Fast or forced to follow: A speed heterogeneous approach to congested multi-lane bicycle traffic simulation

Copenhagen is world-known for its large proportion of cyclists, forming a diverse group with a large variation of equipment and physical abilities. This leads to a considerable speed heterogeneity which needs to be taken into account when modelling the traffic on dedicated bicycle paths. Nevertheless, existing studies on bicycle traffic simulation have either neglected such speed heterogeneity altogether or modelled it by dividing cyclists into a few discrete classes ignoring the entirety of the speed distribution. This paper proposes an efficient bicycle traffic simulation model with continuously speed heterogeneous cyclists and corresponding congestion effects. Based on individual-specific desired speeds and headway distance preferences, the model shows realistic speed-flow relationships validated with on-site observations while being capable of delaying rapid cyclists more often than slower ones in moderate traffic flows. The scalability of the model allows it to be large-scale applicable for network loading purposes, and thus suitable for evaluating impacts of cycling related infrastructure investments.

Hub-based truck platooning: Potentials and profitability

This paper presents a model for optimising truck platoons formed at a platooning hub. Different planning and dispatching strategies, from static to dynamic, are investigated with respect to profitability and fuel savings across a range of input variables. The problem is solved using a dynamic programming based local search heuristic. As a case study, a virtual platooning hub close to the German Elb Tunnel is examined using data from a large European transport network model. It is concluded that profitability crucially depends on; (i) dynamic outlook and (ii) if chauffeurs are allowed to rest while driving in platoons.
Integrating police reports with geographic information system resources for uncovering patterns of pedestrian crashes in Denmark

Promoting walking goes a long way in contributing to the sustainability and health of future cities and regions, and improving pedestrian safety is essential for building more sustainable and healthier communities. As the problem is multifaceted in nature, this study looks at patterns of pedestrian crashes from a perspective that goes beyond the traditional investigation of pedestrian characteristics and behaviour by analysing the contribution of built environment, land use, and traffic conditions. Moreover, this study goes beyond the traditional analysis of traditional police reports by integrating them with rich geographic information system resources. This study analysed a sample of 7469 crashes between a pedestrian and another road user that occurred in Denmark between 2006 and 2015. The crash locations were geocoded and matched to a detailed traffic network, a transport planning model, and several resources detailing building and land use composition. Latent class analysis uncovered patterns of pedestrian crashes for both the fully identified records and the substantial amount of hit-and-run records. Findings from this study reveal a major red thread in the lack of hazard awareness for both pedestrians and road users and suggest solutions from both the behavioural and the infrastructure perspectives. Major needs are (i) educating pedestrians about the risks related to drinking and then walking along major roads in the darkness, (ii) making crossings for pedestrians and approaches for road users easier to understand and to access in order to reduce unnecessary conflicts, and (iii) designing traffic calming solutions around major shopping and leisure locations in dense city centres.

General information

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A Joint Route Choice Model for Capturing Preferences of Electric and Conventional Car Drivers

Battery electric vehicles (BEVs) play an important role in the increasing effort by governments to curtail the pollution from the transport sector and reduce the dependence from fossil fuels of internal combustion engine vehicles (ICEVs). Although traffic assignment models exist for BEVs, the assumption of shortest path search on the basis of time constrained by energy consumption does not have any empirical basis. The current paper presents a revealed preference study of route choice behaviour of drivers participating in a large-scale experiment with BEVs. Observed routes while driving BEVs and ICEVs were map matched and a joint route choice model was specified and estimated to reveal whether the type of vehicle is related to the preference structure. Significantly different parameters for trip length for BEV and ICEV are obtained in the model estimation, indicating a higher sensitivity to the distance travelled when driving BEVs. Moreover, the level of charge of the battery and the travel in the morning peak make drivers less sensitive to distance. The findings from this study suggest the need to revise the cost functions in the literature about traffic assignment with BEVs as these functions should not consider similar parameters regardless of the vehicle type, but instead a higher sensitivity to distance that reflects heterogeneity in driving behaviour with BEVs.
A unified public transport assignment model for mixed schedule- and frequency-based networks

Many public transport systems throughout the world consist of schedule-based (SB) as well as frequency-based (FB) lines. The public transport system of the Greater Copenhagen Area is an example of such a system, where e.g. the Metro operates as frequency-based while most bus lines operate according to a published timetable. Modelling of such mixed systems in which both schedule-based (SB) and frequency-based (FB) services are present have for a long time been considered a topic which deserves further research, as neither of the current modelling approaches of schedule- or frequency-based public transport assignments models can adequately predict the passengers’ behaviour (Gentile et al., 2016). In this paper we propose a novel joint modelling approach combining SB- and FB-modelling, which in a behaviourally realistic manner aims to capture the uncertainty of waiting time when using a FB service and the probabilities of catching a service when transferring between FB and SB services. We exemplify the model using a real-life case-study and compare observed route choices collected from smart card data with the flows obtained from applying the model.

