



## Methodology for TRITIA transport model

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# 1. Introductory chapter

## 1.1. Subject of methodology

The presented methodology defines the standards for the whole procedure of processing the transport model depending on the type of task or the planned investment costs. It should apply to all new projects leading to changes in the quality, scope or use of transport infrastructure or public transport.

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## 1.3. Terms and definitions

Area of interest - the area in which traffic interactions are observed; its arrangement of transport solutions must be in functional and technical interdependence with the settlement unit eventually region.

Attractiveness - when choosing a route to a given zone, it is an expression of its significance (number of jobs, number of places in schools, etc.)

Calibration - comparison of model outputs with actual outputs (measured values) and subsequent adjustment of model parameters to achieve a specified level of model conformity with reality.

Cartogram - schematic representation of the vehicles direction at the intersections; it also indicates the intensity of the vehicles in the respective direction and for the selected time interval.

Catchment area - the area of direct transport links to the area of interest (attendance at work, school, services).

Degree of motoring - the number of inhabitants of a certain territorial unit per passenger car.

Degree of motorisation - the number of inhabitants of a certain territorial unit per motor vehicle.

Distribution function - the probability is assigned to each real number that the random variable will have a value less than that number.

Mobility - in transport planning, transfer of persons to fulfil the purpose of the journey (attendance at work, shopping, school).

Momentum of population - number of trips per inhabitant of a given area per given time unit (e.g. one working day).

Passenger-kilometer - a measurement unit representing the transport of one passenger by road over a distance of one kilometre. The distance actually travelled by the passenger shall be taken into account.

Passenger in road transport - any person transported in a road vehicle. Car drivers other than taxi drivers shall be considered as passengers; service staff in buses, coaches, trolleybuses, trams and lorries shall not be considered as passengers.

Route (in terms of transport modelling) - transfer of person or goods from origin to destination using the selected transport mode.

Traffic forecast - estimation of traffic development for a certain, mostly long, period in advance; it is based on a change in traffic behaviour (mobility), car availability, changes in transport offer (transport infrastructure) and so on.

Transport model - an effort to mathematically imitate the real world of population mobility

Transport network - includes transport routes of road, water, air, rail, urban and other types of transport.

Transport scenario - a model variant of the analysis of the proposed transport measure impacts

Vehicle-kilometer - a measurement unit representing the movement of a motorized road vehicle over a distance of one kilometer. The actually travelled distance shall be taken into account. This also includes the movement of empty motorized road vehicles. Units composed of a tractor and a semi-trailer or a lorry and a trailer shall be considered as one vehicle.

Validation - verification of model accuracy as meaning that its task is to prove whether the calibrated model can adequately describe the transport process in the surveyed area. Validation often means also test of model transfer so that processed model is used under the different conditions or on different territory and model results are compared with actual transport process.

## 2. Transport models

Modelling and analysis of traffic data is a way to professionally predict traffic demand and population behaviour across a land area and to plan perspective traffic scenarios. There are several possible alternative solutions for each transport problem. Some of the alternative solutions are presented in the form of investment projects. However, testing of several alternative projects in the field is practically impossible,

either because of their incompatibility or unbearable costs. Transport modelling allows to check each offered variant in several realistic scenarios, because the financial burden and time consuming examination of alternatives by modelling are minimal compared to realization.

## 2.1. Types of transport models

When creating a traffic model, it is crucial to monitor the purpose for which the model is processed. Transport models can be divided according to:

- the extent of the modelled territory,
- the mode of transport,
- take into account of time - the need for time over the territory,
- access to modelling of daily activities.

Transport models used in practice are often a combination of the types of models listed below. The different types of transport models are not strictly defined and may overlap.

A. Depending on the **extent of the modelled territory**, we divide the models into:

**A.1 Macroscopic models** - are used for large territorial units with an extensive road network, on which the intensity of the transport flow, routing on the area of the solved territory and division of transport work are modelled. They serve mainly as:

- the instrument for evaluating the measures under the strategy papers; and
- for territorially extensive transport measures, e.g. construction of transport infrastructure (bypass, corridor),
- change of transport policy (parking policy, fees).

In most cases, there are deterministic models with a lower level of detail (detail at the level of the selected part of the day/week/month, e.g. morning peak, average day, etc.) in which the interaction between vehicles is not considered.

**A.2 Microscopic models** - focus on a specific vehicle, its behaviour (driver behaviour), characteristics and interaction with other vehicles in the transport flow. High-quality basic documents on a detailed spatial level are the basic presumption, e.g. with processing of detailed geometric arrangement of the solved territory (dimensions of vehicles, their weight, maximum speed or acceleration values). Outputs from the model are:

- time delay,
- vehicle speed,
- length of motorcade,
- permeability of intersections and etc.

Microscopic models are suitable for assessment of the design of infrastructure or transport-organizational measure in a specific area of the solved territory (e.g. intersection in a part of the town).

**A.3 Mesoscopic models** - combine elements of macroscopic and microscopic models. They elaborate the solved territory in detail. They use more detailed division of the territory and characteristics of individual elements of the transport network. They also deal with time loss - delays in crossing intersections. On the contrary, it is not considered the interaction between vehicles in the traffic flow. Like macroscopic models,

they provide data on transport flows and traffic relationships. Due to higher territorial detail, mesoscopic models are suitable for smaller territorial units at the level of districts or cities or agglomerations. They are used e.g. for modelling local public transport preferences, green waves, etc.

**A.4 Nanoscopic models** - are microscopic models with an emphasis on greater detail of selected model parameters. They allow more detailed simulation of the driving characteristics of individual system elements, e.g. journey of lorry driver, bus driver, passenger car driver, cyclist, pedestrian, persons with reduced mobility, etc.

**A.5 Hybrid models** - currently the most used type of transport models that combine the above mentioned types of models. E.g. if the macroscopic model uses a high level of detail in the points of interest. The hybrid model allows simulation of the phenomena concerned in different locations with different levels of detail. This keeps the model in a reasonable size as well as the efficiency of the overall work with the model. To determine the current state of transport for these models, the measured values of traffic flows from traffic surveys are used and only the differential future demand, determined by the classical four-stage approach or traffic prediction, is added to them.

**B.** According to the **number of transport modes models** are divided into:

**B.1 Unimodal models** - consider only one transport mode, for example road and public transport models. The processing of such a model is usually easier due to the absence of a decision algorithm for the choice of means of transport. The unimodal model allows simulation of changes in the routing of traffic intensities on the transport network, including estimate of traffic load. The lack of choice of means of transport limits the possibility to predict the size of demand. The model of road origin and distribution is often missing, so it should be compensated by extensive empirical data on road origins and destinations (O-D matrix). For this reason, public transport and road transport models are not used for midterm and long-term forecasts. The model is calibrated to the current state of traffic demand and supply according to traffic surveys. Any change in traffic intensity is only due to a change in road routing. Unimodal models can be used for technologically closed modes of transport, i.e. for special cases of road transport, water transport or rail transport. It is recommended to use it only in the case of microsimulation or for macroscopic models with balanced and constant division of transport work.

**B.2 Multimodal models** - assess more than one mode of transport and reflect on changes in transport demand due to competition between modes. Examples are freight transport models where rail and water transport is also modelled in addition to road transport. Other examples are models of transport in a city whose inhabitants decide between car transport, local public transport, walking, cycling and etc. The multimodal model compares the supply of the individual transport modes by means of an indicator of generalized travel cost. In the case of passenger transport, this indicator combines data on travel time (including waiting times), transfers, tolls, public transport tolls and fuel costs. In the case of freight transport, the sensitivity of goods to time and costs or the availability of a tranship point or terminal can be included in the calculation. The result is a complex indicator, which is used to decide the participants in the choice of route, choice of destination and choice of transport mode. Based on these inputs, the model calculates the traffic intensities for individual modes of transport and divides them between the total volume of carried persons and goods.

**C.** In **terms of time**, models are divided into:

**C.1 Static models** - do not take into account the dynamics of the transport system over time. Static models calculate traffic volumes (intensities) over a predetermined period of time (e.g. 24 hours or peak hours - local public transport time, hour at AD). The static model results in modelled traffic intensities in the transport network in the form of cartograms that do not change over time.



**C.2 Dynamic models** - some of their features may change over time. They are used to analyse phenomena that change at short intervals. An example is a transport model that provides data on traffic intensities and traffic flows for different times of day (according to national regulations). The basic difference in comparison to the static models is that the traffic density enters into the model, i.e. number of vehicles per 1 km of road. Dynamic models better simulate traffic congestion and are suitable for identifying problematic locations with forward-looking perspective. The dynamic model results in modelled traffic intensities in the form of vehicle animations that change over time or in some cases in the form of cartograms.

**D.** Based on the **daily activity modelling approach**, models are divided into:

**D.1 Models based on individual trips** - Trip is the basic analytical unit of this approach. It models activities realized during a day as a one-way trips between origin and destination that are independent in terms of order and time. Models based on individual trips are currently frequently used, mainly due to data availability. They are used where a simplified modelling approach is possible.

**D.2 Models based on trip chains** - the basic analytical unit of this approach is the trip chain - journey (Tour). It models activities during a day as trip chains - individual journeys that interlock chronologically. The set of activities performed during the day can be divided into several chains, which are however independent of each other in terms of order and time. In practice, this approach is used in both freight and passenger transport (the chain is made up of trips to school, work, shopping, leisure activities, etc.).

**D.3 Models of trip pairs** - The basic analytical unit of this approach is the individual pairs of trip purposes (activities) from which the schedules of daily activities are modelled (activity schedule). It is a complex approach to modelling of daily activities over time, since the parameters of each activity include start and end time, duration, location and conditions related to the history of the trip during the day (e.g. the means of transport used). This is the most credible way to simulate transport demand. It allows to respond to measures of a transport nature (infrastructure, transport-organizational, economic), as well as measures aimed at a complex change of traffic behaviour due to new (not only transport) technologies that affect the course of daily activities. From a practical point of view, it is also the most complex approach. Its use generates high demands on details of traffic behaviour of the modelled population and traffic demand targets (e.g. opening hours of commercial establishment). Models using this approach are also computationally demanding. All of these requirements are currently the main limiting factors for the deployment of activity-based models in practice.

**E.** According to the **required level of detail** based on model tasks, models are divided into:

**E.1 Aggregated models** - this is a simulation of the behaviour of different homogeneous groups of the population by purpose and with specific transport requirements. Its advantage is the iterative (repeated) modelling of volumes, routing and division of transport work, which allows to gradually refine the results of individual steps according to the degree of knowledge of the current transport process.

**E.2 Disaggregated models** - This is a simulation of the individual behaviour of typical individuals in time and space and their aggregation (merging, association) into the resulting transport relations of the territory by subsequent recalculation to the whole team. This modelling method requires the results of a detailed traffic-sociological survey.

In practice, it is recommended to use disaggregated models.

Transport models consist of a **demand model** and a **supply model**.

The **demand model** is created synthetically, i.e. on the basis of (evolution) basic variables (i.e. change in demography, economy, mobility) defines the transport potential of the territory and subsequently models the transport relations, which is then allocated to the network.

Within the transport model, each transport relationship is determined by the origin and destination of the journey in just one zone, whereby the combination of transport relations between all zones can be called the matrix of transport relations or also the origin-destination matrix,

The **supply model** defines the available transport infrastructure to meet the transport needs.

