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Identification of Relevant Aspects for Personal Air Transport System Integration in Urban Mobility Modelling

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Abstract

This research evaluates relevant prerequisites for Personal Air Transport System (PATS) introduction into the urban transport modelling environment. Integrating Personal Air Vehicles (PAV) into existing transport systems poses various questions, which have to be thoroughly assessed. Therefore, different possible concepts of operations are being discussed, including not only ownership structure but also aspects like the adaptability of schedules (on-demand vs. scheduled services). Furthermore different demand drivers, such as job, housing, and retail location, user behaviour and mode choice are being presented with a digression on possible impacts on the city structure. In addition to that, potential cities for PAV introduction and the required properties are examined. Finally, different state-of-the-art approaches for transport modelling are constituted in order to lay the foundation for further research.

Keywords: Urban Air Mobility; Personal Air Transport; Urban Transport Model Prerequisites

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1. Introduction

Population growth and urbanisation are trends that massively affect life in cities. The number of people living in cities is said to double from 2011 to 2054 while urban land cover is expected to already have doubled by 2030 due to decreasing city densities (Angel, Parent, Civco, & Blei, 2011, p. 3). This leads to changes not only in transport demand but also in infrastructure requirements and average travel distances. These developments demand for new transport solutions.

One way to tackle the problem is to add another layer to the urban transport system by introducing urban air transport. This overarching concept is called Urban Air Mobility (UAM). Yet, an introduction of an additional airborne vehicle into the urban environment poses various obstacles, which might be overcome by developing Personal Air or Aerial Vehicle (PAV) which are specifically designed to be capable of performing passenger transport missions in an urban environment. This obligates them to fulfil stringent noise, emission, and safety requirements without demanding traditional airport infrastructure, such as runways for take-off and landing. In combination with an interconnected and managed operational concept, the PAVs form a Personal Air Transportation System (PATS).

Currently a lot of research is being conducted on the manufacturer's side (see e.g. A^3, 2017; Aurora Flight Sciences, 2017; Joby Aviation, 2017; Volocopter GmbH, 2017). Yet, less attention is being paid to the integration of UAM into the existing urban transport system, especially, concerning operational concepts and business models. First considerations of NASA by Kopardekar (2017), or analyses by Holden and Goel (2016), show that several aspects like air traffic control, navigation, scheduling, and fleet mix have to be considered, besides different operational concepts and business models.

Hence, before introducing PAVs to the transport market, the demand driving prerequisites, both on vehicle and system side, should be evaluated to facilitate recommendations on the design, integration, and operation of PATS within urban environments. In order to examine different vehicle concepts and system setups appropriately, several other urban transport modes have to be considered and included into an extensive urban mobility model.

In order to discuss relevant aspects for UAM, different concepts of operations are described, followed by the evaluation of various demand drivers such as mobility behaviour, mode choice, location choice, and possible markets for PAV introduction. For this purpose, a comprehensive literature review was performed, considering nearly all directions of research. Mainly technological papers, yet, were disregarded. Afterwards, a brief overview over state-of-the-art transport modelling approaches and existing models of UAM will be given.

2. Concepts of Operations for Urban Air Mobility

Current literature discusses various concepts of operations for UAM realisation. Schuchardt et al. (2015), for example, envision a system purely for commuting purposes that "allows the user to travel from home to work and back again without using conventional ground based modes of travel and especially without time consuming changes between different modes of travel." Hansman and Vascik (2016), on the other hand, illustrate on their use case of Los Angeles that there might be the possibility of having multiple fields of operations for future PATS, such as intra-city air-taxi operation and charter flights for a city's surrounding metropolitan region. Besides that, they list four different application scenarios:

- daily commute
- weekly commute
- non-commute point-to-point
- non-transportation mission (e.g. sightseeing).

In conclusion, they emphasise the concepts of personal scheduled and unscheduled transportation, with the vehicles either being commercially owned and operated or only commercially operated and privately owned, as being favourable for PAV usage.

Besides that, various PAV ownership structures are being discussed. Nneji et al. (2017), for example, present a differentiation between PAV ownership options (i.e. centralized, decentralized, and self-ownership) and operational models (i.e. professional operator and self-operated). In their paper, the combinations of professional operators with decentralized/centralized vehicle ownership (i.e. "Transportation Network Vehicle" and

"Commercial Vehicle", respectively) are currently being discussed the most vividly for potential realisations of UAM. Hansman and Vascik (2016) also differentiate the business and operational models of potential PATS in that they provide four business concepts:

- private air transport
- personal scheduled transportation
- personal unscheduled transportation (on-demand mobility)
- commercial scheduled transportation.