Considering built environment and spatial correlation in modelling pedestrian injury severity

This study looks at mitigating and aggravating factors that are associated with the injury severity of pedestrians when they have crashes with another road user and overcomes existing limitations in the literature by posing attention on the built environment and considering spatial correlation across crashes. Reports for 6539 pedestrian crashes occurred in Denmark between 2006 and 2015 were merged with geographic information system resources containing detailed information about built environment and exposure at the crash locations. A linearised spatial logit model estimated the probability of pedestrians to sustain a severe or fatal injury conditional on the occurrence of a crash with another road user. This study confirms previous findings about older pedestrians and intoxicated pedestrians being the most vulnerable road users, and crashes with heavy vehicles and in roads with higher speed limits being related to the most severe outcomes. This study provides also novel perspectives by showing positive spatial correlation of crashes with the same severity outcome and emphasising the role of the built environment, as shopping areas, residential areas, and walking traffic density are positively related to a reduction in pedestrian injury severity. Often, these areas have in common a larger pedestrian mass that is more likely to make other road users more aware and attentive, while the same does not seem to apply to areas with lower pedestrian density.
Intelligent truck platooning: how to make it work

Platooning of trucks is a means to improve efficiency in the road transportation of goods. Truck platooning can lead to fuel savings in the order of 5-10%, but may also yield substantially larger benefits by, fully or partially, obviating drivers. This may be possible in situations where drivers, who engage in platooning activities, can rest while they are not the leading truck. In this paper we argue that forming truck platoons is unlikely to be successful if based on an ‘on-the-fly’ principle. Rather, a system of “platooning-stations” is required for forming platoons off the road. In the paper we propose a simple greedy-algorithm and subsequent local search for achieving locally optimal platoons at such stations. The solution reflects an optimisation of shared mileage among members of each platoon and is solved in discrete time-steps at each station. As a final contribution, we investigate the potential of the proposed algorithm in a real-world case by investigating platoon formation under a variety of circumstances for an artificial platooning station located close the Elb-tunnel. More specifically, we consider the generated route-path of 1500 trucks crossing this location and calculate optimal solutions for a variety of different design criteria’s.

Modellering af cykeltrafik

Mange byer investerer i at forbedre transportnettet, så det bedre tilgodeser cyklister. Cykeltransport indgår imidlertid fortalt meget forsimplet i de fleste transportmodeller. Så der er ikke samme grundige grundlag for at vurdere cykelprojekter, som der er for vej og kollektiv trafik. På DTU arbejder vi derfor på at forbedre rutevalgsmodeller for cyklister, så de bl.a. kan tage højde for stigninger, omgivelser og stitype samt cyklisters individuelle præferencer.
Modelling Railway-Induced Passenger Delays in Multi-Modal Public Transport Networks: An Agent-Based Copenhagen Case Study Using Empirical Train Delay Data

Due to lack of punctuality of public transport services, travel times of passengers are often uncertain. Whereas Automatic Vehicle Location (AVL) data makes it easy to measure the punctuality of public transport vehicles themselves, calculating door-to-door passenger delays is challenging as both the intended and realised routes of passengers have to be taken into account. This study introduces an agent-based MATSim simulation framework for evaluating passenger delays caused by delayed trains in multi-modal public transport systems. Three route choice strategies based on different levels of adaptiveness are considered, allowing passengers to intelligently deviate from their intended routes. Using empirical train delay data from the metropolitan area of Copenhagen for 65 weekdays in the autumn of 2014, the model concludes that the passenger delay distribution has a considerably higher standard deviation than the delay distribution of train arrivals. Additionally, the results reveal that a typical realised timetable would allow reduced overall passenger travel time compared to the published timetable.

Output variability caused by random seeds in a multi-agent transport simulation model

Dynamic transport simulators are intended to support decision makers in transport-related issues, and as such it is valuable that the random variability of their outputs is as small as possible. In this study we analyse the output variability caused by random seeds of a multi-agent transport simulator (MATSim) when applied to a case study of Santiago de Chile. Results based on 100 different random seeds shows that the relative accuracies of estimated link loads tend to increase with link load, but that relative errors of up to 10 % do occur even for links with large volumes. Although the proportion of links having large relative errors is roughly the same for all of the investigated seeds, it is shown the variations of individual link loads between seeds largely dominate variations between the two last iterations within a seed.
Stochastic user equilibrium with a bounded choice model

Stochastic User Equilibrium (SUE) models allow the representation of the perceptual and preferential differences that exist when drivers compare alternative routes through a transportation network. However, as an effect of the used choice models, conventional applications of SUE are based on the assumption that all available routes have a positive probability of being chosen, however unattractive. In this paper, a novel choice model, the Bounded Choice Model (BCM), is presented along with network conditions for a corresponding Bounded SUE. The model integrates an exogenously-defined bound on the random utility of the set of paths that are used at equilibrium, within a Random Utility Theory (RUT) framework. The model predicts which routes are used and unused (the choice sets are equilibrated), while still ensuring that the distribution of flows on used routes accords to a Discrete Choice Model. Importantly, conditions to guarantee existence and uniqueness of the Bounded SUE are shown. Also, a corresponding solution algorithm is proposed and numerical results are reported by applying this to the Sioux Falls network.