#### **F. Size of the territory of interest and zonal division**

Transport model zones are areas that describe parts of the real world in terms of territory use and location on a road network.

In macroscopic models, the zonal structure is mostly used at the level of existing administrative units (e.g. territory of municipalities, basic settlement units (BSU) -, statistical districts, etc.) for which basic socio-economic indicators (population number and structure, number of job opportunities) etc.).

The zonal structure should be determined in such territorial detail in order to capture changes in transport relations that will occur as a result of the impact of the measures under consideration and the intentions assessed by the transport model. Zones can be created according to similar traffic behaviour (comparable accessibility), economic activity, population, etc. For each traffic zone, the following shall apply:

- it forms a compact territory characterized by similar traffic characteristics, location and connection to traffic routes,
- the simplification of the real state caused by the merging of smaller units into one zone does not significantly affect the quality of outputs of the transport model.

Generally, in the territory of interest a higher detail is required - the smaller zones, and with the greater the distance from the territory of interest, the more suitable is the smaller the detail - the larger zones.

Due to the increasing complexity of the calculation procedures, the different zonal structure and level of detail is appropriate for the different types of models according to the size of the territory of interest. This section therefore sets out the requirements for minimum detail of traffic zones for each type of model.

**F.1 National model** - the aim is to separate approach centres (regional centres) from their background. The following conditions should be maintained:

- the zone consists of a group of municipalities, larger cities form separate zones. It is recommended to maintain the principle of territorial division, so that traffic zones always lie within the administrative boundaries of districts, i.e. that divide the districts into several traffic zones. Attendance centres - regional catchment centres and important industrial sites that are a significant attendance origin - should be earmarked separately. In the case of large-scale bigger cities (> 50 thousand inhabitants), it is appropriate to divide these cities into several traffic zones,
- individual zones should be connected by connectors so that each municipality is represented by at least 1 connector, the length of the connector corresponds to the average exit time of parked vehicles, in the case of public transport it is the average time of approach to your preferred stop.

#### **F.2. Regional model:**

- the zone represents the municipality. It is possible to aggregate smaller municipalities that are accessible exclusively by the same road. Separate zones should be important traffic

origins/destinations such as industrial/shopping zones and remote settlement units. Regional centres or cities > 10 thousand inhabitants should be divided into several traffic zones,

- the individual zones are to be connected by connectors so that each municipality is represented by at least one connector. Approach centres should be connected by connectors according to the connection point of the main approach roads, the length of the connector corresponds to the average approach distance.

**F.3 Local model:**

- the zone represents BSU. Area-wide BSU as well as selected BSU characterized by different availability of the public transport network are to be divided into several zones,
- the individual zones are to be connected by connectors so that each BSU is represented by at least one connector. Approach centres should be connected by connectors according to the connection point of the main approach roads,
- tourism zones should be defined separately. Connection of PPT (public passenger transport) stops should meet the same criteria as IAD (number of connectors). The actual stop times should be taken into account.

**G. Time aspect**

The following table gives an overview of the timeframe for the model.

**Table 1 Time periods for processing models by size**

		National	Regional	Local	Microscopic
Reference period	24h	x	x	x	
	1h peak			x	x
	morning/afternoon peak hour				x

**2.2. Creation of transport model**

Creation of a transport model consists of the following steps, which interlock:

- 1. Definition of the transport model purpose** - the purpose of the transport model is based on the nature of the study/analysis for which the model is being created. The character, scope and complexity of the transport model should correspond to the purpose of the model. In this initial phase, the future use of the transport model should also be considered, as the model usually does not serve only one study.
- 2. Model parameters** (spatial, temporal and modal extent of the model) - the model parameters (territorial scope, taking into account the time, zonal structure, modes of transport, transport demand units, etc.) are derived according to the purpose of the model. Values given in this methodology or values from foreign sources or own surveys can be used to determine the parameters. In practice, steps 1 and 2 may be carried out in parallel or repeated several times.
- 3. Input data** - model parameters define the structure and scope of the necessary input data, which must be collected or generated (if not available) before the transport model itself is implemented (see step 4). Data collection and production are the most demanding part of model creation in terms of time and money.
- 4. Calibration (refinement)** - model calibration is a specialized activity during the creation of a transport model. The created transport model is calibrated according to empirically obtained data. In some cases,

sponsors or other stakeholders may have a good knowledge of the local situation, which can be very useful for calibration.

The following data can be used to calibrate the model:

- actually detected driving times,
- division of walking distances, resp. time
- division of transport work.

**5. Validation** - is the process of testing the accuracy of a calibrated model by comparing its outputs with the results obtained by collecting field data. Testing is performed on an independent sample of data (e.g. measured traffic intensities - according to national regulations), the data used for validation should be different from the data used for calibration. Validation results are a criteria of the model quality and as such must be submitted to the model user.

The phases of model testing during validation are:

- reality testing (the response of the model to the change of input variables is realistic and corresponds to independent observations)
- sensitivity testing (whether model response to the change all key parameters is adequate)

**The validation data is similar to the calibration data because they are indicators that verify the structure and spatial distribution of traffic demand.**

- the resulting actual driving times,
- division of walking distances, or time
- division of transport work.

**6. Prediction (assumption)** - the basic assumption for creating a prediction of traffic development in zero (development of a situation without measures) or a design scenario is the validity of the model with respect to the current situation. The input parameters of the zero and design scenarios must be defined by the user or by the sponsor of the model in cooperation with the creator who incorporates these parameters (development of transport supply and transport costs, development of transport demand and background socio-economic data.)

## 2.3. Model of supply, creation of digital model network

In developing the transport model, they are used input data on:

- transport infrastructure: motorways, expressways, other categories of roads by national class breakdown, local roads, railways, watercourses, PPT lines and their parameters (see below);
- functional land use - on the attractiveness of the zones: number of jobs, school places, shops, offices, hospitals;
- zone demography: population per each group;
- transport and traffic flows: traffic intensity, transport flow composition, routing, occupancy;
- mobility (transport) of goods and people: momentum, accessibility of the car, accessibility of public transport, length of roads.

### 2.3.1. Data on transport infrastructure

Depending on the number of considered transport modes, which are defined according to the customer's requirements, but at least divided into passenger cars, trucks in the model, we define the following requirements for details of transport infrastructure:

- in unimodal models, it is sufficient to include only the road network for the selected mode of transport, classified by road category and function class
- in multimodal models, at least road and public transport (buses, trains) must be included. In the case of freight transport modelling, it is also necessary to include rail freight transport eventually waterways.

In obtaining the road network is usually based on a national model network, if available, in the case of regional or smaller (more detailed) models, it can be supplemented by map background of modelling software or other sources.

It always use vector data (dwg, shp,)

### 2.3.2. Zone demography data

Socio-demographic data are obtained from various sources (national statistics - population status, data from commercial providers), but there are often specific problems such as :

- incorrectly registered whereabouts
- poor permanent residence statistics
- incorrect vehicle registration
- company cars moving in other regions, company cars with location outside the firm domicile.

If there is a suspicion that the official statistics differ significantly from the facts, these documents may be modified manually.

### 2.3.3. Data on transport and traffic flows

This includes the data needed to calibrate the model (intensity and direction of the transport flows, occupancy, etc.).

Traffic surveys are used as data sources:

- traffic census,
- national traffic census extrapolated to the present (possibility of additional surveys in case of significant deviations),
- origin-destination traffic surveys (important for defining the type of transport),
- questionnaires on the routing of traffic
- public transport censuses with the possibility of automatic census (e.g. local public transport).

The basic conditions for car traffic surveys are described in national standards and regulations.

### 2.3.4. Mobility data

This includes data necessary to create a model, such as momentum, accessibility of the car, accessibility of public transport and length of roads. These are broken down by demographic groups, regions.

The basic structure of mobility data is obtained from:

- traffic-sociological surveys,
- origin-destination traffic surveys and
- public transport surveys.

#### **Traffic-sociological survey**

Developing and conducting a traffic-sociological survey is necessary to set the transport model to the real Slovak conditions. It serves to identify various indicators that characterize:

- traffic behaviour of the population: information on roads, i.e. where, when, how often, how long, how and for what purpose people travel;
- socio-economic, demographic and economic-political trends in society;
- trends in transport systems according to the chosen scenario of their development.

Usually the traffic-sociological survey according to the Austrian Komod methodology is used. Respondents are asked to fill in basic questions about the journeys of individual household members, where:

- the individual PPT subsystems are evaluated separately (urban public transport, suburban public transport by rail, suburban public transport by bus, combined),
- a minimum number of activities and zonal characteristics are defined so that the label matches the structure in the model being processed,
- it is recommended to develop a uniform form of DSP database (\*.xlsx) for need processing of a comprehensive transport model
- sample size: it is recommended to use the minimum sample size table from the publication [12]. It is also important to pay attention to the Komod methodology according to which data is collected,
- output data on journeys of household members: origin, destination, purpose, regularity, distance, hour of the journey start, means of transport used, ownership and availability of means of transport, availability of parking space, car-sharing, public transport fares, distance to the nearest local public transport stop;
- output data on household members: age, gender, social status, education, income.

#### **Origin-destination traffic survey**

It focuses on finding origin and destination of transport relations in the territory of interest. Unlike the traffic census, it not only detects the intensities of transport relations, but mainly their geographical relations (routing from origin to destination).

The survey is carried out e.g. by a questionnaire survey or by a method of recording an VRN (vehicle registration number). Origin-destination traffic survey can be carried out at individual intersections or on the area of the whole territory of interest. In larger cities, continuous directional surveys and traffic censuses are carried out within the city by the method of recording the VRN. At national level, toll system data can be used to analyse routing of freight flows. Their disadvantage is the lack of links to other modes of transport.

Origin-destination survey outputs will be used to calibrate transport models or to build “empirical” transport/traffic relationship matrices. However, they can also be the basis of the transport model in the case of so called hybrid transport models.

#### **Public transport traffic surveys**

The extent of utilization traffic survey of the PPT lines is carried out by a system of counting boarding and alighting of persons at stops and the number of passengers in vehicles. The survey includes all vehicles from the morning exit to returning to the car barn.

Passenger surveys are usually conducted using one of the following techniques or combinations:

- in-vehicle survey (in-vehicle counter),
- survey at the station (counter at the stop),
- survey using questionnaires (counter at the stop, internet questionnaire).

The result is the number of passengers on the individual public transport lines, on the census profiles, the number of boarding and alighting persons per unit of time at the counted stops and data on passenger transport relations.

Traffic surveys on directional relations and public transport transits are usually carried out by interviewing passengers.

The key time interval in the morning peak is from 5:00 to 9:00 and in the afternoon peak from 15:00 to 19:00. The rush hour period may vary according to the local characteristics of the city (size, land use - number of industrial zones, etc.). This applies in particular to local public transport or suburban transport systems. In long-distance transport, a completely different extent of utilization should be considered.

The following principles shall be observed in these traffic surveys:

- in road transport, the reference period (duration, part of the year/day) should also be defined;
- the survey shall achieve the required sample size, which shall be determined on the basis of the total volume of passengers carried; it should be at least 5% in size and the methodology of conducting the survey shall be such that the sample is distributed evenly over the line network and the sample size for the purposes of conversion to total values is sufficiently meaningful and reaches at least 5% of the total number of transported passengers.
- the output is data on traffic volumes, traffic relations, turnover and passenger transits within PPT terminals.

