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Transportation Research Procedia (2017)

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

Multimodal macroscopic transport modelling: State of the Art with a focus on validation & approval

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Abstract

Many authorities are using transport models for modelling and evaluating measures in private and public transport. There is a wide range of models from very simple, e.g. single-modal models up to highly sophisticated and disaggregated multimodal models. This paper will identify the current state of the art of macroscopic transport supply and demand modelling and will give recommendation to the validation of such models. The authors can rely on the experience of many large multimodal transport models.
Some of the key features of the paper are:
- Highly disaggregated demand modelling with many persons groups and activities, e.g. different activities for daily and non-daily shopping, different types of leisure trip
- Activity-chain-based demand modelling instead of the standard 4step-procedure, which ensures consistency of mode choice and closed activity chains.
- Use of local empirical data (household survey) for parameter estimation of mode choice and destination choice per person group and activity to ensure realistic reaction of the model.
- Use of empirical data (household survey, count data, commuter data etc.) for the calibration and validation of the model results.
- Sensitivity analyses to show how the model reacts to certain changes of the supply.
- Detailed criteria list for validation and approval of the model

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2214-241X

Keywords: Multimodal macroscopic transport models; disaggregated demand model; activity chain based; model parameter estimation

1. Introduction

Macroscopic transport models serve as the basis for many long-term strategic decisions in transportation. As decisions such as new road or rail infrastructure are very cost-intensive and often irreversible, the transport models need to create reliable output. To achieve this, it is required to invest sufficient effort into the development of a model with good quality. This starts with a sophisticated call for tender considering all required necessities during the project and ends with reasonable performance review of the model. Consultants on behalf of the authorities usually create the model.

The whole process cannot be described within a single paper and many papers have already contributed to this (e.g. [9], [10], [15]). This paper, however, focuses on important technical aspects of macroscopic transport models. These include:

- Model architecture (see chapter 2)
- Transport supply (see chapter 3)
- Empirical data (see chapter 4)
- Calibration and validation (see chapter 5)

The paper concludes with some applications (see chapter 6) which go beyond the traditional applications as strategic transport model.

2. Architecture of the macroscopic transport model

Implementations of macroscopic demand models are often 4step models that comprise the steps trip generation, destination choice, mode choice and assignment. Further steps can include e.g. time-of-day-choice [13].

2.1. Model calculation flow

The four model steps usually have a complex model calculation flow, which has a feedback-loop from the assignment step to destination and mode choice step (Figure 1).

Such models can have more than 100 calculations steps, each with a large number of parameters for each model step and several land use and population per traffic zone. To handle such model it is highly recommendable to use transportation modelling software, which allows the implementation of the full calculation flow and the storage of data in one version file. This version file contains all necessary network models, population and land use data, additional matrices and procedures of all sub models. Thereby, mistakes due to data inconsistencies or wrong data files are minimized. If required, special procedures can be implemented using python scripts. However, they should also be incorporated into the list of operations be started by the software during a model run. The following Figure 2 shows the user interface of an implemented model calculation flow (group wise representation).

