Paper presented at the ERSA conference, Amsterdam, July 2005

A simultaneous two-dimensionally constraint disaggregate trip generation, distribution and mode choice model: Theory and application for the Swiss national model

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Arbeitsbericht Verkehrs- und Raumplanung 291

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June 2005

Abstract

The Swiss federal government has asked the IVT, ETH Zürich in collaboration with the TU Dresden and Emch+Berger, Zürich to estimate origin-destination matrices by mode and purpose for the year 2000. The complex zoning system employing about 3'000 zones required an algorithm which is fast, but also able to face generation, distribution and mode choice simultaneously.

The EVA algorithm developed by Lohse (1997) was adapted for this purpose. The key properties of the algorithm are a disaggregate description of the demand, and its use of appropriate logit-type models for the demand distribution, while maintaining the known marginal distributions of the matrices generated. The algorithm calculates trip production and attractions by zone using activity pairs. The combined destination and mode choice models are estimated for the different traveller types and activity pairs.

The paper derives and describes for the first time the EVA algorithm in English, including the solution method used. Second, it summarises the results of choice model estimation using the generalised cost elasticities of demand by purpose and traveller type. Third, it presents the quality of the results by assessing the structure of the matrix with the help of actual census data for road and rail traffic.

Keywords

EVA, choice model, trip generation, trip distribution, mode choice, activity pairs, national model, simultaneous solution, O-D matrices, Switzerland.

Preferred citation style

M. Vrtic, D. Lohse, P. Fröhlich, C. Schiller, N. Schüssler, H Teichert and K.W. Axhausen (2005) A simultaneous two-dimensionally constraint disaggregate trip generation, distribution and mode choice model: Theory and application for a Swiss national model, *Arbeitsbericht Verkehrs- und Raumplanung*, **2xx**, IVT, ETH Zürich, Zürich.

1 Introduction

Travel demand models require in practical application, that three constraints are met: consistency of the assumed and obtained generalised costs of travel, reproduction of the marginal totals of trip distribution and attraction and non-violation of the capacity constraints of network elements. Ideally, this overall equilibrium is achieved with an internally consistent and theoretically sound model of individual travel behaviour at all levels considered. By tradition models consider the four partial models of production/attraction, distribution, mode choice and assignment, of which assignment has acquired for some time well established equilibrium formulations. This paper will present an approach to unify the other three steps into a coherent whole, which assures that the second constraint mentioned above is met while employing a sound behavioural model. This approach, called EVA – model in German from the German terms for production (Erzeugung), distribution (Verteilung) and mode choice (Aufteilung) has been developed by Lohse and his collaborators (Lohse, Teichert, Dugge and Bachner, 1997 or Schnabel and Lohse, 1997) and is presented here for the first time in English with a large scale application as a challenging example: the new national transport model for Switzerland. The EVA approach is formulated using a Bayesian approach, while employing the information gain criterion and general solution algorithms for n-linear equations systems to calculate the desired solution.

The Swiss national model is implemented on the basis of 2949 small zones inside the country and 165 increasingly larger zones further away from Switzerland. It distinguishes seventeen combinations of six trip purposes for three modes (motorised private travel, public transport and the combined walking and cycling modes). In total 51 matrices of 3114 * 3114 zones need to be calculated. The differences in data availability and size for the internal and external zones required different treatments for the traffic internal to Switzerland and those leaving, entering and passing through. For simplicity of exposition the paper will focus on the internal traffic and its modelling. The user-equilibrium assignment model of the software package VISUM 8.13 (PTV, 2004) was employed.

The structure of the paper is as follows: the next three sections will discuss the EVA approach first to trip production/attraction, then to distribution and mode choice modelling and finally the solution algorithm. The second part will present the practical application in Switzerland focussing on the simultaneous destination/mode choice model and the quality of the matrices obtained. The paper concludes with an outlook for both the approach and the particular application.

2 Modelling trip generation in EVA

The EVA approach calculates trip production and attraction with deterministic, but finely detailed trip rates on the production side, and proportional to the volume of activity opportunities at the attraction side, but allowing for hard and soft constraints. Total trip making is disaggregated into activity purpose pairs at origin and destination, which are associated with the various trip purposes. For the Swiss National model seventeen pairs were distinguished (Table 1):

Table 1 Definition of the activity-purpose pairs

From	To						Daily weekday trip rate by purpose
	Home H	Work W	Education E	Business B	Shopping S	Leisure L	
Home	-	HW(1)	HE(1)	HB (1)	HS(1)	HO(1)	
Work	WH (2)	WO (1)					2.10/worker
Educatio	EH (2)	OW (2)	BO, SO, OB, OS, OO (3)				0.37/student
Business	BH (2)						0.47/worker
Shopping	SH (2)						0.67/head
Leisure	OH (2)						1.49/head

(*) indicates the type of the pair; O = W,E,B,S,L

These are grouped into types with regard to the involvement of the home, as either at origin or at destination:

- Type 1: origin at home location, which can be home (1st priority) or work (2nd priority)
- Type 2: destination at home location
- Type 3: neither origin nor destination at home location

Additionally, one can attach trip purposes to the pairs as follows:

- Work: HW, WH, HO, OH
- Education: HE, EH
- Business: HB, BH, BO, OB
- Shopping: HS, SH, SO, OS
- Leisure/Other: HO, OH, OO

Each pair is associated with all or subsets of travellers. For example the HW and WH rates are calculated for employed persons, while HS and SH rates refer to all travellers. The number of persons in each set needs to be determined for each zone, so that trip productions can be calculated. The rates summed across trip purposes used in the Swiss National Model are shown in Table 1.

Similarly, the relevant attractors and attraction rates are with each pair (See Table 2 for these links). Again, the numbers or volumes, of for example work places and shop floor areas, were collated for each of the zones. The attraction rates were calculated as the ratio of the produced trips to the total number of attractors. In the case of shopping, the split between trips to normal stores and shopping centres was informed by the data in Bosserhoff, 2000. For certain trip purposes or activity-purpose pairs it is possible and necessary to impose a hard equality constraint, for example work or school, as we expect workers to arrive at their workplaces. In the remaining cases, the attraction rates define an upper limit of what the zone can accommodate, and the number of trips to the zone reflects the spatial competition. Shopping is a good example for such soft constraints.

The ability to distinguish these constraints is a major advantage of the EVA approach, as it avoids the well known pitfalls of unconstraint models, such as simple destination choice models, which only enforce the constraint at the origin. On the other hand, this double constraint formulation has the disadvantage, that any choice model estimated from observed behaviour will need to be adjusted by hand to match the observed trip length distribution under the imposition of the constraints.

