policy lever	Description	Dimensions	Equation	Name in Database
ind^{et}	Emission index road and rail [tonnes/tonnes of oil equivalent]	vehicle type *vt*	125	i_ev_emfactor
ind^{et}	Emission index air vehicles [gram/kilogram fuel]	vehicle type *vt*	128-131	i_ev_emfactor
ind^{et}	Emission index ships [kilogram/tonne fuel]	vehicle type *vt*	134	i_ev_emfactor

3.8 Safety Module

3.8.1 Description

The Safety module (SAF) assesses the impact of transport policy measures on safety. This yields the prediction of numbers of fatalities (and injuries) as well as associated social costs. The required input includes historic mobility (from the Database), predicted mobility (from the Passenger and Freight Demand modules), and user input changes to safety risk and safety risk causal factors. Risk is defined as the number of "occurrences" (fatalities, injuries) per unit of mobility (in vehicle-kilometre or trips).The module distinguishes road and non-road modes, which are dealt with in different levels of detail. Road safety is treated most intricately since, besides fatalities, it also predicts the number of serious and slight injuries.

The road mode is further split into car, truck, powered-two-wheelers, public transport, bike, and pedestrians. Regarding non-road modes, rail, air, short sea shipping, and inland waterways are considered. For road and rail, the Safety module presents results per country *ci* (NUTS-0) and time period *t* (in years). SAF computes risks in 1-year-steps. This is combined with demand predictions from PAD and FRD to produce outputs in the same time aggregation as the other HIGH-TOOL modules. For air, short sea shipping, and inland waterways, results on EU-level are produced. This section first discusses the non-road submodule and then continues with the road submodule. However, both submodules share the following methodology and structure.

Firstly, business as usual (BAU) calculations are performed:

- Calculating BAU risks (historic risks and future predictions)
- Calculating BAU safety predictions (number of accidents) based on BAU risks and mobility predictions.

Secondly, scenario predictions are executed:

- Adapting the BAU risks in the scenario submodules according to the anticipated effect of modelled safety measures. This effect is derived from changes to accident causal factors (which are the policy inputs) and the elasticities and equations relating these to changes in risk. Only for the Inland Waterway and Short Sea Shipping submodules, the anticipated change in risk is used directly as policy input.
- Calculating safety outputs (number of accidents and costs) based on scenario risks and mobility predictions.

Table 30 shows how the Safety module interacts with other HIGH-TOOL modules. In addition, it gives some main outputs that are stored in the Database.

Table 30: Interaction of the Safety module with other HIGH-TOOL modules

I/O	Variable	Description	Dimensions	Module	Name in Database
In	*pkm*	Passenger transport mobility by country [pkm]	time period *t*, mode *m*, country *ci*	Passenger Demand	od_pd_pkm_transit_safety, o_pd_pkm_orig_safety, o_pd_urban_pkm_ctry
In	vkm^{pas}	Passenger transport mobility by country [vkm]	time period *t*, mode *m*, country *ci*	Passenger Demand	o_pd_vkm_orig, o_pd_urban_vkm_ctry
In	T^{pas}	Number of passenger trips [trips]	time period *t*, origin *i*, destination *j*, mode *m*, purpose *p*	Passenger Demand	o_pd_airic_trips_od
In	$vkm^{freight}$	Freight transport mobility in a country [vkm]	time period *t*, mode *m*, country *ci*	Freight Demand	o_fd_vkm_transit

3.8.2 Equations

3.8.2.1 Non-road modes

Since equations used to model modes other than road are largely identical, they are considered jointly in the following. Modes *m* distinguished in the non-road submodule are rail, air, short sea shipping (SSS), and inland waterway transport (IWW). For the mode rail, results are given per EU country *ci* (NUTS-0 level). For the remaining non-road modes, no zonal disaggregation is used and predictions are on EU-level. The indicated year is represented by *t*. The equations in this section indicate the maximum level of disaggregation (as for rail); however, the actual disaggregation depends on the considered mode (as described above).

BAU fatality risk

Risk is defined as the number of fatalities per unit of mobility. For inland waterway transport and short sea shipping, a time-independent BAU fatality risk is included as a fixed model parameter. For rail and air, the time-independent BAU fatality risk is calculated from historic data as the average from previous years until 2010. To this end, the historic number of fatalities is divided by the total historic mobility. Herein, the mobility is aggregated by origin country *ci* (for rail) or for the entire EU (for air). The year *t* used to calculate the business-as-usual fatality risk differs per mode and country, based on the available data. The BAU fatality risk ($FR_{ci,m}^{BAU}$) for rail and air is calculated as:

$$FR_{ci,m=rail}^{BAU} = avg_{t\ldots2010}\left(\frac{F_{t,ci,m}}{vkm_{t,ci,m}^{pas}+vkm_{t,ci,m}^{freight}}\right) \qquad \textit{(equation 137)}$$

$$FR_{m=air}^{BAU} = avg_{t\ldots2010}\left(\frac{F_{t,m}}{\sum_i \sum_j \sum_p (T_{t,i,j,p,m}^{pas})}\right)$$ *(equation 138)*

Where:

$FR_{ci,m=rail}^{BAU}$	Business-as-usual fatality risk for rail transport (*m=rail*) in country c*i* [fatalities/vehicle-kilometre]
$FR_{m=air}^{BAU}$	Business-as-usual fatality risk for air transport (*m=air*) [fatalities/passenger-trip]
$F_{t,ci,m}$	Number of historic fatalities for mode m in country c*i* in time period t [fatalities]
$F_{t,m}$	Number of historic fatalities for mode m in EU in time period t [fatalities]
$vkm_{t,ci,m}^{pas}$	Historic passenger mobility in country ci for mode m time period t [vehicle-kilometre]
$vkm_{t,ci,m}^{freight}$	Historic freight mobility in country *ci* for mode m in time period t [vehicle-kilometre]
$T_{t,i,j,p,m}^{pas}$	Historic number of passenger trips between origin *i* and destination *j* by mode m and purpose p in time period t [passenger-trips];

The number of BAU fatalities and associated social costs are calculated from these BAU risks and the predicted mobility analogously to the scenario case (see paragraph 'Fatalities and costs' further on).

Scenario fatality risk

Scenario fatality risks per mode *m* and country *ci* in time step *t* are calculated from the BAU fatality risks and the impact of policy measures hereon. For the modes rail and air, these impacts ($I_{t,ci,m,cs}^{F}$) are derived from changes to accident causes *cs* and related elasticities:

$$I_{t,ci,m,cs}^{F} = 1 + P_{t,ci,cs} \cdot e_{m,cs}^{F}$$ *(equation 139)*

Where:

$I_{t,ci,m,cs}^{F}$	Impact of cause *cs* on the fatality risk of mode m in country c*i* in time period t
$P_{t,ci,cs}$	Policy input, i.e. percentage change in accident cause *cs* (since causes are mode specific, the subscript m is not included here) in country *ci* in time period t [%]
$e_{m,cs}^{F}$	Elasticity of fatality risk of mode m to accident cause *cs* [%].

Table 31 in the section 'Elasticities' gives an overview of the considered accident causes *cs*. For the modes short sea shipping and inland waterway transport, the impacts $I^{F}_{t,m}$ on fatality risk are direct policy input parameters at EU-level (hence, no subscripts for country *ci* and accident cause *cs* are needed).The scenario fatality risk ($FR^{Scen}_{t,ci,m}$) after 2010 is then calculated as:

$$FR^{Scen}_{t,ci,m} = FR^{BAU}_{ci,m} \cdot \prod_{cs} \prod_{2010 \dots t} I^{F}_{t,ci,m,cs} \qquad \textit{(equation 140)}$$

Where:

$FR^{Scen}_{t,ci,m}$ Scenario fatality risk of mode *m* in country c*i* in time period *t* [fatalities/vehicle-kilometre] or [fatalities/passenger-trip]

$FR^{BAU}_{ci,m}$ Business-as-usual fatality risk for mode *m* in country c*i* [fatalities/vehicle-kilometre] or [fatalities/passenger-trip]

$I^{F}_{t,ci,m,cs}$ Impact of accident cause *cs* on the fatality risk of mode *m* in country c*i* in time period *t*.

Please note that for air transport (*m=air*) the fatality risk is calculated in fatalities/passenger-trip instead of fatalities/vehicle-kilometre.

Fatalities and costs

The predicted number of fatalities ($F^{Scen}_{t,ci,m}$) and the associated social costs ($C^{Scen}_{t,ci,m}$) in the scenario case are calculated as follows:

$$F^{Scen}_{t,ci,m\neq air} = FR^{Scen}_{t,ci,m} \cdot (vkm^{pas}_{t,ci,m} + vkm^{freight}_{t,ci,m}) \qquad \textit{(equation 141)}$$

$$F^{Scen}_{t,ci,m=air} = FR^{Scen}_{t,ci,m} \cdot (\sum_{i\in ci} \sum_{j} \sum_{p} \left(T^{pas}_{t,i,j,p,m} \right)) \qquad \textit{(equation 142)}$$

$$C^{Scen}_{t,ci,m} = F_{ci,m} \cdot \varphi_{m} \cdot c^{F} \qquad \textit{(equation 143)}$$

Where:

$F^{Scen}_{t,ci,m\neq air}$	Number of predicted fatalities for mode m (other than air) in country *ci* in time period t
$F^{Scen}_{t,ci,m=air}$	Number of predicted fatalities for air transport (*m=air*) in country c*i* in time period t
$C_{t,ci,m}$	Predicted total accident costs for mode m in country c*i* in time period t (EUR)
$vkm^{pas}_{t,ci,m}$	Historic passenger mobility in country *ci* for mode m in time period t [vehicle-kilometre]
$vkm^{freight}_{t,ci,m}$	Historic freight mobility in country *ci* for mode m in time period t [vehicle-kilometre]
$T^{pas}_{t,i,j,p,m}$	Predicted number of passenger trips between origin *i* and destination *j* by mode m and purpose p in time period t [passenger-trips]
φ_m	Conversion factor fatality costs to total accident costs (including non-fatal accidents)
C^F	Costs per fatality (EUR).

As indicated, the business as usual fatalities (F^{BAU}) and social costs (C^{BAU}) are calculated analogously by using the BAU fatality risk (FR^{BAU}) instead of the scenario fatality risk FR^{Scen}.

3.8.2.2 Road modes

In the Road safety module, the considered modes m are car, truck (including heavy duty (HDV) and light-duty vehicles (LDV)), powered-two-wheelers (P2W), public transport (PT), bike and pedestrian. For the predicted accident numbers (fatalities, serious injuries, and slight injuries) a further disaggregation by age group a and gender g is made for the modes car, P2W and bike. The calculations and outputs for the mode pedestrian are further disaggregated by 'involved mode' *im*. This involved mode refers to the mode that is responsible for a fatality or injury. Furthermore, for pedestrian calculations, vehicle-kilometres of the involved modes are used for mobility instead of pedestrian mobility itself. For the other modes, no further disaggregation is used other than by country *ci*. The calculated social costs are only disaggregated by mode m and country *ci*. The equations in this section indicate the maximum level of disaggregation; however, the actual disaggregation depends on the considered mode (as described above).

BAU risks per country for non-bike modes

Calculation of the business-as-usual risks is done by extrapolating a trend line from past mobility and accident data, without taking into account the effect of any future safety measures. First, base risk trend lines are constructed per mode *m* and country *ci* based on historic accident and mobility data. In order to consider risk trend lines, it must be possible to associate the evolution in the safety numbers over the reference period (2001–2010) to non-chance or non-error (explainable) events (CADAS, 2015). Therefore, a threshold parameter *tt* is set, above which casualty numbers per year are considered significant enough to form the basis of a trend line.

For the historic fatalities in the period 2001–2010, the following logic is used (except for mode bike, see below):

If $\text{avg}_{\text{t=2001...2010}}(F_{t,ci,m,im}) \geq t^t$: derive BAU fatality risks ($FR^{BAU}_{t,ci,m,im}$) from fatality numbers as follows:

$$FR^{BAU}_{t,ci,m\neq bike,im} = \frac{F_{t,ci,m,im}}{\sum_{i\in ci}\sum_j \sum_p (pkm_{t,i,j,p,m\ or\ im})} \qquad \textit{(equation 144)}$$

If $\underset{\text{t=2001...2010}}{\text{avg}}(F_{t,m,ci,im}) < t^t$: derive fatality risk ($FR^{BAU}_{t,ci,m,im}$) from the serious injury risks, assuming a time-independent ratio between fatalities and serious injuries:

$$FR^{BAU}_{t,ci,m\neq bike,im} = SeR^{BAU}_{t,ci,m,im} \cdot \frac{avg_{t=2001...2010}(F_{t,ci,m,im})}{avg_{t=2001...2010}(Se_{t,ci,m,im})} \qquad \textit{(equation 145)}$$

Where:

$FR^{BAU}_{t,ci,mm\neq bike,im}$	Business-as-usual fatality risk of mode *m* (non-bike) in country c*i* in time period *t*, for involved mode *im* [fatalities/passenger-kilometre]
$F_{t,ci,m,im}$	Historic number of fatalities for mode *m* in country c*i* in time step *t*, for involved mode *im* [fatalities]
$pkm_{t,i,j,p,m\ or\ im}$	Historic passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in in time period *t* [passenger-kilometre]
$SeR^{BAU}_{t,ci,m,im}$	Historic serious injury risk of mode *m* in country c*i* in time period *t*, for involved mode *im* [serious injuries/passenger-kilometre]
$Se_{t,ci,m,im}$	Historic number of serious injuries for mode *m* in country c*i* in time period *t*, for involved mode *im* [serious injuries]

t^t Threshold parameter [fatalities].

When mode m is truck, for the mobility ($vkm_{t,i,j,p,m}$) is used instead of ($pkm_{t,i,j,p,m}$) and the summation is over commodity type c instead of purpose p. In this case, the fatality risk is calculated as fatalities per vehicle-kilometre. For serious and slight injuries, the following logic is used (except for bike, see below):

If $\underset{t=2001...2010}{\text{avg}}(Se_{t,ci,m,im}) \geq t^t$: derive BAU serious ($SeR^{BAU}_{t,ci,m,im}$) and slight ($SlR^{BAU}_{t,ci,m,im}$) risk trend line from serious and slight injury numbers as follows:

$$SeR^{BAU}_{t,ci,m\neq bike,im} = \frac{Se_{t,ci,m,im}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m\ or\ im})} \quad \textit{(equation 146)}$$

$$SlR^{BAU}_{t,ci,m\neq bike,im} = \frac{Sl_{t,ci,m,im}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m\ or\ im})} \quad \textit{(equation 147)}$$

If $\underset{t=2001...2010}{\text{avg}}(Se_{t,ci,m,im}) < t^t$: calculate a constant BAU serious ($SeR^{BAU}_{t,ci,m,im}$) and slight ($SlR^{BAU}_{t,ci,m,im}$) risk by averaging the data over the reference period (2001–2010):

$$SeR^{BAU}_{ci,m\neq bike,im} = avg_{t=2001...2010}\left(\frac{Se_{t,ci,m,im}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m\ or\ im})}\right) \quad \textit{(equation 148)}$$

$$SlR^{BAU}_{ci,m\neq bike,im} = avg_{t=2001...2010}\left(\frac{Sl_{t,ci,m,im}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m\ or\ im})}\right) \quad \textit{(equation 149)}$$

Where:

$SeR^{BAU}_{t,ci,m\neq bike,im}$ Business-as-usual serious injury risk of mode m (non-bike) in country ci in time period t, for involved mode im [injuries/vehicle-kilometre]

$SlR^{BAU}_{t,ci,m\neq bike,im}$ Business-as-usual slight injury risk of mode m (non-bike) in country ci in time period t, for involved mode im [injuries/vehicle-kilometre]

$Se_{t,ci,m,im}$ Number of historic serious injuries for mode m in country ci in time period t, for involved mode im [serious injuries]

$Sl_{t,ci,m,im}$	Number of historic fatalities for mode m in country ci in time period t, for involved mode im [slight injuries]
$pkm_{t,i,j,p,m}$	Historic passenger mobility between origin i and destination j for mode m and purpose p in time period t [passenger-kilometre]
t^t	Threshold parameter [injuries].

Again, when mode m is truck ($vkm_{t,i,j,p,m}$) is used instead of ($pkm_{t,i,j,p,m}$) and the summation is over commodity type c instead of purpose p. In this case, the serious injury and slight injury risks are calculated as injuries per vehicle-kilometre.

BAU risks per country for bike

For the mode bike, we use time-independent BAU risks ($FR^{BAU}_{t,ci,m}$, $SeR^{BAU}_{t,ci,m}$, and $SlR^{BAU}_{t,ci,m}$) since data on bike mobility per year is lacking during the reference period:

$$FR^{BAU}_{t,ci,m=bike} = avg_{t=2001\dots2010}(\frac{F_{t,ci,m}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m})} \quad \textit{(equation 150)}$$

$$SeR^{BAU}_{t,ci,m=bike} = avg_{t=2001\dots2010}(\frac{Se_{t,ci,m}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m})} \quad \textit{(equation 151)}$$

$$SlR^{BAU}_{t,ci,m=bike} = avg_{t=2001\dots2010}(\frac{Sl_{t,ci,m}}{\sum_{i\in ci}\sum_j\sum_p(pkm_{t,i,j,p,m})} \quad \textit{(equation 152)}$$

Where:

$FR^{BAU}_{t,ci,m=bike}$	Business-as-usual fatality risk of bike (*m=bike*) in country *ci* in time period *t* [fatalities/passenger-kilometre]
$SeR^{BAU}_{t,ci,m=bike}$	Business-as-usual serious injury risk of bike (*m=bike*) in country *ci* in time period *t* [serious injuries/passenger-kilometre]
$SlR^{BAU}_{b,ci,m=bike}$	Business-as-usual slight injury risk of bike (*m=bike*) in country *ci* in time period *t* [slight injuries/passenger-kilometre]
$F_{t,ci,m}$	Number of historic fatalities for mode *m* in country *ci* in time period *t* [fatalities]
$Se_{t,ci,m}$	Number of historic serious injuries for mode *m* in country *ci* in time period *t* [serious injuries]

$Sl_{t,ci,m}$	Number of historic slight injuries for mode m in country c*i* in time period t [slight injuries]
$pkm_{t,i,j,p,m}$	Historic passenger mobility between origin i and destination j for mode m and purpose p in time period t [passenger-kilometre].

