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Conference Paper**Author(s):**

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Publication date:

2009

Permanent link:

<https://doi.org/10.3929/ethz-a-005919197>

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Originally published in:

Arbeitsberichte Verkehrs- und Raumplanung 596

Structural Equations Modelling of Travel Behaviour Dynamics Using a Pseudo Panel Approach

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Abstract Induced traffic has been a topic of research for many years. While previous studies have focused on specific and localised changes, the research described in this paper deals with aggregate effects of changed generalised costs of travel on traffic generation: the propensity of participating in out-of-home activities on a given day, the number of trips and journeys conducted, and the resulting total times out-of-home and distances travelled. Thus, induced traffic is defined as additional demand generated by improvements in travel conditions. The generalised cost elasticities computed from a structural equations model with a pseudo panel constructed from the Swiss National Travel Survey datasets are surprisingly substantial even after correcting for socio-demographic effects.

1. Motivation

Induced traffic has been a topic of ongoing research for many years, the main focus being the assessment of side effects of measures bringing about such improvements. While previous studies have focused on specific and localised changes, the research described in this paper deals with the aggregate effects of changing generalised costs of travel on traffic generation: the propensity of participating in out-of-home activities, or being mobile on a given day, the number of trips conducted, and the resulting total times spent out-of-home and distances travelled. Generalised cost is understood as the risk- and comfort-weighted sum of resources consumed for travel: time and (decision-relevant) monetary expenditures. Thus, the phenomenon of induced traffic is

here defined as additional demand for transport services directly caused by improving travel conditions.

The objective of the recently finished project work (Weis and Axhausen 2009) that this paper draws on was to overcome the limitations of previous studies (see next section) by addressing the issue over a longer time period and a wider spatial scale than usual. Accessibility is used as the central explanatory variable, as it is equally important in policy discussions around transport projects and policy making. It is an overall measure of the quality of service offered by the transport system. It is assumed that travel is a normal good (Varian 1992) – travellers respond to changes in generalised costs of travel by adapting their consumption. Individuals can adapt their travel behaviour (see Axhausen 2008 for a classification of movement into consistent elements) on several levels:

- deciding to leave home and to participate in out-of-home activities on a given day;
- adapting of the number of out-of-home activities;
- combining out-of-home activities and trips into tours (journeys) or trip chains;
- scheduling (timing and duration) the activities;
- choosing the locations for carrying out activities (destination choice);
- choosing an origin-destination connection (mode and route choice) to reach the destination.

As the number of existing studies dealing with the latter two dimensions (which represent the second to fourth steps in the classic four step model, see Ortúzar and Willumsen 2001) is large, and the scheduling process very locally specific and personal, this paper focuses on an aggregate analysis of the upper levels, which constitute the demand generation process. The scheduling process and the intra-household interaction issue are being addressed in ongoing work through a stated adaptation survey following the tradition of the Household Activity Travel Survey (HATS; see Jones *et al.* 1980).

When generalised costs sink, both the time and the monetary resources for participating in travel and non-travel activities increase. It is reasonable to expect that this shift in resource availability will lead to a number of demand generation responses:

- the propensity of participating in out-of-home activities should increase;

- the number and duration of out-of-home activities and trips should increase;
- the demand for transport services (distances travelled) should increase;
- the number of trips per journey (succession of trips starting and ending at home) may both decrease, as returning to the home location after carrying out each activity becomes cheaper (in terms of generalised costs), or increase, as the added trips are integrated into existing chains rather than generating new journeys.

Ideally, the analysis of the stipulated effects and of their mixture requires a longitudinal panel data set together with a careful description of the level and changes in generalised costs covering both a long time period and a large area to obtain enough variation for the detection of the effects of any change. However, such combined data sets are not available anywhere. The German Mobility Panel (1994 – 2009; see Zumkeller *et al.* 2009) and the Puget Sound Panel (1990 – 2003; see Yee and Niemeier 2000; Goulias *et al.* 2003) would be suitable in terms of duration and, with some reservation, geographical spread. However, both are missing the necessary panel of network models.

Therefore, a second-best approach was applied, employing a *pseudo panel* (Deaton 1985; Mason and Wolfinger 2004). A *pseudo panel* groups individuals of different cross-sectional surveys into aggregated cohorts with a consistent definition. The mean members of these groups are treated as individuals, which are followed over time, thus constructing an artificial panel dataset from a series of cross sectional datasets.

The modelling framework used for testing the hypotheses formulated above is a *structural equations model*, which allows to model the effects of all exogenous variables on all endogenous variables simultaneously, and also to account for both error correlations and direct effects between the endogenous variables.

A series of *general linear models* (GLM) was first used to test the hypotheses mentioned above separately for all relevant dimensions. Based on these models, the *structural equations* model was formulated. Demand elasticities were computed from the resulting regression weights, thus providing a consistent measure for quantifying and assessing the abovementioned effects.

The paper is structured as follows. The next section provides a brief overview of literature relevant to the subjects treated in this

paper. The subsequent sections describe the construction of the *pseudo panel* dataset, the variables it contains, an explorative analysis of the *pseudo panel* and its variation over time, and the model formulation and estimation steps, followed by considerations on the application of the model results, a brief conclusion and an outlook on further work.

2. Literature Overview

Fröhlich (2003) provides a literature review of models treating the effects of increased road supply. All of these studies deal with the classic definition of induced traffic, namely the reaction of demand for transport services (travel times and distances) to the improvement of the capacities of the transport system and the implied drops in generalised travel costs. Goodwin (1992, 1996), Noland and Levinson (2000), Graham and Glaister (2004) and Goodwin *et al.* (2004) provide overviews of known income, price and supply elasticities of car ownership and demand for transport services, measured in vehicle miles travelled. Similar analyses can be found in the works of Oum (1992), Cerwenka and Hauger (1996), Cairns *et al.* (1998) de Corla-Souza and Cohen (1999), Lee *et al.* (1999), Barr (2000), Fulton *et al.* (2000), Noland and Cowart (2000), Noland (2001) and Cervero and Hansen (2002).

Swiss studies dealing with traffic induced by localised changes to the transport system and the according accessibility changes include Sommer *et al.* (2004), Güller *et al.* (2004) Giacomazzi *et al.* (2004) and Aliesch *et al.* (2006), providing ex-post analyses of the effects of the implementation of various road and rail projects. The mentioned analyses remain vague in their conclusions. Like all ex-post analyses, they suffer from the enormous challenges imposed by the empirical data requirements. In order to provide a detailed assessment of induced travel effects, all re-routed trips would have to be recorded before and after the implementation of the measure under study. Rudel and Maggi (2007) present current results based on the analysis of potential mobility pricing schemes.

The effects of the structural changes of the aggregate system are the subject of three recently completed dissertations at the Institute for Transport Planning and Systems (IVT, ETH Zurich). The studies are partly based on the same data employed here – the

Swiss network models for private and public transport (Fröhlich *et al.* 2005), updated once a decade since 1950, and a detailed database of Swiss municipalities since 1950 which was enriched with spatial and welfare data (Tschopp *et al.* 2003). Fröhlich (2008) uses the data for modelling the development of commuting behaviour since 1970. Tschopp *et al.* (2005) (as well as Tschopp 2007) analyse the influence of changes in the transport system and the corresponding accessibilities on the numbers of residents and workers in the municipalities. Bodenmann (2007) provides an analysis of the interaction of firm locations and the transport system since 1970.

