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Abstract

This paper proposes ways to improve MATSim destination choice for discretionary activities. Naturally, small-scale destination choice models can feature a much higher level of detail than large-scale microsimulation scenarios. This upscaling problem mainly concerns data availability and computational limitations, but, due to the relative novelty of microsimulation destination choice models, also a certain implementation lag exists. This paper discusses on the example of MATSim and in a preliminary sense, where upscaling of small-scale findings for application in large-scale microsimulation scenarios is possible and potentially beneficial.

1 Introduction and Problem

Modeling destination choice for discretionary activities (e.g., shopping and leisure) involves a broad range of disciplines having produced an ample body of research (see Section 2.1). Naturally, a relatively large gap exists between this broad basis of knowledge and its application in large-scale transport microsimulations. Main barriers for application of state-of-art complex destination choice models in microsimulations, are lack of required large-scale data, computational issues and, due to the relative novelty of microsimulations and possibly catalyzed by the fist two barriers, a certain lack of recent implementation progress.

This paper discusses, in a preliminary sense, where upscaling of small-scale findings for application in large-scale microsimulation scenarios is possible and potentially beneficial.

The significance of the upscaling problem is often overlooked, when taking a strictly theoretical focus as its sources are rooted in practice. Consequently, to not miss the crux of the matter, the investigation needs to be grounded on a specific model and specific data. Thus, MATSim, in particular its recently implemented destination choice module, and the Swiss data readily available to modelers is focused.

2 Review

2.1 Small-Scale Destination Choice Models

Shopping and leisure destination choice spans multiple research fields, amongst others transport and urban planning, marketing and retailing science, economics, geography and psychology (see e.g., Brunner and Mason, 1968, Erath *et al.*, 2007, Erath, 2005, Arentze and Timmermans, 2007, Bell *et al.*, 1998, Handy and Clifton, 2001, Orgel, 1997, Bawa and Ghosh, 1999, Baltas and Papastathopoulou, 2003, Innes *et al.*, 1990, Recker and Kostyniuk, 1978, Timmermans, 2008, Timmermans and van der Waerden, 1992, Timmermans *et al.*, 1982, van der Waerden *et al.*, 1998, Yang *et al.*, 2009, O'Kelly, 1983, Kitamura *et al.*, 1998, Barnard, 1987, Bekhor and Prashker, 2008, Burnett, 1977, Davies *et al.*, 2001, Hirsh *et al.*, 1986, Kahn and Schmittlein, 1989, Kim and Park, 1997, Bell, 1999, Teller and Reutterer, 2008) and also Timmermans *et al.* (1992, p.178). Many transport models are based on the discrete choice framework (McFadden, 1978) or production system models (Gärling *et al.*, 1994, p.356). A review combining these different fields is not yet existing but planned as a continuation of this paper.

Prominent choice determinants are *travel time*, *travel distance* and *price and quality level*. The influence of person attributes on store choice is studied in e. g., Uncles (1996), Shim and Eastlick (1998). Many researchers additionally incorporate constraints given by e. g., store opening hours or by the travel time budgets defined within the individuals activity chains (e. g., Arentze and Timmermans, 2005, Delleart *et al.*, 1998, Kitamura, 1984). The moderating influence of the costumers' store loyalty on the choice process is examined in East *et al.* (1998), Knox and Denison (2000). Studies considering region of Zurich are Carrasco (2008), Kawasaki and Axhausen (2009), Horni *et al.* (2012).

2.2 Large-Scale Transport Microsimulation Destination Choice Models

In the microsimulation community the term *microsimulation* is ambiguously used, sometimes denoting movement simulation of persons and vehicles (as a replacement of volume-delay functions in aggregate models) and sometimes additionally including preceding choice processes. As we focus on destination choice, we are interested in comprehensive simulators only and, thus, we use the term microsimulation in this sense throughout the paper. Numerous transport microsimulations are available, amongst others ALBATROSS, AMOS, OpenAmos, CEMDAP, MERLIN, MOBITOPP, New Yorks Best Practice Model, PCATS, Ramblas, San Francisco microsimulation model, TASHA, TRANSIMS, VISEM & Vissim.

However, literature reviews such as Algers *et al.* (1998), Henson and Goulias (2006) are rare and only cover the very basics of each model. An overview of the destination choice models applied in large-scale microsimulation is planned as a continuation of this paper.

MATSim destination choice is discussed in Section 2.4.

2.3 Data Availability

According to the authors' experience and personal communication, Swiss data base mainly provided by BfS (2011) is comfortable; it can thus be interpreted as an upper bound for governmental data availability.

The main Swiss data sets used in MATSim are:

- Census of Population (Swiss Federal Statistical Office, 2000), a full survey, applied to create the MATSim population, including their home and work locations on hectare and municipality level respectively,

- National Travel Survey (Swiss Federal Statistical Office, 2006), an approx. 30'000 person sample, used for MATSim demand creation (activity chains and times)
- Business Census (Swiss Federal Statistical Office, 2001), identifying enterprises at hectare level, utilized for creation of activity locations,
- Network Data, (TomTom MultiNet, 2011, NAVTEQ, 2011, Vrtic *et al.*, 2005), spanning navigation and planning networks,
- Road Counts, (e.g., ASTRA, 2006), specifying hourly traffic volumes per lane, mainly applied for MATSim validation.

Data covering only Zurich region concern parking supply data, green times (Balmer *et al.*, 2009), store service hours (Meister, 2008) and public transport lines and schedules (e.g., Rieser, 2010, p.70ff).

2.4 MATSim Destination Choice

2.4.1 MATSim—In Brief

MATSim is an activity-based, extendable, open source, multi-agent simulation toolkit implemented in JAVA and designed for large-scale scenarios and is a co-evolutionary model. A good overview of MATSim is given in Balmer *et al.* (2006). In competition for space-time slots on transportation infrastructure with all other agents, every agent iteratively optimizes its daily activity chain by *trial and error*. Every agent possesses a fixed amount of day plans memory, where each plan is composed of a daily activity chain and an associated utility value (in MATSim, called *plan score*).

Before plans are executed on the infrastructure in the network loading simulation (e. g., Cetin, 2005), a certain share of agents (usually around 10%) is allowed to select and clone a plan and to subsequently modify this cloned plan.

If an agent ends up with too many plans (usually set to "4-5 plans per agent"), the plan with the lowest score (configurable) is removed from the agent's memory. One iteration is completed by evaluating the agent's day described by the *selected* plan.

