METHODOLOGY AND APPLICATION OF A GERMAN NATIONAL PASSENGER TRANSPORT MODEL FOR FUTURE TRANSPORT SCENARIOS

Christian Winkler
Tudor Mocanu
Institute of Transport Research, German Aerospace Centre (DLR), Berlin

1. BACKGROUND

Mobility is a key element of sustainable development and societal welfare but also contributes significantly to global greenhouse gas emissions, mostly CO_2. In Germany, the transport sector is responsible for almost 20% of state-wide CO_2 emissions and its share on total emissions increased compared to 1990. Any successful climate abatement policy therefore needs to include significant CO_2 emission reductions in this sector. However, choosing meaningful transport policies and measures is not straightforward, since the market is dynamically changing and new technologies and services are emerging. In this context, the calculation of different transport scenarios can aid decision makers for establishing adequate policies and measures. Specific transport models are required for quantifying scenarios of the transport system.

Transport models have been developed and applied for Europe (e.g. Transtools) as well for many European countries. In several countries (e.g. UK, Norway, Netherlands) the developed national transport models are owned by the States and are used for testing different national transport policies. Model users are transport departments staff or in some countries also consultancies and research institutes. In Germany the situation differs: For the government's medium- and long-term infrastructure investment strategy a federal traffic forecast is modelled by a commercial consortium every five years. However, the transport model remains the property of the consortium. As a consequence, the evaluation of national transport policies in a scientific context requires to the development and application of separated own models.

Within the German Aerospace Centre (DLR) Transport Program´s research project "Transport and the Environment" (VEU), different transport scenarios for evaluating developments in the transport system and on the environment have been identified (Seum et al. 2015). For the quantification of changes of travel demand, a German national transport model was indispensable and has been developed by DLR since no accessible official model exists. This paper gives an overview of the complete model landscape and insights into the concept and methodology of the passenger transport modules of the model. In addition, recently finished results of a reference scenario will be shown.

2. OVERVIEW

The purpose of the model landscape DEMO (Deutschlandmodell = German Transport Model) is to forecast all types of traffic in Germany under the influence of social trends, technological advances and policy measures. Achieving this goal requires a multifaceted approach, which takes into consideration the different areas of transport (e.g. passenger, goods) and the specific factors influencing each transport sector.

The model components which make up DEMO are shown in Figure 1. Two modules are used to estimate passenger travel demand for short and long-distance trips respectively. Another two modules deal with demand for commercial traffic, differentiating between freight transportation and service traffic. Finally, network models are employed to jointly assign passenger and commercial traffic and to generate the skim matrices required by the demand modules. Separate DEMO network models exist for road, rail and inland waterways (the later used for freight transportation only). The DEMO road network consists of approximately 1 million links in Germany (high network density) and Europe (lower network density, only major roads). Thus, DEMO not only considers domestic traffic, but outgoing, incoming and transiting flows in Germany as well.

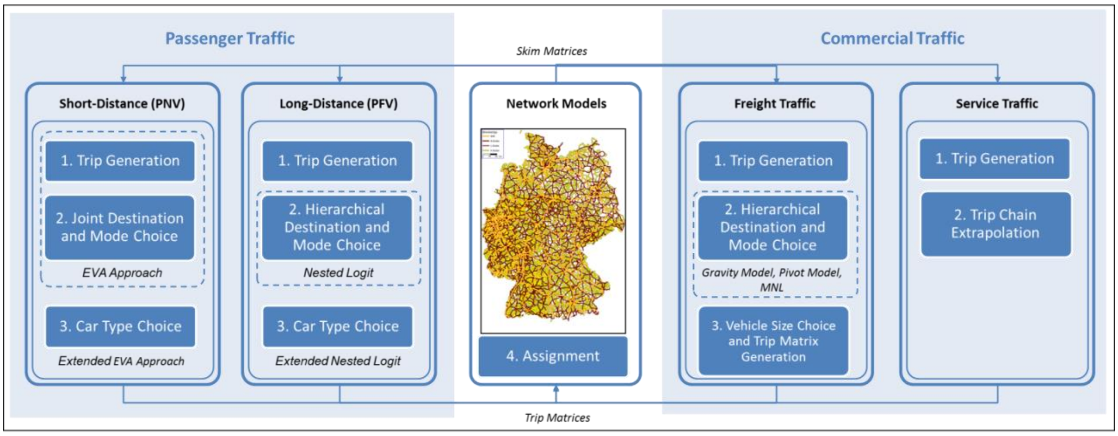

Figure 1: DEMO (German Transport Model) modules

The focus of this paper is modelling the national German passenger travel demand. The theoretical framework on which the two passenger traffic demand modules are based will be briefly discussed, as will the implementation, parameter estimation and model calibration. The validation and application of the model will be shown using base year results and a forecast of passenger travel demand in Germany for 2030 and 2040 in a reference scenario.

For reasons of simplicity the car type choice extensions of the two passenger traffic modules will not be discussed here. More information may be found in Mocanu et al. (2016). Further details about the commercial traffic modules can be found in Burgschweiger et al. (2017).

3. MODELLING PASSENGER TRANSPORT

The modelling of passenger travel demand within DEMO occurs in two separate models – one for short-distance (DEMO-PNV; **P**ersonen**N**ah**V**erkehr = short-distance passenger transport) and one for long-distance trips (DEMO-PFV; **P**ersonen**F**ern**V**erkehr = long-distance passenger transport). Trips either fall into one or the other category depending on the distance, with the threshold being defined at 100km.