An assessment of the different proposed business models and concepts of operations has not yet been performed. This shows that there is no consensus on the preferred concept of operations. Similar discussions arise in the field of autonomous ground vehicles where two options are seen as realistic: either a fleet of shared autonomous vehicles will be introduced (e.g. Fagnant & Kockelman, 2014) or autonomous vehicle will substitute conventional automobiles (e.g. Glancy, 2015). Yet, in contrast to autonomous cars, (autonomous) PAVs have more stringent prerequisites, especially concerning air traffic management, collision control, and infrastructure demand. Particularly in cities, the space for take-off and landing is confined.

Therefore, concepts requiring hub infrastructure are to be evaluated further. Here a distinction between vehicle-sharing, ride sharing, and privately owned concepts has to be made. If the vehicle is not privately owned, different operators such as Original Equipment Manufacturers (OEM), the public transport operators, or new players are possible. Closely related to the operator type is the market structure. In some cases, the public sector may start to regulate the market similar to the taxi market or the public transport sector in most European countries. Besides that, the system either can be operated on-demand or scheduled. All these combinations should be thoroughly evaluated in order to assess the impact of various PATS integration possibilities.

3. Demand Drivers

Travel demand has a vast number of drivers. Cervero and Kockelman (1997) summarise the built environment variables as the "3Ds" consisting of density, diversity, and design. Hereby, density comprises population and employment density, often stemming from accessibility models based on gravity models. Diversity takes the various options for land-use into account, so that the mixture of commercial, residential, and office areas is included. The third built variable regards infrastructure design and the quality of transport infrastructure for different modes. Additionally, the influencing factors of mode choice determine the demand for a specific mode. In order to evaluate possible market shares of PATS, various demand drivers have to be considered more closely. Therefore, mode choice as well as possible changes in the city structure and relevant cities for UAM introduction will be evaluated closer.

3.1. Mode choice

Mode choice plays an important role when new transport systems are to be implemented. Hence, manufacturers and operators have to know the demand driving aspects and be aware of possible obstacles. In order to do so, discrete choice models are applied which base on random utility theory. Hereby, every trip generates a certain disutility. This disutility can, for example, comprise in- and out-of-vehicle time, costs, income, motorization rate, share of students, bike network properties, quality of public transport, city size, share of elderly, weather, and the household size (Santos, Maoh, Potoglou, & von Brunn, 2013). The group of discrete choice models can be distinguished into different types. The basic model is the Multinomial Logit Model (MNL), which assumes that the random residuals are Weibull distributed and therefore have a less complex choice probability function (Ortúzar S. & Willumsen, 2011, pp. 227–234).

An enhancement of MNL is Nested Logit (NL). In contrast to MNL theory, NL theory does not base on the assumption of Independence of Irrelevant Alternatives (IIA). This is made possible by nesting different choice options. Within the nests, different mode choice likelihoods are correlated with each other, while in contrast between the nests this is not the case (Koppelman & Bhat, 2006, pp. 38–41, 157–162).

Besides these two dominant theories (see e.g. Buehler, 2011; Carrasco & de Dios Ortúzar, 2002; Fillone, 2007; Schwanen & Mokhtarian, 2005; Train, 2009), there are other discrete choice models like Multinomial Probit, Nested Probit, and Mixed Logit which will not be discussed in further detail (Ortúzar S. & Willumsen, 2011, pp. 248–252).

Furthermore, enhancements to the random utility approach are possible. Extensions that lead to a generalized random utility model are flexible disturbances, latent variables, latent classes, and combining stated and revealed preference data (Walker & Ben-Akiva, 2002). Latent variables are an appropriate approach to model unquantified aspects of mode choice, such as comfort and safety (Ben-Akiva et al., 1999).

The evaluation of relevant passenger groups can help to specify the offer according to passengers' preferences (Atasoy, Glerum, & Bierlaire, 2006). For example, people with a high price sensitivity will have an increased willingness to pay for higher speeds. Elderly people, on the other hand, may have reservations about technologies, especially regarding safety and reliability and may, therefore, have a decreased level of acceptance.

In addition to that, the different trip purposes have a decisive influence on modal choice; firstly, due to the size of travel groups, e.g. a family member picks up children from school, but also due to differences in the Value of Time (VoT). The VoT for commuting trips and other private trips is way below that of business trips (Zamparini & Reggiani, 2007).