Trip production for each activity-purpose pair in each zone e is calculated as:

$$H_e = \sum_p SV_p \cdot BP_{ep} \cdot u_p \qquad V = \sum_e H_e \tag{0.1}$$

With

SV_p … Production rate of person group p

BP_{ep} … Number of persons of group p in zone e

u_p … Share of intrazonal trips for group p in zone e

The trip attractions for each activity-purpose pair results for those with hard constraints as:

$$Z_j = \frac{\sum_r ER_r \cdot SZ_{rj}}{\sum_{j'} \sum_r ER_r \cdot SZ_{rj'}} \cdot V \qquad (0.2)$$

and for those with elastic constraints as:

$$Zmax_j = \frac{\sum_r Ü_{rj} \cdot ER_r \cdot SZ_{rj}}{\sum_{j'} \sum_r ER_r \cdot SZ_{rj'}} \cdot V \qquad (0.3)$$

with:

ER_r … Attraction rate of attractor r

SZ_{rj} … Number/volume of attractor r in zone j

$Ü_{rj}$ … Load factor of zone j with respect to attractor r

Z_j … Attracted traffic to zone j

$Zmax_j$… Maximum attracted traffic volume zo zone j

V … Total traffic volume

3 Joint destination and mode choice in EVA

The EVA approach extends its person-group activity-purpose pair specific approach to the simultaneous modelling of destination and mode choice. The number of trips generated in zone i for each segment Q_i is assumed to be known, as is the number (hard constraint) or the maximum number (elastic constraint) of trips for the segment to zone j Z_j. The share of trips with mode k between zones i and j are calculated as a function of the generalised costs of travel using different model forms, which will be discussed below. This conditional probability BW_{ijk} is:

$$BW_{ijk} = P\left(W \middle| \left(A_i \cap E_j \cap M_k\right)\right) \qquad 2.1$$

With random events defined as follows:

A_i … zone i has been chosen as origin

E_j … zone j has been chosen as destination

M_k … mode k has been chosen

W … trip from i to j using k is accepted with regard to the generalized costs

The preferred form of the function of the generalised costs is a matter of the quality of fit obtained (See Figure 1 for common examples) and the desired flexibility of the elasticities. Lohse (Lohse, Teichert and Dugge, 2004) has suggested the following non-linear transformation of the generalised costs, which required three additional parameters E,F, and G to obtain a very flexible shape of the elasticity ε over the range of the generalised costs:

$$\mathrm{BW} = \mathrm{f}(\mathrm{w}) = \left[1 + \left(\frac{\mathrm{w}}{\mathrm{F}}\right)^{\mathrm{G}}\right]^{-\frac{\mathrm{E}}{\mathrm{G}}} \qquad \varepsilon(\mathrm{w}) = -\mathrm{E} \cdot \frac{\mathrm{w}^{\mathrm{G}}}{\mathrm{F}^{\mathrm{G}} + \mathrm{w}^{\mathrm{G}}} \tag{0.4}$$

The logit – conform exponential function can be expanded with one or two additional parameters, leading then to a Box-Tukey-transformed formulation:

$$\text{EXP:} \quad \mathrm{BW} = f(w) = \exp(-\beta \cdot w) \qquad \text{EXP\_BTT:} \quad \mathrm{BW} = f(w) = \exp(-\beta \cdot w^{(\lambda,1)})$$

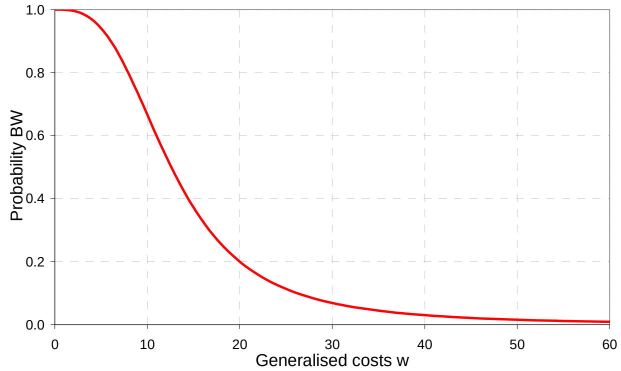
$$\begin{array}{ll|l} \varepsilon(w) = -\dfrac{\beta \cdot w}{w+1} & \text{for } \lambda = 0 & \\ \varepsilon(w) = -\beta \cdot w & \text{for } \lambda = 1 & \text{with}: w^{(\lambda,1)} = \begin{cases} \left((w+1)^{\lambda} - 1\right)/\lambda & \text{for } \lambda > 0 \\ w & \text{for } \lambda = 1 \\ \ln(w+1) & \text{for } \lambda = 0 \end{cases} \\ \varepsilon(w) = -\beta \cdot w \cdot (w+1)^{\lambda-1} & \text{for } \lambda > 0 & \end{array} \tag{0.5}$$

Sometimes, a power function is used:

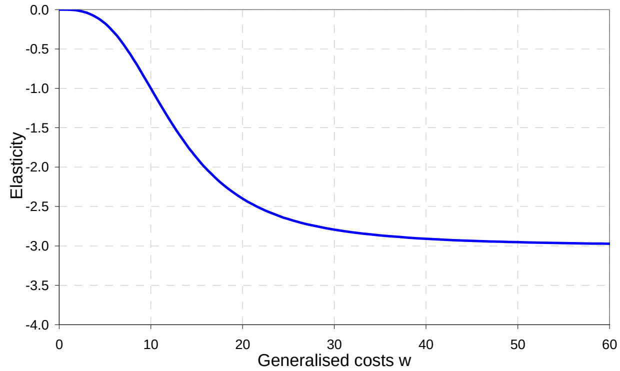
$$\text{POT:} \quad \mathrm{BW} = \mathrm{f}(\mathrm{w}) = \mathrm{w}^{-\alpha} \qquad \varepsilon(\mathrm{w}) = -\alpha \tag{0.6}$$

Figure 1 Probabilities and elasticities of different transformations

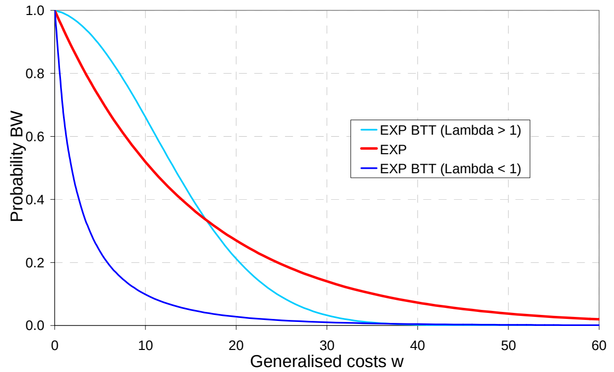
EVA function



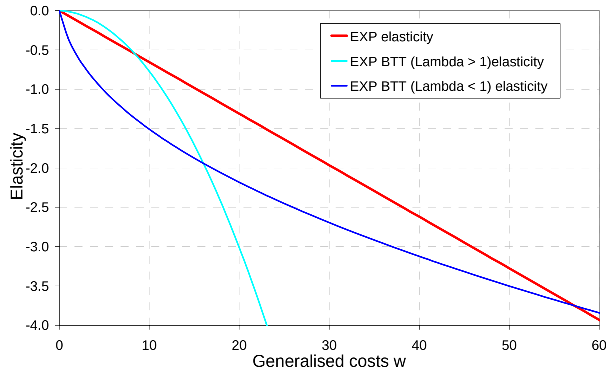
EVA elasticity



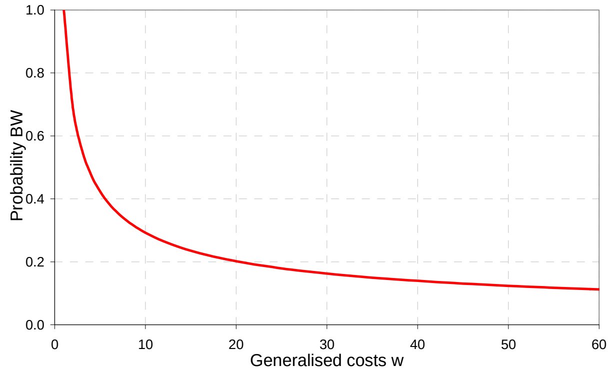
EXP and EXP_BTT function



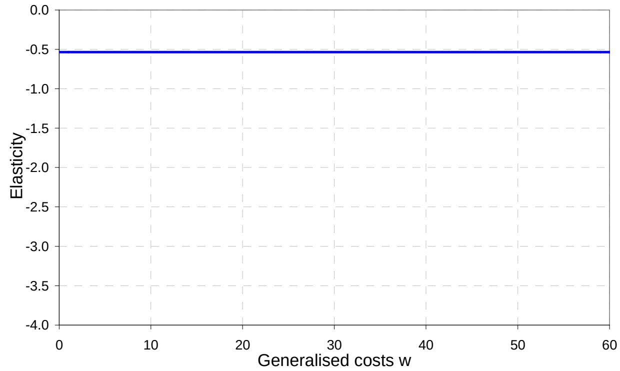
EXP and EXP_BTT elasticity



POW function



POW elasticity



The basic model allocates a share of all trips V to a particular relation v_{ijk}. The formulation is structurally a Bayesian model