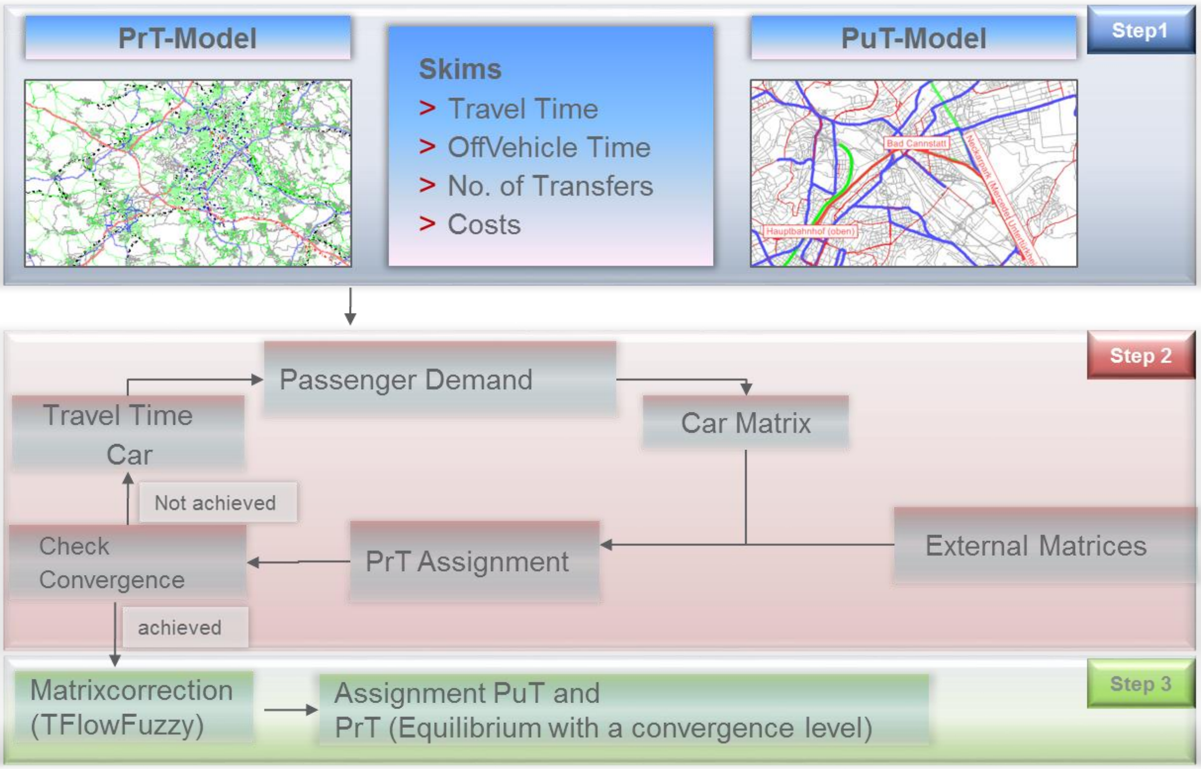

Figure 1: Model calculation flow

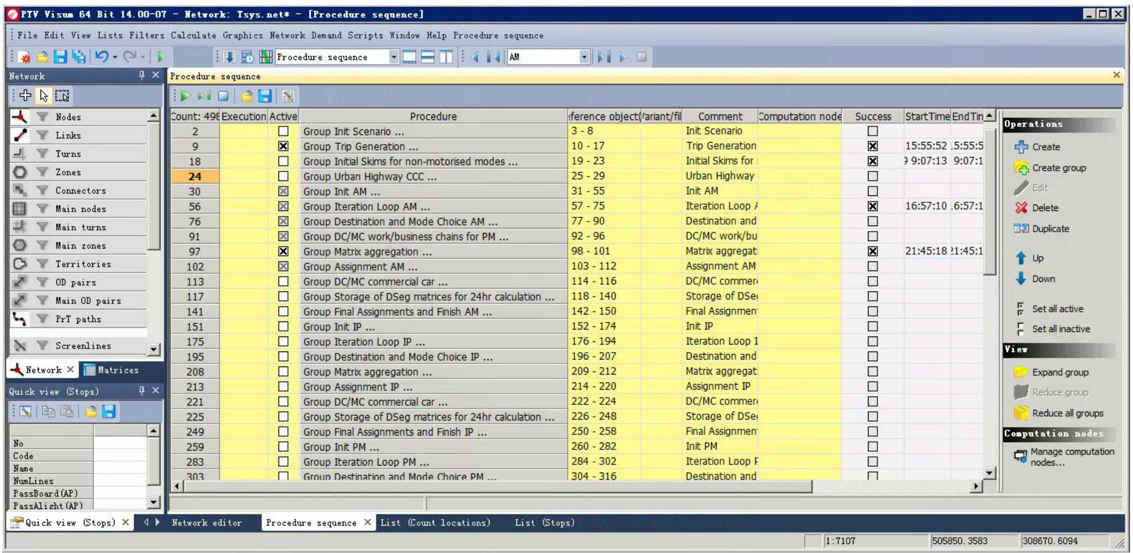

Figure 2: Implementation model calculation flow – group wise representation [11]

2.2. Model segmentation

The population of every traffic zone should be segmented into different persons groups to reflect different mobility behaviour. A large number of person groups allows for a detailed calibration of the model, but also reflect changes of the population in future scenarios (e.g. demographic effects). Factors to distribute population data (provided by age groups) to the person groups can be derived from a household mobility survey conducted in advance.

The following Table 1 shows a highly disaggregated variant of persons groups. The best variant obviously depends on the data availability and the future application of the specific model.

The same is true for the segmentation of the activities. The higher the disaggregation is, the more the model can reflect the real mobility behaviour. As shown in Table 2, we propose, for instance, to differentiate between daily shopping and other purchases. Otherwise, the model fails in the calculation of the trip structure (trip lengths, mode choice) to large building supplies stores.

Table 1: Segmentation of the population (mostly based on Central European data)

Person Group	**Car availability?**		**Comment**
	Yes	**No**	
Employees (High Income)	X	X	• Many monthly ticket users (if no car available) • Only travel by driving (if car available) • Car ownership >= 1 per household (if car available) • Business trips +commute trips
Employees (Low Income)	X	X	• Many monthly ticket users (if no car available) • Car ownership = 1 per household (if car available) • Travel by transit for commute trips (if car available)
Self-employed, freelance	X	X	• Short working trips • Business trips primarily, sometimes by bike
Part-time employees	X	X	• Highest number of trips • Transit user with one time ticket
Unemployed	X	X	• Unusual PuT ticket behaviour
House person	X	X	• Shopping and leisure trips in the weekend
Primary school pupils		X	• Short trips to nearest school • Drop off trips • Travel by bus with monthly student transit pass
Pupils		X	• Travel by bus with monthly student transit pass
Apprentices	X	X	• Transit user • commute trips only
Students	X	X	• on campus dormitory, often no regular daily tripsVery high share of Public Transport (PuT)
Retired persons ≤ 75	X	X	• Leisure trips to parks in weekday and weekends (free park entry) • Transit user with monthly transit pass • Often hospital trips
Retired persons > 75	X	X	• Many short walking trips • Lowest number of trips

Table 2: Segmentation of the model activities (mostly based on Central European data)

No	Main Activity	Activity modelled
1 - 4	Work	Work - High Income, Low Income, self-employed, part-time
5	Shopping	Daily needs
6	Shopping	Other purchases
7	Pers. Business	Doctor, bank, post offices
8	Pers. Business	visits, hospital
9	Pers. Business	Restaurant, cultural events
10	Pers. Business	Sports, recreation area
11	Pers. Business	Bring/Pick up
12	Pers. Business	Walking
13 - 16	Education	Primary school, Secondary school, University, Vocational school
17	Home	Trip to Home

The last segmentation to consider regards the transport modes. Here, the model should contain all relevant modes of transport, both motorized and not motorized modes:

- Walk and Bike as non-motorized modes
- Public Transport (PuT)
- Company buses
- Taxi
- Car driver and car passenger (Private Transport; PrT)
- Park & Ride

The number of modes may vary per region.

