A SIMULTANEOUS DISAGGREGATE DISTRIBUTION AND MODE CHOICE MODEL: THEORY AND APPLICATION FOR A REGIONAL PUBLIC TRANSPORT MODEL

Milenko Vrtic
Institute for Transport Planning and Systems (IVT)
Swiss Federal Institute of Technology, Zurich
Wolfgang Pauli Strasse 15, 8093 Zürich, Switzerland
Phone: 0041-1-633 31 07; Fax: 0041-1-633 10 57
vrtic@ivt.baug.ethz.ch

Philipp Fröhlich (corresponding author)
Verkehrconsulting Fröhlich
c/o Institute for Transport Planning and Systems (IVT)
Wolfgang Pauli Strasse 15, 8093 Zürich, Switzerland
Phone: 0041-1-633 31 96; Fax: 0041-1-633 10 57
office@vcfroehlich.ch

ABSTRACT

The paper describes the EVA model, an approach for unifying the trip generation, trip distribution and mode choice steps of the traditional four-step transport demand model. Transport demand models must meet three constraints: the assumed and modelled generalised travel costs must be consistent; the model must accurately reproduce marginal (zonal) trip distribution and attraction totals; and it cannot violate network element capacity constraints. The EVA model is designed to ensure that zonal trip distribution/attraction totals are met while employing a sound behavioural model. It is formulated apply a Bayesian approach, and uses information gain criterion and general solution algorithms for n-linear equations systems to calculate an optimal solution.

This paper will briefly describe the theory behind the EVA model including the formulation and results for a simultaneous nested logit model of destination and mode choice. It describes the model in the context of developing a public transport model for the canton of Zurich (Switzerland). The resulting model was compared to several independent sources of actual data and found to very accurately reflect real conditions. Finally the paper presents conclusions and recommendations for additional research.

KEYWORDS: EVA, VISEVA, choice model, trip generation, trip distribution, mode choice, activity-purpose pair, regional model, simultaneous solution, O-D matrix, Switzerland, Zurich, public transport.
1. INTRODUCTION

In 2004 the canton of Zurich began developing a multimodal transportation plan. The canton’s existing transport model only included the roadway network, so developing a public transport model was needed for use in developing the plan. Therefore the canton hired the Institute for Transport Planning and Systems (IVT) of ETH Zurich, Ernst Basler & Partner AG, Zurich, and PTV AG, Karlsruhe, to develop a suitable public transport (PuT) model. The project consisted of developing a new public transport network, completing a stated preference (SP) survey for mode and PuT route choice, creating a public transport OD matrix and.

In order to practically apply travel demand models, three constraints must be met: the assumed and modelled generalised travel costs must be consistent; the model must reproduce the marginal (i.e. by zone) totals in the trip distribution and attraction matrices; and it must not violate the capacity constraints of any network element. Ideally, the model will reach equilibrium with an internally consistent and theoretically sound estimate of individual travel behaviour at all levels considered. Traditional travel demand models consist of four partial models (steps): production/attraction, distribution, mode choice, and assignment. Of these, the equilibrium formulations for the assignment model have been well established for some time.

This paper presents an approach for unifying the other three partial models into a coherent whole. It is designed to ensure that the second constraint mentioned above is met while employing a sound behavioural model. The model, called EVA – (from the German terms for production (Erzeugung), distribution (Verteilung) and mode choice (Aufteilung)), was developed by Lohse and his collaborators at TU Dresden (Lohse, Teichert, Dugge and Bachner, 1997 or Schnabel and Lohse, 1997) and is distributed by PTV AG. The EVA model is formulated using a Bayesian approach. It uses the information gain criterion and general solution algorithms for n-linear equations systems to calculate the optimum solution.

The Zurich PuT model consists of 878 internal zones and 26 external zones. It distinguishes seventeen combinations of five trip purposes for three modes (motorised private travel, public transport and the combined walking and cycling modes). In total 51 matrices of 878 * 878 zones needed to be generated. The traffic flow leaving, entering and passing through the model area was generated from the Swiss national transport model (Vrtic, Lohse, Fröhlich, Schiller, Schüssler, Teichert and Axhausen, 2005). This paper focuses on the internal traffic and its modelling.