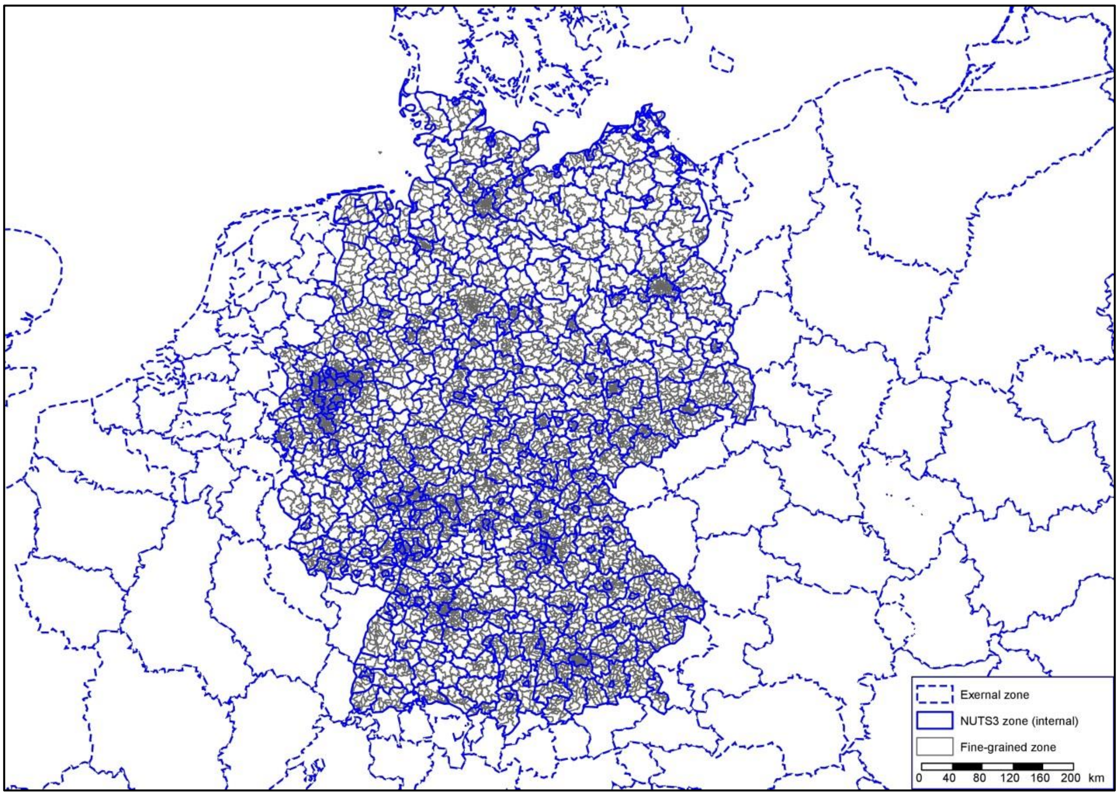

Figure 2: DEMO zoning system

There are several reasons for having two separate models. First, different modes of transport are available for short- and long-distance trips respectively. Walking and cycling are only realistic options for the former, whereas long-distance coach, high speed rail and airplanes are only meaningful options for the latter. Splitting up the modelling setup enables to consider only the relevant modes and thus speeding up the calculation. Secondly, different trip purposes can be considered by splitting in the two models. Some are relevant for both (e.g. business and leisure trips), but certain trip purposes can be found predominantly on short trips (e.g. education or shopping) while others are more commonly associated with long-distances (e.g. holiday trips).

An additional argument in favour of the segmentation by trip distance is given by the zoning system employed (Figure 2). Long-distance trips can be modelled using a coarser zoning system. In the case of DEMO-PFV this is the NUTS3 system, dividing Germany into 412 zones corresponding to its counties. Modelling short-distance trips requires a finer-grained setup, as using the large NUTS3 zones would lead to too much intra-zonal traffic. Therefore, DEMO-PNV consists of 6,561 zones, which are principally based on Germany's communes and city districts. However, as only trips shorter than 100 km are considered in DEMO-PNV, from roughly 43 million possible OD combinations only ca. 3.6 million pairs (approx. 9%) have to be considered. This means that having two separate models will actually speed up the calculation significantly, while at the same time retaining the precision offered by the fine-grained zoning system. Table 1 gives an overview of the number of traffic analysis zones for DEMO-PNV and DEMO-PFV as well as a comparison of the total and relevant number of OD pairs.

Table 1: Traffic zones and comparison of total and relevant number of OD pairs

Model	**No. of zones**	**Total No. of OD pairs**	**Relevant No. of OD pairs**
PNV (short-distance)	6,561	43,046,721	3,647,834
PFV (long-distance)	412	169,744	155,550
		43,216,465	**3,803,384**

3.1. Short-Distance Travel Demand Model

DEMO-PNV is the sub-model which considers trips by all modes and to all purposes with a distance of up to 100 km. This includes the large majority of daily trips (e.g. commuting, education, shopping etc.), as well as some more infrequent journeys (e.g. holiday trips, visiting relatives etc.), as long as they fall into the corresponding trip distance category.

DEMO-PNV uses the EVA (**E**rzegung-**V**erteilung-**A**ufteilung = trip generation, distribution and mode choice) model setup, an approach widely used in the German speaking countries. The key feature of this model approach is the triply-constrained and simultaneous destination and mode choice, whereby the origin and destination constraints for each traffic zone are determined during the trip generation step. This approach has been described by (Vrtic et al. 2007) and (Winkler 2016).