2.3. Sub Model definitions

2.3.1. Trip Generation

Trip generation, destination choice and mode choice is based on frequencies of activity chains. Activity chains consist of two or more trips.

For every modelled person group a set of daily activity chains can be extracted from the database of a household interview survey (HIS). This is at best a local survey or if not available in all details extracted from national surveys. The following table shows a selection of the observed chains of the first two person groups from a European survey (e.g. the number 0.64 means that 64% of the Employees (High Income) with car available do the chain – Work – Home per day):

Table 3: Example activity chain frequencies

Activity chain	Employees (High Income) with car availability	Employees (High Income) without car availability
Home-Work-Home	0.64	0.67
Home-Daily needs-Home	0.06	0.07
Home-Other purchases-Home	0.03	0.05
Home-Work-Daily needs-Home	0.07	0.04
Home-Work-Other purchases- Home	0.02	0.02

The activity chain approach allows a high segmentation of the demand in a clear and easy to understand data model. Classical 4 step models often use only some aggregated trip purposes as, for instance, work, shopping, education and others. They often abstain from the information about the trip conducting person group after the trip generation step by aggregating all generated trips by trip purpose. Variations by trip lengths, destination choice, mode choice and time of day choice regarding the person groups and their activities cannot be respected by that approach. The segmentation is kept over all model steps.

2.3.2. Destination and mode choice

Destination and (nested) mode choice is at best realised by a nested logit approach. The general cost function for destination choice is a logsum function [5] of the utilities of the modelled modes:

$$f_{g,a}(w_{ij}) = \exp\left(\beta_{g,a} \cdot \left(-\ln \sum_m \exp\left(U_{m,g,a,i,j}\right)\right)\right) \tag{1}$$

Using logsums ensures that those modes have the highest influence on the destination choice, which have high utilities for this OD-pair. Thus, e.g. walking is mostly relevant for short distances, while for long distances it is not relevant. Mode preferences are of course person group specific, so that a very attractive bike route has high influence on person groups such as students, while the impact for retired persons > 75 is very low.

For (nested) mode choice we propose a standard multinomial logit model with the following definition of the utility function:

$$V_{ij}^{d} = \ln(A_j) + \beta * \ln \sum_m \exp\left(V_m\right) \tag{2}$$

$$U_{m,g,a,i,j} = C_{m,g,a} - p_{1_{m,g,a}} \cdot \left(InVehicleTime_{mij} + \frac{1}{VoT_{g,m}} \cdot Costs_{m,i,j} \right) - p_{2_{m,g,a}} \cdot WalkTime_{m,i,j} +$$
$$+ p_{3_{m.g.a}} \cdot \ln\left(D_{i,j}\right) - p_{5_{m.g.a}} \cdot WaitTime_{m,i,j} - p_{6_{m.g.a}} \cdot NumberOfTransfers_{m,i,j}$$

with

m	Mode (walking, biking, car, ...)
g	Person group (see Table 1)
a	Activity (see Table 2)
i, j	Origin i and destination j
C	Activity-specific constant
ß	Parameter of destination choice
p1... p6	Parameters of mode choice
VoT	Value of Time
D	Direct Distance

Both trip distribution and mode choice are calculated inside an activity chain (e.g. Home-Work-Shopping-Home). The destination choice is done for every activity inside the chain except the home trip, because the residence zone of the modelled person group is stored. Within each chain, persons can use several interchangeable modes (e.g. walking, PuT) or only not interchangeable mode (e.g. car-driver and bike). This feature assures that the number of cars leaving a zone equals the number of cars returning to a zone (for 24h models).

All OD-variables of the mode choice sub model can be calculated using the multimodal network model. Operational costs for car can be derived based on trip length. Parking costs are estimated by assuming average parking durations, average parking costs and average rates of free of charge parking area.

For the calculation of the public transport fares per OD the complete tariff system must be modelled in the model. Based on the implemented tariff model the single ticket fares and multi journey ticket fares (assuming an average user frequency) per OD can be determined.

2.3.3. Assignment

The matrices of the private motorised transport are assigned to the network separated for car and trucks.

The recommended method for the final assignment is an equilibrium assignment with a high level of convergence (a relative gap of 10^{-5}) to assure a consistent forecast ability.

However, in order to achieve a reasonable run time inside the feedback loop, one can abstain from a high convergence level assuming to get a good estimation of travel time for private transport (PrT) even with lower level of convergence.

The public transport demand is assigned with a timetable based assignment approach. This timetable can change over the day, e.g. for pupil's transport to and from school. Thus, it is important to assure that pupils can use these pupils' services. For this, the PuT-demand must be calculated per time interval. Time series per activity pair should be used analysed from the household survey, if available.

3. Modelling of network supply

An important base data of a transport model is the multimodal network model (road, rail, bike and walk).

The base geometry of the *road network* today is usually based on data from navigation device suppliers (TomTom, HERE) or from authorities' GIS systems. In any case, further work on this network is usually required. This can include e.g.:

- Creating link types with free-flow speeds and capacity.
- Adding network elements for bikes.
- Consideration of z (heights) coordinates, in particular to derive bike speeds.
- Adding rules or a model to calculate turn delays.