If an agent has obtained a new plan, as described above, then that plan is selected for execution in the subsequent network loading. If the agent has *not* obtained a new plan, then the agent selects from existing plans. The selection model is configurable. In many MATSim investigations, a model generating a logit distribution is used.

Computation of plan score is compatible with micro-economic foundations. The basic MATSim utility function was formulated in Charypar and Nagel (2005) from the *Vickrey* model for road congestion as described in Vickrey (1969) and Arnott *et al.* (1993). Plan utility described in detail in Charypar and Nagel (2005) is computed as the sum of all activity utilities plus the sum of all travel (dis)utilities.

2.4.2 State of MATSim Destination Choice

The Swiss Census of Population 2000 (Swiss Federal Statistical Office, 2000) can identify home and work locations for every Swiss resident at hectare and municipality level respectively. Clearly, such information cannot be logged for discretionary activities. However, to run an activity-based simulation, reasonable destinations for these activities must be assigned. First, a simple neighborhood search, as described in Balmer *et al.* (2009), was employed in a pre-processing step. That approach is not part of the optimization process and does not accurately model destination choice.

A first improvement in destination choice—including it in the optimization process—was introduced by Horni *et al.* (2009), based on Hägerstrand's time geography. However, unobserved heterogeneity was not taken into account explicitly in that module or in MATSim. Thus, a significant underestimation of travel demand resulted and the module could not be productively employed. Furthermore, that module is based on local search. Local search applicability, however, is questionable on discontinuous destination choice utility space.

MATSim has been made fully compatible with discrete choice methodology with the integration of the second destination choice module described in Horni *et al.* (2012).

MATSim and its destination choice module takes into account travel time and distance, travel costs, store size and competition effects at activity locations (Horni *et al.,* 2009). Agents' attributes taken into account in MATSim are age, mobility tools, occupancy, home and work location. Destinations are characterized by location, service hours and one of the types home, work, shop, leisure and education. For validation MATSim mainly uses road count data.

2.5 Upscaling Small- to Large-Scale Models

Concluding the Sections 2.1-2.4, the main barriers for upscaling small-scale findings for large-scale application in microsimulations are sketched in this section.

2.5.1 Limited Data Availability

Clearly, models of higher resolution, such as microsimulations, require more and different data than traditional methods (for activity-based models discussions see e.g., Axhausen (1997), Kitamura (1996)). Fortunately, data collection techniques have evolved in the same vein as the models; Nagel and Axhausen (2001, p.6) expect a "virtual explosion of data availability" besides others due the spread of novel communication devices, usually equipped with GPS units. However, data collection is generally associated with privacy, cost and technical issues (for example, precision of GPS and GSM data) generating hard limits of data availability, such that some needed data possibly will always be missing.

This is a serious problem as besides higher resolution and thus potentially higher accuracy, sensitivity to parameters and input data and thus to policy measures is often an argument for disaggregate rather than aggregate methods (Sbayti and Roden, 2010, p.4), (Lemp *et al.,* 2007). Consequently, a weak data base might annihilate the conceptual advantages of microsimulation models. Furthermore, validation as a crucial methodological modeling step, is limited by lack of data (McNally and Rindt, 2008, p.7). Question is here, to which extent local small-scale validation is applicable.

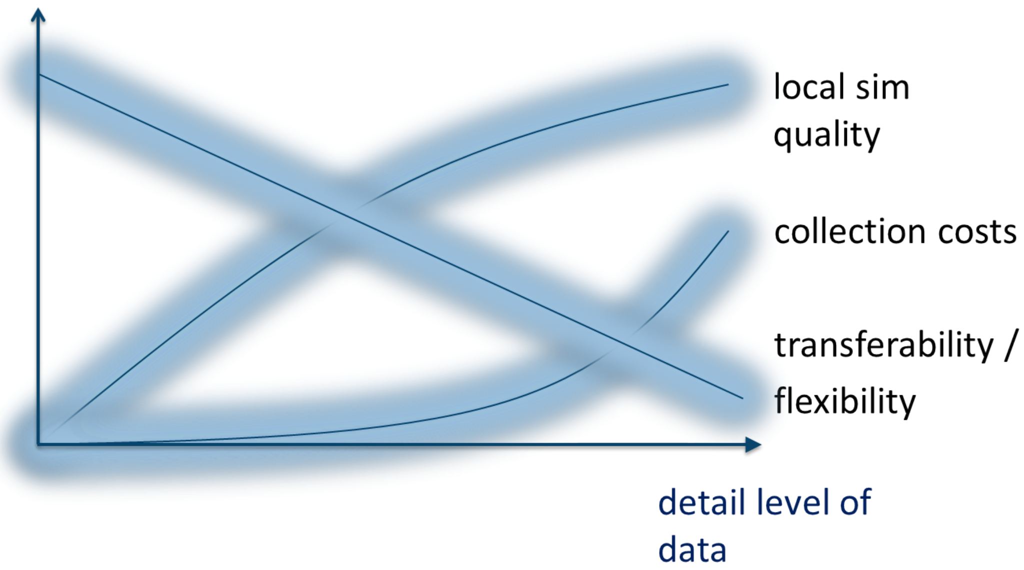
Reliable imputation methods are thus of great importance. Synthetic data can, although a priori only matching marginal distributions, generate value by capturing correlations correctly.

On the other hand, speaking against an extensive data base, models should be general, i.e., flexible and transferable Patriksson (1994, p.5), meaning that they are applicable without extensive data collection and model estimation efforts (see also Figure 1). In other words, data should be condensed in general model concepts.

2.5.2 Computational Difficulties

Another source, limiting fast progress in destination choice modeling, are computational issues. For example, destination choice is associated with large numbers of destinations potentially leading to very large choice sets. In large-scale scenarios this often represents a limiting factor. For a more elaborate discussion and approaches to deal with these problems see Horni *et al.* (2012). Another source for computational problems is the stochasticity of microsimulation runs (Horni *et al.,* 2011a). Dependent on the resolution levels, many simulations runs, i.e., samples are required, which limits level of sophistication for a single run.

Figure 1: Level of Detail



2.5.3 Implementation Backlog

Limited data availability and computational issues slow down implementation of destination choice models in microsimulations. In addition to these factors, the effort for model application in complex large-scale frameworks generates a certain implementation backlog. Clearly, while identifying efficient microsimulation improvements, emphasis should be put on implementation backlog as it is expected that it can be resolved comparatively easy.