$$v_{ijk} = \frac{P\left(\left(A_i \cap E_j \cap M_k\right)|W\right)}{\sum_{i'}\sum_{j'}\sum_{k'} P\left(\left(A_{i'} \cap E_{j'} \cap M_{k'}\right)|W\right)} \cdot V = \frac{P(A_i)\cdot P(E_j)\cdot P(M_k)\cdot P\left(W|\left(A_i \cap E_j \cap M_k\right)\right)}{\sum_{i'}\sum_{j'}\sum_{k'} P(A_{i'})\cdot P(E_{j'})\cdot P(M_{k'})\cdot P\left(W|\left(A_{i'} \cap E_{j'} \cap M_{k'}\right)\right)} \cdot V \quad (0.7)$$

in which one can choose any functional form for the calculation of the probability, for example the universal logit model (Maier and Weiss, 1990).

In the case of hard constraints the conditional probabilities are known:

$$P\left(A_i|W\right) = \frac{Q_i}{V} \quad \text{und} \quad P\left(E_j|W\right) = \frac{Z_j}{V} \quad \text{und} \quad P\left(M_k|W\right) = \frac{M_k}{V}. \quad (0.8)$$

The ratios of the conditional and unconditional probabilities define the initially unknown balancing factors:

$$q_i = \frac{P(A_i)}{P\left(A_i|W\right)} \quad z_j = \frac{P(E_j)}{P\left(E_j|W\right)} \quad a_k = \frac{P(M_k)}{P\left(M_k|W\right)}. \quad (0.9)$$

With $P(A_i) = P\left(A_i|W\right)\cdot q_i$; $P(E_j) = P\left(E_j|W\right)\cdot z_j$ und $P(M_k) = P\left(M_k|W\right)\cdot a_k$ one obtains:

$$v_{ijk} = \frac{P(A_i|W)\cdot q_i \cdot P(E_j|W)\cdot z_j \cdot P(M_k|W)\cdot a_k \cdot P(W|(A_i \cap E_j \cap M_k))}{\sum_{i'}\sum_{j'}\sum_{k'} P(A_{i'}|W)\cdot q_{i'} \cdot P(E_{j'}|W)\cdot z_{j'} \cdot P(M_{k'}|W)\cdot a_{k'} \cdot P(W|(A_{i'} \cap E_{j'} \cap M_{k'}))} \cdot V. \quad (0.10)$$

With the given probabilities $BW_{ijk} = P(W|(A_i \cap E_j \cap M_k))$ and the given conditional probabilities $P(A_i|W) = Q_i/V$, $P(E_j|W) = Z_j/V$ und $P(M_k|W) = M_k/V$ it is possible to determine the balancing factors q_i, z_j and a_k and the probabilities $P(A_i)$, $P(E_j)$ und $P(M_k)$.
After some transformations we obtain the tri-linear system of equations with constraints:

$$v_{ijk} = BW_{ijk}\cdot\frac{Q_i}{V}\cdot q_i\cdot\frac{Z_j}{V}\cdot z_j\cdot\frac{M_k}{V}\cdot a_k\cdot f = BW_{ijk}\cdot fq_i\cdot fz_j\cdot fa_k$$

$$\left.\begin{aligned} Q_i &= \sum_j\sum_k v_{ijk} \\ Z_j &= \sum_i\sum_k v_{ijk} \\ M_k &= \sum_i\sum_j v_{ijk} \end{aligned}\right\} \text{Constraints} \quad (0.11)$$

This model can be derived from the approaches of maximising information retrieval. Schürger (1998) defined information retrieval I as the degree of deviation of a probability distribution α in contrast to a given distribution β.

$$I = -\sum\left[\alpha\cdot\ln\left(\frac{\alpha}{\beta}\right)\right]. \quad (0.12)$$

Lamond and Stewart (1984) explain a relaxation method developed by Bregman to solve convex optimisation problems and portray the application of this method on special transport planning issues. Furthermore they show that the traffic flow matrix, which belongs to a rating matrix BW_{ijk} and has row sum conditions in the form of equations (0.11), can also be described as solution of the convex optimisation problem:

$$\sum_i \sum_j \sum_k \left[v_{ijk} \cdot \ln\left(\frac{v_{ijk}}{BW_{ijk}} \right) - v_{ijk} \right] \rightarrow \text{ Minimum} \tag{0.13}$$

By applying the Lagrange's multiplication method on problem (0.13) with row sum conditions (0.11), the Lagrange function below can be derived:

$$\begin{aligned} \Phi = & \sum_i \sum_j \sum_k \left[v_{ijk} \cdot \ln\left(\frac{v_{ijk}}{BW_{ijk}} \right) - v_{ijk} \right] + \sum_i \lambda_i \cdot \left(\sum_j \sum_k v_{ijk} - Q_i \right) + \sum_j \mu_j \cdot \left(\sum_i \sum_k v_{ijk} - Z_j \right) \\ & + \sum_k \nu_k \cdot \left(\sum_i \sum_j v_{ijk} - A_k \right) \end{aligned} \tag{0.14}$$

If there is at least one valid solution, an unambiguous optimal solution exists, which satisfies the row sum conditions and the equation:

$$\frac{\partial \Phi}{\partial v_{ijk}} = \ln\left(\frac{v_{ijk}}{BW_{ijk}} \right) + \lambda_i + \mu_j + \nu_k = 0 \tag{0.15}$$

From this (0.16) can be concluded for the optimal solution:

$$\begin{aligned} v_{ijk} &= BW_{ijk} \cdot e^{-\lambda_i} \cdot e^{-\mu_j} \cdot e^{-\nu_k} \\ v_{ijk} &= BW_{ijk} \cdot fq_i \cdot fz_j \cdot fa_k \end{aligned} \quad . \tag{0.16}$$

This is the formulation the EVA model requires. It is equivalent to the optimal solution of the optimisation problem because a matrix in this formulation can be unambiguously identified by the row sum conditions (0.11).