Note: issues in obtaining PPT data is the reluctance of carriers to provide data on the number of transported passengers, the occupancy rate of vehicles, etc. These data are usually trade secrets.

### **2.3.5. Mode of transport**

When creating the transport model, the modes of transport are have to be defined. There are two basic groups:

- variable transport modes: pedestrian, passenger car - passenger, public transport,
- fixed transport modes: passenger car - driver, motorcycle, bicycle.

The basic difference between variable and fixed transport modes is the allocation of the number of transported persons to the means of transport. In fixed transport modes, only one person is assigned to one means of transport.

A specific part is formed by PPT. It is recommended to view PPT as one system, as it is also perceived by the population. The problem of transit has to be solved e.g.: train-car (e.g. car parks within the Park & Ride system) as a tool of interconnection of individual car and PPT.

The following requirements are defined for each transport mode:

#### **1. Road transport:**

- The model will usually include motorways, expressways and other categories of roads according to national structure (including their delays across cities and villages). It is based on data from national road managers.
- The following are added to the territory of interest:
  - in a national/regional model of local roads serving to connect important traffic zones or performing a significant transit function;
  - in the local model, in principle also local roads and selected special-purpose roads;
  - in the simulation model on all roads in the affected territory.
- In connection with cross-border models, it includes at least motorways, expressways and other categories of roads as appropriate, as well as all roads equipped with border crossings between countries. In the case of regional models also regional roads around the area of interest.
- The transport network parameters are defined: road type, location (city/suburbs/countryside), number of lanes, capacity, speed (both unloaded and loaded network). It is also recommended to consider the characteristics that lead to speed limitations, the transit time (both unloaded and loaded network), permitted modes of transport, resistance function.
- Nodes (intersections):
  - Parameters: permitted driving directions (including rotation), travel time, delay times in each direction, capacity in each direction.
  - Detailed calculations to determine the passage through municipalities when creating local and simulation models. In regional models, a detailed assessment of selected congested intersections is recommended in the case of a project that addresses the reduction of time losses through the passage (e.g. green wave, bypass, etc.) in accordance with the relevant national regulations.
  - In macroscopic models, it is not necessary to follow intersection branches, neither separately divided by direction.

## **2. Rail transport:**

Rail transport network parameters: track number, number of tracks, capacity, transit time, traction, throughput (relevant for freight modelling).

## **3. Water transport:**

Water transport network parameters: transit time, throughput, technical parameters (relevant for freight transport modelling).

## **4. Public passenger transport:**

It is recommended to:

- model in detail (considering timetables) for: development of transport modes, projects to promote PPT, projects aimed at changing transport modes;
- model simplified (considering system speed for individual transport systems) for: macroscopic models, road traffic loads without modal split;
- does not model at simple unimodal models;

Required data:



- line service: intervals/timetables, travel times between stops, capacity, fares, network density, possibility to release selected special service lines operating several times a day, stops, their connections, delays/transfers on transit.

#### 5. Other transport modes:

**Cycling & pedestrian transport** - always included in multimodal passenger transport models, not assigned to network in national/regional model. Infrastructure is required only in local and simulation models where it is allocated to the network. The parameters should correspond to reality, simplified average passage speed, delays at intersections should be ideally taken into account.

**Freight air transport** - airports (network-linked) and fictitious air routes (= sections in a special type model).

### 2.4. Demand model - 4-stage transport model

The demand model represents the required traffic volume between individual traffic zones for a given demographic group, at a given time, for a given purpose and is represented by an PT matrix.

In simplified modelling, there is the possibility that the demand model is not synthetically modelled but by using the actual transport relationship matrices, if available (simplified approach; e.g. freight toll system output, public transport sales system output, movement data analysis SIM cards, etc.). These matrices can also be used to prepare the forecast for the future, based on appropriate adjustments.

In case of acceptance of PT matrix, eventually incremental approaches of PT estimation for the future state, it is possible to reduce the range of input data appropriately (e.g. it's not necessary to consider mobility data)

The demand model is based on the theory of the classical four-stage model. This is defined in the following steps:

#### 1) Creating (generating trips) trips

- define the way of trip creation (input variables, calculation method),
- define the purposes of trips (disaggregation rate);
- define attractiveness and productivity (input data, structure).

#### 2) Trips division

- define the way of trips distribution (input variables, method of calculation),
- define the selection criteria (shortest trip, fastest trip, trip with the lowest generalized costs);
- define the purposes of trips (disaggregation rate);
- specific problems - gravity.

#### 3) Mode selection

- define the distribution method and selection criteria;
- define the degree of disaggregation (ideally disaggregated way, where the choice of means of transport is independent according to demographic groups or the purposes of trips).

#### 4) Traffic allocation

- choice of road allocation algorithm,
- define the order of allocation according to layers (types of roads or demographic groups).

### 2.4.1. Population groups

The population in the area under investigation is categorized in disaggregated models. Each group is precisely determined by a special characteristic, i.e. the same behaviour in the transport process. The population shall use at least the following basic breakdown:

- economically active with/without car,
- economically inactive with/without car,
- preschool children,
- primary and secondary school pupils
- university students,
- pensioners.

### 2.4.2. Attractiveness of zones

Attractiveness in terms of transport model creation are:

#### 1. Commuting to work

- this includes the number of jobs (employees) by municipality;
- source:
  - a database of work places or a database of employees/employers;
  - labour force sample survey, population census, employer data (variability, etc.);
  - other relevant sources (e.g. surveys, SIM card analysis, etc.);
  - materials from projects under preparation;

Note: in the case of a biased source, the data need to be modified (e.g. all employees of companies with national jurisdiction registered at the place where the company has its registered seat).

#### 2. Attendance at schools

Support for science, research, development, innovation and education

- this includes the number of places in school facilities (or the number of school facilities) - also according to the founder of individual school levels (municipality, region, state).

#### 3. Civic amenities

- includes e.g. public administration, shops and shopping centres (shopping opportunities), health care, leisure time, etc.;
- data are based on actual attendance of facilities serving different purposes;
- in small scale models (national, regional), the purposes of trips can be reduced and attractiveness can be determined in a simplified way, e.g. demographic indicators;
- in large scale models or models by purpose of trips, the purpose of the trips should be specific, typical traffic behaviour (separate/typical distribution curves);
- the natural catchment area of municipalities should also be taken into account; i.e., relatively higher attractiveness when travelling within administrative units. In this case, the types of

attractiveness must be taken into account when defining and dividing the zones (business, recreational, etc., preferably according to the applicable zoning plan).

- In addition to the above cases, external (long-distance) trips, such as weekly, interstate transport, long distance recreation.

### 2.4.3. Trips creation

It is the first of four stages in a classic four-stage model. It identifies origin and destination transports/traffic trips that are not affected by the existing supply.

The output is the availability of the zone (production rate), the attractiveness of the zone (level of attraction) with differentiation to individual groups of inhabitants (workers, students, etc.). In terms of the purpose of the trips, the amount of trips generated from the zone is determined. In the same way, the number of trips ending in a given zone shall be determined, and the total number of trips arising shall be the same as the total number of trips ending (this is applied to 24-hour models, not hourly-peak models).

### 2.4.4. Trips division

For the distribution of trips, the general hypothesis can be made that the transport relations between two zones  $i$  and  $j$  is dependent on:

- production in origin district  $i$  (origin traffic volume  $DZ_i$ );
- attractiveness in destination district  $j$  (destination traffic volume  $DC_j$ );
- the remoteness of the origin and the destination (given by the resistance function  $w_{ij}$ , taking into account in particular the actual distance, but also the average transport time, the need for transfers, economic demands, etc.);
- competition of destinations (when viewed from the origin) as well as origins (when viewed from the destination) in terms of their volume (quantity) or general attractiveness, as well as their accessibility;
- the number of opportunities between origin  $i$  and destination  $j$  to end the trip (as a substitute for the previous hypothesis).

At present, the most used model for generating transport relations in common transport modelling is the so-called. a gravity model, developed in direct analogy to Newton's law of gravity. The gravity model is also used in the processing of the transport model at the national level.

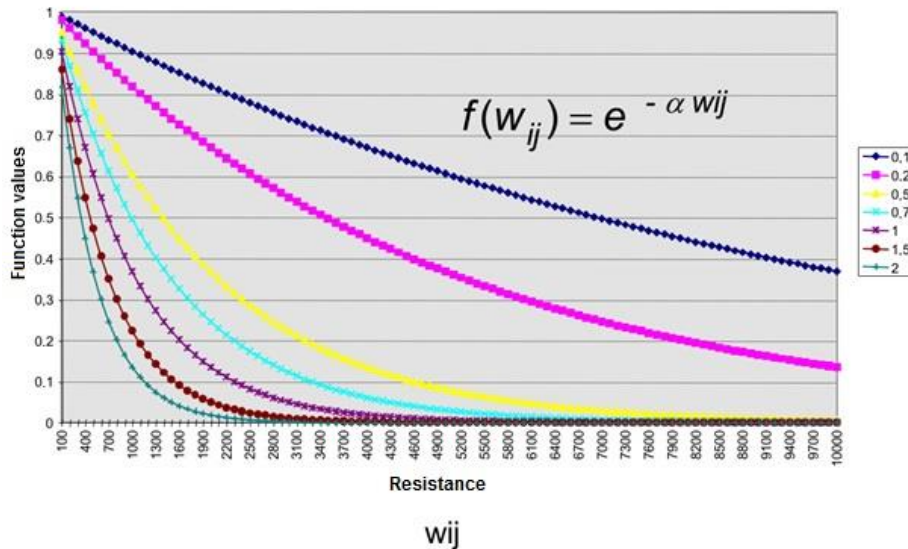
For a gravity model, the number of trips generated from a origin to a particular destination is directly proportional to its attractiveness and inversely proportional to the resistance (expressed by the resistance function) between them. The most important problem of gravity models is the correct expression of the distribution function  $f(w_{ij})$ . In principle, it is a function that expresses the decreasing probability of making a trip with increasing remoteness. A variety of mathematical functions can be used to distribute transport relations, but the most commonly used are:

- exponential or Logit function in the form:

$$f(w_{ij}) = e^{aw_{ij}}$$

where:

$\alpha$  is a parameter that expresses the resistance sensitivity to the destination of the activity,  $w_{ij}$  is resistance between zones.



**Figure 1 - Progress of resistance function for different alpha values**

The main factor for the trips division is the attractiveness of the zone (the number of trips that end in the zone). This depends e.g. from the number of jobs or attendance of commercial establishment. Another parameter of trips division is generalized costs, often simplified for travel time and distance. Given the comparable attractiveness of the territory, the pending zones are more attractive for the given activity. The estimation of the parameters can be determined separately for a given population group, according to the purpose of the trips, population or attractiveness of the zone.

Using gravity theories separately for each demand layer results in an O-D matrix.