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The influence of frequency on route choice in mixed schedule and frequency-based public transport systems – The case of the Greater Copenhagen Area

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The Influence of Frequency on Route Choice in Mixed Schedule- and Frequency-based Public Transport Systems - The Case of the Greater Copenhagen Area

Understanding and analysing passengers’ route choice preferences is critical to realistically predict the level of service for the passengers’, when timetables change or new infrastructure is build. This paper argues and presents evidence on the influence of frequency of public transport services and whether published timetables are schedule- or frequency-based when describing passengers’ route choice in mixed schedule- and frequency-based public transport systems. The study is based on a revealed preference survey with 5,121 reported trips in the Greater Copenhagen Area. Given the observed trips and a corresponding large choice set with alternative routes, passenger preferences are revealed using the well-known Multinomial Logit model. Utilising recently published research on how passengers time their arrival to the first stop, the paper shows how to estimate passengers’ preferences for avoiding waiting at the first stop. The analysis also shows that passengers prefer high frequency routes. This is shown by considering the highest headway in any leg of a trip, as well as by introducing a variable capturing passengers’ higher preference for frequency-based compared to schedule-based services. On the other hand it is shown, that passengers prefer waiting for a schedule-based service compared to a frequency-based service when transferring, implying that passengers want to be certain about the time they need to wait when transferring. Finally, the paper examines the transformation of the in-vehicle time components according to a Box-Cox transformation, and highlights the varying trade-offs between in-vehicle times of different vehicles at different travel time levels.

A Joint Route Choice Model for Electric and Conventional Car Users

Introduction

Worldwide, governments have committed to reducing air pollution and carbon emissions. With a higher share of renewable sources in the electricity production, battery electric cars (EVs) could play a significant role in maintaining these commitments. Growing literature shows an increasing interest in EVs and their market, but current EV travel demand studies are usually based on data collected from users of conventional gasoline or diesel engine cars (CVs) (see e.g. (Golob and Gould 1998; Pearre et al. 2011; Greaves et al. 2014). EVs are however different from CVs in a number of ways, in particular when it comes to the driving range and the refuelling/recharging which can lead to behavioural changes (Jensen and Mabit 2015). EV users might avoid longer and less-planned trips and, when deciding on a route, they might select roads where the general speed is lower, the trip length is shorter, or the charging facilities are better. On the other hand, over a longer period of time, many users do not need charging other than overnight charging at home in order to keep up with their current behaviour (Christensen et al. 2010). Thus, the impact on traffic of a large scale EV adoption is not obvious, as it cannot be assumed that CVs currently on the road are simply replaced by EVs and individual behaviour otherwise stays constant.

Understanding the behaviour of EV users is important in a number of ways. Beside potential environmental effects, there is a need to understand other related effects, such as effects on the electricity network and the transport network. The objective of this study is to use revealed preferences (RP) data to investigate differences in route choice behaviour between CV and EV users. To our knowledge, this is the first time that a state-of-the-art route choice model has been estimated on RP EV data. In addition, the level of detail in the data allows for accounting for congestion, reliability, topology, weather and socioeconomic background.

Method
This study exploits a unique and vast dataset consisting of GPS records from a large demonstration project about EVs conducted in Denmark during the period 2011-2013. Households participating in the trial had an EV available for a period of three months during which all trips were GPS logged. Additionally, some of the households GPS logged trips by their CV in the month before and the month after the EV was received. The GPS traces were matched to the very detailed NAVTEQ street network (NAVTEQ 2010). The high level of detail of the network is crucial, as EV users might use smaller roads with lower speeds in order to save energy due to current technological restrictions on driving distances. Following the procedure in Prato et al. (2014), route choice behaviour is modelled with a two-stage approach consisting of choice set generation and model estimation. The first stage used a doubly stochastic generation process to generate a choice set consisting of a maximum of 100 unique alternatives for each observed route. Subsequently, the observations were filtered to exclude observations for which the choice set contained only one alternative route or did not contain any alternative reasonably similar to the observed route. In the second stage, a mixed path size correction logit model was estimated for modelling route choice behaviour, (Bovy et al. 2008). Comparison of EV and CV preferences is made possible by estimating jointly across data from each technology using a logit scaling approach with at least one generic parameter across data (Bradley and Daly 1997).