For elastic constraints the second set of constraints is changed to inequalities:

$$v_{ijk} = BW_{ijk} \cdot \frac{Q_i}{V} \cdot q_i \cdot \frac{Zmax_j}{\sum_{j'} Zmax_{j'}} \cdot z_j \cdot \frac{M_k}{V} \cdot a_k \cdot f$$

$$\left.\begin{array}{l} Q_i = \sum_j \sum_k v_{ijk} \\ Zmax_j \geq Z_j = \sum_i \sum_k v_{ijk} \\ M_k = \sum_i \sum_j v_{ijk} \end{array}\right\} \text{Constraints}$$

For forecasting, one assumes that the balancing factors fa_k remain constant and obtain two-dimensional problem, which is solved with the same method:

$$v_{ijk} = \left(BW_{ijk} \cdot fa_k\right) \cdot \frac{Q_i}{V} \cdot q_i \cdot \frac{Z_j}{V} \cdot z_j \cdot f$$

$$\left.\begin{array}{l} Q_i = \sum_j \sum_k v_{ijk} \\ Z_j = \sum_i \sum_k v_{ijk} \end{array}\right\} \text{Constraints} \qquad (0.17)$$

There is a need to iterate between the travel demand calculations and the assignment to obtain a mutually consistent solution. The software tool VISEVA (Lohse, Teichert and Dugge, 2004) implements the model and provides tools to implement the full iteration scheme in conjunction with the assignment software VISUM (PTV, 2002)).

4 Solution algorithm

The solution algorithm is based on the idea of the maximisation of the information gain (Bergman, 1976; Lohse, Teichert, Dugge und Bachner, 1997). In an iterative process one identifies that linear transformation of the matrix BW, which satisfies the constraints. The Furness and the Multi-procedure are possible and efficient solutions for this class of problems. The theory is discussed in Teichert, Dugge and Bachner, 1997 , Evans and Kirby, 1974; Furness, 1965; Lamond and Stewart, 1984; Mekky, 1983, while Schnabel and Lohse, 1997 provide practical applications.

The Multi-procedure is an iterative solution, which advances the solution simultaneously for all – here three – dimensions (Schnabel and Lohse, 1997), which is therefore faster than for example the Furness procedure, which deals with only one dimension at a time. Transforming the equation system we obtain the fixed point problem:

$$fq_i = \frac{Q_i}{\sum_j \sum_k BW_{ijk} \cdot fz_j \cdot fa_k} \quad fz_j = \frac{Z_j}{\sum_i \sum_k BW_{ijk} \cdot fq_i \cdot fa_k} \quad fa_k = \frac{VK_k}{\sum_i \sum_j BW_{ijk} \cdot fq_i \cdot fz_j} \quad . \tag{0.18}$$

The three terms are entered simultaneously into other. Using $v_{ijk}(1) = BW_{ijk}$ as the starting point, one obtains:

$$v_{ijk}(p+1) = v_{ijk}(p) \cdot \frac{Q_i}{\sum_j \sum_k v_{ijk}(p) \cdot z_j(p) \cdot a_k(p)} \cdot \frac{Z_j}{\sum_i \sum_k v_{ijk}(p) \cdot q_i(p) \cdot a_k(p)} \cdot \frac{VK_k}{\sum_i \sum_j v_{ijk}(p) \cdot q_i(p) \cdot z_j(p)} \cdot f(p) \tag{0.19}$$

Which in the next step results in:

$$v_{ijk}(p+1) = v_{ijk}(p) \cdot \frac{q_i(p)}{\overline{q_i}(p)} \cdot \frac{z_j(p)}{\overline{z_j}(p)} \cdot \frac{a_k(p)}{\overline{a_k}(p)} \cdot f(p) \tag{0.20}$$

mit:

$$Q_i(p) = \sum_j \sum_k v_{ijk}(p) \quad Z_j(p) = \sum_i \sum_k v_{ijk}(p) \quad VK_k(p) = \sum_i \sum_j v_{ijk}(p) \quad V(p) = \sum_i \sum_j \sum_k v_{ijk}(p)$$

$$q_i(p) = \frac{Q_i}{Q_i(p)}; \quad z_j(p) = \frac{Z_j}{Z_j(p)}; \quad a_k(p) = \frac{VK_k}{VK_k(p)}; \quad f(p) = \frac{V}{V(p)}$$

$$\overline{q_i}(p) = \frac{\sum_j \sum_k v_{ijk}(p) \cdot \left(z_j(p) + a_k(p)\right)}{2 \cdot Q_i(p)}$$

$$\overline{z_j}(p) = \frac{\sum_i \sum_k v_{ijk}(p) \cdot \left(q_i(p) + a_k(p)\right)}{2 \cdot Z_j(p)}$$

$$\overline{a_k}(p) = \frac{\sum_i \sum_j v_{ijk}(p) \cdot \left(q_i(p) + z_j(p)\right)}{2 \cdot VK_k(p)}$$

And starting points: $fq_i(1) = fz_j(1) = fa_k(1) = f(1) = 1$ und $v_{ijk}(1) = BW_{ijk}$

For elastic constraints the solution of the optimisation problem can be derived by the means of an appropriate modification of the Furness procedure (Lohse, Teichert, Dugge and Bachner, 1997), which is shortly indicated below.

$$v_{ijk}(p+1) = BW_{ijk} \cdot fq_i(p+1) \cdot fz_j^*(p+1) \cdot fa_k(p+1)$$

$$fq_i(p+1) = \frac{Q_i}{\sum_j \sum_k BW_{ijk} \cdot Zmax_j \cdot fz_j^*(p) \cdot fa_k(p)}$$

$$fz_j^*(p+1) = \min\left\{x_j(p); \frac{Zmax_j}{\sum_i \sum_k BW_{ijk} \cdot Zmax_j \cdot fq_i(p+1) \cdot fa_k(p)}\right\} \qquad (0.21)$$

$$x_j(p) = F_j\left(x_j(p) \cdot \sum_i \sum_k BW_{ijk} \cdot fq_i(p+1) \cdot fa_k(p)\right)$$

$$fa_k(p+1) = \frac{VK_k}{\sum_i \sum_j BW_{ijk} \cdot Zmax_j \cdot fq_i(p+1) \cdot fz_j^*(p+1)}$$

With the starting points: $fq_i(1) = fz_j(1) = fa_k(1) = 1$.

5 Estimation of the simultaneuous destination and modal choice model

In line with the EVA approach the Swiss national model employs a simultaneous destination and mode choice model. The nested logit model has modes as the upper level and the destinations as the lower level. This form was adopted after experimenting with the alternative. For estimation a random selection of eleven destinations was selected for each mode. In the case of the chosen mode alternative only ten alternatives were added. The sampling was stratified: the origin zone, three zones within 70% of the observed distance, further three within 70% and 130% and the final three beyond 130% of the observed distance. The model was estimated separately for ten of the seventeen activity purpose pairs, as the samples were too small for the remaining ones, using Biogeme 0.7 (Bierlaire, 2003). In the revealed preference data set used, the 2005 Swiss national travel survey Mikrozensus Verkehr (ARE and BFS, 2001), the usual strong correlations between travel cost, distance and travel time made the estimation of the mode choice parameters of the private motorised and public transport impossible. These were taken from an earlier stated preference study (Vrtic *et al.*, 2003) together with the parameters for the socio-demographic variables. The variables describing the destination match the relevant trip purpose.

Table 2 shows that the activity purpose pair specific models have generally reasonable goodness-of-fits and all newly estimated parameters are significant at the 95% level, have the correct sign and credible magnitudes. The low explanatory power for work is the effect of both a large share of intrazonal destinations, as well as the lack of differentiation of the types of work possible.