The supply of *public transport* is often very complex with many lines and many service trips. Here, it is recommended to import the data from existing information or planning systems using existing interfaces such as DIVA, Hafas, RailML or Google Transit. Usually, such data is available from public transport operators or regional transport cooperatives.

The network data model should allow a very detailed representation of public transport stops. Thus walk times inside a station or a major transfer stop can be coded and used for exact skim matrix calculation. The following screenshot from the network model shows the detailed coding of Beijing's Lama Temple Station.

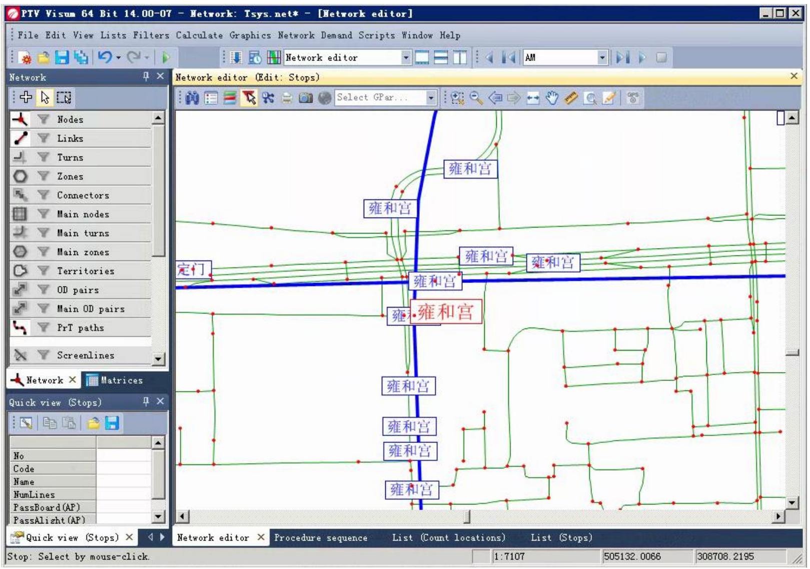

Figure 3: Example for modelling public transport stops in the network model

During import of the data, it should be assured, the network model uses the same reference numbers for lines, stop and stop points as the passenger information system. This will allow an easy regular update of the modelled public transport supply for future applications of the model.

4. Empirical data base

In advance of the model building process a comprehensive household interview survey (HIS) should be undertaken to collect empirical data. Replacing such HIS by nation-wide surveys will significantly decrease the quality of the model.

For the household survey e.g. in Bahrain participants have reported the trips of a full day. The household survey comprises 3,000 households, 9,000 persons and 23,300 trips. Other surveys such as the household survey in the region of Stuttgart consist of the trips of a full week from each participant. Here, the survey comprises 5,500 household, 13,700 persons and 275,000 trips (see [14] for details).

Such a large empirical database can be used for a lot of model related analysis. The derived data can be differentiated into input data (distribution of person groups among age groups, activity chains frequencies or activity pair related time series), data for parameter calibration (destination and mode choice) and data for model result validation (descriptive statistics on trip generation, trip distribution, mode choice and OD flows on an aggregated zone level).

Another important empirical data source may be statistics from the authorities on employment. This data contains the residence and the employment municipality for every employed person with a social insurance inside the model area. From that data a commuter matrix related to municipalities can be derived, which can be used for the determination of k_{ij} Factors for the destination choice calibration step.

Apart from these central data empirical journey data of the public transport users and roadside count data from both permanent installed counting devices as well as manual counts can be used to validate the model.

5. Calibration and Validation of macroscopic transport model

5.1. Model calibration

After collecting all necessary data (network model, population and land use data and survey data), the model parameters of the destination and mode choice sub models must be estimated. Due to the nested logit model formulation this process starts with the estimation of the mode choice sub models. The estimation is conducted by using separate software such as the open source software Biogeme ([1], [2]). This requires the preparation of a data base which holds all relevant observed trip data from the household survey with pertinent attributes (used mode, trip purpose, origin and destination zone, person group, recorded trip time etc.). The data has to be enriched with the attributes of all non-used modes for all observed trips. These data can be provided by using the multimodal network model. The following figure illustrates this approach:

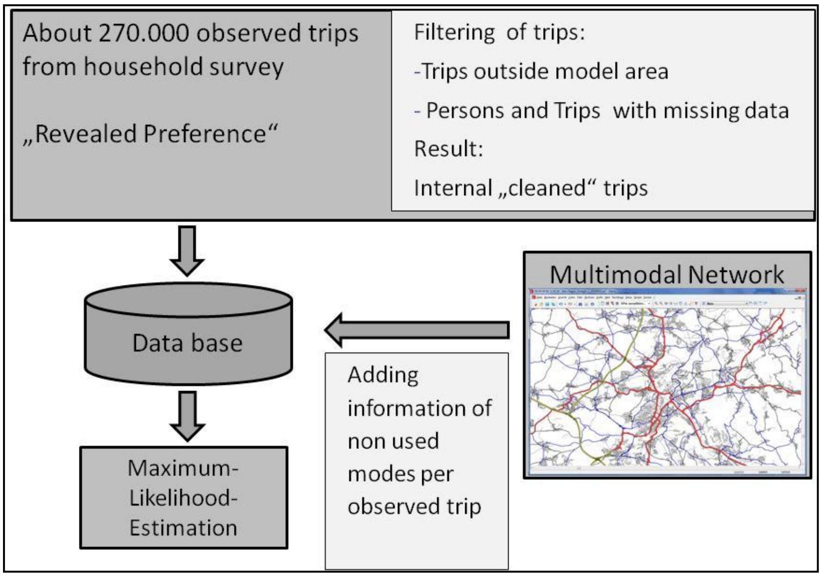

Figure 4: Components of the parameter estimation database

The aim of the estimation is to identify models with statistically significant parameters with a high-level explanation power. This requires clustering of the some activities and / or groups, as there are e.g. very few observations from retired persons ≤ 75 years going to sport facilities.