3 Research Avenues

3.1 Further Heterogeneity of Agents and Alternatives: Prices and Income

Compared to the models mentioned in Section 2.1, MATSim attribute range and thus agents' and alternatives' heterogeneity is very limited. Prices and income and derived measures such as value-of-time (VOT) are essential and central in any econometric model, but they are not yet included in MATSim. Conceptually, prices and income are easy to survey as they are not subject to latency like other choice determinants. Practically, privacy issues and the large number of suppliers render data collection nevertheless difficult and costly.

To generate income models for Switzerland valuable sources are provided such as Swiss Federal Statistical Office (2008b, 2007, 2006). To get a more comprehensive model, usage of rents as a proxy for income could be inspected. At the price frontier very few data is available.

Important to test is spatial price and income heterogeneity, in other words, scale of wealth separation. Smaller heterogeneity means that model resolution must be higher to capture income and price differences. In conclusion, extensive spatial aggregation of incomes and prices thus harbors the risk of not exploiting microsimulation power. This might be true for other choice determinants as well.

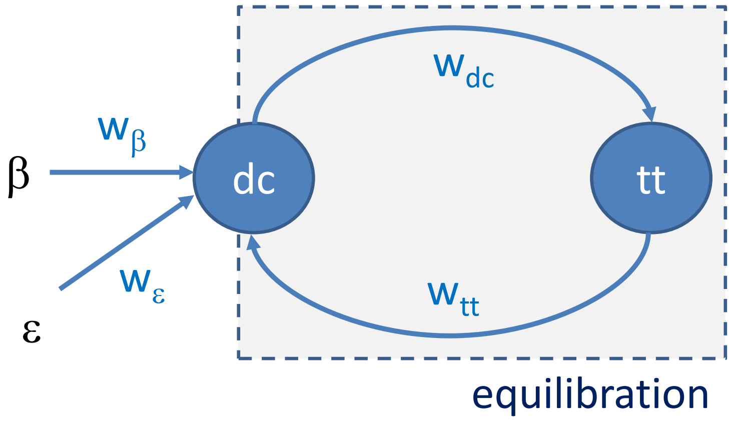
3.2 Destination Choice Equilibration

The central concept in transport modeling is equilibrium (e.g., Wardrop, 1952, Beckmann *et al.*, 1956). Traditionally, assignment procedures, modeling route choice, equilibrate static network flows given a fixed demand. While for route choice a strong influence of attributes governed by competition (e.g., travel time) can be assumed beyond doubt, this is less evident for destination choice. It is thus not clear to which extent destination choice actually needs to be subject of the iterative equilibration process of MATSim. Relaxing the strict equilibrium assumption has potential to strongly reduce the computational burden. In terms of behavioral base, papers, investigating the empirical basis of the convenient assumption of equilibrium (e.g., Mahmassani and Chang, 1986) should be consulted and their applicability to destination choice should be assessed.

3.3 Finer Activity Classification

The most frequently used Switzerland and Zurich scenario contain only 5 activity types (home, work, education, leisure and shop). Improved versions differentiating shopping and leisure activities (Horni *et al.*, 2011b) are available, but only in an experimental manner. The National Travel Surveys (Swiss Federal Statistical Office, 2006) and Swiss Federal Enterprise Census 2001 (Swiss Federal Statistical Office, 2008a) provide a relatively detailed classification of activities for demand and supply side respectively. Most activities are in principle performed by anybody, e.g., grocery and non-grocery shopping does not distinguish person groups. However, the exploitation of the data promises higher quality in particular in connection with agglomeration effects and multi-purpose shopping activities.

Figure 2: MATSim Destination Choice Equilibration



3.4 Spatial Correlations in Destination Choice

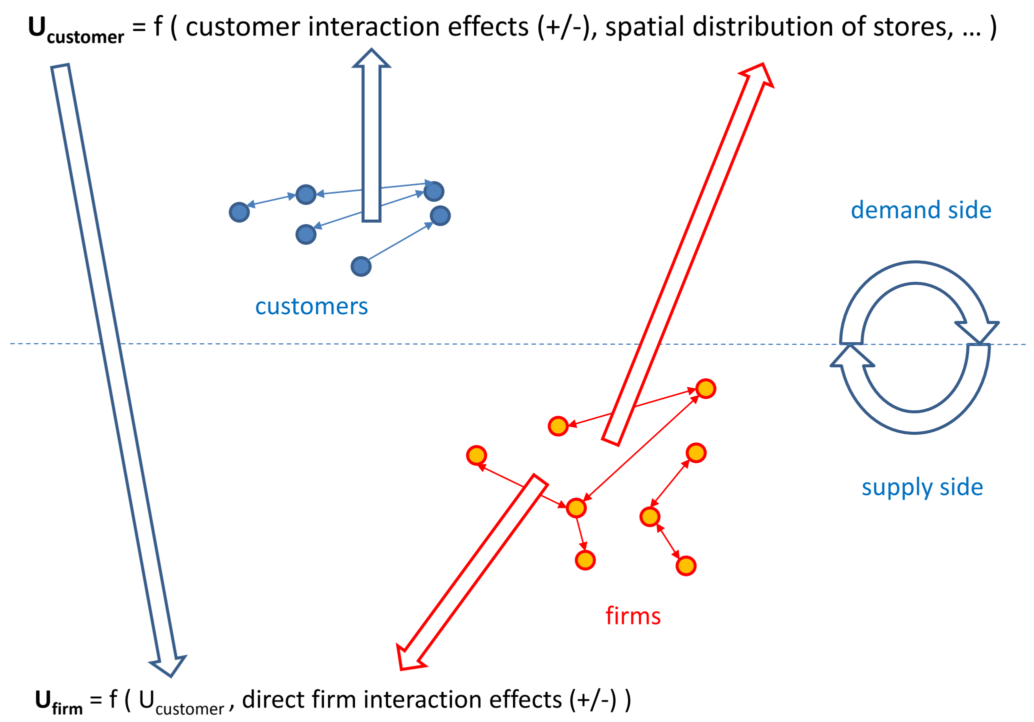
On both supply and demand side, interactions between actors, i.e., customers and firms (see Figure 3) exist, which are observable in spatially correlated destination and location choices and which materialize in agglomerations, a very important topic in economics. In this paper, spatial correlations in customers destination choices are focused.

3.4.1 Customer Interaction Effects at Activity Locations

The central influence of interaction in *transport infrastructure* for people's route and departure time choice has been recognized early (e. g., Pigou, 1920, Knight, 1924, Wardrop, 1952).