As mentioned above, the introduction of the marginal constraints in the EVA approach requires adjusting some of the variables to obtain the observed distance distributions. These additional λ are direct elasticities in a Box-Tukey transformation of the variables (See also Table 2)

Table 2 Simultaneous destination and mode choice model by activity purpose pairs

	Model parameters (β)									
Variable	HW	WH	HE	EH	HB	BH	HS	SW	WL	LW
Constant car	*0.46*	*0.46*	*-0.82*	*0.82*	*3.37*	*3.37*	*1.60*	*1.60*	*1.64*	*1.64*
Travel time car	*-2.92*	*-2.92*	*-2.92*	*-2.92*	*-1.86*	*-1.86*	*-3.19*	*-3.19*	*-1.24*	*-1.24*
Car availability	*1.12*	*1.12*	*1.12*	*1.12*	*1.15*	*1.15*	*1.26*	*1.26*	*0.72*	*0.72*
Costs	*-0.19*	*-0.19*	*-0.19*	*-0.19*	*-0.03*	*-0.03*	*-0.13*	*-0.13*	*-0.05*	*-0.05*
Travel time PuT	*-1.66*	*-1.66*	*-1.66*	*-1.66*	*-1.39*	*-1.39*	*-2.01*	*-2.01*	*-0.82*	*-0.82*
Access time	*-3.35*	*-3.35*	*-3.35*	*-3.35*	*-2.02*	*-2.02*	*-4.49*	*-4.49*	*-1.95*	*-1.95*
Interval	*-0.87*	*-0.87*	*-0.87*	*-0.87*	*-0.59*	*-0.59*	*-0.39*	*-0.39*	*-0.32*	*-0.32*
No of changes	*-0.50*	*-0.50*	*-0.50*	*-0.50*	*-0.52*	*-0.52*	*-0.49*	*-0.49*	*-0.35*	*-0.35*
GA possession	*0.80*	*0.80*	*0.80*	*0.80*	*1.75*	*1.75*	*1.19*	*1.19*	*1.79*	*1.79*
HT possession	*0.89*	*0.89*	*0.89*	*0.89*	*0.87*	*0.87*	*1.04*	*1.04*	*1.03*	*1.03*
Age	*0.00*	*0.00*	*0.00*	*0.00*	*0.04*	*0.04*	*0.01*	*0.01*	*0.01*	*0.01*
Travel time CW[1]	-0.94	-0.94	-0.55	-0.51	-1.62	-1.62	-0.89	-0.91	-0.81	-0.84
Constant CW[1]	0.51	0.51	0.69	0.65	3.50	3.50	2.40	2.39	2.36	2.39
Jobs[2]	0.266				0.339					
Wage earners[2]		0.322				0.413				
Education facilities[2]			0.094							
Residents[2]				0.296				0.384		0.156
Sales area[2]							0.175			
Shopping centre[3]							0.023			
Leisure facilities[2]									0.166	
N-observations	23043	23043	7717	7717	6879	6879	19782	19782	42764	42764
ρ^2	0.03	0.03	0.34	0.34	0.14	0.14	0.22	0.22	0.19	0.17

(1) CW = Cycling and walking; (2) attraction variable = ln (value of attraction variable/1000)
(3) shopping centre: sales area / 10^6

λ-Travel time car[4]	0.97	0.97	0.70	0.70	0.05	0.05	0.72	0.72	0.01	0.01
λ-Costs car	0.97	0.97	0.60	0.60	0.01	0.01	0.72	0.72	0.01	0.01
λ-Travel time PT	0.95	0.95	0.70	0.70	0.05	0.05	0.65	0.65	0.01	0.01
λ-Costs PT	0.95	0.95	0.70	0.70	0.01	0.01	0.65	0.65	0.01	0.01

(4) λ for Box-Tukey transformation were adjusted by hand and not estimated jointly with the other parameters

6 Calculation of the origin-destination matrices

Based on the Swiss national travel surveys weekday generation rates for each of the seventeen activity purpose pairs were calculated and associated with a set of zonal attributes, as appropriate: residents per age group, wage earners, jobs, education facilities, cultural facilities, recreation facilities, amusement parks, leisure centres, sales area and shopping centres.

The model estimates for Switzerland 28.39 M. trips on the average weekday (3.86 trips per person and weekday). In general the marginal sums were treated as hard constraints. The exception were all pairs, which included at least once shopping or leisure/other as a purpose.

As mentioned above three sub-models were developed due to the different level of data available:

- Swiss internal traffic
- Traffic to and from abroad
- Traffic passing through or by-passing the country.

The non-internal flows are not estimated individually, but incorporated from the detailed census of alpine- and border-crossing traffic (ARE, 2003). The by-pass flows are estimated with a separate model and calibrated to traffic counts on alpine passes and tunnels.

The validation and calibration of the model is only carried out for the motorised private and the public transport. A calibration of the slow private transport flows was not intended and would have required a vastly more detailed road network.

7 Validation of the internal matrices

The resulting matrices can be compared and assessed against a number of independent data sets:

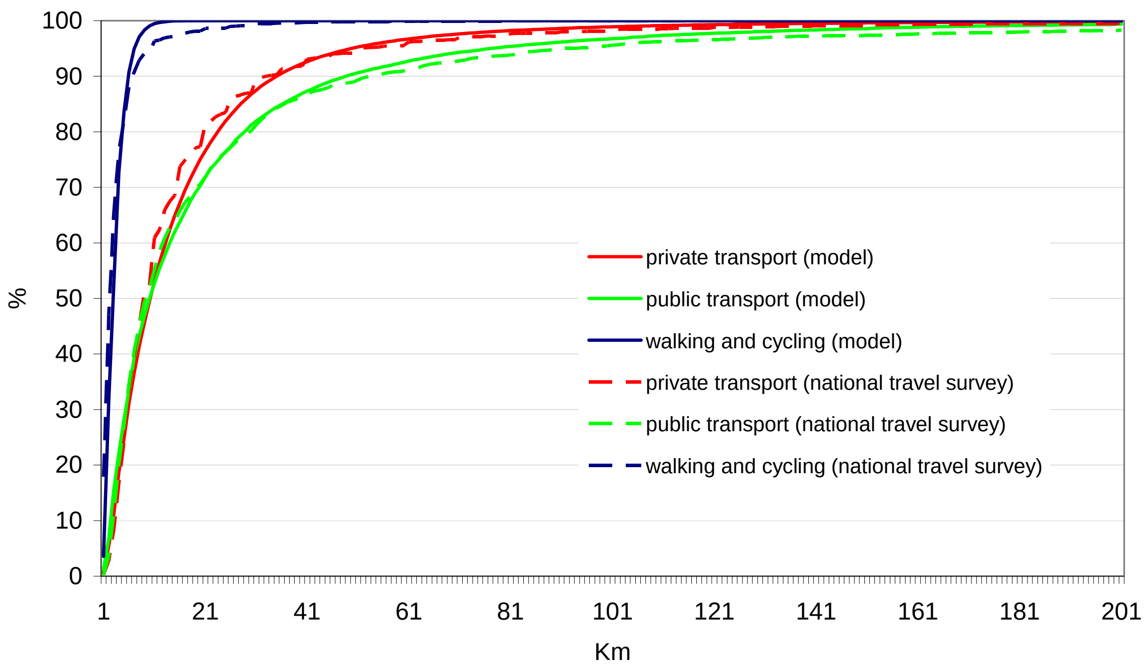
- Trip length distributions from the Population census 2000 for work and education and from the national travel survey for all modes
- Modal shares again from both sources
- Cross-sectional volumes are available for both the railways from an earlier study (Vrtic *et al.*, 2003) as well as for the road network from both federal and cantonal counting stations (ASTRA and Sigmaplan, 2001).