Literature dealing with the demand dimensions that are discussed in this paper is quite sparse, indicating that the generation side of transport demand has been neglected during the past years. Meier (1989) makes an early attempt at explaining general induced travel demand effects in Switzerland, among others by analysing the variation of mobility (expressed by the share of mobiles and number of trips) by accessibility (in classes) and showing higher mobility for regions with superior accessibility. Other examples that draw on concepts similar to those employed here include Kumar and Levinson (1992), the investigation of a generation model for work and non-work trips; Madre *et al.* (2004), a meta analysis of immobility in travel diary surveys; Mokhtarian and Chen (2004), a literature review of studies discussing the concept of constant travel time budget; van Wee *et al.* (2006), a quest for an explanation of increasing total daily travel times; Primerano *et al.* (2008), where definitions for trip chaining behaviour are provided.

3. Pseudo Panel Dataset Construction

The concept of *pseudo panel* data, first introduced by Deaton (1985), consists in grouping individuals from cross sectional observations into cohorts, the averages of which are then treated as individual observations in an artificial panel. These data can be used in the absence of actual panel data to approximate the latter by following virtual persons (created by the aggregation into cohorts; Mason and Wolfinger 2004) over time and test for individual as well as dynamic effects. The approach has seen

common use in the transport planning field in recent years. An example for its application is Bush (2003), an effort to forecast future travel demand of baby boomers. Similar concepts underlie the works by Goulias *et al.* (2007), Dargay (2002, 2007) and Huang (2007), where evidence for the substantial influence of cohort effects on household car ownership is provided.

The *pseudo panel* dataset for the present study was constructed using the Swiss National Travel Survey (named *Microcensus*) data, a person-based survey. In general only one person per household is interviewed. The survey has been carried out approximately every 5 years since 1974. Over the course of time, survey methods have changed several times, complicating the comparison of the resulting data. A brief overview of the various surveys is given in Table 1 (adapted from Simma 2003), along with the sample sizes (number of surveyed households).

Table 1 Key Characteristics of Swiss Microcensus Travel Surveys Since 1974

Year	Survey method	Sample size
1974	Time use surveys	2'114
1979	Combination of pen-and-paper and personal interview	2'000
1984	Trip based diary	3'513
1989	Pen-and-paper survey	20'472
1994		16'570
2000	Stage based diary	28'054
2005	CATI	31'950

Source: Simma (2003)

As the different survey methods lead to discrepancies in the data, the various household, person and travel datasets had to undergo a thorough reformatting in order to obtain a uniform data format for all persons over the different years and a consistent coding for the relevant socio-demographic characteristics and especially for the key mobility indicators (trip numbers et cetera). For example, a severe decrease in reported mobility (as far as increased non-mobility as well as reduced trip numbers are concerned) is obvious in the 1989 dataset (Simma 2003). This discrepancy appears not to be explicable by mere seasonal fluctuations, but rather related to an underreporting of trips in the

corresponding trip diary. These effects, which are likely to be artefacts of survey methods or the fieldwork in the relevant year, are taken into account and corrected for in the modelling procedures that will be discussed in the following sections. Lleras *et al.* (2003) present approaches to account for data inconsistencies across travel behaviour surveys in pooled analyses.

The cohorts for the *pseudo panel* dataset ought to be constructed according to characteristics that are (or can reasonably be assumed to be) time invariant. The most obvious example of such a discriminating variable is the year of birth (which has been used in multiple studies, such as Dargay 2002; Huang 2007). Other criteria, such as gender, education level, or spatial characteristics, are also conceivable as grouping variables.

When constructing a *pseudo panel*, two conflicting aims ought to be met: on the one hand, the cohorts should be constructed in a way that provides sufficient variability in the panel and provides a sufficient number of artificially constructed observations in order to estimate robust models. Thus, the cohort definition should be as detailed as possible. On the other hand though, when the disaggregation level becomes too detailed, the number of observations per cohort will become small for certain time periods, leading to greater weights of potential outliers in computing the cohort averages and thus to biased estimates of the population means (Huang 2007).

As a compromise between a sufficient level of disaggregation and large enough cohort sizes, a cohort subdivision according to three criteria was chosen:

- year of birth (split up into 10 year bands ranging from 1896 through 1985);
- gender;
- region (one out of 7 Swiss regions; the aggregation corresponds to the EU NUTS 2 regions; Eurostat 2008).

The latter was chosen over a spatial definition based on municipality types (urban, suburban, rural, et cetera). Such a classification would be teleological and bias the results, as it can be argued that relocations to better accessible places of residence (to a different municipality type) take place because of a certain desired mobility behaviour. The postulated direct causal effect of accessibility on trip generation would then not be discernible from a confounding residential self selection effect (Boarnet and Crane 2004; Mokhtarian and Cao 2008).

The *pseudo panel* dataset contains 709 virtual observations for the seven considered survey periods between 1974 and 2005. For data consistency reasons, only observations of adult persons (above 18 years of age) were retained in the *pseudo panel* dataset. The distribution of the resulting cohort sizes is displayed in Figure 1.

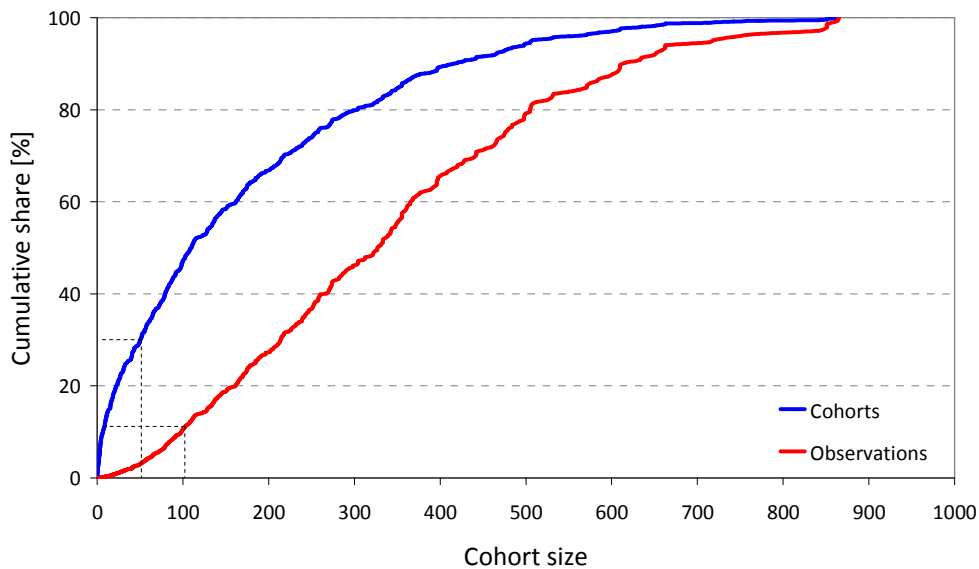


Fig. 1 Distribution of cohort sizes

A large portion of the resulting cohorts are quite small (30 per cent of them have a cohort size of 50 or below). However, these small cohorts contain relatively few of the total observations, approximately 85 per cent of the individual observations being in cohorts of sizes above 100 observations. Consequently, a large portion of the underlying observations will be considered in the analysis, thus leading to reliable modelling results.

