Socio-dynamic discrete choice: Theory and application

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OUTLOOK

In this chapter we make a few recommendations for future work in moving discrete choice models with aggregation social interactions in transportation into practice. We highlight a few of the basic theoretical concepts that we seen throughout the thesis in policy context as speculative avenues for future research. We reflect on the citations by other authors of some of the research in this thesis that has already appeared in conference proceedings and journal publications, and present a general picture of the diffusion in the scientific literature. Finally we suggest research directions related to methodological extensions and innovative data collection.

9.1 CONCEPTS IN POLICY CONTEXT

Although it is not possible in this methodologically oriented thesis to draw concrete policy conclusions, it may nonetheless be worth highlighting a few of the basic theoretical concepts that we seen throughout the thesis in policy context as speculative avenues for future research.

9.1.1 *Multiplicity of Equilibria*

The first concept is the possible existence of multiple equilibria, as already shown theoretically by Brock and Durlauf in the multinomial logit model with social interactions. Here we may think of two highly developed western nations, Germany and the United States, with very different national public attitudes towards public transit as studied and discussed in depth in Buehler and Pucher (2012):

> "... a detailed analysis of public transport demand in Germany and the USA, using uniquely comparable national travel surveys from 2001/2002 and 2008/2009 for both countries [shows] public transport has been far more successful in Germany than in the USA, with much greater growth in overall passenger volumes and trips per capita. Even controlling for differences between the countries in demographics, socio-economics, and land use, logistic regressions shows that Germans are five times as likely as Americans to use public transport. Moreover, public transport in Germany attracts a much broader cross-section of society and for a greater diversity of trip purposes."

Buehler and Pucher attribute this difference to a "*coordinated package of mutually supportive policies*" taken in Germany. If however there is also social influence at play, the transition from one equilibrium to another may not be linear in terms of the policies.

9.1.2 *Initial Conditions*

A second concept is that even if multiple equilibria do theoretically exist, it may not be possible for a population to converge on some of these equilibria depending on the current state of the system. In short, initial conditions may matter depending on the circumstances. This suggests that if social influence is at play, potentially even if a host of complementary policies were adopted in some cities in the United States, perhaps even then it still wouldn't be possible to reach the widespread acceptance of public transit in these cities in the United States, particularly among affluent households, as is the case in Germany, let alone as is the case in Switzerland (Buehler and Pucher 2012), or that of the widespread acceptance of travel to work by bicycle as is the case in the Netherlands (Pucher and Buehler 2008) – without a serious shock to system in the United States, including in a social sense.

9.1.3 *Volatility and Stochastic Cycling*

A third concept is the volatility of social influence in a discrete choice model with social interactions if the network of influence is small. In such case when averaged over time, or averaged over multiple small groups, the modal split outcome can appear purely random when in fact there is significant social influence occurring. This suggests not to immediately discard a possibility of social influence purely on the basis of aggregate measures without looking deeper into possible structure at a lesser level of aggregation in space or time.

9.1.4 *Spread of Influence via Overlapping Groups*

A fourth key concept is the spread of influence through overlapping groups giving a possibility to coordinate on an outcome. Here we may think of an important turning point in Amsterdam transportation policy and mobility behavior described eloquently in Bertolini (2007) in the early 1970's where "*an unorthodox coalition of local inhabitants fearing displacement and emerging youth movements wanting to affirm their alternative visions of urban life*" took to the streets to protect the characteristic Amsterdam city center from demolition for large scale transportation projects. The result of these protests was a sharp turn in local transport policy that favored both accessibility and liveability. It also marked the turnaround of the previously steadily declining bicycle mode share which had reached its lowest point around 1970 with the steadily increasing adoption of the car. By the mid 1990's, the bicycle mode share to work in Amsterdam had returned to more or less the same level as it was just after World War II. In a study of a large number of European cities, Kenworthy and Laube (2005) show that Amsterdam had the highest proportion by far of non-motorized traffic (51% of all trips in 1995, ie. counting all trip purposes, not only commute trips from home to work).