7.1 Trip length distributions

Figure 2 shows the modelled trip length distributions in comparison with the national travel survey (MZ 2000) after an iterative adjustment using the Box-Tukey transformation mentioned above (See Table 2). The need for this adjustment arises from the constraints imposed by the zonal marginal totals, which restrain the unbound choice implied in the MNL.

In total, 13.8 million interzonal trips with private and public transport are calculated. This is equivalent to 48% of all weekday trips.

Figure 2 Trip length distribution: Model and national travel survey (all trip purposes)



7.2 Mode choice

The modal shares are generally reproduced within a 10% error band (See Table 3), which is very satisfactory given the relative coarseness of the network model and the transfer of the model parameters from a different study. Larger deviations can be observed in the case of work and education for the national travel survey (MZ 2000), but the numbers from the population census 2000 are again matched well. Some of the reported differences are due to differences in the zonal systems, which could not be reconciled. In the national travel survey the large cities are coded as one zone, while they were subdivided for the national model. Therefore a larger share of public transport and walking and cycling trips will be categorised as intrazonal for this source, which explains some of the differences.

Note, that little effort was spent on the modelling of walking and cycling. Again, the numbers obtained from the population census were used for working and education, resulting in substantial differences.

Table 3 Modal shares compared (interzonal trips)

Mode and data set	Work	Education	Business	Shop	Leisure	Sum
Private motorised transport						
Model	3.776	0.095	0.949	1.677	4.142	10.633
National travel survey 2000	3.851	0.253	0.911	1.622	3.885	10.522
Population census 2000	3.334	0.082	--	--	--	--
Public transport						
Model	1.367	0.562	0.086	0.346	0.853	3.214
National travel survey 2000	1.031	0.538	0.096	0.409	0.891	2.965
Population census 2000	1.213	0.504	--	--	--	--
Walking and cycling						
Model	0.190	0.144	0.056	0.371	1.046	1.808
National travel survey 2000	0.472	0.383	0.060	0.408	1.203	2.528
Population census 2000	0.186	0.157	--	--	--	--
Sum						
Model	5.327	0.800	1.092	2.395	6.042	15.656
National travel survey 2000	5.379	1.218	1.063	2.402	5.821	15.885
Population census 2000	4.733	0.744	--	--	--	--

7.3 Comparison with traffic counts and cross-sectional surveys

The initial matrices were assigned to their respective networks. The person trips of the matrices were converted into vehicle trips using the observed car occupancy rates in the national travel survey 2000. The fit was surprisingly good given that no calibration on the counts had been performed (See Figure 3). The differences for the most heavily used roads, i.e. those with volumes over 10’000 vehicles per day, are below 20%. Larger differences are observed on less important roads, which generally carry higher shares of non-modelled intrazonal traffic. Heavy goods traffic assigned in advance and considered as a prior load for the purposes of speed calculations. The heavy goods matrix of Francini, 2002 had been updated for this purpose.

The exact appraisal of the public transport results is complicated by the uncertain quality of the cross-sectional counts, especially in agglomerations, due to missing counts from regional trains and due to the less detailed representation of local public transport service in agglomerations, which also carries interzonal traffic. Still, the quality of the initial public transport matrix is nearly as good as the one of the private transport matrix (maximum error of 40 % on links with more than 10’000 trips per day) (See Figure 3).

Another convenient method to appraise the structure of traffic flow matrices is the examination of the origins and destinations of flows passing a particular cross-section. The 2000 Census of Alpine- and Border-Crossing Traffic (ARE, 2003) provides this information for example for the traffic passing through the Gotthard tunnel.

Figure 4 depicts the private transport flows over the Gotthard in the model and in the Census of Alpine- and Border-Crossing Traffic. It can be seen that the distribution of the traffic flows is very similar, but that the model distributes the traffic systematically across locations, while the sample taken for the census does not cover all points.

7.4 Comparison with the commuter matrices of the population census 2000

The commuter matrix of the population census allows a direct comparison at the level of the origin-destination flow. The mean and median differences were 6.02 and 1.13 person trips per day for the 280822 none-zero origin-destination flows in the car – matrix. These numbers are dominated by the large number of small flows in the spatially very disaggregated matrix developed here.

Figure 5 shows the comparison of the assignment results and spatial distribution of the substantial differences between model and population census. The assignment results show the good congruence between modelled and surveyed link volumes. For the spatial distribution of differences, the zones were aggregated into their administrative Bezirke for clarity. While the assigned volumes are little different, there are substantial differences in flows, which balance overall. It is clear, that the model is unable to capture history, such as firms, which have moved over time, or the commuting preferences among certain group or for certain industries. In addition, it should be noted, that the population census is not error free, in particular it included persons which commute biweekly in its counts.

8 Final corrections

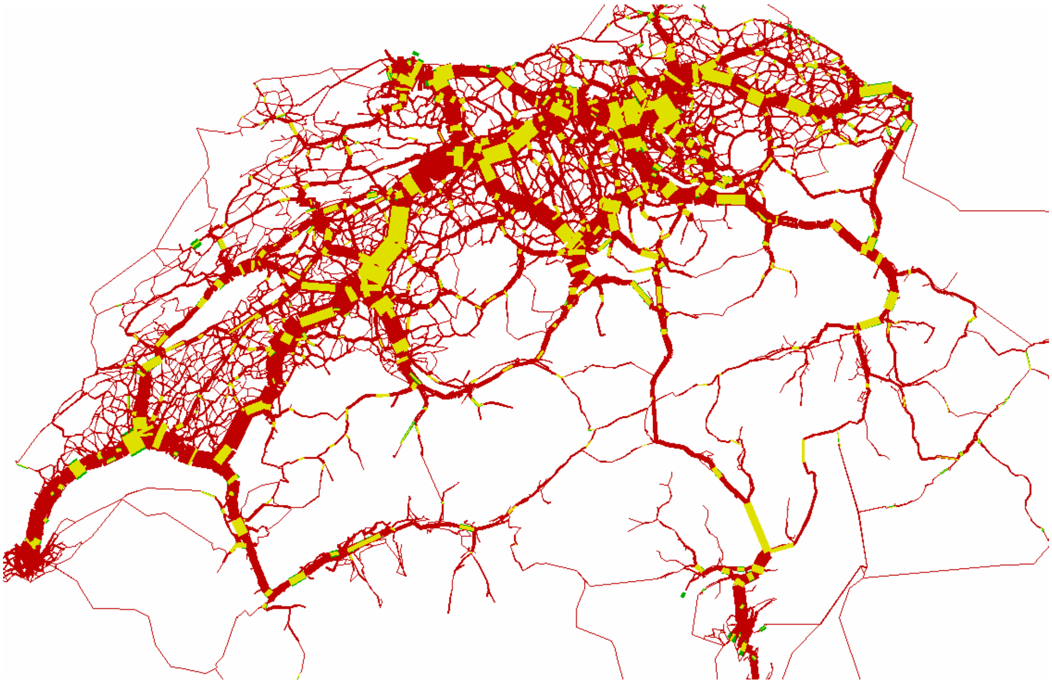
The validation identified a series of errors in the network representation. The most frequent errors in the private transport network are wrong free-flow speeds and incorrect capacity estimates for specific links. These mistakes were mainly found in agglomerations and within built-up areas. Whereas the typical errors in the public transport model are erroneous running and dwelling times, wrong departure times, mistaken number of changes and erroneous routings of lines in the network. The errors lead to asymmetric route choice behaviour and asymmetric network loads.