Even though costs for technology are expected to decrease, an estimate for PAV costs is the level of UBER black prices (Business Insider, 2017; Skift, 2017). With that, PAVs will be a rather expensive transport mode. The main advantage, in comparison to conventional modes of transport, are travel speed and, thus, travel time. One of the relevant target groups could, hence, be passengers with a high willingness to pay for travel time savings especially for trip purposes for which their VoT is high. The most optimistic estimate was made in UBER's Whitepaper (Kopardekar, 2017, pp. 95–96). Prices are even expected to be as low as UberX prices. UberX is Uber's cheapest service, with prices being about one quarter of UberBLACK prices (uberestimate, 2017).

Different estimations concerning modal share and market share of PAVs have already been performed. Yet, due to large uncertainties, the expected mode shares have substantial variety. Kreimeier and Stumpf (2017) predict a thin-haul on-demand air mobility demand of 19% in Germany if the price per kilometre exceeds the price of car travel by 0.02€. If they increase the price difference to 0.20€ per kilometre the share drops to 4%. In contrast, Syed et al. (2017) see 4.5% market share for commuter travel as an optimistic guess for on-demand commuter aircraft. Like Kreimeier et al. (2017), they see the kilometre dependent price as the main demand driving factor. Decker et al. (2013) assume 10% of the demand for commuting via car substituted by PAVs. This again leads to a potential PAV share of about 4%.

This overview over existing literature shows, that several aspects of mode choice including UAM have yet to be evaluated. As a first step dominant factors for mode choice including new technologies have to be determined by analysing further literature. Derived from this a mode choice model accounting also for latent variables and classes is to be determined.

3.2. Changes in city structure

Depending on the achieved modal share, PAVs could cause disruptive change to existing transport systems that, besides inducing additional demand, could even evoke changes in the city structure. The increase in travel speed can drastically decrease travel times from the suburbs to the city centre. According to the bid rent theory (e.g. Wheaton, 1977) land rents decrease with increasing distance to the city centre. If classical utility maximising assumptions are applied, the increasing travel speed could be so severe that overall travel time costs reach a level where people prefer to have larger houses in the suburbs despite increasing commuting distances. This could result in an increasing attractiveness of suburbs as residential areas and hence could cause urban sprawl and could lessen the liveliness of city centres. This effect may not only occur for household location choices but may also influence companies' location choices. Especially land intensive production can minimise their production costs by saving money on rents. Yet, an increase in demand leads to increasing prices. If there is a significant shift in location choice, the rents are likely to adapt.

The changes in location choice do not only influence land prices but also have an impact on commuting connections. If satellite cities emerge, the transport system would have to react. The PATS, for example, would have to offer express transit from suburb to city centre.

In order to evaluate these possible effects and to measure resulting welfare changes a spatial computable general equilibrium (SCGE) model could be applied. Anas and contributors (e.g. Anas & Rhee, 2006; Anas & Xu, 1999) developed an urban model that treats transport endogenously and therefore is capable of modelling massive changes in the transport sector.

3.3. Relevant cities

Yet, not only changes in the city structure are relevant but also relevant cities for UAM introduction have to be discussed for further research. The technological development may enable the introduction of UAM to all different kinds of cities, yet, in the beginning, some regions may be more likely for successful PATS integration than others. In order to find suitable example cities, different city clusters are to be determined.

The literature proposes different options for city clustering in the context of mobility. Shell (2017) focuses on population, population density, and GDP per capita. Different combinations of characteristics led to six city clusters. Even though these characteristics are decisive concerning mobility behaviour, culture specific mode choice is not considered. A different approach was pursued by Priester et al. (2013). By applying a factor analysis, they determined 13 factors, e.g. urban sprawl and automobile dependence, shared taxi traffic, congestion, and scarcity of public transport supply. Performing a cluster analysis with these variables also yields six clusters. This time the city types are mainly distinguished by transport characteristics, resulting, for example, in “non-motorised cities” and “transit cities”.

A third option for clustering is presented by Lerner (2011). The evaluation of 66 cities worldwide determined prosperity (GDP per capita above or below US$ 25,000), city size (agglomerations with more or less than 5 million inhabitants), and modal split (share of more or less than 50% individual travel) as dominant clustering characteristics. Permutation of these three characteristics generated different clusters. Due to the study scope, not all combinations of characteristics were represented by cities and therefore only six instead of eight clusters were determined. A closer evaluation of clusters showed that the agglomerations within one cluster have various similarities concerning mobility properties.