The paper is divided into two main parts. The first part describes theory behind the EVA model with sections describing how EVA models trip generation, and how it simultaneously models destination and mode choice. The second part describes application of the EVA model in Zurich. It focuses on estimation of the simultaneous destination/mode choice model and the quality of the matrices obtained. The paper ends with conclusions and recommendations for both the approach and its application in Zurich.
2. MODELLING TRIP GENERATION WITH EVA

In the trip generation process a model must calculate both trip productions from and trip attractions to all zones. EVA calculates trip productions using deterministic, but finely detailed, trip rates. EVA calculates trip attractions proportional to the volume of activity opportunities in the destination zone. EVA allows the use of hard and soft constraints in the estimation of both productions and attractions.

Once the productions and attractions have been estimated, EVA disaggregates the total trip generation into activity-purpose pairs for origin and destination zones. An activity-purpose pair describes trips made for a particular purpose, for example home-based work trips. Table 1 presents the seventeen activity-purpose pairs that were used in the Zurich model. In order to determine the priority for trip generation, the activity-purpose pairs were grouped into types based on their involvement of the home, as either at origin or at destination. The following types were distinguished:

Type 1: origin at home, 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

Next, the pairs were assigned one of the following five general trip purposes:

Work: HW, WH, WO, OW
Education: HE, EH, (EO, OE)
Business: HB, BH, BO, OB
Shopping: HS, SH, SO, OS
Leisure/Other: HO, OH, OO

Each of the activity-purpose pairs was associated with all travellers or subsets of travellers. For example the shopping trips (HS, SH) rates were used with all travellers, while the work trips (HW, WH) rates were used for employed persons only. A zone’s trip production is calculated by multiplying the rate by the number of persons in the subset of travellers in that zone. The rates summed across trip purposes used in the model are shown in Table 1.

The trip production for each activity-purpose pair in each zone \( e \) is calculated as:

\[
H_e = \sum_p SV_p \cdot BP_{ep} \cdot u_p \cdot V = \sum_e H_e
\]

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 \( e \)
\( H_e \) … Home-based trip generation of zone \( e \)

A similar process was used to estimate the attractions per zone. Table 1 presents the relevant attractors and attraction rates for each pair used in the Zurich model. In this case, the quantities (for example number of work places or shopping floor area) were collated for each of the zones. The attraction rates were then calculated as the ratio of the produced trips to the total number of attractors.
For some trip purposes or activity-purpose pairs it was possible to impose a hard equality constraint between trip productions and attractions (for example work and school trips, since it is expected that workers/students will arrive at their workplaces/schools). 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 between zones. Shopping is a good example of an activity that uses such soft constraints.

For activity-purpose pairs that have hard constraints, the trip attractions for each activity-purpose pair are:

\[ Z_j = \sum_r \sum_{j'} \text{ER}_r \cdot \text{SZ}_{rj'} \cdot V \]  

(2)

For activity-purpose pairs with soft constraints, the maximum trip attractions are:

\[ Z_{\text{max}j} = \sum_r \sum_{j'} \text{Ü}_{rj} \cdot \text{ER}_r \cdot \text{SZ}_{rj'} \cdot V \]  

(3)

with:
- \( \text{ER}_r \) ... Attraction rate of attractor \( r \)
- \( \text{SZ}_{rj} \) ... Quantity of attractor \( r \) in zone \( j \)
- \( \text{Ü}_{rj} \) ... Load factor of zone \( j \) with respect to attractor \( r \)
- \( Z_j \) ... Attracted traffic to zone \( j \)
- \( Z_{\text{max}j} \) ... Maximum attracted traffic volume to zone \( j \)
- \( V \) ... Total traffic volume

The ability to distinguish between hard and soft constraints is a major advantage of the EVA approach. Distinguishing between constraints avoids the well-known pitfalls of unconstrained models, such as simple destination choice models, which only enforce constraints at the origin zones. On the other hand, this double constraint formulation has the disadvantage that any choice model estimated from observed behaviour must be adjusted by hand to match the observed trip length distribution under the imposition of the constraints.

3. JOINT DESTINATION AND MODE CHOICE IN EVA

This section outlines how the EVA model extends its activity-purpose pair approach to the simultaneous modelling of destination and mode choice.