After the correction of these errors it was felt that there was no need for an automatic calibration of the matrices to counts, especially as these methods tend to damage the systematic structure of the matrices in favour a specific count or set of counts, which in itself might be modelling. At a small number of cross-sections the flows passing through these were adjusted with uniform factors by hand. In exceptional cases the flows had to be adjusted differently. The absolute difference matrix between the modelled and adjusted values was retained for forecasting.

The overall change caused by the adjustments for both models is relatively small with a reduction in trip numbers by 3.7%, but the calibrated private transport matrix contains 1.2% fewer trips, whereas the difference between the public transport matrices is around 15.7%. This is equivalent to the observed differences between the non-calibrated matrices and the traffic counts. The trip length distribution improved, while the structure of the matrices was maintained. See Table 4 and Figure 6 for an overview of the remaining differences.

Figure 3 Comparison of the assigned volumes to counts (initial weekday matrices)

Motorised private transport: Model – Count (red = positive; green = negative difference)



Public transport: Model – Count (red = positive; green = negative difference)

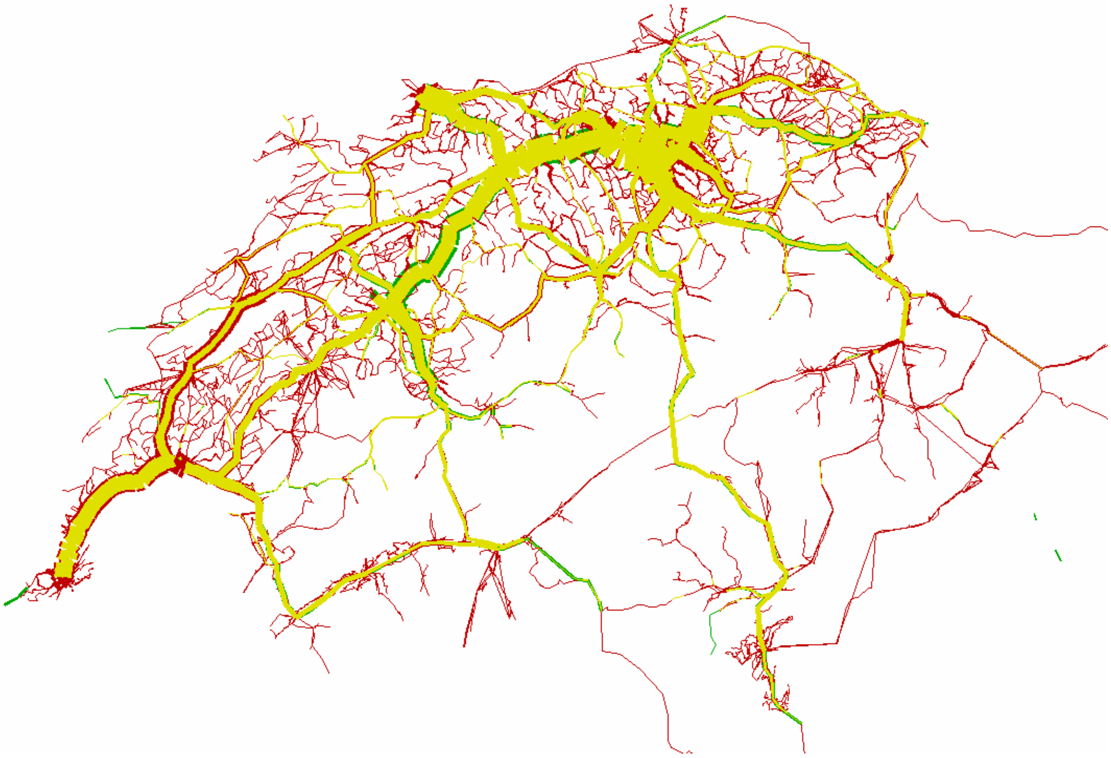
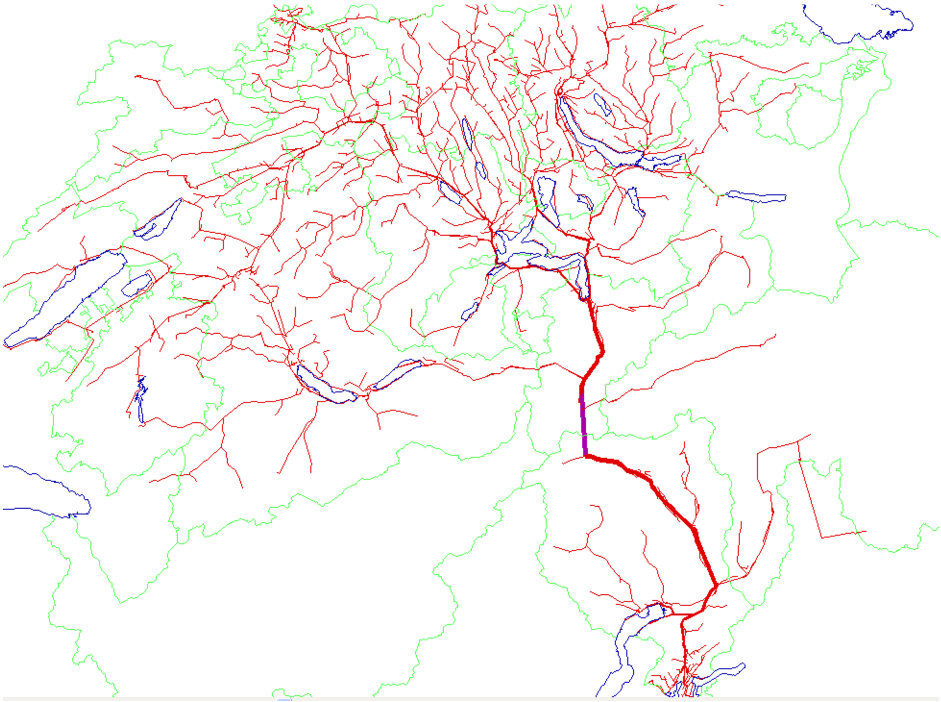


Figure 4 Comparison of origins and destinations of the flow through the Gotthard tunnel