BAU risk trend lines per country per mode

The base risk trends estimated above from the 2001–2010 data are then extrapolated to 2020 and assumed flat afterwards from 2020 up till 2050. Extrapolating a BAU trend from 2001–2010 to 2050 is not considered realistic, since the BAU scenario assumes only a continuation of existing efforts, no new safety measures. It is reasonable to assume that the effect of pre-2010 measures would be (virtually) gone by 2020, as this period corresponds more or less with fleet renewal. The BAU trendlines ($FR^{BAU}_{t=y,ci,m}$) for fatality risk from 2010 to 2020 are described in the following general functional form:

$$FR^{BAU}_{t=y,ci,m} = b_{ci,m} \cdot m^{y}_{ci,m} \qquad \textit{(equation 153)}$$

Where:

$FR^{BAU}_{t=y,ci,m}$	Business-as-usual fatality risk of mode m in country c*i* in time period t [fatalities/passenger-kilometre]
y	Year [year]
$m_{ci,m}, b_{ci,m}$	Parameters by country *ci* and mode m that are fitted to match as closely as possible the 2001–2010 BAU risks.

The trend lines for serious injury risk ($Se^{BAU}_{t,m,ci}$) and slight injury risk ($Sl^{BAU}_{t,m,ci}$) are constructed separately using the same functional form, but with different parameters. All BAU risks for years after 2020 are set equal to the calculated risk for 2020. For mode m is truck, risks are calculated as fatalities/vehicle-kilometre.

Further stratification per age and gender

For the modes truck, PT, and pedestrians, the BAU risk calculation is now completed. For the modes car, P2W, and bike, risks are further stratified into gender g and age group a. This is done using time-averaged stratified crash numbers. This is justified because aggregating over time allows stratification into separate groups for other dimensions (age and gender), and the data shows that the variation over these dimensions is bigger than over time. For the modes car, P2W, and bike, risks are calculated per age-gender group from the yearly value per mode and zone, and the ratio between the average per mode-zone-age-gender group over the average per mode-zone group (for fatality, serious injury, slight injury risk separately). For the fatality risk ($FR^{BAU}_{t,ci,m,g,a}$) this is written as:

$$FR^{BAU}_{t,ci,m,g,a} = FR^{BAU}_{t,ci,m} \cdot \frac{\overline{FR}^{BAU}_{ci,m,g,a}}{avg_{t=2001\ldots2010}(FR^{BAU}_{t,ci,m})} \qquad \textit{(equation 154)}$$

Where:

$FR^{BAU}_{t,ci,m,g,a}$ Business-as-usual fatality risk of mode m in country ci in time period t for gender g and age group a [fatalities/passenger-kilometre]

$\overline{FR}^{BAU}_{ci,m,g,a}$ (Approximation of) average annual business-as-usual fatality risk of mode m in country ci in for gender g and age group a (over period 2001–2010) [fatalities/passenger-kilometre]

$FR^{BAU}_{t,ci,m}$ Business-as-usual risk of mode m in country ci in time period t [fatalities/passenger-kilometre].

Similarly as before, a threshold parameter $\bar{\tau}$ is introduced above where the total casualty number over the reference period (2001–2010) is considered significant (based on expert judgement) enough to be used directly for the calculation of ($\overline{FR}^{BAU}_{m,ci,g,a}$).

For fatalities, the following logic is used:

If $\sum_{t=2001\ldots2010}(F_{t,ci,m,g,a}) \geq \bar{\tau}$: in this case, the average fatality risk ($\overline{FR}^{BAU}_{ci,m,g,a}$) is calculated exactly from the data (all sums are over t=2001...2010):

$$\overline{FR}^{BAU}_{ci,m,g,a} = \frac{\sum_{t=2001\ldots2010}(F_{t,ci,m,g,a})}{\sum_{t=2001\ldots2010}\sum_{i\in ci}\sum_{j}\sum_{p}(pkm_{t,i,j,p,m\ or\ im})} \qquad \textit{(equation 155)}$$

If $\sum_{\mathrm{t=2001...2010}}(F_{t,ci,m,g,a}) < \bar{\tau}$, i.e. if the total number of fatalities is below the threshold, the average age-gender fatality risk ($\overline{FR}^{BAU}_{ci,m,g,a}$) is calculated using the gender-age serious injury risk and the ratios of fatalities over serious injuries for the two dimensions (gender and age) separately (which each have larger casualty numbers than the age-group combination). This way, we still use information of the stratified group itself (on the accident level below) to enrich our prediction (all sums are over t=2001…2010):

$$\overline{FR}^{BAU}_{ci,m,g,a} = \frac{\left(\frac{\sum_{t=2001...2010}(F_{t,ci,m,g})}{\sum_{t=2001...2010}(Se_{t,ci,m,g})}\right)}{\left(\frac{\sum_{t=2001...2010}(F_{t,ci,m})}{\sum_{t=2001...2010}(Se_{t,ci,m})}\right)} \cdot \frac{\sum_{t=2001...2010} F_{t,ci,m,a}}{\sum_{t=2001...2010} Se_{t,ci,m,a}} \cdot \overline{SeR}^{BAU}_{ci,m,g,a} \qquad \textit{(equation 156)}$$

Where:

$\overline{FR}^{BAU}_{ci,m,g,a}$	(Approximation of) average annual business-as-usual fatality risk of mode *m* in country c*i* in for gender *g* and age group *a* (over period 2001–2010) [fatalities/passenger-kilometre]
$F_{t,ci,m,g,a}$	Historic number of fatalities for mode *m* in country c*i* in time period *t* for gender *g* and age group *a* [fatalities]
$pkm_{t,i,j,p,m}$	Historic passenger mobility between origin *i* and destination *j* for mode *m* and purpose *p* in time period *t* [passenger-kilometre]
$\overline{SeR}^{BAU}_{ci,m,g,a}$	(Approximation of) average annual business-as-usual serious injury risk of mode *m* in country c*i* for gender g and age group *a* (over period 2001–2010) [serious injuries/passenger-kilometre]
$Se_{t,ci,m,g,a}$	Historic number of serious injuries for mode *m* in country c*i* time step *t* for gender *g* and age group *a* [serious injuries]
$\bar{\tau}$	Threshold parameter [fatalities].

For the calculation of the average serious injury risk ($\overline{SeR}^{BAU}_{ci,m,g,a}$) we follow the exact same logic and calculations as above, but using the ratio's between serious and slight injuries, analogously to the ratios between fatalities and serious injuries above. Slight injury risks ($\overline{SlR}^{BAU}_{ci,m,g,a}$) are always derived directly from the slight injury data, since lower accident levels are not available. Through this procedure, we obtain BAU risks per year for the three accident levels: fatality, serious injury and slight injury. The corresponding number of BAU fatalities and social costs are calculated from these BAU risks and mobility predictions analogously to the scenario case (see section 'Fatalities and costs' further on).

Scenario risks

Scenario fatality, serious and slight injury risks per time period *t*, mode *m*, country *ci*, gender *g,* (only car, p2w, bike), age group *a* (only car, p2w, bike) and involved mode *i* (only pedestrian) are calculated from the BAU risks and the impact of policy measures on these risks. These impacts ($I^F_{t,ci,m,im,g,a,cs}$) are derived from changes to accident causes *cs* (see Table 31) and corresponding elasticities (except for the accident cause speed, see below):

$$I^F_{t,ci,m,im,g,a,cs} = 1 + P_{t,ci,m,im,g,a,cs} \cdot e^F_{m,cs} \quad \textit{(equation 157)}$$

Where:

$I^F_{t,ci,m,im,g,a,cs}$ Impact of accident cause *cs* on the fatality risk of mode *m* and involved mode *im* in country c*i* for gender *g* and age group *a* in time period *t*

$P_{t,ci,m,im,g,a,cs}$ Policy input, i.e. percentage change in accident cause *cs* for mode *m* and involved mode *im* in country *ci* for gender *g* and age group *a* in time period *t* [%]

$e^F_{m,cs}$ Elasticity of fatality risk of mode *m* to accident cause *cs* [%].

For the cause speed, the following equation is used to calculate the impact *(*$I^F_{t,ci,m,im,g,a,i,cs=sp}$*)* instead of using explicit elasticities:

$$I^F_{t,ci,m,im,g,a,i,cs=sp} = \left(\frac{(100+P_{t,ci,m,im,g,a,cs=sp})}{100}\right)^{\chi^F_m} \quad \textit{(equation 158)}$$

Where:

$I^F_{t,ci,m,im,g,a,cs=sp}$ Impact of accident cause speed (*cs*=*sp*) on the fatality risk of mode *m* and involved mode *im* in country c*i* for gender *g* and age group *a* in time period *t*

$P_{t,ci,m,im,g,a,cs=sp}$ Policy input, i.e. percentage change in accident cause speed (*cs*=*sp*) for mode *m* and involved mode *im* in country *ci* for gender *g* and age group *a* in time period *t* [%]

χ^F_m Variable indicating the impact of accident cause *c* speed on the fatality risk of mode *m*.

Then, the scenario fatality risk ($FR^{Scen}_{t,ci,m,im,g,a}$) is calculated as:

$$FR^{Scen}_{t,ci,m,im,g,a} = FR^{BAU}_{t,ci,m,im,g,a} \cdot \prod_{cs} \prod_{2010...t} (I^{F}_{t,ci,m,im,g,a,cs}) \quad \textit{(equation 159)}$$

Where:

$FR^{Scen}_{t,ci,m,im,g,a}$ Scenario fatality risk of mode *m* and involved mode *im* in country c*i* for gender *g* and age group *a* in time period *t* [fatalities/passenger-kilometre]

$FR^{BAU}_{t,ci,m,im,g,a}$ Business-as-usual fatality risk of mode *m* and involved mode *im* in country c*i* for gender *g* and age group *a* in time period *t* [fatalities/passenger-kilometre]

$I^{F}_{t,ci,m,im,g,a,cs}$ Impact of accident cause *cs* on the fatality risk of mode *m* and involved mode *im* in country c*i* for gender *g* and age group *a* in time period *t.*

The scenario risks for serious *(*$SeR^{Scen}_{t,ci,m,g,a,im}$*)* and slight injuries *(*$SlR^{Scen}_{t,ci,m,g,a,im}$*)* are calculated in exactly the same manner, using the sensitivity parameters *(*$e^{Se}_{m,c}$*,*χ^{Se}_{m}, $e^{Sl}_{m,c}$, and χ^{Sl}_{m}). Please note that when mode *m* is truck, risks are given in accidents per vehicle-kilometre.

Fatalities and costs

The predicted number of fatalities ($F^{Scen}_{t,ci,m}$), serious injuries ($Se^{Scen}_{t,ci,m}$), and slight injuries ($Sl^{Scen}_{t,ci,m}$), as well as the total social costs ($C_{t,m,ci}$) are calculated as shown below. The same method is used for both the business as usual and the scenario case. In the latter case, the subscript *Scen* is replaced by *BAU*:

$$F^{Scen}_{t,ci,m} = \sum_{a} \sum_{g} \sum_{im} (FR_{t,ci,m,im,g,a}) \cdot \sum_{i \in ci} \sum_{j} \sum_{p} (pkm_{t,i,j,p,m\ or\ im}) \quad \textit{(equation 160)}$$

$$Se^{Scen}_{t,ci,m} = \sum_{a} \sum_{g} \sum_{im} (SeR_{t,ci,m,im,g,a}) \cdot \sum_{i \in ci} \sum_{j} \sum_{p} (pkm_{t,i,j,p,m\ or\ im}) \quad \textit{(equation 161)}$$

$$Sl^{Scen}_{t,ci,m} = \sum_{a} \sum_{g} \sum_{im} (SlR_{t,ci,m,im,g,a}) \cdot \sum_{i \in ci} \sum_{j} \sum_{p} (pkm_{t,i,j,p,m\ or\ im}) \quad \textit{(equation 162)}$$

$$C_{t,m,ci} = (F_{t,ci,m} \cdot c^{F} + Se_{t,ci,m} \cdot c^{Se} + Sl_{t,ci,m} \cdot c^{Sl}) \cdot (1 + \omega_{m}) \quad \textit{(equation 163)}$$

Where:

$F_{t,ci,m}^{Scen}$	Predicted number of fatalities for mode m in country ci in time period t [fatalities]
$Se_{t,ci,m}^{Scen}$	Predicted number of serious injuries for mode m in country ci in time period t [serious injuries]
$Sl_{t,ci,m}^{Scen}$	Predicted number of slight injuries for mode m in country ci in time period t [slight injuries]
$FR_{t,ci,m,im,g,a}^{Scen}$	Scenario fatality risk of mode m and involved mode im in country ci for gender g and age group a in time period t [fatalities/passenger-kilometre]
$SeR_{t,ci,m,im,g,a}^{Scen}$	Scenario serious injury risk of mode m and involved mode im in country ci for gender g and age group a in time period t [injuries/passenger-kilometre]
$SlR_{t,ci,m,im,g,a}^{Scen}$	Scenario slight injury risk of mode m and involved mode im in country ci for gender g and age group a in time period t [injuries/passenger-kilometre]
$pkm_{t,i,j,p,m}$	Predicted passenger mobility between origin i and destination j for mode m and purpose p in in time period t [passenger-kilometre]
$C_{t,ci,m}$	Predicted total accident costs for mode m in country ci in time period t [EUR]
c^F	Cost per fatality [EUR]
c^{Se}	Cost per serious injury [EUR]
c^{Sl}	Cost per slight injury [EUR]
ω_m	Conversion factor human capital costs to other accident costs (material damage estimate) for mode m.

Please note that when mode m is truck, risks are given in accidents per vehicle-kilometre. Hence, instead of mobility in passenger-kilometre, vehicle-kilometre is used. Furthermore, the aggregation is over commodity type c instead of purpose p.

3.8.3 Elasticities

Explicit elasticities

Explicit elasticity parameters in the Safety module are listed in Table 31. In fact, these parameters all represent the sensitivity of accident risk to changes in a certain accident cause. To give an overview of all considered accident causes cs, each of them is shown in the table below and the dimension cs is omitted.

Please note, furthermore, that these variables have different values for fatalities (F), serious injuries (Se), and slight injuries (Sl). In the table, only the first category is shown. The adopted values are shown in Annex B in Table 2A (fatalities), Table 3A (serious injuries) and Table 4A (slight injuries).

Table 31: Explicit elasticities in the Safety module

Elasticity	Description	Dimensions	Source
$e^{F,dtce}$	Change in fatality risk relative to changes in Driver and train crew errors	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,osse}$	Change in fatality risk relative to changes in Operating and signalling staff errors	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,tsmse}$	Change in fatality risk relative to changes in Track and switch maintenance staff errors	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,rsf}$	Change in fatality risk relative to changes in Rolling stock faults	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,if}$	Change in fatality risk relative to changes in Infrastructural faults	mode *m*	UIC (2009-2013) reports, ERA (2014), ETAC (2007), DaCoTa (2012) and Schoon (1996)
$e^{F,lcav}$	Change in fatality risk relative to changes in Level-crossing accidents (vehicles)	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,lcapc}$	Change in fatality risk relative to changes in Level-crossing accidents (pedestrian/cyclist)	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,tp}$	Change in fatality risk relative to changes in Trespassings	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,app}$	Change in fatality risk relative to changes in Accidents with person on platform	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,pft}$	Change in fatality risk relative to changes in Passengers falling from train	–	ERA (2014) and UIC (2009-2013) reports
$e^{F,ef}$	Change in fatality risk relative to changes in Engine failure	–	CATS (Ale et al., 2008)
$e^{F,fce}$	Change in fatality risk relative to changes in Flight crew error	–	CATS (Ale et al., 2008)
$e^{F,atf}$	Change in fatality risk relative to changes in Aircraft technical failure	–	CATS (Ale et al., 2008)
$e^{F,rc}$	Change in fatality risk relative to changes in Runway collision	–	CATS (Ale et al., 2008)
$e^{F,fb}$	Change in fatality risk relative to changes in Fire on board	–	CATS (Ale et al., 2008)
$e^{F,mac}$	Change in fatality risk relative to changes in Mid-air collision	–	CATS (Ale et al., 2008)
$e^{F,load}$	Change in fatality risk relative to changes in Weight/balance errors	mode *m*	CATS (Ale et al., 2008) and ETAC (2007)
$e^{F,dui}$	Change in fatality, serious and slight injury risk relative to changes in Driving under influence	mode *m*	CADAS (2015) database

Elasticity	Description	Dimensions	Source
$e^{F,bucr}$	Change in fatality, serious and slight injury risk relative to changes in Belt use & child restraints	country *ci*, mode *m*	CADAS (2015) database
$e^{F,hu}$	Change in fatality, serious and slight injury risk relative to changes in Helmet use	country *ci*, mode *m*	CADAS (2015) database
$e^{F,dis}$	Change in fatality, serious and slight injury risk relative to changes in Distraction (by device)	mode *m*	CADAS (2015) database
$e^{F,fat}$	Change in fatality, serious and slight injury risk relative to changes in Fatigue	mode *m*	CADAS (2015) database
$e^{F,bs}$	Change in fatality, serious and slight injury risk relative to changes in Blind spot	mode *m*	IA blind spots; CADAS (2015); SWOV-factsheet Dodehoek (SWOV, 1996)
$e^{F,vd}$	Change in fatality, serious and slight injury risk relative to changes in Vehicle defect	mode *m*	DaCoTa (2012), ETAC (2007), Schoon (1996)
$e^{F,mc}$	Change in fatality, serious and slight injury risk relative to changes in Time to adequate post medical care	–	Henrikson et al. (2001)
$e^{F,le}$	Change in fatality, serious and slight injury risk relative to changes in Loading error	–	ETAC (2007)

Model variables

The relevant model variables of the Safety module are listed in Table 32. These are the policy levers by which transport policy measures are modelled in HIGH-TOOL.