9.1.5 *Solution Regimes*

A fifth concept is the qualitatively different patterns of theoretically possible solutions. The number and stability of equilibria is qualitatively different in the seven regimes revealed in the the nested logit model with social interactions studied in detail in Chapter 5. This suggests the importance of understanding a system well enough to capture unobserved heterogeneity between alternatives where relevant, and applying the appropriate nesting structure of elemental alternatives, since not doing so seems to yield qualitatively different possible outcomes. If we recall the initial condition effect and consider the following median commuter mode shares to work for the top 60 most "bicycle-friendly" American cities as reported in 2011 by the United States Census Bureau : 2.9% walking, 0.8% bicycle, 74.9% car, 4.3% transit (other modes not cited), and only 4.7% median of this population who doesn't have access to a car, it is not difficult to develop an unlikely picture for escape from the dominance of the car in the United States, if the solution regime would happen to include an unstable equilibrium or saddle point blocking the escape from a corner mode share.

9.1.6 *Speed of Convergence*

A sixth concept is speed of convergence and related to this, the open question of whether complex social systems in practice actually do ever reach convergence. The example time series results from the multi-agent based simulations in Part III of this thesis additionally underscore the key importance of understanding the system well with proper specification of the model, since transition dynamics can apparently also be markedly different, not only the possible outcomes. It also raises the rhetorical question of whether a social system is ever in an "equilibrium" steady state, or whether the system is continuously in a state of dynamic disequilibrium, proceeding in the direction of an equilibrium, but then receiving a shock of varying strength in policy terms, and consequently re-adjusting its path. Empirical longitudinal (pseudo-)panel data is clearly necessary to try to resolve this open question.

9.2 DIFFUSION IN SCIENTIFIC LITERATURE

Given the circumstances of the completion of this dissertation, it is possible to reflect on the diffusion in the scientific literature of some of the work from Chapters 6, 7 and 8. The multi-agent based simulation research reported in Sections 6.2 and 6.3 appeared in internal proceedings of the Conference on Urban Planning and Urban Systems (CUPUM 2003), and Agent 2003. The research reported in Sections 7.3 and 7.4 was originally presented at Agent 2004 and CUPUM 2005 and ultimately appeared in revised and expanded form in Environment and Planning Part B: Planning and Design (2008). The econometric research reported in Chapter 8 was originally presented in 2005 at the Annual Meeting of the Transportation Research Board and appeared subsequently in Transportation Research Record: Journal of the Transportation Research Board (2005). Table 9.1 on page 335 shows citations by other authors of the multi-agent based simulation research. Table 9.2 on page 336 shows citations by other authors of both the multi-agent based simulation research *and* the econometric research. Table 9.3 on page 337 shows citations by other authors of the econometric research. Table 9.4 on page 340 shows citations by other authors of the guest editorials of special issues coming from two workshops in 2005 and 2007 hosted in Amsterdam "Frontiers in Transportation: Social (and Spatial) Interactions" appearing respectively in in Environment and Planning Part B: Planning and Design (2008) and Transportation Research Part A (2011). Table 9.5 on page 341 presents a general picture of scientific literature types and venues of these selected citations. [1]

9.3 FUTURE RESEARCH GOALS

We have extended previous work on discrete choice with social interactions in important ways. Previous theoretical work has assumed homogeneous decision-makers, global interactions and laws of large of numbers. We have allowed for the possibility of unobserved heterogeneity, and through the computational possibilities created by social simulation of multi-agent systems, we have been able to incrementally test the effect of local interactions via abstract network classes over a sweep of parameters such as network density, clustering and average path length, as well as test the effect of varying the initial conditions, network size effects and the effect of local interactions via clustered influence groups and via overlapping influence groups

1 Selected citations by other authors are obtained as of 15 February 2013 via the Netherlands portal for Google Scholar `scholar.google.nl`. As the intention of this reflection is merely to present a general picture of diffusion, and not to compute detailed citation statistics, steps were not taken to systematically search for possible additional citations in other databases such as SciVerse Scopus `www.scopus.com` and Thomson Reuters (ISI) Web of Knowledge `wokinfo.com`.