Data

After the map matching and filtering processes, GPS records were available for about 90,000 EV trips from 379 households. About 6,500 CV trips were logged for about 100 households in the month before and after the EV was used. The sample of households was based on voluntary participation under the condition that the household already owned at least one car and had a dedicated parking space where the EV could be home charged. In the trial period, the household had access to both their CV and EV, but they were encouraged to use the EV as the primary option. The participating households resided in 27 of the 98 municipalities in Denmark and were distributed across the entire country (see Figure 1). For trial participation purposes, one household member filled an online application form with information about the household and its composition. Each trip has been merged with weather information from local weather stations, inducing that information about precipitation, wind speed, temperature and visibility at the time of departure is available. The NAVTEQ network consists of 636,243 links covering the entire country and all road classes from large highways to minor local roads.

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Considering built environment and spatial correlation in modelling pedestrian injury severity

This study looks at mitigating and aggravating factors that are associated with the injury severity of pedestrians when they have crashes with another road user and overcomes existing limitations in the literature by posing attention on the built environment and considering spatial correlation across crashes. Reports for 6539 pedestrian crashes occurred in Denmark between 2006 and 2015 were merged with geographic information system resources containing detailed information about built environment and exposure at the crash locations. A linearised spatial logit model estimated the probability of pedestrians to sustain a severe or fatal injury conditional on the occurrence of a crash with another road user. This study confirms previous findings about older pedestrians and intoxicated pedestrians being the most vulnerable road users, and crashes with heavy vehicles and in roads with higher speed limits being related to the most severe outcomes. This study provides also novel perspectives by showing positive spatial correlation of crashes with the same severity outcome and emphasising the role of the built environment in the proximity of the crash. This study emphasises the need for thinking about traffic calming measures, illumination solutions, road maintenance programs and speed limit reductions. Moreover, this study emphasises the role of the built environment, as shopping areas, residential areas, and walking traffic density are positively related to a reduction in pedestrian injury severity. Often, these areas have in common a larger pedestrian mass that is more likely to make other road users more aware and attentive, while the same does not seem to apply to areas with lower pedestrian density.

General information

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**Dynamisk vejvalgsmodel for Hovedstadsområdet**

Trængselsniveauet i Hovedstadsområdet er stigende. Dette medfører store udsving i trafikmængder og hastigheder over daget og myldretiderne, men dette repræsenteres ikke i traditionelle statiske modeller. Dynamiske modeller opererer på et langt større detaljeringsniveau og modellerer sådanne udsving på realistisk vis. Der er netop blevet udviklet en dynamisk vejvalgsmodel for Hovedstadsområdet, og artiklen præsenterer de indledende resultater.

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**Integrated Optimisation for Public Transport System with Joint Schedule- and Frequency-Based Services**

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**Integrating police reports with geographic information system resources for uncovering multidimensional patterns of pedestrian crashes in Denmark**

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**Joint modeling of schedule- and frequency-based services in public transport assignment models**

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The forming of truck platoons: How to make it work

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The restricted stochastic user equilibrium with threshold model: Large-scale application and parameter testing
This paper presents the application and calibration of the recently proposed Restricted Stochastic User Equilibrium with Threshold model (RSUET) to a large-scale case-study. The RSUET model avoids the limitations of the well-known Stochastic User Equilibrium model (SUE) and the Deterministic User Equilibrium model (DUE), by combining the strengths of the Boundedly Rational User Equilibrium model and the Restricted Stochastic User Equilibrium model (RSUE). Thereby, the RSUET model reaches an equilibrated solution in which the flow is distributed according to Random Utility Theory among a consistently equilibrated set of paths which all are within a threshold relative to the cost on the cheapest path and which do not leave any attractive paths unused. Several variants of a generic RSUET solution algorithm are tested and calibrated on a large-scale case network with 18,708 arcs and about 20 million OD-pairs, and comparisons are performed with respect to a previously proposed RSUE model as well as an existing link-based mixed Multinomial Probit (MNP) SUE model. The results show that the RSUET has very attractive computation times for large-scale applications and demonstrate that the threshold addition to the RSUE model improves the behavioural realism, especially for high congestion cases. Also, fast and well-behaved convergence to equilibrated solutions among non-universal choice sets is observed across different congestion levels, choice model scale parameters, and algorithm step sizes. Clearly, the results highlight that the RSUET outperforms the MNP SUE in terms of convergence, calculation time and behavioural realism. The choice set composition is validated by using 16,618 observed route choices collected by GPS devices in the same network and observing their reproduction within the equilibrated choice sets generated by the RSUET model. Relevantly, the RSUET model is very successful in reproducing observed link.