As Lerner’s approach combines mobility behaviour and possible demand driving characteristics for PAV-usage we opted for this approach. Yet, some of the clusters will have a higher relevance for UAM introduction than others. The take-off and landing time requirements of PAVs will be an inevitable part of the travel time if PAVs are being used. The time savings due to the much faster travel can therefore only be of benefit if the travel distance is sufficiently long. This is only the case in large cities. Furthermore, a certain size is essential for efficiently operating a PATS, which again, is an advantage of larger cities. Regarding the share of public transport, both options are relevant: either the existing transport system could be enhanced or a substitute for the construction of expensive transport infrastructure could be found by implementing UAM. For GDP per capita, it is clear that, at least for first applications, the focus should be on mature cities. In the period of market entry, the concept will be rather expensive and acceptance in cities with higher incomes will be wider. Fig. 1 gives an overview over the relevance of the different characteristics.

Fig. 1 Relevance of different city characteristics for UAM introduction

Hence, special interest will be paid to three clusters, mainly focusing on large and mature cities:

- large and mature cities with public transport affinity (e.g. Hong Kong, Singapore, Paris)
- large and mature cities with a low affinity for public transport (e.g. Los Angeles, Chicago, Toronto)
- large and emerging cities with a high public transport affinity (e.g. Beijing, Santiago de Chile, Ankara).

Due to the differences in mobility behaviour, it is likely that different business models are suitable for various city types. In some cities, an integration into the existing public transport system favouring scheduled application may be the preferable option while for other city types an on-demand solution would be the best. Furthermore, different markets may demand for different operating structure reaching from one monopolistic operator to a varying number of competing operators.

4. Modelling approaches for UAM

The evaluation of a new transport mode requires a suitable modelling approach integrating the different aspects of the identified demand drivers. Especially depicting the interaction with existing transport systems is only possible by building a comprehensive urban transport model, which can be applied to simulate different operational setups and vehicle properties.

In order to find a suitable approach, state-of-the-art transport models have been analysed and a literature review of existing research in the field of UAM has been performed.

4.1. State-of-the-art urban transport modelling

Transport models can be divided into different subcategories. In transport planning most often, the four-step model is applied, whereas more general policy impacts are often measured by using activity-based or integrated land-use transport interaction models. Furthermore, there are approaches like system dynamics that can be used to evaluate changes in the transport sector as shown by Batty (2009).

One of the first models, used to analyse transport systems, is the four-step model, which was already applied in the 1950s (McNally, 2000b). It is a trip-based method and, therefore does not consider trip purpose but only network load, regarding different origin and destination pairs (McNally, 2000b). The approach consists of four sub-models that can be performed in different orders. Yet, traditionally trip generation and trip distribution are followed by mode choice and traffic assignment. While the trip generation determines how many trips originate in a zone and how many trips are attracted by a zone, the distribution part combines these two components to trips. The mode choice module assigns different modes to different trips. Possible approaches, by which this can be done, have been presented in Chapter 3.1. In the last step, trips and vehicles are assigned to specific routes (Ortúzar S. & Willumsen, 2011). A commercial application using the four-step approach is, for example, PTV VISUM.

Besides the tour-based four-step approach, activity-based models make up a large group of models. Hereby, the focus is on trip purpose and trip chaining. Instead of only regarding the single trips, all daily activities are of interest and different purposes can be combined within one tour (Bhat, Guo, Srinivasan, & Sivakumar, 2003). This approach considers trip chaining behaviour during a day, assuming for example that a person on his commute trip home from work may stop as to e.g. shop for groceries (Ortúzar S. & Willumsen, 2011, p. 140). McGuckin and Murakami (1999) show that trip chaining often occurs and should therefore be integrated when evaluating mobility behaviour. Their data sample from the US shows that there is a drastic difference between men and women. Women often have more complex tours than men due to a higher number of family-related trips. This also shows that the household composition and the profession of the individual massively influence the mobility behaviour and transport demand.

By that activity-based models are less static than conventional four-step models. Changes in trip-chaining options and location choice are more adjustable (McNally, 2000a). The approach requires a close look at household behaviour in the relevant study area, as a whole day plan is to be modelled. The passenger faces constraints concerning money and time under which he fulfils mandatory and optional activities always considering the facilities' opening hours in order to maximise his utility (Ortúzar S. & Willumsen, 2011, pp. 473–487).

One way to apply activity-based models is to use agent-based models. The population is modelled by agents, which fulfil a daily plan and maximise their utility. This approach is frequently used in academia, see e.g. Horni et al. (2016) for MATSim, Fagnant and Kockelman (2014) for an agent-based model on shared autonomous vehicles, or Bazzan and Klügl (2013) for a detailed background on agent-based traffic simulation.