Similarly, agent interaction in *activities infrastructure* might affect *destination choice* (Axhausen, 2006), as it generally changes activity utility. Person interactions at activity locations can have positive or negative influence on persons' gained activity utility. Presence of other people at

Figure 3: Demand and Supply Side Interaction Effects



recreational places such as bars, discos or party locations usually increases utility, whereas competition for parking lots (see also Section 3.7) or crowdedness in shops clearly reduce utility (Albrecht, 2009, p.119ff). Marketing science literature provides ample evidence of significance of these effects (Baker *et al.*, 1994, p.331), (Eroglu and Harrell, 1986, Eroglu and Machleit, 1990, Eroglu *et al.*, 2005, Harrell *et al.*, 1980, Hui and Bateson, 1991, Pons *et al.*, 2006).

In modeling, supply side capacities, such as store sizes, parking facility sizes, number of cash points are common. However, demand and supply are only very seldom equilibrated. Rare examples are de Palma *et al.* (2007) for residential location choice and Vrtic (2005) for route and mode choice. Microsimulation models factoring in interaction effects in the activity infrastructure are Vovsha *et al.* (2002), Horni *et al.* (2009), Waraich and Axhausen (2011).

While the inclusion of destination interaction effects in microsimulations is conceptually expedient, before continuing this line of research, the magnitude of interaction effects, i.e., their significance, needs to be quantitatively researched (see also Section 3.2). Furthermore, capacity data is required but difficult to collect. For Switzerland, this might be solved by deriving capacities from the available disaggregate employment information (given by the number of full time equivalents) (Swiss Federal Statistical Office, 2008a). Future analyses must also answer the question if activity infrastructure load should be microsimulated (analog to the network loading simulation) or if the typical aggregate cost-load-curves can be applied approximately.

Different utility-load relationships must be assumed. In relatively static contexts with sharp capacity limits also utility-load function shows a sharp decrease at capacity limit. In more variable contexts, for example, inside stores or on very large parking sites, a softer form of utility-load function can be expected. An example, lying in-between, might are large restaurants.

Models taking into account spatial correlations can be efficiently estimated using copulas (Bhat and Sener, 2009).

3.4.2 Spatial Distribution of Destinations

Clustered destinations, i.e., agglomerations, help minimizing travel effort between the shopping activities of multi-stop shopping trips (see e.g., Bernardin *et al.* (2009, /p.144), Arentze *et al.* (1994, /p.89), Arentze *et al.* (2005), Popkowski Leszczyc *et al.* (2004), Messinger and Narasimhan (1997), Oppewal and Hoyoake (2004). Even for single-purpose shopping, agglomerations might be beneficial due to a risk reduction of not finding specific products at current location or if shopping is done as a leisure activity.

In conclusion, agglomerations generate utility beyond sum of single opportunities (see also Teller and Reutterer (2008), Teller (2008)). Including these effects in the models, and thus capturing frequencies at large shopping malls and nightlife areas better, is particularly important for weekend scenarios currently under development for MATSim. Models considering spatial distribution of destinations are Fotheringham (1985, 1983a,b), Fotheringham *et al.* (2001), Timmermans *et al.* (1992), Berry *et al.* (1962)

3.5 Choice Dimension Dependencies

In MATSim to date, essentially all combinations of choices of different dimensions (i.e., time-route-mode-destination choices) (see e.g., Hannes *et al.* (2008), Timmermans (1996), Cadwallader (1995)) are evaluated over the course of the iterations. However, replanning of agents' day plans is not done under consideration of choice dimensions' dependencies. A priori using knowledge about choice combinations, e.g., its likelihood, might generate a substantial speed-up, also relaxing the computational problems mentioned above.

3.6 Cognitive Spatial Models

Cognitive models of persons' spatial mental map are promising in destination choice context, in particular to get under control its large choice sets. Papers to be regarded are Axhausen (2006), Chorus and Timmermans (2009), Hannes *et al.* (2008), Mondschein *et al.* (2008), Arentze and Timmermans (2004), Golledge and Timmermans (1990), Bettman (1979), Timmermans (2008), Cadwallader (1975). Apart from Dobler *et al.* (2009) cognitive models have not been applied yet in MATSim.

3.7 Parking

According to literature, parking search induced traffic is substantial (Shoup, 2005) and consequently an ample body of parking literature (for a review see e.g., Young *et al.* (1991)) exists, spanning a huge number of empirical studies investigating parking itself but also its interaction with other travel choices (such as destination choice) exist (van der Waerden *et al.*, 2009, 2006, Marsden, 2006, Widmer and Vrtic, 2004, Anderson and de Palma, 2004, Golias *et al.*, 2002, Hensher and King, 2001, Gerrard *et al.*, 2001, Baier *et al.*, 2000, Albrecht *et al.*, 1998, van der Waerden *et al.*, 1998, Axhausen *et al.*, 1994, van der Waerden *et al.*, 1993, Glazer and Niskanen, 1992, Topp, 1991, Axhausen and Polak, 1991, Arnott *et al.*, 1991, Polak and Axhausen, 1990, Feeney, 1989, Miller and Everett, 1982, Gillen, 1978, 1977, Maley and Weinberger, 2011), but also numerous simulations such as Benenson *et al.* (2008), Gallo *et al.* (2011), Thompson and Richardson (1998), Dieussaert *et al.* (2009), Young (1986), Young and Thompson (1987) have been developed.

An experimental parking search model has been implemented in MATSim (Waraich and Axhausen, 2011) and further consideration of parking for destination choice modeling seems reasonable, although, preliminary results of a current GPS data analysis at the authors' institute show that parking search is might basically overestimated in Switzerland.

4 References

Albrecht, B., T. Lütolf and T. Waltert (1998) Verkehrskennwerte von Einkaufszentren: Verkehrsaufkommen, Parkfelder und Verkehrsflächen, *Research Report*, **VSS 7/95**, Schweizerischer Verband der Strassen- und Verkehrsfachleute (VSS), Albrecht & Partner AG, Lucerne.

Albrecht, C.-M. (2009) *Einkaufsstress*, Schriftenreihe des Instituts für Marktorientierte Unternehmensführung (IMU), Universität Mannheim, Gabler Verlag, Wiesbaden.

Algers, S., E. Bernauer, M. Boero, L. Breheret, C. Di Taranto, M. Dougherty, K. Fox and J.-F. Gabard (1998) A review of micro-simulation models, *Research Report*, Smartest: Transport RTD Programme of the 4th Framework Programme, European Commission, Institute for Transport Studies, University of Leeds, Leeds.