### 2.4.5. Choice of mode of transport

It is recommended to model the transport mode in two steps:

**First:** division into individual (car, bicycle, walking) and mass (train, bus, ship, airplane) modes,

**Second:** selection of the transport mode from the given category

In modelling areas where there is (potentially) a significant transfer between individual and public transport (P + R car parks, "taxi" to public transport stops), or if the model is created e.g. the possibility of hybrid modelling should be taken into account when assessing the construction of P + R car parks

The utility function of public transport requires consideration of the scope of service (waiting for the line), e.g. the concept of perceived transportation me, it is necessary to take into account the waiting in the nodes during the transit with the possibility of penalizing the transit depending on the quality of the transfer.

All requirements should correspond to model structure and model purpose (task type)

The values of the variables (transport time, waiting, fares) should be based on actual timetables (recommended for national and regional models) the use of an average interval approach is only recommended if public transport in the territory of interest is operating in tact (interval) mode and the transit times at the nodes are fixed or dependent on the interval of individual lines if these lines run at intervals of 20 min or less.

In the third stage, it is estimated how many people will use public transport for their trips, how many people use individual transport, bike, walking eventually other means of transport. Public transport is often considered as one mode of transport at this stage, the division into individual means of public transport (train, bus, tram, ...) takes place only at the final stage when the network is loaded.

Each mode of transport  $m$  in the model is assigned its own utility function:

$$U(m) = am + bm \cdot IVTTm + cm \cdot OVTTm + dm \cdot COSTm$$

where:

**$IVTTm$**  - time spent in the vehicle for mode of transport  $m$ ,

**$OVTTm$**  - set of journey times spent outside the means of transport (time spent arriving at the stop + time spent by transit + time spent arriving from stop to destination),

**$COSTm$**  - travel cost in means of transport  $m$ ,

**$am$ ,  $bm$ ,  $cm$ ,  $dm$**  - specific coefficients.

Specific coefficients fundamentally affect the division of transport work. In practice, coefficients taken from the national model of the country concerned, where available, are also used. In fact, these coefficients are to be estimated by type of territory.

#### 2.4.6. Allocation of traffic to the network

When allocating traffic to the network, it is recommended to use the Wardrop equilibrium model in which costs vary depending on the congestion in the network. The simplest form of assignment according to the Wardrop principle assumes that all passengers have the same cost perception. However, there are more complex assignment algorithms in which different users can be expected to perceive costs in different ways, such as "Stochastic User Equilibrium (SUE)":

- utility function recommended to be the same as trip division/mode choice
- for (individual) road transport, determine the order of allocation of demand by layers (transport modes, purposes of trips) and always allocate freight transport first, followed by passenger transport.
- in a disaggregated approach to the allocation of passenger transport - first nearby transport (commuting to work, schools, services) and later long-distance transport
- when allocating public transport, account must be taken of capacity restraints (overcrowding)

Results of The modelling of transport relations are origin-destination matrices (O-D matrices) for defined transport modes. These are used in the last modelling step to calculate the load on the transport network. Various standardized algorithms are used for this task:

- "all or nothing",
- progressive (incremental) attribution,
- equilibrium allocation.

The basis of all algorithms is to find one or more alternative best routes between the origin and destination zone. Advantage is assessed on the basis of the total impedance (resistance) calculation of the route.

Often other important parameters (mileage, infrastructure charges, consumption, etc.) are also taken into account.

### 2.4.7. Freight transport modelling

Freight modelling is a complex process and requires a lot of input data that is not usually available.

The basic matrix of freight transport relations (FT) is recommended to be taken from the Transport Model of the Slovak Republic. Then verify it (validate) in the territory of interest according to O-D data from the toll system and calibrate it according to profile and direction data from the toll system, eventually other sources in a similar way to the IPT matrix. Disaggregation according to different categories of trucks (e.g. LGV, HGV, BUS, etc.) is required.

## 3. Sample model types

The presented methodology deals with the following models:

- 1) **strategic models** - multimodal, for municipalities/regions/state,
- 2) **other models** (assessment of investment projects, non-investment measures):
  - a. line constructions (construction/modernization of roads, highways, railways, ...),
  - b. transport policy measures (change in parking policy, change in fees, restrictions on entry, road closures);
  - c. assessment of transport services (reorganization of local public transport, modification of timetables in long-distance railway transport),
  - d. building and organizational measures (rebuilding the intersection, modification of signal plans),
  - e. investment construction in municipalities according to spatial and functional use of the defined territory.
- 3) **specialized models** such as railway simulations (capacity analysis), marginal HDM4 and so on.

**Table 2 Hierarchy of transport models**

Model type	Territory of interest	Zone size	Traffic modes	Time period	Transport network (highest detail)	Use
National	State	Group of municipalities Larger cities separately	Multimodal	24h	According to national structure of road types	Transport corridors, long distance public transport
Regional	Region	Municipality Parts of larger cities separately	Multimodal	24h	Lower road category LC only for zone connection	Regional (Roads, train, bus)
Local	Municipality	Part of the municipality (BSU)	Multimodal	1h (24h)	LC	Urban road, local public transport

Model type	Territory of interest	Zone size	Traffic modes	Time period	Transport network (highest detail)	Use
		Part of the large BSU				
Hybrid	Combination	Combination	Combination	Combination	Combination	
Simulation	Part of the infrastructure	Block of houses	Unimodal, Multimodal	<1h	Traffic lanes	Permeability assessment

### 3.1. Using the Model Type

Will there be a significant increase in the attractiveness of another mode of transport compared to another?

- Yes - multimodal evaluation, transport model
- No - unimodal rating

Will there be a significant redistribution of the traffic flow across several sections of the transport network?

- Yes - synthetic approach (transport model)
- No - analytical approach

Analytical approach use only for very small shipments (as a road pilling strip where large cities do not bypass ...)

Are there means of transport (congestion, capacity overrun) in the territory only at the relevant time?

- Yes - separate model also for peak hour (or gradual loading)
- No - 24h model

Does the model aim to assess or increase road capacity?

- Yes - simulation model
- No - static model

Is the road, we are planning to modernize/build, of a corridor character? (for an important part of the alternative route transport outside the territory of interest)

- Yes - monitor also the impact on possible corridor routes (corridor in terms of traffic used by long-distance transport).
- No - monitor only local/regional impact

In what territory do we monitor the development of transport, respectively expect significant redistribution of transport?

- municipality and its surroundings - local model
- surroundings of new/modernized line construction - regional model
- redistribution at national level, eventually - transregional analysis - national model

## 4. Model calibration and validation

### 4.1. Calibration

Calibration is the process of setting up the model, where its parameters are adjusted (e.g. time intervals - driving time of a bus line) so that the outputs are as close as possible to the observed real state on the road network. After reaching the final values of the model parameters it is necessary to verify in the model and confirm whether the influence of the parameters is adequate, corresponding to the real situation. The basic parameter test is the comparison of the intensities at the control points. The model verification process demonstrates its ability to replicate current transport relationships.

Transport models are based on a large number of parameters and other settings, so the following steps must be taken during calibration:

- adopt those parameters that can be trusted;
- limit calibration to a workable number of parameters;
- global parameters affecting the whole model are calibrated first,
- other parameters that affect e.g. one section, are calibrated later.

Models are created for defined purposes, their structure and degree of detail adapted to these purposes. It is not always possible to cover all monitored indicators with one model, because the degree of detail affects the monitored quantities (it is recommended to have them structured according to the transport/traffic process).

In transport models there are **sources of uncertainty of observed phenomena**, which may be:

- measurement errors
- inaccurate information
- inappropriate use of data
- statistical deviation
- inaccuracy of calculations
- inaccurate model definition (neglecting system elements)
- uncertainty due to computational algorithm
- merging and processing errors.

Because of the uncertainties resulting in errors in the model, it is always necessary to carry out calibration and then validation.

Calibration example: If we expect a certain statistical distribution of passengers between stations on the modelled network, during the model calibration based on empirical data, the parameters of this distribution will be set to generate a similar number of passengers between the selected stops. A properly calibrated model then shows a good match with reality in the partial views. When calibrating, it is compared the same values between each other in the model and in the real state (e.g. results of traffic intensity from the model and traffic survey intensity).

**The transport model calibration phases (comparison of model state and real state)** are performed in sequence:

- calibration of the territory attractiveness,



- calibration of distribution functions for individual purposes of trips and population groups,
- calibration of aggregated traffic flows
- calibration of vehicle selection functions (consideration should be given to when traffic survey data was generated and if any traffic mode was undervalued, comparison can be made at several levels - e.g. .for each population group, for certain geographic units, for the whole model and etc.),
- calibration of resistance function parameters (the exponent height of the function used under load affects the “sudden” deceleration of the traffic flow as the capacity of the road approaches)
- calibration of transport performance (as the last step of the calibration, a check of parameters such as intensity on individual sections or the correct number of leaving passengers at the bus stop is performed).

It is recommended to set certain calibration targets that will determine the accuracy of the calibration (e.g. the maximum percentage difference between modelled and measured intensities).

**Assessment of model and reality conformity using statistical tools**

The used statistical assessment may be GEH statistics (according to engineer Geoffrey E. Havers). This is usually used in a good conformity test and in principle verifies that the random variable has some predetermined distribution. Statistics include relative and absolute error and are thus suitable for expressing the model and reality. The relationship determining the results of GEH statistics is:

$$GEH = \sqrt{\frac{2(M - C)^2}{M + C}}$$

where M is the traffic intensity calculated by the model and C is the traffic intensity obtained empirically in the field.

To verify model and reality conformity is also often used so called “Screenline Analysis” (imaginary line that crosses the model and which evaluates the sum of the modelled traffic intensities of the intersected roads with the measured values). Comparison of individual roads can be fine, but overall, movement in one of the directions can be overestimated or underestimated. Similarly, the model may intersect near the centre and observe movement from the centre outwards and vice versa. In this case, we call this closed curve a cordon.

There are more statistical methods, such as mean absolute error, mean absolute percentage error or mean square deviation. Each of these methods has its advantages and disadvantages. GEH statistics are most commonly used.

Table 3 gives examples of calibration criteria that can be used to assess the transport model. These criteria can also be used for model validation.

**Table 3 Calibration criteria for a four-stage transport model**

Stage	Criterion	Value of the criterion	Note
Time Distance Matrix (travel time from zone A to B)	Travel time difference in model versus travel time according to survey, eventually according to the timetable	< 15 %	Incorrect times due to rounding or incomplete address in the scheduler
Trips creating	momentum of the population (number of trips per day) compared to traffic survey data	overall	< 1 % (< 0,1%)
		for a group of inhabitants	< 3-5% (< 1%)

Stage	Criterion		Value of the criterion	Note
	Percentage of the number of trips per activity compared to traffic survey data	per activity (except trip to home)	< 3 % (< 1%)	for trips to home, the difference may be greater
Trips division	traffic relations between aggregated territory, aggregated traffic flows - the difference between data in the model compared to data from the traffic behaviour survey	at the level of main zones (e.g. city districts)	< 5 %	it depends on the size of the main zones and the size of the traffic behaviour survey data
	number of business trips per municipality, O-D pairs in the model compared to data from the Statistical Office	correlation	> 60 % (> 95%)	it depends on the quality of the statistical data
Choice of means of transport	the share of the number of trips by individual transport modes, the share of the trips for individual activities compared to data from the survey of traffic behaviour	Overall for all population groups and activities	< 5 % (< 0,3 %)	in addition to the share of trips, it is appropriate to control the choice of transport mode also with regard to the transport performance
	choice of means of transport depending on the distribution curve of the trips length, choice of means of transport depending on the trips length compared to data from the survey of traffic behaviour	overall	visual check of distribution curve conformity, check of individual intervals	check that the average trip length of each transport system is consistent with the survey data
Loading of the road transport network	all day intensity	GEH < 5	> 85 %	applies to 24-hour intensities as well as peak hour models
		correlation	> 90 % (> 99%)	
Loading of the public transport network	number of people in public transport per day on profiles	GEH <5	> 85%	depends on data quality
		correlation	> 85 % (> 95%)	
Load on the cycling network	All day intensity compared to cycling census data	GEH < 5	> 85 %	depends on data quality

## 4.2. Validation

Validation of calibrated model data is called validation (verification). Model validation is the ability of a model to predict its outputs. The validation process requires a comparison of model predictions that were achieved based on different input data with model predictions that were evaluated on the basis of the initial setup.