Some results and mentionable remarks from different model estimations are:

- In Vehicle Time: Estimation resulted in different parameters for Public transport, car travel and non-motorized travel.
- Value of time (VoT) was not estimated, but derived based on external sources (e.g. [4], [8]), examples:
  - 10.10 € /h for group Employed with High Income and trip to work
  - 8.20 €/h for group Employed with Low Income and trip to work
  - 4.80 €/h for group Univ. students and shopping trip (daily needs)
- Access Time: Depends largely on the definition of the access time. We incorporated park search time in the access time.
- Wait Time, only PuT: Factor 1.6 regarding in-vehicle time
- Number of Transfers, only PuT: Factor 1.8 regarding in-vehicle time
- Direct Distance, which controls that Public Transport, has a disutility for short distances.
- Constants, different for person groups and modes.

Following to the estimation of the mode choice sub-models the logsums ($\ln \sum_m \exp(V_m)$) for every OD pair can be calculated. Another database must be set up, which contains for every estimation group and for all origin destinations pairs the logsum calculated from the group, mode and activity specific utility functions for the mode choice sub-model. The utility function of the destination choice model results in:

$$V_{ij}^{d} = \ln(A_j) + \beta * \ln \sum_m \exp(V_m) \tag{3}$$

with

V_{ij}^{d} Utility to select zone j when starting in zone i

A_j Zone attraction figure (e.g. working places)

The parameters ß for the destination choice sub-model can also be estimated by using the Biogeme software.

5.2. Model Validation

The online encyclopaedia Wikipedia [16] gives, among others, two appropriate definitions:

- Validation should confirm that a product or a service meets the needs of its users
- Validation should check that a system meets the specification and fulfils its intended purpose.

So far there are no general accepted validation definitions and criteria to prove the usability of a pure synthetic macroscopic model, even though such criteria would be an important relief for both the consultant and the client to find a threshold for a sufficient model quality (see also chapter 5.2.5).

Pure synthetic models are solely based on population and landuse data, skim matrices from network models and behavioural data as trip rates, time profiles or estimated model parameters. If empirical O-D data are used to build a base year matrix (e.g. from a roadside interview survey, plate recognition survey or mobile phone data) the model shall not be called pure synthetic but observation based. Observation based models lead inevitably to an incremental model formulation because in this case the model can only be used to calculate growth factors or skim changes in order to project observed base year flows to the future. Incremental models are a good approach whenever a stable development of the transport demand structure can be expected. In case strong changes of demographics, land use, transport supply or disruptive developments are expected or shall be assumed for scenarios pure synthetic models are necessary. The following information and considerations regarding model validation are referring to pure synthetic models.

The validation can be separated into criteria which should prove the model's fit with the base year situation regarding various empirical comparison data (household surveys, counts) and the models ability to react consistent if important input data change (sensitivity/realism test). The validation criteria have to be defined along the four successive model stages.

An appropriate measure of deviation besides standard measures between model figures and pertinent comparison figures (besides standard statistical measures) is the GEH statistic because it is suitable for the comparison of traffic volumes by considering both the relative and the absolute discrepancy between the model value M and comparison value C [13]:

$$GEH = \sqrt{\frac{2*(M-C)^2}{(M+C)}} \qquad (4)$$

5.2.1. Trip Generation

The number of trips per person group is a direct result of the number of persons multiplied by the chain frequencies. There is no further parameter used, thus a close fit of model data and data observed from the household interview can be expected. The following graphic shows the model results for the trip generation. Here, only very little deviation should be allowed.

5.2.2. Destination choice

When validating destination choice, it is important to start with global values, e.g.:

- Comparing commuting trips with the statistical data. A model calculation with exclusive Home-Work trips can be used to validate the destination choice for work trips.
- Comparing total trips or trips per activity with the trips from the household survey. Here, an appropriate aggregation is required for sufficient statistical significance.

If required, correction values k_{ij} per OD pair shall be applied to correct the destination choice. However, beforehand the land use data shall be critically reviewed.

An important analysis is to compare trip length per activity and person group. The following Figure shows the high compliance of the model and the data from the household interview survey (HIS) in the Bahrain case. The compliance can be lower for activities with low empirical database.