EVA assumes that the number of trips generated in zone \( i \) for each activity-purpose pair \( (Q_i) \) is known. It also assumes that the number (for trip purposes with hard constraints) or the maximum number (for trip purposes with soft constraints) of trips for each activity-purpose pair to zone \( j \) \( (Z_j) \) is known. EVA then calculates the share of trips using mode \( k \) to travel between zones \( i \) and \( j \) based on the mode-specific generalised cost of travel as a conditional probability.
This conditional probability $BW_{ijk}$ is:

$$ BW_{ijk} = P\left( W\left( (A_i \cap E_j \cap M_k) \right) \right) \quad (4) $$

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 mode-specific generalised cost function depends on 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 ($w$), which required three additional parameters $E$, $F$, and $G$ to obtain a very flexible shape of the elasticity $\varepsilon$ over the range of the generalised costs:

$$ BW = f(w) = \left[ 1 + \left( \frac{w^G}{F} \right) \right] \varepsilon(w) = -E \cdot \frac{w^G}{F^G + w^G} \quad (5) $$

The logit – conform exponential function can be expanded with two additional parameters ($\lambda$ and $\mu$), leading to a Box-Tukey-transformed formulation, to get a non-linear elasticity function:

$$ \begin{align*}
  \varepsilon(w) &= -\beta \cdot w + \frac{\lambda}{w+1} \quad \text{for } \lambda = 0 \\
  \varepsilon(w) &= -\beta \cdot w \quad \text{for } \lambda = 1 \quad \text{with } w^{(\lambda,\mu)} = \begin{cases} 
    \ln(w + \mu) & \text{for } \lambda = 0 \\
    w & \text{for } \lambda = 1 
  \end{cases} \\
  \varepsilon(w) &= -\beta \cdot w \cdot (w + 1)^{\lambda - 1} \quad \text{for } \lambda > 0 \quad \text{with } w^{(\lambda,\mu)} = \frac{(w + \mu)^{\lambda} - 1}{\lambda} \quad \text{for } \lambda > 0
\end{align*} \quad (6) $$

The model then allocates a share of total trips ($V$) to a particular relation $v_{ijk}$. The formulation is structurally a Bayesian model in which one can choose any functional form for the calculation of the probability, for example the universal logit model (Ortuzar and Willumsen, 2001):

$$ v_{ijk} = \frac{P\left( (A_i \cap E_j \cap M_k) | W \right) \cdot V}{\sum_i \sum_j \sum_k P\left( (A_i \cap E_j \cap M_k) | W \right) \cdot V} = \frac{P(A_i) \cdot P(E_j) \cdot P(M_k) \cdot P(W | (A_i \cap E_j \cap M_k))}{\sum_i \sum_j \sum_k P(A_i) \cdot P(E_j) \cdot P(M_k) \cdot P(W | (A_i \cap E_j \cap M_k))} \cdot V \quad (7) $$

In the case of activity-purpose pairs with hard constraints the conditional probabilities are known:

$$ P(A_i | W) = \frac{Q_i}{V} \quad \text{and} \quad P(E_j | W) = \frac{Z_j}{V} \quad \text{and} \quad P(M_k | W) = \frac{M_k}{V} \quad (8) $$
The ratios of the conditional and unconditional probabilities define the initially unknown balancing factors:

\[
q_i = \frac{P(A_i)}{P(A_i \mid W)} \quad z_j = \frac{P(E_j)}{P(E_j \mid W)} \quad a_k = \frac{P(M_k)}{P(M_k \mid W)}. \tag{9}
\]

With \( P(A_i) = P(A_i \mid W) \cdot q_i \); \( P(E_j) = P(E_j \mid W) \cdot z_j \) and \( P(M_k) = P(M_k \mid W) \cdot a_k \) one obtains:

\[
v_{ijk} = \frac{P(A_i \mid W) \cdot q_i \cdot P(E_j \mid W) \cdot z_j \cdot P(M_k \mid W) \cdot a_k \cdot P(W \mid (A_i \cap E_j \cap M_k))}{\sum_i \sum_j \sum_k P(A_i \mid W) \cdot q_i \cdot P(E_j \mid W) \cdot z_j \cdot P(M_k \mid W) \cdot a_k \cdot P(W \mid (A_i \cap E_j \cap M_k))} \cdot V. \tag{10}
\]