This is the final test of the model precision, to what extent the model is able to simulate the real ratios of transport demand (traffic relations, division of transport work, traffic intensities in the transport network). A basic prerequisite for correct validation is the separation of data used for calibration and validation. The data for both calibration and validation are very similar in nature, as they are indicators that measure the performance, structure and spatial distribution of transport demand (traffic relationships, division of transport work, traffic intensity, etc.). However, other data than for subsequent model validation should be used for calibration, both physically (different data set) and type. The used tools may be similar or the same.

Example: If data on vehicle intensities or number of public transport passengers are used for calibration, data on the number of persons leaving the zones should be used for validation. This will ensure that the data is physically different by nature and will increase control over the model's operation. It can very easily happen that by carefully modifying specific parameters of the model for the purpose of its calibration, it may unwittingly deform the model in other parameters and completely deviate it from reality. However, these deviations are much easier to detect if validated on other data types. As far as possible, the validation process should also be separated from a personnel point of view, thus validation should be performed by a person other than the one who performed the calibration.

The complexity of the transport model with all its stochastic (random) elements in the load process, input parameters and mathematical functions is so large that even after the validation process, the model's results cannot be expected to be in full compliance with the present, let alone in the future or in a hypothetical scenario. For this reason, the above calibration and validation criteria of the model are set through which the quality of the transport model can be evaluated.

## 5. Prognosis

### 5.1. Transport model scenarios

**Scenarios based on current demand**, eventually current land-use (geographic and socio-economic distribution of elements in the country; no change in population distribution and economic activities, no change in OD matrix by default) - purpose to assess the impact of changes in transport policy/infrastructure (such as restrictions/charges for vehicle entry, public transport reorganization, road closures):

- the creation of a model of the current situation is always required, for the reference period max. 3 years before model submission year,
- the number and nature of other scenarios is defined according to the purpose of the model (eventually study or assignment requirements)
- modelled scenarios should only consider changes in variables and parameters that do not cause significant changes in OD matrices (such as changes in prices and charges, changes in travel and waiting times, etc.)
- there should be no changes in the zoning plan, economic performance

**Scenarios based on future demand**, eventually land-use change (there is a change in the OD matrix; demand forecast in the future, impact of construction of new areas of origins/destinations) - purpose e.g. evaluation of investment projects in the long term, changes in transport habits in the medium term.

We also know the future scenarios for assessing transport investment projects and the future scenarios for strategic models.

The number and nature of the scenarios should be defined according to the purpose of the model and a separate OD matrix should be created for each scenario, based on the expected changes to the following variables:

- (1) attractiveness/instantaneous availability (size, location, e.g. offices, shops, leisure, dwellings),
- (2) infrastructure (physical location of the network, journey times, including capacity (reallocation of road space, signal plans, parking and its limitations, number of parking spaces);
- (3) public transport (travel times, quality of service (service interval));
- (4) financial indicators (parking fees and tolls, public transport fares);
- (5) road quality (including the subjective quality of both public transport and also non-motorized transport);
- (6) economic development
- (7) time values
- (8) future fuel consumption parameters

Each scenario needs to be modelled at a minimum of 2 time horizons (minimum year of opening and end of project lifetime).

**Baseline scenario** (reference forecast / business as usual):

- (1) takes into account the natural development of land-use and the economy (geodemography, motoring, employment, economic growth, distribution of attractions),
- (2) it is also recommended to take into account the increase in the value of time, if applicable the change in public transport fares is to be considered in the same way, and to take into account the increase in revenue.
- (3) it is recommended adequately to take into account of expected natural changes in traffic behaviour
- (4) only those changes in transport infrastructure, transport policy and public transport offer that are bindingly agreed are taken into account
- (5) The most likely change should be considered for changed variables
- (6) Local variations and specificities different from national values may be taken into account for changed variables
- (7) For changed variables, their mutual consequences should be taken into account (e.g. if A depends on B, then A can only be included if B is included).
  - it is recommended to model: both high and low scenario (coef.  $p$  (year 1 -  $1 \cdot p$ , year 36 -  $6 \cdot p$ , quadratic growth), where for unimodal project  $p = \pm 2.5$  (trips),  $\pm 1.5$  (bus),  $\pm 2\%$  (rail) and  $2\%$  for multimodal project
  - other modelled scenarios
- (8) are based on a baseline scenario from which they may differ in changes in the transport offer (infrastructure, charges, public transport offer),
- (9) are defined according to the requirements of a feasibility study or assignment
- (10) each scenario is compared to the baseline scenario.

Future scenarios for strategic models (complete)

- each scenario is modelled at a minimum of 2 time horizons - 10, 20 and 30 years from the state of the art model,
  - baseline scenario (reference forecast/business as usual): same as for investment project models
  - it is recommended to model: also high and low scenario (coef. p (year 1 - 1\*p, year 36 - 6\*p, quadratic growth), where p = +/- 2%)
  - other modelled scenarios
- (11) may include changes in the transport offer (infrastructure, charges, public transport offer),
- (12) may include changes in land-use (geodemography, motoring, employment, economic growth, distribution of attractions),
- (13) are defined according to the requirements of a feasibility study or assignment
- (14) Each scenario is compared to the baseline scenario.
- modelling of future OD matrices (complete)
  - a separate OD matrix needs to be created for each future scenario (investment projects usually lead to a change in generalized costs, which in consequence lead to a change in the OD matrix)
  - possible modelling methods
- (15) fixed (a fixed demand approach) - independent of cost changes, only natural changes (land-use)
- (16) limited elasticity (own cost elasticity) - only those O-D relationships where costs change - simplified approach, suitable for rail and LPT projects (low modal-share)
- (17) full elasticity (full variable demand) - recalculated for all O-D relationships, recommended for road projects

### **Mobility forecast**

- (a) maintaining the current momentum [trip rate] by demographic groups in the future
- (b) when the car is available based on the availability of the car in the household,
- (c) at prognosis in motoring in the future take into account the increase in the order of second and other vehicles in the household
- (d) the average trip length or trip duration will vary solely according to the change in generalized costs (utility function; in particular, changes in transport speed and costs), the value of the utility function being assumed to be maintained.

The quality of transport infrastructure has a decisive impact on the quality of life in cities and regions. The development of settlement units documented by the relevant land-use planning documentation generates new traffic relations and without their knowledge it is not possible to design a quality system of transport service. The task of the traffic forecast is to define these relations both in terms of volume and direction in the conditions of sustainable mobility, in advance of their real establishment, with respect to the transport policy principles of the respective settlement unit, using modern methods.

### **Specific situations of transport model prediction:**

- current (baseline) state - calibrated and validated model with current state input

- English word “business as usual”. The continuation of the current state, when work in progress is completed and transport being influenced by a natural change in fundamental variables,
- reference state - forward-looking scenario, expected development based on strategies, plans and policies
- alternative state - forward-looking alternative scenario, assumes implementation of a set of measures defined by the contracting authority, usually it should be meaningful alternatives, recommendation - iterative procedure of assessment of alternatives - to seek relevant and best possible solutions.

#### **Time horizons of prediction for transport model**

monitored time horizons depend on project lifetime, eventually reference period.

Infrastructure buildings ability to predict traffic in the horizon up to 30 years from the start of construction, eventually 20 years after entry into service. First monitored horizon = time of entry into service. Furthermore, horizons at least every 10 years, eventually required by national regulations

#### **The forecast data requirements are**

##### **Changes in the transport offer (to be specified by the customer)**

- completion of part of the road or rail network,
- cancellation or closure of part of the road or rail network,
- change network parameters (capacity, change in speed limit)
- change in the public transport lines
- rebuilding the intersection.

##### **Land use changes - segmentation of model functional areas (to be specified by the client)**

- housing (data on areas and population)
- workplace (number of jobs)
- education (number of students)
- shopping (number of business units, size of sales areas)
- recreational and leisure facilities of the territory,
- health service (number of facilities, beds, doctors, patients).

##### **Changes in population size and structure, development of demographic variables**

##### **Changes in traffic behaviour**

Changing the distribution of attractions (e.g. distribution of jobs, etc.).

- new development areas are taken into account, distribution between new and existing sites based on appropriate data (e.g. specialised literature, empirical research etc.).
- growth rates in existing zones

## **5.2. Methodology of forecast processing**

For forecasting intensities are also used so called traffic intensity coefficients, broken down separately for light (passenger) and heavy (lorry) vehicles, road function classes and territorial breakdown (e.g. NUTS III) in the country concerned. This methodology is based on extrapolation of historical traffic development, but

due to generalizations and averages it is not able to properly capture the different traffic intensity development on individual roads due to internal demographic and economic factors.

For smaller projects, eventually projects where it is not necessary to create a comprehensive transport model, it may be used by other simplified procedures such as:

- downloading data from higher order models
- models with simplified grades (e.g. without 1 + 2 step - taking OD matrix; without 3rd step, suitable for model where modal split is irrelevant).

Therefore, real modelling is required to be applied and more sophisticated methods are applied worldwide.

In principle, two types of forecast are distinguished:

- regression analysis - obsolete, inaccurate and unsuitable for complex tasks (sufficient for short section of new roads, bypassing a smaller municipality lying on a longer route, partial modification of road parameters without linking to demand),
- a model based on a change in fundamental variables (required to model more significant investment stocks).

Analogous procedures determine forward-looking traffic relationships by analogy from the current state.

Analogous procedures include:

- unified growth coefficient - the assumption that all inter-district relationships grow evenly, i.e. the growth factor is the same for the whole territory under consideration,
- average growth factor - the forward-looking traffic relationship determined by the product of the current relationship and the arithmetic mean of the growth factors of the origin district traffic  $i$  and the destination district traffic  $j$ ,
- Detroit method - the forward-looking traffic relationship is directly proportional to the current relationship and growth factor of the two districts surveyed, inversely proportional to the growth factor of the whole city,
- The Fratar method - in addition to the different development of the both districts traffic, the calculation involves the interaction of the other districts by introducing local factors.

Synthetic procedures look for different ways of expressing factors for the future as they significantly affect the size of the forward-looking traffic relationship  $D_{ij}$ . The gravity model in various modifications is mainly used for synthetic procedures.

When modelling traffic relations, the 4-stage transport model directly assumes the consideration of several indicators of the territory development, and therefore its transport potential and transport attractiveness.