Table 9.1: Selected citations by other authors of the multi-agent based simulation research reported in Sections 6.2 and 6.3 and in Sections 7.3 and 7.4 (excluding works which also cite the econometric research reported in Chapter 8)

AUTHOR(S)	TITLE	PUBLICATION	YEAR
Yuan et al	Service selection modeling in networked environments	IEEE ICEBE	2006
Chen	Computationally intelligent agents in economics and finance	Info Sciences	2007
Paez and Scott	Social influence on travel behavior: a simulation example ...	Env Planning A	2007
Chen	Computational intelligence in agent-based computational economics	Comp Intelligence	2008
Paez et al	A discrete-choice approach to modeling social influence ...	Env Planning B	2008
Zenobia	A grounded agent model of the consumer technology adoption process	Portland State U	2008
Fan and Khattak	Does urban form matter in solo and joint activity engagement?	Landsc Urb Planning	2009
Zenobia et al	Artificial markets: a review and assessment of a new venue ...	Technovation	2009
Sharmeen and Ettema	Whom to hang out with and where? Analysis of the influence ...	WCTR	2010
Smirnov and Egan	Spatial random utility model with an application to recreation demand	Economic Modelling	2010
Zenobia and Weber	Bridging the gap between artificial market simulations and ...	IEEE PICMET	2010
Carrion et al	Monte carlo simulation of adaptive stated preference survey ...	U Minnesota	2012
Jin and White	An agent-based model of the influence of neighbourhood design ...	Comp Env Urb Sys	2012
Kiesling et al	Agent-based simulation of innovation diffusion: a review	CJOR	2012
Ronald	Modelling the effects of social networks on activity and travel behaviour	TU Eindhoven	2012
Han et al	Learning and affective responses in location-choice dynamics	Env Planning B	2013

Table 9.2: Selected citations by other authors of both the multi-agent based simulation research reported in Sections 6.2 and 6.3 and in Sections 7.3 and 7.4 as well as the econometric research reported in Chapter 8

AUTHOR(S)	TITLE	PUBLICATION	YEAR
Hackney	Coevolving social and transportation networks	ETH Zurich	2005
Han	Modelling strategic behaviour in anticipation of congestion	TU Eindhoven	2006
Hackney and Marchal	Model for coupling multi-agent social interactions and traffic simulation	ETH Zurich	2007
Han et al	Modelling strategic behaviour in anticipation of congestion	Transportmetrica	2007
Arentze and Timmermans	Social networks, social interactions, and activity-travel behavior	Env Planning B	2008
Hackney	Integration of social networks in a large-scale travel behavior microsimulation	ETH Zurich	2009
Smirnov	Modeling spatial discrete choice	Reg'l Sci Urb Econ	2010
Smirnov	Spatial econometrics approach to integration of behavioral biases ...	Transp Res Record	2010
Van Acker et al	When transport geography meets social psychology ...	Transport Reviews	2010
Van den Berg et al	Location-type choice for face-to-face social activities and its effect ...	Env Planning B	2010
Gaker and Walker	Insights on car-use behaviors from behavioral economics	Auto Motives	2011
Hackney and Marchal	A coupled multi-agent microsimulation of social interactions and transportation ...	Transp Res Part A	2011
Ronald et al	Modeling social interactions between individuals for joint activity scheduling	Transp Res Part B	2011
Chorus	What about behaviour in travel demand modelling? An overview ...	Transp Letters	2012
Van den Berg	Social activity-travel patterns: the role of personal networks and communication ...	TU Eindhoven	2012
Van den Berg et al	A path analysis of social networks, telecommunication and social activity-travel ...	Transp Res Part C	2013

Table 9.3: Selected citations by other authors of the econometric research reported in Chapter 8 (excluding works which also cite the multi-agent based simulation research reported in Chapters 6 and 7)

AUTHOR(S)	TITLE	PUBLICATION	YEAR
Carrasco and Miller	Exploring the propensity to perform social activities ...	Transportation	2006
Goetzke	Network effects and spatial autoregression in mode choice models ...	West Virginia U	2006
Chorus	Traveler response to information	TU Delft	2007
Markley	Spatially-oriented discrete choice predictions: a case study ...	CS-BIGS	2007
Schuessler and Axhausen	Recent developments regarding similarities in transport modelling	ETH Zurich	2007
Walker et al	Identification of parameters in normal error component logit-mixture models	J Appl Econom	2007
Carrasco et al	Collecting social network data to study social activity-travel behavior ...	Env Planning B	2008
Habib et al	Social context of activity scheduling: discrete-continuous model ...	Transp Res Record	2008
Han et al	Route choice under uncertainty: effects of recommendations	Transp Res Record	2008
Neutens et al	A three-dimensional network-based space-time prism	J Geog Sys	2008
Wang and Kockelman	Bayesian inference for ordered response data ...	J Regional Sci	2009
Abou-Zeid	Measuring and modeling activity and travel well-being	MIT	2009
Bhat and Sener	A copula-based closed-form binary logit choice model ...	J Geog Sys	2009
Carrasco and Miller	The social dimension in action: A multilevel, personal networks model ...	Transp Res Part A	2009
Chorus et al	Spatial choice: a matter of utility or regret	Env Planning B	2009
Dam	Exploring the relationship between social influence and telecommuting	McMaster Univ	2009