With the given probabilities \( BW_{ijk} = P(W \mid (A_i \cap E_j \cap M_k)) \) and the given conditional probabilities \( P(A_i \mid W) = Q_i / V \); \( P(E_j \mid W) = Z_j / V \) and \( P(M_k \mid W) = M_k / V \) 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 and with \( f \) as a correction factor to reach the total traffic volume, we obtain the tri-linear system of equations for activity-purpose pairs with hard constraints:

\[
\begin{align*}
Q_i &= \sum_j \sum_k v_{ijk} \\
Z_j &= \sum_i \sum_k v_{ijk} \quad \text{Constraints} \\
M_k &= \sum_i \sum_j v_{ijk}
\end{align*}
\]

For activity-purpose pairs with soft constraints the second set of constraints is changed to inequalities:

\[
\begin{align*}
v_{ijk} &= BW_{ijk} \cdot \frac{Q_i}{V} \cdot q_i \cdot \frac{Z_j}{V} \cdot z_j \cdot \frac{M_k}{V} \cdot a_k \cdot f
\end{align*}
\]

\[
\begin{align*}
Q_i &= \sum_j \sum_k v_{ijk} \\
Z_j &\geq Z_j = \sum_i \sum_k v_{ijk} \quad \text{Constraints} \\
M_k &= \sum_i \sum_j v_{ijk}
\end{align*}
\]

In the forecasting process, it is assumed that the balancing factor for mode \( k \) (\( a_k \)) remain constant which makes the problem two-dimensional, and therefore it can be solved using the same method.
The EV A solution algorithm is based on the idea of maximizing the information gain (Lohse, Teichert, Dugge und Bachner, 1997) (for more details of this process see Vrtic et al., 2005).

4. ESTIMATION OF THE SIMULTANEOUS DESTINATION AND MODAL CHOICE MODEL

This section describes how the parameters for destination and mode choice were simultaneously estimated, which were used afterward in EVA. The model uses a nested logit model with modes as the upper level and the destinations as the lower level (this form was chosen based on experience with several other model applications).

In the estimation step, a random set of eleven destinations was selected for each mode. In the case of the chosen mode alternative, only ten destinations were added. The sampling was stratified: the origin zone, three zones within 70% of the observed distance, a further three within 70% and 130%, and the final three beyond 130% of the observed distance. The stratified sampling approach was chosen to get a sample with a systematic variation of possible destination. The estimated parameters were robust, and should not suffer from bias as shown by McFadden (Ben-Akiva and Lermann, 1985). The model was estimated separately for ten of the seventeen activity-purpose pairs using Biogeme 1.2 (Bierlaire, 2005) and data from the 2000 Swiss travel survey Mikrozensus Verkehr (ARE and BFS, 2001). There was insufficient survey data to estimate the other seven pairs separately.

The revealed preference data set showed the usual strong correlations between travel cost, distance and travel time. This made estimation of the mode choice parameters for private motorised and public transport impossible. Therefore, these parameters were taken from the stated preference survey completed as part of this project, together with the parameters for the socio-demographic variables. The variables describing the destination match the relevant trip purpose.

Table 2 shows that in general the activity-purpose pair specific models have reasonable goodness-of-fits, and that all newly estimated parameters are significant at the 95% level, have the correct sign, and are of credible magnitudes. The model’s low explanatory power for work trips is caused by both a large share of intrazonal destinations, and the lack of differentiation between types of work.

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 $\lambda$ are direct elasticities in a Box-Tukey transformation of the variables (see Table 2).
5. **CALCULATION OF THE ORIGIN-DESTINATION MATRICES**

Once the models had been developed, weekday generation rates for each of the seventeen activity-purpose pairs were calculated based on the Swiss national travel surveys. These rates were then associated with the appropriate zonal attributes (e.g. residents per age group, wage earners, jobs, education facilities, cultural facilities, recreation facilities, amusement parks, leisure centres, sales area and shopping centres) to estimate productions and attractions by zone for the Zurich model’s 878 internal zones. The variables of impedance for the different modes were calculated using the daily average value. The variables change their value over day (much longer travel time in PrT at peak hour), but the client didn’t request a such detailed approach. Furthermore, the main goal of the project was to build a PuT model and the impedance in PuT doesn’t depend on transport volume.

The model generally treated marginal sums as hard constraints except for activity-purpose pairs that included shopping or leisure/other as a purpose at least once (these were treated as soft constraints). In total, the model estimates 8.89 million trips for the Zurich area on the average weekday (3.93 trips per person per weekday).

The resulting model was validated for all modes as described in the following section. The model was also calibrated for public transport (described in Section 7) but not for the motorized private transport or bike/walk modes (calibration of these modes was not part of the project and for the bike/walk mode would have required a vastly more detailed network).