In principle, the same settings of the basic modelling parameters (the gravitational demand model) are used in this model for the forecast as for the current state model. However, fundamental demographic and socio-economic inputs for resources and attractiveness in individual zones are changing.

## 6. Transport Model Documentation

Each processed model must be accompanied by appropriate documentation - technical report. It must contain a description and analysis of the current state - zero state, socioeconomic conditions in the area and the expected development of these indicators.

The technical report shall describe the entire modelling process, the analysis of the used background, the calibration of the current state model, together with a description of the forecasting methodology for the scenarios.

The documentation should cover not only the creation of a separate transport model, but also the way in which input data is collected. Documentation of input data in road transport is governed according to national regulations.

Furthermore, the documentation shall include model output, traffic intensity cartograms or intersection cartograms according to the subject of the task - peak periods, 24 h load, traffic composition, congestion/decongestion cartogram of traffic/road network.

## 7. Transport model for the TRITIA project

### 7.1. Purpose and objectives of the TRITIA transport model

Transport models currently play an important role in the decision-making process of transport policy direction and investment in the transport sector. Their application varies depending on the scope and subject of the analysis, and recently the issue of assessing measures to mitigate the effects of climate change and environmental burden has come to the forefront. The procedures applied in the design of the transport model largely depend on its purpose and the objectives for which it is developed. The basic purpose of the transport model is to make a qualified examination of the change in transport relations to the capacity of existing and planned transport infrastructure in the TRITIA cross-border region in relation to the potential for shifting part of freight to more environmentally friendly modes (rail and inland waterway). This implies the need to develop a multimodal transport model into which a transport network of those modes of transport relevant for the TRITIA project (i.e. road, rail and inland waterway transport) will be integrated. The very purpose of the model stems from the need to unify the approach of interested countries in the area of transport policy development activities with the aim of creating a modern transport infrastructure with ever increasing demand for transport. In relation to the stated purpose of the transport model, two main objectives are defined:

- 1) Assess the current state of freight transport (road, rail and inland waterway transport, including intermodal transport terminals) in the TRITIA territory with a forecast by 2030. This means taking into account the gradual start-up of already planned strategic measures on the territory of individual regions in the horizon of the year 2030. The modelling will result in an expression of the share of water and rail freight transport and its potential to approach the objectives of the White Paper (shifting of road freight transport over 300 km to other modes of transport at least 30%).
- 2) If the model does not demonstrate a reallocation of traffic in line with the White Paper commitments, the aim is to model alternative development scenarios based on Objective No. 1 (i.e. the planned measures resulting from the strategies) with reallocating freight traffic between modes so that these White Paper commitments are met. Subsequently, an analysis of bottlenecks on the multimodal transport network is carried out to identify those bottlenecks that need to be solved in the territory of the TRITIA regions in individual countries by 2030.

The methods and procedures applied in the development of the TRITIA transport model were based on the above-mentioned purpose and objectives of the project. The TRITIA transport model consists of two submodels:

- a more detailed submodel of the TRITIA territory concerned including inland and interzone traffic relations;
- submodel of the surrounding area, including interzone roads and international traffic.

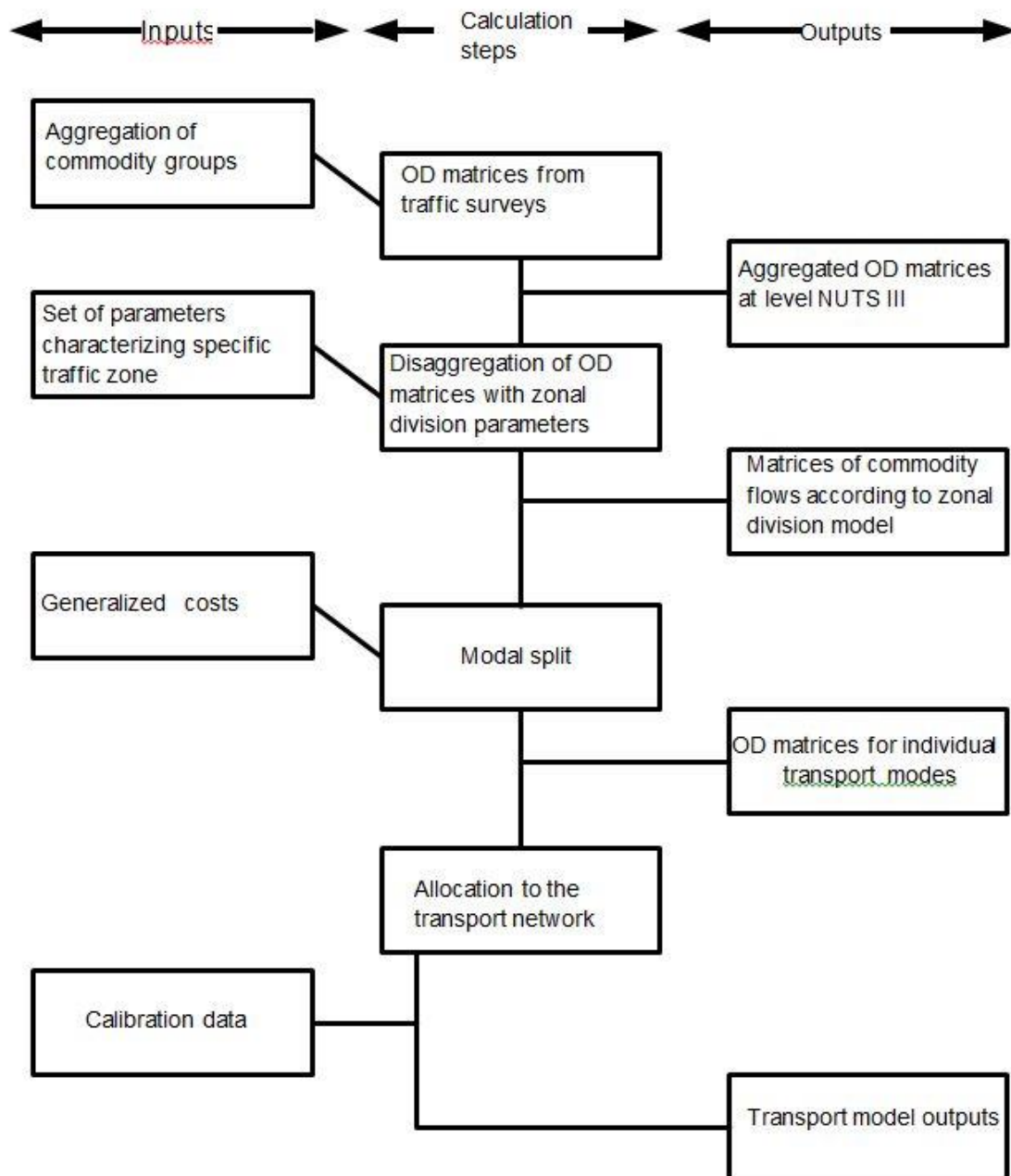
For the purpose, the transport model is designed specifically for freight and passenger transport, with passenger transport being calibrated only to take account of the filling capacity of the infrastructure.



The generally accepted VISUM® program, which is part of the PTV-VISION® transport planning software package from PTV Karlsruhe, was used to create the transport model.

## 7.2. Framework procedure for the calculation of the freight transport model

The TRITIA freight model is based compared to the classical four-stage approach, on a simplified procedure. The current demand for freight transport is processed on the basis of freight transport generation from available statistics for commodity groups, expressed in its terms of quantity (t / year) for each zone. Freight transport distribution is expressed in the form of goods flows (t / year) between zones depending on the parameters characterizing these zones. The subject of traffic modelling is only the steps related to the selection of the traffic mode and the assignment of traffic to the network. The choice of transport mode is expressed by zone-to-zone flows (t / year) for each mode of transport. Subsequently, the volumes of goods flows in quantity units are converted into vehicles as transport between zones. Allocation to the network is carried out by means of its load as transport on individual transport sections of the network. This load on the transport network is handled, including idle journeys.



**Figure 2 Architecture calculation of TRITIA freight transport model**

### 7.3. The territory of interest and its zonal division

The territory in question of the TRITIA project is, for the purpose of creating a transport model, the territory bounded by the administrative boundary of the external part of the connected territory of the Žilina self-governing region (SK), Moravian-Silesian region (CZ), Silesian Voivodship (PL) and Opole Voivodship (PL). Being a macroscopic transport model with significant cross-border traffic relationships, the TRITIA area of interest is extended practically to the entire European continent.

In term of applied zoning of the territory was used the approach in the form of a more detailed division of the relevant territory of the TRITIA project at LAU level 1, with the exception of Silesian and Opole

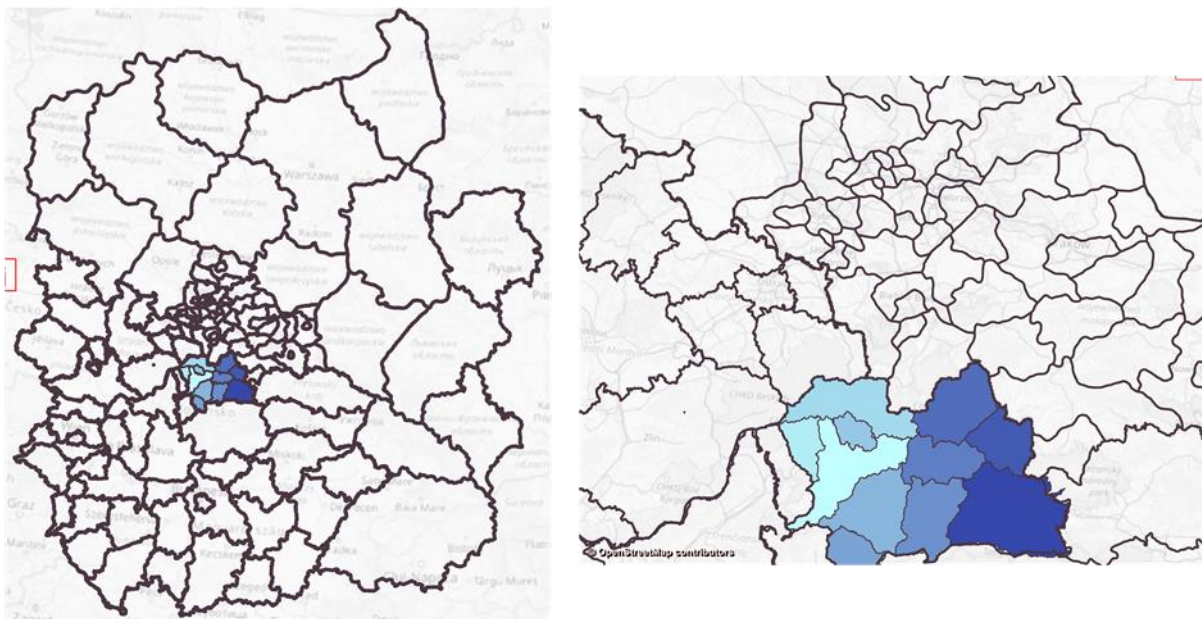
Voivodship, whose territory is divided into zones at NUTS III level. Zoning at the NUTS III level was applied to the rest of Slovakia and the Czech Republic. The rest of Poland territory is divided into NUTS II zones. The territory outside the participating countries of the project was subdivided into NUTS II to NUTS I regions depending on the distance to the territory of interest or the estimated aggregate traffic volume between the centroids of these zones and the territory of interest. The connection of representative centroids to the modelled infrastructure network within the construction of the TRITIA transport model is realized through connectors.