4. Variables relevant to the modelling procedure

4.1 Overview

The selection of exogenous (independent) variables was limited by the differences in the surveys over the decades. The chosen set represents a common core, which, with slight variations, is

regularly used in models of travel behaviour (Dargay 2002; Bush 2003; Huang 2007). The averages for those variables expected to have an impact on the mobility indicators to be modelled were computed.

Furthermore, the dataset was enriched with variables that, individually or in combination, may be used as a proxy for generalised costs of mobility tool ownership, respectively travel:

- accessibility measures (Tschopp *et al* 2005; Fröhlich 2008);
- price indices for individual travel (Abay 2000; values up to 2005 were extrapolated).

Descriptive statistics of the continuous independent variables upon which the final models were fitted are displayed in Table 2.

Table 2 Cohort-level descriptive statistics of variables used in the models

Variable	Mean	Median	Std. Dev.	Min.	Max.
Age	54	54	22	17	99
Household size	2.56	2.59	0.82	1.00	6.00
Employed	0.48	0.51	0.37	0.00	1.00
Car driving license ownership	0.61	0.73	0.32	0.00	1.00
Accessibility	10.15	10.10	0.46	7.70	11.64
Individual travel price index	0.90	0.89	0.04	0.84	1.00

Employment status was used as a second-best approximation for an aggregated welfare measure, as the coding of the more desirable income variable was inconsistent throughout the survey years and missing for some of the periods.

The travel behaviour indicators that are treated as endogenous variables are:

- out-of-home activity (as percentage of mobile persons);
- number of trips;
- number of trips per home-to-home tour (journey);
- total duration spent out of home;
- respondent estimated total trip distance, as geo-coded locations and network derived distance estimates are only available from 2000.

In order to account for the sampling method differences between the various surveys, only weekday mobility figures were considered, thus avoiding biased means due to over- or

underrepresentation of weekends.

The next two subsections are a more detailed presentation of the accessibility and price index variables, which were used as an approximation of generalised costs of travel in the models.

4.2 Accessibility at Municipality Level

Accessibility to population is defined as (Tschopp *et al* 2005; Ben-Akiva and Lerman 1985):

$$A_i = \ln \left[\sum_{j=1}^n X_j \cdot f(c_{ij}) \right] \quad (1)$$

Here, A_i is the accessibility measure for spatial unit i (the spatial unit here being Swiss municipalities), X_i is the number of inhabitants of spatial unit i , c_{ij} is the intercentroid travel time from spatial unit i to spatial unit j (n being the total number of municipalities), and f is a weighting function. Tschopp *et al.* (2005) use a negative exponential function for weighting, ensuring decreasing intercentroid accessibilities with rising travel times. The contribution of a zone to its own accessibility is considered using a calculated mean intra-zonal travel distance; see for example Fröhlich *et al.* 2005 for a computation method for the mean intra-zonal distance).

Increasing accessibility serves as a proxy for decreasing generalised cost of travel and is a possible indicator for testing the hypothesis that travel behaviour reacts to changes in generalised costs. The distributions of the accessibility values of all Swiss municipalities from 1970 through 2005 are displayed in Figure 2. As can be seen, accessibility values have steadily increased over the 35 years under consideration. It should be noted that the observed increase of the median value from 9.13 in 1970 to 9.47 in 2005 reflects an increase in the Swiss population by 1.2 million persons, an additional 840 km of motorways and roughly 29 billion Swiss Francs investment. The accessibility values for the survey years were obtained by interpolation from the available network model data displayed in Figure 2.

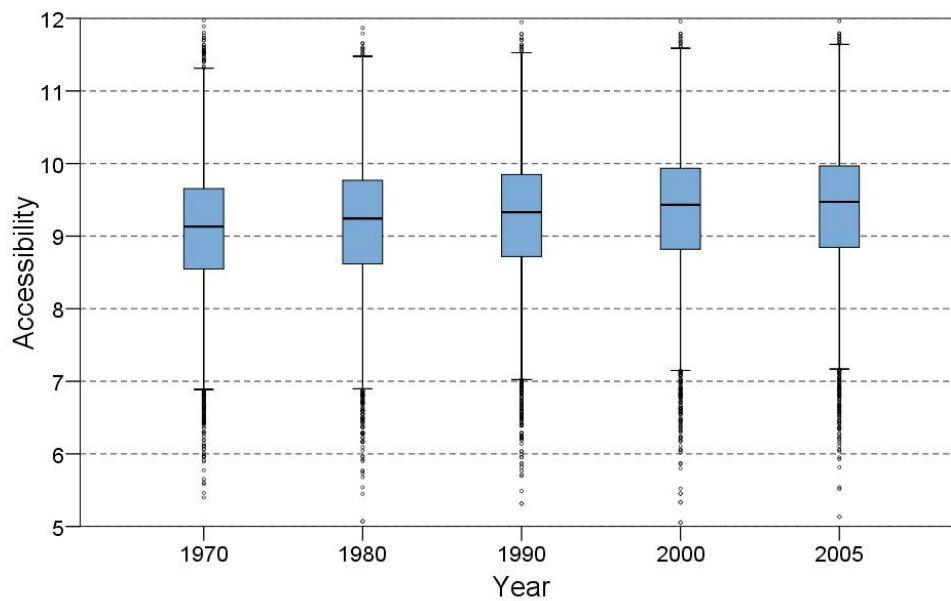


Fig. 2 Distribution of accessibility values (on municipality level), 1970 – 2005

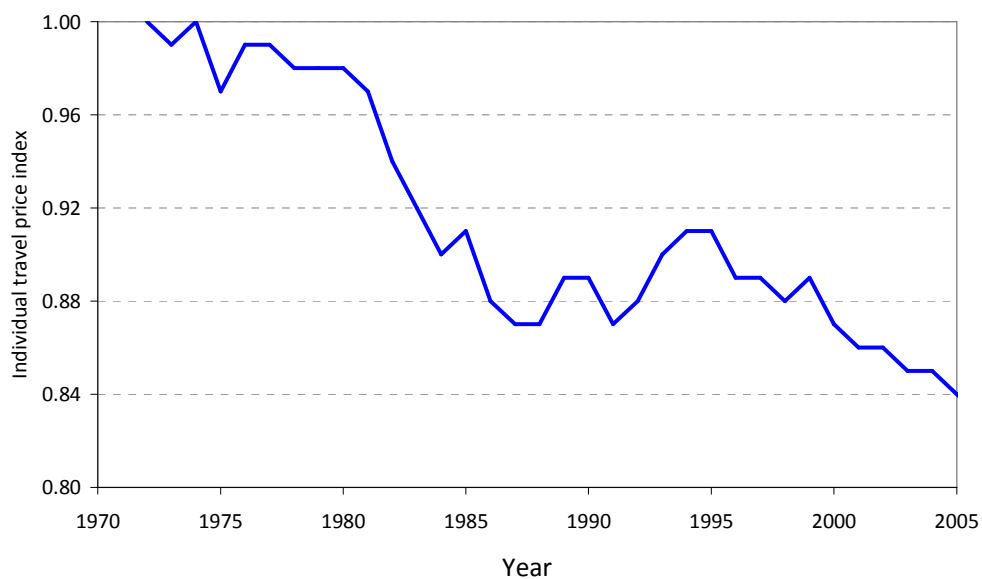


Fig. 3 Evolution of inflation-adjusted individual travel price index, 1970 – 2005