Table 32: Model variables in the Safety module

Policy lever	Description	Dimensions	Equation	Name in database
I_{sss}^{BAU}	Policy impact on fatality risk	time period *t*	140	i_sa_fat_risk_sss
I_{iww}^{BAU}	Policy impact on fatality risk	time period *t*	140	i_sa_fat_risk_iww
P(ce)	Policy change in accident risk driver and train crew error [%]	–	139	i_sa_crew_error_rail
P(osse)	Policy change in accident cause operating and signalling staff error [%]	–	139	i_sa_op_sign_staff_error_rail
P(tsmse)	Policy change in accident cause track and switch maintenance errors [%]	–	139	i_sa_track_staff_error_rail
P(rsf)	Policy change in accident cause rolling stock fault [%]	–	139	i_sa_stock_fault_rail
P(if)	Policy change in accident cause infrastructural faults [%]	mode *m*	139	i_sa_infra_fault
P(lcav)	Policy change in accident cause level-crossing (vehicles) [%]	–	139	i_sa_lc_vuln_acc_rail
P(lcapc)	Policy change in accident cause level-crossing (pedestrians/cyclists) [%]	–	139	i_sa_lc_vuln_acc_rail

Policy lever	**Description**	**Dimensions**	**Equation**	**Name in database**
P(tp)	Policy change in accident cause trespassing [%]	–	139	i_sa_trespasing_rail
P(app)	Policy in change accident cause persons on platform [%]	–	139	i_sa_platform_acc_rail
P(pft)	Policy change in accident cause falling from train [%]	–	139	i_sa_falling_from_train_rail
P(ef)	Policy change in accident cause engine failure [%]	–	139	i_sa_engine_failure_air
P(fce)	Policy change in accident cause flight crew error [%]	–	139	i_sa_crew_error
P(atf)	Policy change in accident cause aircraft technical failure [%]	–	139	i_sa_tech_failure_air
P(rc)	Policy change accident cause runway collision [%]	–	139	i_sa_runway_collision_air
P(fb)	Policy change in accident cause fire [%]	–	139	i_sa_fire_air
P(mac)	Policy change accident cause mid-air collision [%]	–	139	i_sa_mid-air_collision_air
P(load)	Policy change accident cause loading error [%]	mode *m*	139	i_sa_load_error
P(dui)	Policy change accident cause driving under influence [%]	mode *m*	157	i_sa_dui
P(belt)	Policy change accident cause belt use and child restraints [%]	country *ci*, mode *m*	157	i_sa_restraint
P(hu)	Policy change accident cause helmet usage [%]	country *ci,* mode *m*	157	i_sa_helmet
P(dis)	Policy change accident cause distraction [%]	mode *m*	157	i_sa_distraction
P(fatigue)	Policy change accident cause accident cause fatigue [%]	mode *m*	157	i_sa_fatigue
P(bs)	Policy change accident cause blind spot [%]	mode *m*	157	i_sa_blind_spot
P(vd)	Policy change accident cause vehicle defect [%]	mode *m*	157	i_sa_veh_defect
P(mc)	Policy change accident cause adequate post medical care [%]	–	157	i_sa_time_med_care
P(speed)	Policy change accident cause speeding [%]	–	157	i_sa_speed

4 Literature Study on Elasticities

Elasticities are of paramount importance for the design and validation of transportation models. To validate the results from the HIGH-TOOL model, an extensive study to collect elasticities from the literature (both refereed and non-refereed literature) has been carried out. The aim is to collect elasticities relevant for comparison with the HIGH-TOOL outcomes. Therefore, the collection is focused on elasticities obtained in Europe, and relevant for the modes of transportation modelled in HIGH-TOOL. This makes the constructed data set unique compared to other data sets obtained for meta-studies: it aims to be the most recent comprehensive data set relevant for HIGH-TOOL. During this literature study, we collected 2603 values for elasticities (time and cost) from 25 studies.

Interpreting the collected elasticities directly turns out to be far from trivial, as the elasticities are derived in different contexts and with different dimensions (different countries, different variables, different modes, different model specifications, etc.). Finding two elasticity values in the data set that have similar dimensions and can be compared directly to each other is more an exception than a rule. Taking an average in a fair way is therefore impossible as well. One solution is to carry out a regression analysis (meta-analysis) to identify the factors contributing to the size of the elasticities. Obtaining such a model is effective in that it allows for calculating elasticities for combinations of factors that are not available in the original data set. This allows extensive validation of the HIGH-TOOL model. In addition, the presented regression analysis provides confidence intervals on the calculated elasticities. Confidence intervals for outcomes of a regression analysis on elasticity meta-studies are generally not provided, but they help gauging how much one should worry and start to investigate respectively discuss the elasticities used in HIGH-TOOL if the elasticities derived from the HIGH-TOOL model do not correspond one-to-one with those from our elasticity meta-analysis. The results of our meta-analysis on elasticities are validated against the results of other meta-studies found in literature. The study presented in this chapter thus includes the following steps:

- Collection of elasticities form the literature.
- Estimation of four independent elasticity meta-models for HIGH-TOOL:
  a cost and time model for both passenger and freight.
- Validation of the estimated elasticity meta-models for HIGH-TOOL against
  established meta-models in the literature.

4.1 Criteria Used for Selection of Literature

For collecting elasticities, we used several literature reviews on elasticities as a starting point (e.g. De Jong and van de Riet, 2006; de Bok et al., 2010). From there, the references to papers with the original elasticities were followed. Additionally, we consulted our large library with reports on traffic models on their stated elasticities (e.g. EXPEDITE, 2014).

We used the following criteria for selecting the elasticities for the study. Firstly, all the elasticities have to be derived from a study relevant for European countries. Additionally, the data set has to be as inclusive as possible. Both in the number of countries as well as in the modes (for passengers: plane, train, car, moped, bus, bicycle, and foot; and for freight: air, rail, truck, short sea shipping and inland waterways). All variables and purposes relevant for HIGH-TOOL are covered as well as possible. Furthermore, only elasticities from original sources were included, hereby excluding elasticities from studies that were summarizing elasticities (these meta-analyses themselves – see Table 47 – were used for verifying the presented elasticity model). This is to ensure that the same elasticity is not included more than once but also to ensure we do not carry along misinterpretations by previous studies. This also has the additional benefit that we always use the contexts (such as year, kind of elasticity, etc.) of the derivation directly from the source.

4.2 Elasticities Collected

Based on these criteria, we have collected elasticities from the sources listed Table 33. For each paper the number of cost and time elasticities used for constructing the models is shown. Herein, *pas* denotes passenger elasticities, while *fr* indicates freight elasticities.

Table 33: Sources used for collecting original elasticities in alphabetical order

Source	**# cost elasticities**	**# time elasticities**
Atkins (2002): Stated preference and revealed preference surveys, Milestone 6 of High Speed Line Study for Strategic Rail Authority;	2 (pas)	2 (pas)
Beuthe (2001): Freight transportation demand elasticities: a geographic multimodal transportation network analysis, *Transportation Research Part E: Logistics and Transportation Review, Vol. 37, No. 4, pp. 253-266*;	18 (fr)	–
Bjorner (1999): Environmental benefits from better freight transport management: freight traffic in a VAR model, *Transportation Research Part D: Transport and Environment, Vol. 4, No. 1, January 1999, pp. 45–64*;	2 (fr)	–
Bresson, Dargay, Madre, and Pirotte (2003): The main determinants of the demand for public transit: A comparative analysis of England and France using shrinkage estimators, *Transportation Research Part A: Policy and Practice, Vol. 37, No. 7, pp. 605-627*;	8 (pas)	–

Source	**# cost elasticities**	**# time elasticities**
Cabanne (2003): A long term model for long distance travel in France, *Paper presented at the European Transport Conference 2003*;	3 (pas)	–
Carlsson (1999): Private vs Business and Rail vs Air Passengers; Willingness to pay for Transport Attributes, *Working Papers in Economics Vol. 14*;	12 (pas)	12 (pas)
De Bok, Costa, Melo, Palma, and Frias (2010): International comparison of elasticities for long distance travel: benchmarking the Portuguese National Transport Model, *Proceedings from Word Conference of Transport Research 2010*;	3 (pas)	3 (pas)
De Jong, et al. (2002): EXPEDITE Main outcomes of the national model runs for passenger transport (Deliverable 6);	82 (pas)	73 (pas)
De Jong and Gunn (2001): Recent Evidence on Car Cost and Time Elasticities of Travel Demand in Europe, *Journal of Transport Economics and Policy, Vol 35, pp. 137-160*;	–	44 (pas)
De Jong (2003): Elasticities and policy impacts in freight transport in Europe, *Paper presented at the European Transport Conference 2003;*	14 (fr)	10 (fr)
De Jong, G.C, et al. (2010): Schatting BASGOED, rapportage DP1;	3 (fr)	3 (fr)
García-Menéndez, Martínez-Zarzoso, and De Miquel (2004): Determinants of Mode Choice between Road and Shipping for Freight Transport: Evidence for Four Spanish Exporting Sectors, *Journal of Transport Economics and Policy Journal of Transport Economics and Policy Journal of Transport Economics and Policy, Vol. 38, No. 3, pp. 447-466*;	8 (fr)	8 (fr)
Hensher and King (1998): Establishing fare elasticity regimes for urban passenger transport: time-based fares for concession and non-concession markets segmented by trip length, *Journal of Transportation Statistics, Vol. 1, No. 1, pp. 43-57*;	8 (pas)	–
IATA (2007): Estimating Air Travel Demand Elasticities, Final Report	2 (pas)	–
Ibánez-Rivas (2010): Peer review of the TRANS-TOOLS reference transport model (http://energy.jrc.ec.europa.eu/transtools/-documentation.html)	1 (pas)	2 (pas)
Jin, Wiliams, and Shahkarami (2005): Integrated regional economic and freight logistics modelling: Results from a model for Trans-Pennine corridor, UK, *Paper presented at the European Transport Conference 2005*;	1 (fr)	–
Johnson and de Jong (2011): Shippers' response to transport cost and time and model specification in freight mode and shipment size choice, *Paper presented at the second International Choice Modelling Conference, 2011*;	12 (fr)	7 (fr)
Jovicic (1998): Application of Models based and Revealed Preference Data for Forecasting Danish international Freight Transport, *Article presented at the Aalborg Traffic Conference 1998*;	2 (fr)	–
LMS documentatie (2014): Documentatie van GM 2 -- Deel D7-1;	36 (pas)	36 (pas)
Mandel, Gaudry, and Rothengatter (1997): A disaggregate Box-Cox Logit mode choice model of intercity passenger travel in Germany and its implications for high-speed rail demand forecasts, *The Annals of Regional Science, Vol 31, pp. 99-120*;	3 (pas)	3 (pas)
Marzano (2004): Modelling freight demand at a national level: theoretical developments, *Proceedings of the European Transport Conference 2004*;	–	15 (fr)
MVA consultancy (1985): The specification of the long distance travel model;	3 (pas)	4 (pas)
NEA (2007): TRANSTOOLS – Mode Split Model, Revisions for Transtools Version 1.3;	40 (fr)	–
Rich and Mabit (2011): A Long-Distance Travel Demand Model for Europe, *European Journal of Transport and Infrastructure Research, Vol. 12, No. 1, pp. 1-20*;	24 (pas)	30 (pas)
Rohr, Daly, Patruni, and Tsang (2008): The importance of frequency and destination choice effects in long-distance travel behaviour: what choice models can tell us, *Paper presented at the European Transport Conference 2008*;	6 (pas)	6 (pas)

For these elasticities, the characteristics shown in Table 34 were collected.

Table 34: Characteristics of the collected elasticities

Characteristic	Description
Value	Value of the collected elasticity
Uncertainty	Uncertainty on the derived value (when given)
Reference	Where was the elasticity found?
Method	What method was used for obtaining the elasticity? (revealed preference data, traffic model, …)
Mode	Which mode does the elasticity concern?
Varied mode	The mode for which the variable was varied (if "varied mode" equals "mode" the elasticity is a direct elasticity)
Variable	What was varied? (cost, time, ...)
Kind	Is it kilometre elasticities, trips? Or, in case of freight, tonne, or tonne-km?
Purpose/ Kind of freight	In case of passenger elasticities, what was the purpose of the trip; in case of freight, what kind of freight (commodity type)?
Term	Is it a long term or a short term elasticity?
Base year	For which year is the elasticity obtained?
Distance scale	For which distance classes is the elasticity valid?
Country	For which country is the elasticity derived?

Table 35 shows which countries the collected elasticities were derived from. In addition, it makes a separation between direct elasticities (direct) and cross elasticities (cross) passenger and freight. What immediately stands out is the large quantity of cross elasticities compared to direct elasticities. This is somewhat unfortunate, as cross elasticities provide more of a challenge to model coherently than direct elasticities. This is because cross elasticities depend directly on the market shares of modes and this varies between the different sources. Furthermore, it stands out that the majority of the elasticities are derived from Dutch studies. This should not necessarily be a problem, as we estimate corrections for country specific characteristics during the regression. Also, all the country-specific elasticities are derived in the EU15 countries and Norway, not in the New Member States (EU13 countries), nor in Switzerland. We paid extra attention to adding elasticities from the New Member States, but our efforts were fruitless.

Table 35: Number of collected elasticities per country

Country	Cross (passenger and freight)	Direct (passenger)	Direct (freight)	Total
Belgium	79	8	28	115
Germany	0	8	0	8
Denmark	23	5	4	32
Estonia	16	0	16	32
EU	106	18	52	176
France	5	5	0	10
Italy	144	68	17	229
Netherlands	785	199	3	987
Norway	113	24	4	141
Portugal	14	7	0	21
Sweden	38	30	21	89
United Kingdom	64	50	1	115
Total	**1388**	**421**	**146**	**1955**

Table 36 and Table 37 show the number of elasticities for each kind of elasticity[15]. Most elasticities are for trips, tours and distance (kilometres). For freight transport the elasticity is in tonnes or tonne-kilometre. Remarkable is that the vast majority of elasticities are for passenger transport. However, the number of freight elasticities collected is substantial enough to estimate a simple model. Table 36 and Table 37 include both the mean values and their standard deviations per category. Note that for now, we focus on direct elasticities. Their values are all negative. Looking at the different average values per category in Table 36 and Table 37 shows the problem that arises when deriving elasticities by just averaging: this is not comparing apples to apples (like with like). A distance elasticity (-0.75 for cost elasticities) has a different meaning than for instance a trip elasticity (-0.116 for cost elasticities). However, the large differences between the average elasticities for tours, trips and demand are surprising. The same holds for tonnes and tonne-kilometres (-3.63 and -0.75 for time elasticities) for freight transport. Segmenting the elasticities even further will likely resolve part of this issue, but that implies that derived averaged elasticities will be based on less elasticities, up to the level that each estimated elasticity might be based on a single elasticity from the literature only. Please note as well that the underlying data sets or a networks respective impedances are always collected or generated differently, which enlarges the problem of comparability for the elasticities. In case models would have been estimated based on a single data source like ETISplus, this problem could have been circumvented.

[15] Please note that the 'type of elasticity' relates to the independent variable (time or costs) while the 'kind of elasticity' relates to the dependent variable (trips, vehicle-kilometres, etc.).

Table 36: Statistics of the collected direct cost elasticities

Kind of elasticity costs	**Passenger**		**Freight**		**Total**
	Number	**Mean (std.)**	**Number**	**Mean (std.)**	**Number**
Passenger-kilometres	59	-0.75 (0.33)	0		60
Vehicle-kilometres	0		1	-0.47 (n/a)	1
Tours	21	-0.116 (0.10)	0		21
Trips	111	-0.62 (0.40)	0		87
Number of shipments	0		12	-0.26 (0.29)	12
Demand	2	-1.82 (1.36)			2
Tonne	0		55	-0.48 (0.63)	55
Tonne-kilometres	0		21	-1.27 (0.88)	21
Modal split	0		8	-1.08 (0.77)	8

Table 37: Statistics of the collected direct time elasticities

Kind of elasticity time	**Passenger**		**Freight**		**Total**
	Number	**Mean (std.)**	**Number**	**Mean (std.)**	**Number**
Passenger-kilometres	77	-0.94 (0.71)			77
Tours	21	-0.23 (0.09)	0		21
Trips	117	-0.78 (0.96)	0		117
Number of shipments	0		7	-0.62 (0.61)	7
Tonnes	0		17	-3.63 (3.49)	17
Tonne-kilometres	0		8	-0.75 (0.40)	8
Modal split	0		8	-4.10 (6.91)	8

4.3 Regression Analysis

In the process of designing a model that describes the collected elasticities best, a few choices have been made. First of all, only direct elasticities were modelled, as cross-elasticities are largely related to the market shares of the different modes of transportation, which can vary widely from country to country. Secondly, the models are split into a model for passenger elasticities and freight elasticities, as they are expected to respond very differently to varying costs and travel times. Furthermore, the two commonly used regression methods (logarithmic and linear) have been tested. For the passenger elasticities, the logarithmic regression appears to work best, whereas for the freight elasticities, the linear regression works better in terms of log likelihood. Also, some country and year specific information is added to the regression as shown in Table 38.

