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MODEL FOR SUPPLY-DEPENDENT MODAL CHOICE BEHAVIOUR IN URBAN PASSENGER TRANSPORT

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Abstract

In the course of the past two decades, numerous models for determining the choice of transport modes have been developed, and have been continuously improved and sophisticated. An analysis of approximately 25 papers from 1984 [2] deals among other topics with research reports published since 1970 on the subject of 'modal-split'. However, all models proved too insensitive to estimate the effects of demand-influencing measures on transport phenomena. These may, for example, include the reaction of the population to fuel price increases, the introduction of so-called 'environmental tickets' in public transport, parking restrictions in inner-city areas, measures to speed up public transport services or improve their punctuality or increased parking fees for private cars. In each case, the question is: What effect does such a measure have on the expected shift in traffic flows between the various means of transport available in urban transport (walking, cycling, car, bus, light-rail, underground, regional express system (S-Bahn))? The answer to this question in particular forms the overall basis for deciding in favour of or against a specific measure. The decision base may be the transport economics, transport planning, transport policy or environmental policy level. The disadvantages of insufficient sensitivity in the models noted above have still not been eliminated, especially as they fail to achieve adequate qualification of the intricately interlinked supply structures of walking, cycling, public transport and private car transport together with personal income situations.

Keywords: transport, passenger transport, urban transport.

1. Initial Situation

In the course of the past two decades, numerous models for determining the choice of transport modes have been developed, and have continuously been improved and sophisticated. An analysis of approximately 25 papers from 1984 [2] deals among other topics with research reports published since 1970 on the subject of 'modal-split'. However, all models proved too insensitive to estimate the effects of demand-influencing measures on transport phenomena. These may, for example, include the reaction of the population to fuel price increases, the introduction of so-called 'environmental tickets' in public transport, parking restrictions in inner city areas, measures to speed up public transport services or improve their punctuality or increased parking fees for private cars. In each case, the question is: What effect does such a measure have on the expected shift in traffic flows between the various means of transport available in urban transport (walking, cycling, car, bus, light-rail, underground, regional express system (S-Bahn))? The answer to this question in particular forms the overall basis for deciding in favour of or against a specific measure. The decision base may be the transport economics, transport planning, transport policy or environmental policy level. The disadvantages of insufficient sensitivity in the models noted above have still not been eliminated, especially as they fail to achieve adequate quantification of the intricately interlinked supply structures of walking, cycling, public transport and private car transport together with personal income situations.

This problem complex and its effects on the quantification of cause – effect relationships in urban passenger transport may be illustrated by the following example.

A transit authority introduces a low-priced monthly season ticket (environmental ticket) for its entire network. Censuses are conducted prior to the introduction of this measure and after they have been implemented for 12 months, to provide information on the demand-enhancing effects of this pricing measure. The results of this before and after comparison are then usually claimed as an effect of the pricing measure, and may possibly be used as the basis for a similar decision by transit authorities with different public and private transport supply structures.

This can, however, lead to grave misinterpretations, since other demand-determining supply parameters may also have changed well over the same 12-month period, e.g.

- an increase in net income levels with effects on car use,
- altered parking situation,
- fuel price changes,
- slower-moving traffic due to higher car density, etc.

Only if these real influences are modelled will it be possible to isolate a useful value for the effects of the 'environmental ticket', since the census count is an undifferentiated value reflecting the overall effect of all influences including the synergetic effect and is valid solely for the specific supply configuration at the time of the census in a specific transport area. The same measure may have completely different effects under different constraints.

The present study could largely close the current gap in our knowledge of the modal-split. The starting point for analysis was the recognition that all previous models are basically behaviour-oriented. Since, however, behaviour is 'the reaction to internal or external stimuli, insofar as these are regular or can be predicted and analyzed with a high degree of probability on the basis of known situational parameters' [3], the anticipated demand reactions to supply-side changes in urban transport will be calculable only if reactions under corresponding situational parameters have previously been observed and modelled. The new approach emerging in from this 'weak-spot analysis' circumvents the need for measure-related observation of behaviour and situational parameters; it relies instead on quantification of the actual motives for the behaviour. The procedure is broadly comparable with attempts to find a therapy which will tackle the causes of headaches instead of merely treating their symptoms.