EVA trip generation determines the number of individual trips (no trip chains) generated and attracted by each traffic zone. The concept revolves around the idea of homogenous person groups exhibiting similar trip rates, on the production side, and quantifiable activity opportunities (e.g. work places, shopping area surface etc.), on the attraction side.

In DEMO-PNV, 22 behaviourally homogenous person groups were defined according to the following criteria: age, employment status and car availability. Thus, the total number of trips generated in a traffic zone is influenced by the population structure and can evolve over time. Furthermore, the person groups were also differentiated according to the home location type (urban, intermediary, rural), in order to account for the differences in public infrastructure and land use. Separate trip rates are employed for each of the 13 activity pairs shown in Table 2.

Table 2: Activity pairs used in DEMO-PNV

<table>
<tr><th>Origin/Destination</th><th>Home</th><th>Work</th><th>Education</th><th>Shopping</th><th>Leisure</th><th>Other</th></tr>
<tr><td>Home</td><td></td><td>HW</td><td>HE</td><td>HS</td><td>HL</td><td>HO</td></tr>
<tr><td>Work</td><td>WH</td><td></td><td colspan="4">WO</td></tr>
<tr><td>Education</td><td>EH</td><td rowspan="4">OW</td><td colspan="4" rowspan="4">OO</td></tr>
<tr><td>Shopping</td><td>SH</td></tr>
<tr><td>Leisure</td><td>LH</td></tr>
<tr><td>Other</td><td>OH</td></tr>
</table>

The joint destination and mode choice in EVA were applied separately for each of the 13 activity pairs shown in Table 2. As demonstrated in detail by (Vrtic et al. 2007), starting from a Bayesian model and applying the concept of information gain minimisation leads to the following general formulation for the number of trips from origin i to destination j using mode k (for the sake of simplicity, the indices denoting the activity pair are omitted here):

$$T_{ij,k} = f(U_{ij,k}) a_i b_j m_k \tag{1}$$

under the following constraints

$$\begin{aligned} & O_i^{\min} \le \sum_j \sum_k T_{ij,k} = O_i \le O_i^{\max} \\ & D_j^{\min} \le \sum_i \sum_k T_{ij,k} = D_j \le D_j^{\max} \\ & \sum_i \sum_j T_{ij,k} = M_k \end{aligned} \tag{2}$$

with

$f(U_{ij,k})$	function of the utility of mode k on relation ij
a_j, b_j, m_k	balancing factors for origin, destination and mode choice
$O_i^{\min}, O_i^{\max}$	constraints on total number of trips generated by zone i
$D_j^{\min}, D_j^{\max}$	constraints on total number of trips attracted by zone j
M_k	total number of trips using mode k

The constraints on the total number of trips related to a traffic zone result from the EVA trip generation step. These constraints can be elastic, meaning they offer only lower and upper boundaries for the total number of trips, or inelastic. In the latter case, the inequality signs in (2) turn into equalities. Typically, inelastic constraints are used for activities where there is a very clear correlation between zone attributes and the number of trips generated by that activity, e.g. number of employees and work trips. In contrast, elastic constraints are used for activities where this correlation might also be affected by other factors, such as the number of shopping trips per square metre of commercial surface also being influenced by the shop's location, its accessibility etc.

The third constraint in (2) is another important feature of the EVA approach. It ensures that the modelled mode shares will match the pre-defined values M_k.

This means that the overall mode choice does not require further calibration and validation for the base year model run. In DEMO-PNV, the four modes car, public transport (PT), walking and biking are considered.

The balancing factors a_j, b_j, m_k are unknown at first and are generated by the model algorithm itself through an iterative process during the base year model run. The purpose of this iterative process is to determine these balancing factors while minimising the information gain from the (transformed) formulation of utility and ensuring that the conditions in equation (2) are met. For more details on the solution algorithm see (Vrtic et al. 2007).

For forecasting runs, the model formulation is slightly modified. Once the base year model has been completed and the balancing factors a_j, b_j, m_k have thus been identified, the constraints in (2) no longer apply and therefore, only one model iteration using (1) and the balancing factors from base year is necessary. This is a somewhat different approach compared to the original approach discussed in Vrtic et al. (2007). Originally, only m_k is used as a constant for forecasting. Origin and destination constraints still apply as in the base year model. In this case, the same solution method for defining a_i and b_j is used. The approach, which has been applied here, needs significantly less runtime and prevents possible irrational results.

The functional form and definition of utility $f(U_{ij,k})$ are not restricted by the EVA approach. Generalised cost formulations, linear combinations and non-linear transformations can all be employed. Winkler (2016) has shown that, if $f(U) = \exp(U)$, then the EVA approach can be interpreted as a multinomial logit (MNL) model.

The parameters for trip generation, destination and mode choice were estimated from various data sources. The most important of these is the German national travel household survey MiD 2008 (Follmer et al. (2010)), which was used to derive the trip rates, global base year mode shares M_k and trip distance and duration distribution for calibration purposes.

