# Combining a Transport Demand Model with the Network Emission MOdel NEMO – Practical Experiences in "STREET 2030"

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## Introduction and background

As in many other countries, in Austria transport is one of the most relevant sectors in terms of energy use and thus emissions of air pollutants and greenhouse gases. Traffic volumes are expected to further increase which likely involves a rise in energy use and emissions. On the other hand by adopting the EU climate and energy package and EU air quality standards Austria has accepted obligations to reduce greenhouse gas emissions as well as air pollutants.

Against this background the research project "STReet-section specific Energy, Emission and Transport model 2030 – STREET 2030" had been launched to develop and apply a tool which shall serve as a sound basis for decision-making on energy and climate policies for the transport sector. The tool to be developed was expected to cover both policies on mobility behaviour for private and public transport as well as technical improvements in energy consumption and emissions of the propulsion systems. Therefore the chosen approach in STREET 2030 was to connect a macroscopic multi-modal transport demand model (TDM) with the "Network Emission MOdel NEMO" and to process the results in a Geographic Information System (GIS).

STREET 2030 was carried out in cooperation with Umweltbundesamt GmbH Wien, Graz University of Technology, Institute for Internal Combustion Engines and Thermodynamics as well as komobile w7 GmbH and was supported by the Austrian climate and energy fund. This paper deals with some practical experiences in applying the macroscopic TDM of the city of Vienna (Holzapfel and Riedel, 2013) to produce sound input data for network based emission modelling.

## Necessary input data from transport demand model (TDM) for network-based emission modelling

Designed as a network-based model, the energy consumption and emission model NEMO demands the road network´s characterisation as well as a link-based calculation of traffic data. It has proved practical to process the network data together with the traffic data to make sure that both models (TDM, NEMO) are based on the same network data for each scenario.

With regards to spatial resolution and time limits of the investigation area NEMO offers the ability of very detailed energy and emission modelling. As in STREET 2030 a strategic macroscopic TDM with a reference period of one working day was applied to calculate traffic data, the limitations for the break down were defined by the transport model. After the analysis of the implemented and available data it was decided that the following (scenario dependent) data has to be transferred from the traffic model to NEMO for each link: type of road (distinguished in urban, rural and motorway as well as speed limit), length, gradient, total vehicle-kilometres, share of vehicle-kilometres per type of vehicle and average speed per type of vehicle.

## Calculation of driven mileage including intra-zonal trips

The vehicle-kilometres by type of vehicle on each link were calculated by the product of link length and traffic volume. The link lengths are given by the implemented network graph. For the calculation of traffic volumes a multi-modal 4-step approach of transport demand modelling was applied.

Within the first three steps – trip generation/attraction, trip distribution and mode choice – the number of trips from/to zones per mode are derived from a discrete choice model which is based on the quality of transport supply by mode and the assessment of the skims (e.g. distance, travel time, costs, number of transfers, etc.) per mode, group and trip purpose. In the fourth step – the search for appropriate routes and the route choice – the trips are assigned to the network. As a result a loaded network for each mode of transport is given.

(Obermayer et al. 2011) In this fourth step only inter-zonal trips are assigned to the network; so-called intra-zonal trips – starting and ending in the same zone – cannot be allocated to the network methodically and therefore commonly are not considered in energy consumption and emission modelling.

The share of intra-zonal driven mileage on the total vehicle-kilometres depends on the zone sizes, the density of the road network and the trip lengths of the TDM. The product of the number of intra-zonal trips and the average intra-zonal trip length per zone enables a good estimation for this share. The calculation of sound intra-zonal trip lengths is a separate issue which is therefore not treated in detail in this paper.
In terms of the applied transport model the estimation was made by using the intra-zonal trip lengths which had been determined in the three steps of demand modelling. For private cars the share of driven mileage on intra-zonal trips including the driven mileage on the connectors was calculated by 8.4 % of total car-kilometres. It was decided that this order of magnitude should not be omitted in emission modelling. Therefore the characteristics of an intra-zonal network and velocity distribution were definedon the basis of the following reflections:

Intra-zonal traffic strongly correlates with local traffic and mainly occurs on the subordinated road network. Consequently the intra-zonal driven mileage and the traffic on connectors shall be modelled by comparable link characteristics with an appropriate low speed. The zone sizes, the land use structure as well as the intermodal transport supply mainly affect the trip length distribution. Due to the fact that these parameters vary in any planning area the intra-zonal driven mileage should be allocated as close as possible to the points of origin and not equably distributed over the planning area. Traffic is processed in hierarchical networks: it originates and ends in traffic excites, it is gathered by connecting roads and it flows into trunk roads; the traffic volumes correspond with the road classes.

Based on these advisements intra-zonal driven mileage was handled as follows: There were no synthetic road (link) types included. Intra-zonal traffic was assigned to existing, low class developing and connecting roads where the processed type of vehicle is permitted and the speed limits ($v_0$) are lower or equal to 45 km/h. The intra-zonal driven mileage was added up for each political district and distributed to the lower class roads within the district. Finally the sum of intra-zonal traffic per district was allocated to the link loads within the districts proportionally. These calculations were done separately for each vehicle type of private transport and the traffic loads were transferred to NEMO together with the other network data.

These procedures were not necessary for public transport service because of the reason that in the applied transport model the vehicle journeys are routed very precisely on the detailed road network and the bus-kilometres were calculated from the timetable.

## Calculation of correct link speeds

Aside from correct remodelling of link loads for energy consumption and emission modelling it is determining to reproduce realistic vehicle speed levels. Corresponding to the applied model structure it has to comprise the time needed for passing the links as well as the intersections. It also has to achieve the load-weighted average speed within the period of consideration of the TDM.

Typically the link speed - and in some advanced TDMs additionally the time losses at intersections - is described by load-dependent functions (volume-delay or capacity restraint functions - CR functions) which express the relation among vehicular flow, speed and density. For a sound calibration of the assignment, two aspects have to be considered:

Firstly, depending on the road class and the purpose of the road within the road network, the daily variation curve of the capacity utilisation rate can vary distinctively and therefore the variation curve of the speed level can vary too. Since the speed distribution mainly determines the weighted average speed it is crucial to consider significant characteristics of the road network. In previous studies, e.g. (Fellendorf et al.,2011) it was found by cluster analysis that the speed distribution of the following road categories vary typically and hence for the purpose of emission modelling should be differentiated: motorway, country roads, roads of the city centre, tangential city roads, radial city roads. Thus against the detailing of the implemented road network and the zoning of the TDM for these road types characteristic CR functions should be calibrated. Their shape must reflect the relation among vehicular flow, speed and density in their variation curve of the observation period of the TDM.

Secondly, as most strategic TDMs are developed with an observation period of an average working day and the routing-relevant capacity of links and intersections usually is applied to an hour, the CR functions additionally include a scaling factor. In numerous TDMs the scaling factors are estimated regarding the peak hour. Consequently only the volume of the peak hour is considered for the calculation of the link impedance in the step of the assignment. Therefore the reflected speed of the TDM corresponds to the peak hour and does not correspond to the average speed of the total observation period. Due to this fact the modelled speed levels are lower than the average speed which would bias a subsequent energy consumption and emission modelling.