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Threshold-based Stochastic User Equilibrium models

General information
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Infrastructure and spatial effects on the frequency of cyclist-motorist collisions in the Copenhagen Region

Promoting cycling aims at reducing congestion and pollution as well as encouraging healthy and sustainable lifestyles but generally clashes with the perception of crash risk while riding a bicycle that is still the most significant disincentive to cycling. This study sheds light on the factors affecting the probability of cyclist-motorist collisions while accounting for heterogeneity and spatial correlation. The current study analyzed the factors contributing to increase crash risk while riding a bicycle by focusing on 5,349 cyclist-motorist collisions within 269 traffic zones in the Copenhagen Region. The model controlled for traffic exposure for bicycles and motorized transport modes, evaluated the effects of infrastructure and socioeconomic characteristics of the zones, and accounted for heterogeneity and spatial correlation across the zones. A Poisson-lognormal model with second-order conditional autoregressive (CAR) priors confirmed the existence of the safety in numbers phenomenon, contradicted previous literature about bicycle facilities not being helpful in reducing crash risk, highlighted the need for Copenhagen-style bicycle paths especially in suburban areas, and emphasized how heterogeneity and spatial correlation play a significant role in explaining the probability of cyclist-motorist crash occurrence.

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Timetable-based simulation method for choice set generation in large-scale public transport networks

The composition and size of the choice sets are a key for the correct estimation of and prediction by route choice models. While existing literature has posed a great deal of attention towards the generation of path choice sets for private transport problems, the same does not apply to public transport problems. This study proposes a timetable-based simulation method for generating path choice sets in a multimodal public transport network. Moreover, this study illustrates the feasibility of its implementation by applying the method to reproduce 5131 real-life trips in the Greater Copenhagen Area and to assess the choice set quality in a complex multimodal transport network. Results illustrate the applicability of the algorithm and the relevance of the utility specification chosen for the reproduction of real-life path choices. Moreover, results show that the level of stochasticity used in choice set generation should be high in order to provide stable parameter estimates when the choice sets are used for estimation regardless of the initial parameters for choice set generation. Last, results illustrate that adding heterogeneity across travellers should be required because coverage
increases significantly, a relevant result considering that models are becoming more disaggregate in nature in real-life applications.

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**Improved methods to deduct trip legs and mode from travel surveys using wearable GPS devices: A case study from the Greater Copenhagen area**
GPS data collection has become an important means of investigating travel behaviour. This is because such data ideally provide far more detailed information on route choice and travel patterns over a longer time period than possible from traditional travel survey methods. Wearing a GPS unit is furthermore less requiring for the respondents than filling out (large) questionnaires. It places however high requirements to the post-processing of the data. This study developed and tested a combined fuzzy logic and GIS-based algorithm to process raw GPS data. The algorithm is applied to GPS data collected in the highly complex large-scale multi-modal transport network of the Greater Copenhagen area. It detects trips, trip legs and distinguishes between five modes of transport. The algorithm was validated by comparing with a control questionnaire collected among the same persons and a sensitivity analysis was performed. This showed that the algorithm (i) identified corresponding trip legs for 82% of the reported trip legs, (ii) avoided classifying non-trips such as scatter around activities as trip legs, (iii) identified the correct mode of transport for more than 90% of trip legs, and (iv) were robust towards the specification of the model parameters and thresholds. The method thus makes it possible to use GPS for travel surveys in large-scale multi-modal networks.

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Stochastic user equilibrium with equilibrated choice sets: Part II - Solving the restricted SUE for the logit family

We propose a new class of path-based solution algorithms to solve the Restricted Stochastic User Equilibrium (RSUE), as introduced in Watling et al. (2015). The class allows a flexible specification of how the choice sets are systematically grown by considering congestion effects and how the flows are allocated among routes. The specification allows adapting traditional path-based stochastic user equilibrium flow allocation methods (originally designed for pre-specified choice sets) to the generic solution algorithm. We also propose a cost transformation function and show that by using this we can, for certain Logit-type choice models, modify existing path-based Deterministic User Equilibrium solution methods to compute RSUE solutions. The transformation function also leads to a two-part relative gap measure for consistently monitoring convergence to a RSUE solution. Numerical tests are reported on two real-life cases, in which we explore convergence patterns and choice set composition and size, for alternative specifications of the RSUE model and solution algorithm.

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Stochastic user equilibrium with equilibrated choice sets: Part I - Model formulations under alternative distributions and restrictions

The aim of this paper is to remove the known limitations of Deterministic and Stochastic User Equilibrium (DUE and SUE), namely that only routes with the minimum cost are used in DUE, and that all permitted routes are used in SUE regardless of their costs. We achieve this by combining the advantages of the two principles, namely the definition of unused routes in DUE and of mis-perception in SUE, such that the resulting choice sets of used routes are equilibrated. Two model families are formulated to address this issue: the first is a general version of SUE permitting bounded and discrete error distributions; the second is a Restricted SUE model with an additional constraint that must be satisfied for unused paths. The overall advantage of these model families consists in their ability to combine the unused routes with the use of random utility models for used routes, without the need to pre-specify the choice set. We present model specifications within these families, show illustrative examples, evaluate their relative merits, and identify key directions for further research.