2. Formulating Transport Resistance

The key factor in any model of transport events is the formulation of *transport resistance*, and primarily the behaviour-consistent quantification of transport resistance, which entails modelling all individual components of a relocation event. This comprehensive analysis of resistance is all too frequently neglected, so that the effects of resistance components which have been ignored or insufficiently considered are noted only when sub-resistances are being operatively processed by the chosen calculation algorithm as part of a global calibration. As a result, influencing parameters which help to determine transport behaviour and hence the exceptionally com complex cause–effect relationships in urban transport are often lost as operational variables. The general applicability of the models or even the approach itself is then limited.

In view of these fundamental considerations, an attempt has therefore been made to formulate the transport resistance variable as comprehensively as possible, covering both quantitative and qualitative aspects, in order to obtain realistic and largely reliable predictions for transport practice.

The objective of the study was to formulate the resistance for a journey in such a way as to take into account the resistance components with which the potential transport user is – more or less consciously – confronted in the real market, and from which a high level of sensitivity to the measure may also be expected. In general, the decisive factors for a choice of transport mode (i.e. the market response to offers) are, on the one hand, the local and temporal availability of the competing transport modes (walking, cycling, private and public transport), and, on the other hand, the cost involved in their use. The latter aspect can, however, provide useful indicators only if it is directly weighted by its counterpart, the transport user's income.

Consequently, apart from the current income structure of the population in the area under study, the following market-relevant resistance elements for the different transport systems may be discerned:

- Public transport
  - type of transport (bus/tram, underground/light-rail, regional express system),
  - walking distances at beginning and end of the journey (local availability),
  - frequency of service (temporal availability),
  - travel time/speed,
  - transfer requirement/time,
  - fare level/structure.
- Private transport
  - walking distance from house to car,
  - travel time/speed,
  - time spent looking for a parking spot,
  - parking costs,
  - walking distance from car to destination,
  - speed-dependent fuel consumption,
  - fuel price,
  - car running costs (excluding tax and insurance),
  - car occupancy.
- Pedestrian and cycle transport
  - land-use structure (large city, small town, rural area),
  - topography (flat, hilly),
  - road/path network (cycle tracks, pedestrian precincts).

Generally speaking, these supply attributes are comparatively easy to determine. This will be an important factor in practical application of the approach, since costly data acquisition measures are unnecessary.

The new approach is based on the hypothesis that it is possible to determine behaviour and hence, via an algorithm, the modal split, directly from the various physically measurable or calculable supply parameters and from (more or less conscious) basic human attitudes.

This logically implies the formulations of global resistance specified below for different transport modes.

- Public transport

$$w_{OV_{ges}} = t_{Fan} \cdot ZB_F + t_w \cdot ZB_w + \sum t_B + \sum t_u \cdot ZB_U + t_{Fab} \cdot ZB_F + w_K$$

where

$w_{OV_{ges}}$ Total resistance for the relationship under consideration with a public transport mode.

t_{Fan} Access time from the origin of the journey to the boarding stop/station. This value represents the local availability of the public transport mode in the originating area of the journey and is dependent on stopping-point density.

t_w Waiting time at the stop/station. The waiting time is a function of the supply component 'frequency of service' and represents the temporal availability of public transport.

t_B Travel time by public transport (where vehicle transfers are required, the individual travel times for the different sections of the journey are totalled).

t_U Transfer time(s) if different public transport routes or means are used.

t_{Fab} Egress time from debarking stop to destination (see t_{Fan}).

ZB Time evaluation factor for subjective weighting of the real time values t (indices as for corresponding time value).

w_K Resistance components for monetary expenditures for the journey (travel costs, fare structure).

– Private transport

$$w_{MIVges} = (t_{Fan} \cdot ZB_{Fan} + t_B + t_{PS} \cdot ZB_{PS} + t_{Fab} \cdot ZB_{Fab}) \cdot ZB_{MIV}$$

$$+ w_{KBetr.} + WK_{Benzin} + w_{KParken}$$

where

t_f, t_B, ZB Public-transport-analogous resistance components in private transport.

t_{PS} Parking search time in the destination area.

ZB_{MIV} Subjective evaluation of sum of weighted time components in private transport.

w_K Resistance components deriving from the monetary expenditures for the journey by private transport; the operating costs (Betr.) quantify the distance-dependent provision costs; the fuel costs (Benzin) are calculated as a function of the average travel speed, the distance and the fuel price; parking costs (Parken) may represent an additional resistance component.