AUTHOR(S), CONT'D	TITLE	PUBLICATION	YEAR
Farber and Paez	My car, my friends, and me: a preliminary analysis of automobility ...	J Transp Geog	2009
Miller	Integrated urban models: theoretical prospects	IATBR	2009
Ohnmacht	Social-activity travel: do the strong-tie relationships' of a person exist ...	Env Planning A	2009
Ohnmacht et al	Leisure mobility styles in Swiss conurbations: construction and empirical analysis	Transportation	2009
Robertson et al	Investigating the predictive capabilities of discrete choice models ...	Papers Reg'l Sci	2009
Schuessler and Axhausen	Accounting for similarities in destination choice modelling: a concept	ETH Zurich	2009
Wang and Kockelman	Bayesian inference for ordered response data ...	J Reg'l Sci	2009
Adjemian et al	Estimating spatial interdependence in automobile type choice with survey data	Transp Res Part A	2010
Gaker et al	Experimental economics in transportation	Transp Res Record	2010
Ghauche	Integrated transportation and energy activity-based model	MIT	2010
Goetzke and Andrade	Walkability as a summary measure in a spatially autoregressive mode choice model	Progr Spat'l Anal	2010
McFadden	Sociality, rationality, and the ecology of choice	Choice Modelling	2010
Neutens et al	Dealing with timing and synchronization in opportunities for joint activity ...	Geog Analysis	2010
Oakil et al	Longitudinal model of longer-term mobility decisions: framework ...	J Urb Planning Dev	2010
Paez and Whalen	Enjoyment of commute: a comparison of different transportation modes	Transp Res Part A	2010
Spissu et al	Cross-clustered model of frequency of home-based work participation ...	Transp Res Rec	2010
Van den Berg et al	A multilevel path analysis of contact frequency between social network members	J Geog Sys	2010
Van den Berg et al	Factors influencing the planning of social activities	Transp Res Rec	2010

AUTHOR(S), CONT'D	TITLE	PUBLICATION	YEAR
Abou-Zeid and Ben-Akiva	The effect of social comparisons on commute well-being	Transp Res Part A	2011
Ettema et al	Social influences on household location, mobility and activity choice ...	Transp Res Part A	2011
Farber et al	A time-use investigation of shopping participation ...	Transportation	2011
Goetzke and Rave	Bicycle use in Germany: explaining differences between municipalities ...	Urban Studies	2011
Horner et al	Toward an integrated GIScience and energy research agenda	An Assoc Am Geog	2011
Lucas and Markovich	International perspectives	Transp Soc Exclusion	2011
Pinjari and Bhat	Activity-based travel demand analysis	Handbk Transp Econ	2011
Sener and Bhat	On accommodating flexible spatial dependence structures ...	U Texas Austin	2011
Tamblay et al	School locations and vacancies: a constrained logit equilibrium model	Env Planning A	2011
Whalen	Travel preferences and choices of university students ...	McMaster University	2011
Wilton et al	Why do you care what other people think? A qualitative investigation ...	Transp Res Part A	2011
Farber et al	The social interaction potential of metropolitan regions ...	An Assoc Am Geog	2012
Goetzke and Weinberger	Separating contextual from endogenous effects in automobile ownership ...	Env Planning A	2012
Karacuka et al	Consumer choice and local network effects in mobile telecom ...	Univ Düsseldorf	2012
Paleti et al	The modeling of household vehicle type choice accommodating spatial ...	U Texas Austin	2012
Richards et al	Social networks and new product choice	Agr Appl Econ Assoc	2012
Van den Berg et al	A latent class accelerated hazard model of social activity duration	Transp Res Part A	2012
Schneider	Theory of routine mode choice decisions: An operational framework ...	Transp Policy	2013