The formulation of utility U for the joint destination and mode choice has been adopted from a value of time (VoT) study conducted for Germany (Ehreke et al. 2015). The utility components considered include the total trip duration, access and egress time, costs (fares, fuel, parking fees) and the vehicle availabilities. This approach employs a combination of a linear and a "displaced" logarithmic term for each utility component

$$f(U) = \exp \sum_u (\beta_u x_u + \alpha_u \ln(x_u + \gamma_u)) \tag{3}$$

with

x_u	value of utility component u
α_u, β_u	logarithmic and linear preference parameters
γ_u	logarithmic displacement parameter

Table 3 shows the values of the preference parameters as adopted from the German VoT study. Note that the cost parameters are equal for all modes within one activity pair, but differ between the trip purposes, while the time parameters are equal for all activity pairs, but differ between the modes. The logarithmic displacement parameters in (3) were set to the values of 30 min for the time components of utility and EUR 0.5 for the cost component for all modes and activity pairs, in line with the recommendations from the VoT study.

Table 3: preference parameters for DEMO-PNV

	α	β
in vehicle time [min] **(*all activity pairs*)**		
Car	-0.9910	-0.0006
PT	-0.9850	0
Walk	-1.5100	-0.0111
Bike	-0.6790	-0.0443
access and egress time [min] **(*all activity pairs*)**		
Car	0	-0.0138
PT	0	-0.0122
costs [EUR] **(*car and PT*)**		
Work, Education (HW,WH,WE,EH,WO)	-0.6330	0
Shopping (HS,SH)	-0.4920	0
Other	-0.6220	-0.0016

The VoT study was primarily designed as a mode choice model. Therefore, the utility function (3) does not perfectly represent preferences for a simultaneous mode and destination choice. For this reason, the beeline between two traffic zones, as a mode overarching representative of destination cost, was also included in the utility function. Through manual calibration of the corresponding parameters, the modelled trip distance distributions were matched to the empirical ones of the MiD2008 (see Figure 3).

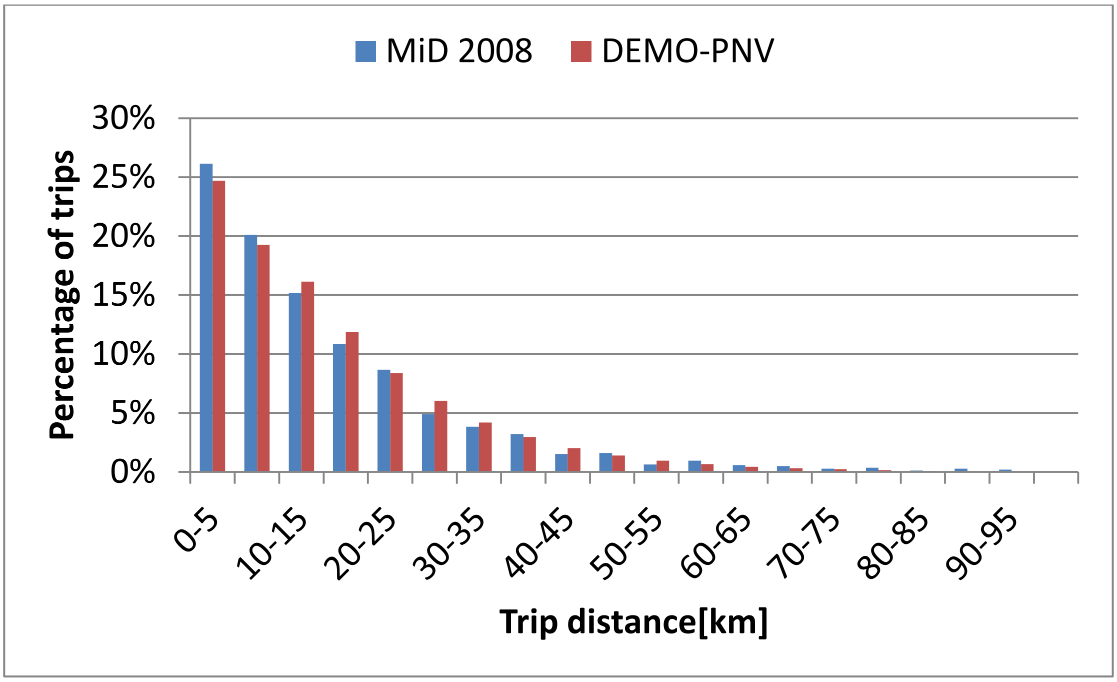

Figure 3: Comparison of modelled and observed trip distance distributions for activity pair HW

3.2. Long-Distance Travel Demand Model

DEMO-PFV is the complement to DEMO-PNV and considers all trips within Germany with a distance per direction of more than 100 km. Long-distance travel is, compared to short-distance trips, a rare event. As a consequence, there is a difficult data situation for long-distance travel behaviour of people. The long-distance travel demand module is therefore less differentiated concerning number of groups of persons. DEMO-PFV comprises the first three steps (trip generation, destination choice and mode choice) of a traditional four-step-model.

In contrast to short-distance, long-distance travel is modelled by a tour-based rather than a trip-based approach. The reason is that the vast majority of long-distance trips are home-based, regardless of whether trips are overnight or not. Therefore, the applied approach jointly considers outward and return trips.

Trip generation is modelled by a person-category approach, which is generally comparable to the DEMO-PNV approach. As a result of the data situation, the model only distinguishes between inhabitants and employees. However, person groups are additionally differentiated by the home location type (urban, intermediary, rural). Four different (home-based) trip purposes are distinguished:

- work trips,
- business trips,
- holiday trips and
- other trips.