4.3 Price Index for Individual Travel

The simple measure of accessibility as described above measures generalised costs of travel as a function of travel time. In order to have a monetary indicator in addition, price indices for individual travel, as provided in Abay (2000) are used. The index, calculated

for years reaching back to 1972 is based on the Swiss national consumer price index, and weighted to reflect inflation-adjusted prices (the base year being 1972, hence the index is set to 1 for that year). It represents a measure of transport prices relative to the general consumer prices for all goods. Figure 3 shows the index' evolution from 1972 through 2005.

5. Descriptive Analysis of the Pseudo Panel Dataset

This section deals with the characteristics of the *pseudo panel* cohorts and their variation over time, and shows the generation and life cycle effects of the representative indicators as well as the above mentioned biases of the different survey methods.

5.1 Household Size

Figure 4 shows the average household sizes for members of the respective year of birth cohorts and their life cycle evolution.

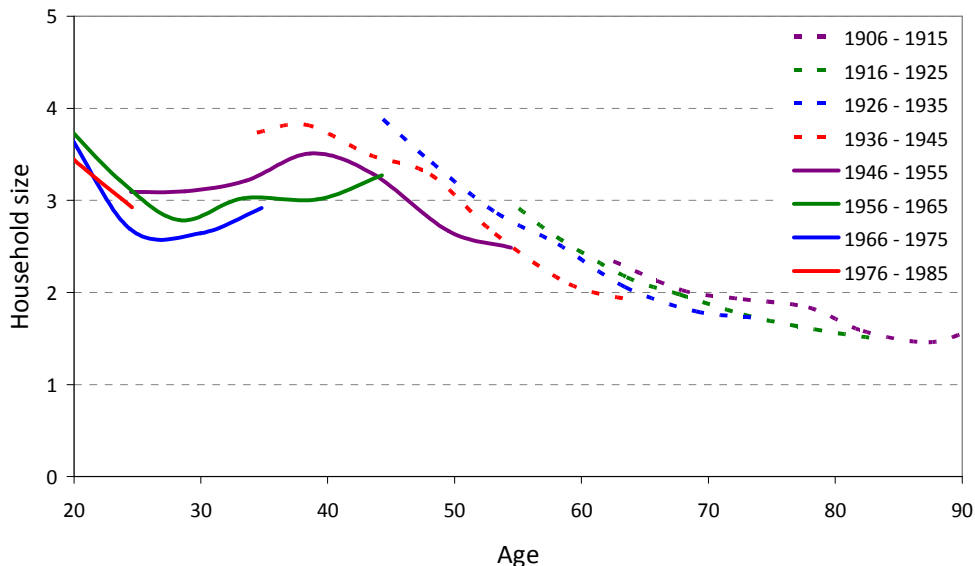


Fig. 4 Household size by age for different cohorts

Both a life cycle and a generation (cohort) effect can be made

out. The life cycle effect for all cohorts shows the expected trends. Young adults tend to live in their parents' homes and thus in large households. As individuals approach their mid twenties, average household size decreases as a consequence of moving out of the family home and setting up their own households. Then, after turning 30, the trend again turns to an increase in household size, as the individuals settle down and have their own families. As the mid 40's pass, household sizes decrease again as an effect of children moving out, and later on of spouses passing away. As for the generation effect, it can be seen that younger cohorts tend to live in smaller households. This can be explained by the larger share of single person households (especially for young adults) as well as by decreasing birth rates. Also, elderly people increasingly tend to live on their own rather than moving back in with their families or moving themselves to nursing homes.

5.2 Ownership of Car Driving License

The cohort and age effects for car driving license ownership are displayed in Figure 5.

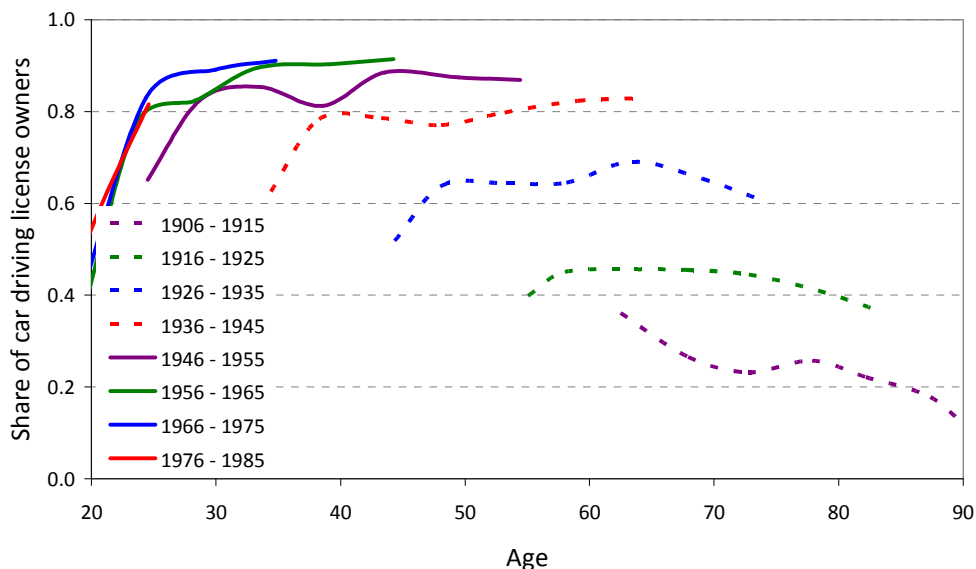


Fig. 5 Car driving license ownership by age for different cohorts

The life cycle effects that are seen here are as expected. In fact,

young adults nowadays tend to acquire a driving license at quite young age. In 2005, there is a practically constant, above 80 per cent, share of car driving license owners throughout age groups, up to the age of around 60. Car driving license ownership decreases with age, and is much lower for cohorts born before the Second World War, when licence holding was uncommon for women in particular. Overall, the generation effect clearly tends towards higher car driving license ownership in younger cohorts, again pointing to an increased general availability of mobility tools over time.

5.3 Key Mobility Indicators

Household size and car driving license ownership, two possible explanatory variables for mobility, exhibit expected and consistent trends over time, over the various age groups and for the different survey periods. The key mobility figures, which will be discussed in the following paragraphs and form the basis for the models estimated subsequently, do not to follow the same clear and consistent scheme.