Table 9.4: Selected general citations of the guest editorials for special journal issues "Social networks, choices, mobility, and travel" (2008) and "Transportation and social interactions" (2011)

AUTHOR(S)	TITLE	PUBLICATION	YEAR
Pultar and Raubal	Progressive tourism: integrating social, transportation, and data networks	Tour Informatics	2010
Van Wee and Chorus	Accessibility and ICT: A review of literature ...	TU Delft	2009
Neutens et al	Arranging place and time: a GIS toolkit to assess person-based accessibility ...	Appl Geog	2010
Hickman et al	Enabling sustainable mobilities: social, cultural and experimental dimensions ...	WCTR	2010
Mote and Whitestone	The social context of informal commuting: Slugs, strangers and structuration	Trans Res Part A	2011
Neutens et al	The prism of everyday life: towards a new research agenda for time geography	Transp Rev	2011
Pultar	The role of geography in social networks: couchsurfing as a case study	UC Santa Barbara	2011
Roy et al	Using social network analysis to profile people based on their e-communication ...	J TranspGeog	2011
Van Acker et al	Understanding modal choices within the built environment ...	Belg J Geog	2011
Bartle et al	Online information-sharing: a qualitative analysis ...	Transp Res Part F	2012
Carrasco and Cid	Network capital, social networks, and travel: an empirical illustration ...	Env Planning A	2012
Firnkorn	Triangulation of two methods measuring the impacts of a free-floating carsharing ...	Transp Res Part A	2012
Van den Berg et al	Involvement in clubs or voluntary associations, social networks and activity ...	Transportation	2012
Whalen et al	T-communities and sense of community in a university town ...	Urban Studies	2012
Widener et al	Simulating the effects of social networks on a population's hurricane evacuation ...	J Geog Sys	2012
Cheng and Qiu	Overview of traffic system modeling research	IEEE CCC	2012
Carrasco et al	Affective personal networks versus daily contacts ...	Transp Surv Meth	2013

Table 9.5: General picture of scientific literature types and venues for selected citations by other authors of research reported in Sections 6.2, 6.3, 7.3, 7.4, Chapter 8 and guest editorials

PUBLICATION TYPES AND VENUES	PUBLISHER	NR
Selected journal articles		
Transportation Research Series	Elsevier	13
Environment and Planning Series	Pion Ltd	11
Transportation Research Record	Transp Res Board	6
Journal of Geographical Systems	Springer	4
Transportation	Springer	4
Annals of the Assoc of American Geog	Taylor & Francis	2
Journal of Regional Science	Wiley	2
Journal of Transport Geography	Elsevier	2
Transport Reviews	Taylor & Francis	2
Urban Studies	Sage	2
Other Elsevier journals		8
Other Wiley journals		3
Diverse international journals		6
Selected theses		
Dept of the Built Environment	TU Eindhoven	3
School of Geography and Earth Sciences	McMaster	2
Dept of Civil and Environmental Eng'g	MIT	2
Other Netherlands and Europe		2
Other USA		3
Selected books and proceedings		
Edited volumes	Emerald Group	5
Edited volumes	Springer	2
Conference proceedings	IEEE	3
Conference proceedings	WCTR	2
Other edited volumes and proceedings		3
Working papers and technical reports		
Inst. for Transport Planning and Systems	ETH Zurich	4
Dept of Civil, Arch. and Environ. Eng'g	U Texas Austin	2
Other Europe and USA		3

in hypothesized sociogeographic networks. Through the deliberate incremental approach we have been able to compare the emergent modal split outcomes from the multi-agent based simulations with the theoretical analytical results and track the changes caused by the relaxation of various restrictive assumptions one-by-one. Through the multi-agent based social simulation, we have additionally been able to observe time-varying trajectories instead of only the steady states. This has yielded key insights regarding the volatility of the influence in small size networks as well as possible consequences this volatility in isolated clusters of influence and when influence groups overlap. Furthermore the simulations have allowed the observation of different speeds of convergence, and lead to the rhetorical question of whether a social system ever in fact reaches a steady-state equilibrium at all.