Anderson, S. P. and A. de Palma (2004) The economics of pricing parking, *Journal of Urban Economics*, **55**, 1–20.

Arentze, T. A., A. W. J. Borgers and H. J. P. Timmermans (1994) Geographical information systems and the measurement of accessibility in the context of multipurpose travel: A new approach, *Journal of Geographical Systems*, **1** (2) 87–102.

Arentze, T. A., H. Oppewal and H. J. P. Timmermans (2005) A multipurpose shopping trip model to assess retail agglomeration effects, *Journal of Marketing Research*, **42** (1) 109–115.

Arentze, T. A. and H. J. P. Timmermans (2004) Capturing the role of awareness and information search processes on choice set formation in models of activity-travel behavior, paper presented at the *83rd Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2004.

Arentze, T. A. and H. J. P. Timmermans (2005) An analysis of context and constraints-dependent shopping behaviour using qualitative decision principles, *Urban Studies*, **42** (3) 435–448.

Arentze, T. A. and H. J. P. Timmermans (2007) Robust approach to modeling choice of locations in daily activity sequences, *Transportation Research Record*, **2003**, 59–63.

Arnott, R., A. de Palma and R. Lindsey (1991) A temporal and spatial equilibrium analysis of commuter parking, *Journal of Public Economics*, **45**, 301–335.

Arnott, R., A. de Palma and R. Lindsey (1993) A structural model of peak-period congestion: A traffic bottleneck with elastic demand, *The American Economic Review*, **83** (1) 161–179.

ASTRA (2006) Swiss Federal Roads Authority, webpage, `http://www.astra.admin.ch/`.

Axhausen, K. W. (1997) Data needs of activity scheduling models, in D. F. Ettema and H. J. P. Timmermans (eds.) *Activity-Based Approaches to Travel Analysis*, 229–241, Pergamon, Oxford.

Axhausen, K. W. (2006) Neue Modellansätze der Verkehrsnachfragesimulation: Entwicklungslinien, Stand der Forschung, Forschungsperspektiven, *Stadt Region Land*, **81**, 149–164.

Axhausen, K. W. and J. W. Polak (1991) Choice of parking: Stated preference approach, *Transportation*, **18**, 59–81.

Axhausen, K. W., J. W. Polak, M. Boltze and J. Puzicha (1994) Effectiveness of the parking guidance information system in frankfurt am main, *Traffic Engineering and Control*, **35** (5) 304–309.

Baier, R., C. Hebel, C. Peter and K. H. Schäfer (2000) Gesamtwirkungsanalyse zur Parkraumbewirtschaftung, *Research Report*, Bundesamt für Strassenwesen (BAST), Büro für Stadt- und Verkehrsplanung Dr.Ing. Reinhold Baier GmbH, Aachen.

Baker, J., D. Grewel and A. Parasuraman (1994) The influence of store environment on quality inferences and store image, *Journal of the Academy of Marketing Science*, **22** (4) 328–339.

Balmer, M., K. W. Axhausen and K. Nagel (2006) An agent-based demand-modeling framework for large scale micro-simulations, *Transportation Research Record*, **1985**, 125–134.

Balmer, M., A. Horni, K. Meister, F. Ciari, D. Charypar and K. W. Axhausen (2009) Wirkungen der Westumfahrung Zürich: Eine Analyse mit einer Agenten-basierten Mikrosimulation, *Final Report*, Baudirektion Kanton Zurich, IVT, ETH Zurich, Zurich, February 2009.

Baltas, G. and P. Papastathopoulou (2003) Shopper characteristics, product and store choice criteria: A survey in the greek grocery sector, *International Journal of Retail & Distribution Management*, **31** (10) 498–507.

Barnard, P. O. (1987) Modelling shopping destination choice behaviour using the basic multinomial logit model and some of its extensions, *Transport Reviews*, **7** (1) 17–51.

Bawa, K. and A. Ghosh (1999) A model of household grocery shopping behavior, *Marketing Letters*, **10** (2) 149–160.

Beckmann, M., C. B. McGuire and C. B. Winston (1956) *Studies in the Economics of Transportation*, Yale University Press, New Haven.

Bekhor, S. and J. N. Prashker (2008) GEV-based destination choice models that account for unobserved similarities among alternatives, *Transportation Research Part B: Methodological*, **42** (3) 243–262.

Bell, D. R., T.-H. Ho and C. S. Tang (1998) Determining where to shop: Fixed and variable costs of shopping, *Journal of Marketing Research*, **35** (3) 352–369.

Bell, S. J. (1999) Image and consumer attraction to intraurban retail areas: An environmental psychology approach, *Journal of Retailing and Consumer Services*, **6** (2) 67–78.

Benenson, I., K. Martens and S. Birfir (2008) PARKAGENT: an agent-based model of parking in the city, *Computers, Environment and Urban Systems*, **32** (6) 431–439.

Bernardin, V. L., F. S. Koppelman and D. Boyce (2009) Enhanced destination choice models incorporating agglomeration related to trip chaining while controlling for spatial competition, paper presented at the *88th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2009.

Berry, B. J. L., H. G. Barnum and R. J. Tennant (1962) Retail location and consumer behavior, *Papers of the Regional Science Association*, **9**, 65–106.

Bettman, J. R. (1979) *An Information Processing Theory of Consumer Choice*, Addison-Wesley, Massachusetts.

BfS (2011) Swiss Federal Statistical Office, webpage, `http://www.bfs.admin.ch`.

Bhat, C. R. and I. N. Sener (2009) A copula-based closed-form binary logit choice model for accommodating spatial correlation across observational units, *Journal of Geographical Systems*, **11** (3) 243–272.

Brunner, J. A. and J. L. Mason (1968) The influence of driving time upon shopping center preference, *Journal of Marketing*, **32** (2) 57–61.

Burnett, P. (1977) Tests of a linear learning model of destination choice: Applications to shopping travel by heterogeneous population groups, *Geografiska Annaler*, **59** (2) 95–108.

Cadwallader, M. (1975) A behavioral model of consumer spatial decision making, *Economic Geography*, **51** (4) 339–349.

Cadwallader, M. (1995) Interaction effects in models of consumer spatial behaviour, *Applied Geography*, **15** (2) 135–145.

Carrasco, N. (2008) Deciding where to shop: Disaggregate random utility destination choice modeling of grocery shopping in canton Zurich, Master Thesis, IVT, ETH Zurich, Zurich.