Besides the average trip lengths also a validation of the length distributions shall be conducted

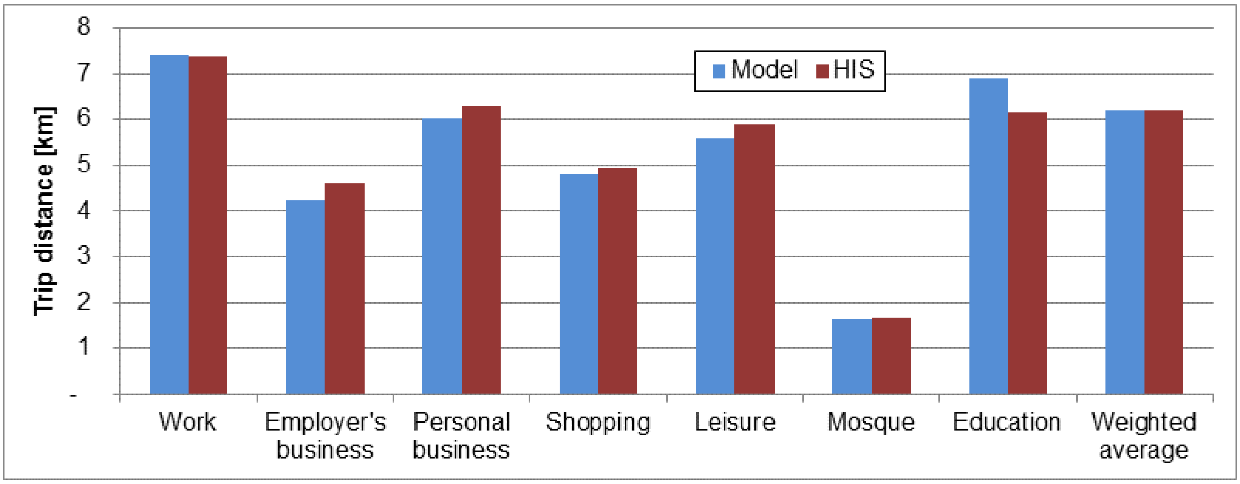

Figure 5: Average trip distances per activity – model figures against figures from household interview survey in Middle East.

In order to measure the model fit regarding trip length distributions the ‘coincidence ratio’ is recommended. The procedure to calculate the coincidence of distributions is as follows:

$$CR = \frac{\sum_T[\min(PM_T, PO_T)]}{\sum_T[\max(PM_T, PO_T)]}$$

with

CR	Coincidence Ratio
PM_T	Proportion of modelled distribution in interval T
PO_T	Proportion of observed distribution in interval T
T	Histogram interval for time, distance, or other impedance measures (e.g., 0…4.9 minutes, 5.0…9.9 minutes).

The coincidence ratio lies between 0 and 1.0, where a ratio of 1.0 indicates identical distributions.

5.2.3. Mode Choice

Mode choice shall be validated on different levels. Most obvious are

- Comparing mode choice of the HIS with the model per person group.
- Comparing mode choice per main zone or main zone pair.
- Comparing total mode choice of the HIS with the model

Furthermore mode choice per distance class shall be plotted as a diagram to observe, whether the deviation to the HIS is acceptable. This also ensures realistic trip lengths per mode.

5.2.4. Assignment

The final validation of the model fit should be conducted after the assignment step. Assuming a good quality of the counts and having achieved compliance in the previous modelling steps, a good compliance against counts can be expected. Deviations shall be thoroughly analysed – it is important to understand that they are mostly an indication for wrong land use data, wrong route choice due to mistakes in the network or unreliable count data.

Depending on the applications of the model, it might be acceptable to have certain deviations. The more strategic the model will be used, the higher deviations might be acceptable as long as global values from the previous steps as well as screenline analyses are good.

The high tender requirements in the case of the model of the Region Stuttgart could only be reached by using a matrix correction approach, which adjusts the pure synthetic model matrix to reliable count figures. The application of the matrix correction should not change the trip length distribution and the symmetry of the trip matrix (24 h matrices) .Thus the matrix structure shall be kept as far as possible by using the correction approach.

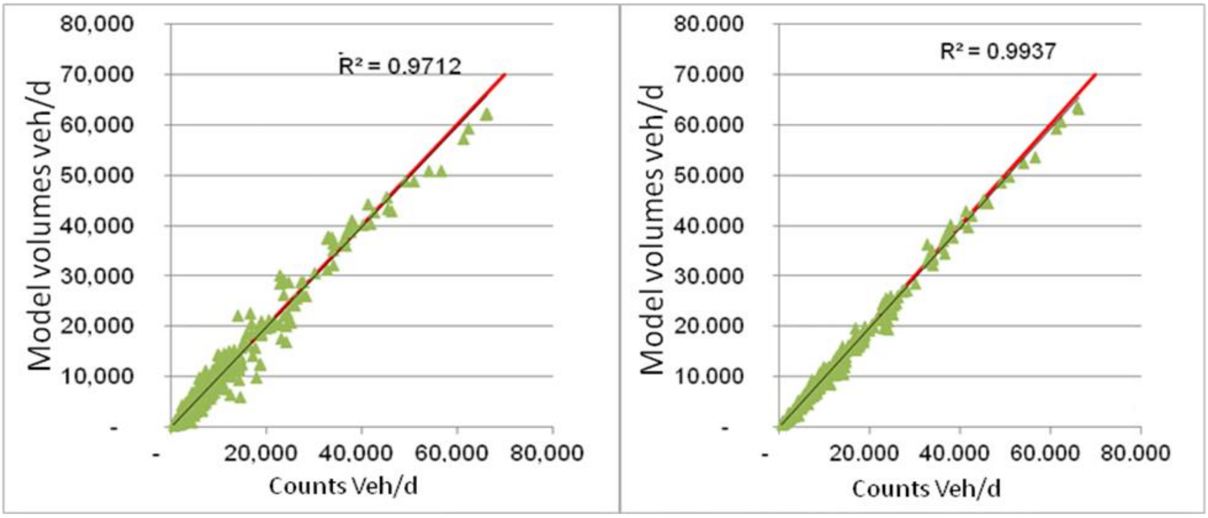

Figure 6: Model volumes against counts without (left) and with matrix correction (right)