6. **VALIDATION OF THE INTERNAL MATRICES**

In order to validate the model results, the origin-destination matrices developed using the Zurich model were compared and assessed against the following independent data sets:

- Trip length distributions from the Swiss population census 2000 (for work and education trips) and from the national travel survey (for all types of trips and modes);
- Modal shares from the same two sources;
- Cross-sectional volumes for public transport lines (from the Swiss Federal Railway and Zurich’s regional public transport authority) and the road network from Zurich’s existing PrT (private transport) model.

Each of these three validation processes is described below.

6.1 **Trip length distributions**

Figure 2 compares the modelled trip length distributions to trip length distributions from the national travel survey (MZ 2000). Note that the modelled trip length distributions were adjusted using the Box-Tukey transformation mentioned above and presented in Table 2. This adjustment was necessary due to the constraints imposed by the zonal marginal totals, which restrain the unbound choice implied in the MNL.
6.2 Mode choice

Table 3 compares mode choice as estimated by the model to surveyed mode choice and shows that the model generally reproduces modal shares within a 10% error band. 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 matched fairly well. Some of the reported differences are due to differences in the zone systems, which could not be reconciled. In the national travel survey, large cities are coded as a single zone, while they were subdivided in the Zurich model. Therefore a larger share of public transport and bike/walk trips were categorised as intrazonal in the national survey, which explains some of the differences.

6.3 Comparison with traffic counts and cross-sectional surveys

In order to compare model results with actual traffic counts, the model-generated PuT and PrT matrices were assigned to the networks and compared to actual count data. For the PrT model the deterministic user equilibrium was used in this comparison. The network and attributes were taken from the canton of Zurich’s existing road model. For the PuT model the time table based assignment (a branch and bound search algorithm) was used. The parameters for connection elements were taken from the SP survey conducted as part of the project. The assignment software used was VISUM 8.1 (PTV, 2002).

The assignment results and the actual link volumes show a very close correlation, especially considering that the matrices had not yet been calibrated. Figures 3 and 4 show that the modelled demand distribution of private motorized transport and public transport (respectively) is close to actual demand. The correlation coefficient is 0.92 for private transport, and 0.91 for public transport. The modelled network loading is very close to the traffic counts. This indicates that the model and the OD-matrices it generates have the same structure as the actual transport demand and that the model structure is fundamentally correct.

Finally, the model-generated matrix for work trips was compared to commuter trip data from the population census. This comparison also showed very close correspondence between modelled and actual data.

7. FINAL CORRECTIONS

The validation process identified a series of relatively common errors in the network representation including incorrect running and dwell times, non-valid connections, inconsistencies between zone size and network fineness, and incorrect line routings. These errors led to asymmetric route choice behaviour and asymmetric network loads.

After the network errors were corrected, the consultants and clients decided not to complete an automatic calibration of the matrices to counts, since this tends to damage the systematic structure of the matrices in favour a specific count or set of counts. However, at a small number of cross-sections the flows were adjusted by hand using uniform factors. In a very few cases the flows had to be adjusted differently. This kind of corrections has to be expected, because not all properties of travel behaviour can be considered.
The overall change caused by the adjustments to the public transport models was relatively small. There was a reduction in trips of 9.9% (since the private transport matrix was not calibrated as part of this project it is not known if the difference is due to intrazonal trips or destination and mode share displacement). The trip length distribution improved, and the structure of the matrices was maintained.

Figure 5 compares the final calibrated OD-matrix for public transport with the actual passenger counts. Figure 6 presents an illustration of the public transport model. Table 4 presents the model statistics based on the final calibrated OD-matrix for public transport and the passenger counts.

8. CONCLUSIONS

This paper describes the EVA model and how it has been applied in developing a public transport model for the canton of Zurich. The EVA model uses an approach that allows users to model travel demand and distribution consistent with trip volume constraints at the zonal level. These zone-based trip volume constraints can be treated as hard or soft. The approach builds upon a simultaneous solution of a nested logit model of destination and mode choice.

The EVA model developed for Zurich reproduced the observed behaviour well when tested against a range of independent data sources. Some 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 that can be formulated in its terms (for example, it has been successfully applied to freight demand forecasting). It is fast enough to accommodate large matrices because it is based on an algorithm that is proven to converge. For example, the algorithm was used for the German National Model, which had about six times the number of zones employed in the Zurich model.