Model



2000 Census of Alpine- and Border-Crossing Traffic

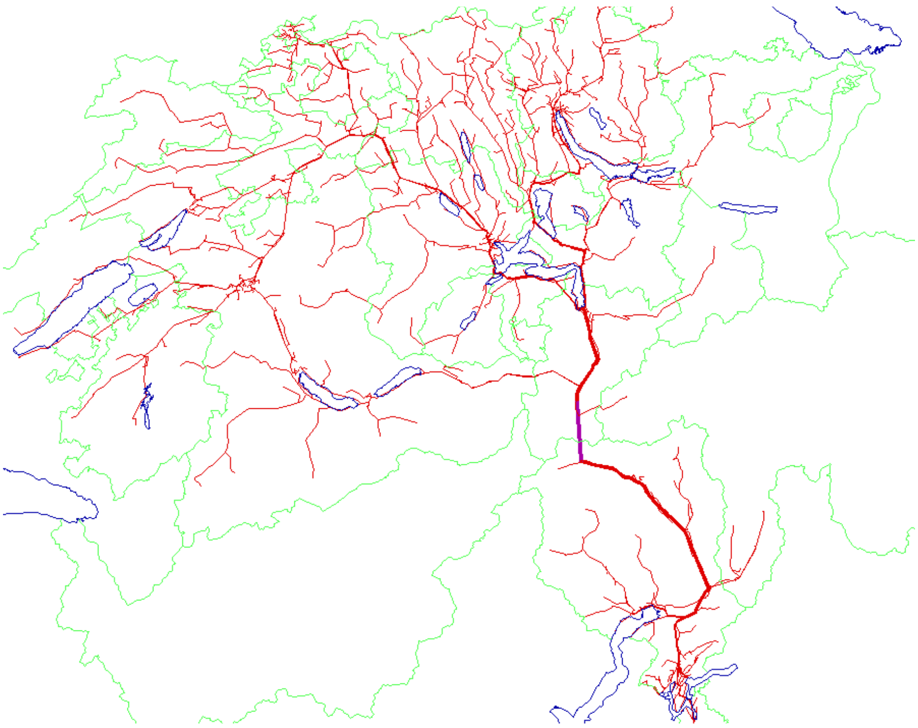
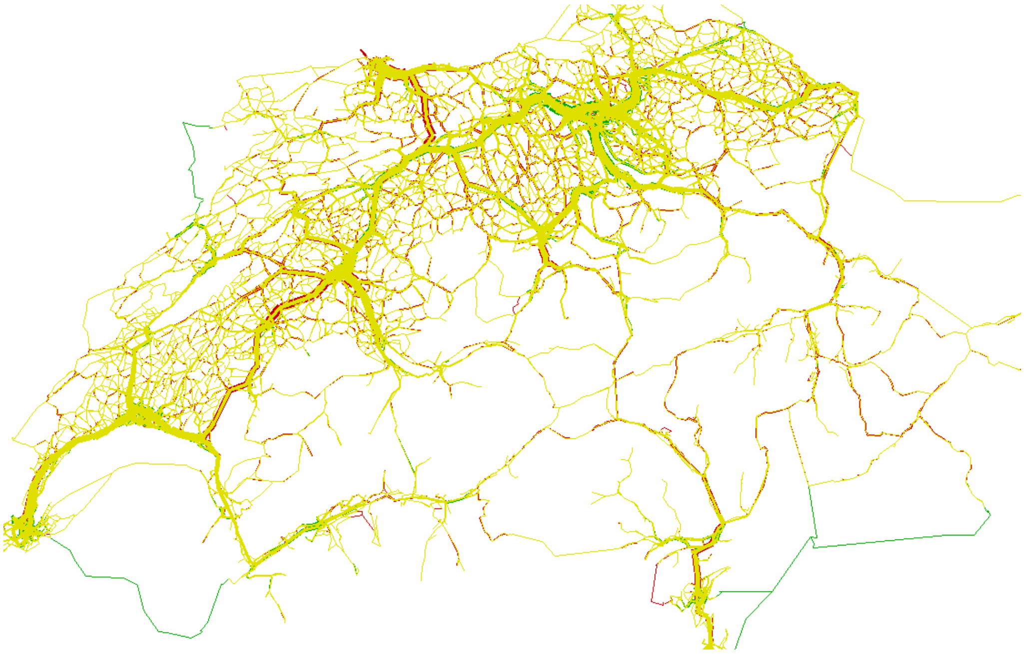


Figure 5 Comparison of origins and destinations commuter flows (private transport)

Comparison of the assigned volumes of the model and population census commuter matrices

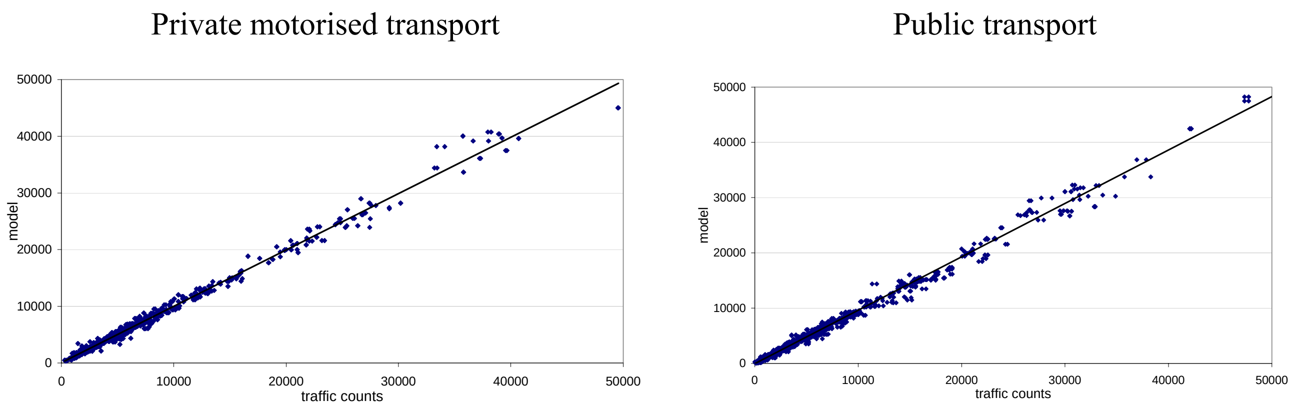


Origin-destinations flows over 100 trips/day and differences over 50%

Table 4 Comparison of traffic counts and the final adjusted matrices: Summary statistics

	Motorised private transport	Public transport
Number of cross-section counts	602	1210
Mean weigthed deviation of absolute values in %	5.97	7.68
Coefficient of correlation	0.9938	0.9968
Root of mean square error	841.98	683.53

Figure 6 Comparison of traffic counts and final adjusted matrices



9 Conclusions

The paper has introduced an approach, which allows to model travel demand and its distribution consistent with the natural volume constraints at the zonal level, which are as binding as the common link capacity constraints. Building on a simultaneous nested logit model of destination and model choice the EVA approach reproduced the observed behaviour well, as tested against a range of independent data sources. The initial inconsistencies due to the logit model were corrected by transforming the cost and time parameters non-linearly.

The EVA approach is flexible enough to accommodate any problem, which can be formulated in its terms. It has successfully been applied, for example, to freight demand forecasting. It is fast enough to accommodate large matrices, such as the one developed here, because it is based on an algorithm, which is proven to converge. Other recent examples are the German National Model, which had about twice the number of zones employed here.

The National Model is a big step forward for transport planning in Switzerland. It will provide a coherent framework for both national and regional, cantonal applications. The very detailed set of 51 matrices will allow matching analyses. It is clear, that the model is not perfect, when broken down to individual flows, as could be seen in the case of the commuter matrices. Further work is needed at this point, especially for local and regional applications.

The first big challenge for the National Model are the discussions about a possible mobility pricing scheme for Switzerland, primarily based on pricing the use of motorways. It will be required to convert the average weekday matrices into hourly matrices to allow the necessary dynamic modelling of the demand.

10 Acknowledgements

The national model was developed for the Swiss Bundesamt für Raumentwicklung, the Swiss Bundesamt für Strassen and the Swiss Bundesamt für Verkehr. The support of the colleagues there, in particular of Micheal Arendt is gratefully acknowledged. The work was undertaken jointly with the Emch+Berger AG, Zürich, especially Stefan Dasen and Stephan Erne.

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