The Multi-Agent Transport Simulation (MATSim) is a state-of-the-art modelling tool, that has frequently been used for research purposes (e.g. Dobler, 2013; Grether, 2014; Kickhöfer, Grether, & Nagel, 2011; Verbas, Mahmassani, Hyland, & Halat, 2016). Developed by ETH Zürich and TU Berlin, it is open-source and java-based and, therefore, an adaption to specific needs is possible. The basic idea behind MATSim is that agents simulate the city population and each agent maximises its utility by performing its compulsory and optional activities in a certain order and at a certain time of day (Horni et al., 2016). A genetic algorithm creates different day plans for the agents in order to give them a choice set (Balac, Janzen, & Axhausen, 2017).

Other options than agent-based modelling are shown in O'Donoghue et al. (2014, pp. 34–36). The activity-based approach has several advantages compared to the conventional four-step model. Sivakumar (2007) points out that an improved simulation of interaction in time and space is possible and that individual behaviour can be modelled more precisely. Yet, these properties lead to disadvantages concerning computing time, calibration, and data-requirement.

The last dominant group of models focuses on the relationship between transport and land-use and, hence, integrates the two. The location choice of households strongly depends on the accessibility of a zone and the daily commuting time. This again strongly relates to the transportation supply. Yet, if a certain zone is more attractive, people will move there and the transport infrastructure faces a higher demand. Therefore, an integration of land-use and transport planning is important (Ortúzar S. & Willumsen, 2011, pp. 493–495). The group of land-use integrating models can be differentiated in four different clusters (Ortúzar S. & Willumsen, 2011, pp. 494–495). The first are the bid-rent or discrete choice approaches, which focus on the housing prices in dependency from their distance to the Central Business District and resulting household location choices (e.g. Wheaton, 1977). The next group are models that focus on demographic changes (birth, death, marriage, changes of workplace or housing location) and, either, try to model them (behavioural approaches), or just regard their impacts as an output (structure-explaining approach) (e.g. Moeckel, 2017). The third group deals with long-term influences on land and housing markets and models them either by applying equilibrium assumptions (Anas & Xu, 1999) or by estimating change rates (e.g. System Dynamics: Ortúzar S. & Willumsen, 2011, pp. 497–498). The last group consists of microsimulations similar to the activity-based models, yet, the main concern are location choices. Exemplary authors in this field are Ettema (2011), Waddell (2002) or Filatova (2009).

Yet, models are subject to uncertainties. In transport demand modelling this fact often stays unconsidered. Rasouli and Timmermans (2012) state that there are two dominant sources of uncertainty in transport modelling – input uncertainty and model uncertainty. This uncertainties and resulting distortions do not receive adequate attention. In addition to that, criticism affecting utility theoretically based models stemming from different fields of behavioural economics has to be taken into account. One of them is prospect theory basing on the findings of Kahneman and Tversky (1979). Hereby the change in utility functions due decisions under risk are considered.

4.2. Existing models on UAM

Despite the extensive theoretical possibilities to model the existing transport systems and its changes due to new transport modes, UAM integration has seldom been evaluated in a whole transport context. The main research focus is on the technical aspects of PAVs (e.g. Kohout & Schmitz, 2003; Rohacs, 2010). An early approach for the placements of PATS in the existing transport system was undertaken by Moore (2003) and DeLaurentis et al. (2002). Both see further technological development as essential to make PAVs a viable mode of transport. More detailed simulations were performed by Lewe et al. (2010; 2009; 2002). By applying agent-based models, required properties, such as cruise speed and range, and the number of seats are determined. First results show that an increase in cruise speed by 50 km/h does not seem impactful for market share (J. Lewe et al., 2002). Yet, Lewe`s studies all focus on inter-city trips.

5. Conclusion

This review shows that for successful large-scale UAM introduction further research can helpful. In section 3 various demand drivers have been discussed. After determining the relevant factors for a decisive impact of UAM on modal split and the possible resulting impact on the city structure possible cities for introduction and vehicle and system prerequisites can be defined. Resulting from that an efficient operational concept can be setup. Possible options for this have been described in section 2.

Integrating these findings, a suitable transport system model can be developed. Creating an urban mobility model that incorporates all existing modes, seems to be the most suitable way to answer this need. Yet, as shown above various aspects have to be considered. Modelling passenger behaviour as realistic as possible is an important aspect, as it determines the demand. Therefore, an agent-based approach that gives the opportunity to incorporate activity-based tour generation appears to be a good approach. For further research, we are, hence, envisaging the development of a MATSim scenario adapted to our needs.

The limitations of MATSim will have to be thoroughly investigated beforehand in order to find ways of either circumventing them or finding solutions to overcome these. One aspect will be the limitations in mode choice modelling (see e.g. Rieser, Grether, & Nagel, 2009). Even though there are first attempts to include land-use models into MATSim (see e.g. Nicolai, 2013), another point will be the missing consideration of changes in the city structure. For both problems, MATSim enhancements and options for exogenous calculation need to be evaluated.