All resistance parameters with the exception of the time evaluation factors are comparatively easy to obtain from such documentation as timetables, fare lists, route and stopping-point plans, street maps, current fuel prices, parking space and cost situation, etc. This represents a substantial simplification of data collection in the practical application of this resistance formulation.

The curves shown in Graphs 1 to 3 in [1] were used to infer the time evaluation factor ZB for public transport.

Investigations of the subjective evaluation of the individual time components for private transport yielded the following results:

$$ZB_{Fan} = 1.0,$$
$$ZB_{PS} = 2.0,$$
$$ZB_{Fab} = 2.0.$$

The function shown in Graph 4 was determined for the estimate of total travel time in private transport ZB_{MIV}.

Transport phenomena in the general sense are dependent on the specific transport resistance. Mobility, as the sum of all relocations (by number and journey distance), may therefore be regarded as a function of the global system resistance (see [1] for more details), while the trip distribution is dependent on the mode specific resistances and the choice of mode is the result of a more or less rational estimation of the advantages and disadvantages of the efforts required (resistances) for the use of competing alternative modes of transport. Economic constraints, i.e. costs and income, are undeniably relevant influencing parameters in all the above decision-making processes. For a transport model based on transport resistances, this implies that costs and income are essential inputs to the model, especially if problems of transport economics need to be considered.

The problem which had to be solved was thus to transform cost variables – weighted by income variables – into resistance values compatible with the subjectively-weighted, travel time equivalent journey time components. A possible solution is to weight the costs K for a yourney with net income E related to e.g. 1 minute, taking into account the proportion a of this income which the traveller is prepared to accept in the form of transport costs. The cost resistance w_K may therefore be formulated as follows:

$$w_K = \frac{K[DM/\text{journey and person}]}{\alpha \cdot E(DM/\text{min})}$$

The resulting dimension [min/journey] ensures compatibility with the time-oriented resistance components.

A value of $\alpha_{OV} = 0.17$ was obtained for the cost-resistance equivalence factor for public transport.

With private transport, a values of 0.43 are obtained for the operating/fuel costs and a value of 0.34 for the parking costs.

This provides the basis for a supply-dependent formulation of the subjective resistances experienced by the potential transport user to public and private transport.

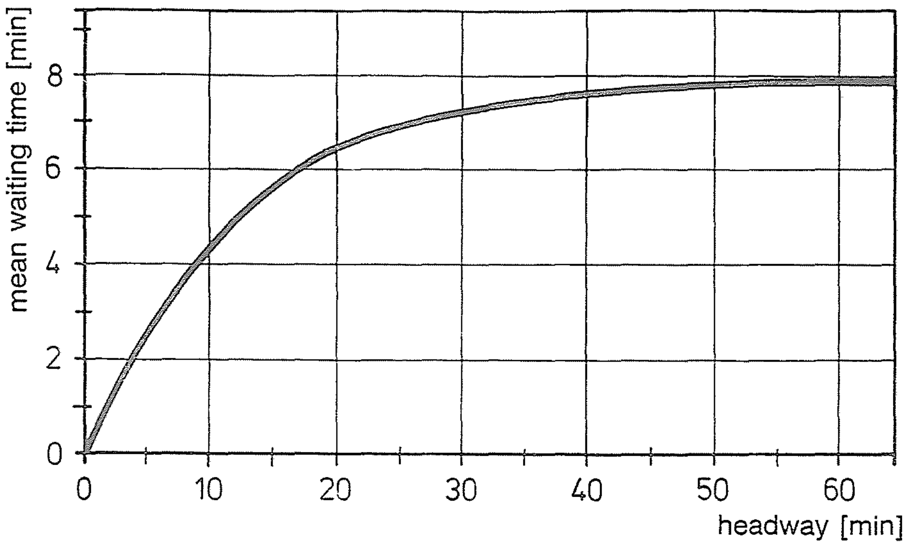

Fig. 1. Time evaluation functions for walking times to and from stops/stations with public transport

Trip-distance-dependent resistance functions were inferred for walking and cycling in large cities, medium-sized towns and rural regions; these need not be discussed in detail in the present context.