Other trips contain e.g. weekend trips or visiting friends and relatives. As for DEMO-PNV, MiD 2008 provides the most important data. Moreover, an additional MiD 2008 data set, which contains specific information about long-distance trips has been analysed as well.

Results of trip generation are purpose-specific numbers of trips originating in each zone. Furthermore, purpose-specific numbers of trips attracted to each zone are defined by a trip attraction model within this model step. These trips are used as attraction capabilities within the destination choice model.

Destination and mode choice are modelled by a combined destination and mode choice that can be formulated as a multinomial logit model. Relevant long-distance modes are car, coach, intercity bus, train and airplane. The number of trips from origin i to destination j using mode k is formally defined as (for the sake of simplicity, the indices denoting the trip purpose is omitted here):

$$T_{ij,k} = \frac{e^{U_{ij,k}}}{\sum_{j'}\sum_{k'} e^{U_{i'j',k'}}} \cdot O_i \qquad (4)$$

with

O_i	total number of trips originating from zone *i*
$U_{ij,k}$	utility function

O_i result from the trip production model (trip generation) and are given within the destination and mode choice step. The utility function is defined in the same line as DEMO-PNV, but with different modes and additional components, due to specific requirements for modelling long-distance trips. The main body of the functional form and preferences are also adopted from the most recent VoT study in Germany (Ehreke et al. (2015)). Due to its nonlinearity, it is appropriate for short and long-distance trips, respectively. The detailed utility function is (denoting of trip purposes is again neglected):

$$U_{ij,k} = ASC_k + (\beta_c c_{ij,k} + \alpha_c \ln(c_{ij,k} + \gamma_c)) + \left(\sum_t (\beta_{t,k} t_{ij,k} + \alpha_{t,k} \ln(t_{ij,k} + \gamma_{t,k}) \right) \\ + \delta \ln\left(D_j\right) + \varepsilon beel_{ij} + \phi dist_{ij,car} \tag{5}$$

with

D_j	destination attraction
ASC_k	mode specific constant for mode k
$beel_{ij}$	beeline between origin *i* to destination *j*
$c_{ij,k}$	travel costs from origin *i* to destination *j* by mode *k*
$dist_{ijcar}$	travel distance between origin *i* to destination *j* by car
$t_{ij,k}$	travel time component from origin *i* to destination *j* by mode *k*
α, β	logarithmic and linear preference parameters
γ	logarithmic displacement parameter

All preferences for costs and travel time components are taken from the VoT study. These values are shown in Table 4. In contrast to DEMO-PNV, mode specific constants have to be taken into account within the utility function. The same applies to the destination attraction, which has been taken into account by a logarithmic transformation of trips attracted to destinations (from trip attraction model). Additionally, beeline between origins and destinations and car travel distance (only for the car mode) are included in the function. The parameters of these additional variables were calibrated heuristically. Table 5 contains these values. It can be seen that almost all mode-specific constants are rather high, which reduces the model sensitivities. The reason is that no sufficient data sets exist for explaining long-distance travel behaviour in Germany, in particular for purposes of modelling travel demand. This is a common problem and numerous long-distance models have to deal with it, which also results in high mode-specific constants (Moeckel et al. 2015).

The discussed approach for long-distance destination and mode choice provides outward trips from home to destinations. As mentioned above, DEMO-PFV is rather a tour-based approach, which is realised by mirroring the outward trip matrices to produce return trip matrices. The summation of outward and return trip matrices provides the final matrices.

Table 4: preference parameters for DEMO-PFV

		α	β
in vehicle time [min] (***all trip purposes***)			
	Car	-0.9910	-0,0006
	Coach	-1,3500	0
	Intercity Bus	-1,3500	0
	Train	-0.9850	0
	Airplane	-0,2700	0
access and egress time [min] (***all trip purposes***)			
	Car	0	-0.0138
	All PT modes	0	-0.0122
waiting time [min] (***all trip purposes***)			
	Coach	0	-0,0283
	Intercity Bus	0	-0,0283
	Train	0	-0,0072
	Airplane	0	-0,0048
costs [EUR] (***car and all PT modes***)			
	Work	-0,633	0
	Business	-0,503	0
	Holiday, Other	-0,622	-0,0016

Table 5: calibrated parameters of DEMO-PFV

	work	**business**	**holiday**	**other**
ASC car	3,5	2,75	2,91	2,88
ASC coach	-	-2,8	3,7	2,25
ASC intercity bus	2,0	-0,8	5,0	3,5
ASC train	2,6	2,0	3,42	2,45
ASC airplane	-4,8	-4,95	-5,0	-4,32
δ	0,000001	0,000001	0,000001	0,000001
ε	-0,007	-0,00075	0,0043	-0,0074
ϕ	-0,002	-0,0013	0,0008	-0,00026

4. MODEL VALIDATION AND APPLICATION

All DEMO modules and their interactions (Figure 1) were developed and applied within the project “Transport and the Environment”. The following section shows an application of DEMO, with a focus on passenger traffic in Germany. Results for the base year (2010) are compared to independent statistical data to validate the model. Subsequently, the model is employed to forecast travel demand up to the year 2040 in a reference scenario.

All DEMO modules were applied for base year and forecasting runs, although only passenger traffic results are shown in the following. These results are based on feedback loops between travel demand modules and the joint assignment of passenger and commercial traffic. These feedback loops were necessary, since DEMO assignment takes account for network capacity constraints and provides achieving an user equilibrium (Wardrop (1952)).