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References

A^3. (2017). Welcome to Vahana. Retrieved August 30, 2017, from https://vahana.aero/

Anas, A., & Rhee, H.-J. (2006). Curbing excess sprawl with congestion tolls and urban boundaries. *Regional Science and Urban Economics*, *36*(4), 510–541.

Anas, A., & Xu, R. (1999). Congestion, Land Use, and Job Dispersion: A General Equilibrium Model. *Journal of Urban Economics*, *45*(3), 451–473. https://doi.org/10.1006/juec.1998.2104

Angel, S., Parent, J., Civco, D. L., & Blei, A. M. (2011). *Making Room for a Planet of Cities*.

Atasoy, B., Glerum, A., & Bierlaire, M. (2006). Mode choice with attitudinal latent class: a Swiss case-study. *Second International Choice Modeling Conference*, 1–16.

Aurora Flight Sciences. (2017). eVTOL. Retrieved August 30, 2017, from http://www.aurora.aero/evtol/

Balac, M., Janzen, M., & Axhausen, K. W. (2017). Alternative approach to scoring in MATSim and how it affects activity rescheduling. *Arbeitsberichte Verkehrs- Und Raumplanung*, *1267*. https://doi.org/10.3929/ETHZ-B-000175254

Batty, M. (2009). Urban Modeling. In *International Encyclopedia of Human Geography*. Oxford: Elsevier. Retrieved from http://www.casa.ucl.ac.uk/rits/BATTY-Urban-Modelling-2009.pdf

Bazzan, A. L. C., & Klügl, F. (2013). A review on agent-based technology for traffic and transportation. *The Knowledge Engineering Review*, *29*(May), 375–403. https://doi.org/10.1017/S0269888913000118

Ben-Akiva, M., McFadden, D., Gärling, T., Gopinath, D., Walker, J., Bolduc, D., … Rao, V. (1999). Extended Framework for Modeling Choice Behavior. *Marketing Letters*, *10*(3), 187–203. https://doi.org/10.2307/40216534

Bhat, C. R., Guo, J. Y., Srinivasan, S., & Sivakumar, A. (2003). *Guidebook on Activity-Based Travel Demand Modeling for Planners*.

Buehler, R. (2011). Determinants of transport mode choice: a comparison of Germany and the USA. *Journal of Transport Geography*, *19*(4), 644–657. https://doi.org/10.1016/j.jtrangeo.2010.07.005

Business Insider. (2017). Airbus Vahana aircraft will cost same as taxi per mile: Zach Lovering - Business Insider Deutschland. Retrieved September 5, 2017, from http://www.businessinsider.de/airbus-vahana-aircraft-cost-same-taxi-zach-lovering-2017-5?r=US&IR=T

Carrasco, J. A., & de Dios Ortúzar, J. (2002). Review and assessment of the nested logit model. *Transport Reviews*, *22*(2), 197–218. https://doi.org/10.1080/01441640110091224

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6

Decker, M., Fleischer, T., Meyer-Soylu, S., & Schippl, J. (2013). Personal air vehicles as a new option for commuting in Europe: vision or illusion? *The 41st European Transport Cconference*, 1–20.

Delaurentis, D., Kang, T., Lim, C., Mavris, D., & Schrage, D. (2002). System-of-Systems Modeling for Personal Air Vehicles. In *AIAA 2002* (pp. 1–12).

Dobler, C. (2013). Travel behaviour modelling for scenarios with exceptional events - methods and implementations, (21272).

Ettema, D. (2011). A multi-agent model of urban processes: Modelling relocation processes and price setting in housing markets. *Computers, Environment and Urban Systems*, *35*(1), 1–11. https://doi.org/10.1016/j.compenvurbsys.2010.06.005

Fagnant, D. J., & Kockelman, K. M. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. *Transportation Research Part C: Emerging Technologies*, *40*, 1–13. https://doi.org/10.1016/j.trc.2013.12.001

Filatova, T., Parker, D., & Van Der Veen, A. (2009). Agent-Based Urban Land Markets : Agent â€™ s Pricing Behavior , Land Prices and Urban Land Use Change. *Simulation*, *12*(1), 3. https://doi.org/3

Fillone, A. M. (2007). Transport Mode Choice Models for Metro Manila and Urban Transport Policy Applications. *Transportation*, *7*, 454–469.