For the Public Transport the tender in Stuttgart asked for a maximum deviation of the passenger kilometres of 5 % for every public transport system (S-Bahn, Stadtbahn and Bus), which could be fulfilled for all systems without matrix corrections. However, additional comparisons have been conducted to prove the realism of the public transport assignment. Both the analysis of passenger kilometres for lines of the various transport systems and analysis of count locations show a very good fit against empirical comparison data (the higher model value for Line S1 can be explained by the extension of the S1 after conduction of the passenger survey):

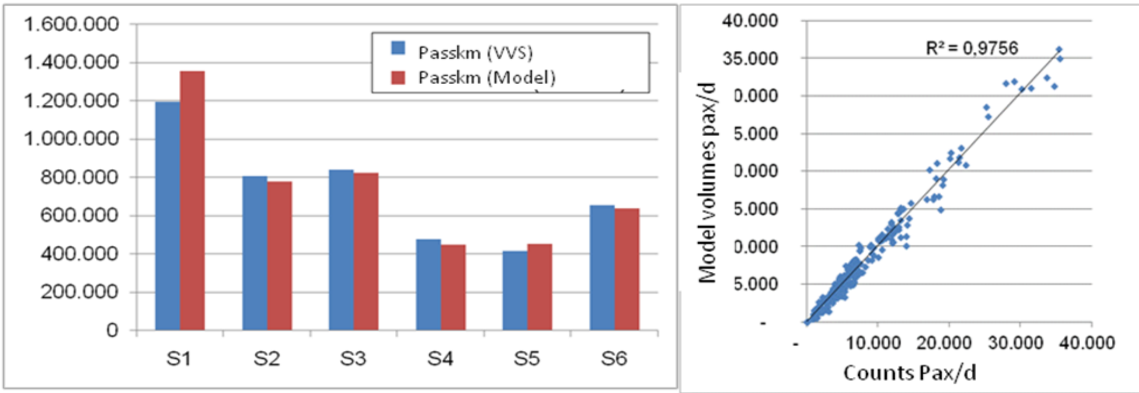

Figure 7: Comparison modelled and observed ("VVS") Passkm per day for S-Bahn lines (left side) and Stadtbahn - link volumes against counts (right side), Model of the Region of Stuttgart

5.2.5. Review of Existing Validation Guidelines

There are existing validation guidelines issued by prominent authorities and used by model operators worldwide are examined and understood. Two documents have been identified for further detailed consideration:

- UK Department for Transport (DfT): WebTAG guidelines [3]; and
- US Federal Highway Administration: Travel Model Validation and Reasonableness Checking Manual [5].

5.2.5.1. UK Department for Transport – WebTAG

WebTAG (Web-based Transport Analysis Guidance) is the UK Department of Transport (DfT) appraisal guidance and toolkit. It consists of software tools and instructions on transport modelling and appraisal methods applicable to highways and public transport interventions (major engineering projects) and demand management measures. This guideline document is considered a requirement for all projects/studies that require government approval and a best practice guide for projects or studies that do not require government approval (https://www.gov.uk/transport-analysis-guidance-webtag).

One key intention of model and appraisal guidelines is to provide instructions on how to prove that a model is "fit for its purpose". WebTAG is predominantly used to provide evidence that a model is qualified to be used for the assessment of a specific scheme. However, for a general purpose model, WebTAG recommends that a series of demonstration tests are undertaken so that potential users of the model can gauge the usefulness of the model for particular applications. The range of tests should cover the range of interventions for which the model is intended to be used. WebTAG guidelines concerning the fitness for purpose can be used for the required demonstration tests.

UK's transport demand development is a seen as s stable process without major structural changes which lead to a preferred use of incremental models based on observed base year matrices. Thus validation targets given in WebTAG shall not be simply applied to pure synthetic models.

5.2.5.2. US Federal Highway Administration (FHWA) – Travel Model Validation and Reasonableness Checking Manual

This validation manual has been developed in order to improve the state of model validation and the resulting forecasts in the United States. The manual has been released in 2010 by the US Federal Highway Administration as part of its Travel Model Improvement Program (TMIP). As part of the TMIP's efforts to improve travel modelling practice, the validation manual provides guidance on:

- The development of model validation plans, including collection of proper validation data;
- The role and specification of validation and reasonableness checks and criteria;
- The role of model sensitivity testing in model validation; and
- The development of validation documentation.

The TMIP manual addresses primarily pure strategic models contains a comprehensive list of various tests on all model stages, which shall be used for model validation of pure strategic models. However, the manual provides no generally binding validation targets but gives validation results of models implemented in the U.S.

5.2.6. Summary of validation

For validation of a model it is very important to do this in an appropriate order. There is no need to look at assignment results before not having very good results in the trip generation, destination choice and mode choice step. Any corrections such as k_{ij} values for destination choice or a matrix correction using count data must be the last choice and should be controlled carefully. Significant deviation from observed data should be checked by the modeller regarding mistakes in the model parameters or the input data.

As previously mentioned, it is desirable that tenders include clear criteria for the desired quality of the model. This gives the authority the possibility to demand this quality, but also the consultant can be sure that – once he reached this quality – the model will be approved.

However, it is difficult to define those criteria beforehand. Large modelling experience and very good knowledge of the available data is required to define reasonable thresholds. The following Table 4 gives a possible set of criteria for a regional model (city with surrounding area or metropolitan area). GEH is used for traffic counts, while correlation or relative deviation is used for comparison of many, often very low values.