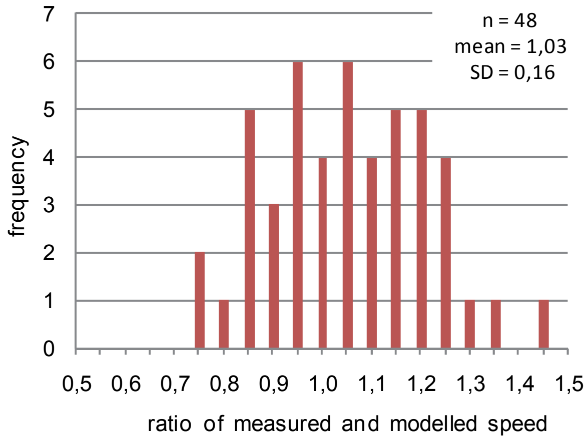


**Figure *1*:** Bar chart of remodelled link speeds

As a consequence the resulting speed levels of the TDM have to be checked with real values of the average speed. If there are decisive deviations they have to be altered for the purpose of emission modelling. The TDM must not be recalibrated if the results of the TDM are sufficient for the aims of strategic transport modelling. The adjustment can be done in a post-process and it is obvious to adapt the parameters of the CR functions. Such a procedure was developed in (Kriebernegg, 2010), however the shape of the CR function was neglected there.

In STREET 2030 average working day´s 24 hourly values for traffic load and speed of all existing Viennese traffic counting systems have been processed and five different road classes in terms of daily variation of capacity utilisation and speed level have been defined by statistical analysis. For each road class alteration parameters were estimated and adjusted link speeds for emission modelling were calculated. Exemplary Figure 1 shows the ratio of measured and modelled link speeds for collecting roads.

The average speeds from the TDM as input-data for NEMO must also depict the time losses at road crossings. In TDMs there are different and the more or less detailed approaches customary to consider the impedance at intersections. The applied method in each TDM depends on the available/affordable data as well as the (main) purposes of the TDM. For load-dependent modelling of node-impedances the same advisements as for links can be taken into account.

For emission modelling with PTV-VISUM an explicit consideration of the time losses at intersections cannot be considered as standard. (Neuhold, 2012) and (Fellendorf et al., 2011) tried to depict this influence by fictitious lengthening of the link lengths corresponding to time losses at the nodes. In this case the modelled node impedance does not correct the total average speed (only the travel time is corrected): Hence this approach does not reflect the average speed comprising links and nodesis not in line with the parameterisation of NEMO.

In STREET 2030 the time losses at the intersections were considered for all private transport vehicles by the following approach: The one directional time losses of nodes are assigned to the preceding link. The total speed is calculated by the link length and the time expenditure for passing the link and the following node. As the impedance at a node is determined by the traffic volumes and the time losses per turning path (straight ahead, right, left), the total one directional time expenditure at a node is calculated by the traffic volume-weighted time losses per turning path. These considerations are shown in Figure 2 and subsequently the formulas of the calculations are given.

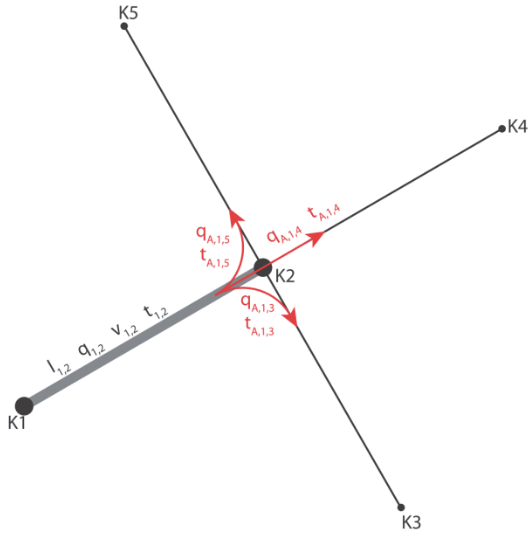


**Figure 2:** Sketch for the calculation of the link speed for emission modelling

$$v_{EM} = \frac{l_{ges}}{t_{ges}}$$

$$t_{ges} = t_{akt,S} + t_{akt,K}$$

$$t_{akt,K} = \frac{\sum(q_{A,i,j} * t_{A,i,j})}{\sum q_{A,i,j}}$$

$$q_S = \sum q_{A,i,j}$$

in which: $v_{EM}$: average vehicle speed for emission modelling, corresponding to the average linkspeed taking into account the time losses at the following node;