Table 38: Added country and year specific information

Variable	Description	Year specific?
GDP	GDP (purchasing power parity) in 2011 US Dollars (World Bank data)	Yes
Percentage urban	Percentage of the population living in an urban area (World Bank data)	Yes
Population size	Number of inhabitants (World Bank data)	Yes
Area	Surface area of the country (World Bank data)	No: 2013 data
Railway	Length of the railroad network (Statistical pocketbook 2012, EC)	In steps of 5 years
Road	Length of the motorway network (Statistical pocketbook 2012, EC)	In steps of 5 years
Rail_pp	Length of the railroad network per inhabitant of the country (combination of the variables above)	Yes
Road_pp	Length of the motorway network per inhabitant of the country (combination of the variables above)	Yes

Adding the lengths of the rail and road network to the equation is not straightforward, as these variables only apply directly to one specific mode of transportation (train and car respectively)[16]. For this reason, it was decided to assign the elasticities that do not relate to the particular mode a neutral value (1 in case of a logarithmic estimation, 0 in case of a linear estimation). Also, it is particularly important for the continuous variables (e.g. *Rail_pp*, *Road_pp*, the base year and the GDP) to offset the variable such that the mean value has a coefficient of 0. This implies for the logarithmic case that the variables are divided by their mean value. For the linear case, the mean value are subtracted from the variable. For all of the variables mentioned in Table 30 and for percentage urban, GDP, *Rail_pp* and *Road_pp* (mentioned in Table 42) we tested whether they provide a significant contribution to the size of the elasticities. The variables that are mentioned as a parameter in the best-fit model are significant at a t-ratio of 2 (GDP and *Road_pp* for the passenger models), the categorical variables that are not mentioned are added to the base category of the model. Note that in the models, the long distance dummy is defined as starting from a trip distance of 50 km. This rather short distance is chosen as the models in literature are mostly national models that focus on short trips as they are the vast majority of all trips. This implies that the determined elasticities cannot be used to predict behavioural changes for long distance travel like holiday traffic. Therefore, it is a valid approach to combine the results from studies that contain the air mode with studies that do not, as the plane is not a realistic mode choice for most trips.

[16] There might also be a second order effect on other elasticities. However, this is here neither analysed nor further taken into account since it is not needed for the purpose to validate HT-elasticities.

4.3.1 Estimating and Forecasting using Regression Models

The meta-analyses found in the literature (see Table 44) all determine regression coefficients. In addition, for these estimated coefficients they provide uncertainties as well as values for the adjusted R-squared. However, few of them present a detailed discussion on uncertainties of the modelled elasticities.

Holmgren (2007) does provide a 95% confidence level for his elasticities. However, this study provides little explanation on the exact method used for calculating these uncertainties. Holmgren put a lot of effort into calculating the uncertainties of the predicted elasticities, which does not seem to be common practice in literature. However, providing uncertainties is necessary for comparing studies and drawing conclusions if results are significantly different or in agreement. A detailed description on linear regression analyses and the calculation of uncertainties is provided by Kutner (2005) and Koutsoyiannis (1977). Here, only a short motivation and the formulas used during the calculations are given. In linear regression a scalar parameter (*Y*) is estimated from a set of explanatory variables (X_i). The general formula is:

$$Y = \beta_0 + \beta_i \cdot X_i + \varepsilon_i \qquad \textit{(equation 164)}$$

Where:

Y	Scalar dependent variable
β_0	Intercept
β_i	Slopes of the linear functions in *i* dimensions
X_i	Value of explanatory variables *i*
ε_i	Error term of variable *i*.

The β's are determined during the regression. For the error term ε_i we assume normal distributions with means of zero and variance σ^2. For normally distributed variables the uncertainty of the mean decreases with the sample size n: $\sigma^2_{(mean)} = \sigma^2/n$. However, in this case we are not interested in the mean as we want to determine the dependencies of the elasticities from other variables. Instead, the idea is as follows: there is a base uncertainty (σ/n, where σ is the standard deviation and n the number of observations in the whole sample). In addition, there is an uncertainty related to what the mean value is $\bar{X}$ of the variable is, as compared to where the variable is evaluated.

In Figure 11, the variable is evaluated at two positions (X_1 and X_2). The two lines in the figure indicate the 95% confidence interval in the analysed dimension. As $|X_1 - \bar{X}| < |X_2 - \bar{X}|$ the spread in $\widehat{Y_2}$ is larger than the spread in $\widehat{Y_1}$.

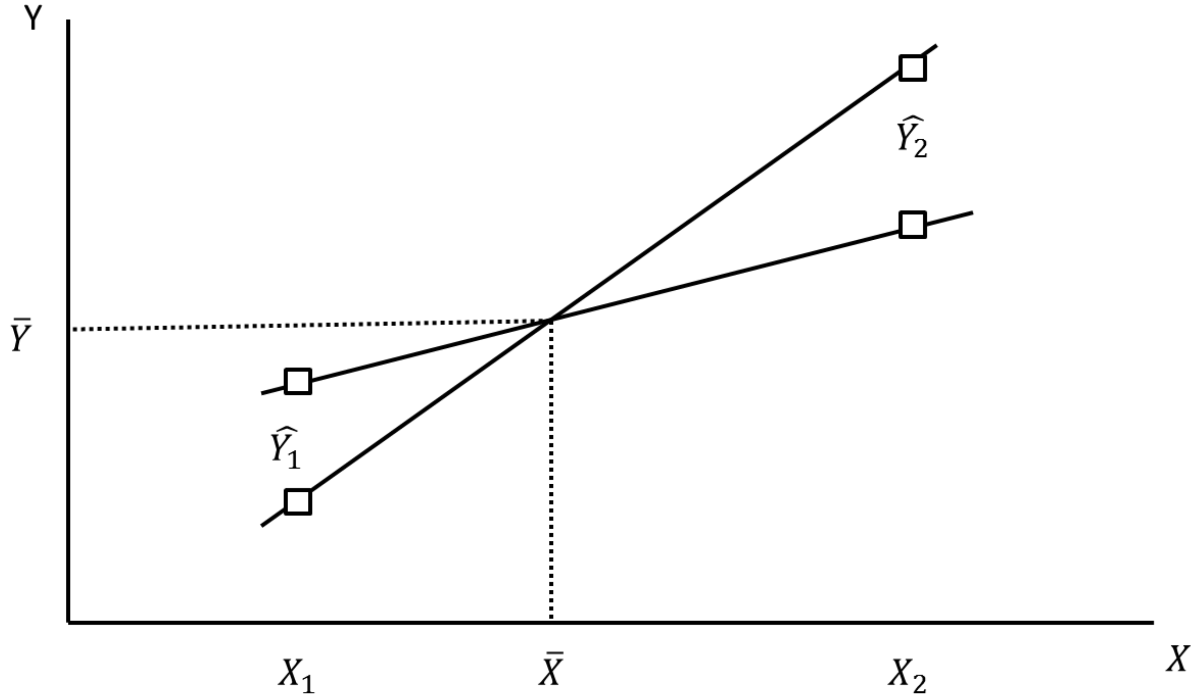

Figure 12: Effect of estimations from two samples with the same mean and different slopes

To take this into account we consider the following example. If the elasticity $\widehat{Y}_k$ is built from intercept β_0 and parameter β_1 for variableX_k:

$$\widehat{Y}_k = \beta_0 + \beta_1 \cdot X_k \qquad \textit{(equation 165)}$$

The uncertainty on $\widehat{Y}_k$ is:

$$\sigma^2(\widehat{Y}_k) = \sigma^2 \cdot \left[\frac{1}{n} + \frac{(X_k - \bar{X})^2}{\sum_{i=1}^{n}((X_i - \bar{X})^2)}\right] \qquad \textit{(equation 166)}$$

The uncertainty of an estimated elasticity e^k if all parameters are known is:

$$\sigma^2(e^k) = \sigma^2 \cdot \left[\frac{1}{n} + \sum_{j=1}^{M}\left(\frac{\left(X_{k(j)} - \bar{X}_{(j)}\right)^2}{\sum_{i=1}^{n}\left(\left(X_{i(j)} - \bar{X}_{(j)}\right)^2\right)}\right)\right] + \sigma^2 \qquad \textit{(equation 167)}$$

Where:

σ	Standard deviation in Y – all elasticities used to estimate the model (data set)
n	Number of data points (elasticities in studies used as input)
$X_{k(j)}$	X-value where the elasticity is evaluated
M	All variables and dummies.

With these equations, we constructed an elasticity meta-model for HIGH-TOOL to predict elasticities in different categories for passenger and freight transport. The uncertainties of the predictions are calculated with the presented methodology to compare these results with other meta-studies (see paragraph 4.5).

4.3.2 Passenger Models

In the passenger elasticity meta-model for HIGH-TOOL, the time and cost elasticities were modelled separately (215 and 193 observations, respectively). For the passenger elasticity meta-models, the logarithmic implementation of the regression appears to work better than the linear implementation, based on the log likelihood. Both models were first modelled using all coefficients, after which the coefficients that were not significant (t-ratio < 1.5) were removed. Subsequently, the models were corrected for so-called fixed effects. Fixed effects are the systemic offsets of the elasticities between studies, likely due to differences in the methods used to calculate the elasticities. To correct for these potential offsets, a dummy variable for each study was included, of which only the dummies with a t-ratio of more than one were retained, following Wardman (2014).

The functional form for cost elasticities is the following (where the coefficients are indicated by $\beta_{\text{name of independent variable}}$):

$$ln(elasticity) = intercept + \beta_{kind\ of\ elasticity} + \beta_{purpose} + \beta_{baseyear} \cdot ln\left(\frac{base\ year^{17}}{2000}\right)$$

(equation 168)

[17] The base year is the year to which the data has been corrected in the individual studies. The average base year for all studies is the year 2000, which is the reference year for this meta-analysis.

All (direct) elasticities used for estimating this function were negative. To be able to put them into a 'log-form', we took their absolute values. This implies that a positive value for the estimated coefficient leads to an elasticity with a larger absolute value (which is in reality negative). A negative coefficient implies a less negative value for the elasticity (smaller absolute value and thus closer to zero). Table 39 and Table 40 show the best-fit models for time and cost elasticities.

Table 39: Coefficients for cost elasticities for passengers, adjusted $R^2 = 0.5515$

Coefficients	**Value**	**Std. Error**	**t-ratio**
(Intercept)	-1.54	0.11	-13.65
Source: Cabanne (2003)	1.15	0.38	3.05
Source: IATA (2007)	0.58	0.47	1.23
Source: LMS (2010)	-1.65	0.22	-7.53
Source: MVA (1985)	0.58	0.42	1.40
Kind: base (trip, tours, demand)	0	0	0
Kind: distance (km)	0.33	0.11	3.09
Mode_base (car driver)	0	0	0
Mode: BTM	0.81	0.14	5.70
Mode: bus	0.98	0.19	5.15
Mode: car driver and car passenger	-0.47	0.25	-1.88
Mode: plane	1.39	0.19	7.28
Mode: public transport	1.13	0.20	5.75
Mode: train	0.80	0.12	6.58
Purpose: base[18]	0	0	0
Purpose: other[19]	0.37	0.17	2.20
Purpose: shop	0.46	0.17	2.72
Purpose: private	0.36	0.24	1.51
Log (base year) base (base is the year 2000)	75.15	25.85	2.91

Table 40 shows the coefficients for the regression analysis of the passenger cost elasticities. The table shows that there is a considerable amount of scatter between the studies from which the elasticities have been gathered. This can be seen from the significant values of source-specific coefficients. Additionally, it turns out that distance (kilometre) elasticities are significantly stronger than trip elasticities, which is a commonly seen phenomenon.

[18] Total, total without business and commute, commute, all non-discounted travel, leisure, education, visiting relatives, home-based business.

[19] All purposes, except for commute, business, education, shopping and performing social recreative activities.

Elasticities involving car are generally smaller than those for public transport. Note that there is a coefficient for bus, tram and subway combined, and a coefficient for bus only. This implies that one has to use the coefficient for bus if one is interested in bus elasticities. However, if one wants to know the elasticity for bus, tram and subway combined, one should use that coefficient. In other words, one does not have to add several coefficients within a certain category. The elasticities for purposes other than shopping and private are stronger than for the remaining purposes, since these purposes are more "optional" in comparison to, commuting trips or trips for education. Therefore, once the costs increase, people are inclined to cut back on these trips before cutting back on trips to their jobs. Also, it appears the cost elasticities become stronger over time.

Table 40: Coefficients for time elasticities for passengers, adjusted $R^2 = 0.5114$

Coefficients	**Value**	**Std. Error**	**t-ratio**
(Intercept)	-1.28	0.11	-11.46
Source: Atkins (2002)	1.18	0.55	2.14
Source: Carlsson (1999)	2.20	0.25	8.83
Source: De Bok et al. (2010)	0.98	0.45	2.17
Source: MVA (1985)	0.67	0.41	1.64
Kind: base (trip, tour)	0	0	0
Kind: distance (km)	0.93	0.11	8.10
Mode: base (car driver, car driver + car passenger, plane)	0	0	0
Mode: bus, tram and subway	0.50	0.16	3.15
Mode: bus	1.01	0.31	3.30
Mode: car passenger	1.03	0.33	3.17
Mode: train and public transport	0.35	0.13	2.65
Term: base (long term)	0	0	0
Term: short term/unknown	-0.56	0.14	-3.86
Purpose: base[20]	0	0	0
Purpose: education	0.35	0.18	1.94
Purpose: non home based business	-1.23	0.38	-3.22
Purpose: other and holiday	-0.61	0.15	-4.13
Log (GDP_pp, base is 24873.59)	-0.53	0.34	-4.54

[20] The class of trip purposes that is called 'base' covers total, commute, visiting relatives, shop, home-based business, leisure, and private.

Table 40 shows the coefficients found for the passenger time elasticities. Again, the distance (kilometre) elasticities are stronger than those for trips. Also, the car elasticities are generally weaker than those of other forms of transportation. Short term elasticities are weaker than long term elasticities. This makes sense as people are for instance, once travel becomes more expensive, move closer to their work in the long run, cutting back on the total kilometres travelled for work, but of course it takes time to make such an adjustment. The GDP coefficient is negative, implying that the time elasticities get smaller in an absolute sense once the travellers have more money to spend.

4.3.3 Freight Models

The elasticity database created for this project has substantially less freight elasticities than passenger elasticities: 97 for cost and 40 for time. Nevertheless, we put in our best effort for designing an appropriate freight elasticity meta-model for HIGH-TOOL. We follow a procedure similar to the procedure for passenger models. Given the low number of elasticities collected for the freight model, it poses quite a challenge to find significant coefficients. In contrast to the log-form which describes the passenger elasticities better, linear models for freight were selected due to a better log-likelihood. The functional forms for time and cost elasticities are:

$$\text{elasticity}_{\text{time}} = \text{intercept} + \beta_{\text{kind}} + \beta_{\text{mode}} + \beta_{\text{source}} + \beta_{\text{baseyear}} \cdot (\text{base year} - 2000)$$

(equation 169)

$$\text{elasticity}_{\text{cost}} = \text{intercept} + \beta_{\text{mode}} + \beta_{\text{source}} + \beta_{\text{GDP}} \cdot (\text{GDP} - \text{GDP}^{\text{avg}})$$

(equation 170)

Herein, GDP^{avg} is 22293.42, which is the average GDP in the dataset. After finding the significant coefficients, we correct for fixed effects by adding the literature sources of the elasticities to the regression. Alternatively, we tested a random coefficient model. Here, we do not put in any coefficients for the individual studies, but rather assume their deviation from each other to be normally distributed with a mean at zero. The main reason for doing this is to cut back on the amount of coefficients, potentially leaving room for more explanatory coefficients, instead of the coefficients for individual studies. After implementing random coefficients, we were unable to identify any significant explanatory coefficients that we could add to the model. For this reason, we stick to the fixed effects models, as shown in Table 45 and Table 47.

Table 41: Coefficients for time elasticities for freight

Coefficients:	**Value**	**Std. Error**	**t-ratio**
(Intercept)	-0.76	0.60	-1.28
Source: Garcia et al. (2004)	2.25	1.45	1.55
Source: Johnson and de Jong (2011)	1.42	1.04	1.37
Mode: base (truck, air)	0	0	0
Mode: rail	-3.77	1.00	-3.76
Mode: road/rail combination	-4.66	1.39	-3.36
Mode: Short Sea Shipping	-7.5	1.68	-4.48
Kind_of_freight: base (total, wdf, general cargo, bulk, agro, tex)	0	0	0
Kind_of_freight: ceramics	-8.93	1.94	-4.61
Base year	-0.20	0.12	-1.65

Table 42: Mean values for the elasticities used for the freight-time model

Average of elasticity	**Air**	**Rail**	**Road/Rail**	**Short Sea Shipping**	**Truck**
Garcia et al. (2004)				-7.87	-0.34
Johnson and de Jong (2009)	-1.24	-0.29			-0.0325
De Jong (2003)		-0.69			-0.63
Marzano (2004)		-6.99	-6.24		-0.24

Immediately obvious are the large values for the coefficients in Table 41. This warrants some further study. In Table 42 the mean values for the freight time elasticities, split by mode and source are displayed. It has to be noted that some studies (Marzano, 2004; and Garcia, 2004) have elasticities with extremely large (absolute) values. Due to the fact that we only collected elasticities from this study for road-rail and short sea shipping this sets the value for these categories. Given this limited information, it is impossible to disentangle whether this is a study-specific effect, or a reflection of the "true" elasticities. Also, given the large value for the "Kind_of_freight-ceramics"-coefficient, transporting ceramics apparently has a very high elasticity. This is a true reflection from the data: there were only two elasticities collected concerning ceramics, with values of -0.88 (truck) and -20.72 (Short Sea Shipping).