Glancy, D. J. (2015). Autonomous and Automated and Connected Cars - Oh My ! First Generation Autonomous Cars in the Legal Ecosystem. *Minnesota Journal of Law, Science and Technology*, *16*(2), 619–691.

Grether, D. (2014). Extension of a Multi-Agent Transport Simulation for Traffic Signal Control and Air Transport Systems.

Hansman, R. J., & Vascik, P. D. (2016). *Operational Aspects of Aircraft-Based On-Demand Mobility Aircraft-Based On-Demand Mobility*. Princeton.

Holden, J., & Goel, N. (2016). *Fast-Forwarding to a Future of On-Demand Urban Air Transportation*. Retrieved from https://www.uber.com/elevate.pdf

Horni, A., Nagel, K., & Axhausen, K. W. (2016). *The Multi-Agent Transport Simulation MATSim*. https://doi.org/http://dx.doi.org/10.5334/baw

Joby Aviation. (2017). Joby S2. Retrieved August 30, 2017, from http://www.jobyaviation.com/S2/

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, *47*(2), 263–292. Retrieved from http://links.jstor.org/sici?sici=0012-9682%28197903%2947%3A2%3C263%3APTAAOD%3E2.0.CO%3B2-3

Kickhöfer, B., Grether, D., & Nagel, K. (2011). Income-contingent user preferences in policy evaluation: Application and discussion based on multi-agent transport simulations. *Transportation*, *38*(6), 849–870. https://doi.org/10.1007/s11116-011-9357-6

Kohout, L. L., & Schmitz, P. C. (2003). Fuel Cell Propulsion Systems for an All-Electric Personal Air Vehicle. *Computing*, (June), 1–9. https://doi.org/10.2514/6.2003-2867

Kopardekar, P. (2017). Urban Air Mobility: Initial Reflections. In *Uber Elevate Summit*.

Koppelman, F. S., & Bhat, C. (2006). A Self Instructing Course in Mode Choice Modeling : Multinomial and Nested Logit Models, *28*(3). https://doi.org/10.1002/stem.294

Kreimeier, M., & Stumpf, E. (2017). Market volume estimation of thin-haul On-Demand Air Mobility services in Germany. In *17th AIAA Aviation Technology, Integration, and Operations Conference*. Reston, Virginia: American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2017-3282

Lerner, W. (2011). The Future of Urban Mobility. *Arthur D. Little*, (October), 28.

Lewe, J.-H., Laughlin, T., & Mavris, D. (2010). Impacts of Design Characteristics on Market Demand of Vertical Takeoff and Landing Personal Air Vehicles. *Aviation Technology, Integration, and Operations (ATIO) Conferences*, (September). https://doi.org/10.2514/6.2010-9344

Lewe, J.-H., Meyer, K. A., Unton, T. J., & Mavris, D. N. (2009). Sensitivity Analysis of Consumer Preference for a Future Small Aircraft with Point-to-point Operations. *9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO) and Aircraft Noise and Emissions Reduction Symposium (ANERS), Hilton Hea*(September), 1–13.

Lewe, J., Ahn, B., Delaurentis, D., Mavris, D., & Schrage, D. (2002). An Integrated Decision-Making Method to Identify Design Requirements Through Agent-based Simulation for Personal Air Vehicle System. *AIAA Aviation*, 1–10. https://doi.org/10.2514/6.2002-5876

McGuckin, N., & Murakami, E. (1999). Examining Trip-Chaining Behavior: Comparison of Travel by Men and Women. *Transportation Research Record: Journal of the Transportation Research Board*, *1693*(202), 79–85. https://doi.org/10.3141/1693-12

McNally, M. G. (2000a). The Activity-based Approach. In D. A. ; Hensher & K. J. Button (Eds.), *Handbook of Transport Modelling* (pp. 53–69).

McNally, M. G. (2000b). The Four Step Model. In D. A. . Hensher & K. J. Button (Eds.), *Handbook of Transport Modelling* (pp. 35–52).

Moeckel, R. (2017). Constraints in household relocation : Modeling land-use / transport interactions that respect time and monetary budgets. *The Journal of Transport and Land Use*, *10*(1), 211–228.

Moore, M. D. (2003). Personal Air Vehicles : a Rural / Regional and Intra-Urban on-Demand Transportation System. *American Institute of Aeronautics and Astronautic (AIAAA)*, 1–20.

Nicolai, T. W. (2013). MATSim for urbansim. https://doi.org/10.14279/DEPOSITONCE-3871

Nneji, V. C., Stimpson, A., Cummings, M. (Missy), & Goodrich, K. H. (2017). Exploring Concepts of Operations for On-Demand Passenger Air Transportation. In *17th AIAA Aviation Technology, Integration, and Operations Conference*. Reston, Virginia: American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2017-3085

O'Donoghue, C., Morrissey, K., & Lennon, J. (2014). Spatial Microsimulation Modelling: a Review of Applications and Methodological Choices. *International Journal of Microsimulation*, *7*(71), 26–75.