One area for further research is in developing automated processes for iterating between the travel demand estimates and the assignments 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)) but to date these applications have not been automatically linked.

The Canton of Zurich’s Model is a major improvement for transport planning in Zurich. However, the model could be further improved by developing a new (more detailed) road network and calibrating the private motorized transport matrix. This will lead to improved forecasting results and provide the transport authorities with more confidence in their use of transport models.
Acknowledgements

The public transport model was developed for the cantonal transport agency of Zurich. The support of the colleagues there, in particular of Dr. Michael Redle is gratefully acknowledged. The project was undertaken jointly with the Ernst Basler + Partner AG and PTV AG.

References


#### Table 1  Definition of the activity-purpose pairs

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Home</th>
<th>Work</th>
<th>Education</th>
<th>Business</th>
<th>Shopping</th>
<th>Leisure/Other</th>
<th>Daily weekday trip rate by purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td></td>
<td>H</td>
<td>W</td>
<td>E</td>
<td>B</td>
<td>S</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>WH (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>WO (1)</td>
<td></td>
<td>1.94/worker</td>
</tr>
<tr>
<td>Education</td>
<td>EH (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.40/student</td>
</tr>
<tr>
<td>Business</td>
<td>BH (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.45/worker</td>
</tr>
<tr>
<td>Shopping</td>
<td>SH (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BO, SO, OB, OS, OO (3)</td>
<td></td>
<td>0.69/person</td>
</tr>
<tr>
<td>Leisure/Other</td>
<td>OH (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.48/person</td>
</tr>
</tbody>
</table>

(*) indicates the type of the pair; O = W,E,B,S,L
## Table 2 Simultaneous destination and mode choice model parameter by activity purpose pairs