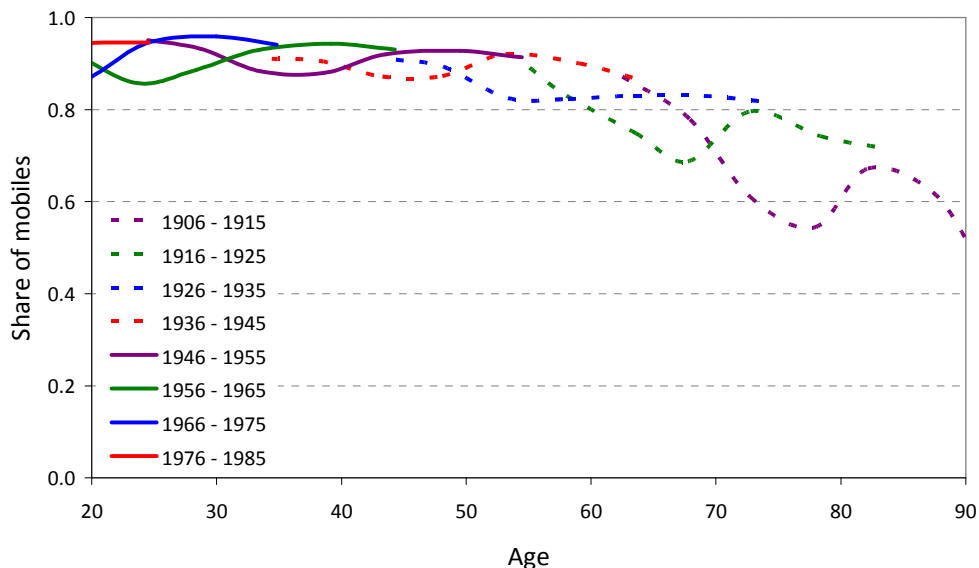


Fig. 6 Reported share of mobiles by age for different cohorts

As can be seen in Figure 6, weekday mobility (as a percentage

of individuals that reported at least one trip or out-of-home activity) approximately reproduces the life cycle effect that one would expect, that is continuously decreasing mobility with increasing age. However, for each cohort, there is a slight drop in reported mobility around the middle of the curve. These decreases coincide with the 1984 and 1989 surveys. No natural reason for this fluctuation being apparent, this suggests measurement errors present in these years.

The undesirable effect of mobility underreporting becomes even clearer when considering the average reported trip numbers displayed in Figure 7.

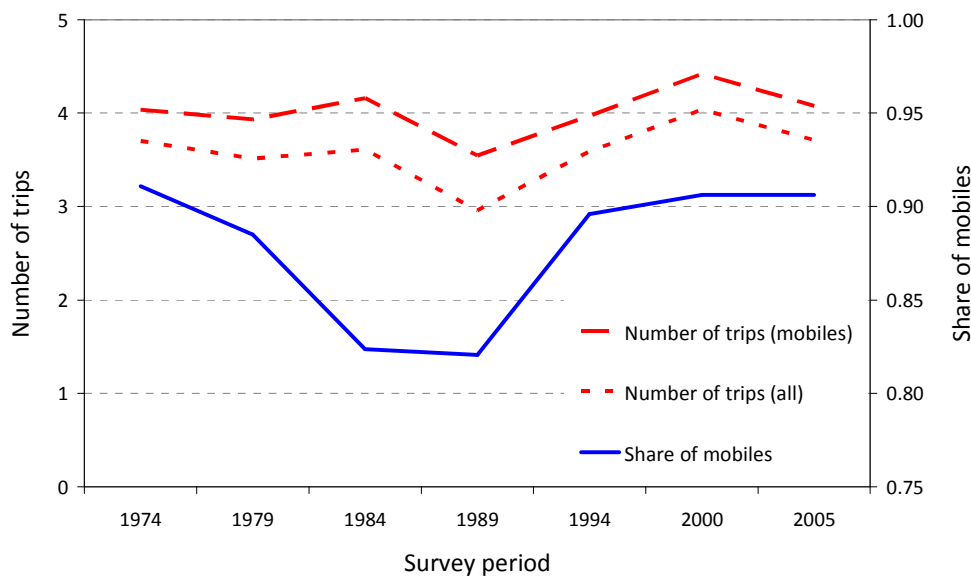


Fig. 7 Reported mobility indicators for different survey years

Even normalizing to number of trips per mobile person does not remove the effect. Mobility underreporting in the trip based self-administered diary surveys of these years appears to have happened on two levels: an overrepresentation of non-mobile persons, and trip underreporting from those that reported mobility. This hints at both a lacking willingness to participate in the surveys, and a considerable attrition effect and a lack of attention of the field work firm in monitoring the surveys.

The estimated models, which will be discussed in the next section, account for the described effects and attempt to reproduce life cycle effects that are smoothed to reflect the actual behaviour, and yield correct parameter values for the remaining variables.

6. Formulation and Estimation of the Structural Equations Model

This section describes the model for the various mobility indicators based on the factors listed above: share of mobiles, number of journeys, number of trips, duration of out-of-home activities, trip duration and estimated distances travelled.

The *structural equations* method (Bollen 1989) has seen wide application in the travel behaviour research field (see Golob 2003 for a description of its benefits to travel behaviour research). Applications include Lu and Pas (1999), an analysis of activity participation and travel behaviour as a function of individuals' sociodemographic attributes; Kuppam and Pendyala (2001), a study of the relationships between commuters' activity participation, travel behaviour and trip chaining patterns; Simma and Axhausen (2004), who analyse the interactions of travel behaviour, accessibility and spatial characteristics in Upper Austria based on a cross sectional dataset; as well as de Abreu e Silva and Goulias (2009), where the influence of land use patterns on adult workers' travel behaviour is analysed.

The final *structural equations* model (SEM) was based upon basic linear-in-parameters regression models (*general linear models*, or GLM). The formulation and estimation of these models yielded the expected effects of the independent variables on the various mobility indicators (Weis 2008). The SEM is a combination of the basic models in a unified framework. It models the effects of the independent (exogenous) variables on all the indicators (endogenous variables) simultaneously. Furthermore, the model structure allows accounting for the reciprocal influences of the endogenous variables on one another. It is a confirmatory method for testing and quantifying assumed causal relationships between various factors. The general formulation of the SEM is as follows:

$$y = By + \Gamma x + \zeta \quad (2)$$

Here, y is an $m \times 1$ vector of endogenous variables, B an $m \times m$ matrix of coefficients associated with the right-hand-side endogenous variables, x an $n \times 1$ vector of exogenous variables, Γ an $m \times n$ matrix of coefficients associated with the exogenous

variables, and ξ an $m \times 1$ vector of error terms associated with the endogenous variables.

The chart in Figure 8 represents the causal effects implied by the basic models, according to which the SEM was constructed.