$l_{ges}$: total length of link and following turn path; as in macroscopic transport models typically the lengths of turn paths are not depicted in detail $l_{ges}$ is equal to the link length;

$t_{ges}$: total expenditure of time for passing the link and the following turn paths;

$t_{akt,S}$: traffic volume-dependent link travel time;

$t_{akt,K}$: traffic volume-dependent time losses at the following node;

$q_{A,i,j}$: traffic volume on the turn path from node i to node j;

$t_{A,i,j}$: traffic volume-dependent time losses on the turn path from node i to node j;

$q_S$: link load.

The schedule of public transport service includes time expenditure at stops and road crossings. In general the timetable-based calculation of the average speed between two stops is in line with the parameterisation of NEMO. Assuming that the schedule reflects real travel time and that the occurrence of different road classes with different speed limits between two stops can be neglected the average speed for public transport service can be calculated from the timetables and used as input data for NEMO. In STREET 2030 this approach was applied for all public transport modes.

## Determining of link slopes

For energy consumption and emission modelling with NEMO among other link parameters the road gradients have to be considered which is decisive for heavily and/or asymmetric loaded links. Since neither the link slopes nor the altitudes of the nodes were given or available for the road network graph of the applied TDM, they had to be calculated in a separate working step. In STREET 2030 this was done by superposing the network graph with an elevation model of the planning area. With this procedure it was possible to calculate the altitude of nodes which makes it easy to determine the link slopes in PTV-VISUM.

Regarding the described procedure it has to be considered that only the heights of the starting and endpoints of links are depicted. The longitudinal profiles along the roads are not taken into account which leads to homogenisation and underestimation of maximum link slopes. Mainly this effect can be handled by a proper definition of link segments and the choice of adequate link lengths in hilly areas.
Furthermore it has to be taken in consideration that in elevation models civil engineering structures as bridges, tunnels, dams, cuts, under- und overpasses typically are not depicted in the necessary detailing. Therefore combining a street network graph with an elevation model can lead to significant inaccuracies in terms of the calculated altitudes of nodes situated on/in civil engineering structures. Regarding energy consumption and emission modelling this hasdual significance: Especially large-sized civil engineering structures are parts of the major road network where the majority of vehicle kilometres is driven. Correspondingly, higher inaccuracies of link slopes arise in connection with highly loaded links which further boosts the inaccuracies of energy consumption and emission modelling. Hence it is necessary to consider maximum plausible gradients per road category and to run additional checks in a rework process.

To achieve high quality link slopes with the above described method a high-resolution road network as well as an elevation model of high density are required. Alternatively the implementation of longitudinal data from a trigonometric survey is recommended at least concerning the main road network.

## Summary

Based on various practical experiences in STREET 2030 three crucial aspects of combining a macroscopic transport demand model with the emission and energy consumption model NEMO are discussed.

In general a transport demand model is an abstraction of the planning area and therefore of the (re)modelled mobility behaviour. Usually the model should be run only to calculate differences or changes between different scenarios. If an estimate of the total magnitude of any value is required – e.g. the driven mileage or the emissions – beyond this the contribution of intra-zonal traffic has to be taken into consideration; especially concerning TDMs where intra-zonal trips are neglected totally.

Vehicle speed as an input data for NEMO highly influences the magnitude of modelled energy consumption and emissions. A close look at the methodological structure and the parameterisation of the TDM is necessary to achieve results for vehicle speeds, which are compatible with the emission modelling approach. For consistency with the parameterisation of NEMO the time expenditure at junctions must also be considered by the calculation of the average speeds.

The slopes of heavily and/or asymmetric loaded roads affect the results of energy consumption and emission modelling significantly. For the purpose of a suitable estimation the introduced approach by superposing the network graph with an elevation model is appropriate on condition of some rework process. For more reliable and detailed modelling the implementation of longitudinal data from a trigonometric survey is recommended at least for main road network.

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