Ortúzar S., J. de D., & Willumsen, L. G. (2011). *Modelling transport*. Wiley-Blackwell.

Priester, R., Kenworthy, J., & Wulfhorst, G. (2013). The Diversity of Megacities Worldwide: Challenges for the Future of Mobility (pp. 23–54). https://doi.org/10.1007/978-3-642-34735-1_2

Rasouli, S., & Timmermans, H. (2012). Uncertainty in travel demand forecasting models: literature review and research agenda. *Transportation Letters*, *4*(1), 55–73. https://doi.org/10.3328/TL.2012.04.01.55-73

Rieser, M., Grether, D., & Nagel, K. (2009). Adding Mode Choice to Multiagent Transport Simulation. *Transportation Research Record: Journal of the Transportation Research Board*, *2132*, 50–58. https://doi.org/10.3141/2132-06

Rohacs, J. (2010). Safety aspects of the personal air transportation system. *27th Congress of the International Council of the Aeronautical Sciences 2010*, *6*, 1–13.

Santos, G., Maoh, H., Potoglou, D., & von Brunn, T. (2013). Factors influencing modal split of commuting journeys in medium-size European cities. *Journal of Transport Geography*, *30*, 127–137. https://doi.org/10.1016/j.jtrangeo.2013.04.005

Schuchardt, B. I., Lehmann, P., Nieuwenhuizen, F., & Perfect, P. (2015). *myCopter Deliverable D6.5 Final list of desirable features/ options for the PAV and supporting systems*.

Schwanen, T., & Mokhtarian, P. L. (2005). What affects commute mode choice: Neighborhood physical structure or preferences toward neighborhoods? *Journal of Transport Geography*, *13*(1 SPEC. ISS.), 83–99. https://doi.org/10.1016/j.jtrangeo.2004.11.001

Shell Global. (2017). Six city archetypes. Retrieved August 28, 2017, from http://www.shell.com/energy-and-innovation/the-energy-future/future-cities/future-city-archetypes.html

Sivakumar, A. (2007). Modelling transport: a synthesis of transport modelling methodologies. *Imperial College of London*, (September).

Skift. (2017). Flying Cars: Separating Hype From Real Potential – Skift. Retrieved September 5, 2017, from https://skift.com/2017/07/05/flying-cars-separating-hype-from-real-potential/

Syed, N., Rye, M., Ade, M., Trani, A., Hinze, N., Swingle, H., … Marien, T. (2017). Preliminary Considerations for ODM Air Traffic Management based on Analysis of Commuter Passenger Demand and Travel Patterns for the Silicon Valley Region of California. In *17th AIAA Aviation Technology, Integration, and Operations Conference*. Reston, Virginia: American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2017-3082

Train, K. (2009). *Discrete Choice Methods with Simulation*. https://doi.org/10.1017/CBO9780511805271

uberestimate. (2017). Uber Fare Estimator & Surge Prices | Estimate Rides. Retrieved September 27, 2017, from http://uberestimate.com/

Verbas, İ. Ö., Mahmassani, H. S., Hyland, M. F., & Halat, H. (2016). Integrated Mode Choice and Dynamic Traveler Assignment in Multimodal Transit Networks. *Transportation Research Record: Journal of the Transportation Research Board*, *2564*, 78–88. https://doi.org/10.3141/2564-09

Volocopter GmbH. (2017). Volocopter - Urban Mobility. Retrieved August 30, 2017, from https://www.volocopter.com/en/urban-mobility/

Waddell, P. (2002). UrbanSim: Modeling Urban Development for Land Use, Transportation, and Environmental Planning. *Journal of the American Planning Association*, *68*(3), 297–314. https://doi.org/10.1080/01944360208976274

Walker, J., & Ben-Akiva, M. (2002). Generalized random utility model. *Mathematical Social Sciences*, *43*(3), 303–343. https://doi.org/10.1017/CBO97811107415324.004

Wheaton, W. C. (1977). A bid rent approach to housing demand. *Journal of Urban Economics*, *4*(2), 200–217. https://doi.org/10.1016/0094-1190(77)90023-7

Zamparini, L., & Reggiani, A. (2007). Meta-Analysis and the Value of Travel Time Savings: A Transatlantic Perspective in Passenger Transport. https://doi.org/10.1007/s11067-007-9028-5