3. Validation

The method used to verify the above-described hypothesis on the formulation of transport resistance was as follows. Combining examples of previously conducted before-and-after censuses with demand-modifying measures in urban areas, the modal-split was first modelled for both the 'before' and the 'after' situation, and the resulting change in demand compared with the census figures. The Kirchhoff rule adapted from electrical engineering applications was used as the split algorithm.

To increase the accuracy of the model, changes in demand due to generated trips (new trips or lost trips) were taken into account in addition to diversion. The generated trip value is also calculated on the basis of subjectively perceived components of the transport resistances for all transport modes. Potential exhaustion functions clarifying the relationship between supply modifications and the time-lagged market reaction can also be developed. These reflect both the intensity of supply-side changes and the influence of advertising campaigns.

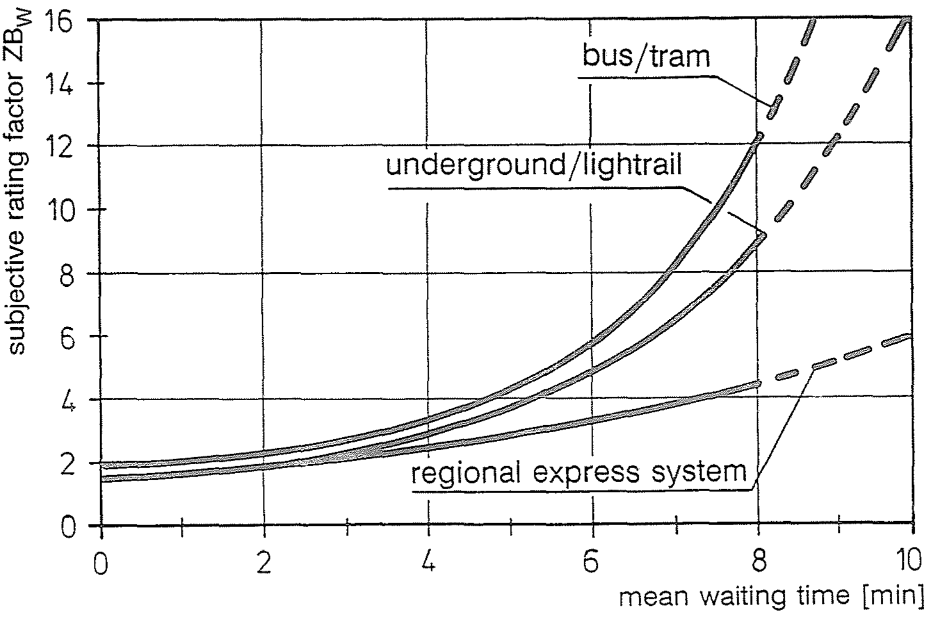

Fig. 2. Time evaluation functions for waiting time at boarding stops/stations with public transport

For practical application of the above research results, the PNV-SPLIT modal-split/elasticity model developed by VIA [4] provided a programme structure which could be updated to match recent insights. The final results of the comparative calculations are collated in *Table 1.*

It could also be shown that the new approach allows prediction of the proportion of captive drivers and captive riders per area, dispensing with the need for preliminary identification of the 'free-choosers'.

On the basis of the results, it may be assumed that the research objective of verifying the hypothesis for the formulation of a measure-reactive resistance in urban transport has been attained. Practical application of the research results is discussed in [1], with the aid of detailed calculated examples.

4. Other Applications

The validation of the above-presented resistance formula is essentially confined to examples from public transport. (The need to adopt this procedure has been justified in detail in [1]). It should not, however, be con-