The coefficients for the cost model (see Table 43) are less extreme than the ones in the time model. Remark that there is always an interaction between time and cost variables. The elasticities for truck and air transport are substantially higher in an absolute sense than those for rail, inland waterways and short sea shipping. This likely has to do with the fact that in those cases there usually is an alternative, whereas for truck and air transport there are fewer alternatives. Also, when the GDP rises, the elasticities get smaller in an absolute sense, implying that transport decision makers care less if the price rises once the GDP is higher.

Table 43: Coefficients for cost elasticities for freight

Coefficients:	Value	Std. Error	t-ratio
(Intercept)	-0.87	0.09	-9.78
Source: NEA (2007)	1.03	0.12	8.47
Source: Johnson and de Jong (2011)	1.11	0.18	6.04
Mode: base (truck, air)	0	0	0
Mode: inland water ways	-0.61	0.15	-3.98
Mode: rail	-0.79	0.14	-5.88
Mode: short sea shipping	-0.52	0.15	-3.39
GDP_ppp	-5.78e-5	0.67	-2.15

4.4 Other Meta-Studies

In the literature study we have considered the meta-analyses listed Table 44. These are recent studies describing meta-models to calculate elasticities from earlier published elasticities. In this section these studies are briefly summarized and in the next section the results from the estimated elasticity meta-model for HIGH-TOOL are compared to these meta-models from the literature.

The most extensive studies with respect to the number of analysed elasticities are the studies by Wardman (1, 2). In his article about the time elasticities he includes 69 United Kingdom studies with a total of 427 elasticities. He first calculates the average elasticities for specific groups of elasticities and finally builds two meta-models. In comparison to our estimated elasticity meta-model only Wardman's second model is considered as it has a better adjusted R^2 due to outlier removal. Wardman finds 20 causal variables and 16 study specific dummies. Together they explain 64.2 percent of the variation.

Table 44: Meta-studies found in the literature

Number	Title
1	Wardman, M. (2014): Price Elasticities of Surface Travel Demand - A Meta-analysis of UK Evidence, Journal of Transport Economics and Policy (JTEP), Vol. 48, No. 3, pp. 367-384
2	Wardman, M. (2012): Review and meta-analysis of UK time elasticities of travel demand, Transportation, Vol. 39, No. 3, pp. 465-490
3	Brons, M, M. Pels, E. Nijkamp, and P. Rietveld (2002), Price Elasticities of Demand for Passenger Air Travel: A Meta-Analysis, Journal of Air Transport Management, Vol. 8, No. 3, pp. 165-175
4	Nijkamp, P. and G. Pepping (1998): Meta-Analysis for Explaining the Variance in Public Transport Demand Elasticities in Europe, Journal of Transportation Statistics, Vol. 1, No. 1, pp. 1-14

Number	Title
5	Kremers, H., P. Nijkamp, and P. Rietveld (2002): A meta-analysis of price elasticities of transport demand in a general equilibrium framework, Economic Modelling, Vol. 19, No. 3, pp. 463-485
6	Holmgren, J. (2007): Meta-analysis of public transport demand, Transportation Research Part A: Policy and Practice, Vol. 41, No. 10, pp. 1021-1035
7	Hensher, D. (2008):Assessing systematic sources of variation in public transport elasticities: Some comparative warnings, Transport Research Part A: Policy and Practice, Vol. 42, No. 7, pp. 1031-1042
8	Melo P., D. J. Graham, and R. Brage-Ardao (2013), The productivity of transport infrastructure investment: A meta-analysis of empirical evidence, Regional Science and Urban Economics, Vol. 43, No. 5, pp. 695-706

Wardman's study on cost elasticities is based on 1633 direct elasticities for surface modes (not including air travel) determined in 167 UK studies. Again, first average elasticities are calculated and two meta-models are developed: a fixed effects model and a random effects model. In comparison to our estimated elasticity meta-model for HIGH-TOOL, only the fixed effect model is considered due to a better R^2. Because of the large amount of elasticities collected, Wardman is able to identify 39 significant variables which explain 64.0 percent of the variation between the cost elasticities. For both types of elasticities, he finds significant variables for different model and data types, purposes, ticket types and additional categories.

In Brons et al. (3), the elasticities for passenger air travel were analysed. Their model is based on 204 elasticities. In the model they find significant coefficients for the year of the study, long-run studies, the travel class, the GDP and the data type. However it was not possible to unambiguously calculate elasticities from their study due to the absence of the exact functional form of the analysis in their paper. Therefore, this paper is not used in the comparison.

Nijkamp and Pepping (4) discuss public transport demand elasticities in Europe. They include 12 studies and conclude that the amount of data is too limited to analyse multiple degrees of freedom. In a "rough set analysis" they give ranges of elasticities depending on the country, the level of aggregation, an indicator of transport demand and geographical coverage. The ranges are not shown in the comparison to the elasticity meta-mode for HIGH-TOOL.

Kremer and co-authors (5) describe a meta-analysis on cost elasticities of transport demand. The focus of the paper is on the analysis of different modelling frameworks like discrete choice, micro-economic and micro-econometric models. In total they include 24 studies and build a meta-model. It includes significant variables for the mode, the distinction between passengers and freight, the data-type, the aggregation level and the urban scale. The results are compared to the estimated elasticity meta-model for HIGH-TOOL.

The meta-analysis of Holmgren (6) contains in total 186 elasticities collected in Europe, the USA and Australia. In the paper he develops different models for the 81 cost elasticities, the 58 vehicle-km elasticities, and additional models with respect to car ownership, the price of petrol and income. In addition to the coefficients of the regression he calculates 95% confidence intervals for short- and long-run elasticities for two regions (Europe and USA/Australia). These elasticities are considered in the comparison with the estimated elasticities meta-models for HIGH-TOOL.

The study by Hensher (7) is about public transport elasticities and does not include the mode car at all. It is based on 319 observations mainly observed in the USA and Australia. He identifies fourteen variables which explain 32 percent of the elasticity variations. His final model includes dummy variables for two vehicle types (bus and train), two time periods (peak and all-day), four ticket classes (multi ride, one hour, four hours, and day), for the trip purpose (student travel), for the location (Australia and US) kind of elasticity (distance), for the data type (combined SP/RP data) and for two types of elasticities (fare elasticity, in-vehicle time elasticity). In the paper, Hensher also tests the effect of dividing the dataset in three individual data sets based on the type of the elasticity. He estimates a meta-model for fare elasticities based on 241 elasticities, for in-vehicle time elasticities (58 observations) and headway elasticities (20 observations). In the comparison with our estimated elasticity meta-models for HIGH-TOOL, only the model of all elasticities are be shown as a reference.

Study 8 by Melo et al. focuses on the linkage of infrastructure investments and economic growths. The meta-model does not provide comparable estimates of time and cost elasticities and is therefore not compared with our estimated elasticity meta-model for HIGH-TOOL.

4.5 Using the Estimated Elasticity Meta-Model and Comparing Results

Now that we obtained both the elasticity model estimated from our own collection of elasticities and a collection of elasticities from other meta-models from the literature, we can make a comparison. We had to limit our comparison to the passenger elasticities due to the non-availability of freight meta-models. For an overview of some basic characteristics of the different meta-models see Table 45.

Table 45: Comparison of the meta-model to meta-models from the literature

Study	Wardman (2014)	Wardman (2012)	Kremer (2002)	Holmgren (2007)	Hensher (2008)	HIGH-TOOL (2015)
Elasticities						
Price	Yes	—	Yes	Yes	Yes	Yes
Time	—	Yes	No	No	Yes	Yes
Other	—	—	—	vkm	headway	—
Dimensions						
Surface-mode	Car & Public Transport	Car & Public Transport	Car & Public Transport	Public Transport	Public Transport	Car & Public Transport
Country	UK	UK	Europe, USA	Europe, USA, Australia	Europe, USA, Australia, New Zealand	Europe
Freight	No	No	Yes	No	No	Yes
Air	No	No	Yes	No	No	Yes

We make our comparison by employing the equations as described in paragraphs 4.3.2 and 4.3.3. However, we make a slight amendment by taking into account the fixed effects for the estimated elasticity meta-model for HIGH-TOOL. The fixed effect coefficients describe the significant systematic offsets in the values for the elasticities found in different studies. The offset can be caused by different methodologies used in the studies or unobserved differences in the data. We have, obviously, no indication which study represents the 'true' elasticities. For this reason, we add the coefficients of the fixed effects, weighted with the number of elasticities from these studies, to the elasticities. Also since we know the parameters that are used to predict elasticities, we use the last equation from paragraph 0 to calculate the standard error.

All studies except (4) give the full list of coefficients in the publication. This makes it possible to calculate elasticities in the analysed parameter range and compare individual studies in overlap regions. Therefore, the described meta-models have been rebuilt to forecast elasticities to validate the meta-analysis for HIGH-TOOL presented here. This allows on the one hand to forecast specific elasticities and on the other hand to explore the range of elasticities for a specific group of elasticities.

In paragraph 0, we described a method to determine uncertainty ranges for the calculated elasticities. In the literature only Holmgren (6) gives uncertainties on a selected set of estimated elasticities. As uncertainties cannot be estimated without knowing the mean and the variance in each dimension (see 0) it is not straight forward to determine whether models are in agreement or disagreement.

Another difficulty in the comparison of meta-models is that the different meta-analyses determine the dependencies of the elasticities in different dimensions. In our meta-analysis of passenger cost elasticities (Table 43) four dimensions have been explored (2 kinds, 7 modes, 5 purposes (see Table 44) and the year in which the elasticity has been published). From this information elasticities can be calculated in these four dimensions. In the study on the same type of elasticities by Wardman the dimensions are model & data, distance, bus fare type, car cost type, mode & ticket type, purpose, area, price index, car ownership and elasticity type.

We want to discuss the challenge of comparing meta-models using the example of the distance and area variables in the Wardman study of cost elasticities. These variables do not occur in the HIGH-TOOL meta-analysis and most other studies. Only in Kremer (5) a distinction between urban-scale and national scale models is made.

Wardman distinguishes between five distance classes. They are Urban (base category, within a city), InterUrban-Rail (not significant, between cities), InterUrban-Bus (1.7, +25.6%)[21], InterUrban-CarTrips (3.8, +77.0%) and InterNonLondon-Rail (2.2, -7.2%). For urban trips (no distinction for not-inter urban trips) different area types are analysed. They are rural (base category), UrbanPTE-Rail[22] (8.3, -40.6%), UrbanPTE-Bus (3.9, -22.9%), UrbanNonPTE-Rail (not significant), UrbanNonPTE-Bus (2.7, -18.6%), London-Rail (3.0, -37.2%) and London-Bus (not significant).

If we, for instance, have calculated an elasticity for rail passengers with the estimated elasticity meta-model for HIGH-TOOL and want to compare it with an elasticity from Wardman, we have to choose a distance (and an area) class. For rail, we made the assumption that most of the trips are inter-urban[23] (a distance-class choice). Therefore, we do not have to specify an area. For bus transport, a reasonable assumption is that most trips are urban trips. This choice requires the additional choice of an area. Also here one might argue that the specific elasticity for London is less representative than a more general region. However, whether a PTE region, a non-PTE region or a non-urban region is the appropriate choice, is hard to estimate without knowing the exact details of the different transport systems like for instance fares, schedules and accessibility.

[21] In brackets the t-ratios of the parameters and their effect on the elasticity in the meta-analysis are given.

[22] PTE stands for passenger transport executive. PTE's provide, plan, procure and promote public transport in six of England's largest conurbations excluding London.

[23] We also assume that the more general category InterUrban-Rail is a better approximation for European transport than InterNonLondon-Rail, which takes into account the effect from the lower fares on these trips compared to trips with origin or destination in London.

Being aware of these limitation, Figure 12 shows a comparison of the calculated elasticities from the estimated elasticity meta-model for HIGH-TOOL (black dot) with the meta-models from Wardman (red triangle pointing up), Hensher (magenta circle), Holmgren (blue triangle pointing down) and Kremers (turquois square) for four passenger time elasticities (top) and four passenger cost elasticities (bottom). The error bars indicate 95% confidence levels.

The estimated elasticity meta-model cost elasticities are evaluated for the year 2000, which is a few years earlier than the average publishing year[24] of the meta-analyses used in the comparison. The time elasticities are calculated with a GDP per capita of 24874 (average value of the European Union in 2000). We show the demand elasticities (base category for kind) for the long run (base category for term). For the time elasticities we compare the modes BTM and car. The latter is included in the base category as car driver and car driver + car passenger (see Table 44). In addition, two purposes are distinguished: The base category including all purposes except for education and non-home-based business (all purposes in Figure 12) and the purpose education.

For the cost elasticities two purposes are analysed: the base category (see Table 43, called all purposes in Figure 12) and the purpose private. For modes we present car driver and car passenger (car in Figure 12) and train as examples. For the other meta-studies we have tried to match these choices as closely as possible. Remark that the studies of Wardman and Hensher include some variable that do not occur in the estimated elasticity meta-models for HIGH-TOOL. Elasticity values thus depend on the choices that are made regarding the values of these variables. Therefore, for these studies, multiple elasticity values are shown in the figure, indicating the spread the results from different assumptions on the value of these variables.

[24] With this time difference we take into account the time differences between the publication of the original elasticities and the meta-analyses.

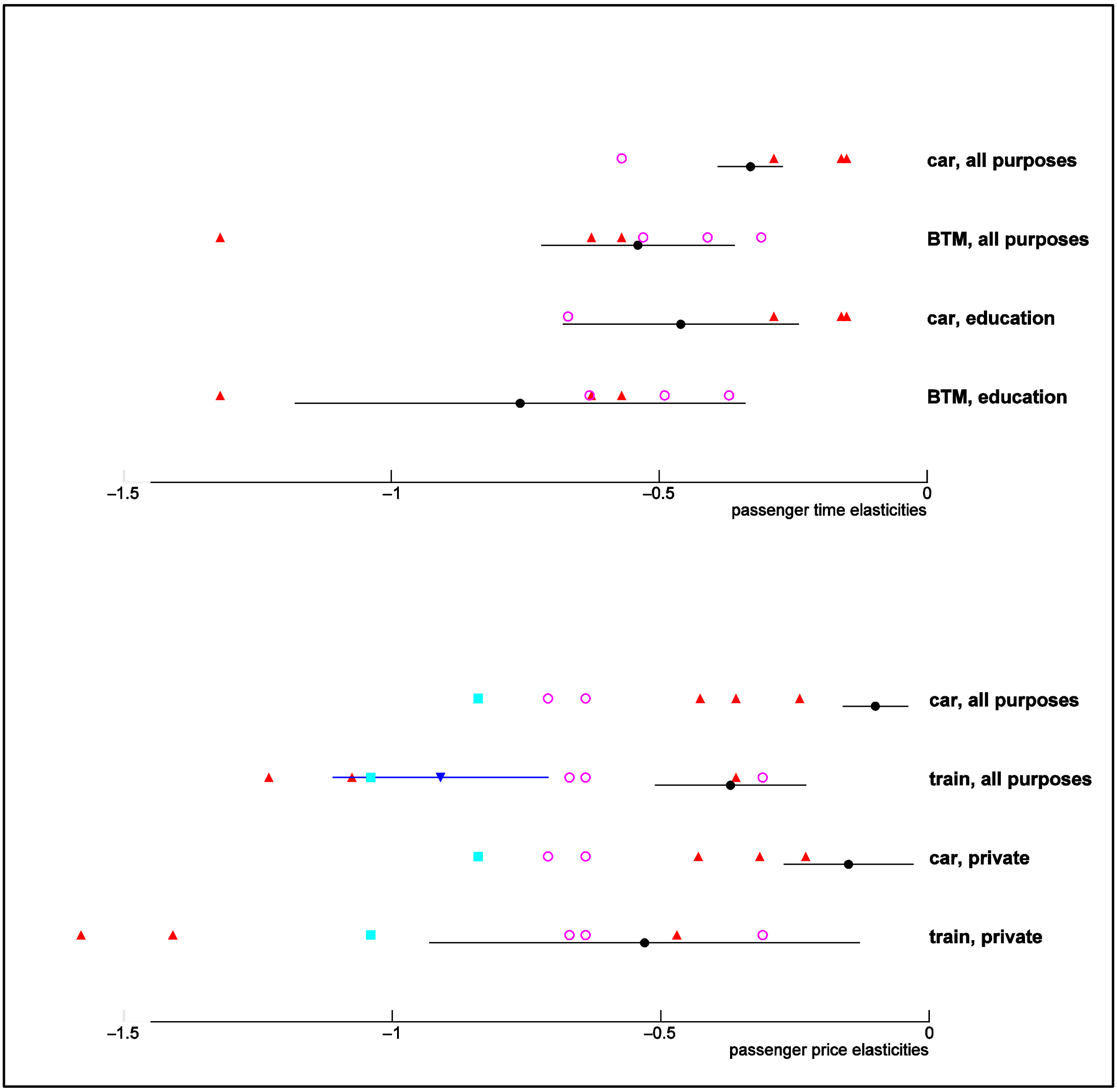

Figure 13: Comparison of calculated elasticities by the meta-model for HIGH-TOOL and other meta-models

For the studies of Wardman and Hensher, multiple elasticities are shown to indicate the spread in the possible outcomes depending on the choices on variables that do not occur in our elasticity meta-model for HIGH-TOOL (for instance ticket-type, area and distance). Figure 12 shows some interesting results. The first and most obvious one is that the elasticities of the different models seem to be all over the place. Our meta-model elasticities are not in particularly good agreement with the other meta-models and the other models also do not agree among each other as well. However, when looking at the time elasticities some general trends can be observed.