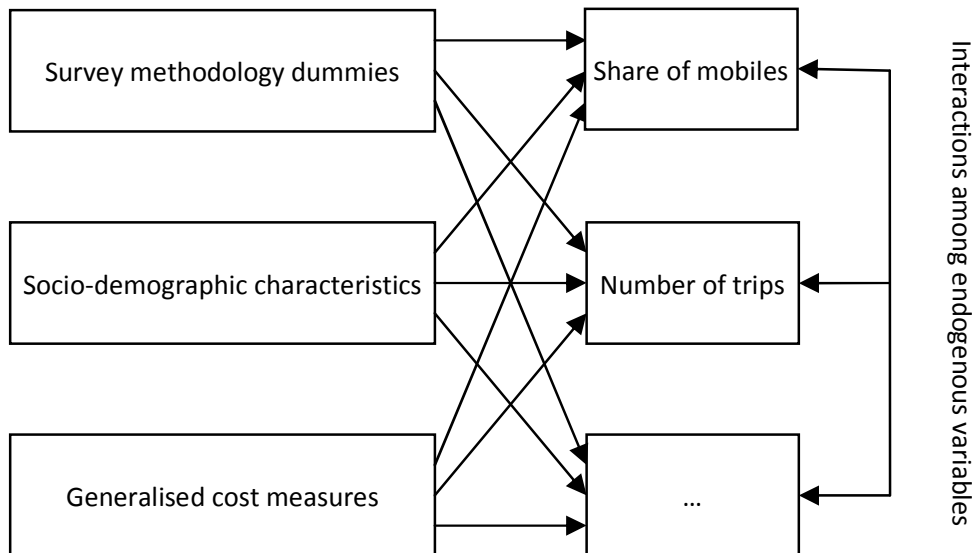


Fig. 8 Structure of the SEM

The SEM is expected to yield a simultaneous computation of demand elasticities for all relevant dimensions. The model assumes direct causal relationships between certain dependent variables, and thus goes further than merely capturing these relationships via error correlations.

The SEM was fitted using the AMOS 16.0 software package (Byrne 2001). SEM fitting is done using a covariance based structural analysis, also referred to as method of moments, consisting in minimizing the difference between the actual sample covariances and those implied by the model parameters (Bollen 1989). Various optimization techniques are available for estimating *structural equations* models. In the AMOS software package, computing intercepts for the endogenous variables is only feasible when using the *maximum likelihood* approach. As literature (Kuppam and Pendyala 2001; Golob 2003; Schermelleh-Engel *et al.* 2003) finds only marginally changing values for the estimated coefficients from this method to the *asymptotically distribution-free* method (ADF) that one would ideally apply to such a problem, the *maximum likelihood* method is used for estimation.

The hypotheses on the direct relationships (which are added to

the effects of the structural and socioeconomic variables described above) between the cohort-level endogenous variables are as follows:

- Increased weekday mobility will increase the number of conducted trips. This conclusion is quite straightforward.
- Increased mobility, respectively the increased trip numbers it brings about, will increase out-of-home-durations as well as distances travelled.
- As a corollary, the number of trips per tour will increase under the assumption that the number of tours remains roughly the same (i.e., the additional trips are integrated into existing chains rather than generating new journeys); or decrease if the reduced generalised costs lead to more returns to the home location in between out-of-home activities.
- As trip chains become longer, the effect on travelled distances described above should be attenuated, as adding new trips to a chain likely produces less mileage than conducting an entirely new journey (as the return home trip is left out).

The expected effects are shown in Figure 9 (highlighted by the expected sign for the relationship), along with the resulting coefficients from the model estimation as well as the regression parameters for the generalised cost variables.

Signs in circles are a-priori expectations on direct effects
 Numbers on arrows are coefficients resulting from model estimation
 Numbers above boxes are regression coefficients for: accessibility / price index

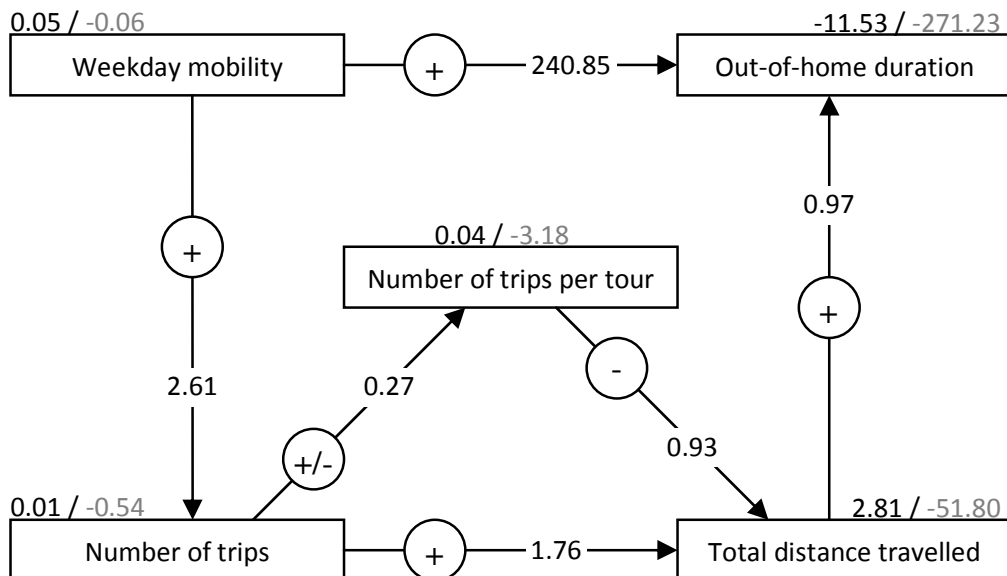


Fig. 9 A-priori assumptions on direct effects vs. model results

All hypothesised effects except those on trip distance are significant at the 5 per cent level and have the expected sign (see above). The effect of trip chain complexity on travelled distance is contrary to the assumptions postulated in the last section. Thus, the addition of trips to existing chains appears to accentuate the increase of covered distances induced by the higher general mobility, instead of attenuating it by suppressing the return home trips.

The regression parameters for the exogenous variables resulting from the SEM estimation are shown in Table 3. Only the results for the number of trips endogenous variable will be discussed in detail here; the interpretations can be extended to the other endogenous variables.

Table 3 SEM estimation results – regression parameters

Exogenous variables		Endogenous variables				
		Share of mobiles	Number of trips	Trips per tour	Out-of-home duration	Travelled distance
Intercept		0.776	2.586	3.045	1472.78	-63.133
Survey method	Time budget ('74, '79)	-0.031	-0.224	-0.143	8.22	5.171
	Trip diary ('84, '89)	-0.108	-0.357	0.019	-9.94	-3.294
Gender	Male	0.099	0.255	-0.056	57.92	18.924
	Linear (*1/10)	0.169	0.503	-0.303	170.08	-17.212
Age	Squared (*1/100)	-0.017	-0.043	0.021	-7.11	0.262
	Natural logarithm	-0.185	-0.760	0.487	-521.25	47.444
Household size		-0.019	0.094	-0.012	-22.45	-3.649
Employed		0.013	0.473	0.103	284.51	4.915
		0.137	0.655	-0.168	119.65	-8.926
Accessibility		0.051	0.012	0.040	-11.53	2.811
Individual travel price index		-0.061	-0.539	-3.186	-271.23	-51.075
Squared multiple correlation (R^2)		0.587	0.766	0.493	0.768	0.596

Values in *italic* are significant at the 5 per cent level (as indicated by the C ratio test).