<table>
<thead>
<tr>
<th>Variable</th>
<th>HW</th>
<th>WH</th>
<th>HE</th>
<th>EH</th>
<th>HB</th>
<th>BH</th>
<th>HS</th>
<th>SH</th>
<th>HO</th>
<th>OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant car</td>
<td>1.609</td>
<td>1.602</td>
<td></td>
<td>2.653</td>
<td>2.653</td>
<td>0.731</td>
<td>0.731</td>
<td>1.008</td>
<td>1.008</td>
<td></td>
</tr>
<tr>
<td>(20.9)</td>
<td>(20.6)</td>
<td></td>
<td></td>
<td>(13.8)</td>
<td>(13.8)</td>
<td>(6.6)</td>
<td>(6.6)</td>
<td>(15.5)</td>
<td>(15.5)</td>
<td></td>
</tr>
<tr>
<td>Travel time car (h)*</td>
<td>-1.654</td>
<td>-1.654</td>
<td>-1.654</td>
<td>-1.654</td>
<td>-1.937</td>
<td>-1.937</td>
<td>-2.496</td>
<td>-2.496</td>
<td>-0.984</td>
<td>-0.984</td>
</tr>
<tr>
<td>(-3.5)</td>
<td>(-3.5)</td>
<td>(-3.5)</td>
<td>(-3.5)</td>
<td>(-3.5)</td>
<td>(-3.6)</td>
<td>(-3.6)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(-7.9)</td>
<td>(-7.9)</td>
</tr>
<tr>
<td>Car availability*</td>
<td>0.637</td>
<td>0.637</td>
<td>0.637</td>
<td>0.637</td>
<td>0.805</td>
<td>0.805</td>
<td>2.752</td>
<td>2.752</td>
<td>1.043</td>
<td>1.043</td>
</tr>
<tr>
<td>(3.7)</td>
<td>(3.7)</td>
<td>(3.7)</td>
<td>(3.7)</td>
<td>(2.5)</td>
<td>(2.5)</td>
<td>(9.1)</td>
<td>(9.1)</td>
<td>(9.2)</td>
<td>(9.2)</td>
<td></td>
</tr>
<tr>
<td>Costs (CHF)*</td>
<td>-0.205</td>
<td>-0.205</td>
<td>-0.205</td>
<td>-0.205</td>
<td>-0.03</td>
<td>-0.03</td>
<td>-0.223</td>
<td>-0.223</td>
<td>-0.067</td>
<td>-0.067</td>
</tr>
<tr>
<td>(-4.9)</td>
<td>(-4.9)</td>
<td>(-4.9)</td>
<td>(-4.9)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(-5.7)</td>
<td>(-5.7)</td>
</tr>
<tr>
<td>Ride Time PuT (h)*</td>
<td>-1.512</td>
<td>-1.512</td>
<td>-1.512</td>
<td>-1.512</td>
<td>-1.208</td>
<td>-1.208</td>
<td>-2.078</td>
<td>-2.078</td>
<td>-0.728</td>
<td>-0.728</td>
</tr>
<tr>
<td>(-3.2)</td>
<td>(-3.2)</td>
<td>(-3.2)</td>
<td>(-3.2)</td>
<td>(-3.2)</td>
<td>(-2.4)</td>
<td>(-2.4)</td>
<td>(-2.4)</td>
<td>(fix)</td>
<td>(-5.7)</td>
<td>(-5.7)</td>
</tr>
<tr>
<td>(-5.4)</td>
<td>(-5.4)</td>
<td>(-5.4)</td>
<td>(-5.4)</td>
<td>(-5.4)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(-2.8)</td>
<td>(-2.8)</td>
</tr>
<tr>
<td>Interval (h)*</td>
<td>-0.638</td>
<td>-0.638</td>
<td>-0.638</td>
<td>-0.638</td>
<td>-1.270</td>
<td>-1.270</td>
<td>-0.393</td>
<td>-0.393</td>
<td>-0.513</td>
<td>-0.513</td>
</tr>
<tr>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-1.9)</td>
<td>(-1.9)</td>
<td>(-1.9)</td>
<td>(fix)</td>
<td>(-3.3)</td>
<td>(-3.3)</td>
</tr>
<tr>
<td>No of transfers*</td>
<td>-0.451</td>
<td>-0.451</td>
<td>-0.451</td>
<td>-0.451</td>
<td>-0.322</td>
<td>-0.322</td>
<td>-0.302</td>
<td>-0.302</td>
<td>-0.340</td>
<td>-0.340</td>
</tr>
<tr>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(-0.2)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(-6.0)</td>
<td>(-6.0)</td>
</tr>
<tr>
<td>Seasonal ticket possession*</td>
<td>2.604</td>
<td>2.604</td>
<td>2.604</td>
<td>2.604</td>
<td>2.767</td>
<td>2.767</td>
<td>3.182</td>
<td>3.182</td>
<td>1.100</td>
<td>1.100</td>
</tr>
<tr>
<td>(10.3)</td>
<td>(10.3)</td>
<td>(10.3)</td>
<td>(10.3)</td>
<td>(10.3)</td>
<td>(5.4)</td>
<td>(5.4)</td>
<td>(3.8)</td>
<td>(3.8)</td>
<td>(4.9)</td>
<td>(4.9)</td>
</tr>
<tr>
<td>Half price card possession*</td>
<td>1.602</td>
<td>1.602</td>
<td>1.602</td>
<td>1.602</td>
<td>2.442</td>
<td>2.442</td>
<td>1.442</td>
<td>1.442</td>
<td>0.880</td>
<td>0.880</td>
</tr>
<tr>
<td>(6.8)</td>
<td>(6.8)</td>
<td>(6.8)</td>
<td>(6.8)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(3.6)</td>
<td>(3.6)</td>
<td>(6.7)</td>
<td>(6.7)</td>
</tr>
<tr>
<td>Age^2*</td>
<td>0.00019</td>
<td>0.00019</td>
<td>0.00019</td>
<td>0.00019</td>
<td>0.00016</td>
<td>0.00016</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.1)</td>
<td>(2.1)</td>
<td>(2.1)</td>
<td>(2.1)</td>
<td>(2.1)</td>
<td>(4.5)</td>
<td>(4.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant CW^1</td>
<td>2.886</td>
<td>2.528</td>
<td>2.855</td>
<td>0.861</td>
<td>3.775</td>
<td>3.759</td>
<td>4.188</td>
<td>4.235</td>
<td>3.532</td>
<td>3.565</td>
</tr>
<tr>
<td>(55.9)</td>
<td>(48.8)</td>
<td>(42.5)</td>
<td>(9.5)</td>
<td>(21.68)</td>
<td>(21.5)</td>
<td>(65.78)</td>
<td>(66.2)</td>
<td>(91.1)</td>
<td>(91.91)</td>
<td></td>
</tr>
<tr>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
<td>(fix)</td>
</tr>
<tr>
<td>Jobs^2</td>
<td>0.303</td>
<td>0.303</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(21.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wage earners^2</td>
<td>0.273</td>
<td></td>
<td>0.253</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(18.2)</td>
<td></td>
<td></td>
<td>(8.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education facilities^2</td>
<td>0.103</td>
<td>0.103</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residents^2</td>
<td>0.286</td>
<td>0.286</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales area^2</td>
<td>0.277</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(22.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure facilities^2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking availability</td>
<td>0.867</td>
<td>0.246</td>
<td>0.385</td>
<td>1.663</td>
<td>0.822</td>
<td>0.332</td>
<td>0.201</td>
<td>0.138</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>(8.3)</td>
<td>(2.3)</td>
<td>(2.3)</td>
<td>(2.1)</td>
<td>(11.6)</td>
<td>(5.8)</td>
<td>(4.0)</td>
<td>(2.41)</td>
<td>(14.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-observations</td>
<td>4319</td>
<td>4319</td>
<td>1252</td>
<td>1252</td>
<td>1062</td>
<td>1062</td>
<td>3681</td>
<td>3681</td>
<td>7139</td>
<td>7139</td>
</tr>
<tr>
<td>adj. r^2</td>
<td>0.124</td>
<td>0.096</td>
<td>0.145</td>
<td>0.030</td>
<td>0.162</td>
<td>0.158</td>
<td>0.207</td>
<td>0.190</td>
<td>0.070</td>
<td>0.068</td>
</tr>
</tbody>
</table>