It is important to note, that these criteria are not a result of any scientific theory or scientific considerations. The criteria shall give a target system for the calibration and validation process. Finally, it will difficult for a model to meet all these criteria. Thus, both model builder and model user shall assess the model's fitness for purpose based on the overall view of model input data, model resolution, model purpose and model validation.

Table 4: Model validation criteria (few criteria and values derived from [9])

Sub-Model	Criterion		Permitted	Comment
Trip generation	Number of trips compared to HIS	Total	< 0.1%	Usually very little need for deviations
		Per person group	< 1%	
	Share of activities of the total trips compared to HIS	Per activity (except home)	< 1%	For home trips it might be higher due to omitting long, run time intensive chains
		For home activity	< 5%	
Trip distribution	Number of trips per main zone OD pair compared to HIS	Correlation (total)	> 98%	Dependent on size of main zones and sample size of the household survey
		Correlation (car, PuT)	> 90%	
		Correlation (other modes)	> 80%	
	Number of working trips per municipality OD pair compared to statistical data	Correlation	> 95%	Dependent on quality of statistical data
	Trip length compared to HIS	Total	< 2%	
		Per activity	< 5% or < 300m	
	Trip length distribution compared to HIS per activity	Coincidence ratio	> 0.7	
Modal split	Share of modes compared to HIS	Total	< 0,3%	
		Per person group (share of mode ≥ 10%)	< 2.5%	
		Per person group (share of mode < 10%)	< 1.0%	
	Modal split distribution over trip distance compared to HIS	Total	Visual control	Check also mean trip length per mode

Sub-Model	Criterion		Permitted	Comment
Assignment PrT	Convergence of final assignment	Relative gap	< 10-5	
	Traffic counts (before matrix correction) in veh/d	Screenlines	< 10%	Only valid for 24h-values! Requires thorough analyses of traffic counts, e.g. counts within large TAZ must be excluded.
		Mean GEH	< 12.5	
		Share of GEH < 10	> 45%	
		Correlation	> 97%	
	Traffic counts (after matrix correction) in veh/d	Screenlines	< 5%	
		Mean GEH	< 6	
		Share of GEH < 10	> 80%	
		Correlation	> 99%	
	PrT-Matrix before and after matrix correction	Matrix sum	< +/- 3%	Structure of the original matrix should be kept as much as possible
		Trip length	< 0.5 %	
		Share of trip length (per 1km-interval)	< +/- 5%	
		Correlation of origin- and destination traffic per TAZ	> 99%	
Assignment PuT	Traffic counts in Pass/d without matrix correction	Mean GEH	< 10	Depends on the transport system (volumes of buses with several stops within one TAZ may have higher deviations)
		Share of GEH < 10	> 50%	
		Correlation	> 95%	
	Evaluations per line	Total PassKM per transport system	< +/- 5%	
		Share of lines with Total PassKM < +/- 10%	> 90%	

The second requirement of the validation process should be the conduction of realism tests, e.g. by decreasing all free-flow speeds for PrT by 10 % or decreasing PuT fares by 100%. The results should be analysed by person group and discussed during the model building process.

It is easy to understand that there is not simply a target figure for the outcome of realism tests. Due to the fact that most models are based on non-linear choice models the reaction of a model is depending on attractiveness of possible choice alternatives on the various model stages. However, the results shall be assessed against expectations of local transport experts and can be checked against comparable tests or experiences in other parts of the world. The WebTAG guideline for example proposes the testing of the model's elasticity of demand by using the formula (arc elasticity):

$$e = (\log(T_1) - \log(T_0))/(\log(C_1) - \log(C_0)),$$

where the superscripts 0 and 1 indicate values of demand T, and cost C, before and after the change in cost, respectively.

WebTAG recommends that:

- the elasticities should be calculated from a converged run of the demand/supply loop;
- a demand weighted average of these elasticities by time period and demand segment should be taken; and
- the elasticities should be calculated using the base year model.

The elasticities to be calculated and their acceptance ranges according WebTAG are listed in the Table 5.

Table 5: WebTAG sensitivity tests

Elasticity of	Input data	Input variation	demand proxy	Target range of demand elasticity
Car fuel cost	Price	+10%/20%	vehicle kilometers	-0.25…-0.35
Public transport fare	Fare	+10%/20%	public transport trips	-0.2…-0.9
Car journey time	Travel time	e.g. free flow	car trips	…< --2.0

6. Applications of Transport Models

A central application of strategic transport models is to assess transport planning schemes within the next 10 to 20 years. However, the paper has shown that setting up a strategic model is a time and cost intensive work. Thus it must be the target to use it for a wide range of tasks. In general, transport models can serve as important database for operational planning and optimisation of traffic inside the model area. Some applications should be mentioned in the following:

- Macroscopic models can serve as data provider for traffic impact studies
- Transport models can be the basis for prediction of traffic conditions, which allow making decisions about the optimal trips of users and vehicles, achieving substantial savings for the society as a whole (e.g. PTV Optima, [7]).
- Macroscopic transport models can be used for the optimization of signal programs [12].
- Macroscopic transport models can provide important data to identify hotspots for an environmental traffic management and can be used to assess schemes to reduce emissions at these hotspots.
- Macroscopic transport models can be the basis for microscopic simulations.

Besides the application of the model for solutions in private transport planning and control it is also an important tool for public transport planning. The model can be used as assessment tool in public transport master plans, in the permanent planning process of a transport operator or as important data provider in a public transport service tender process.

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