Cetin, N. (2005) Large-scale parallel graph-based simulations, Ph.D. Thesis, ETH Zurich, Zurich.

Charypar, D. and K. Nagel (2005) Generating complete all-day activity plans with genetic algorithms, *Transportation*, **32** (4) 369–397.

Chorus, C. G. and H. J. P. Timmermans (2009) An empirical study into the influence of travel behavior on stated and revealed mental maps, paper presented at the *88th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2009.

Davies, F. M., M. M. H. Goode, L. A. Moutinho and E. Ogbonna (2001) Critical factors in consumer supermarket shopping behaviour: A neural network approach, *Journal of Consumer Behaviour*, **1** (1) 35–49.

de Palma, A., N. Picard and P. A. Waddell (2007) Discrete choice models with capacity constraints: An empirical analysis of the housing market of the greater Paris region, *Journal of Urban Economics*, **62** (2) 204–230.

Delleart, B. G. C., T. A. Arentze, M. Bierlaire, A. W. J. Borgers and H. J. P. Timmermans (1998) Investigating consumers' tendency to combine multiple shopping purposes and destinations, *Journal of Marketing Research*, **35** (2) 177–188.

Dieussaert, K., K. Aerts, T. Steenberghen, S. Maerivoet and K. Spitaels (2009) SUSTAPARK: an agent-based model for simulating parking search, paper presented at the *AGILE International Conference on Geographic Information Science*, Hannover.

Dobler, C., M. Balmer and K. W. Axhausen (2009) Simulation of information oriented knowledge models, paper presented at the *9th Swiss Transport Research Conference*, Ascona, September 2009.

East, R., P. Harris, W. Lomax, G. Wilson and K. Hammond (1998) Customer defection from supermarkets, *Advances in Consumer Research*, **25** (1) 507–512.

Erath, A. (2005) Zeitkosten im Einkaufsverkehr, Master Thesis, IVT, ETH Zurich, Zurich.

Erath, A., N. Frank, R. Lademann and K. W. Axhausen (2007) The impact of travel time savings on shopping location choice or how far do people go to shop cheaply?, paper presented at the *14th EIRASS Conference in Advances in Activity Based Approaches*, San Francisco, June 2007.

Eroglu, S. and G. D. Harrell (1986) Retail crowding: Theoretical and strategic implications, *Journal of Retailing*, **62** (4) 346–363.

Eroglu, S. and K. A. Machleit (1990) An empirical study of retail crowding: Antecedents and consequences, *Journal of Retailing*, **66** (2) 201–221.

Eroglu, S., K. A. Machleit and T. Feldman Barr (2005) Perceived retail crowding and shopping satisfaction: The role of shopping values, *Journal of Business Research*, **58** (8) 1146–1153.

Feeney, B. P. (1989) A review of the impact of parking policy measures on travel demand, *Transportation Planning and Technology*, **13**, 229–234.

Fotheringham, A. S. (1983a) A new set of spatial interaction models: The theory of competing destinations, *Environment and Planning A*, **15** (1) 15–36.

Fotheringham, A. S. (1983b) Some theoretical aspects of destination choice and their relevance to production-constrained gravity models, *Environment and Planning A*, **15** (8) 1121–1132.

Fotheringham, A. S. (1985) Spatial competition and agglomeration in urban modelling, *Environment and Planning A*, **17** (2) 213–230.

Fotheringham, A. S., T. Nakaya, K. Yano, S. Openshaw and Y. Ishikawa (2001) Hierarchical destination choice and spatial interaction modelling: A simulation experiment, *Environment and Planning A*, **33** (5) 901–920.

Gallo, M., L. D'Acierno and B. Montella (2011) A multilayer model to simulate cruising for parking in urban areas, *Transport Policy*, **18** (5) 735–744.

Gerrard, B., B. Still and A. Jopson (2001) The impact of road pricing and workplace parking levies on the urban economy: results from a survey of business attitudes, *Environment and Planning A*, **33**, 1985–2002.

Gillen, D. W. (1977) Estimation and specification of the effects of parking costs on urban transport mode choice, *Journal of Urban Economics*, **4**, 186–199.

Gillen, D. W. (1978) Parking policy, parking location decisions and the distribution of congestion, *Transportation*, **7**, 69–85.

Glazer, A. and E. Niskanen (1992) Parking fees and congestion, *Regional Science and Urban Economics*, **22**, 123–132.

Golias, J., G. Yannis and M. Harvatis (2002) Off-street parking choice sensitivity, *Transportation Planning and Technology*, **25**, 333–348.

Golledge, R. G. and H. J. P. Timmermans (1990) Applications of behavioural research on spatial problems: Cognition, *Progress in Human Geography*, **14** (1) 57–99.

Gärling, T., M.-P. Kwan and R. G. Golledge (1994) Computational-process modeling of household activity scheduling, *Transportation Research Part B: Methodological*, **28B** (5) 355–364.

Handy, S. L. and K. J. Clifton (2001) Local shopping as a strategy for reducing automobile travel, *Transportation*, **28** (4) 317–346.

Hannes, E., D. Janssens and G. Wets (2008) Destination choice in daily activity travel: The mental map's repertoire, paper presented at the *87th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2008.

Harrell, G. D., M. D. Hutt and J. C. Anderson (1980) Path analysis of buyer behavior under conditions of crowding, *Journal of Marketing Research*, **17** (1) 45–51.

Hensher, D. A. and J. King (2001) Parking demand and responsiveness to supply, pricing and location in the Sidney central business district, *Transportation Research Part A: Policy and Practice*, **35** (3) 177–196.

Henson, K. M. and K. G. Goulias (2006) Preliminary assessment of activity analysis and modeling for homeland security applications, *Transportation Research Record*, **1942**, 23–30.

Hirsh, M., J. N. Prashker and M. E. Ben-Akiva (1986) Day-of-the-week models of shopping activity patterns, *Transportation Research Record*, **1085**, 63–69.

Horni, A., D. Charypar and K. W. Axhausen (2011a) Variability in transport microsimulations investigated with the multi-agent transport simulation matsim, *Working Paper*, **692**, IVT, ETH Zurich, Zurich.

Horni, A., K. Nagel and K. W. Axhausen (2012) High-resolution destination choice in agent-based demand models, paper presented at the *91th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2012.

Horni, A., D. M. Scott, M. Balmer and K. W. Axhausen (2009) Location choice modeling for shopping and leisure activities with MATSim: Combining micro-simulation and time geography, *Transportation Research Record*, **2135**, 87–95.