(1) CW = Cycling and walking; (2) attraction variable = ln (value of attraction variable/1000)
(3) shopping centre: sales area (m^2) / 10^6; t-stats are in parentheses; values of variables with * were taken from mode choice model and set fixed in the destination choice model

\( \lambda \) for Box-Tukey transformation were adjusted by hand and not estimated jointly with the other parameters
Table 3  Result: Modal share compared (%) of interzonal trips

<table>
<thead>
<tr>
<th></th>
<th>PrT trips</th>
<th></th>
<th>PuT trips</th>
<th></th>
<th>Cycling/Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MZ model</td>
<td>MZ model</td>
<td>MZ model</td>
<td></td>
<td>MZ model</td>
</tr>
<tr>
<td>Work</td>
<td>59,6</td>
<td>54,7</td>
<td>25,7</td>
<td>33,4</td>
<td>14,7</td>
</tr>
<tr>
<td>Education</td>
<td>14,4</td>
<td>3,3</td>
<td>39,1</td>
<td>33,3</td>
<td>46,5</td>
</tr>
<tr>
<td>Business</td>
<td>84,2</td>
<td>83,6</td>
<td>8,5</td>
<td>8,3</td>
<td>7,3</td>
</tr>
<tr>
<td>Shopping</td>
<td>52,6</td>
<td>55,5</td>
<td>19,5</td>
<td>20,0</td>
<td>27,9</td>
</tr>
<tr>
<td>Leisure</td>
<td>58,1</td>
<td>68,0</td>
<td>18,7</td>
<td>14,0</td>
<td>23,2</td>
</tr>
<tr>
<td>All</td>
<td>56,6</td>
<td>57,2</td>
<td>21,4</td>
<td>22,7</td>
<td>22,0</td>
</tr>
</tbody>
</table>

Table 4  Statistic analysis: Final model results and counts

<table>
<thead>
<tr>
<th></th>
<th>Public Transport model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of counts</td>
<td>5916</td>
</tr>
<tr>
<td>Average weighted deviation of the absolute values in %</td>
<td>8.2</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.996</td>
</tr>
</tbody>
</table>

Figures

Figure 1  Probabilities and elasticities of different transformations
Figure 2  Trip length distribution: Model and national travel survey MZ 2000 (all trip purposes)

Figure 3  Comparison of traffic counts and model result – PuT (without Calibration)  
with a correlation coefficient of 0.9064
Figure 4  Comparison of traffic counts and model result – PrT (without Calibration) with a correlation coefficient of 0.9172

Figure 5  Comparison of traffic counts and final adjusted matrices - PuT
yellow = basic loading (no difference), red = relative positive difference (model result higher as counts), green = negative relative difference (model result lower as counts); complete red links = no counts available

Figure 6  Comparison model/counts: Link volumes (40'000 Passengers / 6mm)