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Traffic assignment models in large-scale applications

Transport models are becoming more and more disaggregate to facilitate a realistic representation of individuals and their travel patterns. In line with this development, the PhD study focuses on facilitating the deployment of traffic assignment models in fully disaggregate activity-based model frameworks. In the correct integration, such frameworks allow realistic representation of individual-specific household interactions, time-space constraints and preference structures. Individual trips can also be evaluated on a detailed address-to-address level and aggregation biases are avoided. The study focuses on large-scale applications and contributes with methods to actualise the true potential of disaggregate models. To achieve this target, contributions are given to several components of traffic assignment modelling, by (i) enabling the utilisation of the increasingly available data sources on individual behaviour in the model specification, (ii) proposing a method to use disaggregate Revealed Preference (RP) data to estimate utility functions and provide evidence on the value of congestion and the value of reliability, (iii) providing a method to account for individual mis-perceptions in the choice set generation for complex multi-modal networks, and (iv) addressing the difficulty of choice set generation by making available a theoretical framework, and corresponding operational solution methods, which consistently distinguishes between used and unused paths. The availability of data is essential in the development and validation of realistic models for large-scale applications. Nowadays, modern technology facilitates easy access to RP data and allows large-scale surveys. The resulting datasets are, however, usually very large and hence data processing is necessary to extract the pieces of information relevant to the analysis at hand. Manual processing of the datasets is typically not possible, and it is therefore necessary to have methods available which in some automated ways clean and prepare the datasets for the desired use. The present study proposes a fully automatic post-processing procedure that combines fuzzy logic- and GIS-based methods to process raw individual-based GPS data with no additional information required from the respondent. The method categorises trips and trip legs and associates the trip legs with the most probable mode of transport used. The method was validated through the application to a dataset consisting of raw individual-based GPS logs collected among 183 respondents living in the Greater Copenhagen area. Through the use of a control-questionnaire, the study found that the proposed method (i) vi identified corresponding trip legs for 82% of the reported trip legs, (ii) avoided classifying non-trips such as scatter around activities as trip legs, and (iii) identified the correct mode of transport for more than 90% of the trip legs. These results are very promising, especially when compared to results generated by existing algorithms. The results highlight the potential of the method proposed and the possibility to use individual-based GPS units for travel surveys in real-life large-scale multi-modal networks. Congestion is known to highly influence the way we act in the transportation network (and organise our lives), because of longer travel times, but the reliability of the travel time also has a large impact on our travel choices. Consequently, in order to improve the realism of transport models, correct understanding and representation of two values that are related to the value of time (VoT) are essential: (i) the value of congestion (VoC), as the VoT varies with traffic conditions and hence congestion multipliers reflect the complexity of driving conditions when more vehicles are present on the road, and (ii) the value of reliability (VoR), as the VoT relates to the predictability of travel time and the repeatability of the travel experience. Congestion and reliability highly influence each other, but so far only studies based on Stated Preference (SP) data considered concurrently congestion and reliability variables. The PhD study contributes to the state-of-the-art by presenting a new approach to estimate the VoR and VoC based on RP data. The approach applies a mean-variance model that considers congestion and reliability concurrently. The model was applied to GPS data and it successfully estimated mixed Path Size Logit models, using a sample of 5,759 observations in the peak period and a sample of 7,964 observations in the off-peak period. Results illustrated that the value of the different time components (free-flow, congestion, and reliability) and the congestion multiplier were significantly higher in the peak period. This seems reasonable because of possible higher penalties for
being late and, as a consequence, possible higher time pressure. Results also showed that the marginal rate of substitution between travel time reliability and the total travel time, considering the average congestion level, did not vary across time periods and traffic conditions. The study highlights the potential of exploiting the growing availability of observations of actual behaviour to obtain estimates of the (monetary) value of different travel time components, thereby increasing the behavioural realism of large-scale models. vii The generation of choice sets is a vital component in route choice models. This is, however, not a straightforward task in real-life applications, as: (i) there are almost infinitely many alternatives, but large choice sets are computationally demanding or even unfeasible; (ii) congestion effects need to be considered; (iii) the choice sets should contain all relevant alternatives, including the observed route if one such is available, while leaving out unreasonable and redundant routes; and (iv) the attributes of the alternatives should vary enough to facilitate consistent parameter estimates if the choice sets are to be used for choice model estimation. The PhD study contributes to the state-of-the-art by proposing and validating a simulation-based choice set generation method for general networks. The validation used 5,131 observed route choices collected on the highly complex large-scale Greater Copenhagen area public transport network. By evaluating alternative ways to specify the stochasticity and the level of this, it was found that the level of stochasticity should be high to induce high coverage and statistically efficient parameter estimates when the choice sets are used for estimation. The level of stochasticity should, however, be introduced with parsimony, as significant increases translate into generating redundant and counter-intuitive paths with no considerable improvement in coverage. Adding heterogeneity across travellers improved the results considerably, and induced coverage levels up to a very high 98.8% at an 80% overlap threshold. This shows the potential of the method proposed as well as the importance of accounting for as much individual heterogeneity as possible as models become more disaggregate. A revisit to the original conditions underlying the Stochastic User Equilibrium (SUE) has led to the realisation that the difficulty of specifying the choice set is related to the assumption on the distribution of the mis-perceptions. It is the commonly adopted assumption that the distributed elements follow unbounded distributions which induces the need to enumerate all paths in the SUE, no matter how unattractive they might be. The Deterministic User Equilibrium (DUE), on the other hand, has a built-in criterion distinguishing definitely unused from potentially used routes, but the cut-off in terms of cost differences is strict. Based on this, two new model frameworks and corresponding equilibrium formulations are introduced. Both models combine the strengths of the SUE and DUE by permitting the consistent combination viii of (i) equilibrated non-universal choice sets and (ii) flow distribution according to random utility maximisation theory. One model allows distinction between used and unused routes based on the distribution of the random error terms, while the other model allows this distinction by posing restrictions on the costs of used/unused routes. Generic path-based solution algorithms and convergence measures are introduced for the model which seemed the most straightforward to apply given its connection to existing RUM-based models (the one adding restrictions). Different variants of the algorithms were validated for the MultiNominal Logit and Path Size Logit choice models on the Sioux Falls as well as the large-scale Zealand network. A novel consistent convergence measure verified extremely fast and well-behaved convergence to an equilibrated solution on non-universal choice sets (across different congestion levels, scale parameters and step-sizes). The composition of the choice sets were validated by comparison to real-life route choices of 16,618 individual trips on the Zealand network. The applications were also very successful in reproducing observed link counts. The solution algorithms are thus computationally attractive, and the solutions and the underlying framework are behaviourally realistic. This causes the new framework and solution algorithms to be highly attractive to apply as models become more disaggregate. Summarising, the PhD study has given contributions to several of the components that concern the estimation and solution of traffic assignment models in large-scale applications. Through this, the PhD study has successfully facilitated the consistent integration at the disaggregate level across traffic model parts. This means that the true potential of the activity-based models can be actualised.