Table 6: Validation of base year model results

	ViZ 2010	**DEMO-PNV + PFV + PWV**	**Deviation**
	Number of trips [bn trips/a]		
Walk	24.0	24.6	2.5%
Bike	9.5	10.3	8.4%
Car	56.5	60.1	6.4%
Public Transport	11.7	8.6	-26.5%
Σ	**101,7**	**103,6**	**1.9%**
	Distance travelled [bn pers-km/a]		
Walk	34.6	34.5	-0.2%
Bike	33.9	33.3	-1.6%
Car	902.4	914.5	1.3%
Public Transport	172.7	171.0	-0.9%
Σ	**1143.6**	**1153.4**	**0.8%**

Table 6 shows aggregated traffic demand results for the **base year** with a focus on the modelled total number of trips and distance travelled. The benchmark is provided by figures from the German Annual Statistics publication “**V**erkehr **i**n **Z**ahlen” ViZ 2010 (DIW (2012)), which is (largely) independent from the data employed during model development. It should be noted that, for reasons of comparability with ViZ 2010, number of trips and distance travelled by car also includes commercial transport by car. These trips are modelled by the service traffic module (DEMO-PWV).

The comparison shows that for walk, car and bike numbers of trips only small deviations of fewer than 5% and 10%, respectively, occur. Compared to this, deviation of PT is much higher. There are two main reasons for these differences. One aspect is that DEMO is based on empirical data of MiD 2008. This data set provides slightly different mode shares and total number of trips for each mode than ViZ 2010. Another aspect, only regarding PT, results from a difference in statistics of ViZ 2010 and MiD 2008. In contrast to MiD 2008, ViZ 2010 double counts PT users using two or more PT systems (e.g. bus, tram, train) for a single trip from their origin to destination. That is, if, for example, a public transport user changes from bus to train on his/her trip to work, in ViZ 2010 this single trip to work is counted twice. In context of travel demand forecasting and scenario evaluation, the MiD 2008 approach is much more appropriate and was used for DEMO without adjusting to ViZ 2010.

The comparison of transport performance (distance travelled) shows a very high accordance of empirical and modelled data. Derivation of all modes are less than 2% and for total transport performance even less than 1%. In this context, it is important to note that statistical differences between ViZ 2010 and MiD 2008 concerning PT do not occur for distances travelled.

Passenger transport modules of DEMO were calibrated, among others, on the basis of travel time and distance distributions provided by MiD 2008. Additionally, ViZ 2010 data were also taken into account, since transport performances provided by this statistics is a benchmark and of great importance in Germany. Finally, the comparisons of numbers of trips and transport performance indicate sufficient accordance between DEMO results and reality.

The **reference scenario** includes expected measures, trends and developments in Germany. There are two considered time horizons for this scenario, the years 2030 and 2040. To forecast travel demand, a large amount of (changes in) different input data is necessary to feed DEMO. For this reason, only little information about these trends can be discussed here. Moreover, the focus of the following discussion is on 2040 results.

One major input data in passenger traffic modules of DEMO is the spatially differentiated population in Germany. The population development from 2010 to 2040 is shown in Figure 4. It is obvious that the population in Germany will change differently among regions. In particular, there will be a strong population decrease in the Eastern part of Germany. Population increase will occur especially in metropolitan regions (Berlin, Munich, Hamburg and Frankfurt am Main) and in the Southern part of Germany, which are already today Germany's prospering regions. The total population is assumed to decrease from 80.3 Mio. to 76.8 Mio. The forecasted population data are based on the official population forecast for Germany until 2035 (Schlömer et al. (2015)) and was extrapolated to 2040 and further spatially differentiated by an own approach.