The absolute value of the car elasticities is smaller than for other modes. The fact that longer travel times have only a limited influence on car use is a commonly known. The BTM elasticities from Wardman that are far away from all other elasticities, are extracted from an original table in which he calculates illustrative elasticities [25]. The value of -1.32 corresponds to bus trips with a trip length of 25 km and more for a long run period. The rest of the elasticities are in reasonable agreement if we consider the full range of the variation in the different studies.

For the cost elasticities we have more sources available. It is obvious that the different studies have systematic offsets from each other. The reason for this could be the different regions in which the elasticities have been collected for the different meta-studies. The study of Hensher for instance mainly includes elasticities determined in countries outside Europe and Wardman focuses exclusively on the United Kingdom. The elasticities might not be valid within the European Union as the elasticities strongly depend on policies in specific countries or regions and personal preferences of the users. A possible difference is the degree of subsidy in public transport. Subsidized transport systems tend to have smaller elasticities than systems operating in the free market. In the latter one prices are optimized to maximize profit, which is usually at a point with an elasticity close to minus one.

4.6 Conclusions

This chapter presents an elasticity meta-model for elasticities relevant for the final HIGH-TOOL model. In order to do so, we first collected elasticities from the literature. We used these elasticities to estimate four independent meta-models a cost and a time model for both passenger and freight. We account for, among other effects, several modes of transportation, purposes and kinds of freight. We validated our elasticity meta-models for HIGH-TOOL against established meta-models in the literature and presented the results.

Based on our efforts outlined above, we draw the following conclusions:

- Our literature review yields enough elasticities to make four individual meta-models.
- The coefficients obtained in these models have sizes and signs that are plausible.
- The estimated elasticity meta-models for HIGH-TOOL enable us to calculate elasticities that were not in the original data base.
- We include their uncertainties in the resulting calculation. With this addition it is possible to decide if elasticities are significantly different or in agreement within the uncertainties.

[25] Table 9 in "Review and meta-analysis of UK time elasticities of travel demand". We could not reproduce these elasticities by redoing the calculations. However, even after contacting the author, the exact procedure of the calculation remained somewhat unclear.

- Comparing the established elasticity meta-models for HIGH-TOOL with those found in the literature reveals that the expected range for certain elasticities is rather large.
- This large range might or might not be explained by taking into account certain coefficients that were not estimated in the models.
- Our calculated elasticities are sometimes within the range set out by the established meta-models, and sometimes fall outside the range of the established meta-models.

So, given the above observations, what can be concluded? Can we use our meta-models for elasticities to validate our elasticities from the HIGH-TOOL model? The answer is yes. However, this is not necessarily an easy task. In light of the large variance of results, the difficult interpretation of the elasticity values as they depend on various restrictions, and the uncertainty of data used for estimation, the results obtained have to be handled very carefully. Where the HIGH-TOOL elasticities comply with the meta-model elasticities a positive validation is the conclusion, whereas where the HIGH-TOOL elasticities fall outside the range provided by the elasticity meta-model for HIGH-TOOL the conclusion to simply invalidate the HIGH TOOL results is not necessarily correct. In the latter case the meta-model background provides a basis for further discussion and investigation.

5 Operationalisation of Transport Policy Measures

5.1 Introduction

The main users of the HIGH-TOOL model are transport policy specialists of the European Commission. They will use the HIGH-TOOL model to evaluate the transport, economic, social, and environmental impacts of European transport policies at a strategic level. The HIGH-TOOL model allows a wide range of Transport Policy Measures (TPMs) to be tested and can indicate at an early stage whether a policy is promising or not suitable for further development. Policies that are potentially promising can thereafter be evaluated in more detail.

HIGH-TOOL does not only work with a limited set of pre-defined TPMs that are coded into the model; the model also allows users to analyse a wide range of custom policies by combining existing TPMs and through adjusting the set of input parameters. Therefore, the model provides maximum flexibility in policy specifications and the evaluation of future policies. Moreover, in case of unsatisfactory or undesirable impacts, a TPM can be reconsidered, adapted, and thereafter re-evaluated with the HIGH-TOOL model in a sequence of iterations until the policy target is met. This all implies that before it can be evaluated, a TPM needs to be translated into a set of numerical input parameter values that adequately reflect the policy measure.

Within the HIGH-TOOL project a selection of TPMs is included (Vanherle et al., 2014). Each of these TPMs needed to be translated into viable model input by answering the questions which input parameters have to be adjusted (the policy levers) and to which extent. This chapter describes how these questions have been answered. Paragraph 5.2 first describes the process of modelling TPMs with the HIGH-TOOL model and then focuses on the step of translating policy measures into model input parameter values. Paragraph 5.3 gives an overview of the considered TPMs while Paragraph 5.4 describes the sources that have been used. Paragraph 5.5 then describes how the policy lever values are presented in the accompanying EXCEL sheet[26] and explains how correlated TPMs are dealt with. This chapter is finalized in paragraph 5.6 with a number of concluding remarks.

[26] 2016_03_21 Policy lever values.xlsx

5.2 Modelling Transport Policy Measures

Figure 13 schematically describes the transport policy measure evaluation process. In general, policy making starts with the specification of initiatives that describe certain policy goals and targets. Next, these initiatives are translated into more concrete transport policy measures that can be assessed by a strategic transport model such as HIGH-TOOL. For each of these TPMs a set of impact indicators is constructed. These impact indicators reflect the underlying goals and targets of a TPM and allow its quantitative evaluation. Furthermore, in order to use HIGH-TOOL to evaluate transport policy mearures, TPMs are translated into model input. That is, it is determined by which model parameters a TPM can best be described and how much to adjust these parameters.

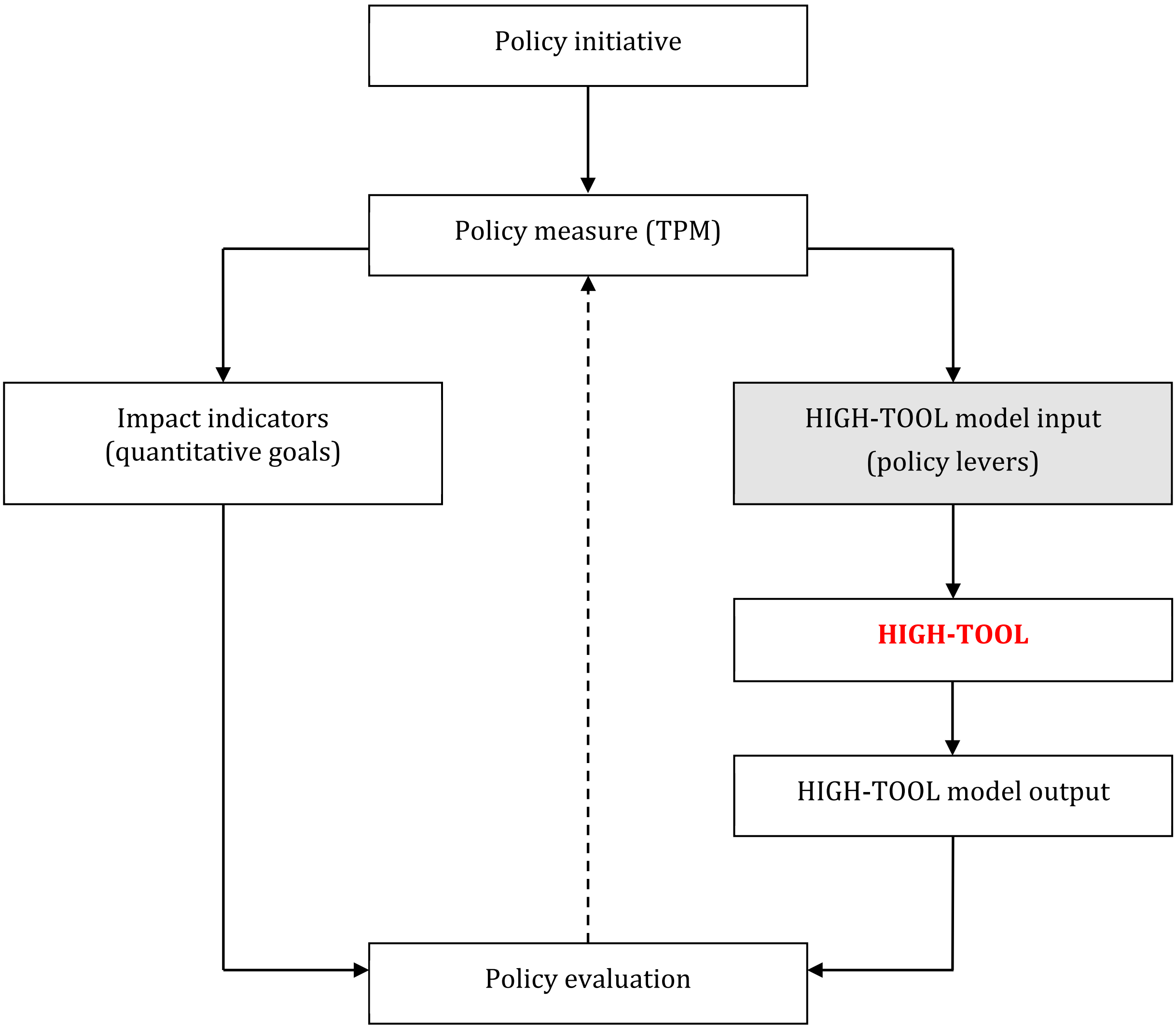

Figure 14: Transport policy measure evaluation process

This chapter focuses on the step from transport policy measure to model input. The HIGH-TOOL model provides a range of input parameters that can be adjusted; these are the so-called 'policy levers'. For each TPM, one or more policy levers need to be selected that can be used to represent it. Next, realistic values need to be assigned to these policy levers. The HIGH-TOOL model can then be used to predict the direct and indirect effects of a transport policy measure. As an example, the road speed reduction TPM can be modelled by adjusting the 'highway speed' policy lever. TPM content and policy levers are further dealt with by Mandel et al. (2016).

The best way to model a specific transport policy measure in the HIGH-TOOL model depends on the available policy levers that can be adjusted. In the best case, each TPM is directly represented by a policy lever. However, as the HIGH-TOOL model is designed as a high level-strategic modelling tool, it does not always have the required level of detail to do so. Hence, in some cases a TPM can only be modelled indirectly. Whether or not a TPM can be modelled directlydepends as well on the nature of the TPM. Whereas the example of speed limits is very clear, for a TPM like 'opening the rail market' it is less straightforward to identify appropriate policy levers. Finally, not all TPMs are described in the same level of detail. Where some are very specific, others cover a package of measures. In the latter case, the set of selected policy levers need to reflect the combined effects of these measures. In general it has to be considered as well that the HIGH-TOOL model is based on NUTS-2 level and the underlying data sample is quite different from other studies so that values to be applied always need the expert judgement of a HIGH-TOOL modeller.

The first step of identifying appropriate policy levers (model input parameters) has been done for each of the seven HIGH-TOOL modules: Economy & Resources, Demography, Passenger Demand, Freight Demand, Vehicle Stock, Environment, and Safety. Herein, a distinction is made between first order TPM policy levers and second order influences. First order policy levers are the model input (variables and their values) that describe a TPM. Second order influences are the affected variables that are passed on between different modules of the HIGH-TOOL model. An overview of selected policy levers can be found in Annex A. The HIGH-TOOL model only produces useful model output if the selected policy levers have realistic values that adequately reflect the intensity by which a certain transport policy measure can be implemented. Therefore, the remainder of this chapter discusses how reasonable policy levers have been defined and how they are used to evaluate (combinations of) TPMs.

5.3 Considered Transport Policy Measures

In total, 34 transport policy measures (see Table 46) are considered. These can be classified as belonging to one of the following policy areas:

- Pricing
- Research and Innovation
- Efficiency standards and flanking measures
- Internal market.

Within each of these classes, TPMs are further grouped into policy categories that are adopted from the ASSIST project (Maurer et al., 2011). An overview of this classification structure can be found in Vanherle et al. (2014). The majority of TPMs are adopted from the transport White Paper (European Commission, 2011). This document describes an inventory of 40 policy initiatives that each represents a set of transport policy measures that have a common purpose. From these, a selection of 22 TPMs is considered to be crucial for evaluation in HIGH-TOOL. During the development of HIGH-TOOL additional effort has been put into developing the required model functionalities at the desired level of detail. Another 12 policy measures are adopted from the ASTRA project (Fermi et al., 2014).

Table 46: Considered transport policy measures (TPMs)

TPM	Policy area	Source
1. Opening the internal rail market	Internal market	White Paper
2. Single rail vehicle autorisation and certification	Internal market	White Paper
3. Freight corridor management	Internal market	White Paper
4. Access to rail infrastructure	Internal market	White Paper
6. Enhance service quality at airports	Efficiency standards and flanking measures	White Paper
10. Maritime traffic management system	Internal market	White Paper
12. Enhance service quality at ports	Internal market	White Paper
14. Opening the internal IWW market	Internal market	White Paper
16. Single European road market	Internal market	White Paper
23. Harmonized social rules for truck drivers	Internal market	Astra
33. Safety systems for road vehicle users	Research and Innovation	Astra
37. Road vehicle safety technology protecting other transport users	Research and Innovation	White Paper
42. Harmonisation of rail safety	Internal market	White Paper
44. Harmonized handling of dangerous goods	Internal market	White Paper

TPM	Policy area	Source
50. Deployment of efficient vehicles	Efficiency standards and flanking measures	White Paper
56. European Rail Traffic Management System	Internal market	White Paper
57. River information system	Internal market	Astra
58.1. Intelligent traffic information system for road	Research and Innovation	White Paper
58.2. Dynamic traffic management for road	Research and Innovation	White Paper
58.3. Intelligent road vehicles	Research and Innovation	White Paper
63.1. Replacement of inefficient cars	Efficiency standards and flanking measures	Astra
63.2. Diffusion of electro cars	Efficiency standards and flanking measures	Astra
63.3. Diffusion of H_2 fuel cell cars	Efficiency standards and flanking measures	Astra
78. LDV speed limit	Efficiency standards and flanking measures	White Paper
81. Urban road charging	Pricing	White Paper
83. HDV limitation for urban areas	Efficiency standards and flanking measures	Astra
86. Acceleration of TEN-T implementation	Internal market	Astra
92. Replacement of inefficient LDVs and buses	Efficiency standards and flanking measures	White Paper
98. HDV infrastructure charge	Pricing	White Paper
100. Internalisation of external costs	Pricing	White Paper
102. Circulation tax for cars	Pricing	Astra
109. Improving local public transport	Efficiency standards and flanking measures	Astra
110. CO_2 certificate system for road transport	Pricing	Astra
111. CO_2 feebates for road transport	Pricing	Astra

5.4 Data Sources

To determine how the considered TPMs can be translated into appropriate values for the input parameters of the model, several sources have been checked. These sources differ in the strength of their underpinning and the scalability of parameter values to the spatial level that is considered in HIGH-TOOL. The following sources have been reviewed:

Large-scale (European) model applications: these sources provide direct examples of how TPMs were translated into quantitative model input parameters. Projects that have been studied include SUMMA, EXPEDITE, and TRANSTOOLS. Other modelling projects, such as TRANSVISONS and ASTRA either do not model individual TPMs or do not describe the exact way they are implemented. In general, these findings are well-scalable to the required spatial level-of-detail, but sometimes lack a strong theoretical underpinning.

Examples from practice: in some cases TPMs are already implemented in practice and described in the literature. Whereas these examples often provide realistic policy lever values, their scalability largely depend on the scale by which the transport policy was applied in practice and on the local circumstances.

Research publications: for some TPMs useful information was found in research publications. Most of these studies describe model simulations, field tests, surveys, or expert judgement on specific TPMs. In general, these findings have a strong underpinning, but are less easily scalable to the spatial level that is considered in HIGH-TOOL. It is not always clear how a measure is applied and the influence of local circumstances may have a substantial influence on the results.

Qualitative guidelines: the last data source yields the qualitative description of policy impacts from the ASSIST project. This project delivered factsheets for a wide range of TPMs, describing their social and economic impacts.

The TPMs considered in these sources are generally not identical to those considered in HIGH-TOOL. In many cases TPMs were found that were more specific, either by focussing on a sub-element of a TPM or by geographic description. On the other hand, some TPMs found were more general. Therefore, expert judgement as well played an important role in defining appropriate policy lever values.

5.5 Results

Each Transport Policy Measure (TPM) is modelled by one or more policy levers. For each of these policy levers a default value is defined as well as a lower and upper bound. When a TPM is selected by the user the default values are automatically used; however, the user can adjust these values within the range of the lower and upper bound. Paragraph 5.5.1 describes how the chosen policy lever values are presented in the accompanying EXCEL sheet. Thereafter, Paragraph 5.5.2 addresses how HIGH-TOOL deals with overlapping TPMs.

5.5.1 Policy Lever Values

Where possible, policy lever values are expressed as a percentage of change compared to its reference scenario value. For example, a default travel time reduction of 10%, which can be adjusted by the user within the range from 5 to 15%. Alternatively, there are some policy lever values defined as a percentage of another variable. Infrastructure investment, for example, is defined as a percentage of the Gross Domestic Product (GDP). Finally, there are some policy levers where absolute values have been used. As an example, toll costs are given in Euro/kilometre as some countries do not use tolls up to now and a relative change does not allow applying a toll policy.

Depending on the nature of a TPM, its corresponding policy levers might impact only a subset of modes *m* or vehicle types *vt*. A TPM can, for example, specifically focus on passenger transport (and thus not on freight) or on a specific fuel type (electric vehicles instead of traditional fuels). Moreover, the magnitude of the impact may be different among modes and vehicle types. In these cases, separate policy lever values have been defined for all (relevant) modes and vehicle types. Most policy levers for the Passenger Demand, Freight Demand, and Safety modules are defined per mode *m*. For the Vehicle Stock and Environment modules often a distinction is made by vehicle type *vt*.