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**Estimating Value of Congestion and of Reliability from Observation of Route Choice Behavior of Car Drivers**
In recent years, a consensus has been reached about the relevance of calculating the value of congestion and the value of reliability for better understanding and therefore better prediction of travel behavior. The current study proposed a revealed preference approach that used a large amount of GPS data from probe vehicles to provide insight into actual behavior in choosing a route. Mixed path size correction logit models were estimated from samples of 5,759 observations in the peak period and 7,964 observations in the off-peak period, while a mean-variance model was specified to consider both congestion and reliability terms. Results illustrated that the value of time and the value of congestion were significantly higher in the peak period because of possible higher penalties for drivers being late and consequently possible higher time pressure. Moreover, results showed that the marginal rate of substitution between travel time
reliability and total travel time did not vary across periods and traffic conditions, with the obvious caveat that the absolute values were significantly higher for the peak period. Last, results showed the immense potential of exploiting the growing availability of large amounts of data from cheap and enhanced technology to obtain estimates of the monetary value of different travel time components from the observation of actual behavior, with arguably potential significant impact on the realism of large-scale models.

Risk Factors Associated with Crash Severity on Low-Volume Rural Roads in Denmark
Safety on low-volume rural roads is drawing attention due to the high fatality and severe injury rates in comparison with high-volume roads and the increasing awareness of sustainable rural development among policy makers. This study analyzes the risk factors associated with crash severity on low-volume rural roads, including crash characteristics, driver attributes and behavior, vehicle type, road features, environmental conditions, distance from the nearest hospital, and zone rurality degree. The data consist of a set of crashes occurred on low-volume rural roads in Denmark between 2007 and 2011. The crashes were identified by map-matching the crash location to the geographic information system representing the national transport network and extracting the relevant crashes based on annual average traffic volumes. Injury severity was modeled by estimating a generalized ordered logit model due to its advantage in accommodating the ordered-response nature of severity while relaxing the proportional odds assumption. Model estimates and pseudoelasticities show that aggravated crash injury severity is significantly associated with (1) alcohol and failure to wear seatbelts, (2) involvement of vulnerable road users (i.e., pedestrians, cyclists and motorcyclists), (3) involvement of heavy vehicles, (4) speed limits of 80–90 km/h, (5) longer distance to the nearest hospital, and (6) peripheral rural regions.
**A disaggregate pseudo-dynamic assignment for the activity-based model of the Greater Copenhagen Area**

The COMPAS (Copenhagen Model for Person Activity Scheduling) model being developed for the Greater Copenhagen Area recognizes the limitations of traditional approaches to transport planning, and embraces the active stream of research focusing on the activity-based paradigm for predicting travel demand and supply. On the demand side, the COMPAS model proposes a micro-simulation approach to the representation of activity and travel patterns of Copenhageners as individuals and household members. On the supply side, the COMPAS model proposes a disaggregate pseudo-dynamic approach to the assignment of Copenhageners to the multimodal network of the Greater Copenhagen Area. This paper focuses on the development of the framework for the supply side of the COMPAS model. The framework is developed by considering that using an activity-based paradigm with a static traffic assignment negates much of the advantages of predicting travel patterns at the disaggregate level in continuous time. Accordingly, the proposed traffic assignment is individual-based, pseudo-dynamic, and multi-modal. Firstly, the assignment loads onto the network activity and travel patterns of the individuals between parcels. Secondly, the framework uses a pseudo-dynamic approach able to capture the dynamic nature of the travel pattern of the individuals and hence the building of congestion. Last, the framework loads onto the network car users, public transport users and the important share of cyclists commuting in the Greater Copenhagen Area.