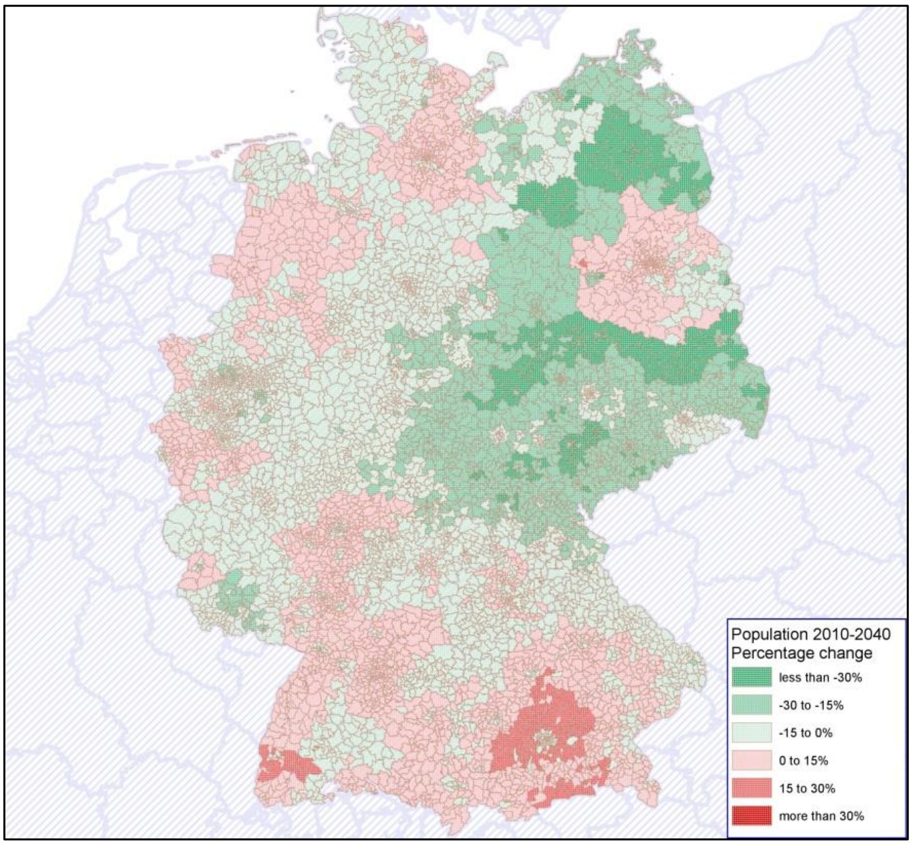

Figure 4: Population development 2010 to 2040 in Germany

Besides official forecasts for input data as GDP, population, households, workplaces, numbers of schools and so on, further trends and developments had to define. For example, it was supposed that within metropolitan regions PT travel time decreases by 10% and in rural regions increases by 10%. Car kilometre costs decrease by about 20%, due to higher efficiency, though costs per litre increase by higher tax. For bike it was assumed that average speed grows by 15%, due to higher rates of E-Bikes.

Table 7: Summary of forecast results

	2010	2040	Change
	Number of trips [bn trips/a]		
Walk	24.6	21.9	-10.9%
Bike	10.3	10.5	1.8%
Car	60.1	62.2	3.4%
Public Transport	8.6	8.0	-6.8%
Σ	**103,6**	**102.6**	**-1.0%**
	Distance travelled [bn pers-km/a]		
Walk	34.5	30.9	-10.5%
Bike	33.3	37.6	12.8%
Car	914.5	1004.9	9.9%
Public Transport	171.0	186.4	9.0%
Σ	**1153.4**	**1259.8**	**9.2%**

Table 7 shows a comparison of passenger traffic results for the base year and 2040. Again, car also includes commercial service traffic. Firstly, it becomes clear that the total number of trips is quite stable, though population decreases by almost 4 million people. However, there are some interesting differences between different modes. Car and bike trips increase by almost 2% and more than 3%, respectively. Reasons are, for example, lower car kilometre costs, higher car availability and higher average bike speed. In contrast, there are significant reductions for walk and PT. One major reason is the demographic effect, i.e. in 2040 there will be far less young people, who walk and use PT above average, since these modes are of major importance for trips to school. Furthermore, direct mode competitors of walking and PT benefit from supposed mode-specific trends and improvements and improve their attractiveness compared to walk and PT.

Results of transport performances show a slightly different development. Walking also loses more than 10%, but all other modes, including PT, realise considerable gains. The reason is that most supposed future trends and developments improve the transport system and modes. Therefore, travel costs decrease and trip and tour lengths increase. A special case is the change within the PT system, since there are contrary developments for short and long-distance travel. Number of short-distance trips decrease strongly and even longer short-distance trip lengths cannot compensate, i.e. also short-distance PT transport performance decreases. However, long-distance

PT benefits from future developments and overcompensate reductions in short-distance market. In particular, the long-distance intercity bus market liberalization after 2010 leads to a significant higher attractiveness and demand for long-distance PT within Germany.

The results discussed above seem to be plausible and show interesting trends for the reference scenario 2040 for Germany. The results are highly aggregated and it is not possible to discuss all results and findings in detail. However, one detailed result is illustrated in Figure 5. On the left side, changes in short-distance traffic flows are shown and on the right side changes in long-distance traffic flows. Short-distance traffic shows very heterogeneous changes with significant reductions within big cities and rural areas, in particular in Eastern Germany. Reasons are changes in population and better PT services within cities. Long-distance traffic increases in particular between cities as a result of an ongoing process of long-distance commuting and business trips. Reductions in rural areas results, again, mainly from changes in population.