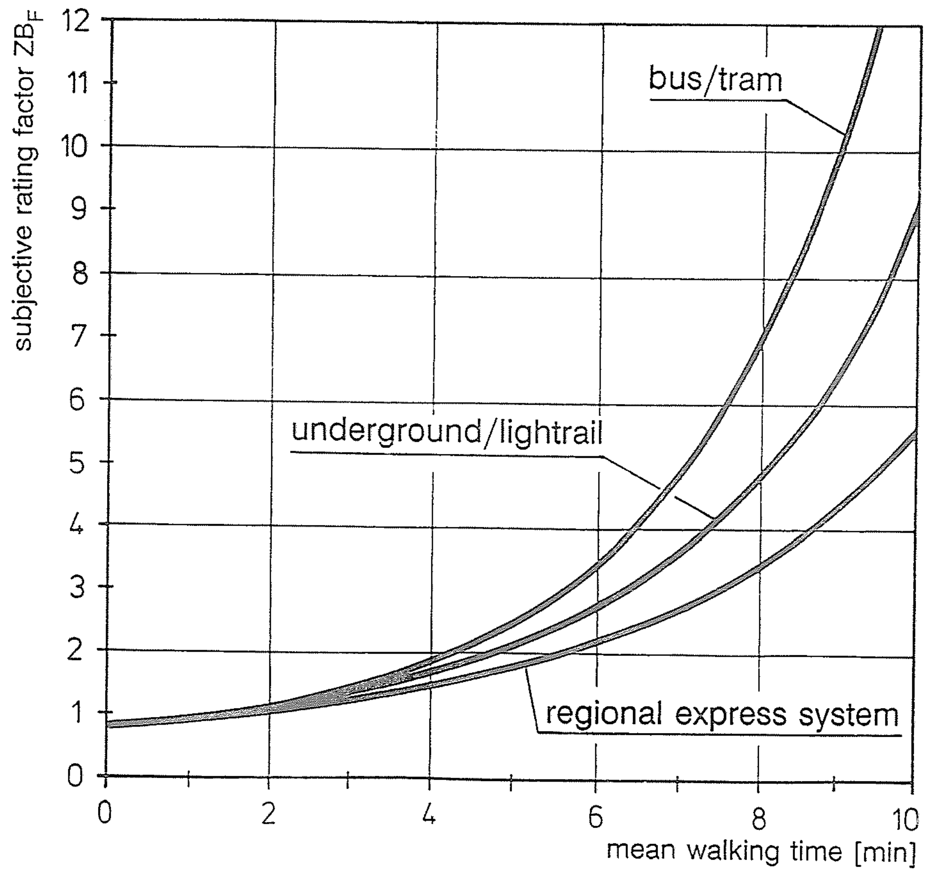

Fig. 3. Time evaluation functions for mean transfer time in public transport

cluded that applications are likewise restricted to this sector of overall urban transport. As indicated by the examples, it is necessary to take all the parameters of each resistance of the competing modes into account in any effectiveness calculation, allowing calculation of the effects of a change in any parameter on the demand for any transport mode. It is important that the initial situation together with the prevailing supply structure of the transport modes and the socio-economic environment in the reference year should be established. On this basis, questions on the anticipated market reaction to complex changes in supply and costs structures can then be answered with comparative ease. It should, however, be emphasized that the

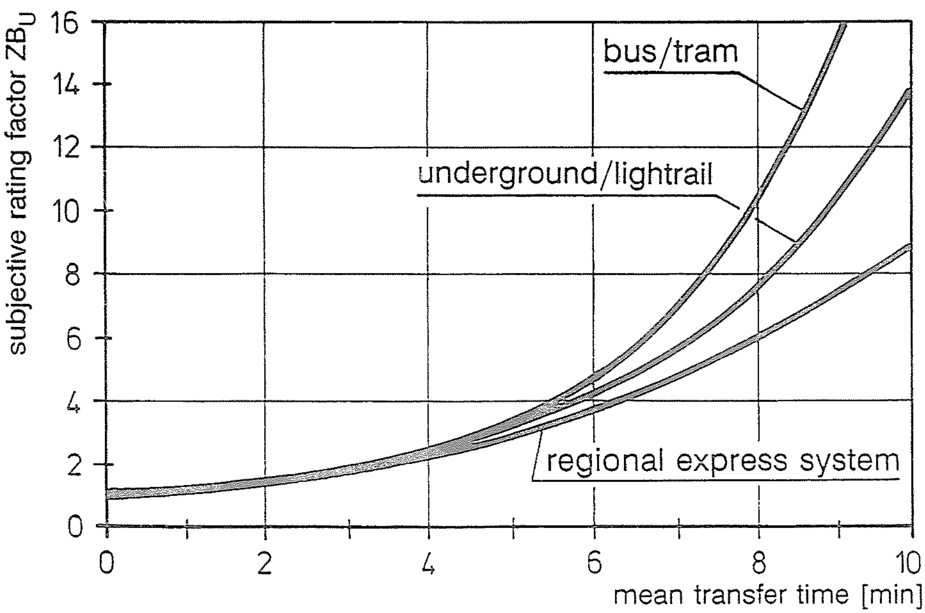

Fig. 4. Mean evaluation of private transport travel time

predictions are valid only in relation to a given initial situation and are not automatically transferable to other areas.