The framework proposes interesting insights from a behavioral and a time perspective. From a behavioral perspective, the framework allows representing individual preference structures depending on individual attributes (e.g., value-of-time, income, age) and incorporating non-linear terms in the utility functions. The calculation of level-of-service for non-chosen alternatives (e.g., non-chosen routes, non-chosen modes, non-chosen destinations) may be solved with ghost probes running (but not loading) the network. From a time perspective, the proposed framework has a complexity similar to the static assignment. While adding the time dimension to a matrix-based assignment increases the calculation complexity significantly, proposing an individual-based approach requires only some more updating of speed-flow and flow-density functions is required. The advantages are the complexity similar to static assignment, the absence of loss of information on the trips from the demand model, the increase in explanation and prediction abilities, and the avoidance of aggregation bias of the level-of-service variables in the feedback to the demand models.

The disaggregate pseudo-dynamic traffic assignment allows: (i) capturing time-dependent interactions of travel demand and network supply of the network; (ii) representing the network at a disaggregate level; (iii) representing congestion build-up and dissipation; (iv) evaluating the effect of traffic management measures and traffic policies. When considering the main policies discussed in the Greater Copenhagen Area (e.g., measures of traffic control management, adoption of intelligent transport systems, adoption of road pricing policies), a state-of-the-art instrument such as an activity-based model with an individual-based pseudo-dynamic traffic assignment will prove highly valuable to decision makers.
are computationally expensive by requiring simulation. Additionally, identifying all possible routes for realistic-scale networks quickly gets intractable, and most algorithms require pre-specification of ‘relevant routes’, which can be a difficult task. Recognizing the limitations of solution algorithms to the behaviourally sound SUE and the efficiency of solution algorithms to the DUE, we introduce a transformation of the cost function. This transformation function opens up a larger array of possible solution algorithms to the SUE, as it allows us to apply any path-based DUE solution algorithm and then obtain a flow solution which satisfies the RSUE or SUE on a pre-specified choice set. The underlying choice model is however restricted to being logit-type. Due to the consistency with the IIA property of logit-type models, we propose heuristic solution algorithms where the direction finding is based on a pair-wise path-swapping algorithm. The transformation function also leads to the proposal of a new Relative GAP-measure (convergence measure) valid for any SUE or RSUE solution algorithm based on the logit-type choice models. Numerical tests on a synthetic network as well as the Sioux Falls network indicate that the proposed solution algorithms induce interesting and promising convergence patterns.

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Risk factors associated with crash severity on low-volume rural roads in Denmark
Safety on low-volume rural roads is drawing attention due to the high fatality and severe injury rates in comparison with high-volume roads and the increasing awareness of sustainable rural development among policy makers. This study analyzes the risk factors associated with crash severity on low-volume rural roads, including crash characteristics, driver attributes and behavior, vehicle type, road features, environmental conditions, distance from the nearest hospital, and zone rurality degree. The data consist of a set of crashes occurred on low-volume rural roads in Denmark between 2007 and 2011. The crashes were identified by map-matching the crash location to the geographic information system representing the national transport network and extracting the relevant crashes based on annual average traffic volumes. Injury severity was modeled by estimating a generalized ordered logit model due to its advantage in accommodating the ordered-response nature of severity while relaxing the proportional odds assumption. Model estimates and pseudo-elasticities show that aggravated crash injury severity is significantly associated with (i) alcohol and failure to wear seatbelts, (ii) involvement of vulnerable road users (i.e., pedestrians, cyclists and motorcyclists), (iii) involvement of heavy vehicles, (iv) speed limits of 80-90 km/h, (v) longer distance to the nearest hospital, and (vi) peripheral rural regions.

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Generation and quality assessment of route choice sets in public transport networks by means of RP data analysis
Literature in route choice modelling shows that a lot of attention has been devoted to route choices of car drivers, but much less attention has been dedicated to route choices of public transport users. As modelling route choice behaviour consists of generating relevant routes and estimating discrete choice models, this paper focuses on the issue of choice set generation in public transport networks. Specifically, this paper describes the generation of choice sets for users of the Greater Copenhagen public transport system by applying a doubly stochastic path generation algorithm and evaluating the ability to reproduce choices collected in the Danish Travel Survey.

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