Horni, A., B. J. Vitins and K. W. Axhausen (2011b) The Zurich scenario: A technical overview, *Working Paper*, **687**, IVT, ETH Zurich, Zurich.

Hui, M. K. and J. E. G. Bateson (1991) Perceived control and the effects of crowding and consumer choice on the service experience, *Journal of Consumer Research*, **18** (2) 174–184.

Innes, J. D., M. C. Ircha and D. A. Badoe (1990) Factors affecting automobile shopping trip destinations, *Journal of Urban Planning and Development*, **116** (3) 126–136.

Kahn, B. E. and D. C. Schmittlein (1989) Shopping trip behavior: An empirical investigation, *Marketing Letters*, **1** (1) 55–69.

Kawasaki, T. and K. W. Axhausen (2009) Choice set generation from GPS data set for grocery shopping location choice modelling in canton Zurich: The comparison to Swiss Microcensus 2005, *Working Paper*, **595**, IVT, ETH Zurich, Zurich.

Kim, B.-D. and K. Park (1997) Studying patterns of consumer's grocery shopping trip, *Journal of Retailing*, **73** (4) 501–517.

Kitamura, R. (1984) Incorporating trip chaining into analysis of destination choice, *Transportation Research Part B: Methodological*, **18** (1) 67–81.

Kitamura, R. (1996) Applications of models of activity behavior for activity based demand forecasting, paper presented at the *Activity-Based Travel Forecasting Conference*, New Orleans, June 1996.

Kitamura, R., C. Chen and R. Narayanan (1998) Traveler destination choice behavior: Effects of time of day, activity duration, and home location, *Transportation Research Record*, **1645**, 76–81.

Knight, F. H. (1924) Some fallacies in the interpretation of social cost, *Quarterly Journal of Economics*, **38** (4) 582–606.

Knox, S. D. and T. J. Denison (2000) Store loyalty: Its impact on retail revenue. an empirical study of purchasing behaviour in the UK, *Journal of Retailing and Consumer Services*, **7** (1) 33–45.

Lemp, J. D., L. B. McWethy and K. Kockelman (2007) From aggregate methods to microsimulation: Assessing benefits of microscopic activity-based models of travel demand, *Transportation Research Record*, **1994**, 80–88.

Mahmassani, H. S. and G.-L. Chang (1986) Experiments with departure time choice dynamics of urban commuters, *Transportation Research Part B: Methodological*, **20** (4) 297–320.

Maley, D. W. and R. R. Weinberger (2011) Food shopping in the urban environment: Parking supply, destination choice, and mode choice, paper presented at the *90th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2011.

Marsden, G. (2006) The evidence base for parking policies - a review, *Transport Policy*, **13**, 447–457.

McFadden, D. (1978) Modeling the choice of residential location, in A. Karlqvist (ed.) *Spatial Interaction Theory and Residential Location*, 75–96, North-Holland, Amsterdam.

McNally, M. G. and C. R. Rindt (2008) The activity-based approach, *Working Paper*, **UCI-ITS-AS-WP-07-1**, Institute of Transportation Studies, University of California, Irvine.

Meister, K. (2008) Erstellung von MATSim Facilities für das Schweiz-Szenario, *Working Paper*, **541**, IVT, ETH Zurich.

Messinger, P. R. and C. Narasimhan (1997) A model of retail formats based on consumers' economizing on shopping time, *Marketing Science*, **16** (1) 1–23.

Miller, G. K. and C. T. Everett (1982) Raising commuter parking prices - An empirical study, *Transportation*, **11**, 105–129.

Mondschein, A., E. Blumenberg and B. D. Taylor (2008) Accessibility and cognition: Effect of transportation mode on spatial knowledge, paper presented at the *87th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2008.

Nagel, K. and K. W. Axhausen (2001) Workshop report: Microsimulation, *Working Paper*, **49**, IVT, ETH Zurich, Zurich.

NAVTEQ (2011) NAVTEQ Maps and Traffic, webpage, `http://www.navteq.com`.

O'Kelly, M. E. (1983) Multipurpose shopping trips and the size of retail facilities, *Annals of the Association of American Geographers*, **73** (2) 231–239.

Oppewal, H. and B. Hoyoake (2004) Bundling and retail agglomeration effects on shopping behavior, *Journal of Retailing and Consumer Services*, **11** (2) 61–74.

Orgel, D. (1997) Consuming issues: Responses to a SN consumer survey show preferences about supermarket shopping and reveal merchandising oportunities, *Supermarket News*, **47** (34) 1–4.

Patriksson, M. (1994) *The Traffic Assignment Problem, Models and Methods*, VSP, Utrecht.

Pigou, A. C. (1920) *The Economics of Welfare*, Macmillan and Co., London.

Polak, J. W. and K. W. Axhausen (1990) Parking search behaviour: A review of current research and future prospects, *Working Paper*, **540**, Transport Studies Unit, University of Oxford, Oxford.

Pons, F., M. Laroche and M. Mourali (2006) Consumer reactions to crowded retail settings: Cross-cultural differences between North America and the Middle East, *Psychology & Marketing*, **23** (7) 555–572.

Popkowski Leszczyc, P. T., A. Sinha and A. Sahgal (2004) The effect of multi-purpose shopping on pricing and location strategy for grocery stores, *Journal of Retailing*, **80** (2) 85–99.

Recker, W. W. and L. P. Kostyniuk (1978) Factors influencing destination choice for the urban grocery shopping trip, *Transportation*, **7** (1) 19–33.

Rieser, M. (2010) Adding transit to an agent-based transportation simulation, Ph.D. Thesis, Technical University Berlin, Berlin.

Sbayti, H. and D. Roden (2010) Best practices in the use of micro simulation models, *Research Report*, American Association of State Highway and Transportation Officials, AECOM, Arlington.

Shim, S. and M. A. Eastlick (1998) The hierarchical influence of personal values on mall shopping attitude and behavior, *Journal of Retailing*, **74** (1) 139–160.

Shoup, D. (2005) *The High Cost of Free Parking*, Planners Press, Chicago.

Swiss Federal Statistical Office (2000) Eidgenössische Volkszählung 2000, `http://www.bfs.admin.ch/bfs/portal/de/index/infothek/erhebungen__quellen/blank/blank/vz/uebersicht.html`.