Further research is needed to systematically explore more comprehensive utility specifications, including for example the specific effects of availability of alternatives, agent-specific socio-demographic characteristics and agent-specific attributes of choice alternatives. Also very important for any policy application, particularly for transportation mode choice, would be the introduction of not only positive feedback, but also negative feedback into the model to account for congestion effects in addition to agglomeration effects. Other relevant variations may include time-varying propagation of effects from separate coefficients for the influence from different reference groups (as estimated in Chapter 8 but not yet studied when embedded in a multi-agent based simulation), as well as the estimation of a separate effect for an agent's own past choices (although this latter effect may already to some extent be captured by the inclusion of socio-demographic characteristics and agent-specific attributes of choice alternatives in the systematic utility).

In order to be able to apply the multi-agent based simulation model in this dissertation for policy purposes, more extensive data would be desirable than what was available at the time for this exploratory methodological study applying abstract classes of networks and hypothesized sociogeographic network scenarios. Manski (1995) highlights three hypotheses in his classic monograph

> "to explain the common observation that individuals belonging to the same group tend to behave similarly... *endogenous effects*, wherein the propensity of an individual to behave in some way varies with the prevalence of that behavior in the group; *contextual effects*, wherein the propensity of an individual to behave in some way varies with the distribution of background characteristics in the group; and *correlated effects*, wherein individuals in the same group tend to behave similarly because they face

similar institutional environments or have similar individual characteristics."

The first two hypotheses express inter-agent causality in a model. The third hypothesis does not. The important distinction between the two inter-agent causal effects is that the first involves feedback that can be reinforcing over the course of time depending on the strength of the coefficient on the feedback effect in relation to the rest of the utility function. The policy implications of the approaches are widely different, especially if there exists a case of an inherent dynamic with feedback. Access to temporal panel data is highly desirable in order to better empirically distinguish the effects during the estimation of the utility parameters.

In addition to the availability of empirical data on the change in the choice distribution over time and the changes in agent characteristics, and the changes in agent-specific attributes of the choice alternatives over time, another consideration in applying the agent-based model for policy purposes is the availability of data on the possible change in the population itself, both its size and its network structure. The agent-based models in this thesis operated on the basis of a fixed number of agents given by the survey sample collected by Hague Consulting Group in Chapter 6, and the microdata collected by the Agency for Infrastructure, Traffic and Transport of the Municipality of Amsterdam in Chapter 7. We have fixed the population in the initialization phase of the models and these populations continue at each time step throughout all iterations of a simulation run. In a policy application however, the links in the base population may change among existing agents, and furthermore perhaps some agents may leave and other new agents may enter.

A challenging direction of research addresses evolving networks, in coupling with the evolving behavioral dynamics (Gulyás and Dugundji, 2006). A motivation for this direction of work is to be able to account for residential mobility, occupational mobility and other life cycle changes in social-spatial networks impacting transportation mode choice (Dugundji et al, 2001). An important distinction can be namely understood in the land use transportation planning problem domain between network interactions impacting choices, such as transport mode choice, which do not endogenously affect the decision-maker's reference position in the network (eg. whether an agent chooses to travel by car versus rail for an intercity trip will not affect the fact of who the agent's neighbors are), as opposed to network interactions impacting "sorting" type choices, such as residential location choice, which do indeed endogenously affect the decision-maker's reference position in a spatial network and potentially also within a social network (eg. in moving to a new neighborhood an agent per definition acquires new neighbors). The econometric aspects of estimating utility parameters for a residential location choice model with social and spatial network interactions are non-trivial and data intensive (Dugundji 2006). Some considerations are addressed in Appendix D.

In absence of survey data on interaction between identifiable decision-makers at inter-household level, in the dissertation we instead consider aggregate decision-makers and use a priori beliefs about the social and/or spatial dimension of interactions to formulate the connectivity of the network. Using rich socioeconomic data for each respondent as well as the geographic location of each respondent's residence and workplace, we define aggregate interactions by grouping agents into geographic neighborhoods or into socioeconomic groups where the influence is assumed to be more likely. Technically, however, interactions between identifiable decision-makers may also be modeled using the approach described in this dissertation given the availability of suitable data.