The chosen policy lever values are presented in the accompanying EXCEL sheet. This EXCEL sheet includes a table with policy levers for each HIGH-TOOL module. The different columns in these tables are further explained in Table 47.

Table 47: Columns in the policy lever value sheet

Column	Name	Description
1	Transport Policy Measure	Name of the TPM that is modelled by the policy lever
2	HIGH-TOOL module	The HIGH-TOOL module the policy lever works on
3	Policy lever	Name of the policy lever in the DataStock
4	Policy lever description	Description of the policy lever
5	Symbol	Symbol of the policy lever as it is used in this deliverable
6	Dimensions	Dimensions of the policy lever such as time *t*, mode *m*, country *ci*, region *i*, and vehicle type *vt*
7	Type	Percentage (1), percentage of another variable (2), or absolute value (3)
8	Default value	The default value that is used when a TPM is selected
9	Lower bound value	The lower bound to which a policy lever value can be lowered by the user
10	Upper bound value	The upper bound to which a policy lever can be raised by the user
11	Source	The source of the presented policy lever value

5.5.2 Correlated Transport Policy Measures

When the user selects a single TPM, the default policy lever values as presented in the accompanying EXCEL sheet are used to adjust the reference scenario values of these variables. However, it is also possible to combine multiple TPMs. In this context the occurrence of interdependence between TPMs and non-additivity needs to be considered (see e.g. Szimba 2008). Most TPMs can be combined without any problem because they use different policy levers (or they share policy levers that work on different modes or vehicle types). Such TPMs are neither conflicting nor overlapping and can be modelled simultaneously. In some cases, however, TPMs may share the same policy levers that work on the same modes and vehicle types.

In these cases special care is needed in the implementation of policy lever values, because these TPMs may not be completely independent. Depending on the nature of the involved TPMs, the combined effect of their policy levers might be as following:

- **Reduced**: When TPMs are conflicting, they might cancel each other out. For the pre-specified TPMs in the HIGH-TOOL module, such pairs have not been identified.
- **Maximized**: When TPMs are largely overlapping, the combined effect is equal to the strongest TPM. In these cases the second TPM has no affect anymore.
- **Limited**: In these cases TPMs only partly overlap. Combining them therefore has some effect, but this effect is limited.
- **Maximum:** Even when TPMs share the same policy levers, they may be completely independent. That is, there policy lever values are additive and these TPMs can be freely combined.

There are no pairs of TPMs that fall into the first group, while pairs in the last group can be freely combined by adding up their policy lever values. However, six groups of TPMs have been identified that share the same policy levers and are considered to be partly or largely overlapping. These groups are presented in Tables 48–53.

For the shared policy levers of these groups it has been defined how to model them simultaneously. Three different rules have been applied to combine their policy levers:

- **Rule 1 (additive)**: Even if TPMs are overlapping, some of their policy levers may simply be additive.
- **Rule 2 (maximum)**: When a group of TPMs fall in the second category (maximized) the highest policy lever value among them is taken as input to the HIGH-TOOL module.
- **Rule 3 (limited)**: When TPMs fall in the third category (limited) the highest policy lever counts for the full 100%, the second for 50%, the third for 25%, and so on. That is, the contribution of every next policy lever is a factor two lower than the one before. In order to apply this rule, the involved TPMs have to be order by the magnitude of their policy levers;

For some groups (group 2 and 6) the last two rules are combined. That is, the policy levers of the first two TPMs are combined by rule 2. Thereafter, the resulting policy lever is combined with the third TPM through rule 3. This is indicated in the tables below in the 'Combination' columns. The remaining columns show for each of the TPMs within the group whether it includes the shared policy lever that is specified in the first column.

The first group (Table 48) includes the following TPMs: Rail market, Freight corridor, Access. Each of these TPMs relate to competition in the rail market.

Table 48: Overlapping TPMs group 1

Policy lever description	**1. Rail market**	**3. Freight corridor**	**4. Access**	**Combination**
Access and egress travel time	1		1	**Limited**
Change in level-of-service indicator	1		1	**Limited**
Waiting time	1	1	1	**Limited**
Other costs for rail passenger and freight demand	1	1	1	**Limited**
Average freight load factor		1	1	**Limited**

The second group (see Table 49) includes the TPMs ERA, ERTMS, and Rail safety. These TPMs all relate to rail safety. Remark that the effect of shared policy levers among TPMs 2 and 56 is limited. The resulting policy levers values are combined with those of TPM 42 through the maximization rule.

Table 49: Overlapping TPMs group 2

Policy lever description	**2. ERA**	**56. ERTMS**	**Combination**	**42. Rail safety**	**Combination**
Change in level-of-service indicator	1	1	**Limited**	1	**Maximized**
Travel time	1	1	**Limited**	1	**Maximized**
Waiting time	1		-	1	**Maximized**
Average rail vehicle purchase price		1	-	1	**Maximized**
Other costs for rail passenger and freight demand		1	-	1	**Maximized**
Policy change accident cause operating and signalling staff error		1	-	1	**Maximized**
Policy change accident risk driver and train crew error		1	-	1	**Maximized**
Policy change accident risk track and switch maintenance errors		1	-	1	**Maximized**

Group three includes the TPMs Road safety and New vehicles (Table 50). Both of these TPMs stimulate the use of safer vehicles.

Table 50: Overlapping TPMs group 3

Policy lever description	**33. Road safety**	**92. New vehicles**	**Combination**
Policy change accident cause speed	1	1	**Limited**
Policy change accident cause driving under influence	1	1	**Limited**
Policy change accident risk distraction	1	1	**Limited**
Policy change accident cause fatigue	1	1	**Limited**
Policy change accident cause vehicle defect	1	1	**Limited**
Policy change accident cause belt use and child restraints	1	1	**Limited**

The fourth group (see Table 51) includes TPMs on Intelligent Traffic Systems (ITS): ITS traffic information, ITS dynamic traffic management, and ITS intelligent vehicles.

Table 51: Overlapping TPMs group 4

Policy lever description	**58.1 ITS traffic infor-mation**	**58.2 ITS Dynamic traffic management**	**58.3 ITS Intelligent vehicles**	**Combination**
Change in level-of-service indicator	1	1	1	**Limited**
Travel time	1	1	1	**Limited**
Speed	1	1	1	**Limited**
Technology related additional capital costs	1	1	1	**Limited**

The fifth group include the TPMs Car replacement, Electric cars, H_2 cars, New vehicles, and CO_2 feebates (seeTable 52). These TPMs all relate to the diffusion of cleaner vehicles.

Table 52: Overlapping TPMs group 5

Policy lever description	**63.1 Car replacement**	**63.2 Electric cars**	**63.3 H2 cars**	**92. New vehicles**	**111. CO_2 feebates**	**Combination**
Average vehicle purchase price without VAT	1	1	1	1	1	**Additive**
Technology related additional capital costs	1	1	1	1	1	**Additive**
Emission index	1	1	1	1		**Limited**
Load capacity				1		**Limited**
Load factor				1		**Limited**

The last group of overlapping TPMs consist of Urban road, Heavy duty charge, and External costs (seeTable 53). These TPMs all relate to road charging.

Table 53: Overlapping TPMs group 6

Policy lever description	**81. Urban road**	**98. Heavy duty charge**	**Combination**	**100. External costs**	**Combination**
Toll cost rate	1	1	**Limited**	1	**Maximized**

5.6 Concluding Remarks

Within the final version of the HIGH-TOOL model 34 Transport Policy Measures (TPMs) are evaluated. Each of these TPMs is modelled by adjusting a number of selected model input variables. These variables are the so-called 'policy levers'. First, a selection of appropriate policy levers for each TPM was made by the developers of each module. Thereafter, an appropriate default, lower bound, and upper bound value was assigned to these policy levers for each relevant dimension (mode and vehicle type). Special attention was given to the combination of overlapping TPMs. For these cases a set of rules has been implemented in the model to derive realistic policy lever values that adequately represent the combined effect of overlapping TPMs.

6 References

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7 Other Project Resources

ASSIST (Assessing the Social and Economic Impacts of Past and Future Sustainable Transport): http://www.assist-project.eu

CARE (Crash database): http://ec.europa.eu/transport/road_safety/specialist/statistics/care_reports_graphics/index_en.htm.

ETISplus (European Transport Policy Information System Development and Implementation of Data Collection Methodology for EU Transport Modelling): http://www.etisplus.eu.

EUROSTAT (EUROSTAT database): http://ec.europa.eu/eurostat.

EXIOBASE (Global, detailed Multi-regional Environmentally Extended Supply and Use/Input Output database): http://exiobase.eu/component/content/?view=featured.

EXPEDITE (Expert System based Predictions of Demand for Internal Transport in Europe): http://www.transport-research.info/web/projects/project_details.cfm?id=13605.

HIGH-TOOL (Strategic high-level transport model): http://www.high-tool.eu.

iTREN (integrated TRansport and ENergy Baseline until 2030): http://www.transport-research.info/web/projects/project_details.cfm?id=11061.

MOVEET (Mobility, vehicle fleet, energy use and emissions forecast tool): http://www.tmleuven.com/methode/moveet/home.htm.

NEAC (Freight network model): http://www.efreightproject.eu/knowledge/Info.aspx?docID=129.

PRIMES (Partial equilibrium model for the European Union energy markets): http://ec.europa.eu/environment/archives/air/models/primes.htm.

RHOMOLO (Regional Holistic Model): http://www.tmleuven.be/project/rhomolo/home.htm.

SUMMA (Sustainable Mobility, policy Measures and Assessment): http://www.transport-research.info/web/projects/project_details.cfm?id=8117.

TRACCS (Transport data collection): http://traccs.emisia.com.

TRANSTOOLS (Tools for Transport Forecasting and Scenario Testing): http://www.transport-research.info/web/projects/project_details.cfm?ID=11088.

TTv3 (Research and development of the European Transport Network Model, TRANSTOOLS Version 3): http://www.transport-research.info/web/projects/project_details.cfm?id=41354.

TREMOVE (Economic transport and emissions model): http://www.tmleuven.com/methode/tremove/home.htm

Deliverable D4.3 Annex

Elasticities and Equations of the HIGH-TOOL Model (Final Version)

Table of Contents

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1 Policy Levers

Table 1: Policy lever overview

Policy lever	Description	Module	Name in Database
INV	Investment into fixed capital formation	Economy and Resources	i_er_delta_inv
Infinv	Infrastructure investment	Economy and Resources	i_er_delta_inf_inv
RTD	Investments in research and development	Economy and Resources	i_er_delta_rtd
timeae	Access and egress travel time [min]	Passenger Demand	i_pd_core_lever_ae_time
Δlos	Change in level of service indicator	Passenger Demand	i_pd_core_lever_delta_los
costtoll	Toll costs [EUR/vehicle-kilometre]	Passenger Demand	i_pd_core_toll_cost
dist	Travel distance [kilometre]	Passenger Demand	i_pd_core_lever_net_dist
time	Travel time [min]	Passenger Demand	i_pd_core_lever_net_time
timeae	Urban ccess and egress travel time [min]	Passenger Demand	i_pd_urban_duaetime
costtoll	Urban toll costs [EUR/vehicle-kilometre]	Passenger Demand	i_pd_urban_dutoll
dist	Urban travel distance [kilometre]	Passenger Demand	i_pd_urban_dutraveldist
time	Urban travel time [min]	Passenger Demand	i_pd_urban_dutraveltime
crfix	Fixed cost [EUR/vehicle-hour]	Freight Demand	p_fd_fixed_cost
crvar	Variable cost [EUR/vehicle-kilometre]	Freight Demand	p_fd_var_cost
load	Average freight load factor [tonnes/vehicle]	Freight Demand	p_fd_load_factor
cap	Loading capacity [tonnes/vehicle]	Freight Demand	p_fd_load_capacity
costtoll	Toll cost rate [EUR/vehicle-kilometre]	Freight Demand	i_fd_toll_cost
timeload	Loading time [hour]	Freight Demand	p_fd_load_time
timeunload	Unloading time [hour]	Freight Demand	p_fd_unload_time
timewait	Waiting time [hour]	Freight Demand	p_fd_wait_time
v	Speed [kilometre/hour]	Freight Demand	p_fd_speed
i_vs_nf_rail_othc	Other costs for rail passenger and freight demand [EUR/tonne-kilometre]	Vehicle Stock	i_vs_nf_rail_othc

i_vs_nf_taxfuel	Energy tax part in total fuel costs [EUR/1000 litre]	Vehicle Stock	i_vs_nf_taxfuel
i_vs_nf_rof_cst_othr	Other non-fuel operational costs for freight road transport [EUR/tonne-kilometre]	Vehicle Stock	i_vs_nf_rof_cst_othr
i_vs_cap_rpcs_mkt	Average road vehicle purchase price without VAT [EUR/vehicle]	Vehicle Stock	i_vs_cap_rpcs_mkt
i_vs_cap_tech	Technology related additional capital costs [EUR/vehicle]	Vehicle Stock	i_vs_cap_tech
i_vs_nf_mar_opcost	Non-fuel operating cost for maritime transport [EUR/vehicle]	Vehicle Stock	i_vs_nf_mar_opcost
i_vs_cstiww	Freight inland water ways prices [EUR/tonne-kilometre]	Vehicle Stock	i_vs_cstiww
i_vs_nf_rof_cst_labo	Labour costs for freight road transport [EUR/tonne-kilometre]	Vehicle Stock	i_vs_nf_rof_cst_labo
i_vs_nf_cstinsu	Insurance costs for road transport [EUR/tonne-kilometre]	Vehicle Stock	i_vs_nf_cstinsu
i_vs_nf_air_neoe_fre	Non-energy related variable air transport costs [EUR/passenger-kilometre]	Vehicle Stock	i_vs_nf_air_neoe_fre
i_vs_fu_exduty_eur_1000l	Fuel costs	Vehicle Stock	i_vs_fu_exduty_eur_1000l
indet	Emission index road and rail [tonnes/tonnes of oil equivalent]	Environment	i_ev_emfactor
indet	Emission index air vehicles [gram/kilogram fuel]	Environment	i_ev_emfactor
indet	Emission index ships [kilogram/tonne fuel]	Environment	i_ev_emfactor
P(bs)	Policy change in accident cause blind spot truck [%]	Safety	i_sa_blind_spot_truck
P(ce)	Policy change in accident cause flight crew error [%]	Safety	i_sa_crew_error_air
P(ce)	Policy change in accident risk driver and train crew error [%]	Safety	i_sa_crew_error_rail
P(dis)	Policy change in accident risk distraction bike [%]	Safety	i_sa_distraction_bike
P(dis)	Policy change in accident risk distraction car [%]	Safety	i_sa_distraction_car
P(dis)	Policy change in accident risk distraction p2w [%]	Safety	i_sa_distraction_p2w
P(dis)	Policy change in accident risk distraction pt [%]	Safety	i_sa_distraction_pt
P(dis)	Policy change in accident risk distraction truck [%]	Safety	i_sa_distraction_truck

P(dui)	Policy change in accident cause driving under influence bike [%]	Safety	i_sa_dui_bike
P(dui)	Policy change in accident cause driving under influence car [%]	Safety	i_sa_dui_car
P(dui)	Policy change in accident cause driving under influence p2w [%]	Safety	i_sa_dui_p2w
P(dui)	Policy change in accident cause driving under influence pt [%]	Safety	i_sa_dui_pt
P(dui)	Policy change in accident cause driving under influence truck [%]	Safety	i_sa_dui_truck
P(ef)	Policy change in accident cause engine failure air [%]	Safety	i_sa_engine_failure_air
P(pft)	Policy change in accident cause falling from train [%]	Safety	i_sa_falling_from_train_rail
I(iww)	Policy impact on fatality risk iww [%]	Safety	i_sa_fat_risk_iww
I(sss)	Policy impact on fatality risk sss [%]	Safety	i_sa_fat_risk_sss
P(fatigue)	Policy change in accident cause fatigue bike [%]	Safety	i_sa_fatigue_bike
P(fatigue)	Policy change in accident cause fatigue car [%]	Safety	i_sa_fatigue_car
P(fatigue)	Policy change in accident cause fatigue p2w [%]	Safety	i_sa_fatigue_p2w
P(fatigue)	Policy change in accident cause fatigue pt [%]	Safety	i_sa_fatigue_pt
P(fatigue)	Policy change in accident cause fatigue truck [%]	Safety	i_sa_fatigue_truck
P(fb)	Policy change in accident cause fire air [%]	Safety	i_sa_fire_air
P(hu)	Policy change in accident cause helmet usage bike [%]	Safety	i_sa_helmet_bike
P(hu)	Policy change in accident cause helmet usage p2w [%]	Safety	i_sa_helmet_p2w
P(if)	Policy change in accident cause infrastructural faults rail [%]	Safety	i_sa_infra_fault_rail
P(lcapc)	Policy change in accident cause level crossing (pedestrians/cyclists) rail [%]	Safety	i_sa_lc_vuln_acc_rail
P(load)	Policy change in accident cause loading error air [%]	Safety	i_sa_load_error_air
P(load)	Policy change in accident cause loading error truck [%]	Safety	i_sa_load_error_truck