The zoning of the area of interest of TRITIA was carried out in a way that would allow the mutual exploitation of the source data and the acquired knowledge about the regularities of transport relations with existing national transport models.

**Table 4 Frequency and distribution of zones of the TRITIA transport model**

	PL	SK	CZ	Other	Total
Number of zones	72	18	19	106	215

To interconnect the transport network and zones are used connectors, which ensure the interaction of transport offer and demand. With a higher number of connectors to one zone, it is possible to refine the distribution of the transport offer in the territory in question.



**Figure 3 Zoning of TRITIA modelled area (left - zoning of traffic model, right - detailed zoning of the area of interest)**

## 7.4. Transport offer

The transport offer of the TRITIA transport model is defined by a transport network made up of nodes (respective centroids) and edges (links between transport zones). Edges are assigned the following transport offer parameters:

- length
- time of transport;
- price of transport for the monitored modes of transport;

- other parameters affecting the time and cost of transport (e.g. capacity, mountain areas).

The transport network is the basis for traffic load modelling, with the data characterizing the transport network through its parameters being relatively accessible and of varying quality levels. The scope of the structure of the transport network varies depending on the purpose for which this model is developed. As mentioned above, the TRITIA transport network consists of road, rail and inland waterway infrastructure with the following level of detail for the reference year:

- 1) The road network of the transport model of the area of interest includes the complete road infrastructure up to the level of detail of the roads of lower importance. In the transport model, local roads are used to distribute roads only to a limited extent and replace their connectors. Outside the TRITIA area of interest, the road network is represented by a transport infrastructure of higher importance, in particular by the network of European roads in the context of the deployment of the model's external transport zones.
- 2) The railway transport network covers the complete railway network within the territory concerned with stations including carriage able routes not currently used for passenger transport. In the case of international railway lines the network is subject to a zonal division of foreign countries taking into account all lines crossing the boundaries of the TRITIA area of interest.
- 3) The inland waterway network has been integrated into the model to the extent of navigable sections of waterways of IV. class and higher for the area of interest, and for the rest of the monitored area were selected waterways that are relevant to the purpose of the transport model.
- 4) Within the national model the freight transport network is taken into account in the defined types of link for road, rail and inland waterway freight transport, and also contains individual intermodal terminals as important nodes of potential multimodal transshipment. The total modelled area contains 97 terminals in the form of network nodes.

Each transport type of the modelled infrastructure has been assigned appropriate transport subsystems and basic transport characteristics and network technical parameters. In addition to the links, the national model transport network also comprises nodes representing intersections, points of interconnection of traffic zones or public transport stations with specific indicator parameters.

## 7.5. Calculation of transport demand

### 7.5.1. Source data for the passenger transport model

In relation to the purpose of the TRITIA transport model is the position of passenger transport in the analysis of transport relations defined exclusively in the context of the capacity assessment of the loading on the transport network. In the case of road transport, data from profile traffic surveys at selected locations are used. The rest of the road network in the traffic model is loaded on the basis of the current data from national road traffic censuses and permanently installed automatic traffic counters on the profiles of roads of higher traffic importance. The source of data on railway transport is data from national transport models and operational data from railway infrastructure managers.

### 7.5.2. Source data for freight transport model

The data characterizing the freight transport offer are different from the usual data structure applied to passenger transport models. In regard to the fact that for the purposes of the TRITIA transport model it is decisive to identify the potential for shifting goods from road to rail and inland waterway respectively, the structure of the transport network parameters also includes data on load capacity, freight capacity, tolls and freight traffic restrictions.

In order to quantify and define the transport demand for freight transport, the structure of the source data is also different from that of passenger transport. The determination of traffic demand in the form of O-D matrices in the TRITIA model is based on the demand for freight commodities. Data sources are statistical reports on production / consumption and import / export of individual commodities. The submodels of loading, unloading and transport mode options for a specific commodity group are derived from them and represent a calculation framework for subsequent transport modelling steps. Data from the freight demand survey carried out between significant carriers and carriers established in the territory of Slovakia, the Czech Republic and Poland will be used as an additional source of data. For the redistribution of aggregated reports of commodity groups into individual zones are used data characterizing these zones in terms of the occurrence of significant sources / objectives of freight transport, population, employment in sectors related to commodity groups and other parameters. Similar matrices are also generated for zones outside the TRITIA area of interest, where there is a potential for transit traffic to this area. The distribution of goods flows is derived from the characteristics of logistics systems. Calibration and validation of the TRITIA transport model is based on survey data at the border crossings of Makov, Svrčinovec, Skalité, Trstená, Vysoká/Bartultovice, Antošovice/Šilheřovice, Český Těšín on vehicle movements and available data from the road and rail traffic census of countries participating in the project.

The socio-economic data characterizing the attractiveness of each zone to freight is used to the following extent for the TRITIA transport model:

- Population data:
  - population data at municipal level;
  - number and population structure;
  - share of employees, primary school pupils, secondary school students and university students;
  - number of employees and their structure.
- Employment data:
  - professions by sectors and addresses;
  - professions in European countries.

Regarding to the availability of statistical reports describing relational relations in the carriage of goods (usually at national level), they need to be disaggregated into smaller spatial units (zones) in accordance with the available data and spatial logic. The process of disaggregation is based on the application of a relativizing attribute, which will allow the redistribution of total volumes of goods flows into a zonal division of the transport model. The total commodity streams are consequently divided according to the commodity composition applied within the TRITIA transport model. For this step of disaggregation of the total volume of goods into commodity groups at the zone level, data on the number of employees in the production / consumption spheres of the specific commodity group or the occurrence of a significant center of production / consumption of the specific zone will be used. For each commodity group are created several pairs of source-target relationships, to which the probability of their occurrence is indicated. The sum of the probabilities of the source paths constitutes then the zone's productivity and, for the target paths, the zone's attractiveness for a specific commodity group.

### 7.5.3. Generalised costs

Specificity of modelling freight transport is that in relation on availability of demand matrices it is not essential to make calculation steps in transport modelling, which are related to creation and distribution of roads. In general, the procedure is established on calculations of transport labour, for which are specified generalised costs for every single mode of transport. It is a monetary expression of monetary and non-

monetary travel expenses, the largest share of which is the time parameter, which is converted into monetary units through the perceived cost of time. For each edge of the transport model, generalized costs are determined according to the following formula:

$$GN = (1 + \sum A_{SIT}) \times (VT_{KS} \times t + TC_{DS} \times I) + K_{DS} , \text{ where:}$$

$GN$  - generalised costs;

$A_{SIT}$  - transport network attribute;

$VT_{KS}$  - perceived cost of time for given commodity group;

$t$  - travel time in hours;

$TC_{DS}$  - transport costs for given mode of transport;

$I$  - distance in km;

$K_{DS}$  - constant for given transport system.

The concept of perceived value of time represents the price of the time of goods in terms of their perception by carriers and freighters on the merits of the decision on the choice of transport mode. In addition to the commodity price component, the group also consists of the perceived value of the time of the goods, which is derived from traffic behaviour surveys examining preferences for transport issues such as reliability of transport mode, risk of congestion or transport safety. The monetary expression of these preferences is usually determined on the basis of the results of foreign studies.

## 7.6. Trip distribution and modal split

For the current state of the TRITIA transport model, the calculation of trips distribution based on the gravity method did not enter directly. This is due to the fact that, compared to passenger transport, the choice of destination for freight transport is influenced by several parameters for which descriptive statistics are not available. However, it is necessary for the model of forecasts to know the course of distribution curves and their elasticity in dependence on the change of generalized costs in the relation of transport of individual commodity groups. In order to derive distribution curves, the classification of demand matrices for the given commodity groups was carried out, and traffic between zones outside the TRITIA area of interest was excluded from these OD matrices due to the risk of the curve deformation. In other words, for current state of demand matrices, trip volume was calculated according to transport distance.

Subsequently, the variability of the transport distance change to the volume of the commodity group transported was tested. Distances intervals at which significant changes occur over the distribution curve were determined. A separate coefficient is created for each interval so that after multiplying the values in the base OD matrix, the total traffic volume is consistent despite the change in transport distance. This intervention will change the course of the distribution curve and thus the representation of long-distance or shorter trips. A similar procedure is implemented for each commodity group. The elasticity of the change in generalized cost and transport distance was tested based on the results of available transport surveys and the conclusions of the related literature.

Trips distribution was calculated similarly to generation, separately for each category. The distribution was calculated using a two-way defined interaction model that divided the traffic volumes between origin and destination zones. The result is the flow between zones in tonnes per year. Distribution was calculated in two steps:

1. calculation of indicator matrices based on impedance between transport zones; and

2. calculation of commodity flow matrices (expressed as tons per year flow) based on evaluation matrices, origin and target quantities.

The cost matrix was used in monetary terms as the impedance effect of distance matrix. The matrix values expressed in euro were calculated using the impedance function. The place of origin and destination of the commodity flow matrix expressed in net tonnes per year were calculated for each commodity.

The distribution was synthetically calculated only for transport within the TRITIA area of interest. Experience gained with long-distance flow distribution classification models has shown that synthetic models only imperfectly describe the true state and achieve very poor correlation with the true observed state. Therefore, the synthetic model is not used to determine the allocation between origin and destination zones.

The existing distribution was based on Eurostat statistics and national statistics. According to the sectoral workplace (agriculture, construction and industry), these flows were divided by commodity at traffic zone level. This means that potential future changes in the distribution of origin and destination and transit flows were dependent only on changes in generation and not on changes in the impedance matrix.

However, changes in the impedance matrix should have an impact on the choice of mode and route of transport. As mentioned above, the amount of traffic generated was expressed in tonnes per year. The same unit was used to distribute and express the flow between zones.

The choice of modal split or their combination is determined by the load on the multimodal network by individual commodities. Mode selection and route selection are based on generalized costs and are calculated at the same time. Generalized costs and generalized time were monetary and non-monetary costs for road, rail and national waterways and logistics. They therefore included costs related to time, transport distance and logistical tasks. Cost within the model was determined as:

- time-related costs: costs related to transport modes and the loss of value of goods by category;
- distance related costs: costs related to transport modes; and
- logistics costs: loading / unloading and transshipment costs.

Transport costs are attributed to network links. The following have been taken into account when using modes of transport:

- Link attributes: enable usage for a given traffic mode, speed, and length; and
- logistics system, division of commodities.

The costs thus consisted of costs which were dependent on the transport distance and time as well as the transshipment activities. Subsequently, the most advantageous combination of the mode of transport was chosen. Each commodity was assigned to the multimodal network by an iterative procedure using flow matrices in tonnes. The result was the most cost-effective choice of transport mode and route selection for each possible origin and destination pair. As mentioned above, for each of the logistics systems, share costs consisting of distance-dependent costs, time-based costs of loading, unloading and handling as well as fixed costs at the terminal have been established. Time of transport consisted of driving, loading, unloading and handling times, as well as a delay time at the border.