In an application of the agent-based model for policy purposes, it may furthermore be useful to scale up the number of agents in the simulation to the actual relevant population size. In the domain of transportation land use planning, simulation on the basis of a realistic number of agents can be critically important for understanding congestion on the transportation network. Iterative proportional fitting is a well-established technique applied in transportation modeling for the purpose of generating synthetic populations, eg. see Arentze, Timmermans and Hofman (2008) for an example in an operational model in the Netherlands. An open question however is how to scale up social networks from survey data to a synthetic population. In Chapter 7 we have seen that network size and connectivity do indeed impact emergent outcomes of a discrete choice model with social and spatial interactions. This underscores of the key importance of pioneering modeling efforts (see e.g. Maxwell and Carley 2009 and Barrett et al. 2009 for reports on on-going work) as well as other recent modeling efforts to depict and understand realistic social networks at the population level in geographic space (Butts and Acton, 2011; Butts, Acton, Hipp and Nagle, 2012; Arentze, van den Berg and Timmermans, 2012; Hackney and Kowald, 2011; Arentze, Kowald and Axhausen, 2012).

Putting these desirable data and modeling features together for policy purposes, a challenging set of statistical questions also arises for the econometric estimation with regard to the sampling frame for data collection. If it can be assumed that the sample of decision-makers is drawn at random from the population, or more precisely, that the combinations (i, S, z_i) are chosen at random from the population where we conceptualize the population distribution as defined over the choice i in universal choice set C, as well as over the agent characteristics S, the agent-specific attributes z_i of the choice alternatives, then the maximum likelihood estimates of the utility parameters of the binary logit model are consistent and asymptotically efficient. Various extensions of the maximum likelihood procedure for discrete choice models have been developed for estimation with general stratified samples (eg. *exogenous* samples, where sampling strata are segmented by the decision-maker characteristics S and/or attributes of alternatives z_i, and *choice-based* samples, where each choice alternative in C corresponds to a separate stratum), *enriched* samples (eg. pooling of exogenously stratified samples with one or more choice-based samples), and double or *multi-stage* samples (eg. carrying first a small survey and then using information obtained to design a second survey). See for example, Manksi and Lerman (1977), Manski and McFadden (1981), Cosslett (1981) and Daganzo (1980, 1982) for early work. An intriguing direction for further research, when collecting data on data on social networks using a technique such as snowball sampling (Goodman, 1961; Kowald and Axhausen, 2012), is what modifications may be necessary in the estimation procedure for the utility parameters of (complex) discrete choice models capable of capturing endogenous effects, contextual effects and correlated effects, and what the formal properties of estimates are under such a sampling scheme where the selection of decision-makers is inherently interdependent by design and the choice behavior, characteristics, choice attributes and links are followed over time.

A traditional obstacle however to having such rich temporal data sets in the past has been the respondent burden in documenting their behavior over an extended time. New possibilities created by modern information and technology change this. As a spin-off from one of the student term projects in the interdisciplinary research master course module *Advanced Network Analysis* which I have taught for four years at the Universiteit van Amsterdam, we have applied discrete choice models with social interactions to data collected from the on-line social networking site Twitter. This modeling effort was made possible on the basis of rich temporal panel data obtained conveniently over an extended period of time. The Twitter data namely allows both the definition of identifiable network interactions, as well as the possibility to separate causal, correlated and contextual effects. Dugundji, Poorthuis and van Meeteren (2011) present an example of the empirical estimation of discrete choice model with network interaction effects, specifically testing for correlation among agents in the error structure in the particular empirical case study, through the use of a mixed multinomial panel logit model. The data set furthermore contained more than one million tweet records, giving us the opportunity to explore the performance of the models with different log likelihood optimization algorithms with large data. Making excellent use of high performance computing facilities at SARA, the methods reported in this dissertation are also indeed proven to be useful in this realm as well.

With primary sponsorship respectively from the NWO in the Netherlands and the NSF Office of International Science and Engineering in the USA, two high-level international workshops were coordinated and hosted in Amsterdam in 2005 and 2007, *Frontiers in Transportation: Social Interactions* bringing together different disciplines ranging from civil engineers to urban planners to economists to sociologists to computer scientists to transportation practitioners to put social networks on the international research agenda in the transportation field (http://www.e-du.nl/frontiers). The two sessions on "Innovative Data Collection" in the 2005 workshop highlighted two new directions: using techniques from sociology to study individual level ego-networks; and using emerging technologies such as intelligent bus cards and mobile phones to collect massive dynamic, longitudinal real-time data from personal electronic streams. This second session was notably inspired by an artist's project already as early as 2002 at the Waag Society for new media, Realtime Amsterdam (http://realtime.waag.org). In 2009 the Waag Society has recently contributed to the development of a pre-alpha version of a Personal Travel Assistant for public transit spearheaded by the Municipality of Amsterdam Agency for Infrastructure, Traffic and Transport, giving a timely impulse for a new data analysis project.