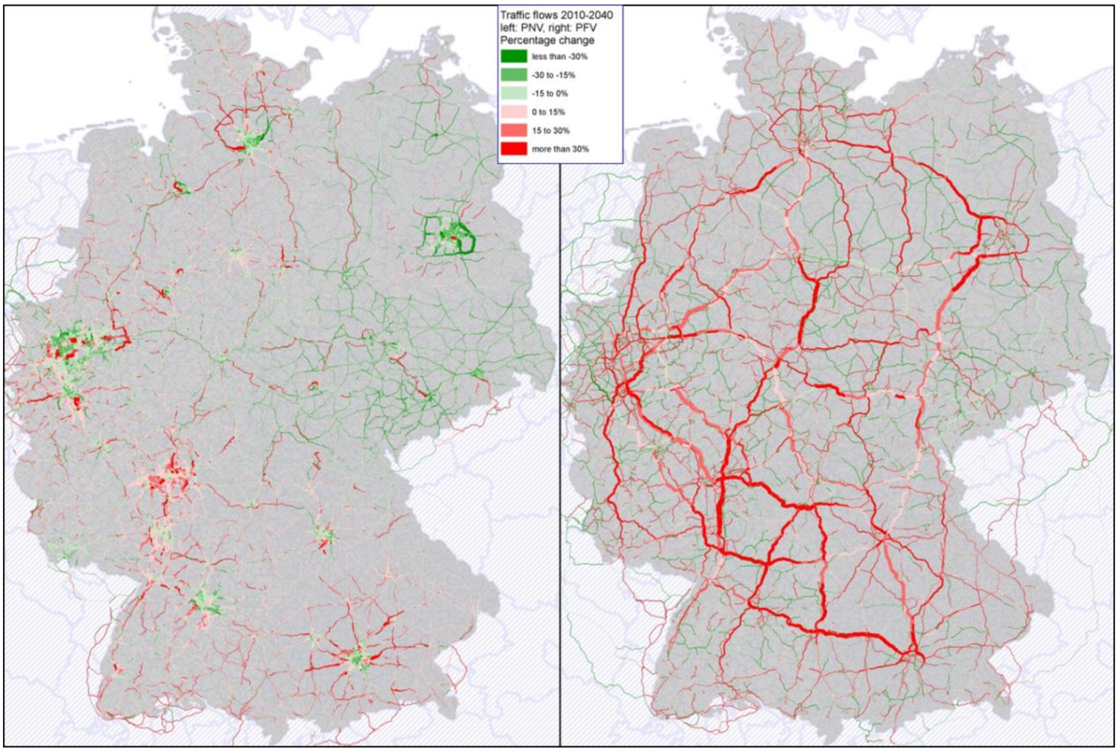

Figure 5: Changes of short and long-distance passenger traffic flows 2010-2040

5. CONCLUSIONS AND OUTLOOK

In this paper the national transport model for Germany DEMO, which has been developed by the Institute of Transport Research at the German Aerospace Centre, was presented. Moreover, detailed insights of the passenger transport modules were given. The functionality of DEMO for future transport scenarios were proven by a successful application to a reference scenario for the years 2030 and 2040. The reference scenario was defined within the project “Transport and the Environment”.

DEMO provides a differentiated approach to forecast travel demand in Germany. The model, in its current state, is primarily based on state of practice methods, but refined with some additional features. In general, it is comparable to other national transport models for similar study areas. Such models have been used for many years, in particular for evaluating infrastructure investments. However, new challenges for transport models occur, since we live in highly dynamic times and new technologies and services are emerging.

In this context, also further developments of DEMO are necessary. For instance, integrating and evaluating of autonomous vehicles and systems are key questions for the future. Transport modellers need to find solutions for integrating those and other developments into models, also in nation-wide large-scale models such as DEMO. Other challenges, maybe more specific to Germany, are the need of more detailed travel behaviour data. In particular, long-distance travel behaviour data are rare, although long-distance travel is responsible for a large amount of transport performance and therefore for transport CO_2 emissions. At present, a new national household travel survey is undertaken in Germany. This data likely will provide new and more detailed information about travel behaviour and could be one basis for further developments and differentiations of DEMO.

BIBLIOGRAPHY

Burgschweiger, S., Wolfermann, A., Liedtke, G. (2017) *A Macroscopic Freight Transport Demand Model for Policy Analysis in Germany*, Proceedings of the 3rd Interdisciplinary Conference on Production, Logistics and Traffic, Darmstadt.

DIW (2012) *Verkehr in Zahlen*. Bundesministerium für Verkehr, Bau und Stadtentwicklung, Berlin.

Ehreke, I., Hess, S., Weis, C., Axhausen, K.W. (2015) Reliability in the German Value of Time Study, *Transportation Research Record: Journal of the Transportation Research Board*, **2495** 14-22.

Follmer, R., Gruschwitz, D., Jesske, B., Quandt, S., Lenz, B., Nobis, C., Köhler, K., Mehlin, M. (2010) *Mobilität in Deutschland 2008 - Ergebnisbericht*, In: Bundesministerium für Verkehr, B.u.S. (Ed.), Bonn, Berlin.

Mocanu, T., Winkler, C. (2016) *Petrol, Diesel or Electric? An Extension of Passenger Transport Models for Differentiating Car Travel Demand*, Proceedings of the 6th Transportation Research Board Conference on Innovations in Travel Modeling (ITM), Denver.

Moeckel, R., Fussell, R., Donnelly, R. (2015) Mode choice modeling for long-distance travel, *Transportation Letters*, **7**(1) 35-46.

Schlömer, C., Bucher, H., Hoymann, J. (2015) *Die Raumordnungsprognose 2035 nach dem Zensus*. Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR), Bonn.

Seum, S., Henning, A., Plohr, M., Özdemir, D., Hepting, M., Keimel, H., Sanok, S., Sausen, R., Pregger, T., Heinrichs, M., Müller, S., Winkler, C., Neumann, T., Seebach, O., Matthias, V., Vogel, B. (2015) *The DLR Transport and the Environment Project - Building competency for a sustainable mobility future*, In: Sausen, R., Unterstasser, S., Blum, A. (Eds.), 4th International Conference on Transport, Atmosphere and Climate (TAC-4), Bad Kohlgrub, pp. 192-198.

Vrtic, M., Fröhlich, P., Schüssler, N., Axhausen, K.W., Lohse, D., Schiller, C., Teichert, H. (2007) Two-dimensionally constrained disaggregate trip generation, distribution and mode choice model: Theory and application for a Swiss national model, *Transportation Research Part A*, **41**(9) 857–873.

Wardrop, J.G. (1952) *Some theoretical aspects of road traffic research*, Proceedings of the Institute of Civil Engineers - Road Paper. Institute of Civil Engineers, London, pp. 325-378.

Winkler, C. (2016) Evaluating Transport User Benefits: Adjustment of the Logsum Difference for Constrained Travel Demand Models, *Transportation Research Record: Journal of the Transportation Research Board*, **2564** 118-126.