P(mac)	Policy change in in accident cause mid-air collision [%]	Safety	i_sa_mid-air_collision
P(osse)	Policy change in accident cause operating and signalling staff error rail [%]	Safety	i_sa_osign_staff_error_rail
P(app)	Policy change in accident cause persons on platform rail [%]	Safety	i_sa_platform_acc_rail
P(belt)	Policy change in accident cause belt use and child restraints car [%]	Safety	i_sa_restraint_car
P(belt)	Policy change in accident cause belt use and child restraints truck [%]	Safety	i_sa_restraint_truck
P(rc)	Policy change in in accident cause runway collision air[%]	Safety	i_sa_runway_collision
P(fatigue)	Policy change in accident cause speed bike[%]	Safety	i_sa_speed_bike
P(fatigue)	Policy change in accident cause speed car [%]	Safety	i_sa_speed_car
P(fatigue)	Policy change in accident cause speed p2w [%]	Safety	i_sa_speed_p2w
P(fatigue)	Policy change in accident cause speed pt [%]	Safety	i_sa_speed_pt
P(fatigue)	Policy change in accident cause speed truck [%]	Safety	i_sa_speed_truck
P(rsf)	Policy change in accident cause rolling stock rail [%]	Safety	i_sa_stock_fault_rail
P(atf)	Policy change in accident cause aircraft technical failure air [%]	Safety	i_sa_tech_failure_air
P(mc)	Policy change in accident cause adequate post medical care car [%]	Safety	i_sa_time_med_care_car
P(mc)	Policy change in accident cause adequate post medical care p2w [%]	Safety	i_sa_time_med_care_p2w
P(mc)	Policy change in accident cause adequate post medical care pt [%]	Safety	i_sa_time_med_care_pt
P(mc)	Policy change in accident cause adequate post medical care truck [%]	Safety	i_sa_time_med_care_truck
P(tsmse)	Policy change in accident risk track and switch maintenance errors rail [%]	Safety	i_sa_track_staff_error_rail
P(tp)	Policy change in accident cause trespassing rail [%]	Safety	i_sa_trespassing_rail
P(vd)	Policy change in accident cause vehicle defect bike [%]	Safety	i_sa_veh_defect_bike

P(vd)	Policy change in accident cause vehicle defect car [%]	Safety	i_sa_veh_defect_car
P(vd)	Policy change in accident cause vehicle defect p2w [%]	Safety	i_sa_veh_defect_p2w
P(vd)	Policy change in accident cause vehicle defect pt [%]	Safety	i_sa_veh_defect_pt
P(vd)	Policy change in accident cause vehicle defect truck [%]	Safety	i_sa_veh_defect_truck

2 Direct Elasticities Safety Module

Table 2: Direct elasticities Safety module regarding fatalities

Elasticity	Country	Mode	Value	Source
eF,ce			0.010	ERA (2014) and UIC (2009-2013) reports
eF,osse			0.017	ERA (2014) and UIC (2009-2013) reports
eF,tsmse			0.025	ERA (2014) and UIC (2009-2013) reports
eF,rsf			0.005	ERA (2014) and UIC (2009-2013) reports
eF,if		rail	0.004	ERA (2014) and UIC (2009-2013) reports
		car	0.09	DaCoTa (2012)
		truck	0.075	ETAC (2007)
		p2w	0.093	DaCoTa (2012)
		pt	0.075	ETAC (2007)
eF,lcav			0.211	ERA (2014) and UIC (2009-2013) reports
eF,lcapc			0.096	ERA (2014) and UIC (2009-2013) reports
eF,tp			0.53	ERA (2014) and UIC (2009-2013) reports
eF,app			0.024	ERA (2014) and UIC (2009-2013) reports
eF,pft			0.019	ERA (2014) and UIC (2009-2013) reports
eF,ef			0.346	CATS (Ale et al., 2008)
eF,fce			0.227	CATS (Ale et al., 2008)
eF,atf			0.154	CATS (Ale et al., 2008)
eF,rc			0.07	CATS (Ale et al., 2008)
eF,fb			0.065	CATS (Ale et al., 2008)
eF,mac			0.045	CATS (Ale et al., 2008)
eF,load		air	0.03	CATS (Ale et al., 2008)
eF,le		truck	0.005	ETAC (2007)
eF,dui		car	0.143	BOSETTI ET AL. (2009), CADAS (2015) database
		truck	0.084	
		p2w	0.077	
		pt	0.074	
		bike	0.09	
eF,bucr	AT	car	0.063	Evans (1995), Elvik & Vaa (2004), CADAS (2015)
	BE	car	0.104	
	BG	car	0.253	
	CH	car	0.215	
	CY	car	0.126	
	CZ	car	0.139	
	DE	car	0.104	
	DK	car	0.142	
	EE	car	0.125	

ES	car	0.106
FI	car	0.104
FR	car	0.09
EL	car	0.251
HR	car	0.192
HU	car	0.164
IE	car	0.133
IT	car	0.104
LT	car	0.104
LU	car	0.125
LV	car	0.104
MT	car	0.104
NL	car	0.139
NO	car	0.128
PL	car	0.104
PT	car	0.06
RO	car	0.178
SE	car	0.104
SI	car	0.149
SK	car	0.157
UK	car	0.024
AT	truck	0.113
BE	truck	0.138
BG	truck	0.237
CH	truck	0.161
CY	truck	0.166
CZ	truck	0.162
DE	truck	0.138
DK	truck	0.185
EE	truck	0.187
ES	truck	0.136
FI	truck	0.138
FR	truck	0.133
EL	truck	0.238
HR	truck	0.128
HU	truck	0.195
IE	truck	0.136
IT	truck	0.138
LT	truck	0.138
LU	truck	0.141
LV	truck	0.138

	MT	truck	0.138	
	NL	truck	0.186	
	NO	truck	0.17	
	PL	truck	0.138	
	PT	truck	0.094	
	RO	truck	0.175	
	SE	truck	0.138	
	SI	truck	0.113	
	SK	truck	0.174	
	UK	truck	0.124	
eF,hu	AT	p2w	0.004	Elvik et al. (2009), CADAS (2015) database
	BE	p2w	0.052	
	BG	p2w	0.162	
	CH	p2w	0.031	
	CY	p2w	0.11	
	CZ	p2w	0.035	
	DE	p2w	0.052	
	DK	p2w	0.064	
	EE	p2w	0.059	
	ES	p2w	0.032	
	FI	p2w	0.052	
	FR	p2w	0.017	
	EL	p2w	0.205	
	HR	p2w	0.089	
	HU	p2w	0.048	
	IE	p2w	0.052	
	IT	p2w	0.028	
	LT	p2w	0.052	
	LU	p2w	0.13	
	LV	p2w	0.052	
	MT	p2w	0.052	
	NL	p2w	0.07	
	NO	p2w	0.008	
	PL	p2w	0.052	
	PT	p2w	0.029	
	RO	p2w	0.175	
	SE	p2w	0.052	
	SI	p2w	0.031	
	SK	p2w	0.08	
	UK	p2w	0.03	
	AT	bike	0.078	

	BE	bike	0.071	
	BG	bike	0.071	
	CH	bike	0.135	
	CY	bike	0.071	
	CZ	bike	0.154	
	DE	bike	0.071	
	DK	bike	0.114	
	EE	bike	0.071	
	ES	bike	0.108	
	FI	bike	0.071	
	FR	bike	0.085	
	EL	bike	0.071	
	HR	bike	0.182	
	HU	bike	0.207	
	IE	bike	0.071	
	IT	bike	0.168	
	LT	bike	0.071	
	LU	bike	0.071	
	LV	bike	0.071	
	MT	bike	0.071	
	NL	bike	0.071	
	NO	bike	0.052	
	PL	bike	0.071	
	PT	bike	0.142	
	RO	bike	0.071	
	SE	bike	0.071	
	SI	bike	0.115	
	SK	bike	0.159	
	UK	bike	0.002	
eF,dis		all	0.075	TRACE (Schick et al., 2008), DaCoTa (2012)
eF,fat		car	0.078	CADAS (2015) database, DaCoTa (2012)
		truck	0.091	
		p2w	0.011	
		pt	0.041	
		bike	0.008	
eF,bs		p2w	0.07	IA blind spots; CADAS (2015); SWOV-factsheet Dodehoek (SWOV, 1996)
		bike	0.07	
		pedestrian	0.07	
eF,vd		car	0.032	DaCoTa (2012)
		truck	0.039	ETAC (2007)

	p2w	0.03	DaCoTa (2012)
	pt	0.039	ETAC (2007)
	bike	0.067	Schoon et al. (1996)
eF,mc	all	0.236	Henrikson et al. (2001)

Table 3: Direct elasticities Safety module regarding serious injuries

Elasticity	Country	Mode	Value	Source
eSe,dui		car	0.119	BOSETTI ET AL. (2009), CADAS (2015) database
		truck	0.07	
		p2w	0.064	
		pt	0.062	
		bike	0.075	
eSe,bucr	AT	car	0.013	Evans (1995), Elvik & Vaa (2004), CADAS (2015)
	BE	car	0.049	
	BG	car	0.17	
	CH	car	0.075	
	CY	car	0.076	
	CZ	car	0.067	
	DE	car	0.049	
	DK	car	0.058	
	EE	car	0.052	
	ES	car	0.049	
	FI	car	0.049	
	FR	car	0.021	
	EL	car	0.157	
	HR	car	0.052	
	HU	car	0.07	
	IE	car	0.072	
	IT	car	0.049	
	LT	car	0.049	
	LU	car	0.038	
	LV	car	0.049	
	MT	car	0.049	
	NL	car	0.052	
	NO	car	0.079	
	PL	car	0.049	
	PT	car	0.026	
	RO	car	0.193	
	SE	car	0.049	

	SI	car	0.056	
	SK	car	0.087	
	UK	car	0.036	
	AT	truck	0.026	
	BE	truck	0.064	
	BG	truck	0.161	
	CH	truck	0.131	
	CY	truck	0.073	
	CZ	truck	0.065	
	DE	truck	0.064	
	DK	truck	0.101	
	EE	truck	0.096	
	ES	truck	0.066	
	FI	truck	0.064	
	FR	truck	0.035	
	EL	truck	0.203	
	HR	truck	0.059	
	HU	truck	0.082	
	IE	truck	0.062	
	IT	truck	0.064	
	LT	truck	0.064	
	LU	truck	0.067	
	LV	truck	0.064	
	MT	truck	0.064	
	NL	truck	0.12	
	NO	truck	0.14	
	PL	truck	0.064	
	PT	truck	0.03	
	RO	truck	0.193	
	SE	truck	0.064	
	SI	truck	0.039	
	SK	truck	0.099	
	UK	truck	0.05	
eSe,hu	AT	p2w	0.003	Elvik et al. (2009), CADAS (2015) database
	BE	p2w	0.035	
	BG	p2w	0.18	
	CH	p2w	0.021	
	CY	p2w	0.098	
	CZ	p2w	0.019	
	DE	p2w	0.035	
	DK	p2w	0.064	

EE	p2w	0.038
ES	p2w	0.03
FI	p2w	0.035
FR	p2w	0.013
EL	p2w	0.217
HR	p2w	0.066
HU	p2w	0.041
IE	p2w	0.035
IT	p2w	0.02
LT	p2w	0.035
LU	p2w	0.139
LV	p2w	0.035
MT	p2w	0.035
NL	p2w	0.08
NO	p2w	0.016
PL	p2w	0.035
PT	p2w	0.019
RO	p2w	0.223
SE	p2w	0.035
SI	p2w	0.037
SK	p2w	0.072
UK	p2w	0.005
AT	bike	0.088
BE	bike	0.097
BG	bike	0.097
CH	bike	0.134
CY	bike	0.097
CZ	bike	0.172
DE	bike	0.097
DK	bike	0.138
EE	bike	0.168
ES	bike	0.099
FI	bike	0.097
FR	bike	0.081
EL	bike	0.097
HR	bike	0.191
HU	bike	0.212
IE	bike	0.097
IT	bike	0.181
LT	bike	0.097
LU	bike	0.097

	LV	bike	0.097	
	MT	bike	0.097	
	NL	bike	0.097	
	NO	bike	0.086	
	PL	bike	0.097	
	PT	bike	0.156	
	RO	bike	0.097	
	SE	bike	0.097	
	SI	bike	0.144	
	SK	bike	0.17	
	UK	bike	0.004	
eSe,dis		all	0.075	TRACE (Schick et al., 2008), DaCoTa (2012)
eSe,fat		car	0.073	CADAS (2015), DaCoTa (2012)
		truck	0.085	
		p2w	0.01	
		pt	0.038	
		bike	0.007	
eSe,bs		p2w	0.017	IA blind spots; CADAS (2015); SWOV-factsheet Dodehoek (SWOV, 1996)
		bike	0.017	
		pedestrian	0.017	
eSe,if		car	0.09	DaCoTa (2012)
		truck	0.075	ETAC (2007)
		p2w	0.093	DaCoTa (2012)
		pt	0.075	ETAC (2007)
		bike	0.088	Schoon et al. (1996)
eSe,vd		car	0.032	DaCoTa (2012)
		truck	0.039	ETAC (2007)
		p2w	0.03	DaCoTa (2012)
		pt	0.039	ETAC (2007)
		bike	0.067	Schoon et al. (1996)
eSe,mc		all	0	assumption
eSe,load		truck	0.005	ETAC (2007)

Table 4: Direct elasticities Safety module regarding slight injuries

Elasticity	Country	Mode	Value	Source
eSl,dui		car	0.119	BOSETTI ET AL. (2009), CADAS (2015) database
		truck	0.07	
		p2w	0.064	
		pt	0.062	
		bike	0.075	
eSl,bucr	AT	car	0.004	Evans (1995), Elvik & Vaa (2004), CADAS (2015)(2015)(201 (2015)
	BE	car	0.02	
	BG	car	0.088	
	CH	car	0.016	
	CY	car	0.028	
	CZ	car	0.016	
	DE	car	0.02	
	DK	car	0.02	
	EE	car	0.034	
	ES	car	0.018	
	FI	car	0.02	
	FR	car	0.004	
	EL	car	0.045	
	HR	car	0.012	
	HU	car	0.025	
	IE	car	0.01	
	IT	car	0.02	
	LT	car	0.02	
	LU	car	0.011	
	LV	car	0.02	
	MT	car	0.02	
	NL	car	0.017	
	NO	car	0.023	
	PL	car	0.02	
	PT	car	0.006	
	RO	car	0.135	
	SE	car	0.02	
	SI	car	0.005	
	SK	car	0.031	
	UK	car	0.01	
	AT	truck	0.01	
	BE	truck	0.024	
	BG	truck	0.085	

	CH	truck	0.037	
	CY	truck	0.039	
	CZ	truck	0.026	
	DE	truck	0.024	
	DK	truck	0.044	
	EE	truck	0.062	
	ES	truck	0.021	
	FI	truck	0.024	
	FR	truck	0.009	
	EL	truck	0.083	
	HR	truck	0.018	
	HU	truck	0.034	
	IE	truck	0.022	
	IT	truck	0.024	
	LT	truck	0.024	
	LU	truck	0.022	
	LV	truck	0.024	
	MT	truck	0.024	
	NL	truck	0.042	
	NO	truck	0.045	
	PL	truck	0.024	
	PT	truck	0.008	
	RO	truck	0.132	
	SE	truck	0.024	
	SI	truck	0.009	
	SK	truck	0.047	
	UK	truck	0.019	
eSl,hu	AT	p2w	0.001	Elvik et al. (2009), CADAS (2015) database
	BE	p2w	0.019	
	BG	p2w	0.104	
	CH	p2w	0.013	
	CY	p2w	0.063	
	CZ	p2w	0.011	
	DE	p2w	0.019	
	DK	p2w	0.049	
	EE	p2w	0.026	
	ES	p2w	0.016	
	FI	p2w	0.019	
	FR	p2w	0.003	
	EL	p2w	0.062	
	HR	p2w	0.034	

HU	p2w	0.024
IE	p2w	0.019
IT	p2w	0.013
LT	p2w	0.019
LU	p2w	0.078
LV	p2w	0.019
MT	p2w	0.019
NL	p2w	0.057
NO	p2w	0.007
PL	p2w	0.019
PT	p2w	0.003
RO	p2w	0.149
SE	p2w	0.019
SI	p2w	0.019
SK	p2w	0.04
UK	p2w	0.002
AT	bike	0.118
BE	bike	0.108
BG	bike	0.108
CH	bike	0.144
CY	bike	0.108
CZ	bike	0.167
DE	bike	0.108
DK	bike	0.137
EE	bike	0.168
ES	bike	0.107
FI	bike	0.108
FR	bike	0.097
EL	bike	0.108
HR	bike	0.19
HU	bike	0.209
IE	bike	0.108
IT	bike	0.181
LT	bike	0.108
LU	bike	0.108
LV	bike	0.108
MT	bike	0.108
NL	bike	0.108
NO	bike	0.09
PL	bike	0.108
PT	bike	0.157

	RO	bike	0.108	
	SE	bike	0.108	
	SI	bike	0.137	
	SK	bike	0.172	
	UK	bike	0.004	
eSl,dis		all	0.075	TRACE (Schick et al. 2008), DaCoTa (2012)
eSl,fat		car	0.05	CADAS (2015), DaCoTa (2012)
		truck	0.059	
		p2w	0.007	
		pt	0.026	
		bike	0.005	
eSl,bs		p2w	0	IA blind spots; CADAS (2015); SWOV-factsheet Dodehoek (SWOV, 1996)
		bike	0	
		pedestrian	0	
eSl,if		car	0.09	DaCoTa (2012)
		truck	0.075	ETAC
		p2w	0.093	DaCoTa (2012)
		pt	0.075	ETAC
		bike	0.088	Schoon et al. (1996)
eSl,vd		car	0.032	DaCoTa (2012)
		truck	0.039	ETAC
		p2w	0.03	DaCoTa (2012)
		pt	0.039	ETAC
		bike	0.067	Schoon et al. (1996)
eSl,mc		all	0	assumption
eSl,load		truck	0.005	ETAC (2007)