Furthermore in 2009, two important and timely developments with respect to intelligent travel information in the Netherlands were publicly announced: the inauguration of cooperation of provinces and the central government to provide a common national data warehouse for electronic streams from roadside equipment and cameras; and the intention to develop a parallel cooperation to provide a common national data warehouse for public transportation data. By analyzing dynamic data from different sources and coupling with other spatial and non-spatial databases, relations with land use, weather, trip attributes, socio-economic characteristics of the passengers and possible social and spatial consumer interaction in travel behavior of the population can be established. Based on this, predictions of passenger flows can be made. Accordingly in the spirit of rapid technological developments, one of the outcomes of the innovative data collection discussion group at the 2009 *Frontiers in Transportation* workshop held in Canada was the perceived need to collaborate internationally to develop best practices for fusion of electronic data streams (mobile phones, roadside equipment, on-board navigation devices, intelligent transit cards, etc), incorporating where possible the richness of social interactions (at aggregate and/or disaggregate level as appropriate) in mobility analysis both for short term traffic management and for long term transportation land use planning applications.

In early 2010, Barabási and colleagues report on "Limits of Predictability in Human Mobility" in Science magazine:

> "A range of applications, from predicting the spread of human and electronic viruses to city planning and resource management in mobile communications, depend on our ability to foresee the whereabouts and mobility of individuals, raising a fundamental question: To what degree is human behavior predictable? Here we explore the limits of predictability in human dynamics by studying the mobility patterns of anonymized mobile phone users."

Notably, however the reported research only deals with the geo-trace information from mobile phones. Yet there are additional aspects of mobile phones that make this an even richer medium for empirical data collection and analysis, such as the call and SMS records of mobile phones, and the possibility to install a researcher-designed application on mobile phones (Lee, Lippman, Pentland and Dugundji 2011), or a publicly provided application such as the Personal Travel Assistant developed at the Municipality of Amsterdam – let alone the additional possibilities created by data fusion.

With the advent of nearly 5 billion mobile phone users on the planet and every increasing personal electronic information traces of all sorts, we are at the dawn of new data possibilities with synergies between communications science, physics, mathematics, economics, behavioral science, computer science, engineering, and spatial planning. It is my aim to join forces with colleagues around the world to push forward the boundaries of this promising line of research.

9.4 BIG PICTURE

In closing, this brings us to two projects that had been proposed in 2007 in the SURFNET/NWO Enlighten Your Research optical path competition: one addressing long term land use transportation planning, the other addressing short term intelligent traffic management. Both make innovative use of travel information through modern ICT in their respective time frames, and address the impending global importance of state-of-the-art green solutions. Both projects were just a bit ahead of their time in 2007, but ICT developments since then have brought these ideas into hand reach now. Radio-astronomers in Netherlands and China now indeed make excellent use of optical technology for their cooperation. If the inter-continental ICT infrastructure is in place, perhaps transportation and urban planning researchers and practitioners can also now partially make use of the same ICT infrastructure to intensify collaboration as well.

Education, research and development are rapidly globalizing. It is critical for western countries' position in the knowledge economy, for companies, researchers, academics, and students, to have a robust, high quality-of-service platform for distance interaction (communication, decision-making, learning). Furthermore, tackling of major global issues requires intensified global cooperation, beginning with cross-cultural awareness. Climate change is arguably one of the most significant global issues of our time. Given the unprecedented rapid rate of urbanization and motorization already taking place in megacities in China and India and other populous metropolitan regions worldwide, it is critical that countries and cities work together to leap-frog to state-of-the-art clean solutions. Compounded by land use and infrastructural decisions having sometimes practically irreversible consequences, there is no time to wait.

The Netherlands has world-class innovative knowledge and experience in civil and environmental engineering, spatial planning, and networked governance. However, how can this be transferred to conditions in megacities in China or India? That is a complex question involving not only technical and economic aspects but also questions of policy-making and local and national governmental decision-making processes. The situation offers a huge potential for government bodies, NGOs, knowledge institutes and private sector to play a strategic role in global developments by connecting their expertise abroad.