Most variables were found to have a significant effect on cohort

level trip generation. The estimated fixed effects for the survey methodologies confirm their above mentioned impact on the dependent variable. The most significant negative effect on trip reporting results for the trip based diary surveys in the 1980's, which confirms the conclusion drawn from Figure 7.

Males throughout generations are slightly more mobile than females. The same holds for employed individuals as well as for car driving license owners, the latter being an indication of a direct effect of mobility tool ownership on reported mobility. Household size has a slight negative effect on the dependent variable, thus individuals from family households tend to be slightly less mobile than those from single households.

The effect of age on weekday trip making follows the trend shown in Figure 10.

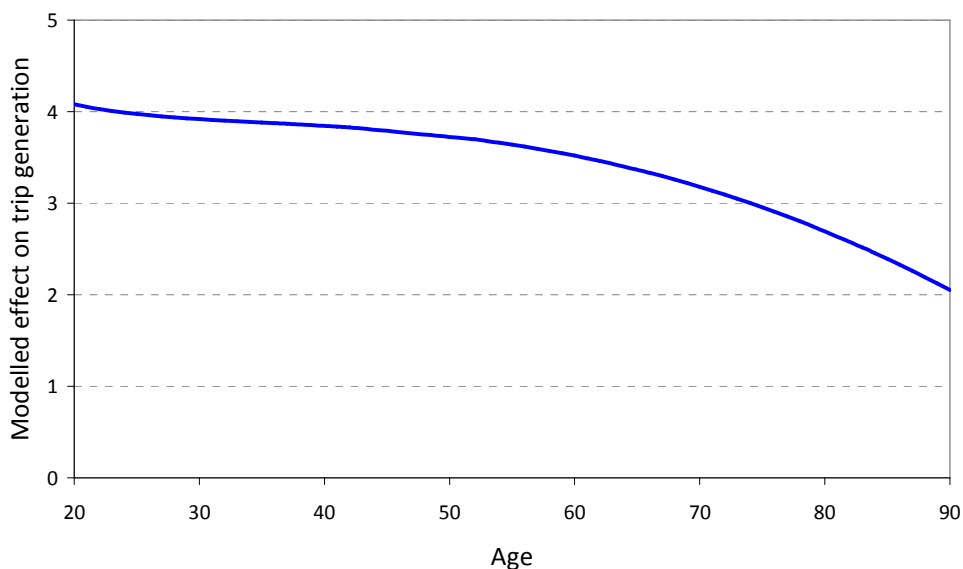


Fig. 10 Modelled age effect on number of trips

As can be seen, the expected life cycle effects are well reproduced by the model: mobility decreases with age, the slightly S-shaped curve resulting from the functional form of the relationship (summation of a linear, squared and logarithmic term) that was assumed based on the descriptive analysis.

Intriguingly, the cohort effect on trip generation was found to be insignificant when included in the model alongside both the accessibility and price index variables and was therefore left out of the final model. Thus, all other effects taken being accounted for,

behaviour does not seem to vary much between birth year cohorts. The life cycle effect is clearly dominant over the generation effect. This absence of a generation effect is rather surprising given the wide literature on long term effects of the improved childhood nutrition of the post-war generations (for example Fogel 2004).

The most interesting effect is observed for the generalised cost measures. In fact, all other influence factors being accounted for, accessibility (here computed as the sum of the road and public transport accessibilities) to population has a significant positive effect on mobility. The inverse holds for the price index variable: the negative effect implies that higher transport price levels cause lower mobility and vice-versa. These findings suggest that reductions in generalised costs do indeed increase travel demand.

The same conclusions hold for the other mobility indicators. Accessibility has a significant positive influence, travel price a negative one on all endogenous variables. The only endogenous variable for which this does not hold is total out-of-home duration. However, as this variable is part of a succession of reciprocal effects between the other endogenous variables (see Figure 9), all influenced positively by the accessibility variable, the total effect of increasing accessibility on out-of-home duration is positive in turn, as shown in the next section.

As far as trip chaining, defined here as the average number of trips in a home-to-home tour, is concerned, the model shows that, with decreasing generalised travel costs, the propensity to chain trips seems to increase, as contrary to the postulated effect of the cheaper home trip between two activities. Thus, additional trips are integrated into existing chains rather than generating new tours. An argument for this observation is that the increased distances (see below) place the travellers at locations from which a return home is not reasonably possible anymore.

The relative valuations for the generalised cost variables in the various sub-models, as well as the total effects induced by the generalised costs and the interrelations between the endogenous variables, will be discussed in the next section.

7. Demand elasticities

Elasticities for the various demand variables are better suited for

the assessment of effects than the consideration of raw parameter values. The values are computed at the sample means for all variables and reflect the estimated effect of a 1 per cent increase in accessibility, respectively price index, on the endogenous variables. The results shown in Table 4 for the SEM include both the effects of accessibility and price index on all dependent variables and the direct influences of the endogenous variables on one another, resulting from the coefficients shown in Figure 9.

Table 4 Accessibility and price index elasticities for GLM and SEM models

Demand elasticity	Value
Weekday mobility	0.61
Number of trips	0.44
Accessibility	
Number of trips per home-to-home tour	0.24
Total out-of-home duration	0.10
Total trip distance	1.14

Weekday mobility	-0.06
Number of trips	-0.19
Price index	
Number of trips per home-to-home tour	-1.66
Total out-of-home duration	-0.84
Total trip distance	-1.95

The values imply that, as a consequence of accessibility increasing by 1 per cent:

- the share of mobiles increase by 0.6 per cent;
- 0.4 per cent more trips will be carried out;
- the number of trips per journey will increase by 0.2 per cent, thus people will form slightly more complex trip chains;
- travelled distances will increase by 1.1 per cent.

The very high elasticities for travelled distances are rather surprising at first sight, as they imply that a one per cent increase in accessibility will generate roughly the equivalent relative increase in daily mileage. The historical data confirm this trend though (mileage increased substantially over time, from 26 kilometres per day in 1974 up to 40 in 2005). Thus, as a result of a 10 per cent increase in accessibility, the daily distance travelled by an average individual would increase by roughly 4 kilometres (that is, from 40 to 44 kilometres per day).

The findings suggest a substantial influence of changed generalised costs of travel (as implied by the rising accessibility and decreasing price index) on individual mobility and trip generation. Thus, accounting for relevant socioeconomic influences, an induced travel effect for demand generation of substantial size has been found.

However, the investment needed to increase it by about 3% since 1970 should be kept in mind when conducting such thought experiments. Further investigations on the necessary efforts to bring about substantial accessibility increases are discussed in the following section.

8. Interpretation of the results

The efforts that would be necessary to bring about massive accessibility increases from the already high current levels were assessed by the means of fictive scenarios. It was expected that even large projects would induce only slight effects on global accessibility values and thus the induced effects on travelled distances should remain minor. The scenarios that were evaluated (using the Swiss road network model) include:

- a global reduction of all travel times by 10, respectively 25, per cent (with no new traffic assignment step);
- a capacity increase of one additional lane on all national roads, respectively on all roads in the canton of Zurich (and the subsequent computation of resulting travel times by a new traffic assignment step);
- an increase of maximum speeds on all national roads by 10 kilometres per hour, respectively on all roads in the network model by 10 kilometres per hour (and the subsequent computation of resulting travel times by a new traffic assignment step).