Almost every commodity loses value over time. The more time spent handling and transporting, the greater the loss of value of the goods. This loss is different for different commodities, so a specific value was assessed for each commodity. In the case of freight transport, the choice of mode of transport depends primarily on the size and volume. Cost and time are decisive factors that have had a different impact on different product groups. For example, given the high value of non-durable goods, time plays a much more important role for certain commodities. Commodity traffic flows, expressed in tonnes per year, are converted into daily transport, taking into account the average load of each type of vehicle (about 12-15

tonnes for heavy goods vehicles, about 1-2 tonnes for light goods vehicles) and idling ( about 30%). This procedure results in road matrices by mode of transport during the normal working day.

The internal freight transport demand model in Slovakia had three steps by default:

- production and attraction;
- distribution;
- choice of transport mode.

At a level outside the TRITIA area, distribution was not modelled synthetically, but took into account current results from business statistics. Distribution for the TRITIA area of interest was determined by a two-sided model of spatial interaction, while elsewhere it was based on existing distribution.

The prediction of traffic demand was based on the calibration model of the current situation and the prediction of the future socio-economic situation. In freight transport models, the basis for forecasting future demand for freight transport was, besides gross domestic product, also production by sector. Of course, this was not only dependent on economic growth and employment rates, but also on potential consumption and added value.

## 7.7. Allocation of traffic on the network

The density of the transport network is carried out on the basis of a stochastic algorithm that takes into account that carriers and freighters tend to routes with the lowest generalized costs, but part of which are also deviations caused, for example, by lack of comprehensive information about the transport offer or certain business conditions. The extent of this deviation is determined on the basis of the Box-Cox distribution model. The allocation of traffic to the network also takes into account the possibility of combining several modes.

The stochastic network allocation algorithm is based on the determination of all alternative routes to which the demand for transport is subsequently distributed by applying a distribution model. For freight transport, the Equilibrium assignment method is used, taking into account the capacity of the transport network. To eliminate errors from interacting with the calculation steps, the entire network assignment process takes place through multiple iterations.

Selection of a particular transport mode, or their combination, is determined based on the density of the multimodal network by individual commodities. Mode selection and route selection are based on generalized costs and are calculated simultaneously for all possible combinations of transport routes. Generalized costs and generalized time include monetary and non-monetary costs for road, rail and inland waterway transport and the logistics system. Transport costs within the model are determined as:

- time-related costs: costs related to transport modes and the loss of value of goods by category;
- distance related costs: costs related to transport modes;
- logistics costs: loading / unloading and transshipment costs.

Transport costs are a quantitative expression of the weight of the transport network link, taking into account the following when selecting a transport mode:

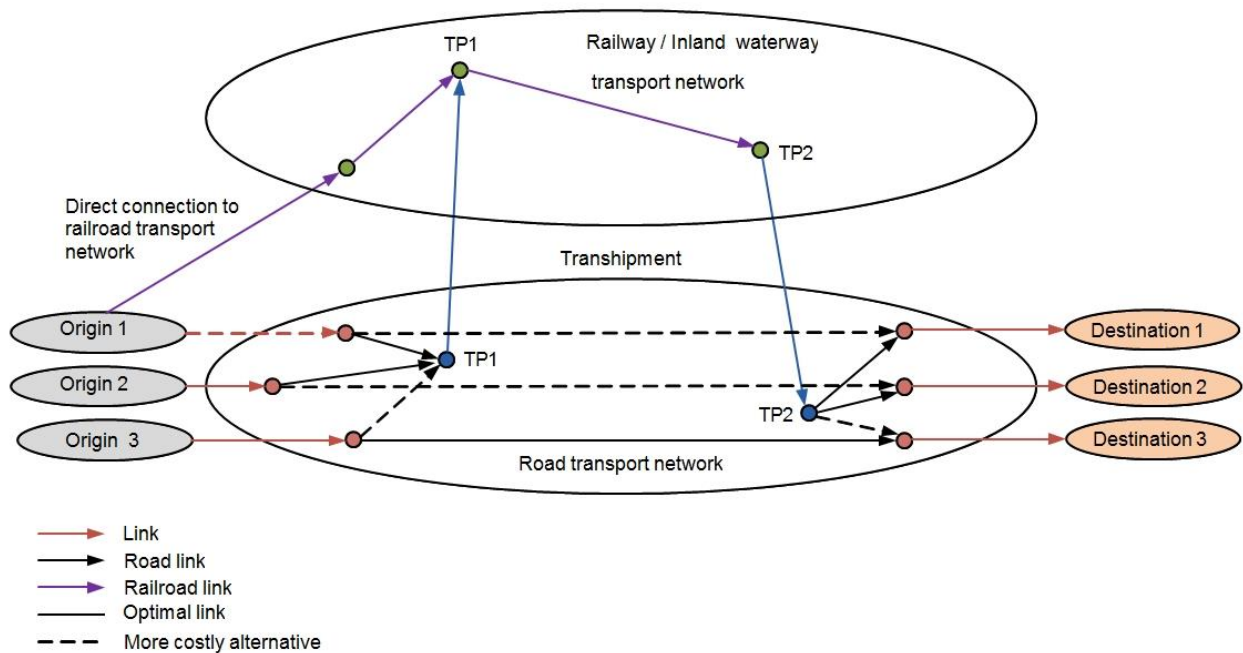
- link attributes: enabled usage for given traffic mode, speed, length;
- logistics system, distribution of commodities.

Logistics systems describe a method of transporting goods for commodities with similar requirements, as demonstrated by the use of similar transport modes and similar handling costs. Logistic systems in the model are divided into:



1. liquid: petroleum products;
2. liquid: food;
3. bulk goods: raw material;
4. bulk goods: construction material;
5. bulk goods: food and feed;
6. goods packed in bags;
7. the containers;
8. special lorries (trucks);
9. fresh food.

Costs thus consist of costs that depend on the transport distance and transport time as well as on the transshipment activities. The value of unit transport costs is derived from the conclusions of foreign studies on this issue. An iterative procedure by means of flow matrices is each of the monitored commodities assigned to the transport network. Subsequently, the most advantageous combination of the mode of transport is chosen in terms of the total amount of transport costs. The whole process is shown schematically in the following figure.



**Figure 4 Allocation of transport to the network depending on the amount of generalized costs**

The incremental method together with the information on capacity limitations of the transport network were chosen to calculate the network allocation. The freight transport model can thus enter the passenger transport model into the passenger transport model and thus test the capacity parameters of individual transport sections of the network. To increase the time costs related to the capacity saturation of the transport network, the BPR function is applied similarly to the usual passenger transport models.

$$T = T_{ff} \times \left( 1 + \alpha \left( \frac{q}{q_{pc}} \right)^\beta \right), \text{ where:}$$

- $T_{ff}$  - time of transport for free traffic flow
- $\alpha, \beta$  - calibration coefficients affecting the shape of the curve
- $q$  - the volume of traffic on a given section
- $q_{pc}$  - capacity of the section

It follows from the above dependence that at low traffic volumes, the function has a flat course and the real time of transport corresponds to the time of transport under free traffic conditions. In the case of higher traffic volumes on a given section of the transport network, the coefficient  $\beta$  determines the limit at which the course of the function starts to grow significantly. The transport time increases with the value of the share of the volume of transport and capacity in the given section of the transport network.

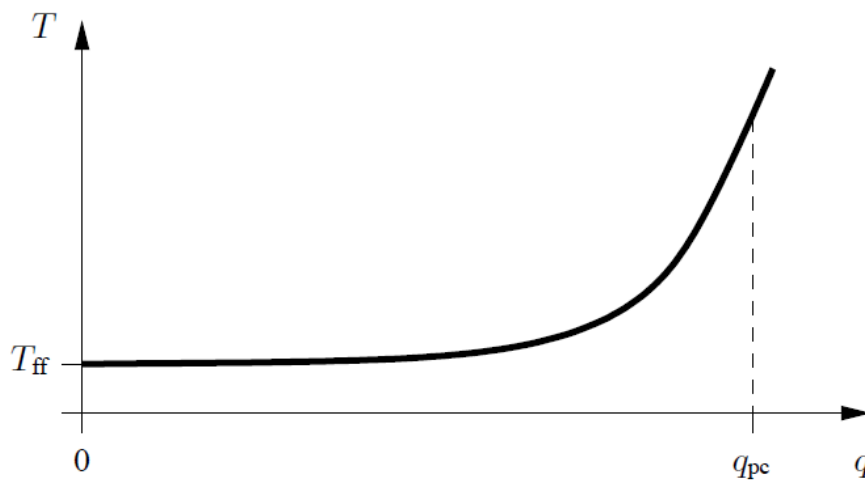


Figure 5 Typical course of BPR dependence function of transport time and transport volume

### 7.8. Calibration and validation of transport modelling TRITIA

Calibration is called adjusting the model in such a way that the modelled quantities correspond to the best found values. The quality of the calibration is statistically evaluated by the VISUM software and the conformity of modelled and observed data was tested. For quantitative expression of calibration quality is applied generally accepted method GEH statistics, whose mathematical notation is as follows:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}, \text{ where:}$$

- $M$  - hourly intensity calculated by the traffic model;
- $C$  - hourly intensity actually recorded by the survey.

The choice of this method was based on the need to eliminate the problems associated with the percentage deviation of intensities detected by the model and traffic survey. This method, in contrast to the linearly increasing deviation, where there is a risk of exceeding the allowable tolerance on high intensity sections, creates a non-linear function and thus eliminates this risk.

Verification of the transport modelling is carried out continuously in the individual steps of its creation and focuses on the following subject areas:

- verification of methodological procedure (e.g. input data, type of transport modelling);
- verification of partial segments (e.g. matrix, model analysis methods);

- functionality check (e.g. parameters of transport network and transport systems).

The basic level of validation of the transport modelling is carried out through the basic unit of the freight transport model - the number of net tonnes per year. However, for the purposes of transport planning, these units should be related to freight means of transport, which are the number of trucks, trains or ships, on an average working day.

During the calibration phase of the freight transport modelling, the distribution of commodity travel and transport costs is adjusted so that the model sufficiently reproduces the real situation. The basic unit of the freight transport model is net tonnes per year, which also determines the basic level of validation. The following limitations are identified during freight validation, in particular with regard to the availability of data:

- the quantity of goods transported on the section is available only for rail transport,
- only general statistics of average vehicle weight and idle ratio are available for heavy goods vehicles (general European data),
- there are no reliable data on the average number of working days (250 days for heavy goods vehicles, 300 days for freight trains) and no guidelines or validation assessment criteria (except for the validation of commercial vehicles during the average working day).

Due to the lack of reliable data for the calculation of the net tonnage conversion factors in freight units per day, it is proposed that in the last step of trip allocation the estimation matrix procedure is used. The changes that result from this are considered in the forecast using the rotation point method. In the validation of freight transport, it is appropriate to use the established criteria (correlation coefficient corresponding to the RMSE deviation, GEH) at the level of strategic direction. Validation criteria are:

- traffic on roads and railways;
- net tonnes of goods transported on the railway network in the territory of interest;
- correlation of the net tonne sector on the rail section;
- number of freight trains per year and per day;
- correlation between the number of freight trains per year and per day;
- criteria for road motor vehicles for the transport of goods in Slovakia:
  - transport labour;
  - correlation;
  - standard deviation.

The next step in rail freight validation is the number of net tonnes by section.