Swiss Federal Statistical Office (2001) *Eidgenössische Betriebszählung 2001 - Sektoren 2 und 3, GEOSTAT Datenbeschreibung*, Swiss Federal Statistical Office, GEOSTAT, Neuchatel, `http://www.bfs.admin.ch/bfs/portal/de/index/dienstleistungen/geostat/datenbeschreibung/betriebszaehlung05.Document.111424.pdf`.

Swiss Federal Statistical Office (2006) *Ergebnisse des Mikrozensus 2005 zum Verkehrsverhalten*, Swiss Federal Statistical Office, Neuchatel.

Swiss Federal Statistical Office (2007) *Einkommens-und Verbrauchserhebung 2004 (EVE 2004)*, Swiss Federal Statistical Office, Neuchatel, `http://www.bfs.admin.ch/bfs/portal/de/index/infothek/publ.Document.89847.pdf`.

Swiss Federal Statistical Office (2008a) *Eidgenössische Betriebszählung 2008 - Sektoren 2 und 3, GEOSTAT Datenbeschreibung*, Swiss Federal Statistical Office, GEOSTAT, Neuchatel.

Swiss Federal Statistical Office (2008b) Haushaltsbudgeterhebung, `http://www.bfs.admin.ch/bfs/portal/de/index/infothek/erhebungen__quellen/blank/blank/habe/intro.html`.

Teller, C. (2008) Shopping streets versus shopping malls—determinants of agglomeration format attractiveness from the consumers' point of view, *The International Review of Retail, Distribution and Consumer Research*, **18** (4) 381–403.

Teller, C. and T. Reutterer (2008) The evolving concept of retail attractiveness: What makes retail agglomerations attractive when customers shop at them?, *Journal of Retailing and Consumer Services*, **15** (3) 127–143.

Thompson, R. G. and A. J. Richardson (1998) A parking search model, *Transportation Research Part A: Policy and Practice*, **32** (3) 159–170.

Timmermans, H. J. P. (1996) A stated choice model of sequential mode and destination choice behaviour for shopping trips, *Environment and Planning A*, **28** (1) 173–184.

Timmermans, H. J. P. (2008) Consumer choice of shopping centre: an information integration approach, *Regional Studies*, **16** (3) 171–182.

Timmermans, H. J. P., A. W. J. Borgers and P. van der Waerden (1992) Mother logit analysis of substitution effects in consumer shopping destination choice, *Journal of Business Research*, **24** (4) 177–189.

Timmermans, H. J. P., R. van der Heijden and H. Westerveld (1982) The identification of factors influencing destination choice: An application of the repertory grid methodology, *Transportation*, **11** (2) 189–203.

Timmermans, H. J. P. and P. van der Waerden (1992) Store performance, pedestrian movement, and parking facilities, in G. Heinritz (ed.) *The Attraction of Retail Locations: IGU-Symposium*, Verlag Michael Lassleben, Kallmünz.

TomTom MultiNet (2011) MultiNet: The most powerful map database ever built, webpage, `http://licensing.tomtom.com/OurProducts/MapData/Multinet/index.htm`. Accessed 25/05/2011.

Topp, H. H. (1991) Parking policies in large cities in Germany, *Transportation*, **18**, 3–21.

Uncles, M. D. (1996) Classifying shoppers by their shopping-trip behaviour: a polythetic-divisive method, *Marketing Intelligence & Planning*, **14** (1) 35–44.

van der Waerden, P., A. W. J. Borgers and H. J. P. Timmermans (1998) The impact of the parking situation in shopping centres on store choice behaviour, *GeoJournal*, **45** (4) 309–315.

van der Waerden, P., A. W. J. Borgers and H. J. P. Timmermans (2006) Attitudes and behavioral responses to parking measures, *European Journal of Transport and Infrastructure Research*, **6** (4) 301–312.

van der Waerden, P., A. W. J. Borgers and H. J. P. Timmermans (2009) Consumer response to the introduction of paid parking in a regional shopping center, paper presented at the *88th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2009.

van der Waerden, P., H. Oppewal and H. J. P. Timmermans (1993) Adaptive choice behaviour of motorists in congested shopping centre parking lots, *Transportation*, **20**, 395–408.

Vickrey, W. S. (1969) Congestion theory and transport investment, *The American Economic Review*, **59** (2) 251–260.

Vovsha, P., E. Petersen and R. Donnelly (2002) Microsimulation in travel demand modeling: Lessons learned from the New York best practice model, *Transportation Research Record*, **1805**, 68–77.

Vrtic, M. (2005) Simultanes Routen- und Verkehrsmittelwahlmodell, *Straßenverkehrstechnik*, **49** (8) 393–401.

Vrtic, M., P. Fröhlich, N. Schüssler, S. Dasen, S. Erne, B. Singer, K. W. Axhausen and D. Lohse (2005) Erstellung des nationalen Personenverkehrsmodells für den öffentlichen und privaten Verkehr, *Research Report*, Swiss Federal Department for Environment, Transport, Energy and Communication, Swiss Federal Office for Spatial Development, Swiss Federal Roads Authority and Swiss Federal Office of Transport, IVT, ETH Zurich, Emch und Berger and Institute for Transportation Planning and Traffic, Technical University Dresden, Zurich.

Waraich, R. A. and K. W. Axhausen (2011) An agent-based parking choice model, *Working Paper*, **696**, IVT, ETH Zurich, Zurich, August 2011.

Wardrop, J. G. (1952) Some theoretical aspects of road traffic research, *Proceedings of the Institution of Civil Engineers*, **1** (3) 325–362.

Widmer, J.-P. and M. Vrtic (2004) Einfluss von Änderungen des Parkierungsangebots auf das Verkehrsverhalten, *Research Report*, **VSS 1997/46**, Schweizerischer Verband der Strassen- und Verkehrsfachleute (VSS), Büro Widmer, Frauenfeld.

Yang, M., W. Wang, X. Chen, W. Wang, R. Xu and T. Gu (2009) Influence of spatial factors, individual sociodemographics and travel mode on destination choice in China, paper presented at the *88th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2009.

Young, W. (1986) PARKSIM/1: a simulation model of driver behaviour in parking lots, *Traffic Engineering and Control*, **27** (12) 606–613.

Young, W. and R. G. Thompson (1987) PARKSIM/1: a computer graphics approach for parking lot layouts, *Traffic Engineering and Control*, **28** (3) 120–123.

Young, W., R. G. Thompson and M. A. P. Taylor (1991) A review of urban car parking models, *Transport Reviews*, **11** (1) 63–84.