Answers can be found to the following possible question complexes (in addition to the cases already outlined above):

- What will be the effects of an increase in fuel prices (e.g. due to higher mineral oil taxes) on public transport demand and on overall fuel consumption in the area under study?
- What public transport fare measures will reduce car traffic, and to what extent?
- What will be the effects on demand for public and private transport and on fuel consumption (or pollutant emissions) of an increase in parking charges or a reduction in the number of parking slots available in innercity areas?
- After what period will a specific measure have a particular effect?
- How great will be the diversion between transport modes and generated new or lost trips once a measure takes effect?
- Where there are trip increases due to packages of measures, what proportion of the increase may be attributed to specific submeasures?

Table 1

Comparison of the effects of measures on public transport demand as shown by census results and as predicted by the PNV-SPLIT model

EXAMPLE	YEAR	MEASURES	CHANGES IN DEMAND FOR PUBLIC TRANSPORT MODEL	CENSUS/POLL
Tübingen	1985 to 1989	– Improved route structure – Increased frequency – Fare measures (staggered)	+ 42.0%	+ 40.8 %
H-Bahn Dortmund (University)	1984	– Introduction of system (initially free)	49.0% of users were former car-users; 33.5% were pedestrians; 16.6% were cyclists	44.5% of users were former car-users; 38.5% were pedestrians; 16.6% were cyclists
	1985	– Introduction of half-yearly tickets (equivalent to monthly season ticket for an average price of DM 2.76 for 30 journeys/ticket or DM 0.092/journey acc. to VÖV statistics 1986)	−4.1% (considering 35% VRR passengers with tickets valid for H-Bahn)	−4.4% of
S-Bahn Düsseldorf	1967/ 1968	– Shift from SPNV to regional express system – Headway decrease from 30' to 15' – 11 stops instead of 6 – Reduction of train speed from 54 km/h to 40 km/h through extra stops	+29.8%	+30%
Mannheim Rheinau-Süd	1985	– Headway decrease from 30' to 15'and gradual introduction of free weekly season tickets ('getting-to-know-you tickets')	+31.3% (headway decrease) 44.1% (headway decrease and free)	Between + 33% and +46% (depending on number of 'getting-to-know-you' tickets')
Hamm	1988/ 1989	No changes in transport supply	+1.1%	+1.3%

(This question presents itself, for example, where income has to be shared out within transport associations or where cost allocation plays a part in determining success).

- How large is the synergetic effect when various measures are combined?
- How large is the potential for traffic diversion to public transport in highly-loaded corridors and what strategies can be used to realize it?

This random selection of questions on urban transport and on its influencability and the predictability of effects indicate the wide range of practical applications for the research results in the fields of transport economics, transport policy making and transport planning. For strategy discussions in particular, they provide a theoretical base and, with the PNV-SPLIT model, an effective tool for creating a decision making base quickly (without costly expert studies); if the initial situation (supply structure at a specific time) for the questions has once been fixed, the predicted results for the complex cause–effect relationships following a modification in the relevant supply parameters can be invoked at the 'press of a button' and can then be discussed immediately in the appropriate decision-making body and modified as necessary.

In many cases, time- and cost-intensive market research will be unnecessary since the behaviour of the transport users, which they are intended to determine, is made largely calculable by the new research results on resistance formulation presented in this paper. It is now possible to infer the transport behaviour and hence the modal-split directly from the physically measurable or calculable supply parameters of the various transport modes (walking, cycling, bus, light-rail/underground, regional express system, car) and from basic human attitudes to transport resistances.

5. Conclusions

- Each transport-mode-specific supply is important only in the context of the overall supply situation composed of the competing transport modes and the economic environment.
- Consequently, it is very rarely possible to transfer observed market reactions to a measure to other areas.
- Elasticity models which fail to take account of non-motorized trips (walking and cycling) should not be used to predict urban transport, owing to the travel- distance related demand structure. This applies equally to models which take no account of generated trips (new trips or lost trips).

- If the period intervening between the two censuses is not taken into account in interpreting the results of a before-and-after study, incorrect conclusions on the effects of the measures under consideration cannot be excluded.
- Advertising measures affect market response time rather than behaviour itself.

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