The population weighted distribution of the accessibility increases induced by these scenarios is shown in Figure 11. Even the dramatic investments needed to bring about capacity increases as drastic as implied by the scenarios would lead to under-proportional accessibility increases and thus have little impact on induced traffic on an aggregate scale.

However, the effects on a local scale could be quite sensible, as represented by the outliers in Figure 11. In the fictive example of a 10 per cent increase in maximum speeds, accessibility for certain municipalities would increase by 7.5 per cent, thus leading to approximately 3 per cent more trips made by the residents of that region (as implied by the demand elasticities shown above).

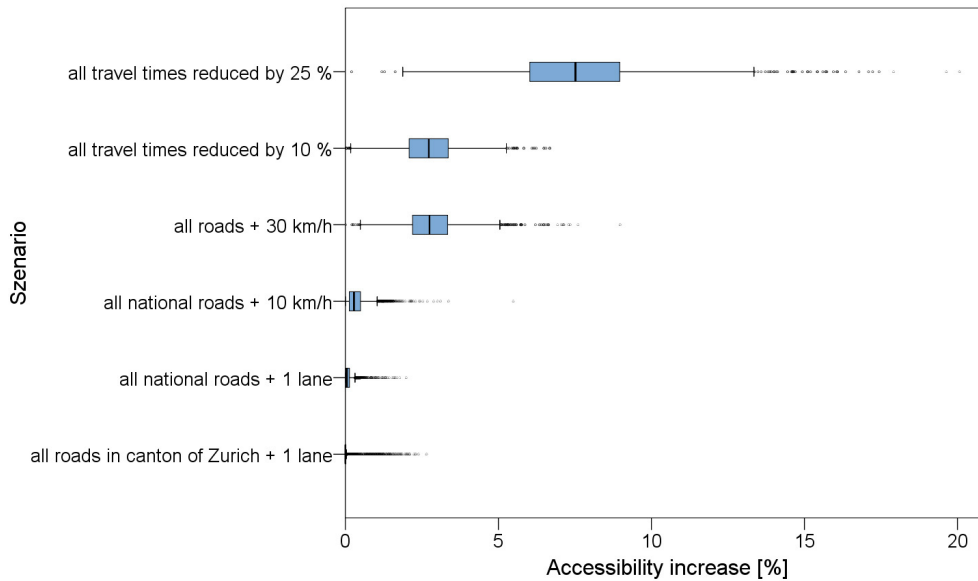


Fig. 11 Distribution of accessibility changes in various scenarios

9. Application for policy assessment

The following procedure (schematically displayed in Figure 12) is recommended for applying the models described in the present work.

First, new travel times should be computed at the existing demand level by the means of a new traffic assignment step to the modified network model. These travel times can then be used to calculate new accessibility values for all the relevant municipalities. By applying the abovementioned demand elasticities, the origin-destination-matrix will be updated using the new accessibilities (that is, the new traffic generation will be computed). The resulting matrix should then again be assigned to the network in order to recalculate the travel times.

These steps may need to be iterated several times until consistency

between travel times (respectively, accessibilities) and travel demand is reached (that is, until a stable equilibrium state – using pre-established threshold values – is achieved).

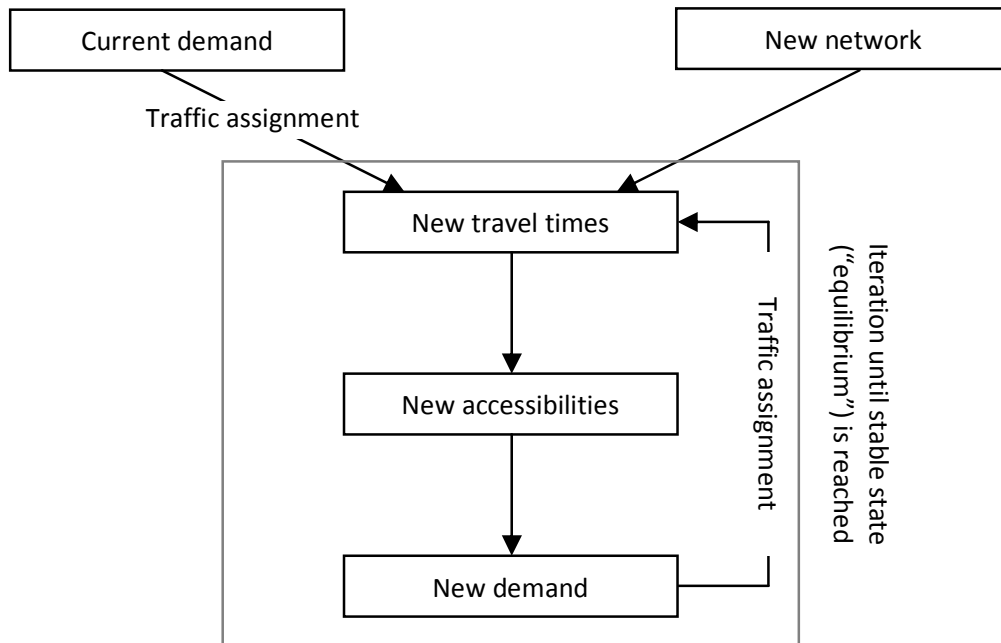


Fig. 12 Application procedure

10. Conclusion and outlook

The hypotheses postulated in the introduction were confirmed by the results obtained through the estimation of the *structural equations* model. Decreases in generalised costs of travel are found to induce higher mobility at the cohort level, as the significant effects of the accessibility measure and price index, used as approximations for generalised costs, on mobility behaviour confirm. The substantial induced travel effect on the upper levels of travel demand generation is certainly a policy relevant finding that has, to the authors' best knowledge, so far not been shown in the literature. It has to be noted however, that the induced travel effects are attenuated by the difficulty to generate substantial accessibility increases on an aggregated level.

Further work will test the trends exhibited by these first results on a disaggregated level. A five day household travel diary survey will be conducted. Based on the resulting data, the general

conditions for a given day of the household will be altered, thus leading to changes in generalised costs for the planned activity schedule. The household will then be asked to adapt their schedule to the hypothetical situation by the means of an interactive software tool.

It is hoped that this experiment will lead to further estimates of the elasticities of the relevant travel demand dimensions and help to validate the results that were obtained on the aggregate scale. The results will help to improve the modelling of demand induced by changing the generalised costs in agent-based travel demand micro-simulations, such as MATSim (Balmer 2008), which will also be used for the validation and an application of the obtained results, especially as far as feedbacks from the transport system (again modifying the generalised costs) are concerned.

Acknowledgments The authors gratefully acknowledge the financial support of the SBT-Fonds administered by the Swiss Association of Transport Engineers (SVI 2004/012) and the advice of the steering committee chaired by Michel Simon, also including Helmut Honermann, René Zbinden, Samuel Waldvogel and Stefan Dasen.

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